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A Laboratory Study of Cement and Resin Plugs Placed With Thru-Tubing Dump Bailers

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ABSTRACT

Laboratory experiments were conducted to study the factors that influence the successful placement of cement and resin plugs using thru-tubing dump bailers. The five-phase study included: (1) cement slurry design, (2) full-scale visual tests, (3) full-scale cured plug tests, (4) shear bond tests, and (5) gravel pack penetration tests.

This paper presents results from the test program and provides data on commonly used dump bailer practices and equipment. Recommendations are made for placing cement and resin plugs utilizing dump bailers. This information should be useful to operators in planning and completing successful thru-tubing plugbacks.

INTRODUCTION

Oilfield operations often require that cement or resin plugs be placed downhole.[1,2] Reasons for this operation vary, ranging from isolation of zones to water shutoff to well abandonment. Frequently, operators only need to place small volumes of cement or resin without pulling the existing well completion; this can be accomplished by using thru-tubing dump bailers to convey and dump the plugging material downhole.

Dump bailers are relatively simple pieces of equipment and are generally classified into two types: gravity and positive displacement. Figure 1 schematically shows these two types. Gravity bailers dump their contents by using an explosive blasting cap to shatter a frangible nose at the bottom of the bailer. The material then dumps by gravity, provided the density of the plugging material is greater than the density of the surrounding fluid.

Positive displacement bailers release their contents under the urging of a spring-assisted weight. The initial movement of the weight causes a pressure rise inside the bailer which opens ports at the bailer bottom. The propelled weight then displaces the bailer contents through the open ports as it travels through the inner diameter of the bailer.

Two general situations exist when performing thru-tubing dump bailer operations: (1) the plugging material may be dumped inside casing, or (2) the plugging material may be dumped inside a gravel pack screen and allowed to migrate into the sand pack outside the screen. These are referred to as conventional and gravel pack plugbacks, respectively. In both cases the plugging material is often dumped on top of a thru-tubing bridge plug which was previously set. Figure 2 shows a schematic representation of these two situations.

Problems have been encountered in the field when trying to place plugs using dump bailers. These include failure to dump, incorrect fillup heights, and inability to hold pressure. In recognition of these problems, a laboratory study was undertaken to investigate the factors that influence the successful placement of cement and resin plugs using dump bailers. The test program encompassed five areas: (1) cement slurry design, (2) full-scale visual tests, (3) full-scale cured plug tests, (4) shear bond tests, and (5) gravel pack penetration tests.

The information presented in this paper will include data on commonly used dump bailer practices and equipment, results of the test program, and recommendations for conducting plugback operations.

CEMENT SLURRY DESIGN

One of the major problems in designing a dump bailer slurry is the development of gel strength in the cement slurry.[3] Gel strength development is the internal rigidity or, the shear resistance, of the cement system which acts on the walls of the bailer and resists natural or induced movement when attempting to dump the slurry. Premature development of gel strength is undesirable and can occur while the slurry is still inside the bailer. It can be reduced or delayed by thinning the slurry with a dispersant, or by adding excessive amounts of retarder. Both of these methods, however, have drawbacks. If the slurry is thinned too much with a dispersant, it may have solids settling problems which could possibly prevent the slurry from dumping. Similarly, if excessive retarder is added to the slurry, it takes longer for the slurry to set and develop adequate compressive strength. Longer set times of the cement generally mean longer waiting times before operations continue with the well.

Ideal cement slurry properties for dump bailer applications include (1) good particle suspension with low free water, (2) slow or delayed static gel strength development, (3) short initial set time, and (4) adequate compressive strength development. To address these properties, a new material has been found which is ideally suited for dump bailer cement slurry designs.[4] It is a delayed-gel-strength additive which adds viscosity to the slurry and helps inhibit settling while the bailer is being lowered into the well. At the same time, it delays gel strength development of the slurry so that it will easily flow out of the bailer when it reaches placement depth. This means the entire operation can be accomplished without having to add excessive concentrations of retarder. The material is non-retarding to cement slurries and can be used over a wide temperature range. Figure 3 (after Sykes and Logan)[4] shows the development of gel strength for cement mixtures with and without the delayed-gel-strength additive. It is clearly seen that the delayed-gel-strength slurry takes longer to reach a gel strength of 100 lbf/100 ft^2 than the slurry without the additive. This is important since 100 lbf/100 ft^2 represents the approximate value beyond which cement (at 16.0 lbm/gal) will not dump from a 1.0-inch ID bailer in 9.0-lbm/gal wellbore fluid.

To simplify field operations, a special blend of materials has been formulated for dump bailer applications and packaged into cement kits. In addition to delayed-gel-strength characteristics, the formulation features strength retrogression protection and post-set expansion. This formulation was tested at various temperatures and retarder concentrations; the final result was a bracket of six temperature ranges that varied only by the retarder type and concentration. To evaluate the slurry under worst-case conditions, the blend, with a given retarder concentration, was tested for gel strength development at the upper end of its particular temperature bracket and for compressive strength development at the lower end of the bracket. Even under these extreme condition test parameters, the results in Table 1 show that desirable characteristics for a dump bailer slurry were achieved:

(1) The time to 100 lbs static gel strength was adequately long;

(2) The initial set times were all less than 12 hours, and

(3) Good compressive strength was obtained in 24 hours.

During the full-scale and shear-bond test programs, cement slurries were mixed according to directions in the prepackaged kits. This generally consisted of adding the proper retarder packet and amount of water until a slurry density of 15.8 to 16.0 lbm/gal was obtained. It was necessary to use proper mixing equipment to ensure the slurries were adequately blended. An air-operated motor driving a paint stirrer was found to be ideal for this purpose. Also, mud scales were necessary to make certain the target density was achieved. Either pressurized or non-pressurized mud scales were shown to be satisfactory; the difference in measured slurry density between these two devices was only 0.1 lbm/gal. This indicates the mixing apparatus did not induce significant aeration to the slurry during mixing. Figure 4 shows the cement kits and associated mixing hardware.

FULL-SCALE VISUAL TESTS

During this test series, cement dumping was observed in visual test fixtures that were configured to represent different types of downhole situations in which dump bailers are used. To accomplish these tests, four visual tests cells were constructed from clear plexiglass pipe to represent 3-1/2-, 5-1/2-, 7-5/8-, and 9-5/8-inch casing. Each cell was 18 feet long and could be positioned to any desired deviation by means of a movable cradle. Figure 5 schematically shows this arrangement.

Various dump bailers which are commonly used in the field were utilized in the test program. These included 1-3/8-, 1-5/8- and 2-inch gravity bailers, and a 1-11/16-inch positive displacement bailer. The bailer sections during this test series were 10 feet long.

A typical test was conducted according to the following procedure:

(1) One of the visual test cells was selected and placed in the cradle; the deviation was set to the desired angle. The test cell was then filled with fluid.

(2) An appropriate bailer was selected and filled with cement.

(3) The bailer was positioned at a prescribed distance from the bottom of the test cell; centralization means were not employed.

(4) The bailer was activated using a blasting cap (gravity bailer) or internal spring release (positive displacement bailer).

(5) The dumped cement was allowed to settle for approximately five minutes, at which time a sample was withdrawn from a bottom valve and measured for density.

The visual tests were conducted at ambient temperature and pressure using different wellbore fluids, including, fresh water, 2% KCl water, and 9.0- and 9.8-lbm/gal NaCl brines.

One of the most significant observations during these tests was the discovery of circulation currents that were maintained in the cement column for times that exceeded 1-1/2 hours after dumping. It is surmised that the circulation results from the displacement of lighter fluid by heavier cement particles. The circulation paths were especially discernable at deviated conditions greater than 10°.

Also noted was the dispersion of fine particles uphole as the cement dumped from the bailer. The degree of fines dispersion was related to several factors, but the greatest influence was that due to the annular gap between casing ID and bailer OD. As shown in Table 2, substantial dispersion was visually evident when the gap was small; far less dispersion occurred when the gap was large. A 2-inch bailer inside 3-1/2-inch casing had fines disperse 108 inches uphole, while the same bailer inside 9-5/8-inch casing caused a dispersion of only 12 inches. Similarly, a 1-3/8-inch bailer inside 3-1/2-inch casing caused fines to disperse only 39 inches. The table also shows that dispersion in fresh water and 2% KCl were greater than that obtained in 9.0- and 9.8-lbm/gal NaCl solutions.

An interesting effect was also noticed when dumping in deviated conditions -- the slurry exited the bailer and slid down the low side of the pipe with minimal dilution. Results from Table 3 show that excellent densities were maintained when dumping at 60° deviations. These densities were significantly higher than those obtained at 30°; similarly, the densities at 30° were higher than those obtained during vertical runs.

Another important observation was confirmation that dumping as close to a bridge as possible is desirable. A comparison of tests in Table 4 shows how greater cement density is maintained as the distance between the bailer nose and bridge is decreased. At a dump height of 1 foot, the 5-minute slurry density was 77% of the original value, whereas at 3-feet and 6-feet, less than 60% of the original density resulted.

Table 5 compares the results of dumping at 30° using gravity versus positive displacement bailers. The data are similar, and indicate both methods of placing cement give equivalent results. This is notable since the use of positive displacement bailers has often been considered in the past to be a preferred placement technique for dump bailer slurries.

FULL-SCALE CURED PLUG TESTS

The purpose of these tests was to evaluate the integrity of cured cement plugs that had been placed in casing by dump bailers. To conduct these tests, several pieces of casing were procured for use as test fixtures; the length of each piece was 18 feet. The casing fixtures were filled with water and lowered into a heated chamber. A schematic of the test arrangement is shown in Figure 6. A typical test was conducted according to the following procedure:

(1) An appropriate dump bailer was selected and filled with cement.

(2) The bailer was lowered to a prescribed distance from the bottom of the fixture and activated.

(3) Cement was allowed to fall from the bailer to build a plug. The bailer was pulled after waiting three minutes.

(4) Subsequent runs were made with bailers after waiting an appropriate time. After the last run, the cement was allowed to harden at temperature (nominally 160°F).

(5) The casing fixtures were pulled, cut apart to reveal the condition of the cured plug, and photograped.

Figure 7 is a photograph of a typical test specimen. This result was obtained by making three 2-inch bailer runs in 7-5/8-inch casing. The time between the first and second dumps was 1-1/2 hours; the time between the second and third dumps was 2-1/2 hours. Examination of this sample revealed an observation that was common to all tests, in that, whenever plugs are placed by dump bailers, three distinct regions are formed:

(1) A lowermost area of competent cement. This cement can be considered set, and has measurable compressive strength. (In this test program, the values ranged from 1200 psi to over 11,000 psi after 42 hours cure). Cement in this category is colored black in Figures 7 to 11.

(2) A transition section of material that ranges from firm to soft. It is set cement, but possesses little or no measurable compressive strength. This material cannot be considered competent as a plug, but it will however, support the mechanical weight of a bailer. Cement in this category is colored grey in the figures.

(3) An upper region of gel material. This portion of the plug is too dilute to harden and will not support the mechanical weight of a bailer. It will, however, support the column weight of additional runs of dumped cement. This region is colored white in the figures.

The photograph (and its schematic representation) in Figure 7 shows how segregation occurs with multiple bailer runs. In this test, each of the three runs should give a calculated fillup of 10 inches (30 inches total). It is clearly seen that only about half of the dumped material (5 inches per run) contributes to the formation of a competent plug; the remainder disperses up the hole and forms a barrier that prevents cement from subsequent runs from falling to bottom. Thus, in this instance, a plug with a calculated fillup of 30 inches grew 77% to yield a 53-inch plug. This type of unanticipated growth shows why it can be difficult to predict downhole fillup heights.

Examination of Figure 8 shows the benefit of dumping as close to the bridge as possible. Whenever the bailer is one foot from the bridge, less growth (or overfill) occurs, fewer segregated regions are formed, and a longer competent plug is created than when dumping at heights of 3 feet or 6 feet. The amount of overfill at one foot is 46%, as compared to 85% and 92% for 3 foot and 6 foot dump heights, respectively. These results were obtained by running 1-5/8- inch gravity bailers in 5-1/2-inch casing. It should be noted that no region of competent cement was found in the case of dumping six feet above the bridge. This indicates that the sometimes used field practice of "yo-yoing" the bailer several feet above the bridge to make certain the cement is dumped is actually detrimental to forming an effective plug.

Figure 9 compares the placement of plugs at different deviations. The results were obtained by making three runs of 1-5/8-inch gravity bailers in 5-1/2-inch casing. The interval between dumps was 1-1/2 hours. The figure shows it is indeed possible to place competent plugs in deviated wellbores.

Figure 10 compares plugs that were created in two different fluids using gravity and positive displacement bailers. The results show neither bailer has clear advantages over the other, again reinforcing the notion from visual tests that gravity bailers are adequate for placing properly designed cement slurries.

Figure 11 shows how over-retarding (or alternately, decreasing the time between bailer runs) results in the formation of more compact plugs.

SHEAR BOND TESTS

The purpose of this test series was to determine the bonded shear strength of cured cement plugs which had been set in fixtures representing four different casing sizes (3-1/2-, 4-1/2-, 5-1/2-, and 7-5/8-inch). Figure 12 schematically shows a typical shear bond fixture. Situations representing both water-wet and oil-wet casing were investigated.

Shear bond values in water-wet casing ranged from a high of 250 psi to a low of 9 psi. The reasons for this wide variation are not presently known and warrant further study. The tests did show, however, that shear bond strengths in water-wet casing generally ranged three to six times greater than in oil-wet pipe.

GRAVEL PACK PENETRATION TESTS

During this test series, the penetration characteristics of plugging materials in gravel pack completions were investigated. For the first part of the test series, a visual test cell was constructed to observe migration characteristics of microgrind cement in a gravel pack environment. Figure 13 schematically shows the arrangement. The plexiglass fixture was semi-cylindrical and was configured to represent 9-5/8-inch casing in which an 8-gauge, 5-inch gravel pack screen had been installed. Simulated perforation tunnels were made from plexiglass also, and were mounted around the fixture according to a typical high-density (12 shot/ft) gravel pack shot pattern. The annular gap between screen and casing ID was packed with the desired gravel size, either 20/40 or 40/60.

The cement slurries for these tests were based on microgrind cements (10 micron average particle size); the slurry weights ranged from 11.4 to 12.6 lbm/gal.

Three observations were noted from these tests:

(1) Cement migration into the gravel pack occurred very rapidly as long as a path (such as an open perforation tunnel) was nearby to allow fluid displacement. In regions where fluid was static (between perforation tunnels or at blocked tunnels), cement penetration was minimal.

(2) The microgrind cement penetrated the 20/40 pack faster and more completely than the 40/60 gravel pack.

(3) The cement that did penetrate both gravel packs appeared to be dilute.

For the second part of the test series, the penetration characteristics of phenolic resin in full-scale gravel pack models under temperature were investigated. The experimental setup consisted of two 9-5/8-inch gravel pack fixtures; the first was configured with a 12-gauge screen and 20/40 sand, while the second used an 8-gauge screen with 40/60 sand. Figure 14 shows the test setup. Circulation ports that represented open perforations were positioned on the outside of the fixture; in addition, recirculation tubes (which served as a path for displaced fluid) were routed from the circulation ports back to near the top of the fixture. The gravel pack screen was plugged approximately two feet from the bottom of the fixture in order to provide a bridge on which to dump resin.

The test procedure consisted of the following steps:

(1) Each fixture was lowered into a heated oil bath whose temperature was maintained between 140°F and 170°F for the entire test (nominally 160°F).

(2) The fixtures were filled with 9.0-lbm/gal NaCl and then packed around the screen/casing annulus with either 20/40 or 40/60 sand.

(3) Phenolic resin (10.2 lbm/gal) was loaded into a specially constructed dump bailer that was made from 1.062-inch ID line pipe; a 3-gallon reservoir was mounted on top of the line pipe to give additional volume.

(4) The loaded dump bailer was lowered inside the gravel pack screen and positioned 4 feet from the top of the plug. The bailer remained static for 45 minutes (to achieve thermal equilibrium) and was then activated using a conventional blasting cap at the lower end.

(5) The open bailer was allowed to drain and then pulled from the fixture. It was subsequently cleaned with methanol and prepared for the next run.

(6) A second dump was made in each fixture 1-1/2 hours later. This time was typical of run times encountered in Gulf Coast field operations.

(7) The resin was allowed to cure at temperature for 36 hours. The fixtures were then pulled from the heated bath and a hydraulic hand pump attached to selected circulation ports. Pressure was applied to determine the degree of seal obtained at the port.

(8) The plugs were then cut apart and examined visually.

Figure 15 is a photograph of the cured plug that formed inside the 40/60 model. As can be seen, the upper third of the plug is tapered, or cone-shaped, while the lower two-thirds extend to the full ID of the casing. Thus, in the lower region, the resin was able to penetrate to the ID of the 9-5/8- inch casing; in fact, the resin in that region actually penetrated most of the open ports. When hydraulic pressure was slowly applied using a hand pump, it was found that most ports would hold approximately 100 psi during pumping and then bleed back to about 30 psi a few seconds after pumping stopped. The ports would maintain 30 psi for a minute or so before slowly bleeding to zero. One port, however, did hold 100 psi for over 15 minutes. These results may confirm a field observation, namely, resin plugs do not always completely shut off water production, but they do often significantly reduce it. The photograph also shows that the resin in the annulus did not appreciably fall below the level of the barrier inside the screen (only about 1 inch).

Figure 16 is a photograph of the cured plug which formed inside the 20/40 model. Qualitatively, this plug differs from the one set in 40/60 sand in two respects.

(1) The upper portion is not cone-shaped; instead, it is rather flat.

(2) The resin in the annulus dropped somewhat lower than in the previous case (4 inches below the barrier versus 1 inch).

Both of these effects are probably attributable to the greater permeability in the 20/40 pack.

During pressurization tests with a hand pump, the ports held pressure in about the same fashion as the 40/60 test, that is, they would maintain about 30 psi for a minute or so before bleeding to zero.

CONCLUSIONS AND RECOMMENDATIONS

As a result of this laboratory study, information has been obtained which should lead to the successful placement of cement and resin plugs using thru-tubing dump bailers.

(1) It is possible to design cement slurries that are tailored for dump bailer operations. Delayed gel strength additives are ideally suited for these applications. Determination of static gel strength as a function of time is recommended to ensure mixtures are dumpable.

(2) Prepackaged cement kits are available for thru-tubing dump bailer applications. Instructions included with the kit should be followed closely to ensure proper mixing and performance. A mixing device, screen, and standard mud balance should be used with all cement kits. The cement should be weighed within ±0.1 lbm/gal of the recommended mix weight, and the slurry should be filtered through a screen to remove any large particles. Downhole temperature must be accurately known so the proper retarder package can be used.

(3) Dumping cement from dump bailers can be a highly dispersive process. Only a portion of the dumped cement actually contributes to formation of a competent plug, and even this material is diluted from its original density. The dilution that occurs during dumping can cause greater fillup heights to be obtained than calculated.

(4) Substantial dispersion occurs when a small annular gap exists between bailer OD and casing ID. Bailer diameter should not be maximized in these situations.

(5) To minimize contamination and dilution, cement should be dumped as close to the bridge as possible. The practice of "yo-yoing" the bailer several feet above the bridge to dump cement is undesirable. Ideally, the bailer should remain stationary for 2-3 minutes after dumping.

(6) Neither gravity-type or positive-displacement-type bailers showed clear advantages over the other. A gravity bailer is adequate with a properly designed cement slurry.

(7) Cured plugs segregate into hard to soft regions (bottom to top) with distinct boundaries between multiple runs. The gel layer in the diluted, upper portion of a plug can support subsequent dumps of cement and yield higher than expected plug tops. Minimizing time between dumps or over-retarding cement will minimize segregation between runs and lead to a more compact plug.

(8) Higher density slurries are maintained whenever the cement is dumped in deviated wells. The presence of a boundary (the casing) seems to protect the slurry from contamination as it slides down the low side. At higher deviations, the velocity at which cement exits a gravity bailer is less; this may also contribute to less contamination.

(9) Shear bond values in water-wet casing were inconsistent; the reasons are not presently known and warrant further study. Even with this inconsistency, shear bond strengths in water-wet casing generally ranged three to six times greater than those in oil-wet casing.

(10) This testing indicates microgrind cement (10-micron average particle size) does not appear to be effective for plugging back 20/40 and 40/60 gravel pack wells using thru-tubing dump bailers. Visual inspection during the test program showed that the cement suffered dilution as it penetrated through the pack.

(11) Phenolic resins are effective for plugging back gravel pack wells. Tests showed resins can be dumped from a bailer and penetrate 20/40 and 40/60 gravel packs that are typical of Gulf Coast completions. Plugs created by this method typically do not hold high static pressure, but instead, provide some degree of resistance to flowing fluid.

FUTURE STUDY

This laboratory investigation revealed areas for future study:

(1) The role of expansive additives in increasing shear bond strengths (across several temperature ranges).

(2) The use of oil-based cements as a means to reduce dispersion during dumping.

(3) The use of microgrind cements with particle sizes less than 10 microns to plug back gravel pack completions.

(4) The testing of other resin systems in gravel pack models at temperatures other than 160°F.

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SI METRIC CONVERSION FACTORS

ft	x 3.048*	E-01	= m
°F	(°F-32)/1.8		= °C
gal	x 3.785 412	E-03	= m^3
in.	x 2.54*	E+00	= cm
lbf/100 ft^2	x 4.788 026	E-01	= Pa
lbm	x 4.535 924	E-01	= kg
psi	x 6.894 757	E+00	= kPa

*Conversion factor is exact.

Table 1. Static Gel Strength and Compressive Strength Development

			SGS[1] DEVELOPMENT			COMPRESSIVE STRENGTH[2]		
Temperature Bracket (°F)	Retarder System	Test Temperature (°F)	Time To Temperature (Hr:Min)	Time To 100 lbs SGS[1] (Hr:Min)	Time To 500 lbs SGS[1] (Hr:Min)	Initial Set[3] Time (Hr:Min)	Time To 500 psi (Hr:Min)	Strength @ 24 Hr (psi)
80 - 125	None	80	-	-	-	10:09	17:43	820
	None	125	0:28	1:42	2:20	5:12	8:21	1500
125 - 180	A	125	-	-	-	4:37	7:06	1825
	A	180	0:50	3:36	4:21	4:16	5:45	1900
180 - 225	B	180	-	-	-	5:37	7:15	1800
	B	225	1:13	1:18[4]	1:39[4]	5:53	6:50	1975
225 - 250	C	225	-	-	-	7:57	10:14	1825
	C	250	1:25	2:30[4]	2:55[4]	4:34	6:05	2050
250 - 275	D	250	-	-	-	9:30	11:25	2025
	D	275	1:38	2:34	3:00	3:34	5:07	2125
275 - 300	E	275	-	-	-	10:56	13:18	1450
	E	300	1:50	2:19	2:31	6:24	8:25	2850

[1] SGS = Static Gel Strength in units of lbf/100 ft^2.

[2] Measured by Ultrasonic Cement Analyzer (UCA)

[3] The SGS equivalent of initial set is estimated to be 72,000 lbf/100 ft^2.
This is approximately equal to a compressive strength of 15 to 20 psi (from Reference 5).

[4] These values generated from a different batch of cement.

Table 2. Visual Tests - Height of Fines Dispersion in Different Bailer and Casing Combinations (Vertical Conditions)

Casing Size (in)	Bailer Size (in)	Well Fluid	Height of Fines Dispersion Above Bailer Bottom (in)
3-1/2	2	Fresh Water	108
9-5/8	2	Fresh Water	12
3-1/2	1-3/8	Fresh Water	39
5-1/2	1-5/8	Fresh Water	25
5-1/2	1-5/8	2% KCl	36
5-1/2	1-5/8	9.0 lbm/gal NaCl	22
5-1/2	1-5/8	9.8 lbm/gal NaCl	19

Table 3. Deviation Comparison (1-5/8-inch bailers in 7-5/8-inch casing)

Deviation	Initial Cement Density (lbm/gal)	Density After Five Minutes Settling (lbm/gal)	Percent of Initial Density
Vertical	16.0	9.5	59%
30°	16.0	13.4	84%
60°	16.0	15.2	95%

Table 4. Dump Height Comparison (1-5/8-inch bailers in 7-5/8-inch casing)

Dump Height (ft)	Initial Cement Density (lbm/gal)	Density After Five Minutes Settling (lbm/gal)	Percent of Initial Density
1	16.0	12.3	77%
3	16.0	9.5	59%
6	15.9	9.3	58%

Table 5. Comparison of Gravity and Positive Displacement Bailers (inside 5-1/2-inch casing at 30° deviation)

Bailer Size and Type	Initial Cement Density (lbm/gal)	Density After Five Minutes Settling (lbm/gal)	Percent of Initial Density
1-5/8-inch Gravity	15.9	14.2	89%
1-11/16-inch Positive Displacement	16.0	14.4	90%

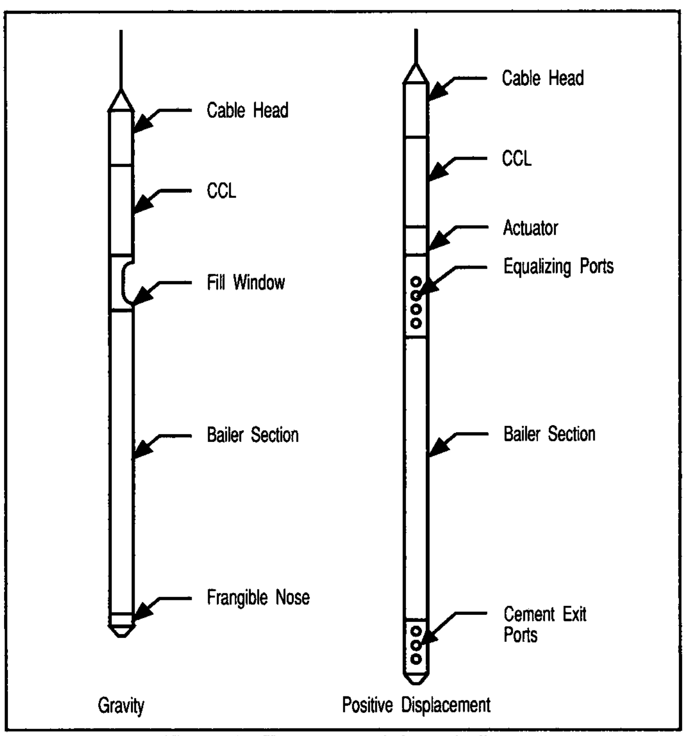

Figure 1. Two types of dump bailers.

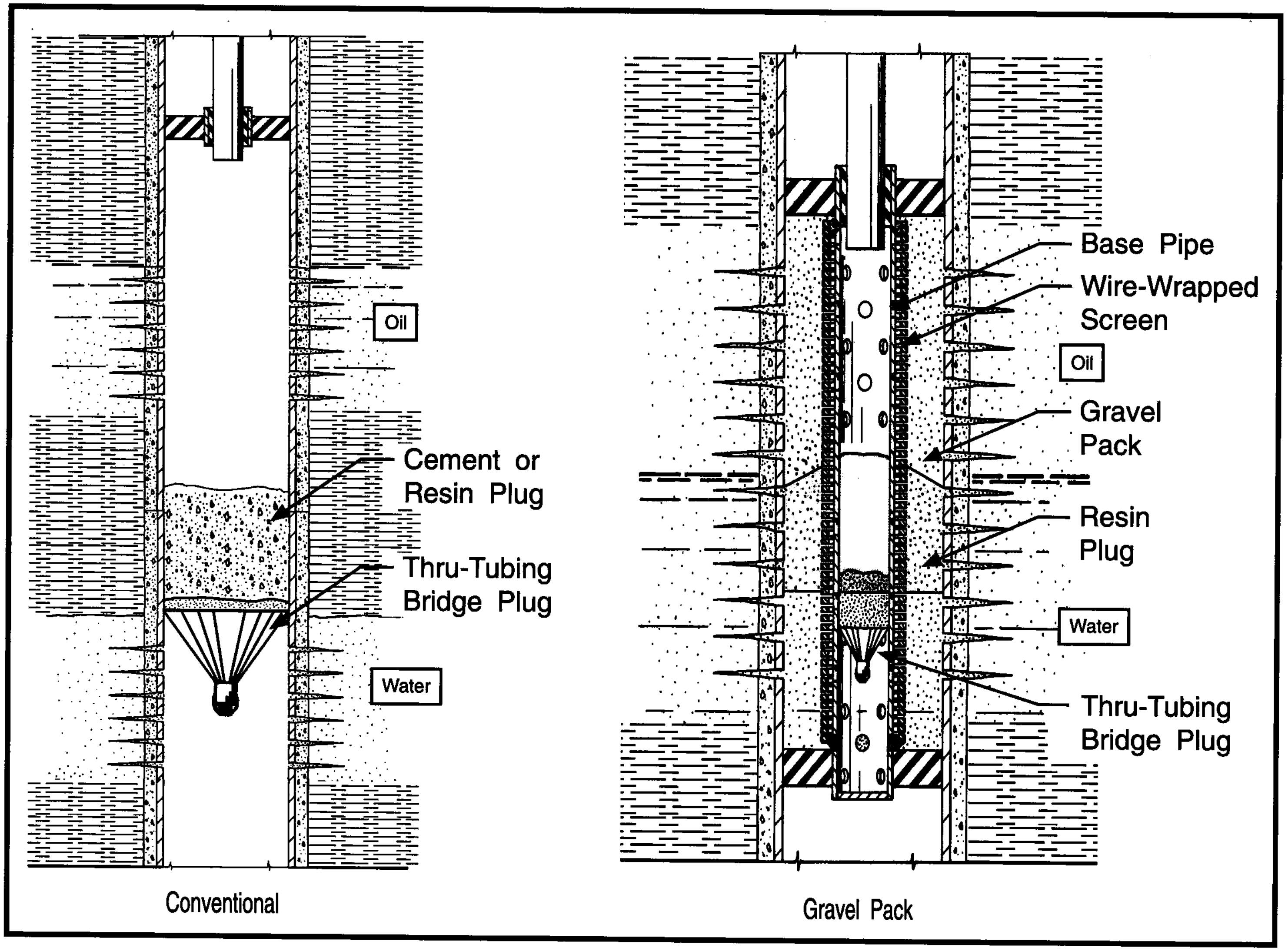

Figure 2. Types of thru-tubing plugbacks.

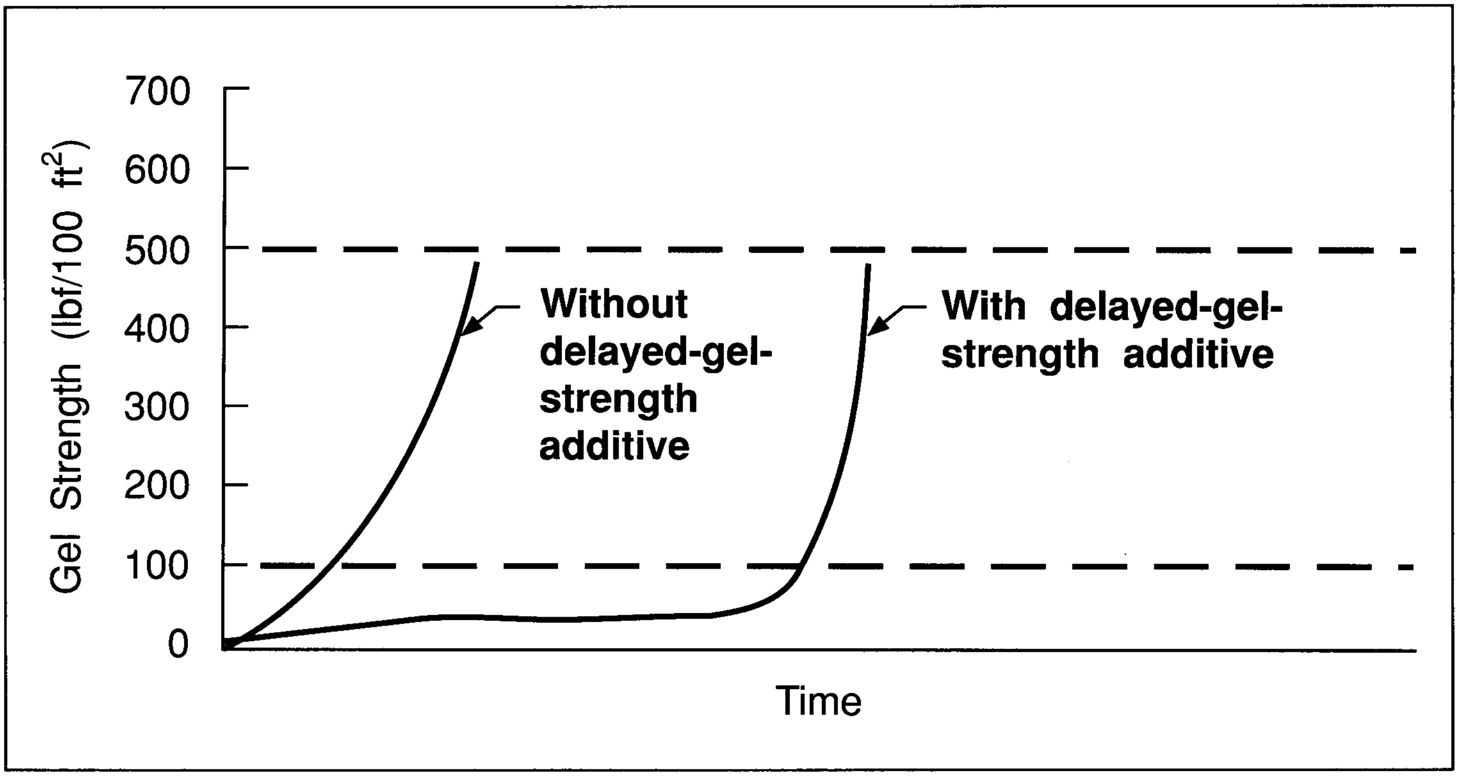

Figure 3. Comparison of gel strength development (after Ref. 4).

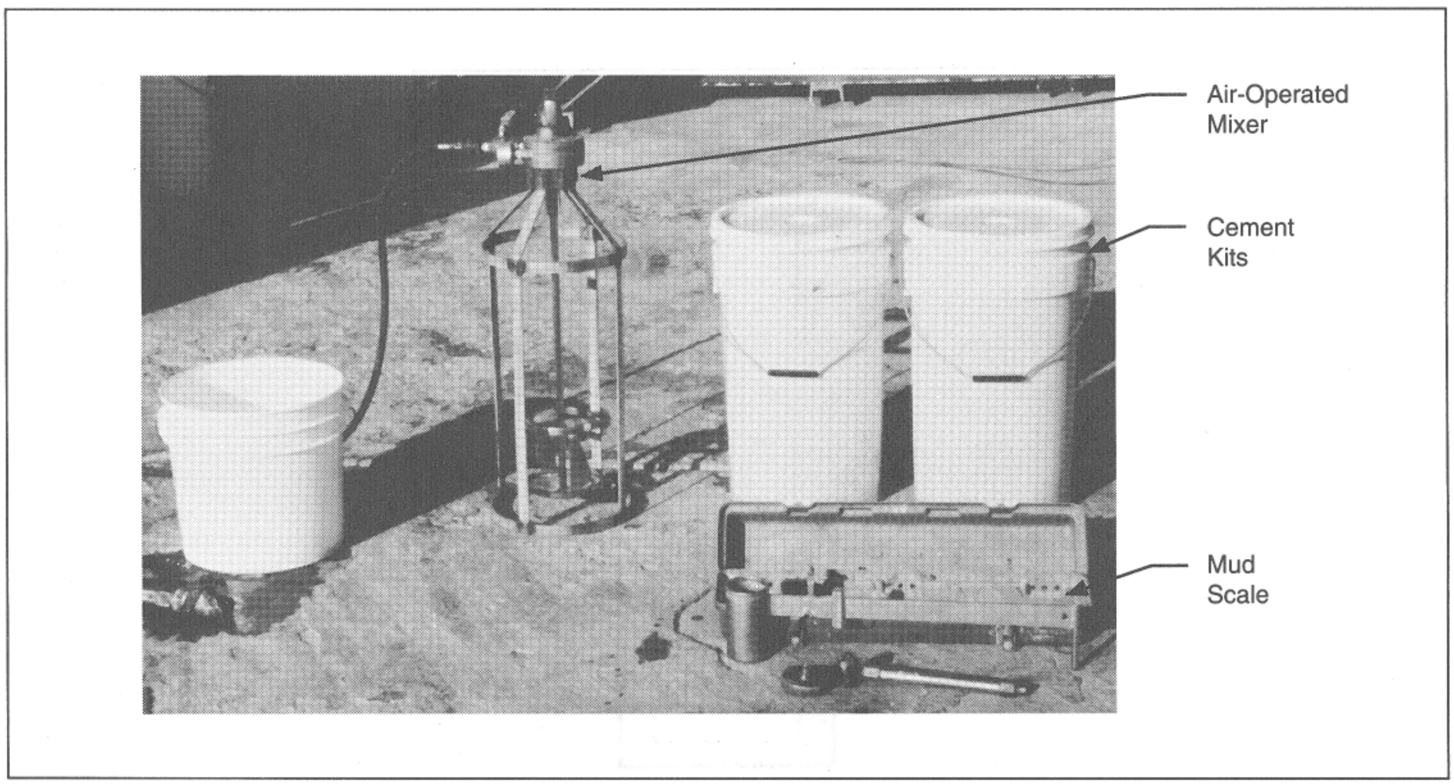

Figure 4. Support equipment for dump bailer operations.

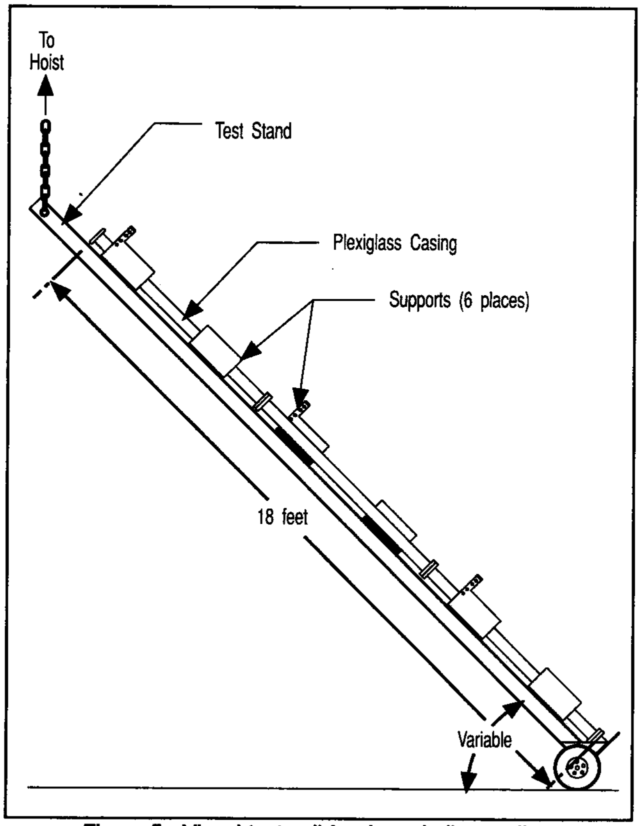

Figure 5. Visual test cell for dump bailer studies.

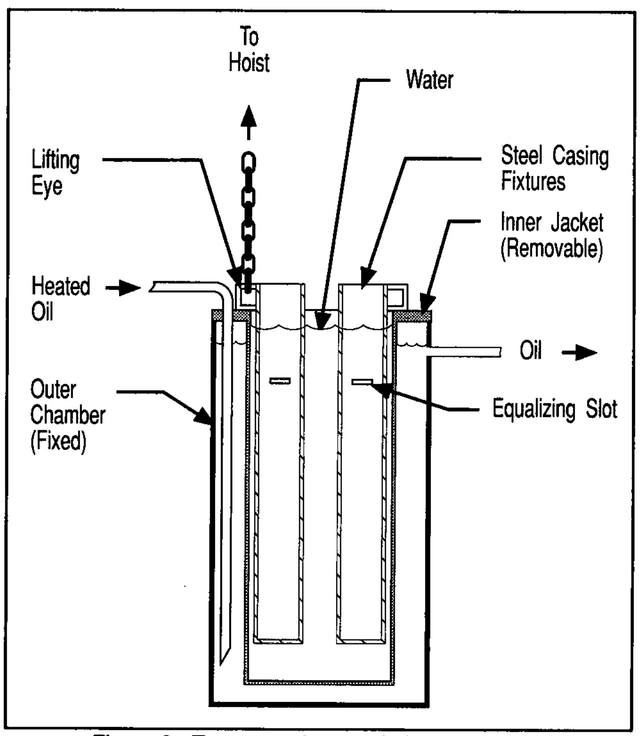

Figure 6. Test setup for cured plug test series.

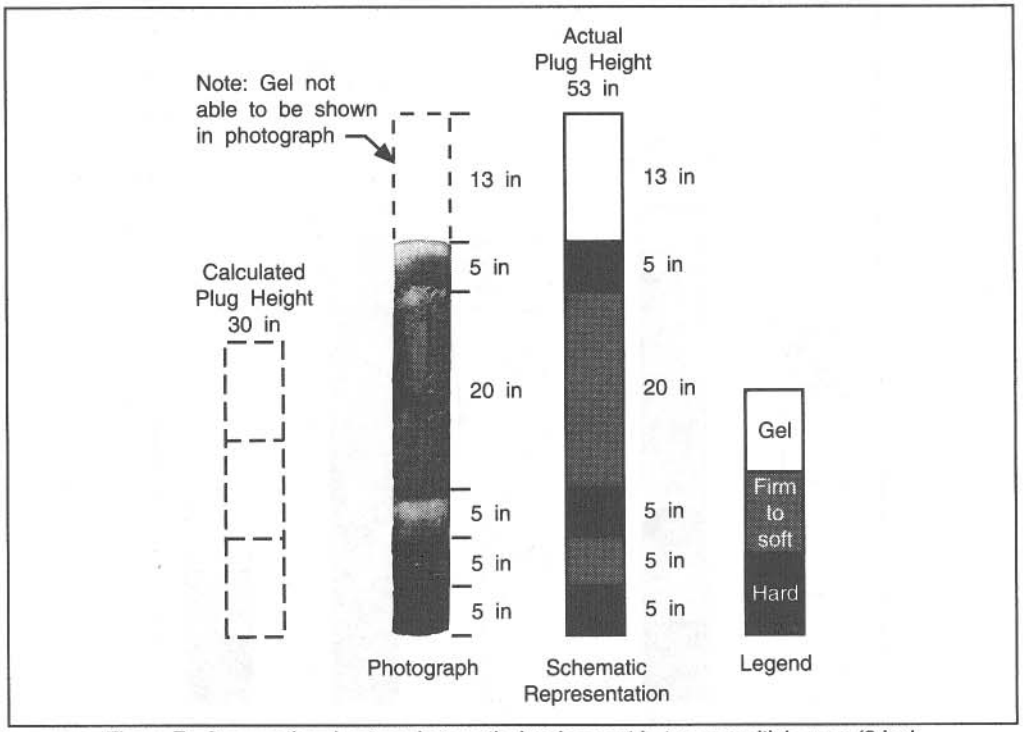

Figure 7. Segregation due to gel strength development between multiple runs (2-inch bailer in 7-5/8-inch casing; three runs).

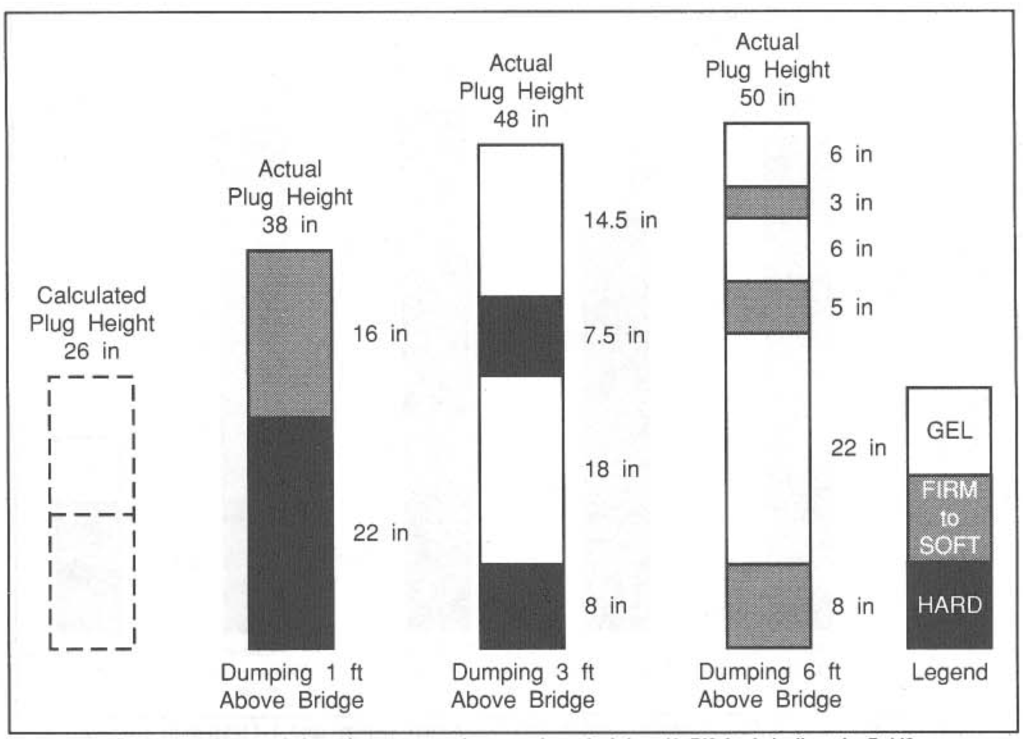

Figure 8. Effect of dumping cement from various heights (1-5/8-inch bailers in 5-1/2-inch casing; two runs each case).

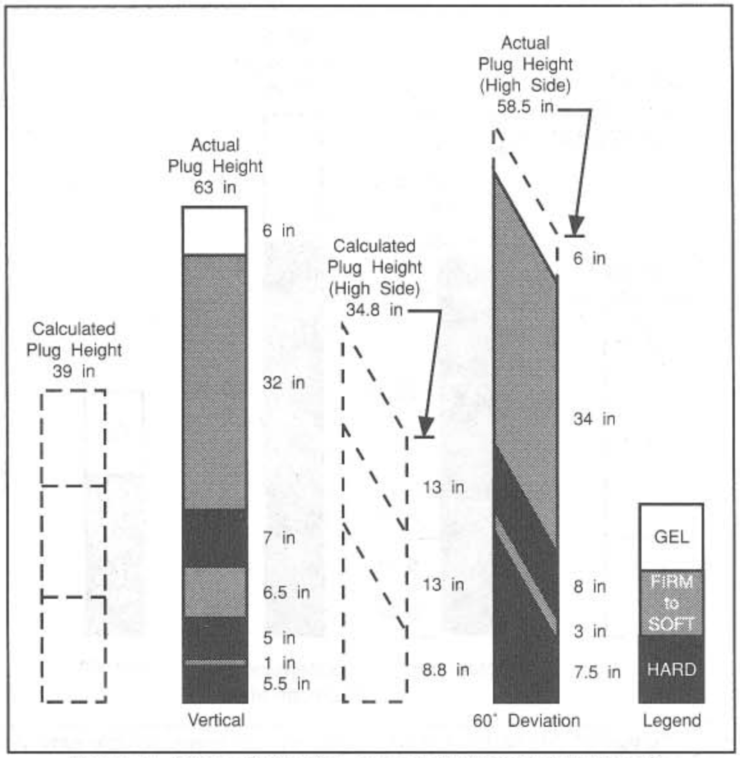

Figure 9. Effect of dumping cement at different deviations (1-5/8-inch bailers in 5-1/2-inch casing; three dumps each case).

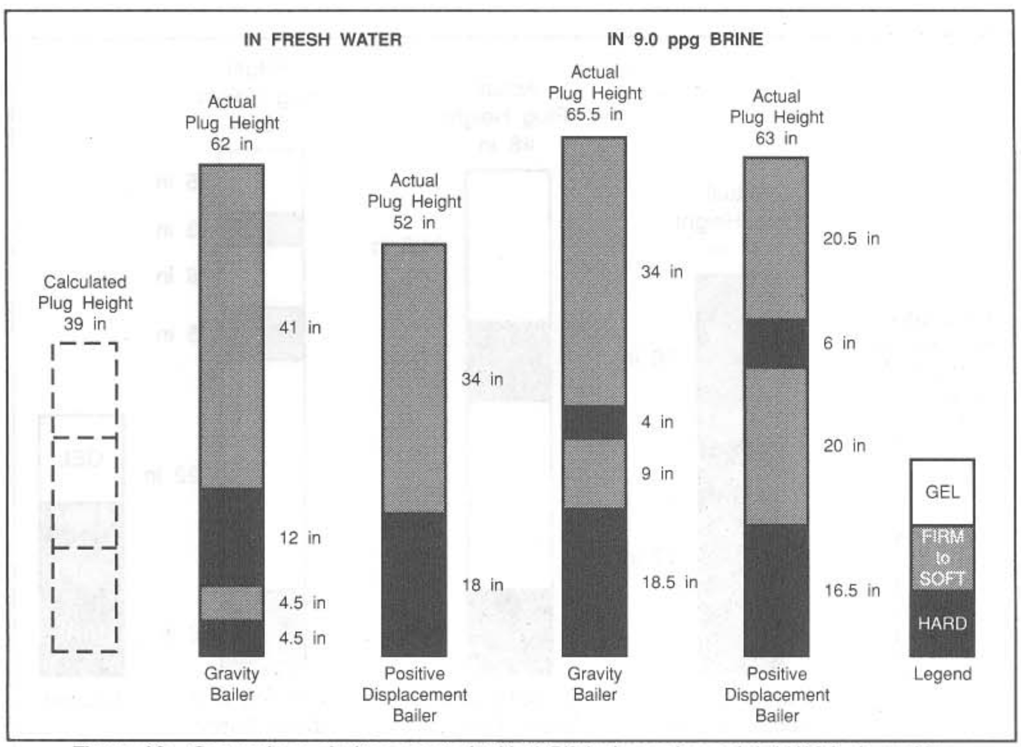

Figure 10. Comparison of plugs created with 1-5/8-inch gravity and 1-11/16-inch positive displacement dump bailers (5-1/2-inch casing; three runs each case).

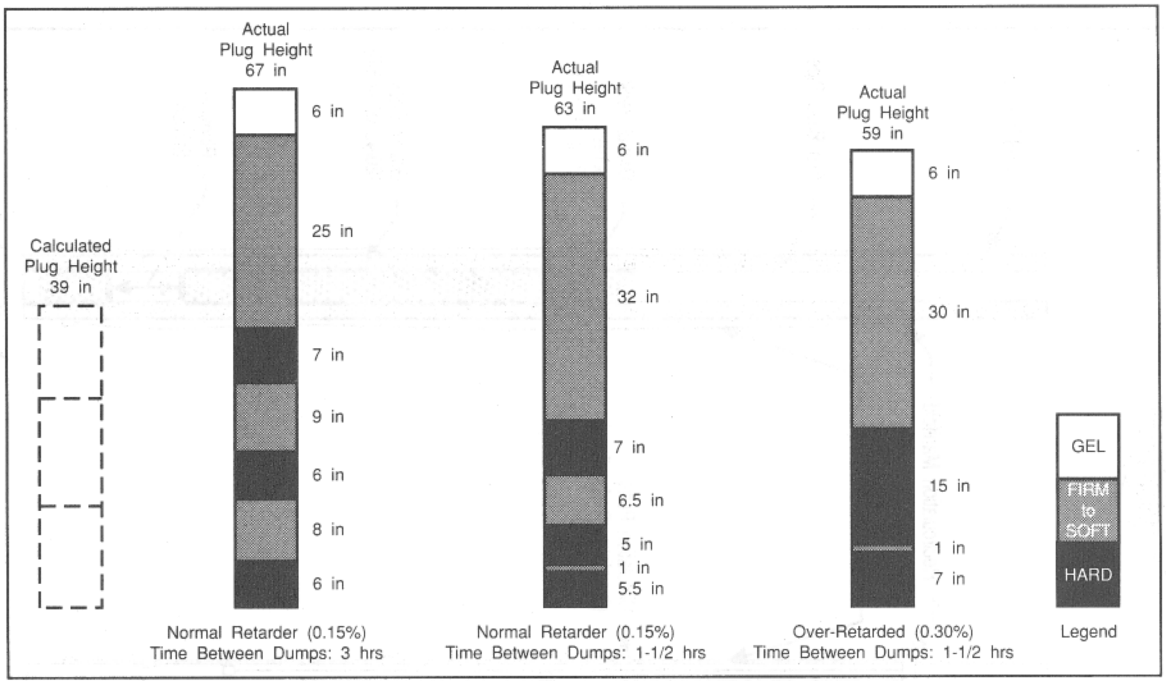

Figure 11. Effect of over-retarding cement and changing time between dumps (1-5/8-inch bailers in 5-1/2-inch casing; three dumps each case).

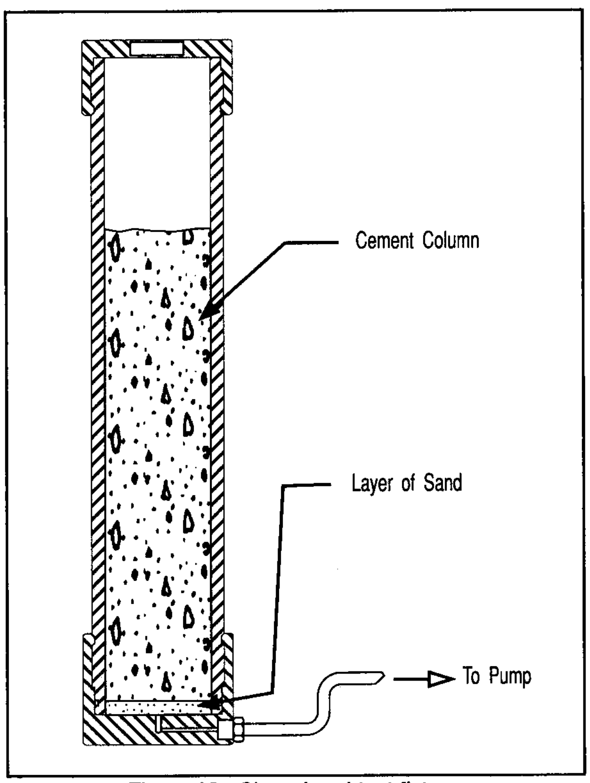

Figure 12. Shear bond test fixture.

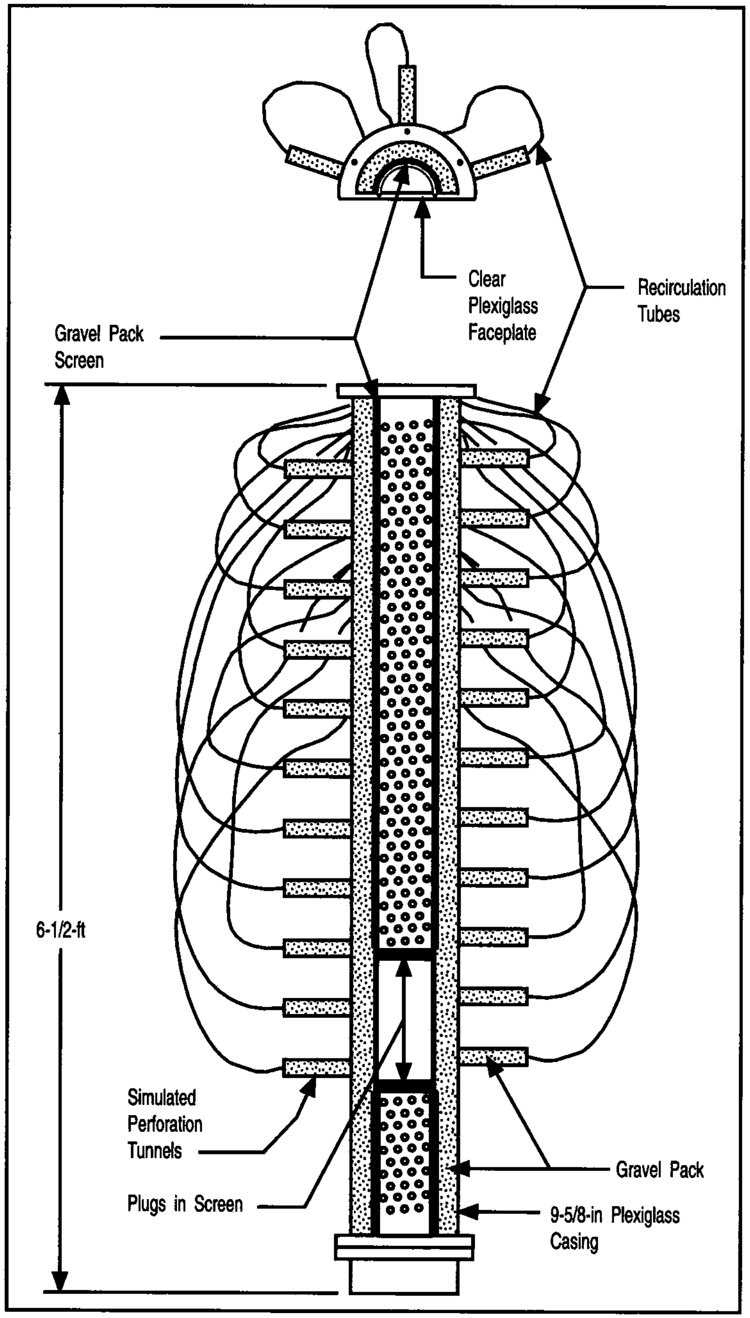

Figure 13. Semi-cylindrical gravel pack test fixture.

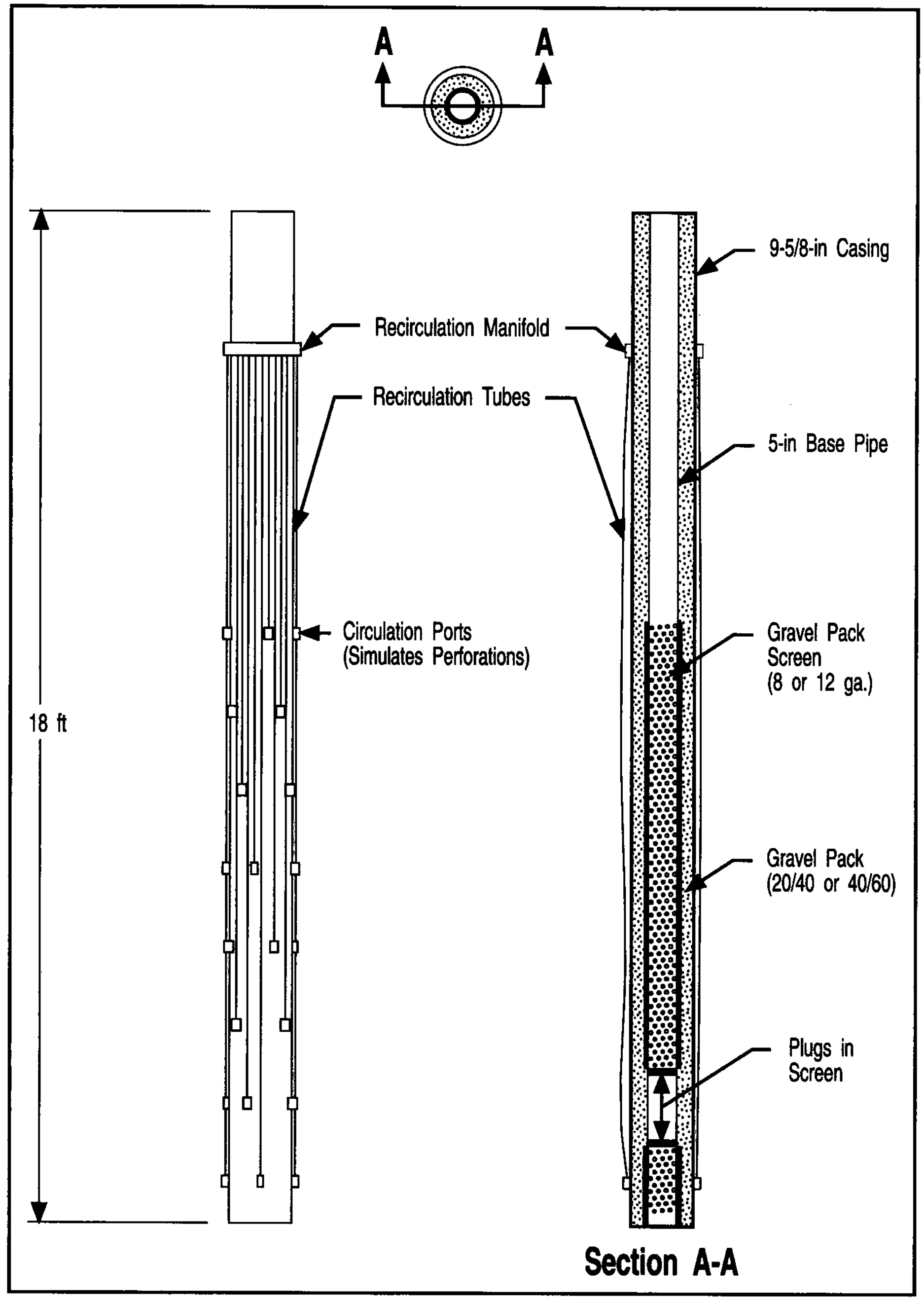

Figure 14. Test setup for full scale resin tests.

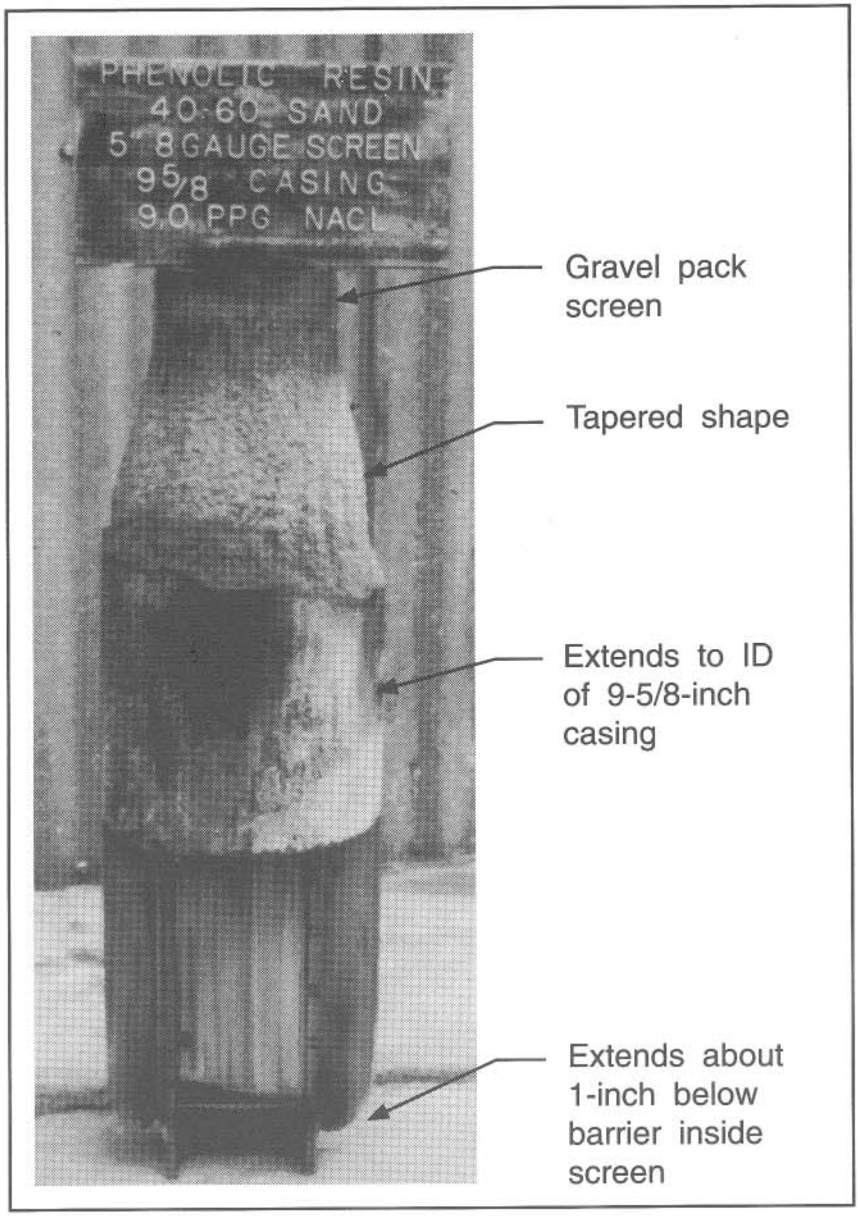

Figure 15. Photograph of resin plug formed in 40/60 gravel pack.

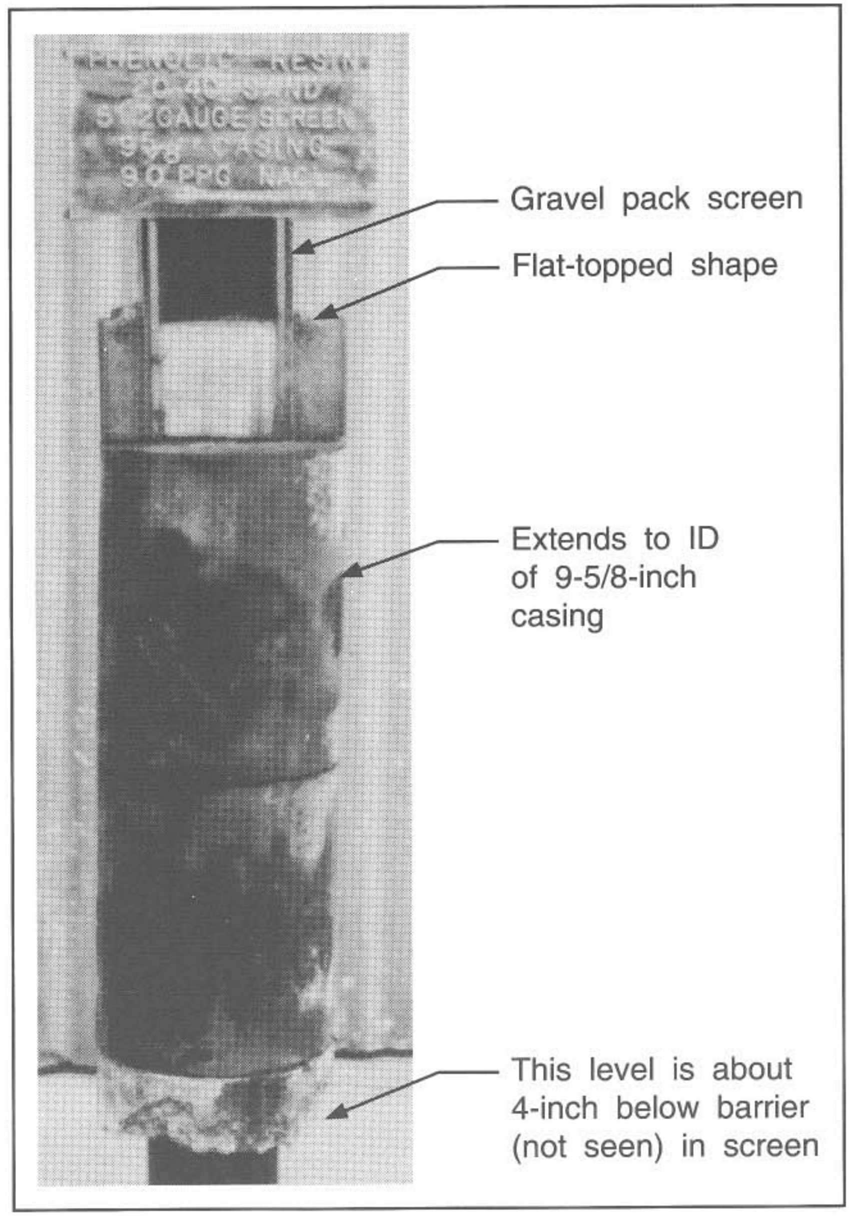

Figure 16. Photograph of resin plug formed in 20/40 gravel pack.