GOW, MOHR, TERZAGHI, AND THE ORIGINS OF THE STANDARD PENETRATION TEST

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Innovation is generally bred by necessity….

- Our story begins with the development of deep foundations, beginning around 1885
- Up until this time, multi-story buildings were constructed of heavy masonry elements; chiefly, dimension stone (granite, limestone, and sandstone) and brick.

- The Hotel Vendome in Boston was typical of massive masonry structures when it was constructed in 1881.
- At seven stories, it represented the zenith of Second Empire architectural style which emanated from Paris

The Home Insurance Building (1885-1931) in Chicago was originally 138 ft high

Home Insurance Building - 1885

- Skeletal construction was a novel structural support system utilizing iron or steel members
- These structures only weighed 25% of the equivalent height masonry structures, so taller buildings became popular

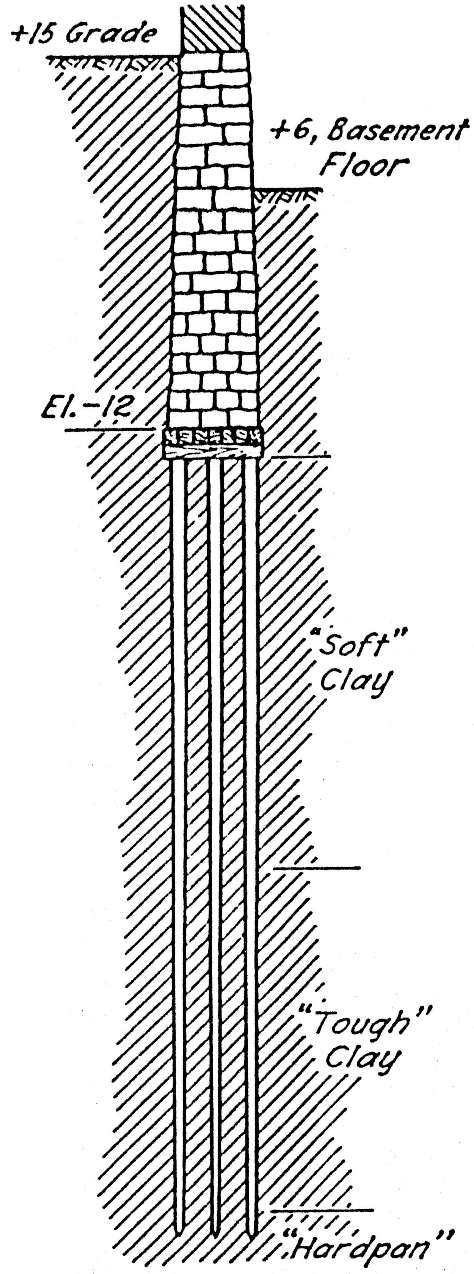


FIG. 29. BEARING-WALL FOUNDATION FOR PUBLIC LIBRARY

Wood Piles

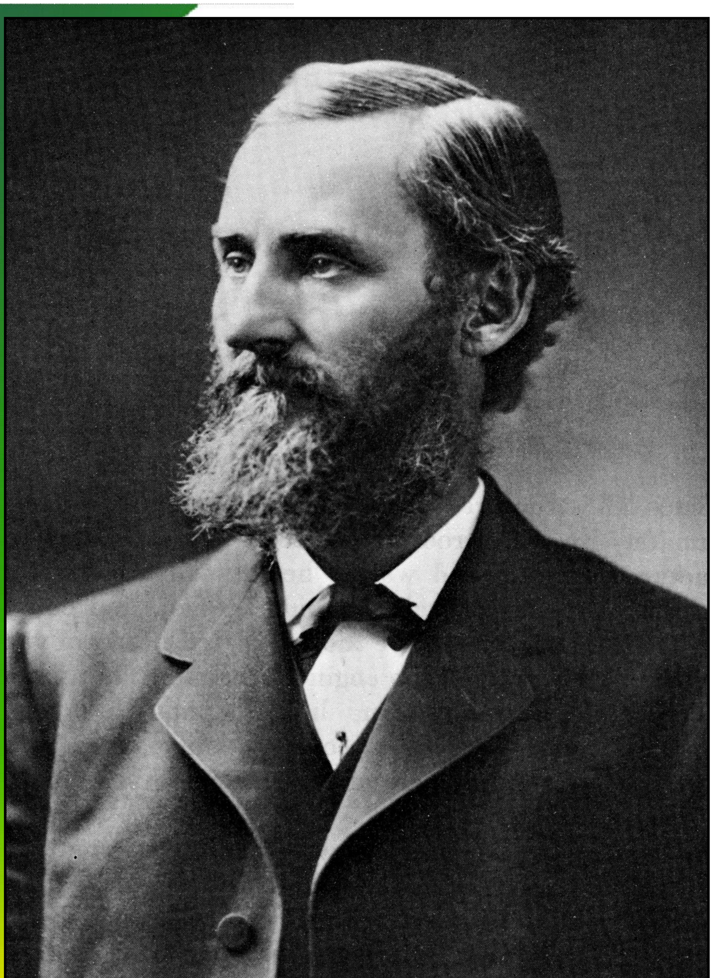
- In the 1890s Chicago's tall structures were founded on wood piles 40 to 60 ft long, thru 30 ft of soft compressible clay into the underlying yellow hardpan, just 5 to 6 ft thick. The hard pan could support pile loads of 2 tons/square ft.

Old Chicago Stock Exchange

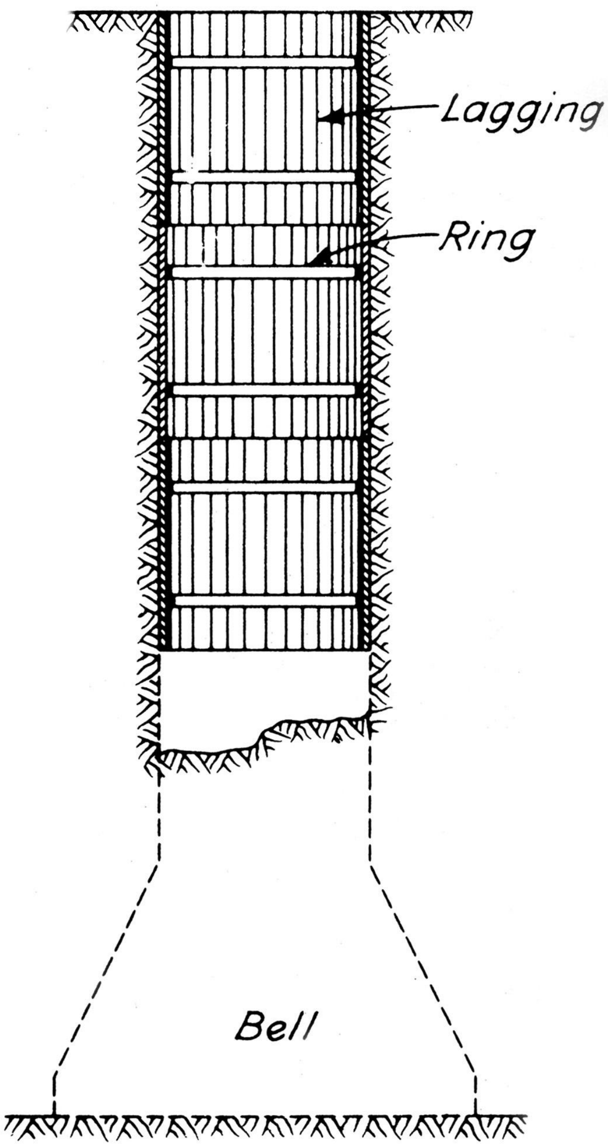
Chicago Stock Exchange Building 1894-1972

- When pile driving began on the old stock exchange in 1894, the design called for timber piles carrying 15 to 20 tons of load.
- As these piles were driven they densified the compressible clay and caused severe heaving of the adjacent building owned by the Chicago Herald newspaper.

William Sooy Smith 1830-1916



- The Herald succeeded in getting a court injunction shutting down construction of the stock exchange foundations because of structural damage to their building. William Sooysmith was brought in as a foundation consultant. He suggested the use of hand-excavated cylindrical shafts, extended below the water table, down to the yellow hard pan.



Advancing the shaft

- The tongue and grooved lagging was driven ahead of the excavation, with successively smaller diameters.
- Iron hoops provided bracing and water was pumped as the excavation was advanced using hand methods.
- The bell was also hand-excavated on top of the hard pan

Evolution of foundation footings

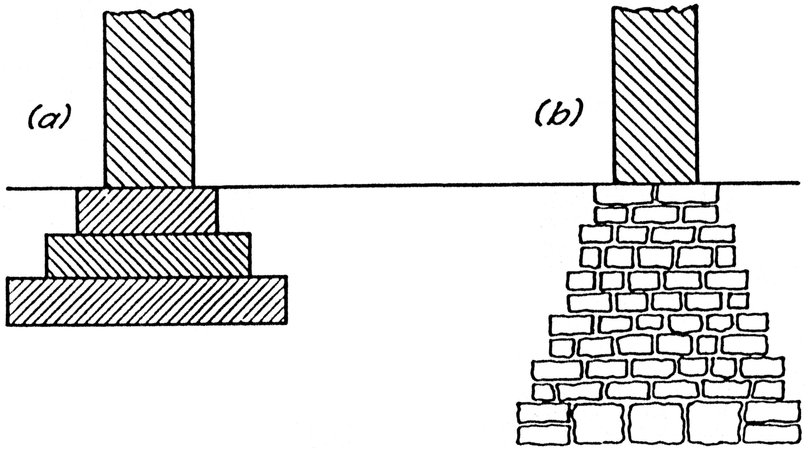


FIG. 4. (a) TYPICAL FOOTING OF DIMENSION STONE; (b) RUBBLE STONE PIER

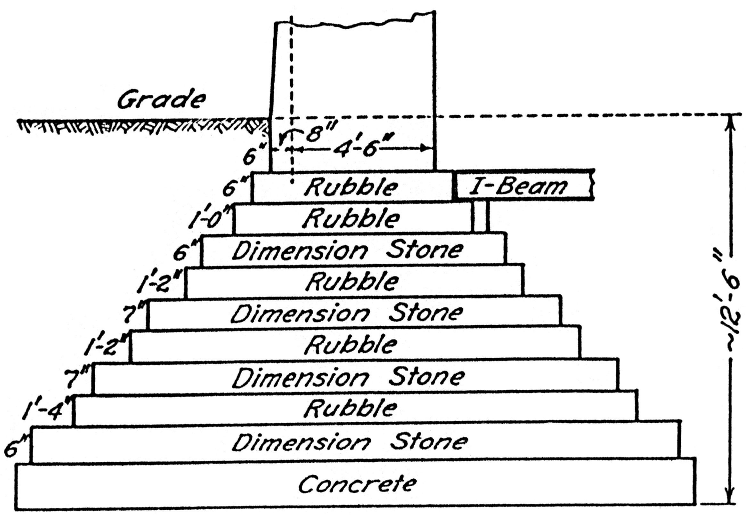


FIG. 6. SECTION THROUGH EXTERIOR PIER OF HOME INSURANCE BUILDING

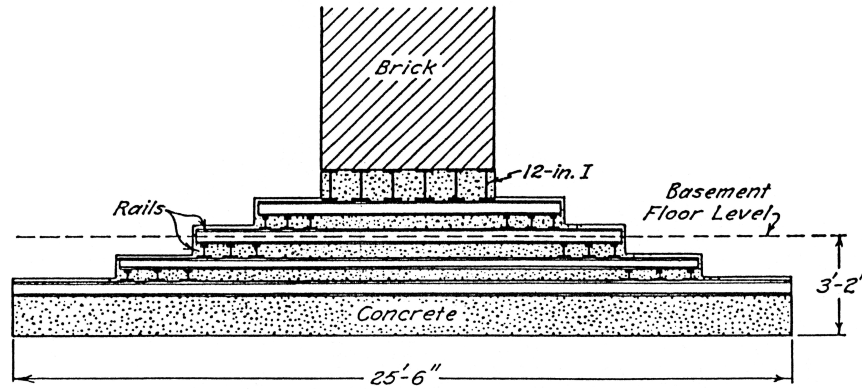
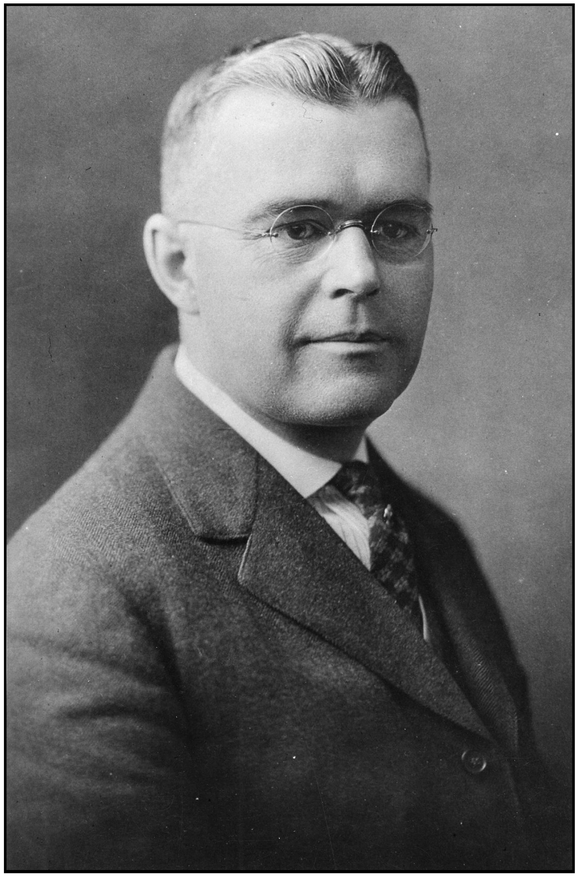


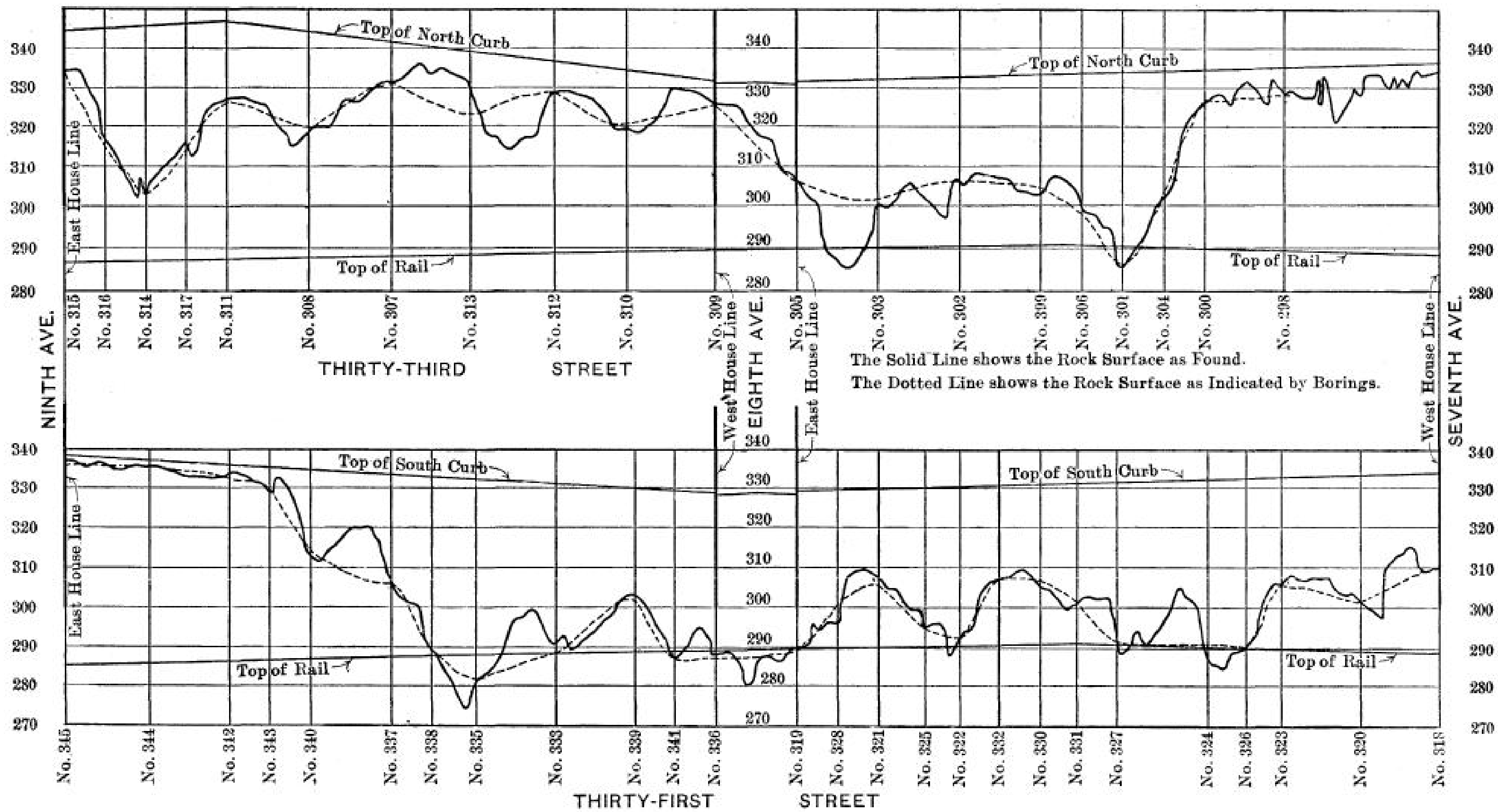
FIG. 7. SECTION THROUGH RAIL-GRILLAGE FOOTING OF MONADNOCK BLOCK

Foundations for heavy structures were evolving rapidly in the 1890s, mostly through the use of grillage to spread loads over a larger bearing area



Col. Charles R. Gow 1872-1949

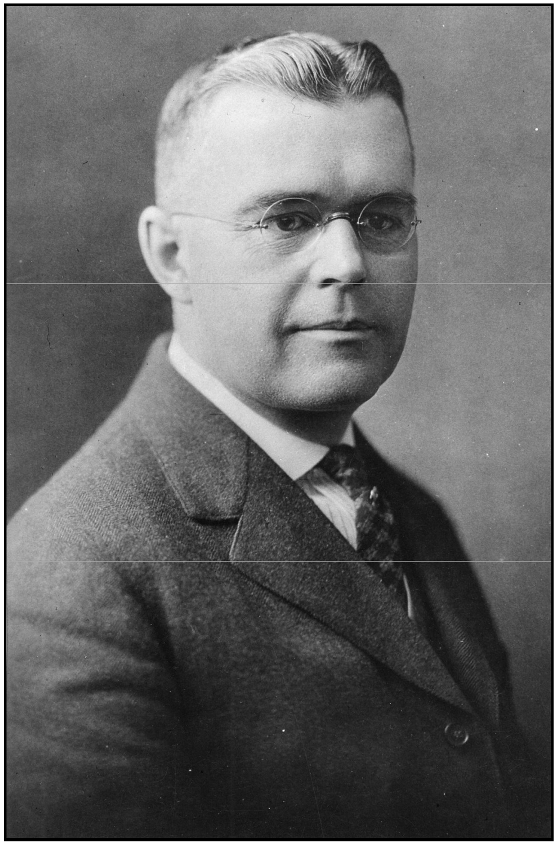
- BSCE Tufts College in 1893
- Medford Water Dept and City Eng'r office 1893-95
- Asst Eng'r Boston Transit Commission from 1895-1908
- Started Gow Construction Co. in 1899, which he sold to Raymond Concrete Pile Co in 1922
- LCOL in Massachusetts National Guard 1898-1908
- Lectured at MIT on foundations 1913-20
- Consultant on transit systems in Boston, New York, and Philadelphia 1922-30; 3 honorary doctorate degrees
- Professor of Humaincs at MIT 1928-30
- Boston Postmaster (1929-30) and State Engineer (1933)
- Pres (1933-42) and CEO (1942-49) of Warren Bros Company



- Gow became familiar with exploratory soundings while working for the Boston Transit Commission on subway construction
- The geotechnical soundings of that era were crude by today's standards; simply delineating the soil/rock interface using cuttings from wash borings

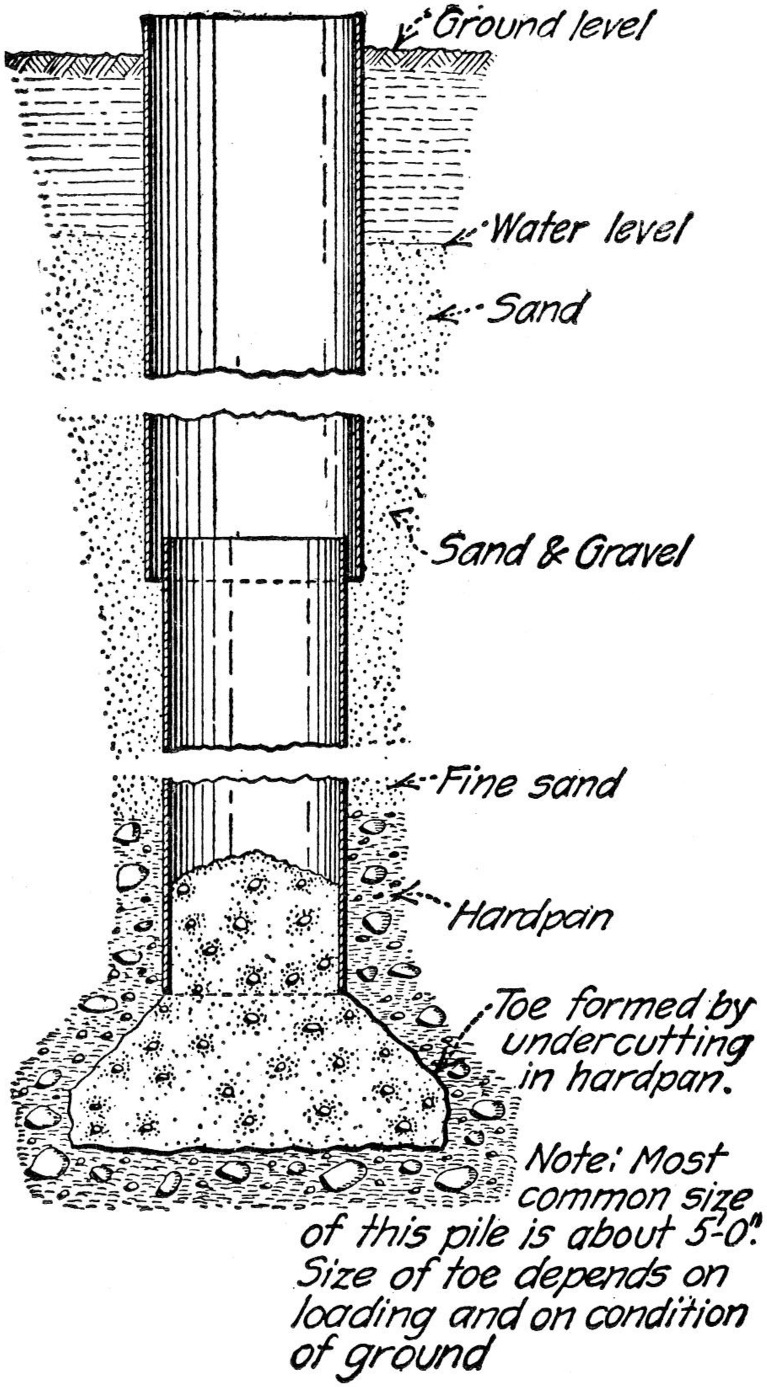
Wash Borings

- Until 1902, wash borings were the dominant technique used to advance water wells or exploratory soundings, for exploration of foundation conditions
- Cuttings from wash borings were of limited value in distinguishing the character and consistency of unconsolidated sediments, such as Boston's yellow hard pan.



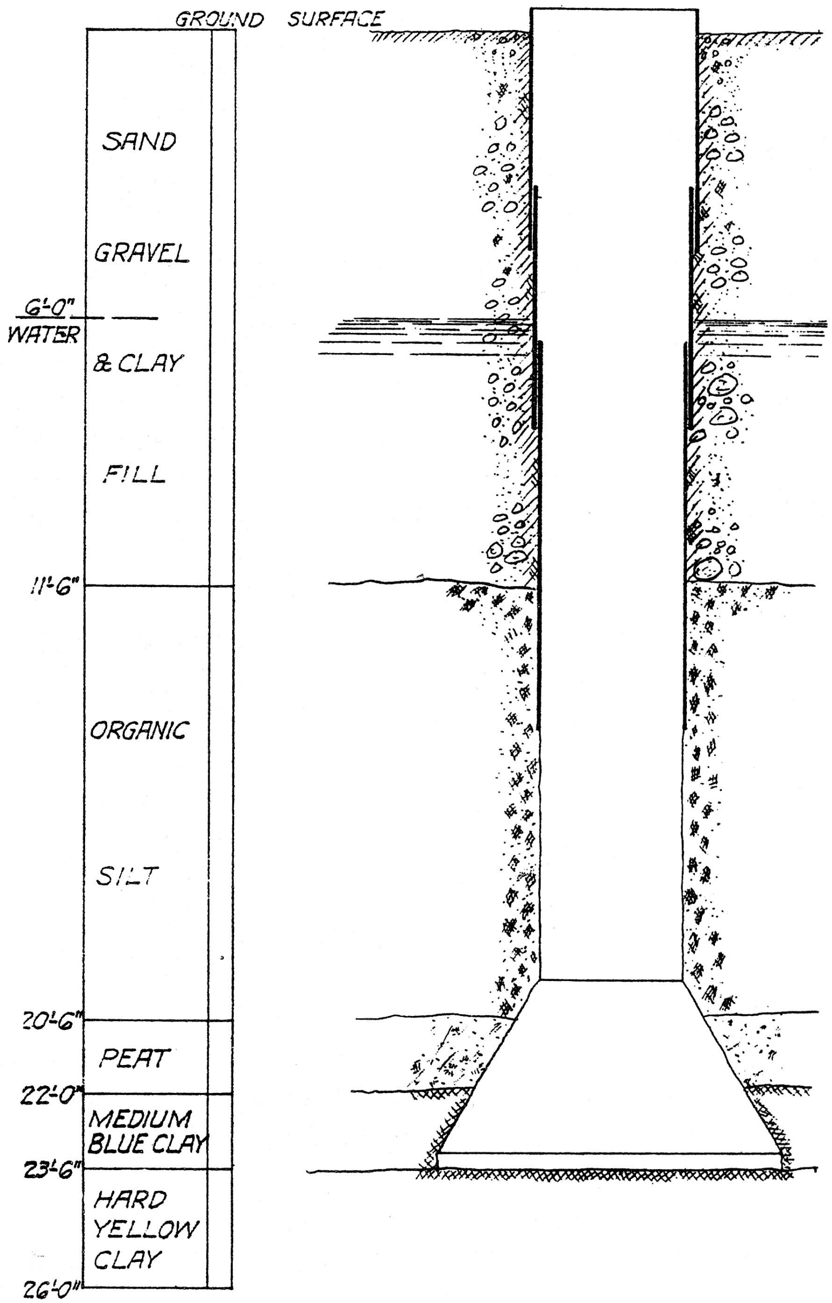
Assistant Engineer for the Boston Transit Department 1895-1908

- While working on the Tremont Street Subway structure for the Boston Transit Department, Gow familiarized himself with the behavior of the various soils encountered
- Gow determined that the various soil layers exhibited dramatically different capacities to support structural loads, what we now refer to as bearing capacity.
- He noted that the most suitable bearing stratums were buried organic soils which had developed "weathering crusts", more colloquially known as the "yellow hard pan"



Gow Caisson

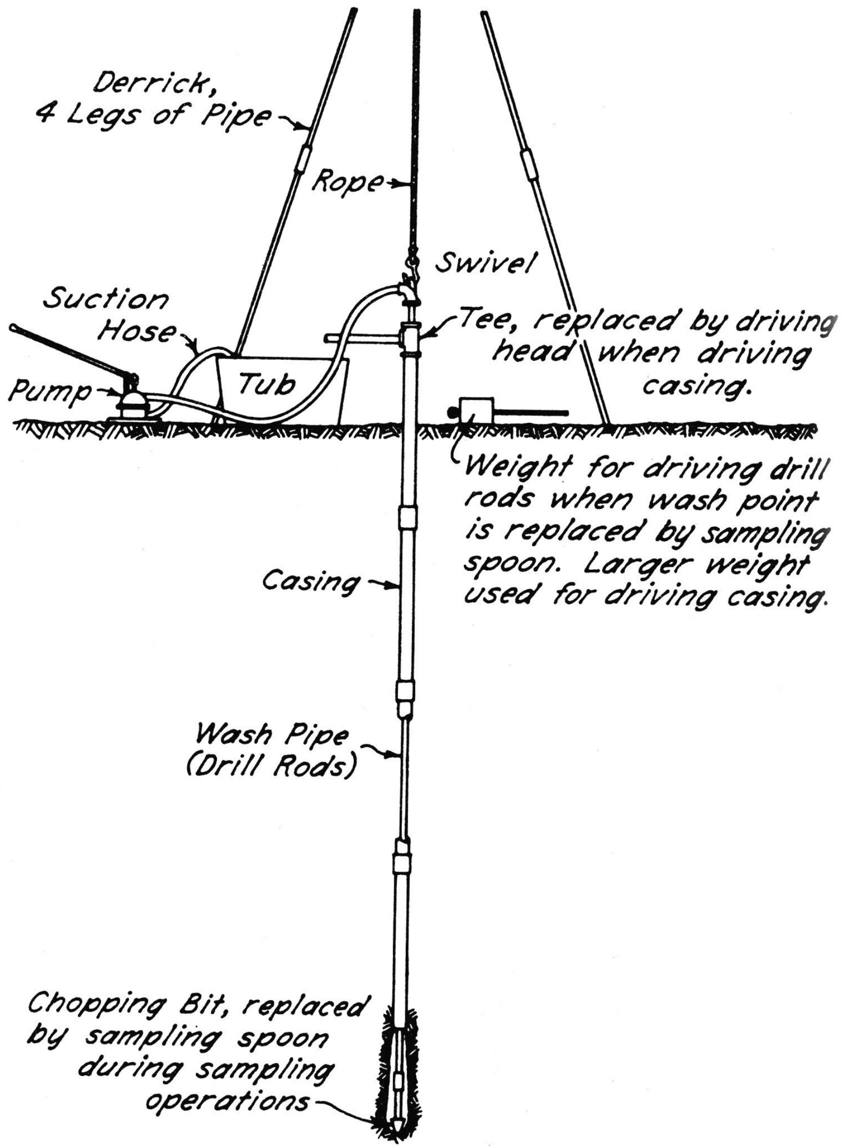
- Hand-dug shaft with truncated cone (bell)
- The telescoping forms were 4 to 8 ft deep, with each ring 2 inches less diameter than that above it. It was advanced 2 ft ahead of the hand excavation.
- The circular rings could be recovered during pouring of the concrete.
- No reinforcement, unless designed to resist uplift along waterfront areas.
- Soils exposed to visual and manual examination.



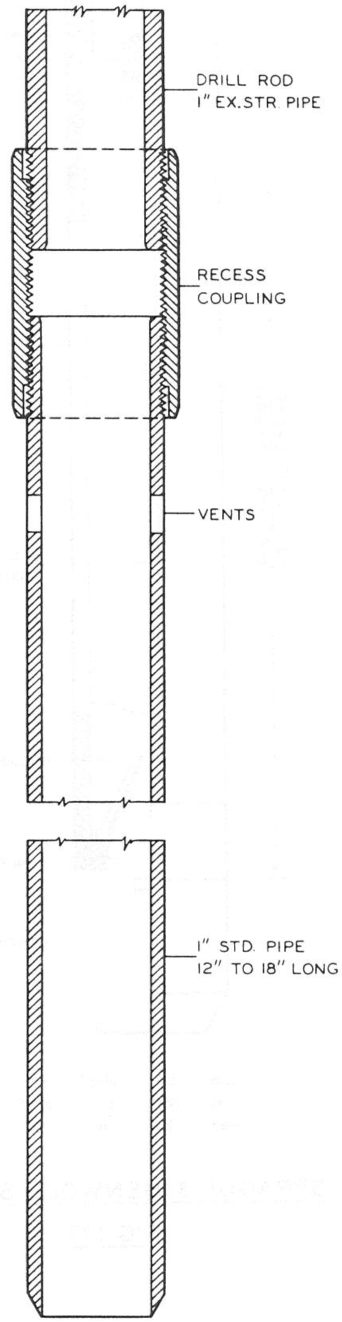
Bearing on the hard pan

- Design of the Gow Caisson required accurate subsurface soils information, preferably, hand samples of the hard pan the caisson bell would be excavated in
- No bells excavated in clean sands

Dry Sampling



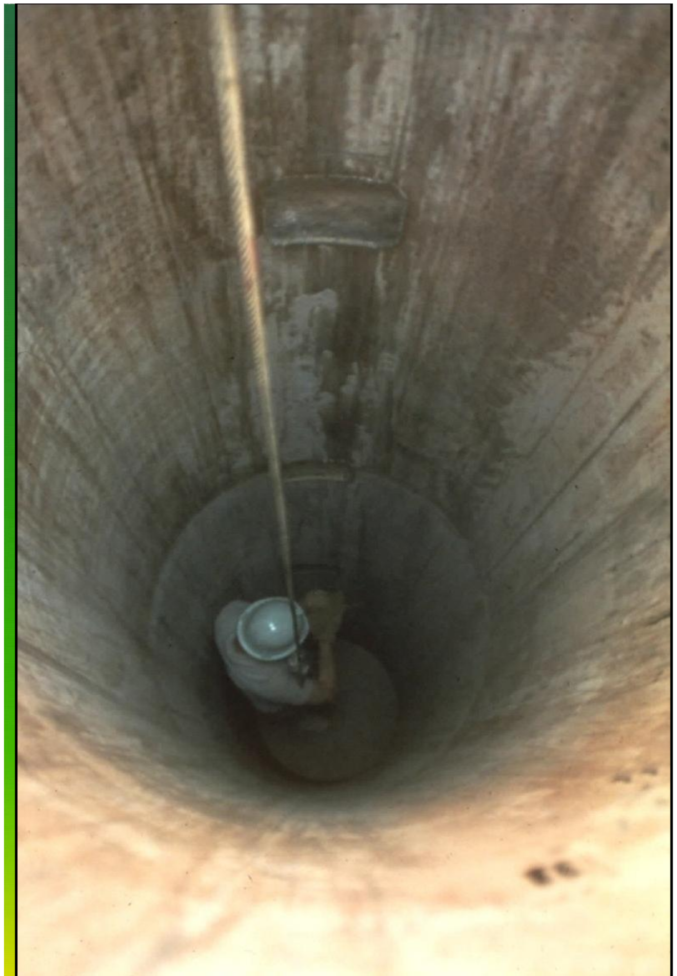
- Around 1902 Gow began taking "dry samples" using a chomping bit, searching for the hard pan
- Gow began the practice of taking drive samples every time there was a noticeable change in soil type



GOW PIPE SAMPLER

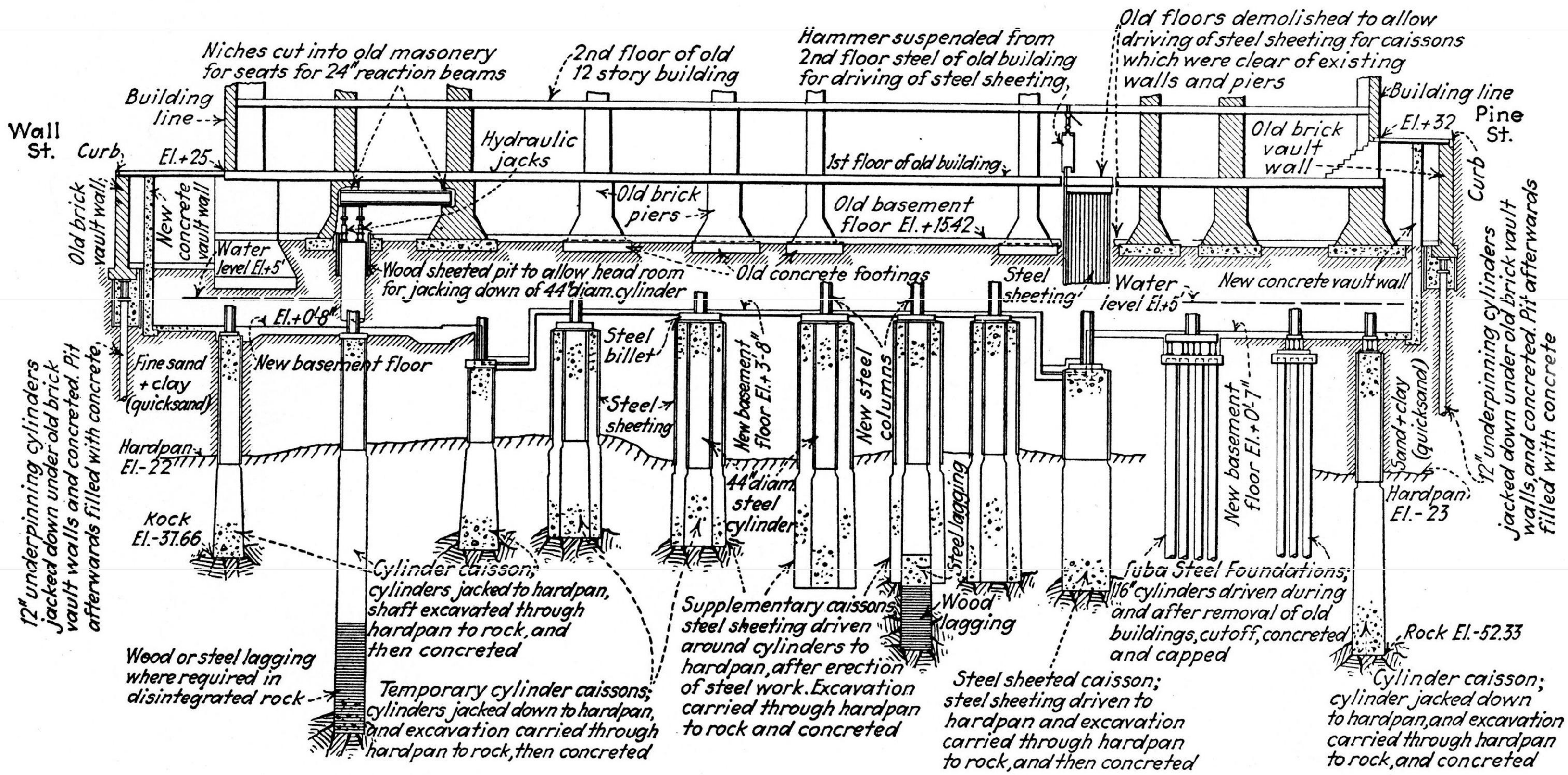
The Gow Pipe Sampler

- Gow initially employed a crude 1-inch diameter pipe to recover drive samples.
- He used the same hollow rod through which drilling circulation water ('dirty water') had been used to flush cuttings up out of the borehole.
- He would clean the hole out of all loose cuttings and debris before taking a drive sample.
- The pipe sampler was 12" to 18" long, with small air vents and tapered beveling of one end to fashion a crude cutting shoe.



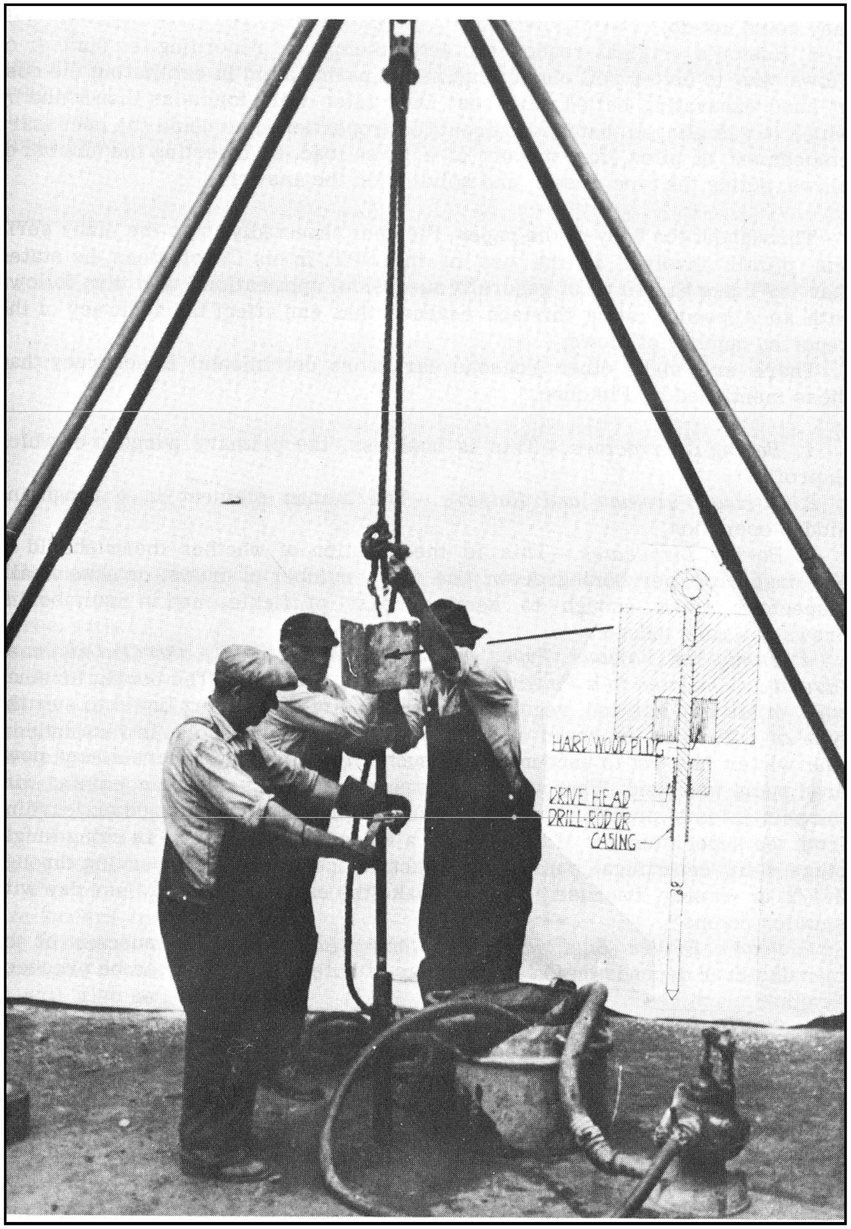
Gow Construction Division of Raymond Concrete Pile Co.

- In 1922 Charlie Gow sold his construction company to the Raymond Concrete Pile Company, headquartered in New York City.
- Raymond expanded their operations to become a coast-to-coast operation by 1927, and pioneered a numbered of patented products, such as the Raymond Step-Tapered Pile.



- Foundation engineering developed rapidly during the 1920s and 30s. This shows Moran & Proctor's scheme for the new Bank of Manhattan site in 1929, when deeper foundations were constructed between older, shallow footings. Reliable site exploration and subsurface sampling became increasingly important.

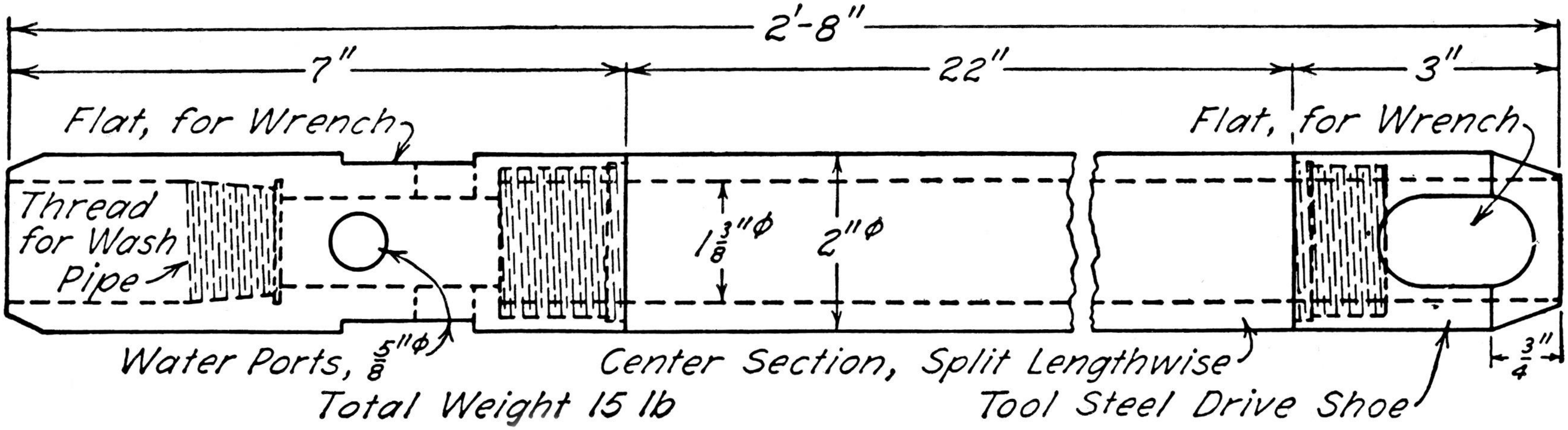
Standardizing the sampling process



One of Gow's 3-man drilling crews in 1930, advancing drive samples

- By the late 1920s Gow was employing three-man drilling crews to take drive samples at their job sites in Boston, New York, and Philadelphia
- Harry Mohr (1885-1971) joined the Gow Division of RCPC in 1926 in their Boston office.
- He began collecting blow count data using 22" samplers with 140 lb donut weights falling 30"

Raymond Drive Sampler

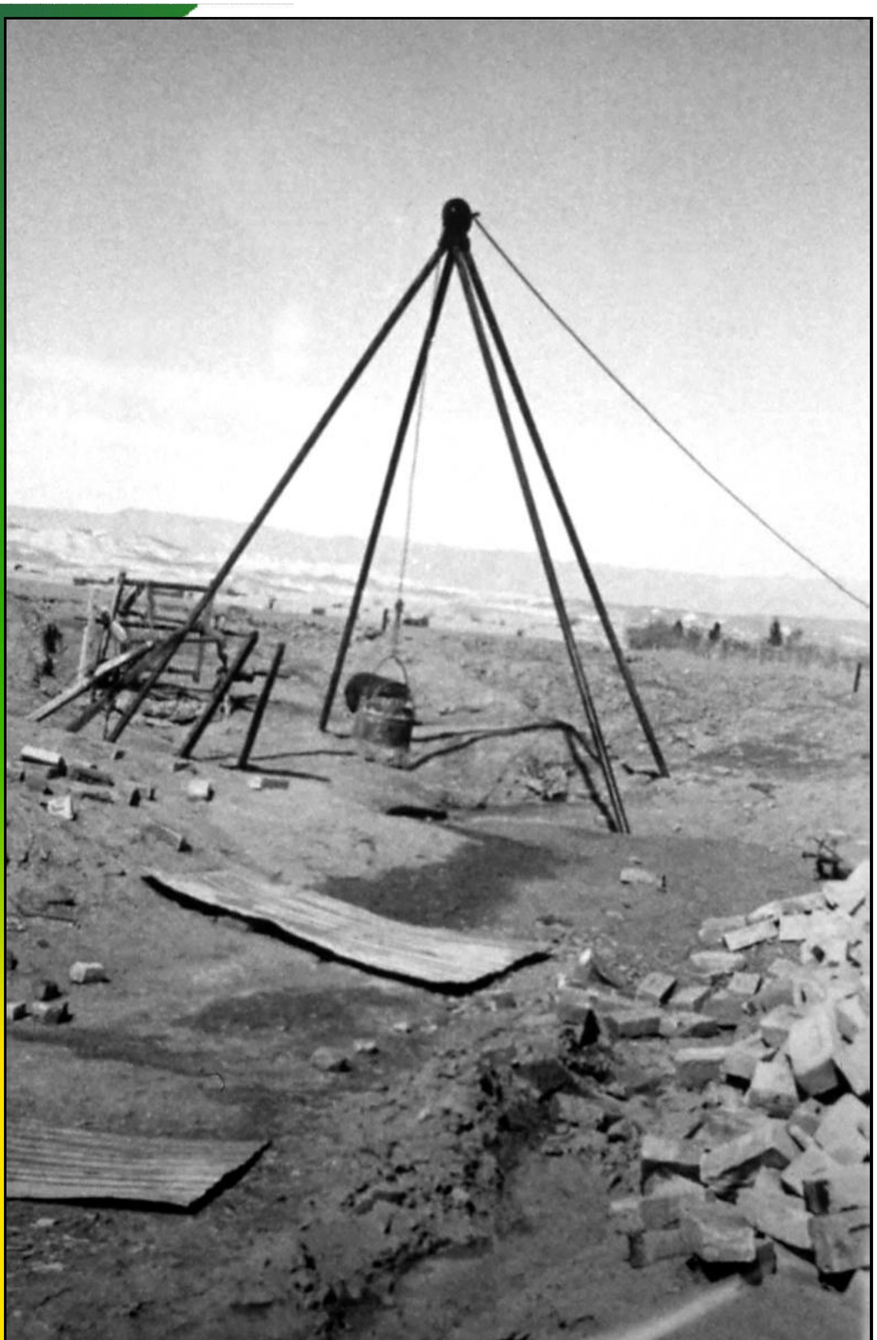


- During the 1930s Gow engineers continually improved their drive sampler, originally conceived by Charlie Gow back in 1902. It was used extensively in Boston, New York, Philadelphia, Chicago, and San Francisco.

EXPANDING OPERATIONS

- The Gow Foundation Division of Raymond Concrete Pile Company expanded the firm's capability across the United States in 1927 when they opened an office in San Francisco.

- By the late 1920s Gow's sampling operations employed standardized drive sampling techniques under the direction of Harry Mohr in Boston, Linton Hart in New York; and Gordon Fletcher in Philadelphia.
- They began collating blowcount data collected from hand-operated drive samplers, similar to that shown here.



Hand-excavated shafts were slow

- The first generation of Gow Caissons were hand-excavated, using post derricks like that shown here
- An iron muck bucket was raised and lowered into the hole using a block and tackle assembly.
- Progress was slow, esp. in the bell at bottom of the shaft

Mechanization drilling for caisson excavation

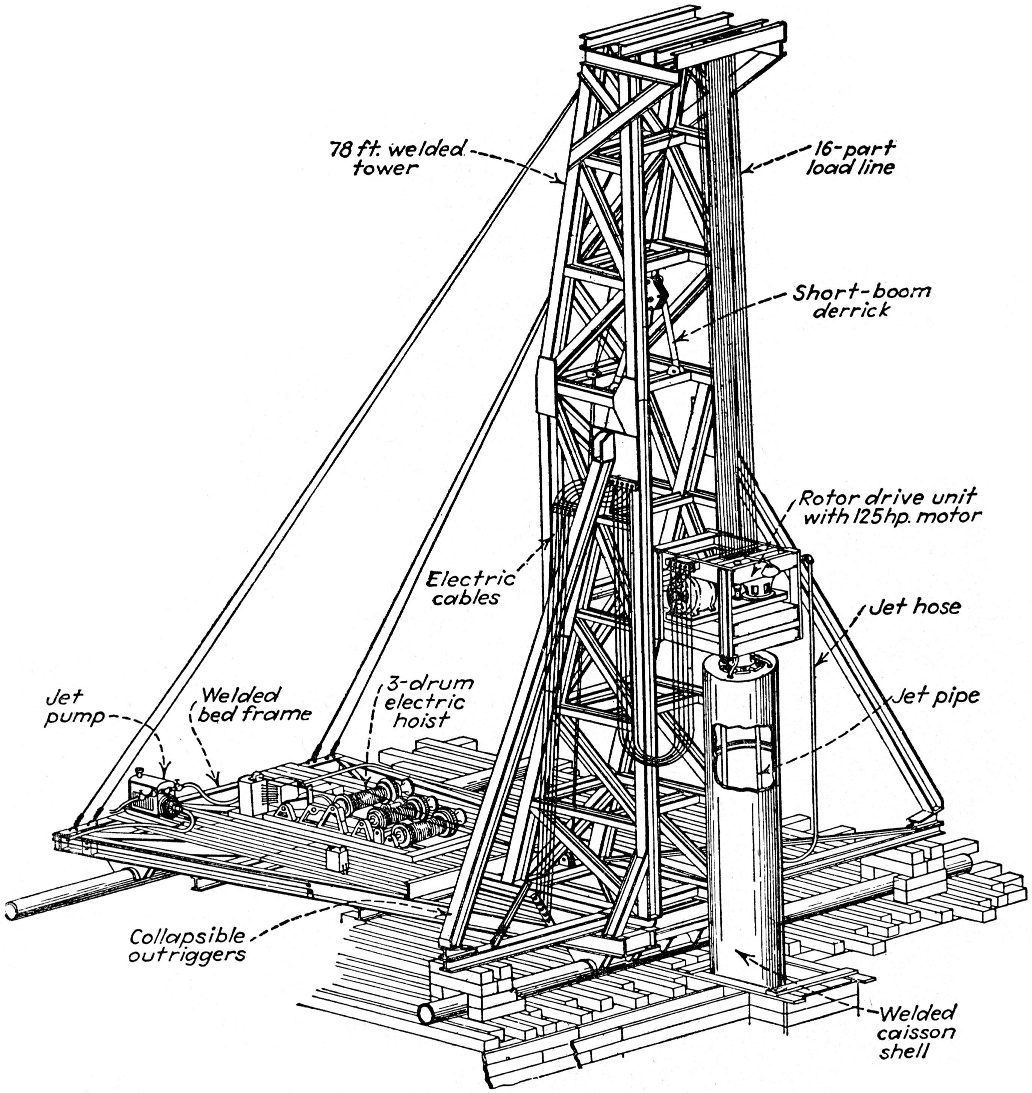
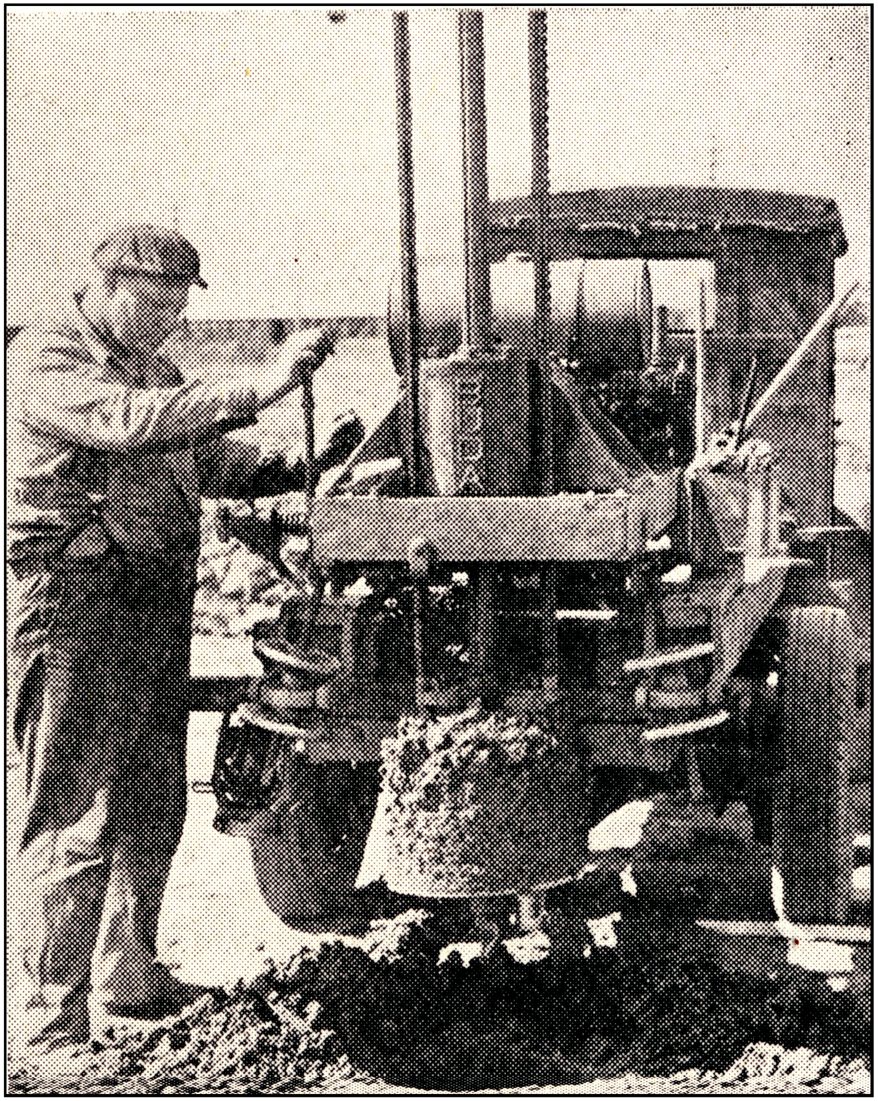
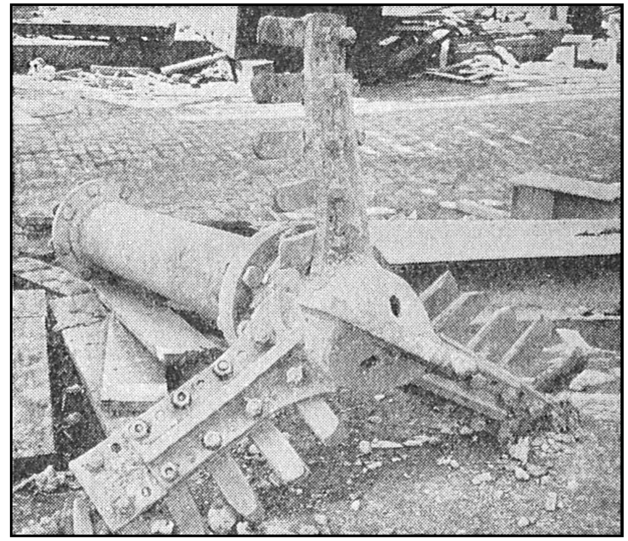


FIG. 9-7a.—Machine Used for Boring Metal Cylinder Caissons into Position.

- In the 1920s Gow's engineers began experimenting with mechanized drilling to decrease time of excavation.
- The rapid excavation gave them a significant advantage because it allowed the bells to be excavated much more quickly.
- Stand-up time in the bell excavations was always critical.

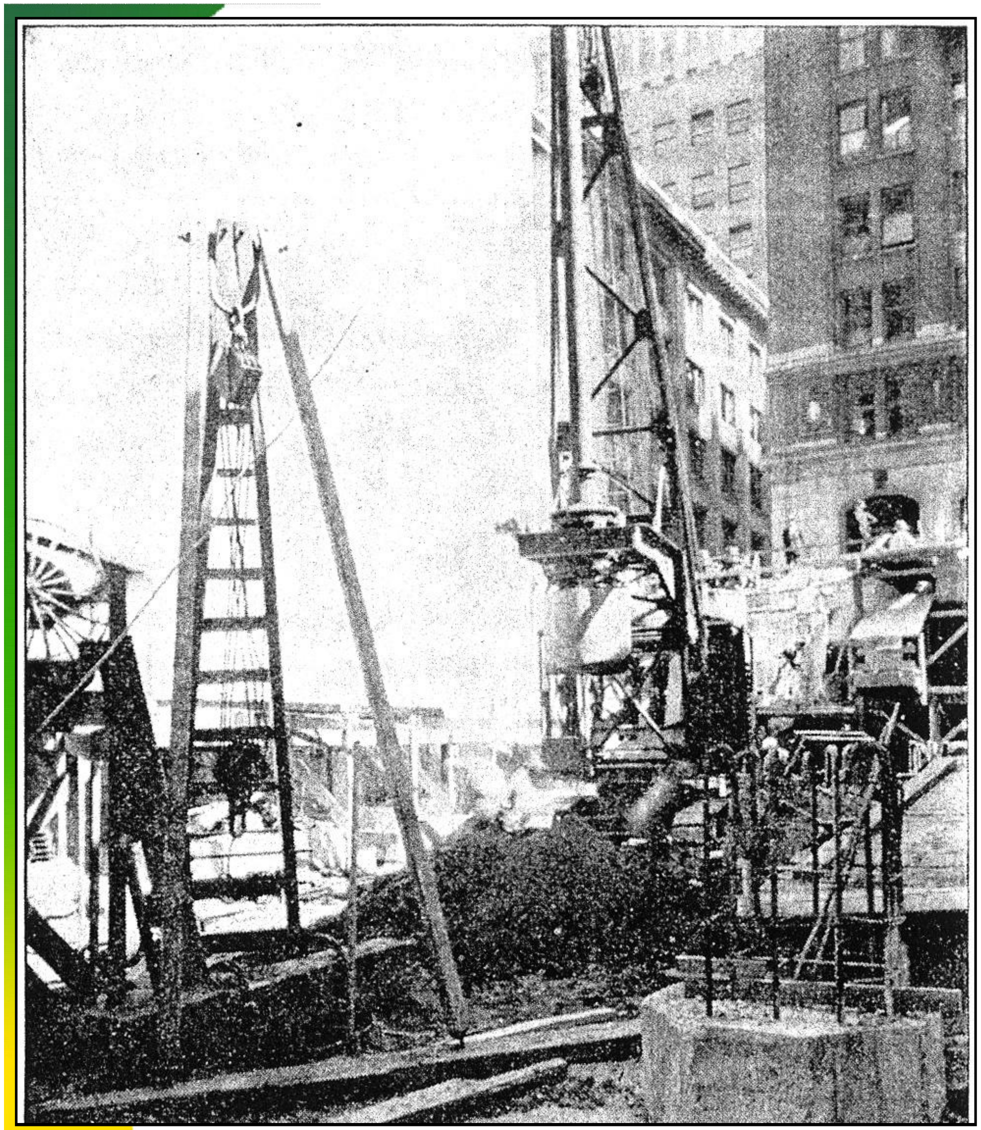


MOBILE DRILL RIGS



Spud drills were used to excavate large diameter shafts using wet drilling

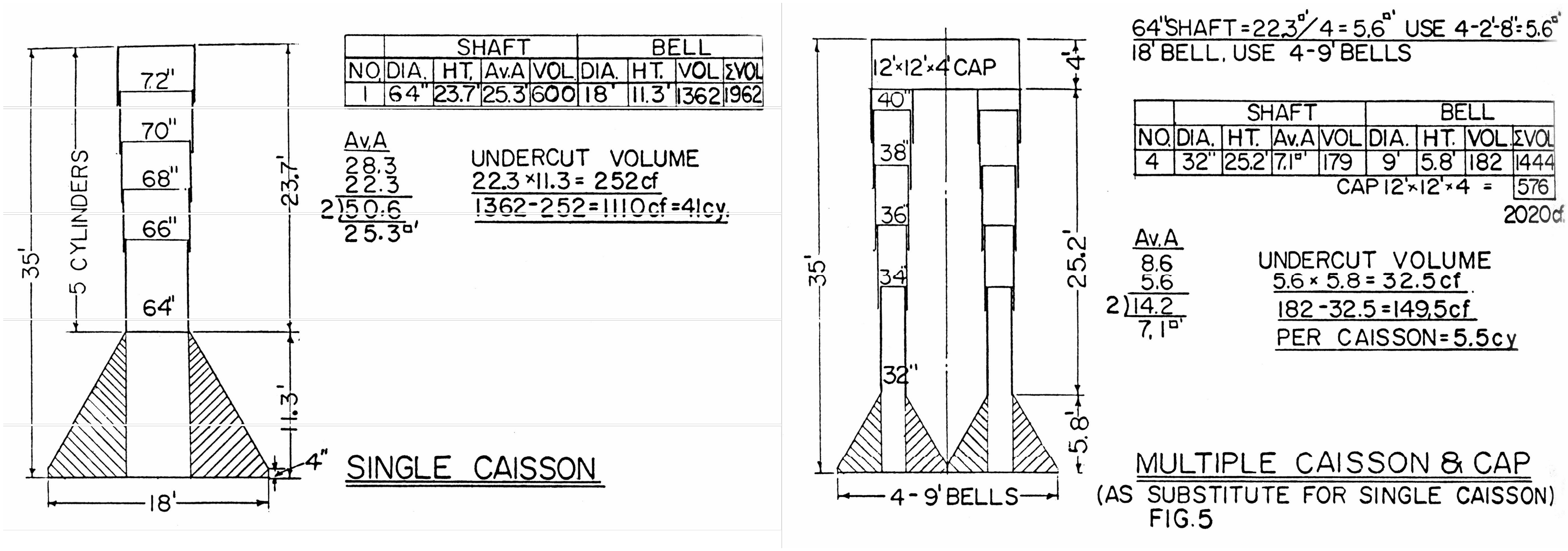
- In the 1920s Gow pioneered drilling shafts with gasoline powered engines, using spud and bucket augers, up to depths of 160 feet by 1928.



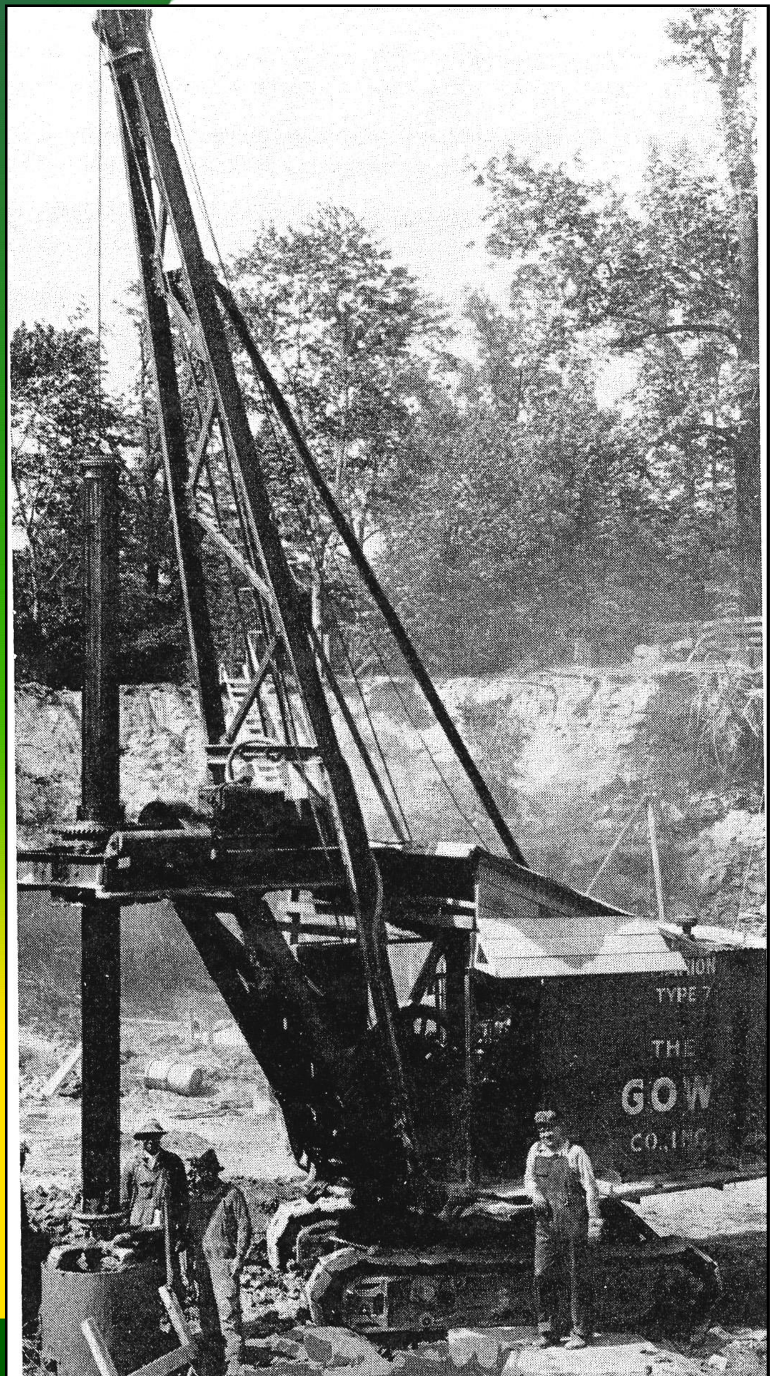
Excavation of Gow Caissons for the Phoenix Assurance Building on Pine Street in San Francisco in July 1928.

Machine excavated caissons

- In the summer of 1928 Gow constructed their first drilled pier foundation on the west coast, in San Francisco.
- They employed a Hunt vertical caisson-cylinder excavator using a P&H crane to excavate 4-ft diameter caissons 38 ft deep, with 57 ft^2 hand-excavated bells in sandy clay, 10 ft below the water table.



- **Gow Division engineers also perfected many techniques for dealing with difficult ground conditions**
- **The most vexing problem was dealing with low cohesion materials & stand-up time in the hand-excavated bell excavations**
- **One solution was employing smaller diameter caissons, shown at right**

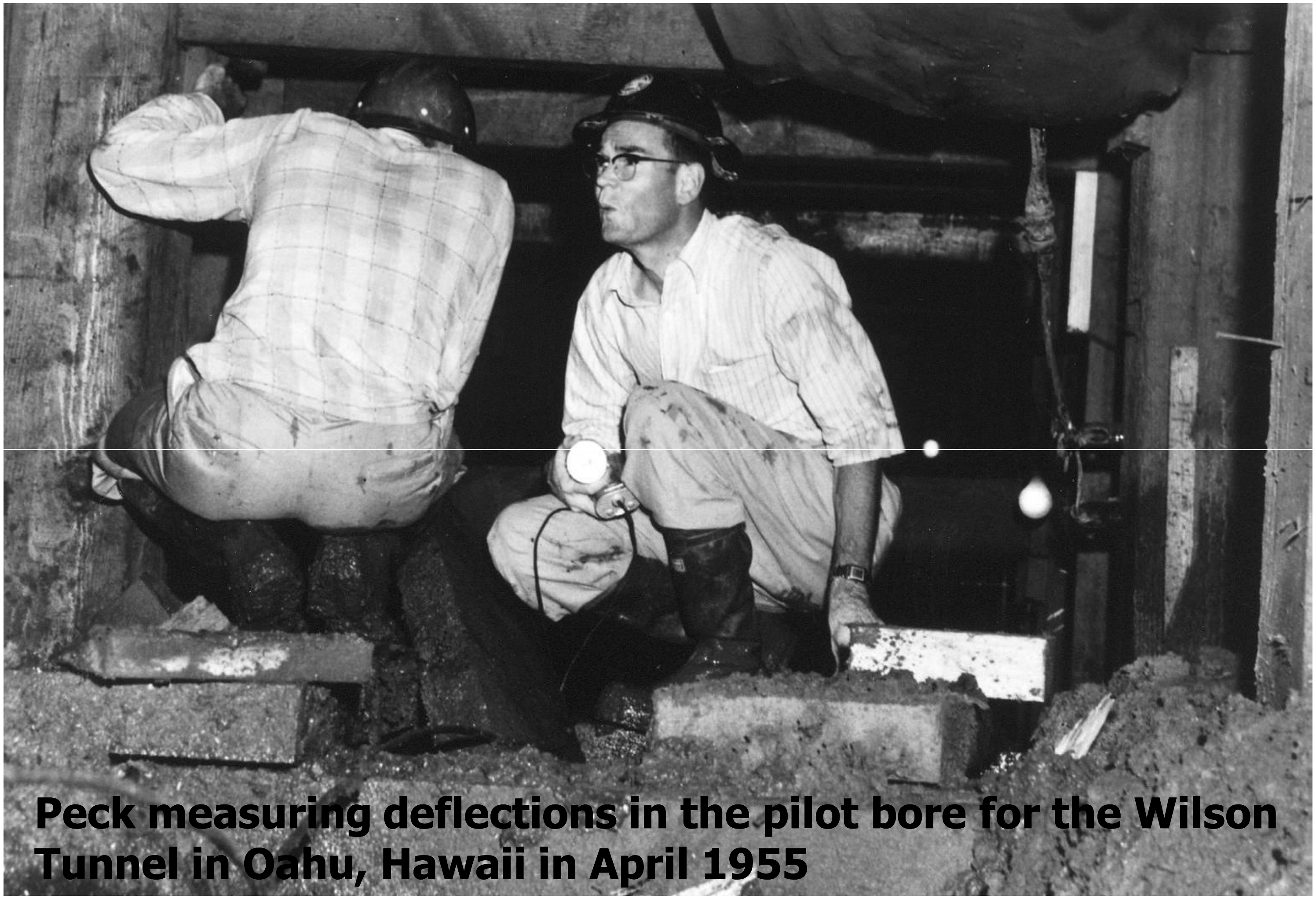


Innovation and expansion

- During the Second World War, Gow developed increasingly capable drill rigs, like that shown here.
- The large mechanized rigs were able to drill deep holes with under reamers to cut the bells, much more quickly than hand-excavation methods. This became common practice after 1945.

Origins of The Observational Method

…. Which emanated from the first phase of the Chicago subway project 1939-42



Peck measuring deflections in the pilot bore for the Wilson Tunnel in Oahu, Hawaii in April 1955

- This portion of our story revolves around Professor Ralph Peck at the University of Illinois. His engineering expertise was sought on a wide range and scale of fascinating projects, world-wide, between 1942 and 2007.

KARL TERZAGHI

father of soil mechanics

Karl Terzaghi strikes a typical pose during one of his lecture tours at the University of Illinois in the late 1920s. At that time he usually signed his name "Dr. Terzaghi," and smoked 5 cent cigars, almost nonstop.

Terzaghi admired the Illinois program because they had developed a tradition of performing practical, problem-solving research, with faculty members actively engaged in consulting.

Terzaghi had little respect for university bureaucracy, warning Peck to: "*avoid committees, becoming a dean or university administrator,*" for fear he would become "*altogether useless to the profession of civil engineering*".

Al Cummings
(1894-1955)

Another of Peck's early mentors was Al Cummings, who worked for the Raymond Concrete Pile Co. for 40 years.

A self taught geotechnical engineer and pioneer in pile foundations, he played a key role in enabling Karl Terzaghi's return to the United States in November 1938, by suggesting consulting work to support him. His first lead (in December 1938) was the Chicago Subway project, for which Raymond provided the rigs and drillers, crucial to the work at hand.

When he passed away in 1955, his extensive technical library was bequeathed to Ralph Peck.

Soil experts find ours good— Dr. M. J. Hvorslev (left), research expert for American Society of Civil Engineers, and Dr. Arthur Casagrande (right), co-founder of new science of soil mechanics, study sample of soft clay taken from Chicago subway, and assure R. S. Knapp and Dr. R. B. Peck that local underground project is "outstanding." (TIMES Photo)

MASTER MANAGER RAY KNAPP

Juul Hvorslev, Ray Knapp, Peck and Arthur Casagrande in Chicago, 1940. Peck's immediate supervisor for the City was Ray Knapp, a combat veteran of the First World War and Army Reserve officer. Peck would later state: "*I learned as much from Ray Knapp as I did from Terzaghi, not about soil mechanics, but about how a geotechnical engineer can go about doing some good in an organization.*" Ray Knapp served as the consummate interface between job site and management, facilitating whatever needed doing to accomplish the tasks at hand."

Impacts on adjacent building foundations

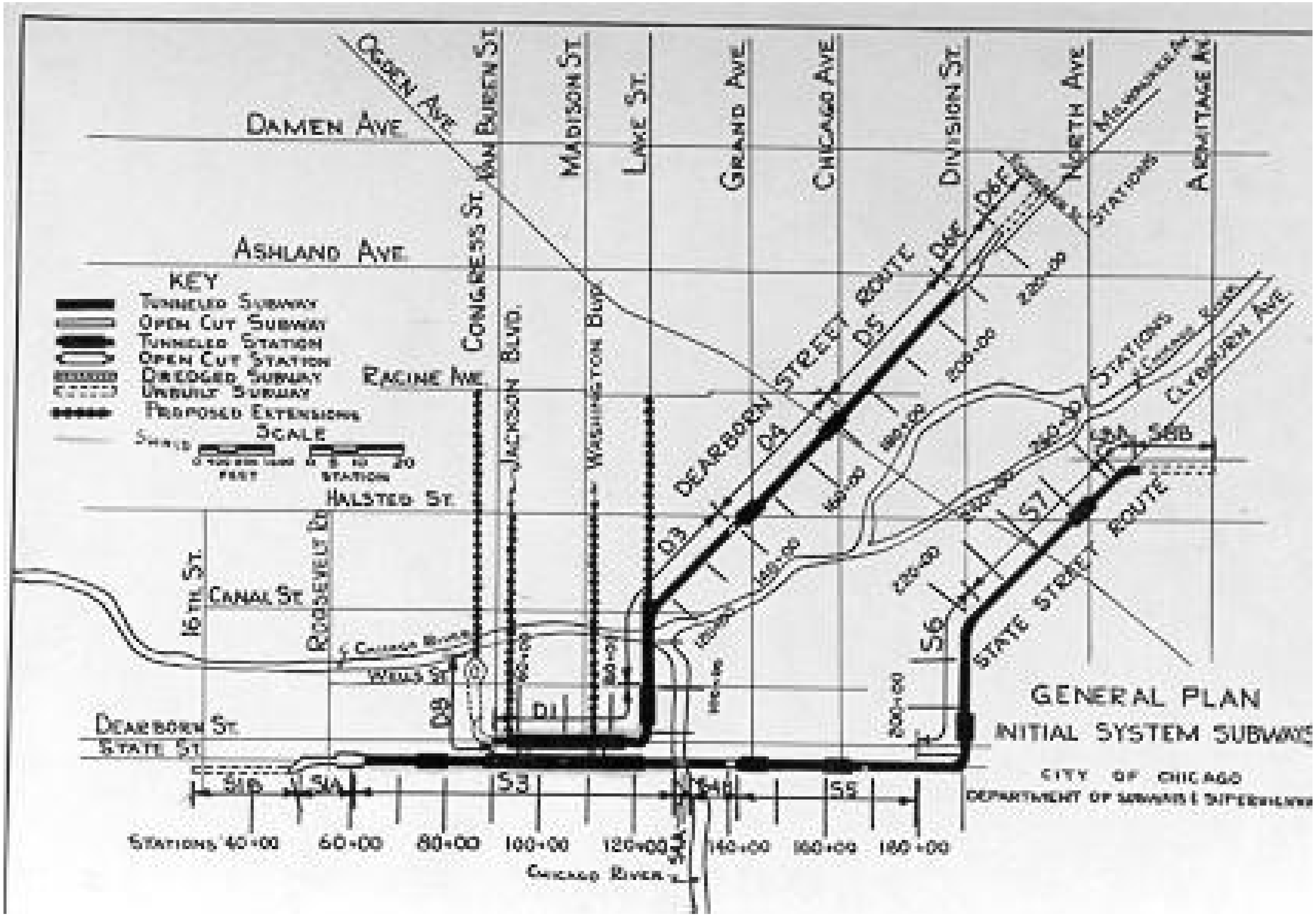
- The primary reason subway engineer Ray Knapp engaged Terzaghi, and he, in turn, recommended hiring Peck, was to monitor deflections of adjacent building foundations and to advise the city on the best practices to avoid costly damage to these older structures

The Chicago Subway

- In January 1939 Ralph Peck departed Harvard for Chicago, to serve as Karl Terzaghi's "eyes and ears" on that landmark project

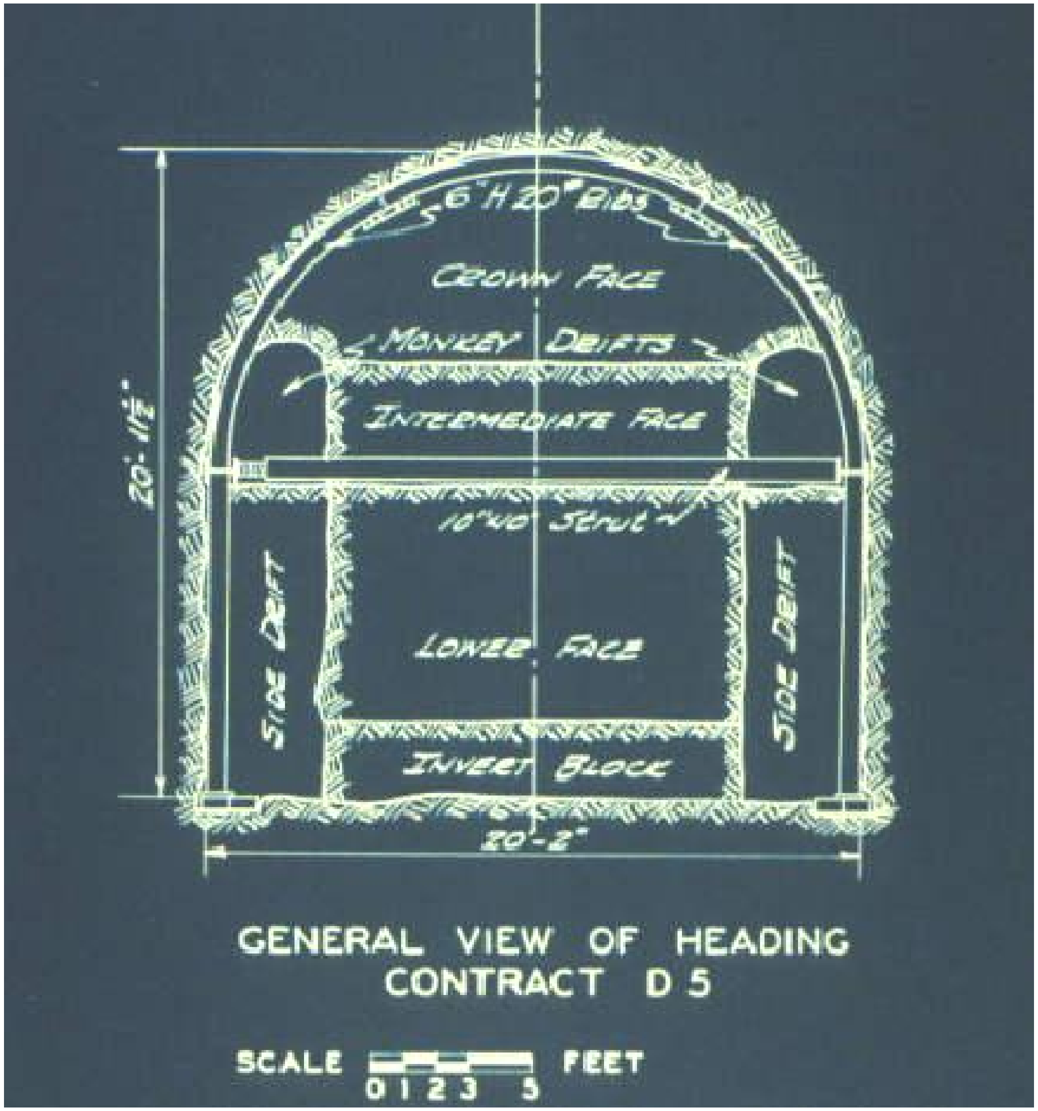
- Peck thought that he was selected for the position because, unlike his classmates, he was not enrolled at Harvard for a post-graduate degree.

- Terzaghi was a determined task master, requiring constant recording of of a variety of measurements, inked figures, and daily typed reports. Terzaghi would visit Chicago for an entire week, about once every 4 to 6 weeks. During these visits he would discuss Peck's findings and provide guidance on what to do next.



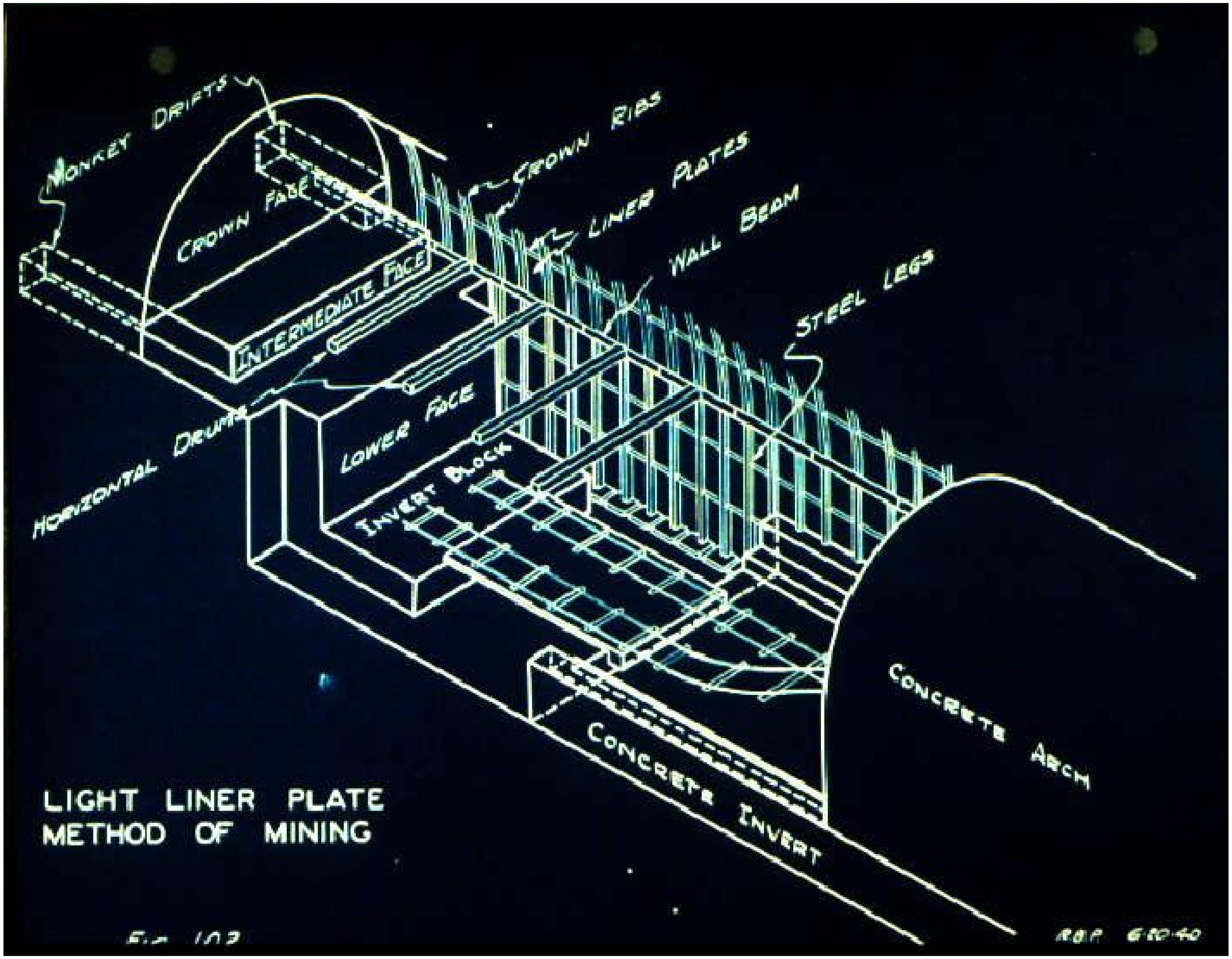
THE CHICAGO SUBWAY PROJECT January 1939 - May 1942

Map of the Chicago Subway project. When Peck arrived on January 14, 1939, the first segment was being excavated along the State Street Route, at far right.



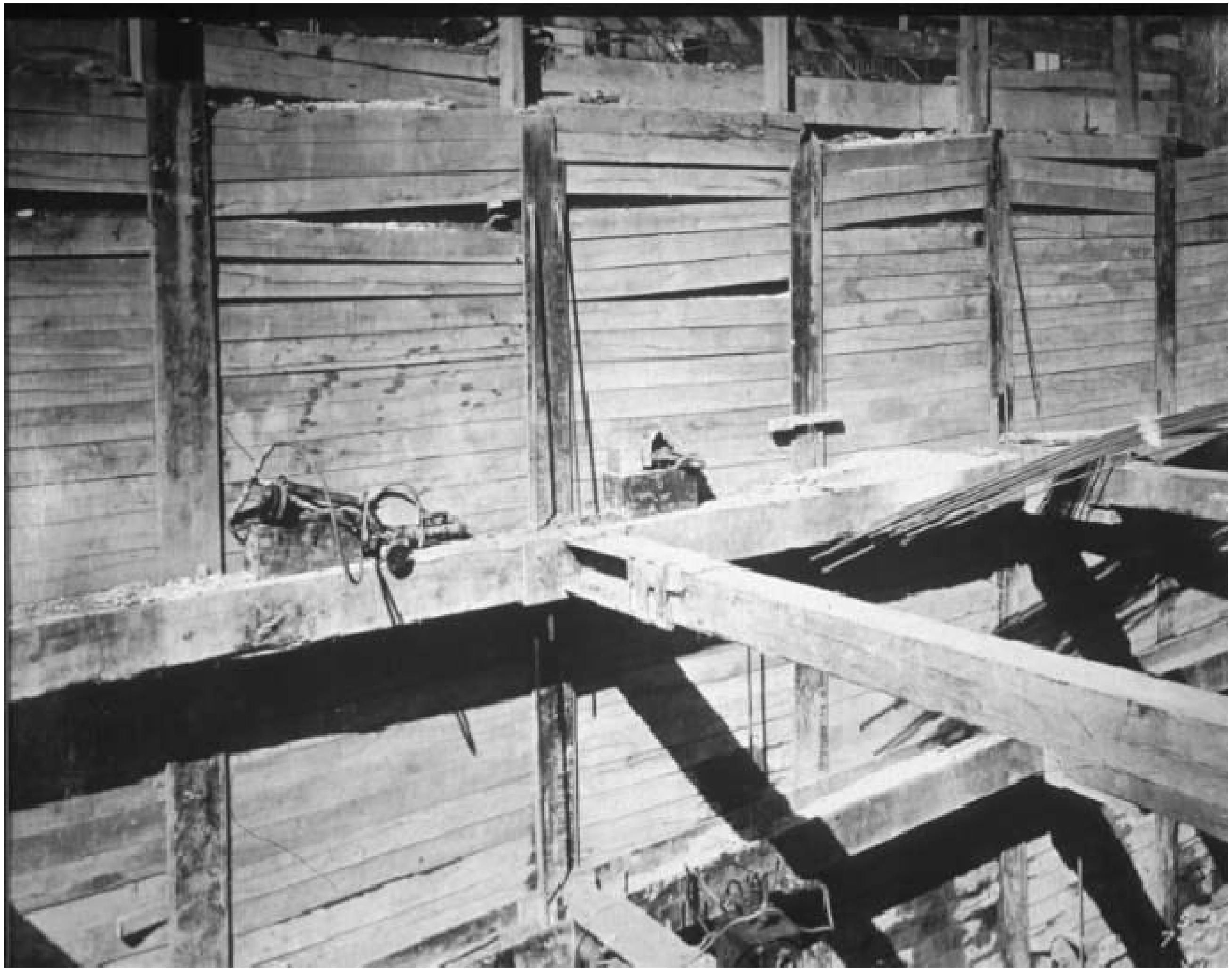
THE CHICAGO SUBWAY

Typical ink on vellum sketch of excavation sequences on one portion of the Chicago Subway project, drawn by Ralph Peck



THE CHICAGO SUBWAY

Sketch showing sequence of excavation and placement of steel liner plates, traced by Ralph Peck in June 1940



BRACED EXCAVATIONS

Close up view of steel H-piles, timber struts, steel walers and timber lagging used to support an open cut of the Chicago Subway, late 1939 - early 1940. Terzaghi wanted Peck to measure strut loads, to see if clays adhered to the wedge theory of lateral soil pressure for sands he had proposed after studying the Berlin Subway collapse in 1936.

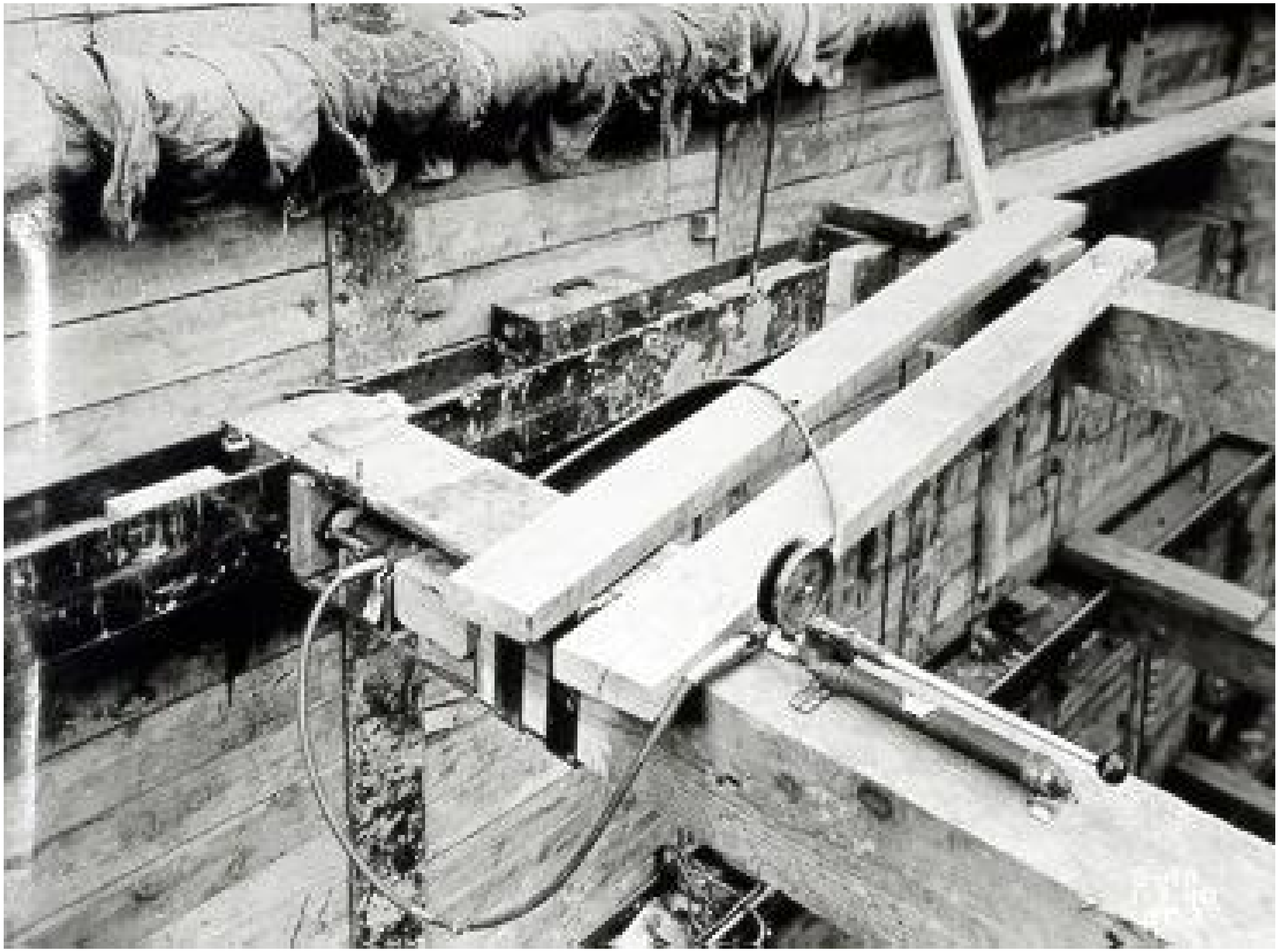
Braced open cut on Contract S-1A of the Chicago Subway

This view shows the transition between the elevated and below ground sections of the State Street line, towards its north end, near the intersection with Clybourn Ave. In July 1940

DEEP BRACED EXCAVATIONS IN CHICAGO

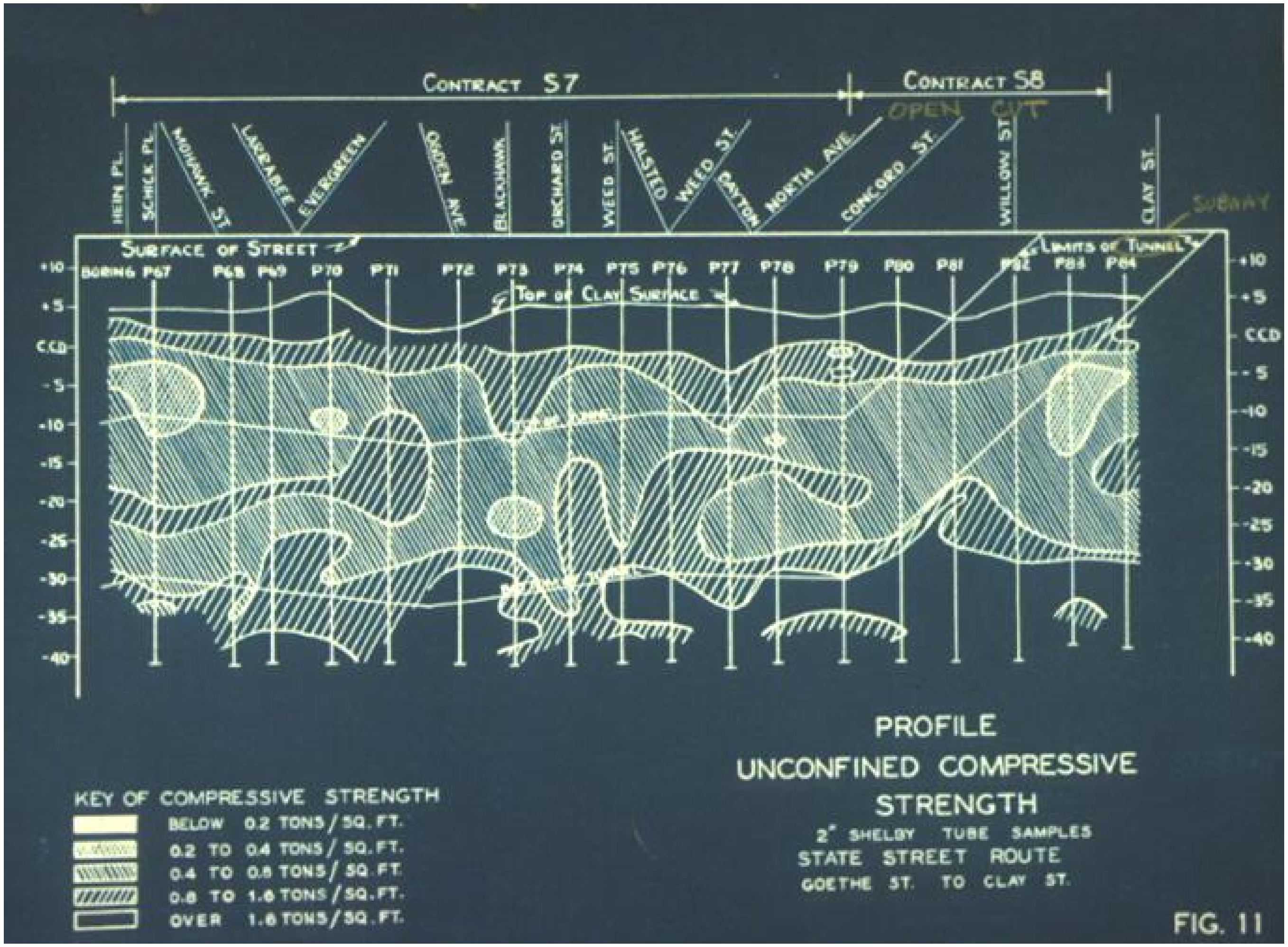
The deepest braced excavation for the Chicago Subway system was at a station near the crossing beneath the Chicago River, shown here in February 1940.

Peck's group measured strut loads with mechanical strain gages, providing the first such readings made in cohesive materials. This work confirmed Terzaghi's wedge theory of [lateral] soil pressure, which evolved from his study of the collapse of bulkhead walls against sands on the Berlin Subway project in 1936.



MEASURING STRUT LOADS

In 1940 Peck began measuring loads on timber struts, using hydraulic jacks, as shown here.



GRAPHICAL REPRESENTATIONS OF GEOTECHNICAL DATA

Typical strip section assembled from borings taken along the State Street route of the Chicago Subway, with Raymond's dill rigs. This view shows the unconfined compressive strength from recovered samples. This data was assembled by the soil laboratory personnel under Peck's supervision.

OBSERVATIONAL METHOD BORN OF NECESSITY

Three level bench excavation in soft glacial clay for the Chicago Subway, in May 1939. When he arrived in January 1939, there was no soils lab or test equipment.

The principal concern of the city and its merchants was the settlement of streets and businesses caused by the subway excavations. Peck's group surveyed spearheads pushed into the tunnel face to measure relaxation, and compared these data to that being recorded on survey pins placed along the streets above.

Ralph Peck measured strut loads and deflections in braced open cuts and inside driven tunnels of the Chicago Subway project between 1939-42. He and Karl Terzaghi developed apparent pressure theorems from these data.

THREE ARTICLES

As the Chicago Subway project progressed, it generated a great deal of interest. Terzaghi and Peck collaborated to prepare summary reports for the City, out of which three landmark articles evolved.

In October 1941 ASCE sponsored a session on soil mechanics in Chicago. Terzaghi applied his name to an article on the liner plate tunnels, while Peck's was affixed to a companion article describing "equivalent pressure distribution" on open cuts. These were then published in the June 1942 ASCE Proceedings and, later, in the 1943 Transactions (with discussions). Terzaghi's second article on the shield tunnels was later published by the Boston Society of Civil Engineers

EARTH-PRESSURE MEASUREMENTS IN OPEN CUTS, CHICAGO (ILL.) SUBWAY

BY RALPH B. PECK,[1] JUN. AM. SOC. C. E.

SYNOPSIS

Systematic field observations on open-cut portions of the Chicago subway provided a constant check on the loads carried by the bracing as well as the soil movements associated with the excavations. Results of the measurements are given in this paper, together with a comparison of the measured earth pressures with generally accepted theories. It was found that the magnitude of the total lateral pressure was in satisfactory agreement with either the plane or general wedge theories for purely cohesive soils, having no effective internal friction, but that the distribution of the pressure was non-hydrostatic. Measured movements of the sheeting were found to be in accordance with those theoretically necessary for non-hydrostatic distribution. Simple rules are given which are believed to be applicable to the design of bracing for similar cuts in plastic clay deposits.

Title page of Peck's Norman Medal-winning article on earth pressure measurements in open cuts, which appeared in the June 1942 ASCE Proceedings and the 1943 Transactions.

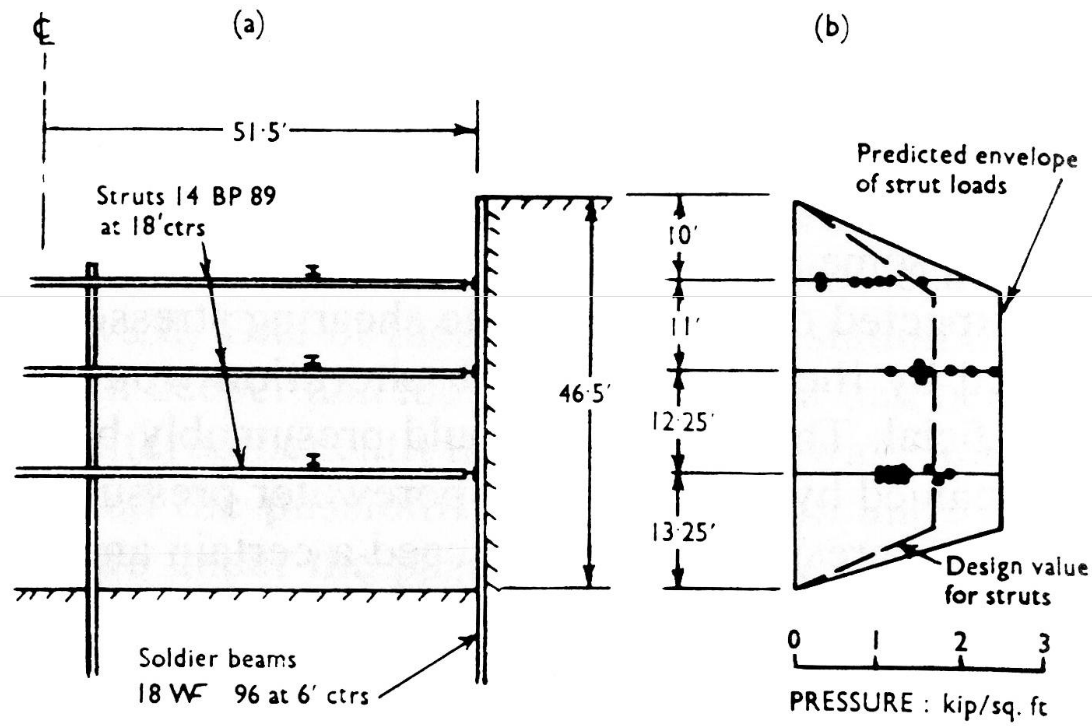


Fig 3. **Braced cut for Harris Bank and Trust Co., Chicago:** (a) Section through cut showing bracing; (b) Comparison of pressures computed from measured strut loads with those used for design and with those predicted from semi-empirical envelope.

Trapezoidal-shaped equivalent pressure diagrams for retained excavations in clay, which appeared in Peck's award wining article. The trapezoidal shape was a dramatic departure from the Rankine earth pressure theory, introduced in 1857, which predicted a triangular pressure distribution.

Ralph Peck's 1944 Norman Medal

This was awarded for the first journal article (other than a discussion) he ever published with ASCE, titled "Earth Pressure Measurements in Open Cuts, Chicago (Ill.) Subway", contained in the 1943 ASCE Transactions. Back in 1938, ASCE had declined to publish his article with Bert Ingalls summarizing their doctoral research at Rensselaer Polytechnic Institute. Peck was stunned by the awarding of such prestigious recognition to someone of his age. The Collingwood Prize was reserved for recognition of contributions by junior members of ASCE, such as himself.

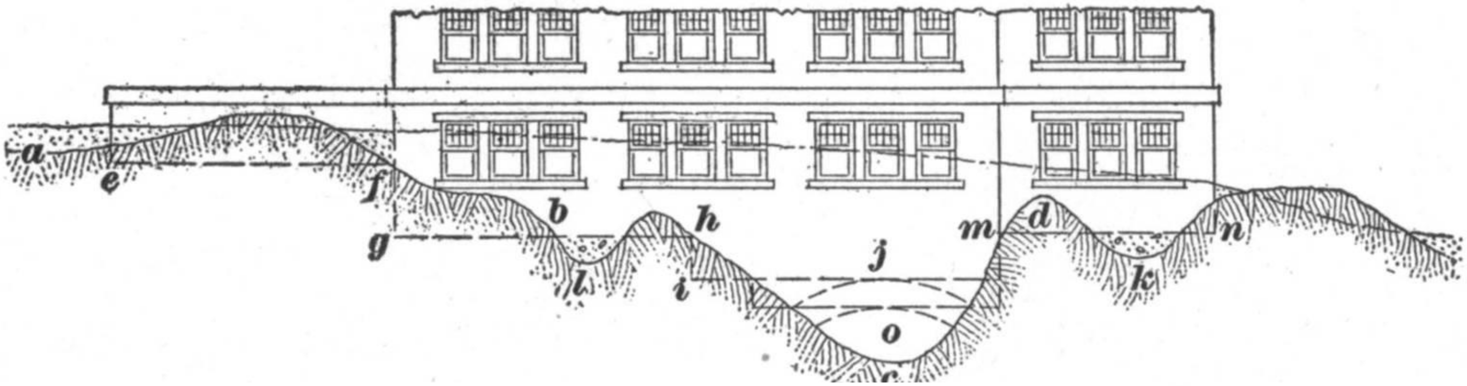
Teaching the art of Foundation Engineering…

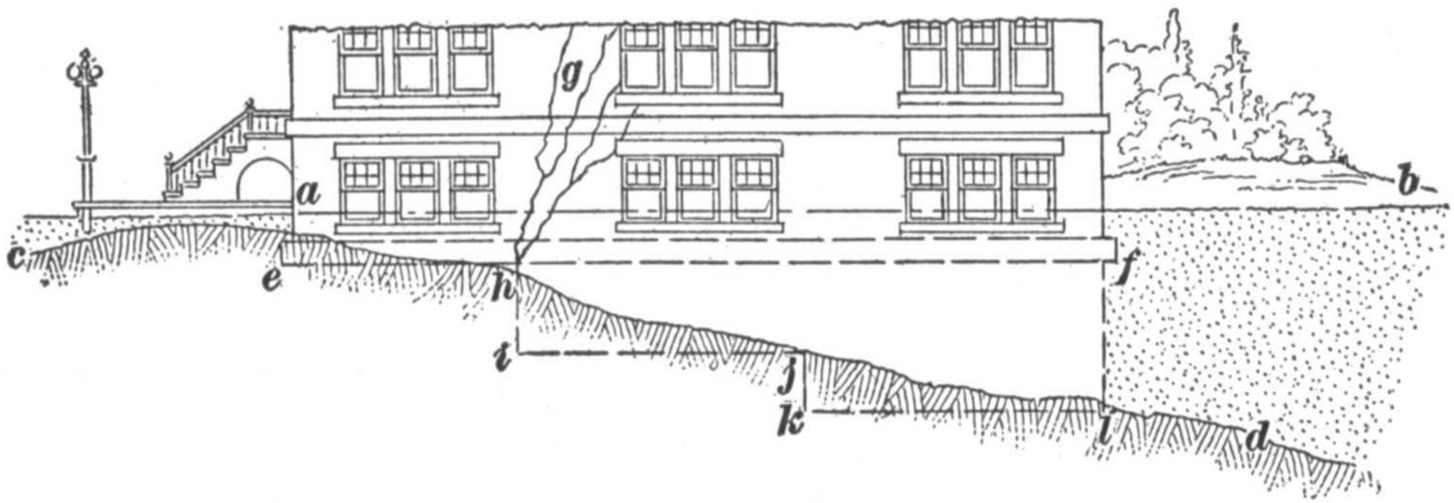
the University of Illinois assumes a leading role

RALPH BURKE - ANOTHER MEMORABLE MENTOR

Another man who shaped Ralph Peck's remarkable career was Ralph Burke (shown above with Peck), chief engineer of many notable Chicago projects, including: the Subway (pictured here in 1951), Grant Park Garage, Meigs Field, and O'Hare Airport. When he opened up his own consulting firm in 1951, he tried to induce Peck to come work for him. Peck drew upon Burke for professional advice in many of his consultations.

Lack of suitable case histories





- **When Peck began teaching foundation engineering right after the war, very few case studies of foundation problems had been published. These are from Lowndes (1928).**

Teaching foundation engineering

- In fall of 1949 Ralph Peck, Walt Hanson, and Tom Thornburn began teaching a course on foundation engineering at the University of Illinois
- Used case studies of structures built in Chicago
- The three faculty wrote a text on Foundation Engineering between 1948-52, which appeared in the fall of 1953

Peck studied the foundations for all the taller structures in Chicago

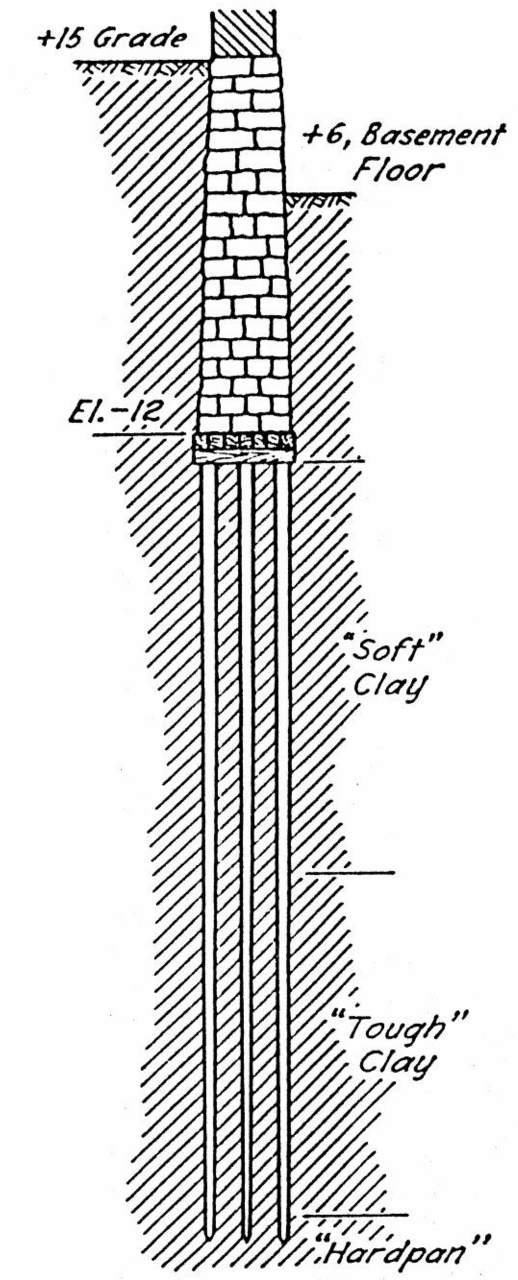


FIG. 29. BEARING-WALL FOUNDATION FOR PUBLIC LIBRARY

Above-Home Insurance Building in Chicago

Left- Wood piles founded on the hardpan

Right – Chicago caissons founded on the hardpan

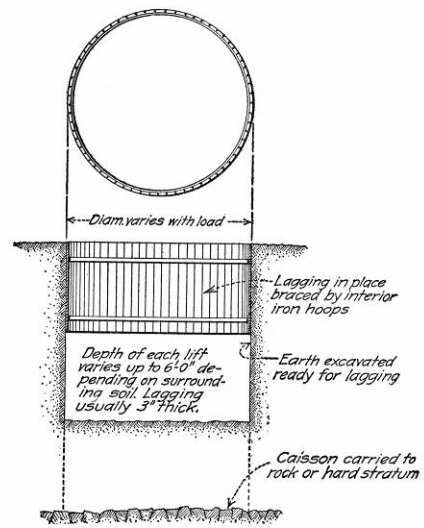


FIG. 4.—Chicago open caisson.

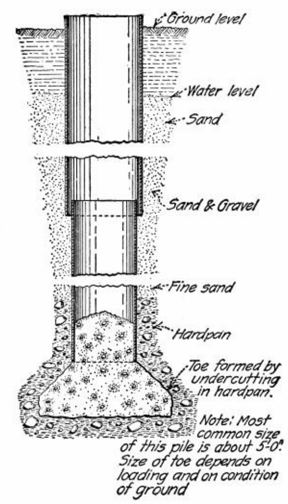


FIG. 5.—Gow pile.

History of Building Foundations in Chicago (1947)

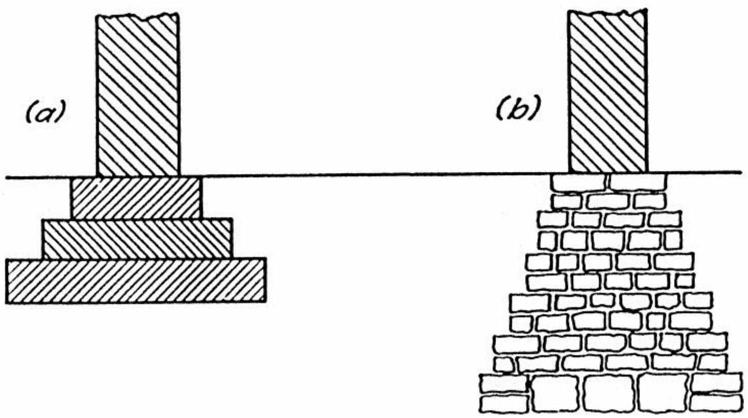


FIG. 4. (a) TYPICAL FOOTING OF DIMENSION STONE; (b) RUBBLE STONE PIER

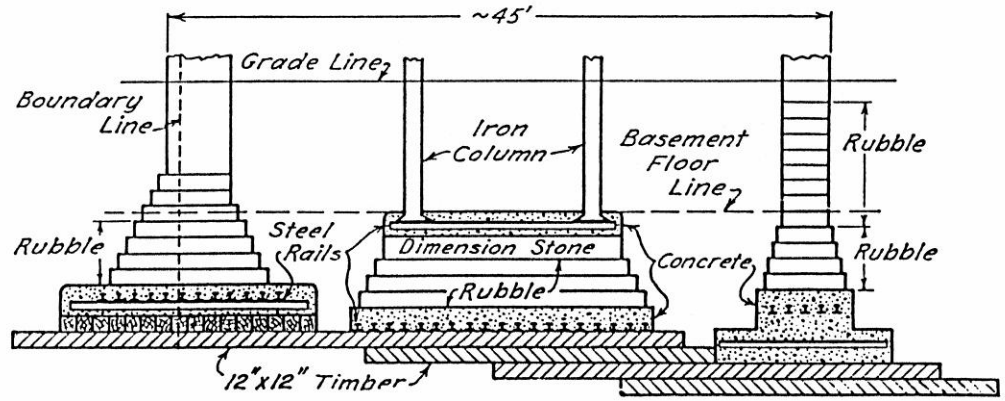


FIG. 10. SECTION THROUGH COMBINED FOOTINGS OF AUDITORIUM

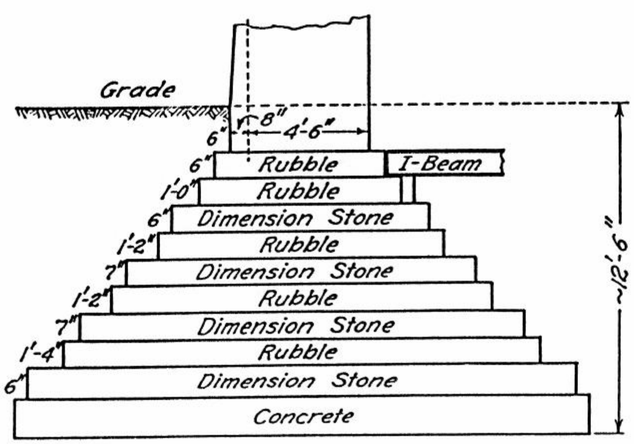


FIG. 6. SECTION THROUGH EXTERIOR PIER OF HOME INSURANCE BUILDING

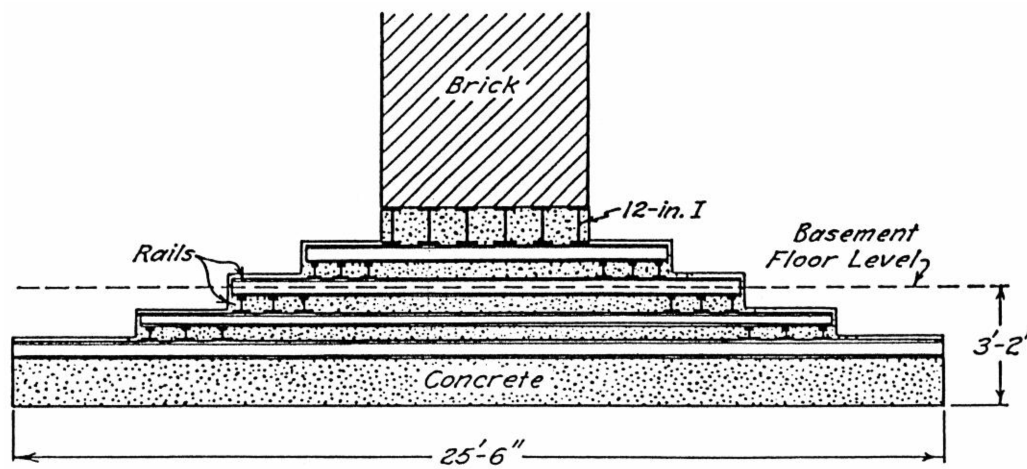


FIG. 7. SECTION THROUGH RAIL-GRILLAGE FOOTING OF MONADNOCK BLOCK

Monitoring Chicago Foundations

- Major lessons emerged from the observed measurements of foundation settlement in Chicago
- The use of uniform bearing loads did not prevent overt and damaging differential settlement
- The influence of group action and position in the foundation soon emerged, leading to the development of Newmark's influence diagrams

CE 484–Geotechnical Case Histories

- Evolved from course titled "*Advanced Foundation Construction,*" around 1957; Taught until 1974 by Ralph Peck
- Prerequisites were a full year of graduate study in soil mechanics and foundation engineering
- Open to graduate students in geotechnical engineering, structural engineering, construction management, and applied geology

Three principal goals of the case histories course….

- Problem Solving: learn how to solve real engineering problems
- Develop an appreciation of the *intimate relationships* between foundation engineering, industry, finance, politics, and human relations
- Learn how to express one's view, conclusions, and recommendations clearly and succinctly in writing

Most common scenario used in Peck's course

- The students assumed the role of a ***board of consultants***, comprised of various specialists
- The instructors presented a synopsis of the situation, as presented to the geotechnical engineer
- In some instances, the client was an engineering company with considerable skill and ability, which had amassed expansive geodata
- This allowed presentation of a rather comprehensive engineering picture to the inexperienced students

Student's expected response

- The students were expected to play role of a 'consulting board,' asking ***very specific questions***
- The instructors played the role of the client's engineer and endeavored to answer whatever questions the "board" proposed; *nothing more* and ***nothing less…***

Student's duties.....

- It was the duty of each class to discuss the problem amongst themselves, to determine whether a solution could be reached with the *available data*, and to determine what additional information, if any, was required, and to make specific request for said additional information.
- If the class decided that further exploration, tests, or measurements were needed, they had to request these data.

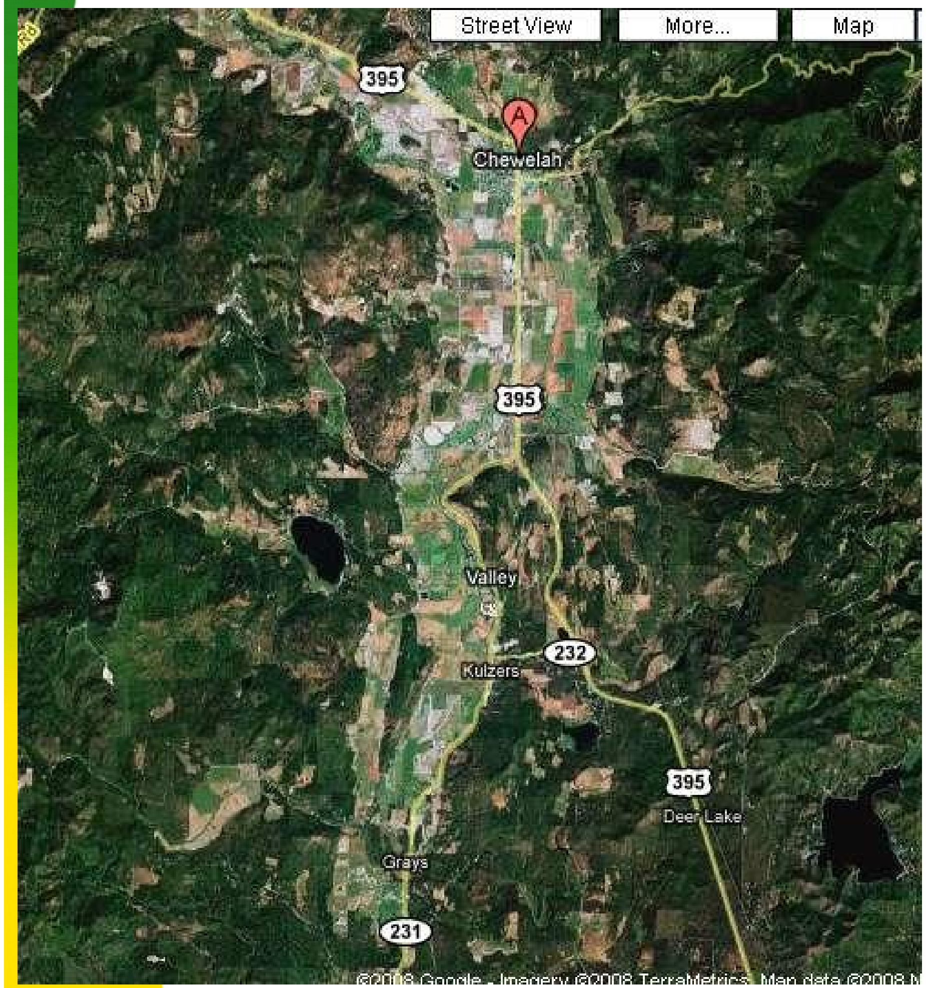
Honing engineering judgment…

- The class was advised that they must ultimately reach a decision as to when additional information could not profitably be utilized, and they must then arrive at a 'satisfactory conclusion.'
- After the class had presented their decisions, the instructor would tell the class about the conclusions reached on the actual project and how the project performed after completion.

The Chewelah Chimney case

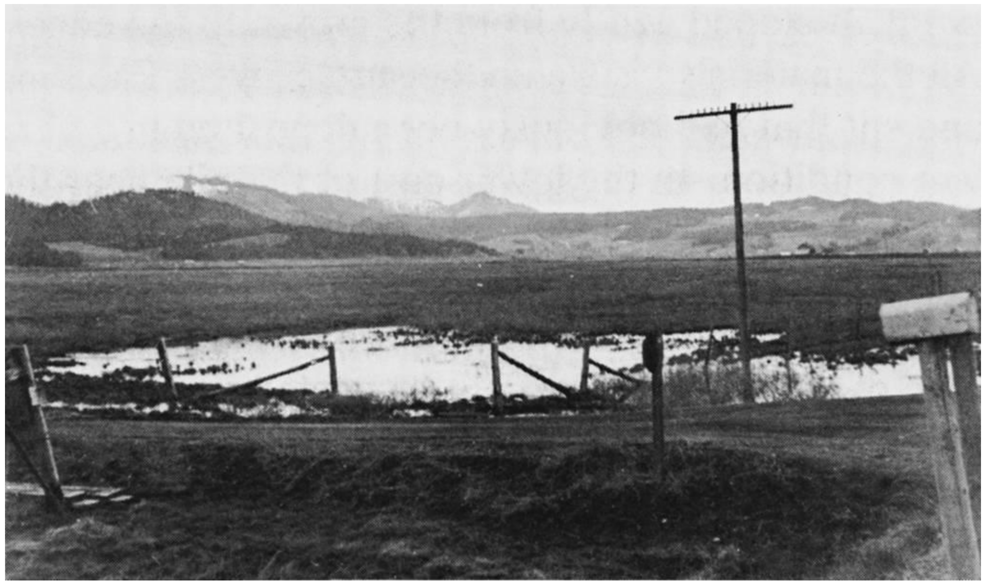
- Smelter chimney for a mine just south of Chewelah, WA-late 1940s
- The mining co drilled a hole 100 ft deep, about 100 ft from the proposed site
- The casing dropped 45 ft under its own weight and soft soils oozed upward 60 to 80 ft

Noting the *geologic setting* and backing out the *bearing capacity*…



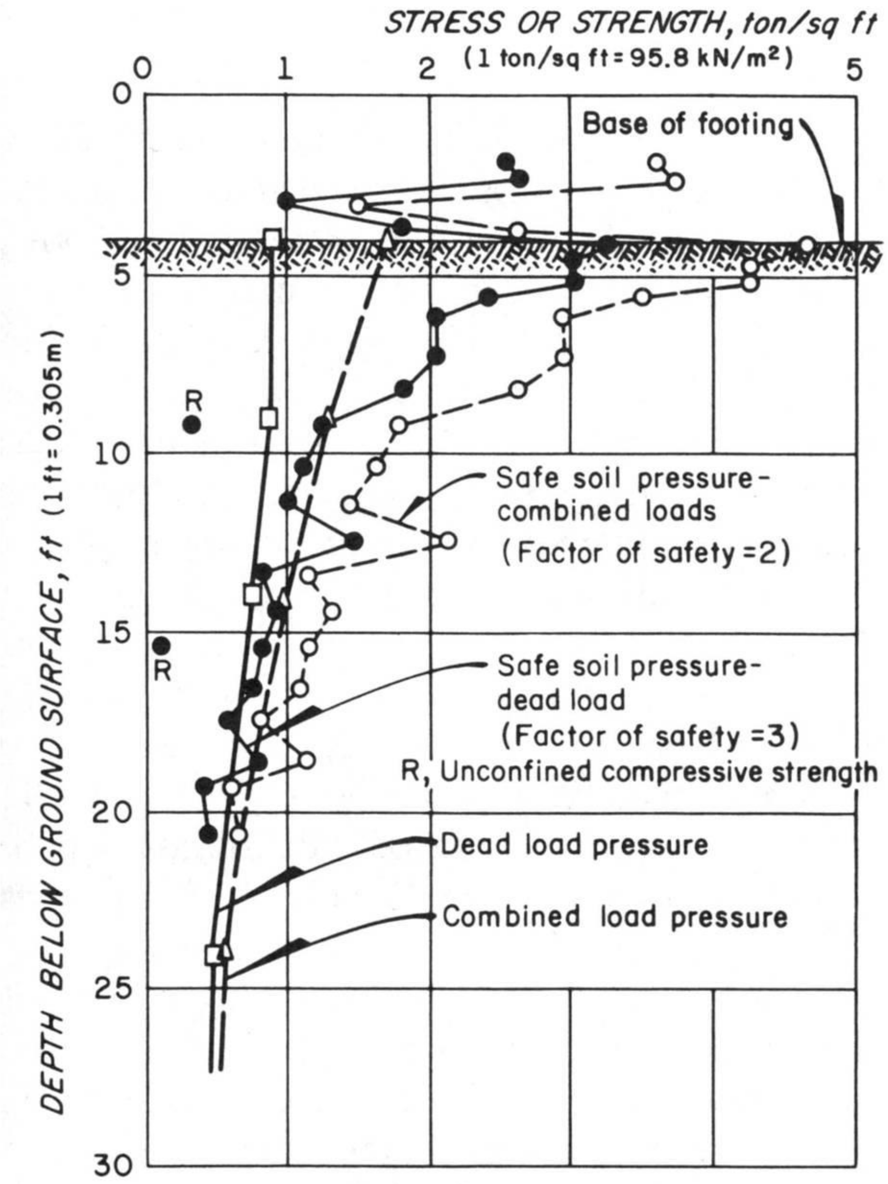
- Peck noted that the mine was located in a valley that had been blocked by a glacial ice dam, forming a deep lake
- Back-analyses of two 20-ft diameter storage silos suggested an average soil pressure of about 2 tsf (192 kN/m3)

Dissecting the drill spoils…



- Peck reconstructed the boring log by dissecting a 20 ft diameter pile of drill spoils…
- Cap was 4 ft zone of wet sand and silt, capped by oxidized clay, underlain by 16 to 26 ft of blue lacustrine clay, underlain by fine sand
- The overconsolidated crust allowed the 2 tsf bearing capacity

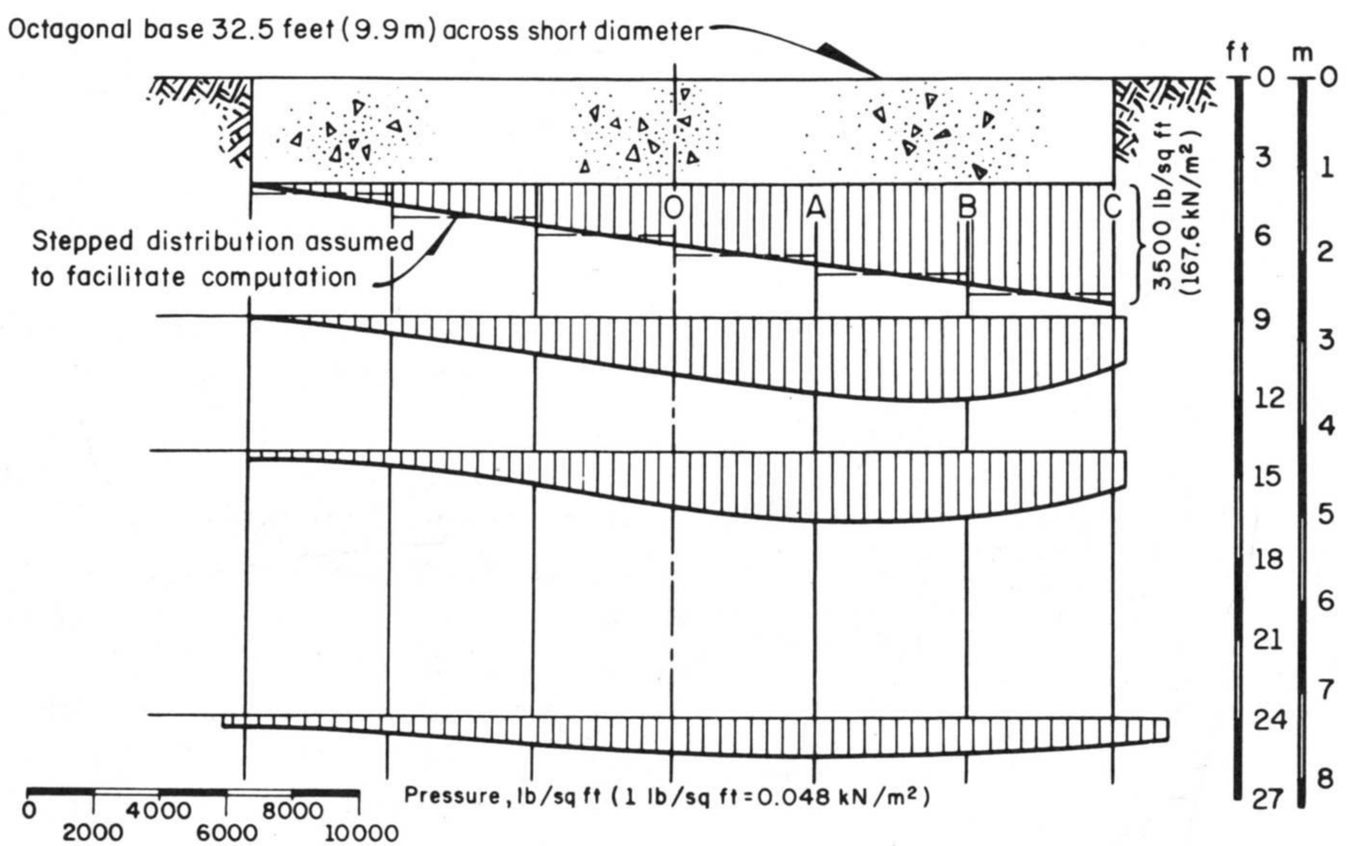
- Peck reasoned that if the bearing loads for the proposed chimney 100 ft away could be kept below 2 tsf, it would work
- The proposed octagonal footing for the chimney exerted a pressure of 3,500 psf, about 500 psf less than the ore silos
- Peck asked for a simple auger boring 25 ft deep with Shelby Tube samples….



Freeze-thaw effects cause spurious results in upper few feet

Elegant, but simple work products

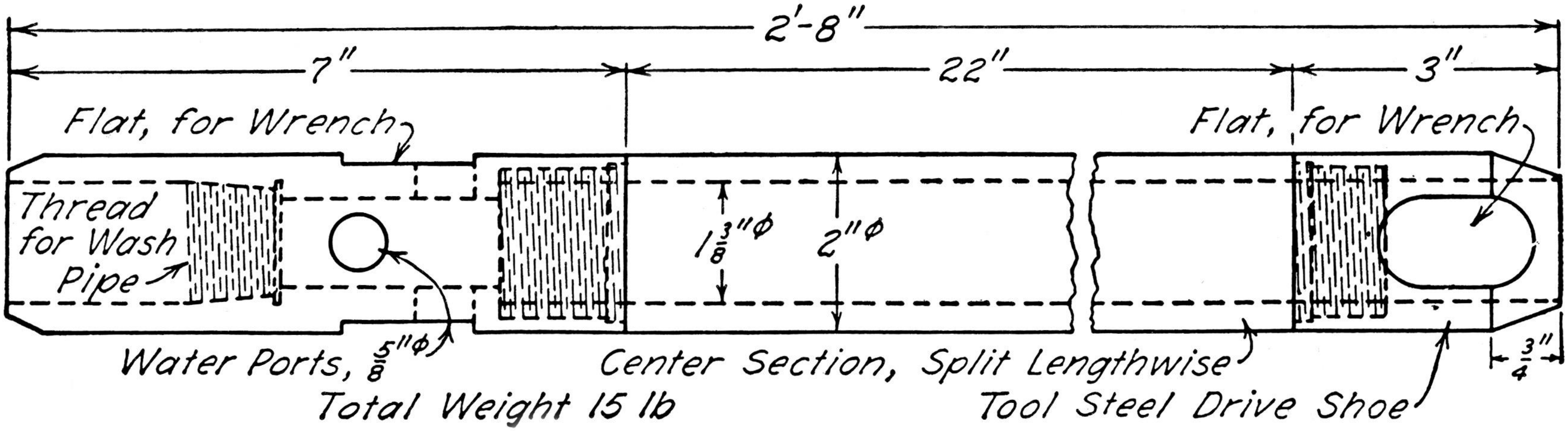
- Chart relating unconfined compressive strength (solid circles), safe soil pressures (open circles), dead load pressures (open squares) and combined load pressures (open triangles) for the Chewelah chimney site, from one 25 ft deep auger with thin wall sampling.



- **Newmark pressure diagrams** beneath the proposed chimney footing under maximum wind loading. Students found this to be a valuable graphic representation of the field situation, which required more than a simple check of bearing capacity of the hardpan layer

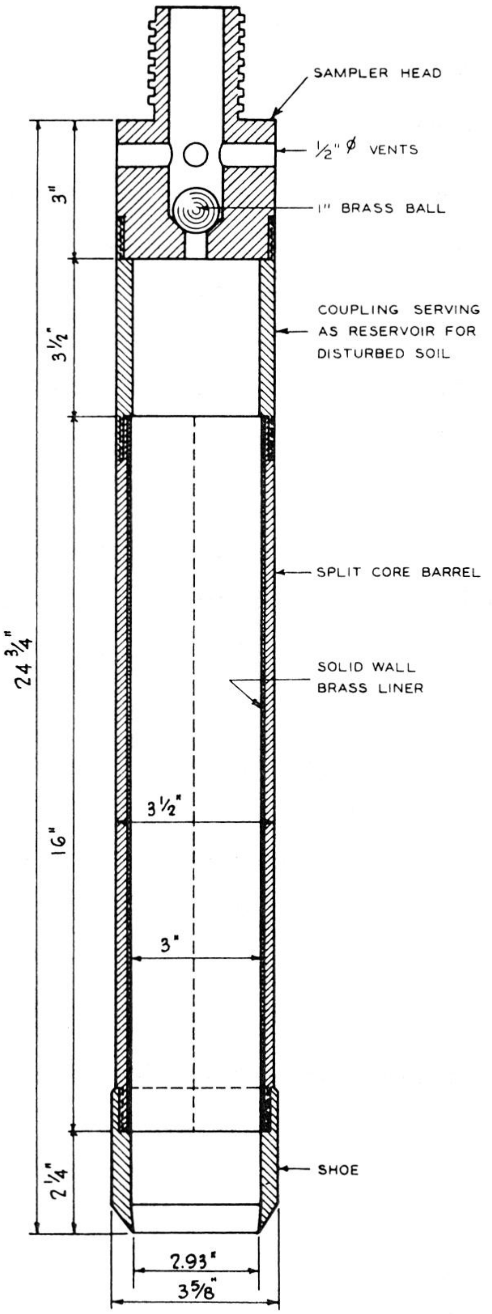
Origins of the Standard Penetration Test

The Raymond Sampler



- By 1940, the Gow Division of Raymond had standardized their 15-pound drive sampler, shown here. It employed a tool steel driving shoe with a 22-inch sample barrel. These were manufactured for Raymond by Sprague & Henwood.

Moran & Proctor 3-inch Drive Sampler



GEORGE L. FREEMAN: SOIL SURVEY FLUSHING MEADOW PARK SITE – PROC. FOUNDATION CONFERENCE, 1936, VOL. I

3" MORAN & PROCTOR SAMPLER

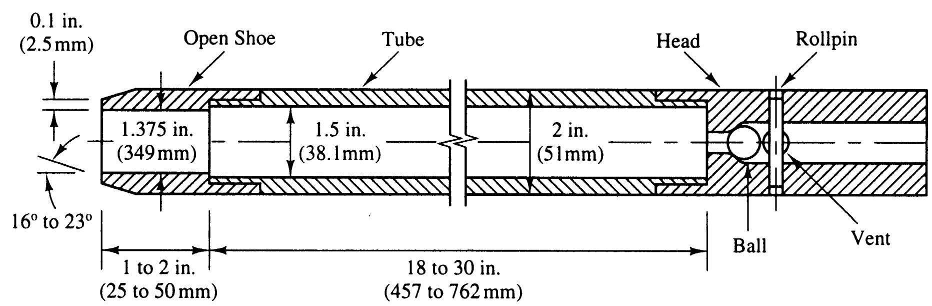
The Moran & Proctor drive sampler was developed in 1939 for the New York World's Fair site , working with Prof. Donald Burmister at Columbia University

It was much larger than the (Gow) Raymond Sampler, being 3-5/8" outside diameter, capable of recovering 3-inch diameter samples, in lieu of 1-3/8 inch.

Other geotechnical firms in the New York area began using the barrel, which was also manufactured by Sprague & Henwood.

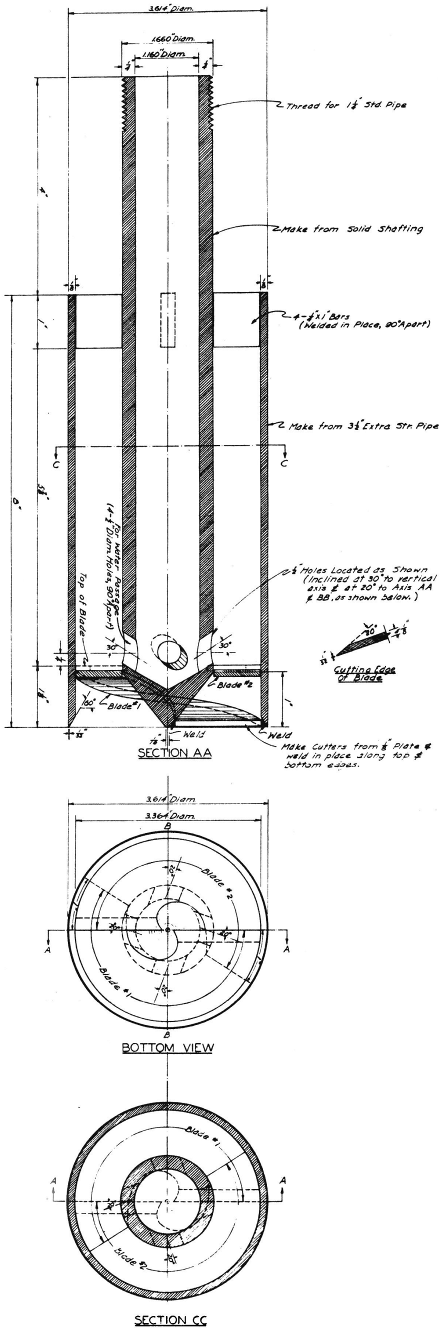
Juul Hvorslev

Developing standardized procedures



The SPT sampler (Adapted from ASTM D1586; Copyright ASTM, used with permission)

- The ASCE Committee on (soil) Sampling & Testing of the Soil Mechanics & Foundations Division was formed in 1938, and standardized procedures for drive sampling were written by Juul Hvorslev in 1940, and adopted nationally by the Engineers Joint Council in 1949.



The Jet Auger

- In 1940 James D. Parsons, a 1936 MSCE graduate of Harvard's fledgling soil mechanics program under Arthur Casagrande, joined Moran, Proctor, Freeman and Mueser and began developing a state-of-the-art soils laboratory.
- He developed a simple clean-out jet auger which was also manufactured by Sprague & Henwood, shown here
- It used horizontal jets near the tip to clean out the borehole before advancing drive samplers.

The Standard Penetration Test

- While writing the text *Soil Mechanics in Engineering Practice* with Ralph Peck in 1947, Karl Terzaghi was asked to speak on the subject of "Recent Trends in Subsoil Exploration" at the 7th Conference on Soil Mechanics & Foundation Engineering at the University of Texas at Austin

- In that lecture he coined the term *Standard Penetration Test* to describe the correlations assembled by the Gow Division of Raymond Concrete Pile Co. by Harry Mohr over the previous 20 years in major American cities.

- Foundation engineers in New York City preferred the larger M&P drive sampler, which recovered a less disturbed sample, but the SPT sampler became the favorite of most practitioners because it was simple, inexpensive, and SPT data was correlated with soil strength and consistency useful for design.

Mohr-Terzaghi Classification Scheme

SANDS AND GRAVELS	BLOWS/FOOT N_{SPT}
VERY LOOSE	0 - 4
LOOSE	4 - 10
MEDIUM DENSE	10 - 30
DENSE	30 - 50
VERY DENSE	OVER 50

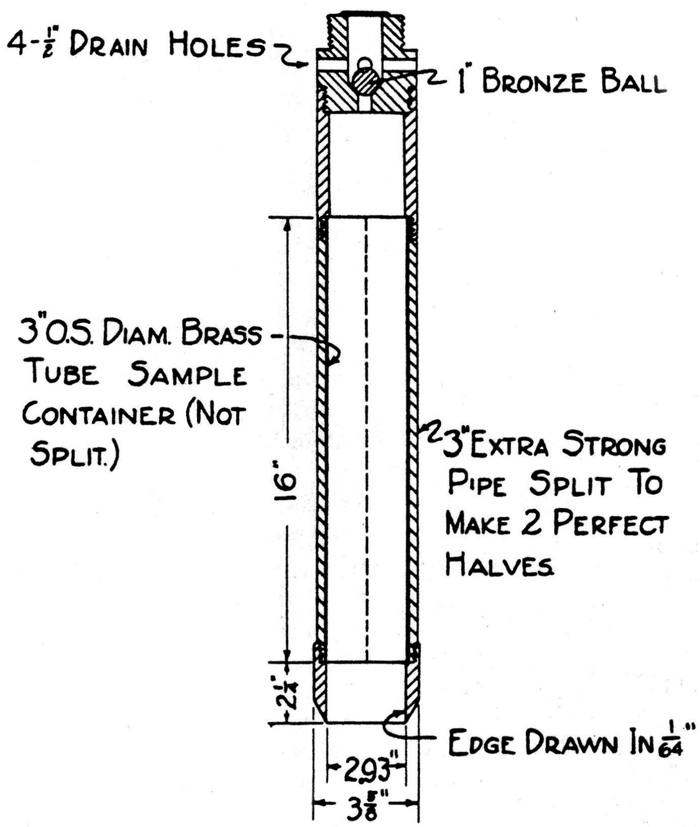
RELATIVE DENSITY

SILTS AND CLAYS	STRENGTH tsf	BLOWS/FOOT N_{SPT}
VERY SOFT	0 - ¼	0 - 2
SOFT	¼ - ½	2 - 4
FIRM	½ - 1	4 - 8
STIFF	1 - 2	8 - 16
VERY STIFF	2 - 4	16 - 32
HARD	OVER 4	OVER 32

CONSISTENCY

- The first SPT correlations appeared in *Soil Mechanics in Engineering Practice* in 1948.
- Additional correlations with soil strength appeared in the literature as more and more people began using the SPT sampler, until it became the dominant tool for soil sampling by 1960.

Different drive sampler sizes



The M&P sampler recovered a 3-inch diameter soil sample

- The larger M&P drive sampler recovered 3-nch diameter samples using 5000 inch-lbs per blow in lieu of the Raymond SPT Sampler's 4,200 inch-lbs
- In 1947 Moran, Proctor, Freeman and Mueser engaged Professor Donald Burmister of Columbia University to develop a suitable correction factor

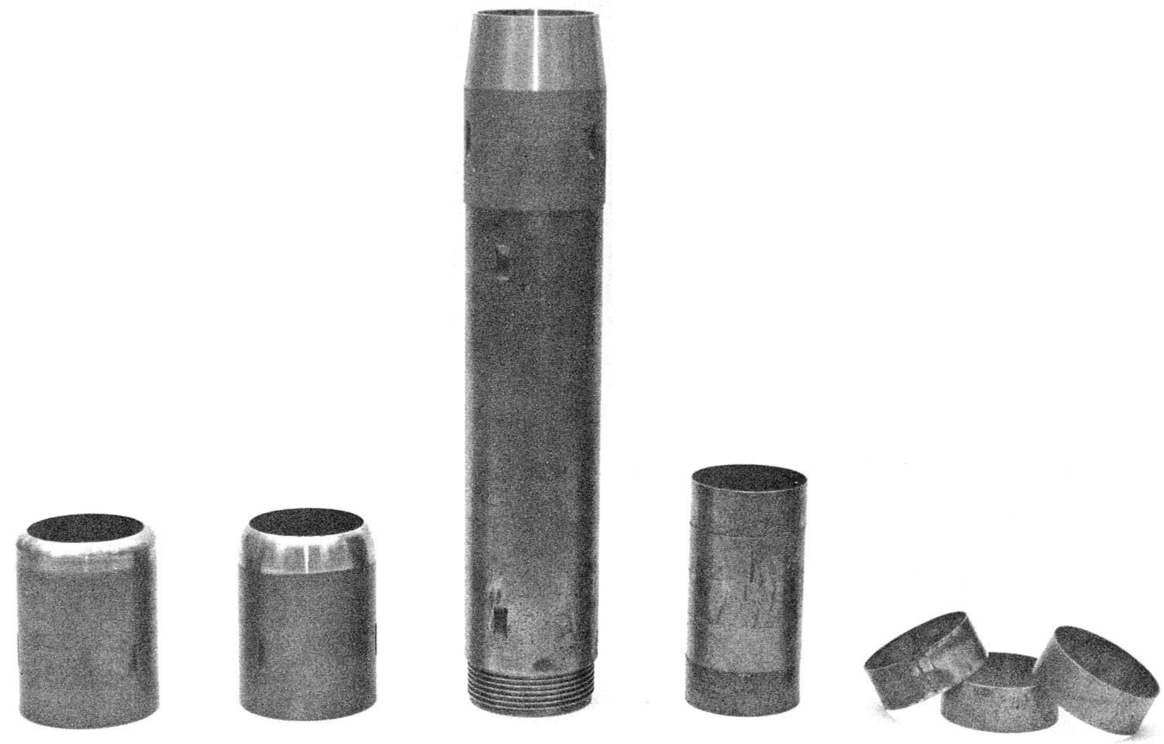
Missouri University of Science and Technology

Don Burmister 1895-1981

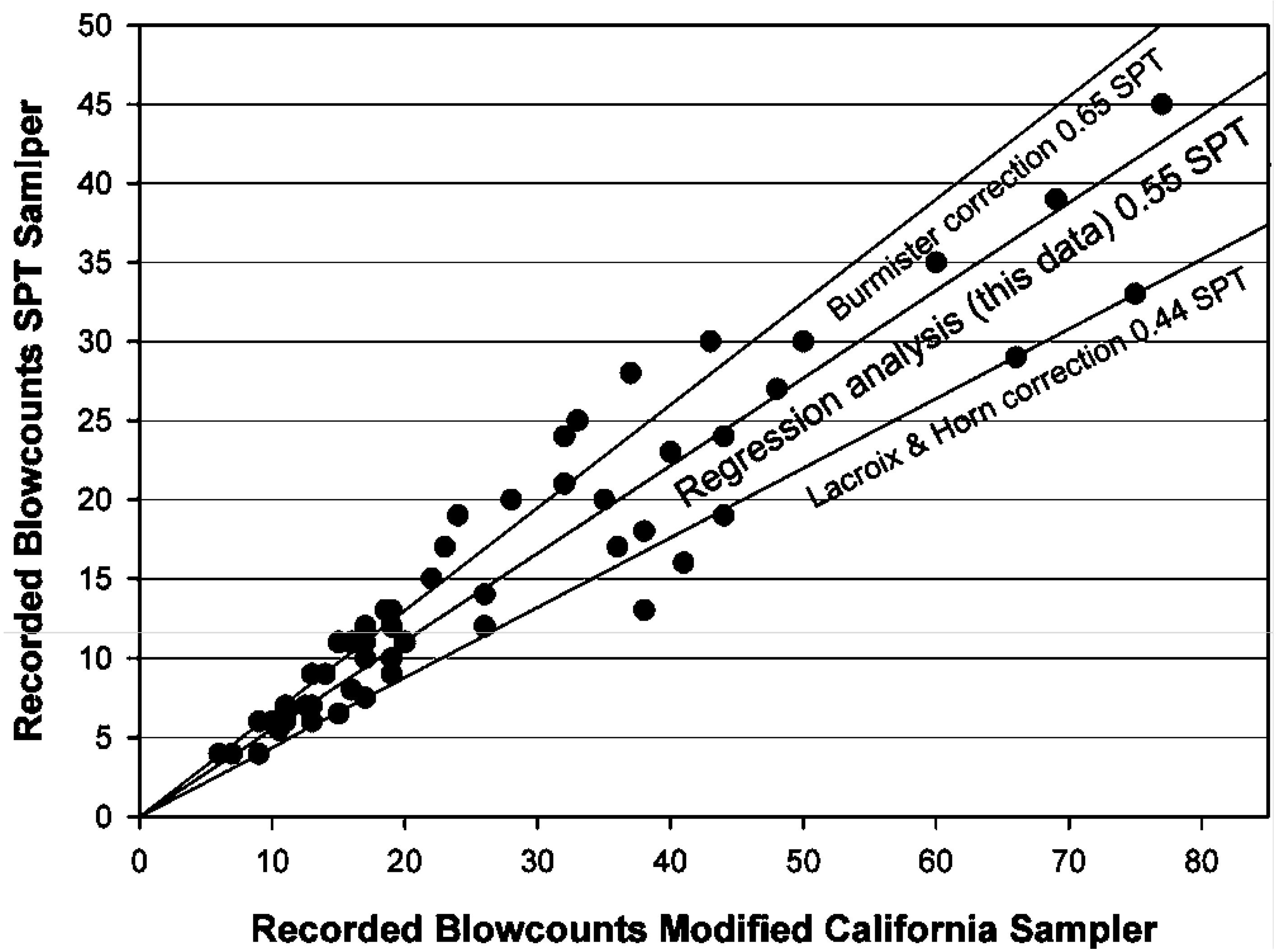
Burmister's 1948 Energy-Area Correction

$$N^* = N_R \frac{(W \text{ lbs})(H \text{ in.})}{(140 \text{ lbs})(30 \text{ in.})} \left[\frac{(2.0 \text{ in.})^2 - (1.375 \text{ in.})^2}{(D_o)^2 - (D_i)^2} \right]$$

- **Burmister's relationship considered energy input as the weight of the hammer multiplied by the drop height, the diameter of the recovered sample, and the sample barrel diameter. These were combined to provide input energy and diameter corrections to compare with conventional SPT values. This was published by ASTM in 1948.**



- In the late 1950s the Los Angeles office of Dames & Moore began employing a 3-inch diameter drive samplers, which recovered a 2.4-inch diameter sample.
- Around this same time, the Donald R. Warren Co., also of Los Angeles, also developed a somewhat smaller sampler, with a 2.5 inch outside diameter, recovering 1.875 inch diameter samples.
- These became known as the "Modified California Samplers," and have been employed along side conventional 2-inch SPT samplers in California over the past 50 years). Most workers employed Burmister's 1948 Energy-Area correction to the blow counts recorded using these larger samplers.



- **Comparison of uncorrected blow counts for SPT and the larger diameter Modified California sampler. The regression analysis suggests that the best fit lies somewhere between the 1948 Burmister energy-area correction and the 1973 LaCroix and Horn procedure, all of which are shown (figure from Rogers, 2006).**

Reporting of SPT blow counts

- In 1954 Jim Parsons of Moran, Proctor, Freeman and Mueser introduced the conventional procedure wherein blows are recorded for each of three 6-inch increments, using an 18-inch sample barrel
- The value recorded for the first round of advance is discarded because of sample disturbance and fall-in. This saved money and time by bypassing the jet auger cleanout procedure he had introduced in 1940.
- The second pair of numbers are then combined and reported as a single value for the last 12 inches.
- This value became known as the standard blow count, N, or N_{spt}

Standardizing Components

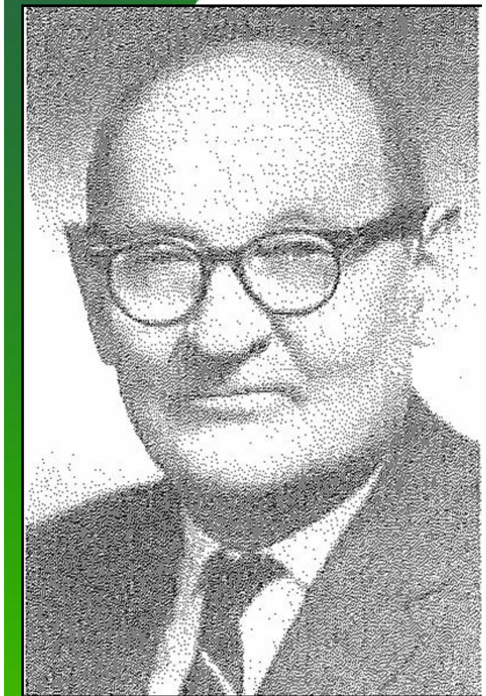
- Throughout the 1950s the various components of the SPT sampler became standardized.
- Sprague & Henwood began manufacturing an 18” long sample barrel, in lieu of the Raymond Sampler’s 22” barrel.
- The SPT procedure was adopted as ASTM Test D 1586 in 1958
- Various cutting shoes shown at lower left

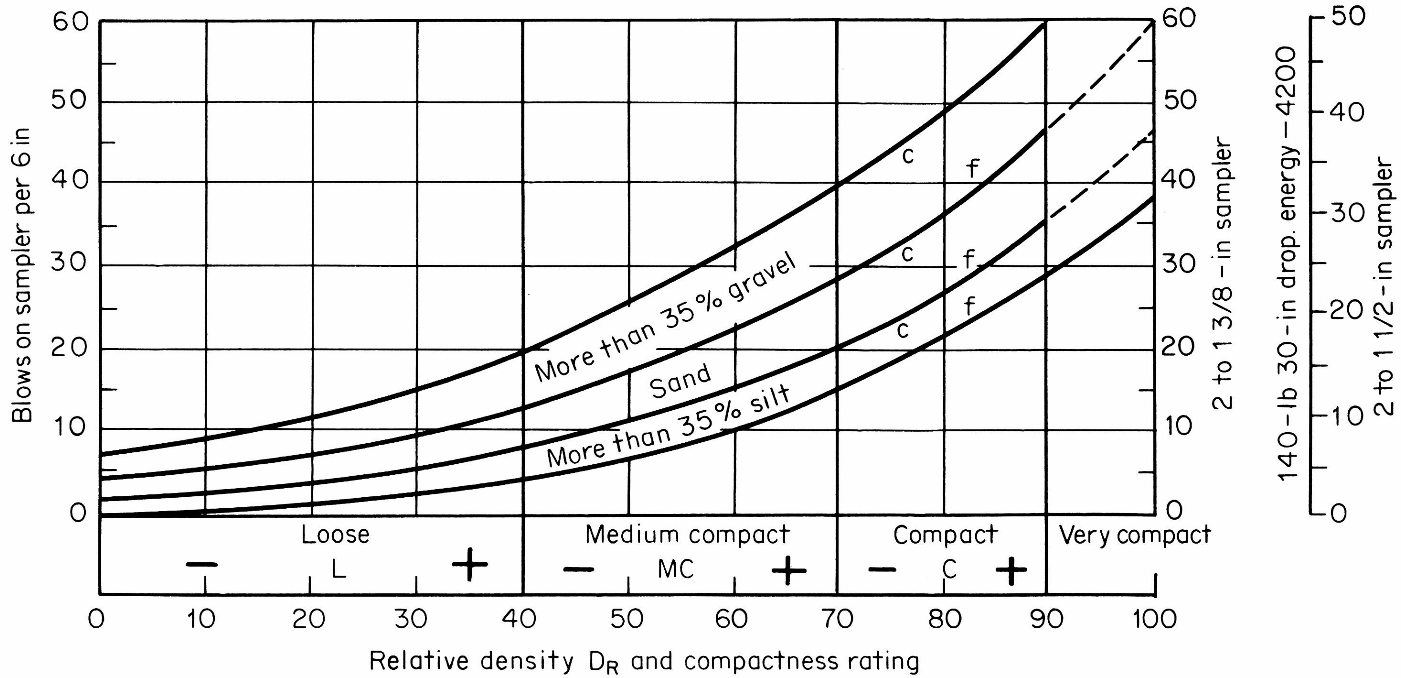
In building anything big, the first step is soil sampling. Gow Division of the Raymond Concrete Pile Company, 57-year-old construction company with projects around the world, keeps its 28 'Jeeps' going eight hours a day in its work of investigating soil conditions to furnish information to architects and designers so they can determine the best type of foundations for construction projects of all kinds. Here is one of Raymond's 'Jeeps' with power take-off being used to operate an exploratory boring outfit. The manager of Raymond's Gow Boring Division says: "We were the first to use the 'Jeep' in soil testing work, and we have been using more and more 'Jeeps' ever since. The 'Jeep' helps cut our costs by getting more done. It can maneuver over rough ground in the country and get into tight spots between buildings in the city. It furnishes the power for operating our rigs and carries our equipment quickly from job to job so that we're always ready to go."

- **This advertisement in the August 1954 issue of *Fortune* magazine highlighted Gow's use of Willys Jeeps to perform SPT tests on remote sites. Note the cathead mounted on a power take-off on the rear end of the Willys Jeep.**

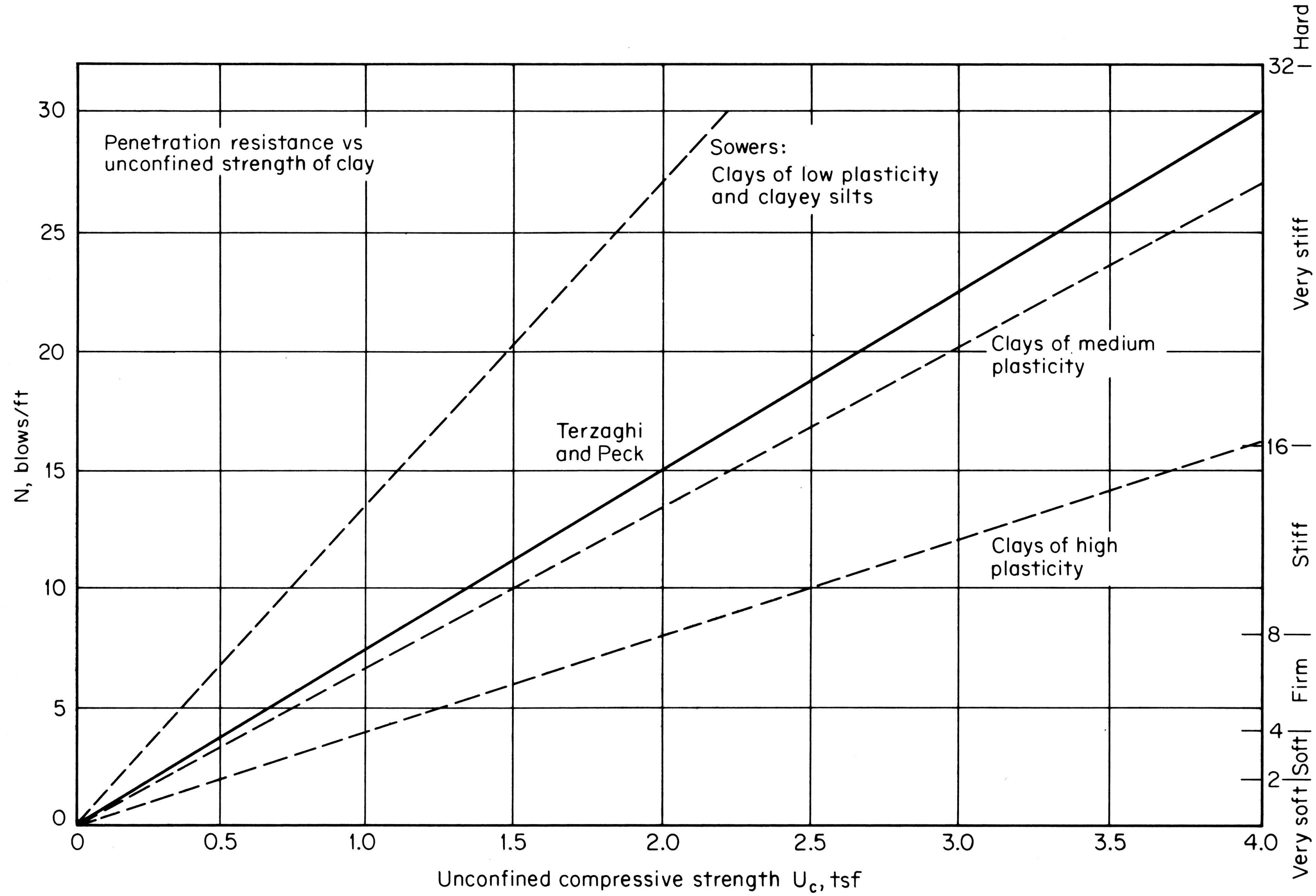
Soil Type		Undisturbed Soil Cohesion (psf)	Undisturbed Soil Friction Angle (Degrees)
Cohesive Soils			
Very Soft	(< 2)	250	0
Soft	(2 - 4)	250 - 500	0
Firm	(4 - 8)	500 - 1000	0
Stiff	(8 - 15)	1000 - 2000	0
Very Stiff	(15 - 30)	2000 - 4000	0
Hard	(> 30)	4000	0
Cohesionless Soils			
Loose	(< 10)	0	28
Medium	(10 - 30)	0	28 - 30
Dense	(> 30)	0	32
Intermediate Soils			
Loose	(< 10)	100	8
Medium	(10 - 30)	100 - 1000	8 - 12
Dense	(> 30)	1000	12

- Estimates of soil friction and cohesion based on uncorrected SPT blowcounts began appearing in soil mechanics textbooks around 1960. Although bereft of overburden corrections, these correlations were generally used for design of shallow foundations.

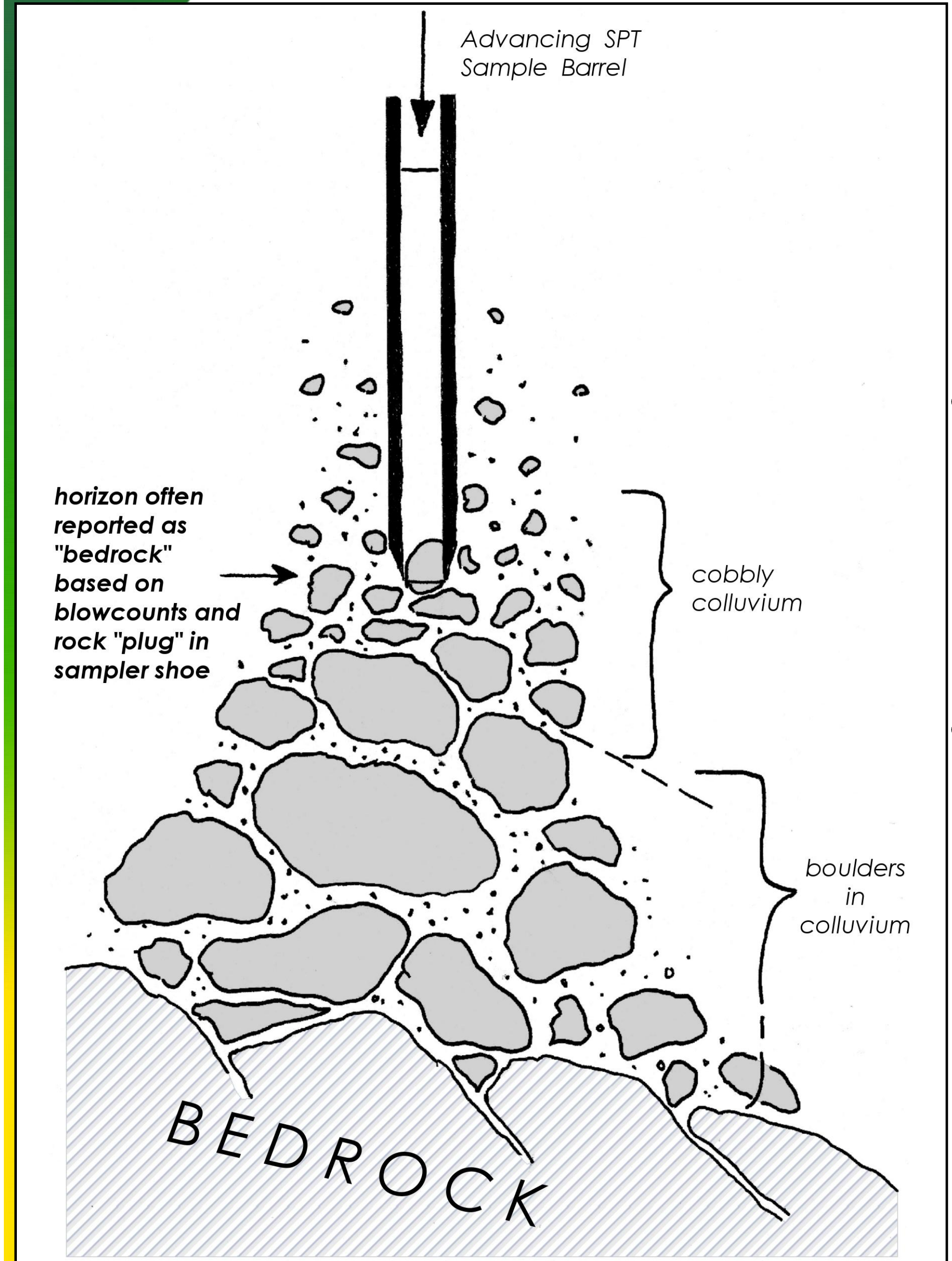




- In 1962 Prof. Don Burmister at Columbia published this chart showing the experimental relationship between raw 6-inch blow counts, sample diameter, gradation, and compactness.
- These data demonstrated the significant impact of gravel on recorded blow counts. This has been a nagging problem in characterizing fills that contain dense fragments or gravel clasts.

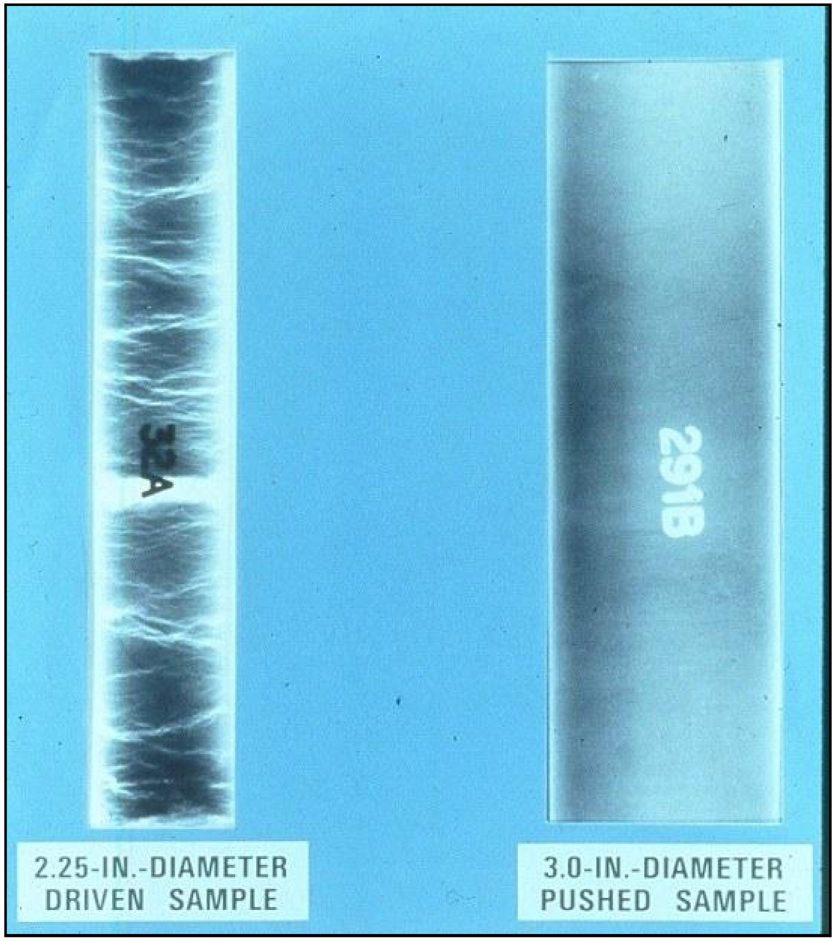


- By 1971 NAVFAC DM-7 was publishing charts like this one, which related SPT blow counts with unconfined compressive strength in cohesive soils.



Common interpretive errors

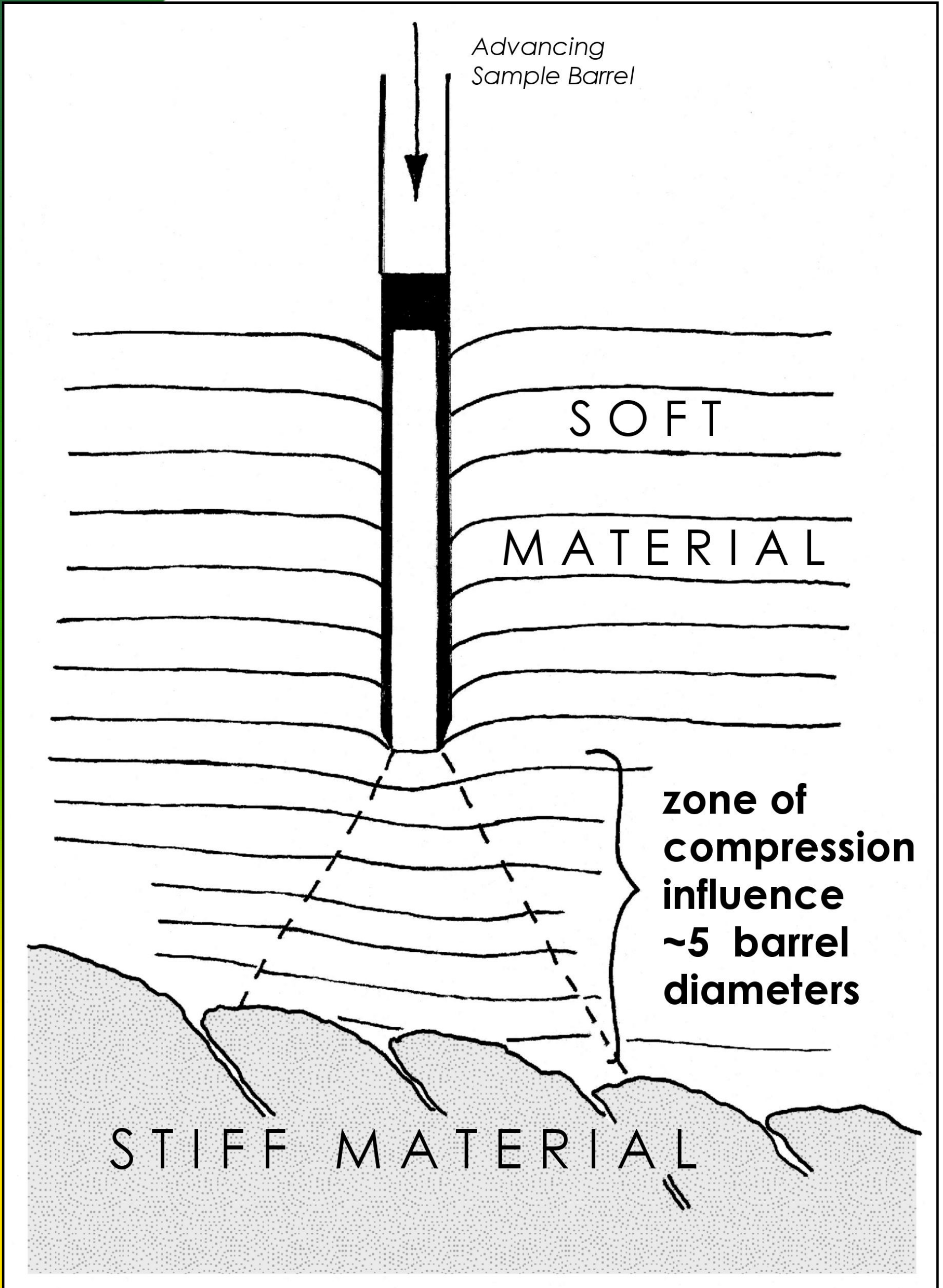
- A major disadvantage of the SPT method is the small diameter of the cutting shoe.
- The SPT cannot recover clasts > 1.375" diameter, which often leads to erroneous interpretations about "bedrock" contacts or drilling refusal.



Sample Disturbance

- Though inexpensive, a vexing problem with drive sampling is *sample disturbance*, as shown in these examples. This was recognized by the mid-1930s, when piston samplers began to evolve.

Stiffness changes



- As the drive sampler barrel approaches a stiffness boundary, it senses increasing resistance to penetration, as sketched here.
- This is a problem with sampling geologic contacts, which is usually the goal of any exploration program

Factor	Equipment Variable	Term	Correction
Overburden pressure		C_N	$(Pa/\sigma'_{vo})^{0.5}$ but $C_N \leq 2$
Energy ratio	Donut hammer	C_E	0.5–1.0
	Safety hammer		0.7–1.2
	Automatic hammer		0.8–1.5
Borehole diameter	65–115 mm	C_B	1.0
	150 mm		1.05
	200 mm		1.15
Rod length	3–4 m	C_R	0.75
	4–6 m		0.85
	6–10 m		0.95
	10–30 m		1.0
	>30 m		<1.0
Sampling method	Standard sampler	Cs	1.0
	Sampler without liners		1.1–1.3

- **During the past 20 years a number of corrections have been introduced to the SPT procedure; for overburden, energy input, borehole size, drilling rod, sampling method, etc. These allow more accurate correlations between data gathered across the world. The $(N_1)_{60}$ value is used for seismic performance assessments.**

This lecture will be posted on my website at

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