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Casing Pull Tests for Directionally Drilled Environmental Wells

G. E. Staller, R. P. Wemple, R. R. Layne

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Casing Pull Tests for Directionally Drilled Environmental Wells

G. E. Staller and R. P. Wemple
Environmental Drilling Projects

R. R. Layne
The Charles Machine Works, Inc.

Abstract: A series of tests to evaluate several types of environmental well casings have been conducted by Sandia National Laboratories (SNL) and its industrial partner, The Charles Machine Works, Inc. (CMW). A test bed was constructed at the CMW test range to model a typical shallow, horizontal, directionally drilled wellbore. Four different types of casings were pulled through this test bed. The loads required to pull the casings through the test bed and the condition of the casing material were documented during the pulling operations. An additional test was conducted to make a comparison of test bed vs actual wellbore casing pull loads. A directionally drilled well was emplaced by CMW to closely match the test bed. An instrumented casing was installed in the well and the pull loads recorded. The completed tests are reviewed and the results reported.

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CONTENTS

	Page
1.0 Introduction	1
1.1 Background	1
1.2 Technical Strategy	1
2.0 Test Bed Design and Installation	2
2.1 Test Bed Design	2
2.2 Test Bed Installation	2
3.0 Test Bed Casing Pull Tests	5
3.1 Pulling Hardware and Design Parameters	5
3.2 Data Acquisition Instrumentation and Test Setup	8
3.3 Casing Types and Test Results	9
4.0 Horizontal Wellbore Casing Pull Tests	25
4.1 Wellbore Design and Installation	25
4.2 Test Results	25
5.0 Conclusions	32
6.0 References	35
Appendix A - Project Photographs	A-1
A1-Selected Test Bed Installation Photographs	A-1
A2-Selected Casing Pull Test Photographs	A-6

Figures

1	Plan view of test bed configuration	3
2	Field layout of test bed centerline	4
3	Clay pipe, 8" ID for test bed	4
4	Two-celled concrete boxes	6
5	Clay pipe being installed in curved trench of test bed	7
6	Concrete pour to secure clay pipe in test bed	7
7	Wire rope pulling cable, swivel, pulling plug and pull back rope	10
8	Pulling plug loads in test bed, pulled with wire rope cable	11
9	Centron fiberglass casing assembly	12
10	Centron fiberglass casing pull loads in test bed, pulled with a wire rope cable . .	14
11	Centron fiberglass casing pull loads in testbed, with no geologic materials in concrete boxes	15
12	Centron fiberglass casing pull loads in test bed, pulled with JT 440 drill pipe . .	17
13	Smith fiberglass casing assembly	18
14	Smith fiberglass casing pull loads in test bed pulled with JT 440 drill pipe . . .	19
15	Aluminum conduit casing assembly	21
16	Aluminum conduit casing pull loads in test bed, pulled with JT 440 drill pipe . .	22
17	CertainTeed Yelomine PVC casing assembly	23
18	CertainTeed Yelomine PVC casing pull loads in test bed, pulled with JT 440 drill pipe	24
19	DITCH WITCH™ Jet Track 440 directional boring system	26
20	Wellbore test pulling tractor and field layout of well centerline	27
21	Pull plug loads in wellbore, pulled with JT 440 drill pipe	28
22	Centron fiberglass casing pull loads in wellbore, pulled with JT 440 drill pipe . .	30
23	Centron fiber casing after exiting wellbore	31
24	Aluminum conduit with surface scratches and Yelomine PVC coupling damage after pull test	34

Table

1	Peak average casing pull loads	33
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1. Introduction

1.1 Background

Sandia National Laboratories (SNL) has been involved in environmental directional drilling development with the Charles Machine Works, Inc. (DITCH-WITCH®) since 1990. Results of this previous work¹ revealed that available commercial well casings and line pipe were not designed for use in shallow horizontal environmental well applications. Selection of the most desirable casing for a particular well in a specific geology was difficult because very little published data was available to assist in this selection.

Further technical evaluations of commercially available tubing and pipe for use as well casings were required. These investigations were to be done under controlled conditions, in an effort to evaluate the casing material, design, and performance by observing the physical conditions of the casing and recording the axial pull loads developed as the casing was being installed in a typical horizontal wellbore². This information could then be used when planning future horizontal environmental wells or lead to the development of better casing designs and/or materials.

1.2 Technical Strategy

The initial approach considered for this investigation was to directionally drill a series of "typical" parallel horizontal boreholes at the CMW experimental test range in Perry, OK. Various casings would then be instrumented to monitor their condition and measure the loads required to emplace them in the typical wellbores. Since each wellbore is considered to be unique, direct comparison of the various casings would be difficult and questionable.

This approach was discarded in favor of constructing a permanent test bed that could be used to evaluate all casings in essentially the same wellbore. The test bed would be constructed to closely model a typical horizontal directionally drilled well.

To establish a baseline for comparison with an actual horizontal wellbore, a follow-on well would be drilled at the test range, and one type of casing would be instrumented and monitored as it was being installed in the drilled well.

Appendix A provides a pictorial overview of both the test bed installation and the casing pull test operations.

2. Test Bed Design and Installation

2.1 Test Bed Design

The test bed was designed to permit testing of various casings under controlled conditions. The configuration, as shown in Figure 1, was fashioned to provide typical bend radii encountered in shallow directionally drilled wells. In addition, the test bed contains provisions to permit different geologic materials to contact the test casing at three locations or zones along its length. To minimize the external loads on the test bed during test operations, it was installed in a shallow (<4' deep) trench and backfilled with soil. Project team casing installation experience in horizontal wells has primarily been with wells requiring 4" ID casings installed in wellbores normally reamed to an 8" diameter. An 8" diameter test bed bore was therefore selected to model these conditions.

Several different types of material (concrete pipe, steel pipe, etc.) were considered for constructing the test bed wellbore. Based on availability, ease of installation and wellbore-to-casing friction properties, the material selected to best model the wellbore was 8" ID plain end clay pipe manufactured by Mission Clay Products Inc., Pittsburg, KS.

Since the depth of the test bed was to be less than four feet, the bend radii (125' and 250') were placed in a plane parallel to the ground surface. To introduce and monitor the effects of various geologic materials on the casings, three two-celled, concrete boxes were placed in series with the wellbore, at the intervals shown in Figure 1, along the test bed. Holes in the end and center walls allow the casing to pass through the boxes. The first cell of each box was designed to contain the geologic material and has a removable side door to permit removal of the material after each test. The second cell of the box remains unfilled during the test to permit visual monitoring of the physical condition of the casing after it passes through the geologic material. The presence of the geologic material is intended to closely simulate the localized slumping of a wellbore and its subsequent additional friction loads on the casing string.

2.2 Test Bed Installation

The test bed was installed at a site selected by CMW on their experimental test range, located northeast of the main CMW manufacturing facility, in Perry, OK. This site is a field that has a slight elevation increase from south to north or from the selected entry toward the exit end of the test bed. The trench centerline was marked in the field according to the grid pattern shown in Figure 1, and a 24" wide trench was dug along the marked centerline to the desired 40" depth (see Figure 2). The trench slope, and therefore the test bed slope, parallels the ground surface topography. The 8" ID X .875" wall clay pipe shown in Figure 3 was purchased in 5' and 6' lengths for

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Figure 1. Plan view of test bed configuration.

Figure 2. Field layout of test bed centerline.

Figure 3. Clay pipe, 8" ID for test bed.

installation in the test bed. Two 6' lengths of clay pipe were positioned in the trench at the entry end to reach the first geologic material concrete box location.

The three reinforced concrete boxes used to contain the geologic material are modified sand and mud traps manufactured by Hausner's Precast Concrete Products, Inc., Drumright, OK. They are 95" long X 62" wide X 59" high and weigh approximately 5500 pounds. They have 10.5" diameter holes for the casing to pass through and a 36" X 47" opening in one cell side for geologic material removal, as shown in Figure 4. Pits were dug at the box locations shown in Figure 1. An access ramp was provided on the side of the pit containing the box material removal door. The first box was positioned in the south pit and aligned with the clay pipe. The clay pipe was installed so it was approximately flush with the inside edge of the concrete box end walls. Fourteen 5' lengths of clay pipe were then assembled and positioned in the trench to reach the middle pit and the middle box was installed. The pipe and north box were similarly installed with two 6' lengths of pipe finally being emplaced to reach the exit end of the test bed. Two spare 5' and 6' lengths of clay pipe were procured as replacements for any pipe broken during installation. Since none of the pipe was broken during installation, it was decided to extend the entry and exit pipe lengths 11' and locate the pipe closer to the ground surface. This was done by adding a 5' and 6' length of pipe to each end of the test bed. The overall length of the test bed was nominally 210'. The clay pipe joints were secured and sealed with a PVC ring as shown in Figure 5. The PVC ring fit is such that the pipe could be positioned to adhere to the test bed design radii and still maintain the sealed joints. To provide a sealed secure joint at the entry and exit ends of the test bed and at the entry and exit holes in the concrete boxes, plywood forms were constructed and concrete was poured around the clay pipe (see Figure 6). Prior to backfilling the trench with soil, the clay pipe was additionally secured in the trench by pouring concrete around the pipe at several locations between the concrete boxes. After the concrete properly cured, the trenches were backfilled with the soil removed during excavation. The voids around the boxes were also backfilled, except for the side access ramps, and all backfilled areas were tamped. The material removal doors were installed in the concrete boxes. The entry and exit ends of the test bed and the concrete boxes were covered to minimize debris entry until the casing pull tests could begin. The test bed installation was completed on May 20, 1994.

3. Casing Pull Tests

3.1 Pulling Hardware and Design Parameters

The test bed was constructed to provide a consistent, reusable facility that can be employed to measure the pull loads required to emplace various types of casing in a horizontal wellbore. Our experience with previous casing installations, in horizontal wells, indicates that the peak pulling loads could approach 18,000 pounds. Therefore, the selected casing was pulled through the test bed using a DITCH-WITCH® HT100

Two-celled concrete boxes.

Figure 4. Two-celled concrete box in pit.

Figure 5. Clay pipe being installed in curved trench of test bed.

Figure 6. Concrete pour to secure clay pipe in test bed.

tractor with a maximum drawbar pulling capacity of 25,000 pounds. The casing was attached to a special pulling plug that was designed to pull a specific type of casing. The design strength of the pulling plug exceeds the breaking strength of the casing. A swivel, with a proof-test load rating of 34,000 pounds, was attached to the pulling plug to eliminate any rotational loads caused by the pulling operation from being transferred to the test casing.

A 3/4" diameter, 6X25 IWRC wire rope cable, with a certified working load of 10,200 pounds (breaking strength = 5 X working load), was used as the pulling cable, and was attached to the swivel. The pulling cable was then attached to a SNL designed and tested break-link that was manufactured to fail at a 27,500 pound load. The break-link was used as an additional safety precaution to control the point of failure and protect the tractor operator from a rebounding wire rope if the peak pull loads unexpectedly exceeded the cable breaking strength. The break-link was then attached to an 80,000 pound capacity load cell that had been calibrated from 0 to 20,000 pounds. The load cell was then attached to the drawbar of the tractor. Based on the weight of the test casings and associated pulling hardware, the estimated maximum peak loads required to pull the casings through the test bed was 10,000 pounds.

3.2 Data Acquisition Instrumentation and Test Setup

The battery-operated electronic control box for the load cell was electrically connected to the load cell and placed in the pulling tractor cab to provide the tractor operator with real time load information as he was pulling the test casing through the test bed.

The SNL Mobile Field Support Unit (MFSU) van was positioned approximately 10' to the left and 60' behind the test bed exit port. The cable from a wireline logging winch located in the MSFU was attached to the tractor. A cable counter on the logging winch was used to measure and record the distance the tractor moved as it was pulling the test casing through the test bed. Load data from the load cell control box was transmitted from the control box to the MSFU through the wireline cable and recorded at one second intervals to document the pull load as a function of distance during the casing pull tests. The data was recorded on a HP-85 computer and the files transferred to a Compac portable PC for plotting.

The MFSU operator and the tractor operator were in constant radio contact during the pull tests. In addition, the tractor operator was also in radio contact with the field test coordinator to minimize the risk of injury to field personnel and damage to equipment or to the test bed during the pulling operations.

The casing pull tests began on August 1, 1994. The test bed was swabbed to remove mud and rain water and verify that the clay pipe was clear of obstructions. The three concrete boxes contained approximately 12" of standing rain water which was pumped

out prior to beginning the pull tests. A nylon rope was emplaced in the test bed and used to pull the wire rope cable into position in the test bed.

The geologic materials were procured and positioned near each concrete box for installation in the test cell. The geologic materials were as follows: south box (first box in pull path), 3/8" crushed stone; middle box, 1.5" crushed stone; north box, 1.5" to 6" river rock. The stone and rock was placed in the test cell of each box, up to the level of the bottom of the clay pipe. After the pulling plug and the leading edge of the test casing was pulled beyond the viewing cell of each box the pull was temporarily stopped. A commercial pipe wiper, used by the drilling industry, was installed around the casing in the test cell. This rubber pipe wiper was used to prevent the geologic material from being pulled into the open viewing cell of the box, when the remainder of the test cell was filled with the crushed stone or rock, during the pull tests.

The test plan was to first pull only the wire rope pulling cable, swivel, pulling plug, and the pull back rope (see Figure 7) through the test bed while documenting the loads. This permitted separating the effects of the pulling hardware loads from the casing loads. A plot of the resulting loads vs pull distance is shown in Figure 8. The gradual increase in pull load as the pull distance increased could be the result of electronic instrument drift, pulling debris in the test bed ahead of the pulling plug, the increase of the pulling cable drag as it exited the test bed, or combinations of all these factors.

3.3 Casing Types and Test Results

The most conservative approach to conducting these tests was to pull the strongest casing through the test bed first, then proceed through the other available test samples, ending when the weakest casing was pulled through the test bed. Due to the reduced budgets, the full series of pull tests planned for FY-94 could not be conducted, but four different types of casing materials that were on hand were tested.

The first test casing investigated was Centron 4.5" DH2000 Integral Joint Tubing. It is a fiberglass epoxy tubing that is constructed to provide high axial modulus and tensile strengths. It has a 3.98" ID and a .385" nominal wall thickness. The published axial tensile strength is 30,000 psi, the ultimate axial thread load is 90,000 pounds, and the ultimate axial wall load is 136,000 pounds. This tubing is manufactured by Centron Corporation, Mineral Wells, TX. The cost of the tubing was approximately \$14/foot. It should be noted that any cost data provided in this report is for information only and may not reflect current costs, which can vary greatly due to market conditions, quantities purchased, etc. This tubing was purchased in 30' lengths and six pieces were assembled to produce a 180' long pull test casing, as shown in Figure 9.

Figure 7. Wire rope pulling cable, swivel, pulling plug and pull back rope.

Figure 8. Pulling plug loads in test bed, pulled with wire rope cable.

Figure 9. Centron fiberglass casing assembly.

The casing was attached to the pulling plug and a pull back plug was attached to the rear of the casing. The pull back plug provided an attachment for a trailing nylon rope that was pulled into the test bed during the test and then used to pull the wire rope pulling cable back through the test bed for subsequent tests.

The casing was pulled into the test bed and stopped after being pulled approximately 40' just after the pulling plug exited the south (first) concrete box. The pipe wiper was installed on the casing and the test cell was filled with the 3/8" crushed stone. The casing was then pulled to the 118' distance, or same location in the middle concrete box, and the pipe wiper and 1.5" crushed stone was emplaced and the casing pulled to the north concrete box at approximately the 196' distance. After the 1.5" to 6" river rock and pipe wiper was emplaced in the north box, the casing was pulled until it exited the test bed.

Review of the load vs distance data indicates that the loads vary greatly over short distances, and increase overall as the pull distance and added geologic material loads increase (see Figure 10). The average pull loads peaked at approximately 2200 pounds, while the short duration loads peaked as high as 3700 pounds. It was noted during the pull that the wire rope pulling cable caused the swivel to rotate as the rope was being tensioned, then the casing would slip forward a short distance (approximately 2" to 4") and stop while the swivel would rapidly rotate in the opposite direction. This tensioning and relaxing of the pulling cable occurred constantly during the test with this stick-slip effect being more pronounced as the pull loads increased.

After some discussion it was decided that this test, with this casing, should be repeated without the added geologic material in the test bed. This was done in an attempt to determine how to minimize the effect of the spring action of the wire rope pulling cable. The loads required to pull the casing into the test bed with the wire rope cable would be measured, then the pulling cable would be disconnected from the test casing and tractor. The casing would then be attached directly to the tractor and the loads required to pull only the casing from the test bed would be recorded. This data would be compared to determine what, if any, effect the pulling cable had on the test data.

The pulling cable and casing was disconnected from the tractor. The pulling cable was pulled back through the test bed, and the casing was pulled on the ground back to the entry end of the test bed and re-attached to the pulling cable. The Centron 4.5" test casing was again pulled through the test bed, pausing only to add the pipe wipers at each box. When the casing pulling plug exited the test bed, the pulling cable was removed and the casing pulled the rest of the way from the test bed with the tractor. As shown in Figure 11, the short duration loads decreased beyond 230 feet when the wire rope pulling cable was disconnected. The average pull loads, for either pull method, also fell to less than 1000 pounds as a result of eliminating the geologic

Figure 10. Centron fiberglass casing pull loads in test bed, pulled with a wire rope cable.

Figure 11. Centron fiberglass casing pull loads in test bed, with no geologic materials in concrete boxes.

materials. Based on the results of these two tests DITCH-WITCH® JT440 drill pipe (1.75" OD X 10' long) was selected to replace the wire rope pulling cable. The drill pipe also more closely modeled the actual pulling operations in a typical horizontal wellbore.

The drill pipe was assembled and pulled back through the test bed using the wire rope cable and pull back rope. The casing was disconnected from the tractor and again pulled on the ground to the entry end of the test bed and attached to the drill pipe. The wire rope cable was attached to the rear of the casing to be used to pull the drill pipe back through the test bed after the casing was removed.

The Centron 4.5" test casing was again pulled through the test bed, this time stopping at each concrete box to install the pipe wiper and add the crushed stone or rock. Figure 12 shows the loads as the casing was being pulled through the test bed. The average peak loads are approximately 3200 pounds. The short duration load frequency was reduced by pulling with the drill pipe, but the peak values still remained high, peaking occasionally at approximately 5300 pounds. The peak loads increased as a result of the added weight of the JT 440 drill pipe. The test casing was disconnected from the tractor and pulled aside, the geologic materials and pipe wipers were removed from each concrete box, and the drill pipe was pulled back through the test bed for the next test.

The second casing selected for testing was Smith 4 5/8" SFT Flush Joint Fiberglass Reinforced Tubing. This material has an ultimate tensile strength of 12,000 psi and a calculated maximum axial thread load of 41,000 pounds. It was procured from Smith Fiberglass Products Inc., Wichita, KS. The tubing has a 4.65" OD and a 3.75" ID with flush joints on both the OD and ID. The cost of the tubing was approximately \$23/foot. The tubing was purchased in 30' lengths and six pieces were assembled to produce the 180' test casing, as shown in Figure 13.

The test casing was attached to the drill pipe and pulled through the test bed stopping to install the pipe wipers and add the crushed stone or rock as required at each concrete box. The loads shown in Figure 14 indicate that less force was required to pull this casing through the test bed, with the peak average load being approximately 2800 pounds and the peak short duration loads reaching 3500 pounds. After completing this test the casing was again disconnected from the tractor and pulled aside, the geologic materials and pipe wipers were removed from the concrete boxes, and the drill pipe repositioned for the next test.

The third candidate casing selected was 4" V.A.W. Rigid Aluminum Conduit. The conduit is manufactured from 6063-T1 aluminum with a published tensile strength of 22,000 psi and a calculated maximum axial thread load of 45,000 pounds. It was procured from V.A.W. of America, Inc., Phoenix, AZ. The conduit has a 4.5" OD and a 4.026 ID, and is joined with threaded aluminum couplings. The couplings have

Figure 12. Centron fiberglass casing pull loads in test bed, pulled with JT 440 drill pipe.

Figure 13. Smith fiberglass casing assembly.

Figure 14. Smith fiberglass casing pull loads in test bed, pulled with JT 440 drill pipe.

a 5.0" OD and are 3.5" long. The cost of the aluminum conduit was about \$5.40/foot. The conduit was purchased in 10' lengths and, as shown in Figure 15, 18 pieces were assembled to form the 180' long test casing.

This test casing was attached to the drill pipe and pulled through the test bed, again stopping to install the pipe wipers and add the crushed stone or rock as required at each concrete box. The measured loads shown in Figure 16 indicate that the softer aluminum conduit required substantially more force to pull it through the test bed. In addition, the couplings at each joint also added extra load to the pulling system. The peak average load was approximately 18,500 pounds and the peak short duration loads were as high as 22,000 pounds. After completing this test the casing was again disconnected from the tractor and pulled aside, the geologic materials and pipe wipers were removed from the concrete boxes, and the drill pipe repositioned for the next test.

The fourth and final test casing was 4" CertainTeed Yelomine Certa-lok pipe. This is a PVC pipe that has an impact resistance of up to four times that of conventional PVC. The minimum published tensile strength is 7000 psi and it has a calculated maximum axial joint strength of 7,785 pounds. It was procured from CertainTeed Corp., Pipe & Plastics Group, Valley Forge, PA. The pipe has a 4.5" OD and a .214" minimum wall thickness. The sections of pipe are joined by sliding the pipe into a coupling and securing it in place with a circumferential spline. This is the special CertainTeed Certa-lok joint design. A spline groove is provided in both the coupling and pipe. The pipe is slipped into the coupling until the spline grooves align. The flexible spline is then pushed into place securing the coupling to the pipe. The couplings are 5.47" OD X 8.25" long. The cost of the Yelomine PVC Pipe was approximately \$2.80/foot. The pipe was purchased in 20' lengths and nine pieces were assembled, as shown in Figure 17, to provide the 180' long test casing.

The test casing was attached to the drill pipe and pulled through the test bed, again stopping to install the pipe wipers and add the crushed stone or rock as required at each concrete box. Since the PVC couplings provided such a large step on the exterior surface, each coupling dragged the crushed stone and rocks past the pipe wipers and into the open test cell. The loads recorded in Figure 18 show that the average force required to pull the PVC casing was low, but the couplings caused high short term loads as they passed through the crushed stone and rocks in the concrete boxes. The peak average pull load was approximately 2000 pounds, while the peak short duration loads were as high as 5500 pounds.

These tests were completed on August 4, 1994.

Figure 15. Aluminum conduit casing assembly.

Figure 16. Aluminum conduit casing pull loads in test bed, pulled with JT 440 drill pipe.

Figure 17. CertainTeed Yelomine PVC casing assembly.

Figure 18. CertainTeed Yelomine PVC casing pull loads in test bed, pulled with JT 440 drill pipe.

4. Horizontal Wellbore Pull Tests

4.1 Wellbore Design, Installation, and Test Setup

In order to obtain a data point for comparison of the test bed data with an actual wellbore casing installation, one additional pull test was planned. A directionally drilled horizontal well was conceived that would closely match our test bed design. This horizontal well was to be drilled by CMW personnel on their test range and located approximately 50' west of the existing test bed.

The well was drilled and back-reamed to an 8" diameter using a DITCH-WITCH® Model 440 Jet Trac Directional Boring System (see Figure 19). The well was placed at a depth of 5' and contained the same horizontal radii (125' and 250') as the test bed (see Figure 1). The well length was approximately 275' from the entry to exit openings. Upon completion of the wellbore the JT 440 drill pipe was left in the well for use in pulling the casing. This was the same size drill pipe used to pull the casings through the test bed. The water used during the drilling operations (2-3 gal/min) left the wellbore wet and therefore the casing pull would be done in a slightly lubricated wellbore, similar to a normal field operation. The well was completed on September 29, 1994.

The setup used to pull the casing into the wellbore was identical to that used to pull the casing through the test bed. As shown in Figure 20, the HT-100 Tractor was used to pull the casing through the wellbore. The SNL load cell was attached in series with the tractor and the drill pipe. The load cell control box was mounted in the tractor cab to permit the tractor operator to monitor the pull loads as the casing was being pulled through the wellbore. The data from the load cell control box was transmitted to the new MFSU truck through a wireline cable attached to the tractor. The cable counter on the wireline cable winch was used to measure and record the distance the tractor moved during the pulling operation. The pulling direction was again from south to north, with the assembled casing laying on the ground behind the entrance to the wellbore.

4.2 Test Results

The first pull through the wellbore was done using only the pulling plug with a wire rope cable attached to the back of the plug. The wire rope was used to pull the drill pipe back into the wellbore after this initial pull. The pulling plug acted like an additional reaming operation on the wellbore, even though the maximum diameter of the pulling plug was only 6.625", and some wet mud was pulled out the exit end ahead of the pulling plug. The loads recorded during this pull (see Figure 21), can be compared to the final pull load data recorded when the casing was attached. The peak average loads recorded were approximately 4500 pounds, while the peak short duration loads were close to 6000 pounds. It is unknown how much of this load was

Figure 19. DITCH WITCH™ Jet Trac 440 directional boring system.

Wellbore test pulling tractor.

Figure 20. Field layout of well centerline.

Figure 21. Pull plug loads in wellbore, pulled with JT 440 drill pipe.

caused by the reaming and/or swabbing action of the pulling plug, since the well was drilled three days before this pull. After the pull was completed, the pulling plug was removed and cleaned for attachment to the casing, and the drill pipe was attached to the wire rope cable and pulled back through the wellbore.

The casing selected for this final pull test was again the Centron 4.5" DH2000 Integral Joint Tubing. This casing exhibits superior strength, was used during various pulls in the test bed, and therefore was best suited for the resulting comparisons. The 180' assembled casing (six pieces) was attached to the pulling plug and in turn the pulling plug was attached to the drill pipe. The wire rope cable was attached to the pull back plug located at the aft end of the casing. The wire rope was for use in pulling the drill pipe back through the wellbore, if another pull was required. This assembly was pulled through the wellbore with the HT 100 tractor and, as shown in Figure 22, the peak average loads required to pull the casing into the wellbore were approximately 10,500 pounds and the peak short duration loads were about the same at 12,000 pounds. The constant drag of the full casing string and the pulling plug in the wellbore resulted in a more uniform, but three to four times higher, load than was recorded when this same casing was pulled through the test bed.

Again when the pulling plug and casing exited the wellbore some wet mud was forced from the hole, as shown in Figure 23. This wet mud provided an unknown amount of lubrication for the casing, but is expected to be encountered during any normal field operation using this type of drilling technology in this type of soil. The test was completed on October 3, 1994.

Figure 22. Centron fiberglass casing pull loads in wellbore, pulled with JT 440 drill pipe.

Centron fiberglass casing being pulled from wellbore.

Figure 23. Centron fiberglass casing after exiting wellbore.

5. Conclusions

The data recorded during the test bed casing pull tests indicate that the test bed design and construction was adequate to provide consistent test results. The preferred test plan would have been to pull each test casing through the test bed at least three times, average the pull loads, and compare the casings. Again, due to time and budget constraints this could not be done, and only the first test casing was pulled through the test bed several times, but under different loading conditions. The test results were also predictable based on the physical variations of the different types of casings. For example, as expected, peak short duration loads on the flush joint casing were much less than the same type loads on casings containing the coupling joints with external upsets.

The casing pull loads are caused by several different factors including the radius of the borehole well centerline, the magnitude of the deviations of the borehole from the well centerline, the clearance between the borehole and the outside diameter of the casing, the stiffness of the casing, the weight of the casing, and the coefficient of friction between the casing and the wellbore geology. Previous studies have been done by SNL and computer models developed to calculate the loads required to install steel liners in horizontal boreholes at nuclear waste repositories³. Computer models developed during these studies could be modified to provide a mathematical solution for determining analogous casing pull loads.

The magnitude of the loads required to pull the aluminum conduit through the test bed was unexpected (see Table 1). The softer aluminum material was easier to scratch, had a high coefficient of friction with the test bed, and with the threaded coupling joints located every ten feet, was more rigid than the other test casings. The loads required to pull the Centron fiberglass casing through the wellbore were 3 to 4 times higher than the loads recorded when this same casing was pulled through the test bed. If this ratio is applied to the other types of casings tested, several failures would have been expected (i.e. the aluminum conduit and the Yelomine PVC) during a wellbore installation. The higher wellbore loads are attributed to the deviations in the directionally drilled well and the resulting increased contact between the wellbore and the casing.

We also observed that the joint design will directly affect the peak short duration pull loads, and consideration of this should be made when selecting a horizontal well casing. The coupling joint designs could be improved and the loads probably reduced if the couplings were beveled on the pulling edge prior to installation.

None of the test casings exhibited mechanical failure as a result of being pulled into and through the test bed. As stated earlier, the softer aluminum material had deep scars on the exterior surface due to contact with the crushed stone and rock in the concrete boxes. The leading edge of the larger joint couplings in both the PVC and

Table 1. Peak Average Casing Pull Loads

Casing Type	Peak Average Load in Test Bed	Peak Average Load in Wellbore
Pulling Plug No Casing Attached	380 lbs.	4500 lbs.
Centron 4.5" DH200 Fiberglass Tubing	3200 lbs.	10,500 lbs.
Smith 4-5/8" Flush Joint Fiberglass Tubing	2800 lbs.	Not Tested
4" Aluminum Conduit with Threaded Coupling Joints	18,500 lbs.	Not Tested
4" CertainTeed Yelomine PVC with Spline Coupling Joints	2000 lbs.	Not Tested

aluminum casings also exhibited scraping and impact scars from the crushed stone and rock (see Figure 24). All casings had some scratches on the exterior surfaces, but these were considered only superficial and had little effect on the casing integrity.

The test bed casing loads documented during these tests were completed under controlled conditions. Variables such as wellbore size, well geology, well trajectory variations, well length, and the general condition of the wellbore did not change in the test bed and therefore did not impact the load differences between the various types of test casing. These loads should not be used to size casings, but are for relative comparison of the different types of casing materials.

During casing installation in a horizontally drilled well, in addition to the casing pull loads, other loads on the drilling and pull-back equipment are;

- 1) loads due to the reamer, if used during pull back
- 2) loads due to the drill rig carriage drag
- 3) loads due to the size and rotation of the pull back drill pipe
- 4) loads due to the casing pulling plug design

When selecting casing for use in horizontal environmental well applications, consideration must be given to the final use requirements for the well and should include attention to all of the above mentioned parameters.

Aluminum conduit surface scratches.

Figure 24. Yelomine PVC coupling damage after pull test.

6.0 References

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2. R. P. Wemple, R. D. Meyer, G. E. Staller and R. R. Layne, *Final Report for SNL/NM Environmental Drilling Project*, Sandia National Laboratories, SAND94-2388, December 1994.
3. David A. Glowka, *Effects of the Deviation Characteristics of Nuclear Waste Emplacement Boreholes on Borehole Liner Stresses*, Sandia National Laboratories, SAND87-1075, September 1990.

APPENDIX A

A1. Selected project photographs taken during Test Bed installation.

Concrete box test cell with clay pipe installed.

Concrete box viewing cell with clay pipe installed.

Test bed view from middle concrete box.

Test bed view from south concrete box.

Test bed with concrete poured around clay pipe.

Test bed entry with concrete seal.

Test bed entry after backfilling operations.

Concrete box access after backfilling operations.

A2. Selected project photographs taken during Casing Pull tests.

Wire rope pulling cable, break link, & load cell attached to HT 100 tractor.

Centron fiberglass casing with wire rope, swivel and pulling plug after exiting test bed.

Wire rope, swivel, pulling plug and Centron casing attachment.

JT 440 drill pipe, swivel, pulling plug and Centron casing attachment.

3/8" crushed stone being installed in south concrete box during casing pull test.

Casing pull back plug in Centron casing in south concrete box viewing cell.

Aluminum conduit casing with pipe wiper and 3/8" crushed stone in south concrete box.

Aluminum conduit casing with pipe wiper and 1.5" crushed stone in middle concrete box.

Yelomine PVC casing with pipe wiper and 3/8" crushed stone in south concrete box.

Yelomine PVC casing with pipe wiper and 1.5" crushed stone in middle concrete box.

Yelomine PVC casing with pipe wiper and 1.5" to 6" river rock in middle concrete box.

Yelomine PVC casing after exiting test bed.

Yelomine PVC casing coupling damage after pull through test bed, note left spline damage.

Yelomine PVC casing coupling damage after pull through test bed, note impact damage to leading (left) edge of coupling.

Centron casing being pulled from wellbore.

Centron casing being disconnected from pull back cable after exiting wellbore.

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