Screenings
from the Soil Research Lab

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CARE AND SHOOTING OF GROUTS

Early man, the hunter, seldom dug a hole in the ground except to cool a watermelon or bury a ripe neighbor. Furthermore the Great Spirit usually tabooed hard work on Sundays and other days, except by the women.

Now in the cadence of decades, the Twentieth Century is turning a deep revolution in architecture. When man took to the air he soon became so afraid of himself he is a new burrowing animal, brave and wise like a rabbit. Fortunately he still has his wits--save the governments first; women and children come after.

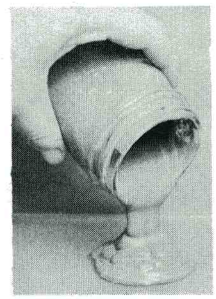
Shelters, mines, tunnels, basements, wine cellars, trenches, subway excavations, etc., often introduce seepage water, mold and untidiness, plus occasional trench-foot, -mouth, and -fever. Tunnels are usually pressurized to help keep water out during construction, and cemented to keep it out later. Otherwise, man the pumps, sink, swim, or pump grout.

Don't Be Gruel

Grout, not to be confused with gout, which is unrelated, is thin, soupy mortar. In Anglo-Saxon, grout or "grut" meant grain soup or gruel. Modern gruts are oatmeal, popular because it "sticks to the ribs," and the new liquid diets, popular because they do not. Similar mixtures once favored by librarians have largely been replaced by rubber cement.

Habana Castro is firmly founded on capitalistic grout. Coral underneath the block-long hotel took 5500 cu yd of grout. (See inset at right.)

Perhaps from the flavor of it, the word "grut" or "grout" came to mean dregs. "Grouty" means grouchy, probably from drinking too much grout.



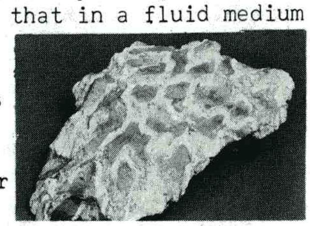
Grout.

Maybe from the thickness of it, "grout" also came to be applied to any soupy or pasty mortar which could be used to fill voids, whether in stomachs or between bricks or stones. It is in this latter sense that "grout" has stuck with us until now. For example, stone pavements or walls were once grouted wi.. mud to add strength and waterproofing.

Pressure

For centuries the art of grouting bricks and stones was as routine as the art of lying and not nearly so common; then modern innovations elevated both into respective realms of engineering and practical politics.

The transition came about through diligent application of a legislative principle called pressure. Anybody knows that in a fluid medium like grout or politics a little pressure carries a long way. Pressure forces grout into fine rock fissures or soil pores, increasing strength and water tightness.



APPLICATIONS

Presently the major use of grout is to improve natural rocks and soils, where it functions as a combination rubber pants and foundation garment. Either it reduces threat of flooding, firms up a sloppy undercarriage, or does both.[1,2]

[1] There is no footnote 1.
[2] See footnote 1. This way we keep the footnotes straight--very necessary when you write things backwards.

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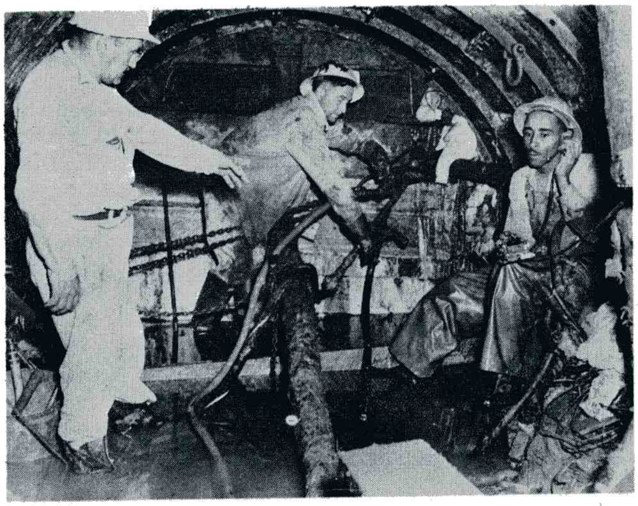
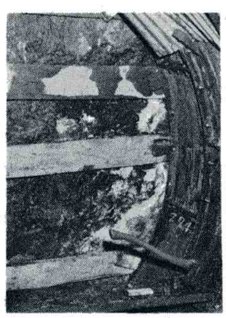
For example, tunneling into a fast flowing water zone such as gravel could cause an unreasonable number of drownings among the crew. Before this happens, pipes can be set out from the tunnel to pump the gravel full of grout, which sets tighter than an old maid's jaw at a romantic movie.



Grouting of a leaky sand in a mine tunnel near Grand Rapids, Minn.; note water seeping in at right. Pipes and valves are arranged for a two-shot (Joosten) grouting process, discussed later. Below, same tunnel after grouting; sand tests at 480 psi.

Alternately the tunnel, subway, mine shaft, privy or fallout shelter might encounter loose rock or quicksand, making further digging impossible. One remedy is hardening by grouting. A bad dose of tunnel quicksand is practically impossible to handle any other way.

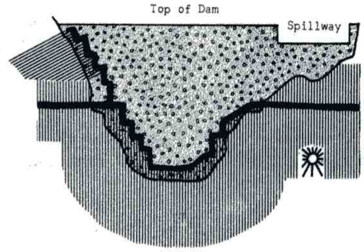


Still Water Runs Deep

Unfortunately still water which runs deep under dams does not stay in the reservoir. This is one way to combat water skiing.

Most dams rest on permeable strata which require sealing if the dam is to hold water. Leaks may be through buried gravel--very common in river valleys--or through cracks or caverns in the bedrock. A cutoff wall of concrete, clay, or sheet pile may do the job, but deep troubles are best handled by grouting.

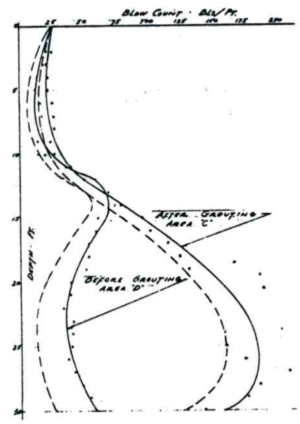
"Curtain grouting" is achieved by drilling one or more lines of closely spaced holes where you want the curtain, for example under the axis of a dam. When the holes are pumped they form a more or less solid vertical wall.



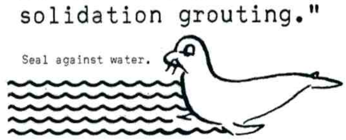
Downstream look at Kortes Dam, Wyoming. Parallel lines show curtain grouting 100' deep in fractured granite, with holes spaced 5' apart. Drilling and grouting were done from inside tunnels and galleries (heavy line) after dam was built.

Consolidation Grouting

Another arrangement which puts in a grout layer horizontally is "Blanket grouting" done with a network of shallow holes. Blanket grouting is particularly useful to increase bearing capacity, for example under a building. It then becomes "consolidation grouting."



Penetration tests of Polaris missile site, before and after grouting.



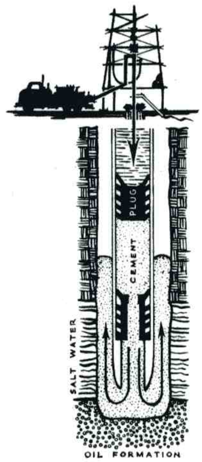
Speaking of under a building, some basements occasionally turn into swimming pools, indicating the time is right to tile, grout, or hire a slick realtor. Excavations for buildings sometimes strike more water than the pumps can handle, or if they can handle it the neighbor's wells go dry. Because most workmen object to working in 12 feet of water without overshoes, a needed remedy may be grouting. The bordering areas can be curtain-grouted or the bottom blanket-grouted or both.

Frequently in city excavations the problem is not water so much as to avoid unwanted calls from the neighbors, who may drop in unexpectedly any time the soil next to the excavation happens to give away. Answers are shoring and perhaps grouting.

Oil's Well that Ends Well

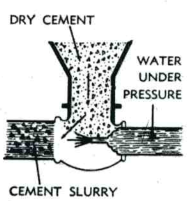
As soon as man dropped his harpoon and took to close order drill, the crude began to erupt, "crude" meaning oil? It was soon discovered that a well drilled through both oil bearing and water bearing strata would show a deceitful tendency to produce water. Initial grouting tries about 1903 involved drilling through the water zone, dumping cement grout in the bottom of the well with a special trap-door bailer, and lowering well casing into the cement. After a month's wait for the cement to harden, drilling would be resumed into the oil zone.

About 1910 a Californian named A. A. Perkins played it cool and cogent by pumping cement directly through the well casing. Drilling mud already in the well was pushed ahead and kept separate by a travelling plug which ruptured when it hit bottom in order to let the cement through. Another plug introduced at the top of the cement column cleaned out the casing and pushed the cement down, out and up where it was supposed to be, between the casing and the rock.



Perkins patented his method and started the first oil well cementing company. But it was an age of conservatism, and most operators preferred to do their own.

By the 1920's a former Perkins truck driver and well cementer named Erle Halliburton, operating with war surplus trucks and a string of anxious creditors, introduced innovations and portability. Not the least of his improvements was a continuous water-jet mixer that did away with the old mortar box and hoes. Jet mixers now in use can consume from 15 to 50 sacks of cement per minute. Halliburton also invented a measuring device: a weight suspended on a wire rides the top plug down, showing progress of cementing. Special high pressure pumps were used, and business caught on. The ex-truck driver eventually bought out his former boss.



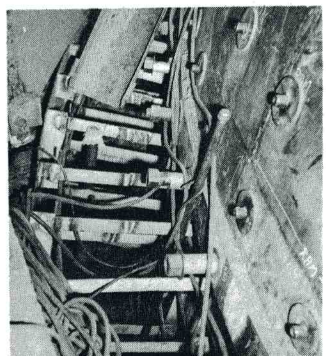
Once an oil well is cemented bottom to top, troublesome water flows no more, but neither does oil. Drilling can open up the bottom, but other potential oil zones farther up the well remain entombed. The Roaring Twenties introduced the wider civilian use of guns, and in 1932 an Iowa State graduate named Walter Wells together with William Lane found a better use than bank robbing. Soon cemented oil well casings were being shot from within. Electrically detonated .45 caliber cartridges shoot radially from a "gun perforator" lowered the proper distance in the well, and holes penetrate casing, cement, and rock to allow hopeful entry of oil.

A special procedure in oil well cementing is called the "squeeze job," which despite the romantic implications is akin to pressure grouting. If a previously cemented and perforated well is flowing all wrong, a special packer may be inserted for local grouting under high pressure.

PREPAKT CONCRETE

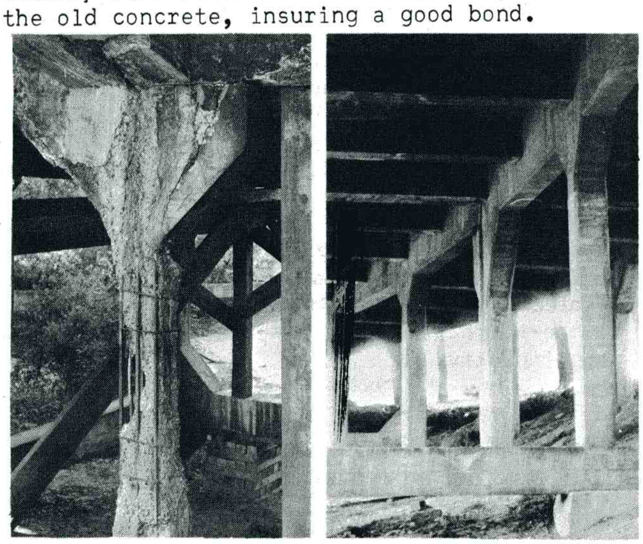
Another most intriguing use of grout is to make a kind of instant concrete. In the Prepakt or Colcrete processes, forms are filled with coarse aggregate, then the aggregate is grouted with sand-cement-water to build concrete. A principle advantage is better interlocking of aggregate, minimizing shrinkage, and increasing strengths to as high as 13,000 psi (one year) or allowing use of less cement--as low as two bags to the cubic yard though three to five is normal.

The grouted concrete process is nicely adapted to fitting concrete in tight places like tunnels, piles, or around closely knit steel. Not that ordinary concrete can't be pumped; it can be and is, but not so far. Underwater installations are also a favorite for the grouted concrete method--they require no de-watering and nobody climbing down into a caisson, and are built quicker in fewer lifts because some 60 percent less material goes through the concrete mixers. Mighty Mackinac bridge sits on Prepakt piers, as does an occasional Texas Tower.



Nuclear reactor shields require special high-density (220 to 275 pcf) concrete with steel, barytes, and iron ore aggregate. This grouted concrete reactor shield is for the good ship Savannah. Note chute for the aggregate, vertical pipes for the grout. To reduce pressure on forms, rate of grout rise was limited to 1 foot per hour.

Grouted concrete does nicely at repairing old crumbly structures because the grout penetrates the old concrete, insuring a good bond.



Highway bridge at Erie, Pa., condamned (left) but then rejuvenated with Prepakt concrete.

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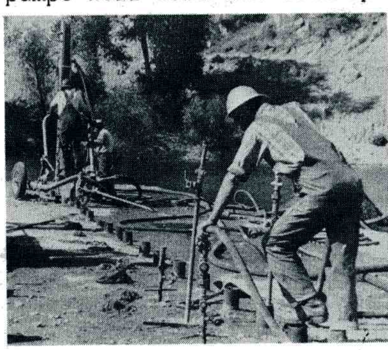
GROUTS

Your doctor would be amazed at the number, variety, and combinations of internal medicines that are pumped down holes in the ground. Everything from sand to cement, clay, acid, water, plastic, asphalt, oat hulls, cellophane, temperament, and chewing tobacco.

Many of the chemical grouts carry trade names loosely connotative of the ingredients, if you already know what they are. Actually the exact recipes are trade secrets, secrecy being the best patent[3]. There also is a little of that chemical or drug industry aura of mysterious nonsense to increase customer loyalty, i.e., augment the snow job.

Cement Grouts

By far the most common grout material is also one of the oldest, called neat cement, neat meaning pure as our tender hearts, and cement meaning portland cement plus water. Neat cement pumps well well and sets up admirably.




Drilling (left) and grouting of river alluvium for a cofferdam. Below, after grouting.

Unfortunately cement mixed with generous amounts of water tends to segregate, allowing the water to "bleed" out. In oil well cementing the weak and segregated bleedings are merely left inside the bottom sections of casing and are later drilled out. Where bleeding is objectionable, as in grouted concrete, high energy mixing applies a tourniquet, by increasing dispersion of the cement with trace hydration. This is so-called "activated" or "colloidal" grout (patd.).

Another alternative is to add something, for example a trace of a rugged detergent which gives similar fluidity with less water and less tendency to bleed. One such additive (patented) is lignin (ligno-sulphonates), a by-product of the paper pulp industry.

Still another tack is to add a trace of gelatin, casein, soap, etc., which tends to coat the cement grains and make a stable colloid. Thus two of the most embarrassingly complex chemical sciences, colloid chemistry and cement chemistry, join hands like Jack and Jill. There is a lot of trial-and-error (often patented).

Cement shrinks a bit on setting, a peculiarly unfortunate circumstance in grouting. Shrinkage is sometimes prevented by addition of a sprinkle of metal dust such as aluminum, calcium, magnesium, or zinc. The metals react with alkali from the cement to produce bubbles of hydrogen gas which not only counteract shrinkage but build up a pressure, aiding grout penetration. Other bubblers which may be used are peroxide, calcium hydride, etc. Very important is not to use too much, or the grout may float off to the moon.

Cement + Filler

Cement is costly enough that where holes are deep or voids are large it is not improper to think of adding a little extender. Sand does nicely in soils with large pore openings, and does not decrease strength of the grout. Usually a little bentonite (montmorillonite clay) also is added to help keep the sand dispersed.

In cavernous problem areas such as limestone (as under most of the dams for TVA) a "prescription" grout may be concocted to try and reduce pumping losses; in goes the sawdust, rock flour, or whatever else looks cheap, bulky, and inanimate.

In many soils and rocks to be grouted, sand grains would cause clogging, and clay may be used as the extender. Whereas a cubic yard of neat cement grout might use 10 sacks of cement, a cubic yard of clay-cement grout may contain one sack (100 lb) of clay and only three of cement, because of the expansion and colloidal behavior of the clay. Lower strength after setting often rules out clay-cement for consolidation grouting, but it is still adequate for sealing leaks. Incidentally, in mixing, the bentonite is added first. That way it disperses better and goes farther.

Cement + Pozzolan

As you may gather, nowadays very little cement and water go into grout holes unaccompanied. Currently the favorite companion is a pozzolan. Pozzolans are fine grained and do not subtract appreciably from long-term strength because they react with lime released by the cement on hydration, building more cementing compound. Fine pozzolans aid dispersion and reduce bleeding. In most areas the cheapest pozzolan is fly ash, a waste product from power plants burning powdered coal. Fly ash has a property admirably suited to pumping--grains are spherical, noticably reducing friction. Most grout now contains up to 50 percent fly ash. Pozzolan also slows the set and allows a longer pumping time, needed in grouting hot rocks in deep tunnels or oil wells.

[3]It is also the best protection against a patent, if through some legal mishap the patent happens to belong to somebody else.

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In very hot rocks or where fast hardening is not required, admixing lime can allow a further saving of cement, replacement going as high as 80 or 100 percent.

Grouting into Sand

Grout, like women and automobiles, can push its way into very tight spaces, but much energy is expended with little corresponding gain in beauty or convenience. Better is to use a finer grout.

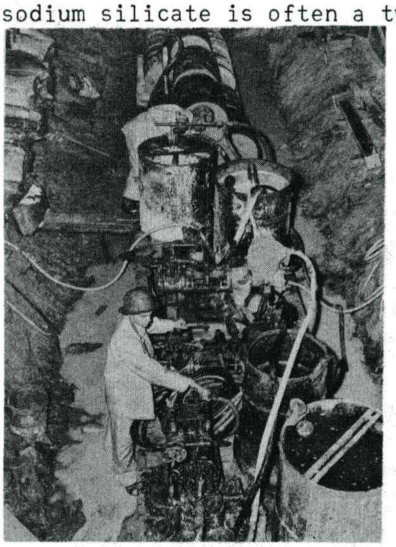
Voids in sands are about borderline for ordinary cement grouting, although a finer grind such as high early strength (Type III) cement will still go. Alternately blast-furnace slag can be wet-ground to extreme fineness and used with NaOH (lye) or to replace up to 70 percent of the cement. If the only object of grouting is to stop leaks, clay alone may still be used.

A common criterion to check whether a grout will go is to divide the D_{15} size of the soil (size which has 15 percent finer) by D_{85} of the grout. For good grouting the ratio should be at least 15 or 20.

CHEMICAL GROUTING

The above grouts are all suspensions of solid particles, leading to clogging problems. More expensive but far more penetrating in fine pores are the chemical grouts, most of which are true solutions. They do cost more.

One of the oldest and best known chemical grouts, dating from the 1920's, is sodium silicate, or water glass. As the name implies, sodium silicate is soluble in water, but it will react with any number of other chemicals to make silica gel. Therefore grouting with sodium silicate is often a two-shot process--first the silicate, then the other chemical, usually a solution of calcium chloride. This goes by the name the Joosten process, which sounds like getting the juice in. The name comes from the inventor, a Dutch Mining Engineer named Dr. Hugo Joosten. The Joosten process chemicals do well in soils as fine as fine sands, but silts and in particular clays usually remain inhospitable to grouting. In some cases Joosten chemicals have even been used to further plug a soil already cement grouted.

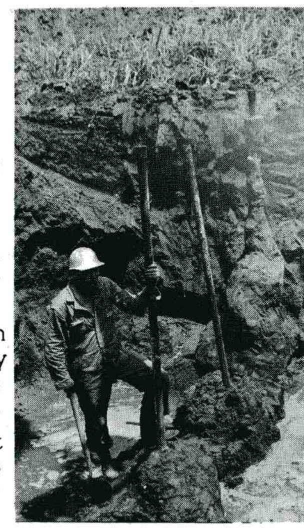


On-the-job mixing of Joosten process chemicals for grouting around a D.C. storm sewer. Calcium chloride bags at left, sodium silicate barrels at rear on tunnel railway.

Where pore size allows it, chemical grouts can be effectively diluted with clay to still give better penetration than cement or cement-clay. Compressive strength goes down, but may not be needed, particularly if the main goal is to seal off water.

Single Shots

An objection to the Joosten method is that it requires two shots of chemicals, meaning duplicate pumps and no control on mixing, which takes place after injection. Many one-shot chemical grouts have been discovered; unfortunately the added conveniences is usually paid for by lower strength. The two-shot process gives compressive strengths in sands of about 400 to 600 psi, while one-shot strengths run about 50 to 200 psi.



Experimental one-shot chemical curtain grout exhumed to show the curtain.

A one-shot timed-set sodium silicate grout may be concocted using any number of second chemicals or combinations such as sodium bicarbonate, hydrochloric acid, sodium aluminate, copper sulfate, or grandma's lye soap. Setting time is controlled by dilution, temperature, and amount of the second chemical(s).

A one-shot grout used at Heart Butte Dam, N. D., employed lignin (where did we see that before?) and sodium dichromate, which polymerize to chrome-lignin. Acid and ferric chloride controlled time of set.

Calcium acrylate polymerizes in the lab to a rubbery mass, but proved unduly sensitive to trace comicals in the soil. More successful have been trials with acrylamide methylene bis acrylamide (AM-9), a current hot prospect. Variations used in oil wells include gypsum cement (plaster-of-paris), phenol-formaldehyde, gypsum-resin cement, and a host of other mixtures which make resins.

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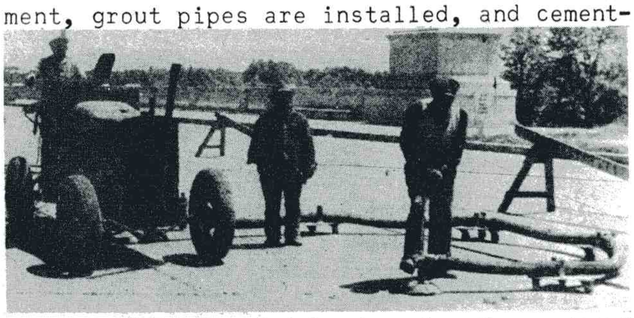
PRESSURES AND TECHNIQUES

Grouting pressure is a highly versatile variable, and is adjusted to either intrude grout into existing pore spaces, or ram it in where ordinarily it would not go.

In the early 1930's an Iowa State Highway Commission man named John Poulter invented a high pressure specialty called "mud jacking" to lift tired pavements. Mud jacking now saves many a mile where good pavement rests on sagging subgrade, and gives benevolent taxpayers that bad ride. Holes are drilled through the pavement, grout pipes are installed, and cement-



soil grout is pumped under to raise the pavement as much as needed. To prevent cracking of large slabs, the several holes either may be pumped at one time, or pumped a little here, a little there. Mud jacking also is used by railroads, in which case the grout is not shot in right under the slab because there isn't any; the grout is intruded perhaps 10 feet down into the embankment.

Similarly, grouting can be used to jack many settled or tilted structures, such as foundations, retaining walls, or leaning towers.

The oil industry makes unique use of super-pressure techniques to increase flow of oil by fracturing the oil-bearing rock. Water is pushed in to do the fracturing; then near-spherical grains of Ottawa sand prop the cracks open and make artificial sand lenses for the oil to creep through. Alternately acid may be used to add zest to the fracturing. Pressure fracturing has rejuvenated many otherwise dry holes for the oil industry.

No Lift Needed

Much more common is to keep grouting pressures under control so as not to cause lifting. Higher pressures are allowable in deeper holes because of the greater weight of overburden. Allowable pressure varies from about one to four psi per foot of depth, depending on competance of the rock.

The next question is how to apply higher pressures at greater depth, all in the same hole. Two procedures are used: packer grouting, where a packer is inserted to seal off portions of the grout hole, or stage grouting, where each hole is drilled shallow and grouted with low pressure, then re-drilled deeper before the grout fully hardens and re-grouted with higher pressure. The procedure is then repeated. Grouting under heavy structures such as dams is usually done after the structure is built, to gain the advantage of higher confining pressures.

Refusal

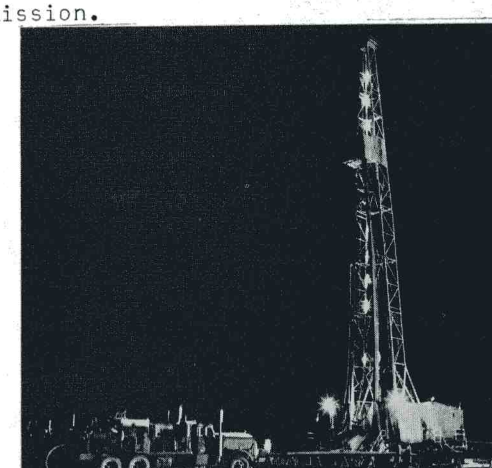
An important part of grouting, like eating, talking or making love, is to know when to stop. The end point is called "refusal" when even under pressure the formation won't take any more. Sometimes curtain grout holes are drilled on "split spacing," where initial grout holes are widely spaced and tested with water pressure, then secondary grout holes are drilled in between and tested to check the effectiveness of grouting. Tertiary grout holes between the others are drilled only where needed.

REFERENCES AND ACKNOWLEDGEMENTS

For generous help, literature, and photos we owe thanks to the Chemical Soil Solidification Co., 7650 S. Laflin St., Chicago (p. 2L, 5L); The Halliburton Oil Well Cementing Co., Duncan, Oklahoma (p. 3L, 5R, 6R); and Intrusion-Prepakt, Inc., Union Commerce Bldg., Cleveland 14, Ohio (p. 1, 2R, 3R, 4).

Vast symposia on foundation grouting have been published over the past four years in A.S.C.E. Proceedings 83:SM2, 83:SM4, 84:SM1, and 87:SM2. Oil well uses are described in "Oil-Well Cementing Practices in the United States," American Petroleum Institute, 297 pp., 1959.

Iowa State University studies in soil stabilization are sponsored by the Iowa Highway Research Board with funds from the Iowa State Highway Commission.



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