THE NEW TECHNOLOGY [1]

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SYNOPSIS

In June of 1916, the Massachusetts Institute of Technology (MIT) moved its campus from Back Bay in Boston, across the Charles River to Cambridge. The founding of the New Technology, as the Cambridge campus was known, served as a laboratory for the development of a new technology called soil mechanics.

Although foundations which support the New Technology were designed and constructed in accordance with the state-of-the-art at the time, the buildings settled at an alarming rate for the first 10 to 15 years, prompting stories that MIT students would some day be entering the buildings on the second floor.

In 1925, President Samuel Stratton invited an Austrian engineer named Karl Terzaghi to lecture at MIT and to apply his knowledge of soil mechanics to an evaluation of the subsidence.

With Dr. Terzaghi's arrival at the Institute, MIT became a center for the development of the science of soil mechanics, which is the foundation for the practice of geotechnical engineering.

Many outstanding and dedicated alumni of MIT played important roles in the founding of the New Technology, but the real hero in this case study of the evolution of a new technology, is a remarkable alumnus of the Department of Civil Engineering, John R. Freeman, '76.

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1 This paper was presented at a Symposium entitled the "Past, Present and Future of Geotechnical Engineering" held at the Massachusetts Institute of Technology, September 24-25, 1981. Proceedings of that conference are available through the Constructed Facilities Division of the MIT Department of Civil Engineering. The authors acknowledge the generosity of MIT for permitting publication of this paper in the Journal of the Boston Society of Civil Engineers Section, ASCE.
Also presented at a 22 April 1982 meeting of the Geotechnical Group of The Boston Society of Civil Engineers Section, ASCE.

2 Respectively, President and Staff Engineer, Haley & Aldrich, Inc. Cambridge, Massachusetts.

BOSTON TECH

The Massachusetts Institute of Technology, commonly called Boston Tech for 50 years, was founded by William Barton Rogers, a geologist. First classes were held on February 20, 1865. Following a year in crowded classrooms rented at the Mercantile Library Building, located at the corner of Summer and Hawley Streets in downtown Boston, students occupied the new Rogers Building on Boylston Street. The tuition fee was set at $100 per year for first year students.

The Rogers Building was joined in 1883 by the Walker Building and together they served as the center of the campus until 1916.*

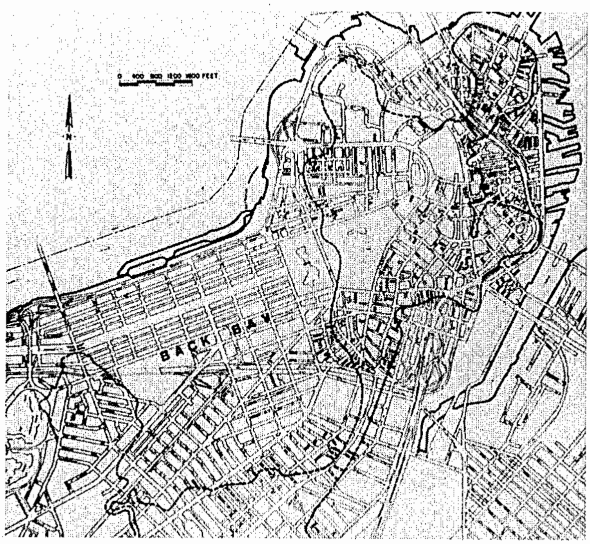

Figure 1. Boston's colonial shoreline superimposed on a modern map.

*Robert H. Richards, a member of the first graduating class in 1868, founded the Alumni Association in 1875 and served as its first president. In addition, he and other young civil engineering graduates from MIT met in May 1873 "to form a junior engineers' association", the members of which were elected to the then dormant Boston Society of Civil Engineers founded in 1848. The BSCE, now the Boston Society of Civil Engineers Section of the ASCE, continues today as the oldest engineering society in America.

The Boylston Street site for Boston Tech was located in the Back Bay, a former tidal embayment of the Charles River, Figure 1. Colonial Boston was a hilly peninsula connected to the mainland by a narrow causeway which is now Washington Street. Major filling of the Back Bay mud flats began in 1858 and construction of buildings followed close behind.

On April 10, 1861, an act chartering MIT and granting the Institute two-thirds of a block of land between Berkeley and Clarendon Streets was signed by Governor Andrew of Massachusetts. The remaining one-third of the block was granted to the Boston Society of Natural History.

A diorama of the site, Figure 2, prepared for the New England Mutual Life Insurance Company which now occupies the Boylston Street site of MIT, shows construction of the Rogers Building in about 1864. To the east is the completed Boston Society of Natural History (now housing the Bonwit Teller store). Back Bay filling is in progress west of the site and row houses on Beacon Street have been completed to about Dartmouth Street. The future site of MIT across the Charles River in Cambridge appears at the top of the diorama.

Figure 2. Diorama looking northwest across the Back Bay filling towards Cambridge. The Rogers Building is shown under construction in the foreground.

Following the Civil War, enrollment at MIT grew to 348 students in 1872-73. In that year, tuition was raised from $150 to $200 where it remained for 30 years. During the first decade, a third of the graduates were civil engineers.

By the turn of the century, enrollment had grown to 1300, the campus had scattered to other locations and the Institute was in dire need of additional space and the financial resources to relocate.

A 1904 map of the campus, Figure 3, shows the Rogers and Walker Buildings as well as other engineering buildings and the Lowell School located on land now occupied by the John Hancock Tower, the YWCA, the Massachusetts Turnpike Extension and the John Hancock Garage. The mechanical engineering laboratory appears in the left corner of the figure. A gymnasium was located behind the Lenox Hotel. The Institute also had an athletic field in Brookline.

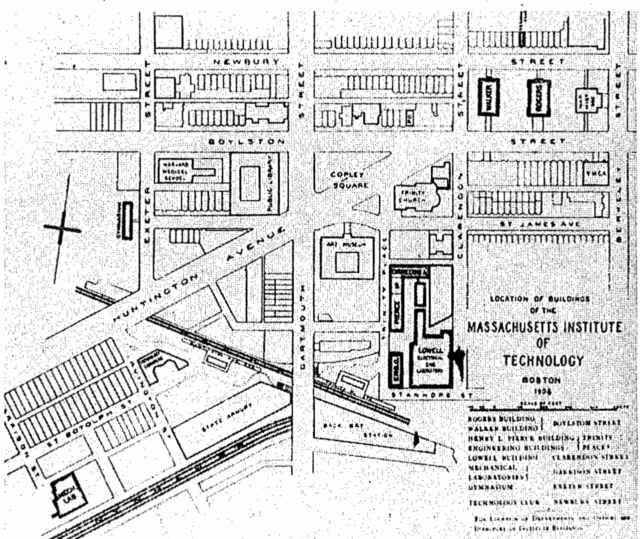

Figure 3. 1904 Map of MIT's Boston Campus.

There was a serious proposal to merge with Harvard in 1905. The faculty and the angry alumni voted against the plan, and the alumni pressured for the resignation of President Henry Pritchett who favored the merger.

Nevertheless, the Corporation voted in favor of a merger on condition the Back Bay land and buildings be sold to pay for new buildings. The Supreme Judicial Court held that MIT could not sell the land it had been granted, so MIT had no dowry and the marriage with Harvard University was called off.

At the end of 1905, Pritchett did resign to become president of the Carnegie Foundation for the Advancement of Teaching.

SITE SELECTION FOR THE NEW TECHNOLOGY

In 1906, a site committee was appointed by the Corporation to study the possible alternatives to solving the need for more land. At various times in the next five years, MIT considered a tract of land in the Fenway, a golf club in Allston near the Boston University Bridge and a site in Jamaica Plain. Several suggestions were proposed that an island be built in the Charles River.

The site that appealed most to President Richard C. Maclaurin, Figure 4, who had become the Institute's sixth president in 1909, was an area of filled land along the Charles River in Cambridge, Figure 5. When Maclaurin visited Boston in April of that year, his host was Charles A. Stone, '88. Stone pointed out the site from his windows on the water side of Beacon Street, but counseled Maclaurin that Harvard University and the City of Cambridge would be opposed to the purchase because of the great amount of tax-exempt property already held by Harvard.

In January 1911, a delegation of MIT alumni from Springfield called on President Maclaurin and offered Technology a site of 30 acres bordering the Connecticut River and overlooking the valley and the Berkshires. When news of this proposal appeared in the local press, Cambridge citizens suddenly began petitioning for the Institute to move to Cambridge. After the Cambridge City Council formally approved a move, MIT began negotiations to purchase the land.

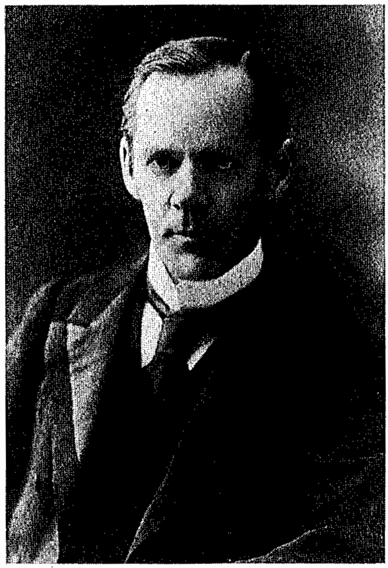

Figure 4. MIT President Richard Maclaurin.

Figure 5. MIT's Cambridge site before completion of site filling. The new Harvard Bridge is shown.

Later in 1911, MIT had completed negotiations with 35 property owners to sell about 46 acres of land east of Massachusetts Avenue for the New Technology, Figure 6. T. Coleman duPont, '84, president of E. I. duPont, had contributed $500,000 toward the final purchase price of $775,000.

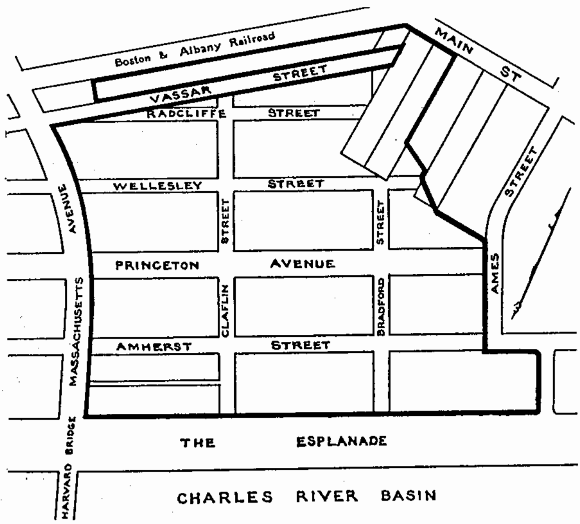

Figure 6 Map of property purchased for the New Technology.

In October of 1911, President Maclaurin boldly announced that construction would begin the following year, although at the time, he had no idea where funds for the building would be found.*

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*When Boston alumni met in January 1912, Maclaurin announced alumni gifts making possible the opening of a Civil Engineering Summer School at E. Machias, ME. H. Farwell Bemis, '93, had given a 1,000-acre lot and supplied equipment for the camp. Charles W. Eaton, '85, gave $10,000 for the construction of buildings. The camp opened the following year.

On February 22, 1912, Frank Lovejoy, '94, general manager of Eastman Kodak Company, wrote to Maclaurin saying that George Eastman "would be inclined to help out". Subsequently, Maclaurin met with Eastman and he anonymously gave $2,500,000 for construction of the New Technology. Eastman was known as the mysterious "Mr. Smith" until his identity was disclosed in 1920.

TOPOGRAPHIC DEVELOPMENT OF THE SITE

The site for the New Technology had been part of the tidal estuary of the Charles River, land partially filled by dredging from the riverbed. In fact, in colonial times the entire contemporary campus bounded by Vassar Street, Main Street and Memorial Drive was primarily tidal mud flats with some bordering salt marsh, Figure 7.

Figure 7. Map showing development of Cambridge shoreline from 1777 to the present.

The proposed site for the new buildings was crossed by a tidal stream the thread of which passed through the Metropolitan Storage Warehouse and MIT's present Building 10 and Building 2. The location of this channel was to have a major impact on the construction and performance of foundations for the New Technology.

Following construction of the West Boston Bridge (site of the Longfellow Bridge) in 1793, the Kendall Square area was developed as a port with canals, wharves and warehouses which handled shipping off the Charles River.

In 1853, an embankment for the Grand Junction Railroad was constructed across the tide flats and marsh, parallel to which Vassar Street was constructed years later. Heavy industry developed around the future MIT site, stretching along the westerly side of the railroad and around Kendall Square.

In the early 1880's, the Charles River Embankment Company undertook to fill the land and construct a granite seawall between the West Boston (Longfellow) and Brookline Street (Boston University) Bridges. The company controlled a triangle of approximately 215 acres bounded by the railroad on the west, Main Street on the north and the Charles River. Promoters of the project, led by Charles Davenport, hoped to create a fashionable residential district comparable to the successful development in the Back Bay across the Charles.

Completion of the Harvard Bridge in 1890 and construction of Massachusetts Avenue along its present route east of Lafayette Square encouraged the developers. However, the Company collapsed in the panic of 1893, but not before organic soils, silt and sand were dredged hydraulically from the riverbed to partially fill the land which MIT would occupy.

With completion of the esplanade (Memorial Drive) by the Cambridge Park Department, and construction of the Charles River Dam in 1910, which stabilized water level in the Basin, one of Cambridge's most important topographic and environmental assets was assured. MIT was to become the beneficiary of that asset.

The Metropolitan Storage Warehouse was the first large building constructed on the filled land between the railroad and the Harvard Bridge. The front section was built in 1895 and the remainder some years later. The Riverbank Court Hotel (purchased in 1939 by MIT for a graduate student dormitory and later named Ashdown House) was a luxurious apartment hotel constructed in 1900 on the tip of Whittemore Point, a marshy point underlain by gravel. Shortly thereafter, in 1902, the City built an armory which is now the duPont Center Gymnasium.

East of the site for the New Technology, beyond Ames Street, the dominant structure was the International Shoe and Leather Exposition Building, a stucco-covered structure built in 1908 on the site of the present 100 Memorial Drive apartment house. Its domes foreshadowed MIT's domed classical style, Figure 8.

Figure 8. International Shoe and Leather Exposition Building.

Subsequent to the time MIT purchased the site, additional earth fill was placed. The hydraulic fill, predominantly organic silt with sand and often bearing shells, was supplemented by hauled sand and gravel and by miscellaneous fill including earth from subway construction. (The subway from Park Street to Harvard Square across the Longfellow Bridge was opened in 1912.)

GEOLOGY AND SUBSURFACE CONDITIONS

Soil conditions in Boston and Cambridge, and indeed the topography of the area in the seventeenth century, owe their origin to events which took place during the Pleistocene.

During this geologic period, there were successive advances and retreats of glacial ice followed by extreme variations in climate and sea level, all of which influenced the sediments and their engineering properties.

A generalized soil profile below the MIT campus is shown in Figure 9. Bedrock occurs at a depth of from 120 to 135 ft. below the main buildings. The rock is part of the Cambridge Slate formation which underlies most of the Boston peninsula and Cambridge. Often called Cambridge Argillite, it is a fine-grained clayey rock formed in the Permian-Carboniferous periods.

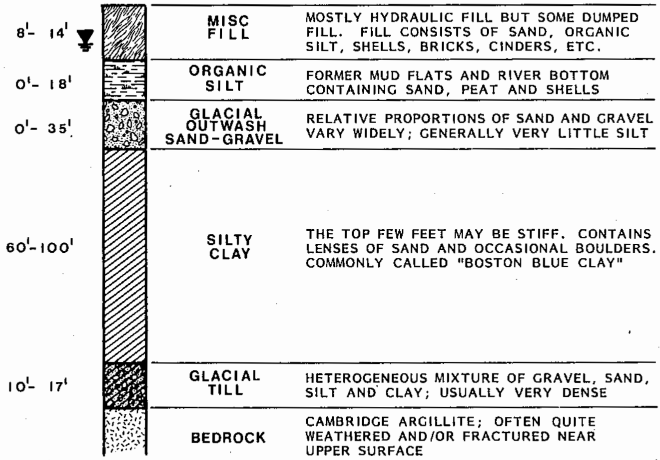

Figure 9. Generalized soil profile for the New Technology.

From 10 to 17 ft. of glacial till overlies the rock. The till, laid down at the base of glaciers during the Boston substage of the Wisconsin glacier, is a very compact heterogeneous mixture typically gray silty sandy gravel with cobbles and boulders.

A stratum of inorganic silty clay from 60 to 100 ft. thick and known locally as Boston Blue Clay, was formed when silt and clay-size particles were sorted from the till by glacial melt-water streams and deposited in quiet marine waters.

The clay, gray to olive-green in color, is generally medium to soft in consistency. The top of the stratum was subjected to desiccation and oxidation at a time when the sea was below its present level relative to the land, resulting in a stiff crust of yellowish or buff colored clay.

Some 12,000 to 14,000 years ago, following a readvance of glacial ice during the Lexington substage, medium compact to compact well-graded gravelly sand was deposited over the clay by fast moving streams. The sand stratum varies considerably in thickness, typically from 5 to 25 ft.

In recent times following the glacial age, plastic organic silt was deposited by river and tidal currents, and salt marsh peat accumulated in the tidal estuary of the Charles River due to the slowly rising sea. The topography of seventeenth century Cambridge was thus established.

The final episode in the development of subsurface deposits occurred during the late nineteenth and early twentieth centuries when man-made fills were placed over the organic soils to raise the grade a safe distance above water level.

With construction of the Charles River Dam in 1910, water level in the Charles River Basin was controlled at El. 13.2 ft., Cambridge City Base (El. 8.0, Boston City Base). Groundwater levels on campus are typically somewhat lower, from El. 10.5 to 12.

The organic soils, sand-gravel stratum and underlying clay bear especial significance to foundations for the New Technology.

JOHN R. FREEMAN'S PRELIMINARY DESIGN

In February of 1912, President Maclaurin turned to a civil engineering alumnus and member of the Corporation, John Ripley Freeman, '76, Figure 10, to study the engineering problems of building on the new site. As a loyal alumnus, Freeman was pleased to donate his time for the work.

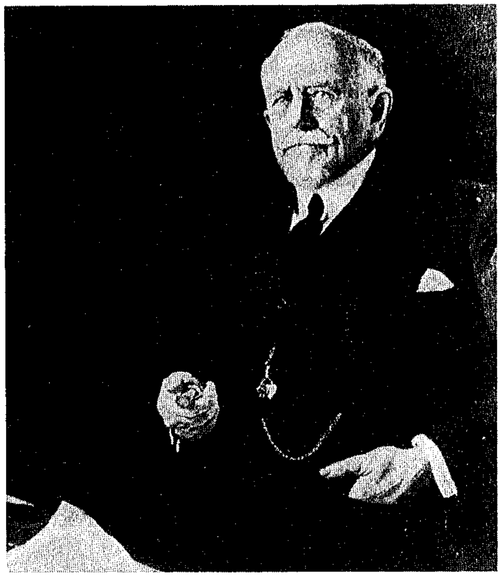

Figure 10. John Ripley Freeman.

Freeman was one of MIT's most distinguished alumni. He led a double life as businessman and engineer. He was President and Treasurer of the Manufacturer's Mutual Fire Insurance Company of Providence. This company later affiliated with others and, during his tenure, became the largest of its kind in the country.

In addition to his role as a business executive, Freeman was an eminent consulting engineer with a world-wide reputation. His specialty was large hydraulic projects.

His consulting projects included:

- Locks and dams for the Panama Canal
- Water supply systems for New York, Los Angeles, San Francisco, Baltimore, and Boston
- Regulation projects on the Great Lakes
- Water power development on the St. Lawrence River

Freeman also practiced structural and industrial engineering in association with repairs and redesign from his insurance work. He was very familiar with the state-of-the-art of industrial architecture, and had even studied the construction of large auditoriums and theaters.

He held honorary doctorates from five universities in this country and abroad. He had been president of the Alumni Association for two years, president of the Boston Society of Civil Engineers and president of the national ASCE and ASME.

Some years before, President Henry Pritchett of MIT made an "earnest suggestion" as to Freeman's "undertaking the management of this institution" (10). He declined, having "grave doubts about my possibilities in the dinner jacket end of such a job." (10).

Freeman was also one of the foremost experts in soils and foundation engineering. He was one of the first engineers to realize the importance of geology to civil engineering. He was the principal investigator for the Charles River Dam (at the present Museum of Science) and consequently was familiar with subsoils in the former Charles River estuary.

In all, John R. Freeman was one of the most qualified individuals for the job of planning the New Technology.

He initiated his study with characteristic thoroughness, dispatching teams of recent MIT engineering and architecture graduates equipped with notebooks and cameras to inspect the great colleges and technical schools in the United States, Canada and Europe.

He was convinced that the new campus presented an "opportunity for a vast improvement in the efficiency of college architecture" (5, p. 12). He believed that college buildings were usually of an inefficient monumental style in which the outward appearance, to please the benefactor, was the paramount consideration. The internal function of the buildings was generally considered secondary and sacrificed, if necessary. Freeman regarded the design of the New Technology as "one-fifth architecture and four-fifths a problem of industrial engineering" (5, p. 12).

The budget of $2.50 per square foot for 1,000,000 sq. ft. of floor area precluded consideration of a monumental style structure, which he felt was poorly suited for the Institute in any case.

Freeman proposed a structure with a classical facade comprised of narrow, interconnected wings enclosing interior courtyards, Figure 11. High ceilings and large windows were provided for light and ventilation. He provided an architectural layout and structural framing system that would allow for future expansion and renovation.

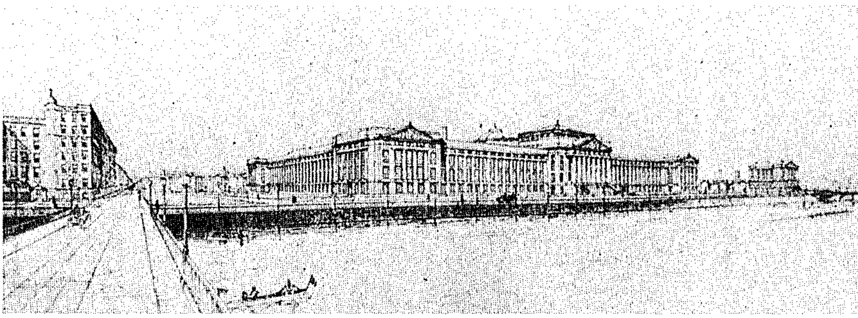

Figure 11. Freeman's proposed New Technology.

At one time, he considered moving the shell of the old Rogers Building to Cambridge for sentiment and for use as a technical museum. It was to be located at the site now occupied by the President's House.

Freeman's most radical proposal was the use of architectural concrete. Concrete had never been used for the exterior of college buildings. In fact, concrete technology was not available to provide architectural quality concrete. Freeman's opinion was "that it is highly probable that goodlooking, impervious durable concrete can be had if one will only study the subject faithfully, and will give a building at lower cost than any possible building material that would give equal architectural effects" (5, p. 34). He also proposed the use of precast concrete elements for most of the facade.

His preliminary study was accompanied by a companion report, prepared under his supervision, which detailed the subsidence of the land and existing buildings in the Cambridgeport area near the new campus. Data collected by Freeman indicated that ground surface in the area of recent landfill had settled two feet or more at some locations. In addition, some buildings had settled, notably the Metropolitan Storage Warehouse where settlement of 14 in. had been recorded during a period of 15 years.

Freeman identified the cause of the subsidence as the increased load on the substrata due to the building weight and the weight of 12 to 15 ft. of recent land fill. He concluded that the cause was "an extremely slow squeezing out of the water contained within the pore space of a deep and relatively soft bed of clay", Figure 12 (17, p. 1).

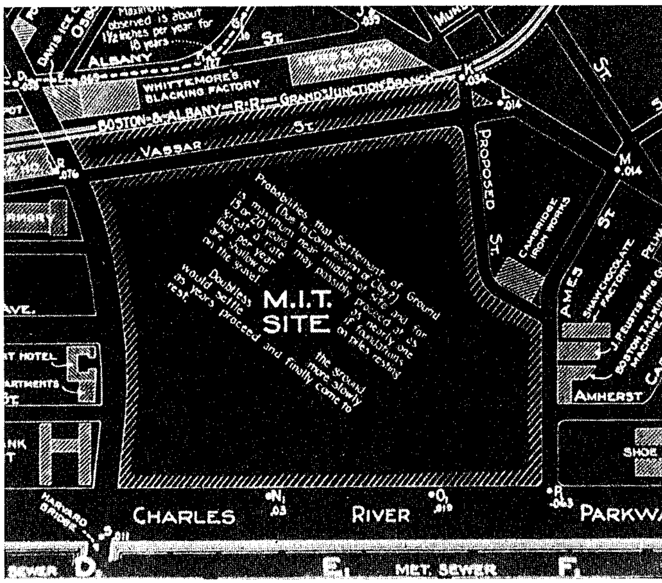

Figure 12. Figure from Freeman's report with note warning of probable settlements at the M.I.T. site.

Freeman made no mention of the possibility that compression of peat and organic silt under the weight of recent earth fill could be a contributing factor to settlement of streets and sewers. He attributed the great variations in observed settlements primarily to variations in the depth to bedrock.

Although he was unable to predict the magnitude of the settlement, he said, "Nor is there reason to expect that the settlement at any point on the Technology site may not be as great as that of the Metropolitan Storage Warehouse which has gone down at the rate of nearly 1 in. per year and which now stands 14 in. lower than when built". He also said, "obviously the motion should decrease from year to year or decade to decade and ultimately stop" (17, p. 2).

Freeman initiated a program of 22 deep test borings over the 46-acre site. He engaged his classmate and frequent collaborator, Professor William Otis Crosby, '76, to prepare an interpretative report of the geology and subsurface conditions. Both the conclusions and timing of Crosby's report would have serious consequences for the design of foundations for the New Technology.

Crosby disagreed with Freeman's conclusions regarding the cause of observed settlements in the neighborhood of the new campus. Crosby believed that the surface settlements were a result of densification of the recent fill and compression of the peat stratum. He attributed observed structural settlements to inadequate foundations rather than compression of the clay. Freeman noted these views in his preliminary study and referred to Professor Crosby's forthcoming report.

As a possible foundation system for the buildings, Freeman considered long concrete piles, bearing below the clay, but rejected the concept as uneconomical. He proposed instead to found the buildings on the sand-gravel outwash stratum. Spread footings dimensioned for a bearing pressure of 2.5 tons per square foot would be used where the top of the glacial outwash was at or above El. 0. Where the stratum was below El. 0, end-bearing timber piles would be used with a working load of approximately 8.5 tons per pile.

Freeman believed that the structures would experience settlement of a magnitude he could not predict. His solution was to stiffen the substructure to redistribute the building load as settlement occurred so as to avoid differential settlement. He termed the foundation "a floating foundation" and described it as follows:

> It is feasible to "float the entire group of buildings upon a foundation designed to withstand uplift like the bottom of a ship, and thus competent to support the entire weight of the structures, however soft the substrata might be" (5, p. 99).

Freeman proposed to support the columns on continuous foundation walls that were actually gigantic girders of reinforced concrete. The proposed girders beneath the longitudinal column lines ranged from 18 ft. to 26 ft. deep. They were intersected by 7-ft. deep girders 15 ft. on center, Figure 13.

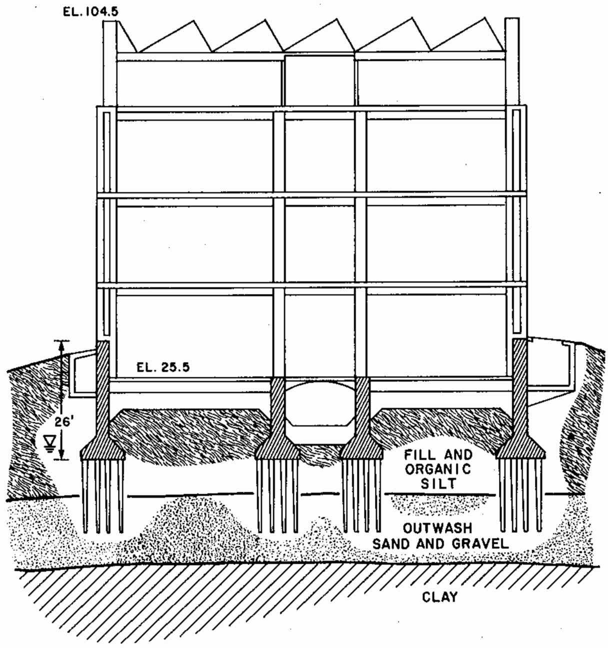

Figure 13. Cross section showing Freeman's proposed foundation. Cross hatching indicates longitudinal grade beams.

Freeman submitted his preliminary design report to the Corporation in January 1913 with an offer to prepare complete working drawings and supervise the construction.

The preliminary plans were exhaustive, as Freeman hoped they would be adopted as the plans for the New Technology. He provided complete architectural renderings of the exterior facade, the courtyards, the corridors, the classrooms, and even the professors' offices.

WILLIAM WELLS BOSWORTH SELECTED AS ARCHITECT

Freeman's plans for the New Technology were rejected by President Maclaurin because of Maclaurin's belief that the new Institute buildings had to be of monumental quality, in direct conflict with Freeman's design philosophy. Maclaurin was appalled at Freeman's recommendation that the facade be architectural concrete, stating that nothing less than stone would do.

On February 17, 1913, the Institute engaged an architect, William Wells Bosworth, '89, to prepare final plans under the review of the head of the Department of Architecture, James Knox Taylor, '79.

Bosworth was a relative unknown in the Boston area. He had practiced several years in New York and had acquired a reputation for skill in combining architecture and landscaping. Perhaps his most important credential was that he was John D. Rockefeller's private architect.

Freeman was furious with the choice of Bosworth. He had offered to supervise the preparation of working drawings and the construction, partly out of his enthusiasm for the project and partly due to his concern that "lack of economy would follow the adoption of ordinary architectural methods on these special problems" (11). In addition to his low opinion of architects as "beauty doctors", he considered Bosworth to be unqualified. Freeman was convinced that Bosworth's plans for the academic buildings would consume all of the available funds, leaving nothing to equip the laboratories or to build dormitories.

His fears concerning cost were well justified. In spite of Maclaurin's insistence that the cost of the buildings should not exceed $2,500,000, the monumental facade and other design changes resulted in significantly less floor area in the academic buildings than Freeman believed he could provide, no dormitories, and a cost close to double the budget.

In the months which followed, Freeman's input and influence in the architectural design and foundation engineering for the buildings would be removed, even though he attempted to intervene.

Bosworth's original plan for the New Technology, prepared in 1913, is shown in Figure 14. His design was described by Freeman as incorporating between a quarter and a half of the ideas which he, Freeman, had presented in his preliminary study.

Figure 14. Bosworth's proposed New Technology.

Fundamental similarities between the two were:

° Interconnected buildings, primarily to encourage interdisciplinary work

° Standardized reinforced concrete frame with non-load bearing partitions to allow flexibility for expansion or renovations

The difference between the schemes was primarily architectural and included:

° Arrangement of the buildings to create the Great Court (now the Killian Court, named in honor of the Institute's tenth president, James R. Killian, '26).

° Indiana limestone for the facade, rather than architectural concrete made from crushed marble and white cement

° The Great Dome

The Great Dome was to have a profound effect because of the increased height and weight of Building 10, which would aggravate the settlement problem.

The prototype of Bosworth's plan, with its dome and pilastered wings enclosing a spacious open court, was Thomas Jefferson's rotunda and colonnades at the University of Virginia. It was a symbolically appropriate precedent because MIT's founder, William Barton Rogers, had come from that university.

WILLIAM O. CROSBY'S REPORT ON GEOLOGY

Professsor Crosby's report on the geology of the new site, which Freeman had referred to in his preliminary study, was submitted to President Maclaurin in July 1913. The report was accepted by the Institute as definitive.

William O. Crosby had been a professor of geology at MIT until he resigned in 1907 because of deafness. He was the first engineering geologist in the country and a leading authority on the geology of the Boston area. He and Freeman started a life-long friendship during their student days. Freeman engaged Crosby to perform geologic investigations on numerous dams and large hydraulic projects and had a high regard for his practical approach to engineering problems. Generally he placed ultimate confidence in Crosby's conclusions regarding geology. However, on this occasion they disagreed.

Crosby's interpretation of the geology of the site is essentially consistent with our current interpretation, with several significant exceptions.

In his description of the soil strata present at the site, Crosby made the following statement: "Although the drillmen make a distinction between 'soft' and 'stiff' blue clay, it is probable that in its normal condition in the ground, all of the clay is devoid of excess moisture and fairly to be described as stiff. In brief, the blue clay is undoubtedly a far more stable formation than it is commonly supposed to be." (3, p.7).

In essence, Crosby concluded that sample disturbance was responsible for the softer consistency of the clay samples from the lower region of the stratum. Crosby had held his opinion for some time. He had stated it ten years earlier in a paper on the geology of the Boston Basin.

"Superficially", Crosby stated, "the clay is usually more or less yellowed by oxidation, as the result of exposure to atmospheric influences before it subsided below the level of the sea..." (3, p.7). He was not aware, however, that desiccation had precompressed the clay to a considerable depth below its top surface, increasing its strength and reducing its compressibility.

The most curious interpretive error Crosby made was in a section of his report headlined "Stability of the Blue Clay" which reads, in part, as follows:

> "The tendency of the blue clay to yield under long-continued heavy pressure is, apparently, demonstrated by the fact that the upper surface of the clay, that is, the contact of the clay and overlying gravel, sinks as the gravel becomes thicker and rises as it becomes thinner, the clay seeming to have responded to the inequality of load. It is improbable, however, that this isostatic tendency to respond to variations of load, still exists to such a degree that the weight of the proposed buildings will cause further sensible yielding of the clay. We must suppose, rather, that, although the clay, as originally deposited, was supersaturated with water and hence soft and yielding (plastic), the long-continued pressure due to its own mass and the weight of the overlying gravel, sand and silt has squeezed the excess water out of the clay, and forced the clay and quartz particles into the closest possible relations, the remaining water acting as a cement instead of a lubricant, the mass as a whole becoming semi-dry, well compacted and relatively resistant." (3, p.11).

The logic expressed above is attractive. It was reasonable to believe that if the clay at the top of the deposit is hard, the clay on the bottom, under the added weight of the clay above, must be hard as well.

Having concluded that the clay stratum was unyielding, Crosby concluded that the surface settlements in the area of recent filling and the settlements of the neighboring structures documented by Freeman were due to densification of the recent fill, compression of peat and inadequate foundations.

Since no peat was found in any of the borings and glacial gravel was present over the clay, Crosby concluded that "... we are certainly justified in regarding the new site as virtually above suspicion." (3, p.15).

STONE & WEBSTER SELECTED AS ENGINEERS AND CONTRACTORS

On July 25, 1913, the Corporation voted to accept Bosworth's preliminary plans for the New Technology. During the same month, the Stone & Webster Engineering Corporation was selected to engineer the design and construct the buildings.

Charles A. Stone and Edwin S. Webster had been classmates at MIT and were two of the Institute's earliest graduates in electrical engineering. After receiving their degrees in 1888, they formed a partnership as consulting engineers in the then new field of electricity. At the time they were chosen as engineers for the building construction, their firm had grown to be one of the leading construction companies in the world, known for the efficiency and quality of its work.

Stone and Webster were both enthusiastic alumni and members of the Corporation. Webster had been president of the Alumni Association in 1909 and Stone would become president in 1916.

As the structural engineers, Stone & Webster was given responsibility for all of the underground work, including the design of the foundations. Stone & Webster in turn engaged Charles T. Main, '76, a classmate of Freeman's, as a consultant on the foundations.

Main was also an active alumnus and member of the Corporation. He had been president of the Alumni Association for two years at the turn of the century. In addition, he served as president of the Boston Society of Civil Engineers in 1911.

FOUNDATION DESIGN

Stone & Webster's and Charles T. Main's interpretation of the nature of the blue clay agreed with the geological report prepared by Professor Crosby. Their foundation system was intended to limit expected settlements to small values in contrast to Freeman's proposed "floating foundation" which was intended to prevent differential settlement that would lead to distortion of the building frame.

In a paper published in Technology Review in 1915 and in the Journal of the BSCE in January 1918, Charles T. Main stated:

> "It has been assumed.....that if settlement occurs, it will be in the clay, and in order to reduce this settlement to a minimum it was decided to spread the building loads over the glacial gravel as much as practicable which in turn would still further distribute the loads over the clay bed.
>
> In order to provide for a wide distribution of load on the gravel in the most uniform manner, with a resulting low pressure per square foot, it was decided to use a large number of wood piles, each sustaining a relatively small load, rather than a few heavily loaded piles." (16, p.7).

The load was assumed to be distributed at an angle of 60 degrees from horizontal from the elevation where the piles entered the glacial outwash stratum, resulting in an increase in load on the top of the clay of approximately 1500 lb. per sq. ft. which was well below the commonly used "safe bearing pressure".

The heavily loaded piles which Main referred to were Simplex and Raymond concrete piles, both installed to bear in the glacial outwash.

Pile cutoff was established at El. 13, with the bottom of the pile caps at El. 12.5. The piles were spaced between 2 ft. and 3 ft. on center. The deep girders of Freeman's design were not incorporated.

The design was very conventional, Figure 15. Timber piles bearing in the sand-gravel stratum overlying the clay supported most of the buildings neighboring the site in Cambridgeport as well as those in the Back Bay where the gravel occurs. Nevertheless, the engineering community was expressing concern, in addition to Freeman's warnings, that settlement of the clay was being observed at existing structures and must be considered in the foundation design.

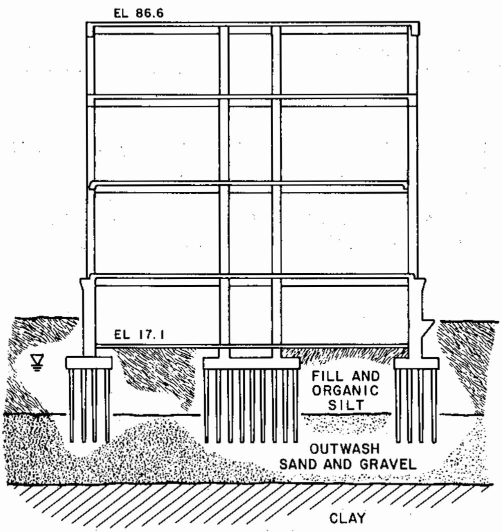

Figure 15. Cross section showing Main's foundation.

PILE TESTING PROGRAM

Although the Engineering News pile driving formula was in common use for calculating pile capacity, Charles T. Main decided to establish pile capacities on the basis of load tests. Load testing of piles was, apparently, a relatively recent innovation. Two plate bearing tests, also apparently rare, were performed to investigate the load-settlement characteristics of the glacial outwash and the clay.

The objectives of the field testing program were to:

- Verify Professor Crosby's conclusion that the clay would not settle significantly under load, and

- Compare the driving characteristics and load carrying ability of different species of timber piles at different locations over the site.

Two plate load tests, one on the glacial outwash and one on the clay, were performed by Charles Gow.

The test procedures were as follows:

- An excavation was made to the top of the glacial outwash and clay, 20 ft. and 30 ft., respectively, using a 3-ft. diameter steel casing.

- Load was transmitted to a 12-in. square cast iron bearing plate by a 10-in. square wood post. The post was surrounded by a wooden box to isolate it from friction. The annular space between the box and the steel casing was backfilled and the casing removed before the test was run.

- Load was applied by filling a box constructed on the post with concrete. Five tons per sq. ft. (tsf) was applied to the clay. Five tsf, later increased to 8.5 tsf, was applied to the outwash.

Gow reported the following results:

> "Owing, probably, to the imperfect bedding of the 12-in. cast-iron plates on the underlying soil, there was in the case of each test an initial reading of one inch of settlement when the load was applied, but no further settlement has occurred, although the load on the gravel was later materially increased and both tests have now been under observation for more than nine months."(14).

The difference between these tests and modern plate bearing tests was the time interval between the settlement readings. Initial elevations were measured before the load was applied. The next elevations were shot nine days following application of the load, missing the time dependent effects in the clay.

The plate load test suffered primarily from insufficient scale. The 1-ft. square loaded areas were inadequate to predict the influence of the proposed 60-ft. wide buildings on the clay stratum, even if the properties of the clay stratum were constant with depth. Although the designers assumed a stress distribution 60 degrees from the horizontal below the proposed pile groups, the limited zone of influence and the rapid attenuation of stress below the 1-ft. square plate were not appreciated.

A test pile program was conducted consisting of 81 timber piles, 10 concrete piles and 25 load tests. The tests were conducted to determine acceptable driving criteria for the different species of timber piles (spruce, southern pine, and oak) and to establish correlations for allowable pile load as a function of driving resistance.

The test pile driving did not go smoothly. Freeman's 22 preliminary borings were spaced across the entire 46-acre site. It soon became evident that significant local variations occurred in the thickness and elevation of the glacial outwash. As a result, an additional 106 shallow test borings were performed within the footprint of the proposed buildings.

Final design criteria for the wood pile foundation were described by Main as follows:

> "The varying conditions found made it necessary to take particular care to design the pile foundations on the basis of as nearly uniform settlements as possible. This uniformity is highly desirable in order to prevent overstressing the more or less continuous concrete floor beams and slabs used in the superstructure of the buildings.
>
> The working values have been taken at about 1/16-in. settlement, as shown by the tests, as it is believed that most piles have an initial settlement, whether noted or not, and considerable care was taken at these tests to note settlements at all times of changes as small as 1/64 in. It is also believed that the effect of a difference in settlement of 1/16 in. in the foundations can be safely ignored.
>
> A settlement of 1/4 in. was considered to be the limit of usefulness of a pile, and it was assumed that greater settlements than 1/4 in. might create conditions which would cause very unsatisfactory results.
>
> It was also considered necessary that the piling have a safety factor of not less than 2-1/2 based on the limit of 1/4-in. settlement." (16, p.23).

The test pile program revealed that spruce piles could not be driven safely into the thicker, denser portions of the glacial outwash. Many of the spruce piles, which had appeared to drive satisfactorily, failed during load tests and were found to be broken or broomed when extracted.

Main concluded that the use of spruce piles was a likely cause for the excessive structural settlements that had been reported in the vicinity of the site.

The additional shallow test borings had revealed that the sand-gravel outwash was thin or non-existent at some locations notably along the thread of the creek channel which crossed the site. Thus, some piles were driven into the clay to provide the required safe load.

A maximum load of 10 tons was allowed for spruce piles and 14 tons for oak piles. Final design loads averaged 9.0 to 9.5 tons, less than one-half the load customarily used in design of timber pile foundations today.

Criteria were established for the production piles that were intended to protect spruce piles from damage due to hard driving and to achieve as uniform settlement between the piles as possible.

The Engineering News formula, the same as in the present Massachusetts State Building Code, was used for establishing end bearing pile capacities. The formula is as follows:

$$P = \frac{2\,Wh}{S + 1}$$

where: P = allowable load in pounds
W = weight of hammer in pounds
h = fall of hammer in feet
S = penetration in inches

The load tests indicated that the coefficient could be increased to 3 for friction piles bearing in the clay.

False driving resistance in the fill was considered by deducting the formula value calculated during driving through the fill from the allowable load calculated for the final penetration resistance.

STATE-OF-THE-ART IN 1914

A state-of-the-art paper titled "Boston Foundations" by J. R. Worcester was published in the Journal of the BSCE in January 1914.

In his discussion of the geology of the Boston Basin, Worcester made the following statement:

> "Consistency of (the) deep clay formation.....appears to vary in different parts of the Boston Basin. Under the Boston peninsula it is generally fairly hard....Under a section of Cambridgeport and a part of the Back Bay the material is extremely soft, so soft in fact that it appears to flow freely from heavily loaded areas toward places where the load is less. It is not definitely determined, so far as the writer knows, whether such a flow is taking place, or the clay is gradually being compressed. It is certain, however, that widely-spread settlements have occurred." (27, p.3).

Worcester went on to state that:

> "This tendency to settle will have to be taken into consideration...in the future. It is not enough to gain the necessary support in piles which may rest in a gravel crust, but the settlement of the crust may seriously injure important structures, as it is believed to have already done in the case of the (Boston) Public Library and The New Old South Church." (27, p.4).

Thirteen discussions were submitted for Worcester's paper. Five of the discussions comment on the observed settlements in the Back Bay and Cambridgeport and attribute the cause to either consolidation or displacement of the soft clay.

Many of the respondents expressed confusion over contradictory settlement data. The granite sea wall along the present Memorial Drive, constructed without piling, was reported to have experienced virtually no settlement, except where it was constructed over fill, whereas surface settlements were measured in the roadway behind it. The absence of structural distress for buildings reported to have settled significantly added to uncertainty about the quality of the data.

There were clear warnings, however, from some members of the engineering community that the Cambridgeport area was treacherous and that the cause of the structural settlements was the thick deposit of blue clay.

On December 19, 1917, Charles T. Main and H. E. Sawtell, a structural engineer with Main, presented a paper to the BSCE on foundations for the New Technology. At the time, data on settlement of the buildings during and immediately following construction were known to Stone & Webster and probably to Main, but the data were not disclosed in the paper.

In a discussion of Main's paper, Worcester states:

> "It will be a very pleasing surprise if a gradual settlement of the whole group (of buildings) does not develop, through the subsidence of the glacial deposit below the mud. Such a settlement might not be noticeable or injurious if it were uniform over the whole area, but the area covered by the connected buildings is so large that it would appear hardly probable that they could all move together. The outcome will be awaited with great interest." (28, p. 137).

FREEMAN QUESTIONS FOUNDATION DESIGN

Freeman had no contact with those involved in the design process during preparation of the final design until January 1914, partly because he was not consulted and did not want to appear angry about the turn of events, and partly because he was indeed soreheaded.

In a letter to Professor Crosby dated January 12, he raised several questions concerning Crosby's geological report. He asked, "Did you have any determinations made of the quantity of water contained in the blue clay or any experiments upon an undisturbed sample, by compressing it as in a testing machine to see if water could be squeezed out?" (16). He also corrected Crosby regarding the performance of the timber pile foundations of the Boylston Street buildings, noting that serious cracks had developed in the Walker Building due to unequal settlement.

Crosby replied to Freeman, "I satisfied myself by actual test in the Mechanical Eng. lab. that no important amount of water could be squeezed out of the blue clay." (7).

Freeman wrote to his friend Charles A. Stone on March 5, 1914, sending him the data he had collected regarding surface settlements at the site and the settlements of neighboring buildings. He referred to a note on his drawing which attributed the settlements to compression of the clay. He also sent a drawing of his proposed foundation scheme with the deep girders. He told Stone that he felt that Crosby's report was inconclusive.

Freeman also contacted Charles T. Main to voice his concerns, and provided him with the same documents. He gave Main "...friendly warning that while Crosby was a most excellent geologist, when he attempted to play engineer he sometimes made mistakes." (8).

In a letter to consulting engineer Allen Hubbard dated March 7, 1914, Freeman stated, "I have yet seen no sufficient assurance that there may not be the same difficulties of settlement near the middle of this site that have been experienced...a few hundred feet to the north...on ground which present indications indicate may perhaps be duplicated beneath the Architect's lofty dome."

Stone's response to Freeman regarding his concerns was to say that they had adopted the foundation scheme presented in his preliminary study although they raised the pile cutoff grade about six feet. The change in the pile cutoff grade when added to the revision incorporating a basement meant that Freeman's girder system had been eliminated.

By the beginning of May 1914, Freeman gave up. In a letter to a fellow alumnus who shared his concerns he said:

> "I believe that those actively engaged in building the new structures are satisfied (with the results of the pile load tests) and they have entirely failed to grasp the fact that tests of that kind prove nothing about the slow flow of clay or the squeezing out of water of supersaturation...I am inclined to believe that you and I are regarded as well-meaning cranks on this particular subject and are to be dealt with politely rather than seriously." (9).

BUILDING CONSTRUCTION

Constructing the New Technology was an immense undertaking. The building was to be one of the largest single structures in the country at that time.

The project was, using modern terminology, "fast tracked". Construction started as soon as the foundation plans were prepared but well before the plans for the frame were complete.

Excavation for the buildings began on September 15, 1913, and the first of 25,000 wood piles was driven on December 4. Construction started to appear above ground in August 1914. All of the buildings assumed an outward appearance of completion by November 1915.

Building materials were delivered on a system of more than seven thousand feet of spur tracks leading off the nearby Boston & Albany railroad line. A lumber yard and sawmill were set up near the Esplanade, as were machine and blacksmith shops. Concrete was batched at the site and reinforcing steel was cut and bent on site. Eight huge gantry cranes, 110 ft. tall with a working radius of 250 ft., were erected at strategic points to handle materials, Figure 16.

Figure 16. Construction of the New Technology showing Room 10-250.

One and a half million board feet of lumber were used in constructing the forms for the reinforced concrete. In all, 5,000 tons of steel, 15 million bricks and 50,000 cu. yd. of concrete were used. Four hundred and fifty carloads of Indiana limestone were used for the facades of the buildings.

The Great Dome, which rose 147 ft. above street level, was the central feature of the whole structure. The dome consisted of 3 parts - a lower drum, 120 ft. in diameter and 37 ft. high, formed by concrete columns in two concentric rings; an upper drum 108 ft. in diameter and 18 ft. high, also formed by two concentric rings of columns; and a spherical cap rising 23.5 ft. which rested on the inner ring of the upper drum, Figure 17.

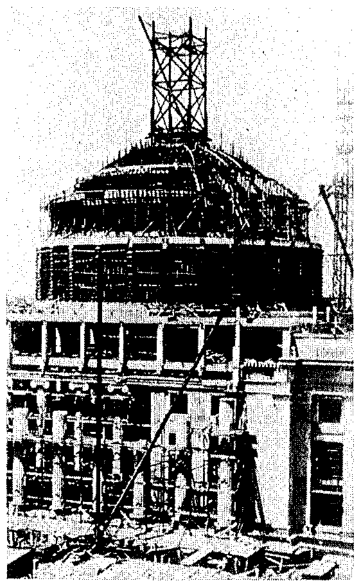

Figure 17. Construction of Building 10 showing the Great Dome.

As Freeman had predicted, the cost of construction for the New Technology exceeded original estimates by 100 percent. President Maclaurin reported frequently to George Eastman in Rochester and he made further donations to be added to those of a thousand loyal alumni and friends of the Institute to assure completion of the buildings, Figure 18.

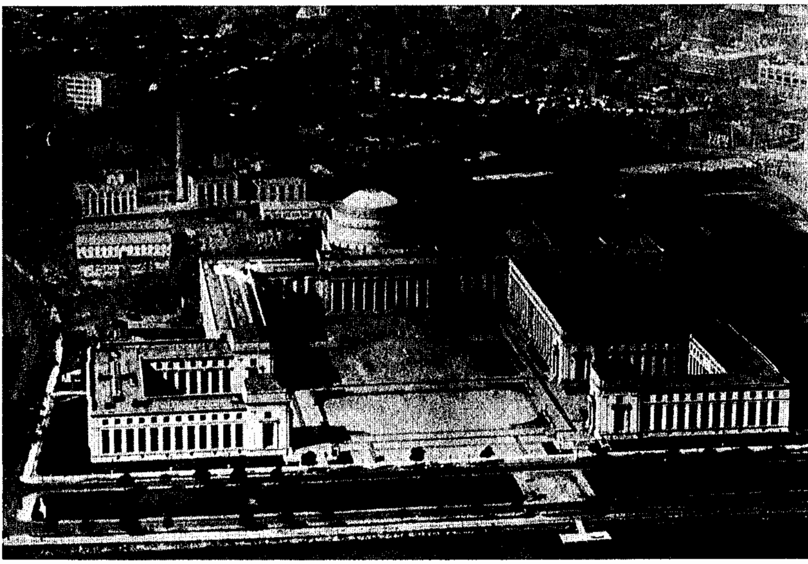

Figure 18. The New Technology; circa 1916.

The building was completed and occupied in 1916 amid great celebration and fanfare. Stone and Webster had generously contributed the President's House. Funds raised by alumni over a period of 18 years provided for construction of the Walker Memorial Building which was completed in 1917.

FOUNDATION SETTLEMENT

Engineers for the New Technology had expected settlements to be very small, less than one quarter of an inch. Nevertheless, as well-trained alumni, they inserted plugs in the basement columns of the buildings during construction so that subsidence could be measured.

Stone & Webster established initial elevations on settlement plugs during construction in February 1915. First observations were made in January 1916 and the second set of readings after occupancy in December 1916.

Both the magnitude and rate of settlement were alarming. By December 1916, the present Building 10 had settled more than 2 in., and Building 2 more than 1.5 in. Cracking began to occur in the terrazzo floors and in the plaster. Fortunately, no significant structural damage was experienced.

The greatest settlements occurred in sections of the building over the creek bed which traversed the mud flats before the site was filled, Figure 19. The outwash sand-gravel stratum was thin or absent at this location, presumably due to erosion. Unfortunately, the Great Dome (now Building 10), the heaviest structure, was located directly over the old drainage course.

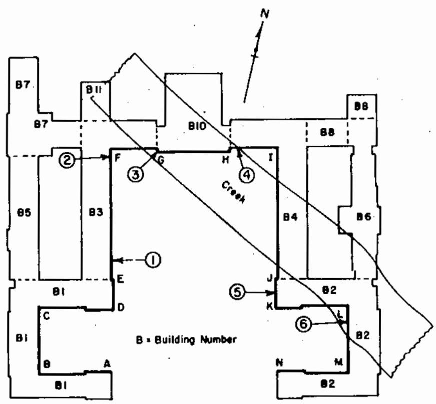

Figure 19. Plan showing location of settlement profile, shown in Figure 20, as bold line, and location of former creek channel.

Stone & Webster made two sets of readings after December 1916, the records of which were not complete nor have they been located. The next complete set of observations was made in July 1926 by Kenneth A. Smith, '27, and a party of other students. In 10 years, Buildings 10 and 2 had settled approximately 7.5 and 6.0 in., respectively. (Settlement in Building 1, Civil Engineering, was as little as 1 in.)

The Institute could do nothing but watch the buildings settle.

Figure 20 shows settlement profiles through January 1963, for the exterior building wall along a line around the inner courtyard, beginning at the left, with point A at the corner of Building 1. The upper part of the figure includes a soil profile showing the variation in thickness of the sand-gravel stratum below the building wall and locations where wood piles were driven through the outwash into the clay, noted as "long piles". These locations generally occur where the creek bed traversed the site and the outwash is thin.

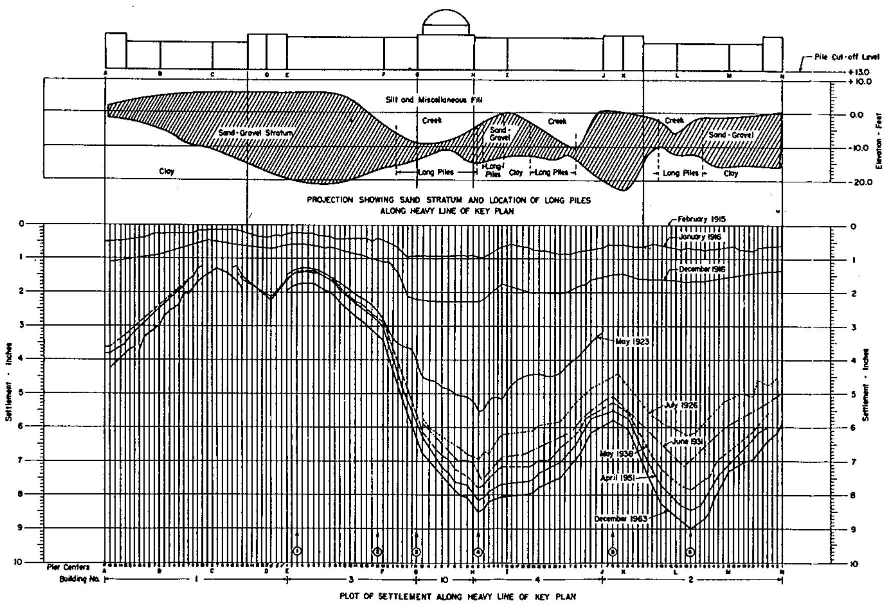

Figure 20. Settlement history of the New Technology.

Since the foundation loading for all buildings in the complex, with the exception of Building 10, is approximately the same, the extreme variation in settlement must be attributed to another source. Undoubtedly, the variation in the thickness of the clay was a contributing factor. However, the principal cause was not fully understood until years later.

Today, we recognize that settlement occurred primarily as a result of compression of the normally consolidated lower region of clay, a gradual squeezing out of the pore water in the voids of the clay, foretold by Freeman.

The long friction piles transmitted the building load more directly to the soft compressible lower region of the clay. Where the building load was carried by short piles bearing near the top of a thick deposit of sand-gravel outwash, the building load had been distributed more widely over the surface of the clay. By applying the load well above the top of the clay, the stress increase in the lower region was smaller and settlement was less.

In his 1944 BSCE paper, MIT Professor Donald W. Taylor stated, "The main reason for the difference in settlements resides in the variable thickness of a sand layer which overlies the blue clay."

Figure 21 shows the time rate of settlement, at representative points, plotted as a function of square root of time. Today, the maximum settlement of the main Institute buildings is approximately 10 in. in Building 10. Fortunately, due to the nature of the phenomenon, the rate of settlement decreased with time and is near zero today.

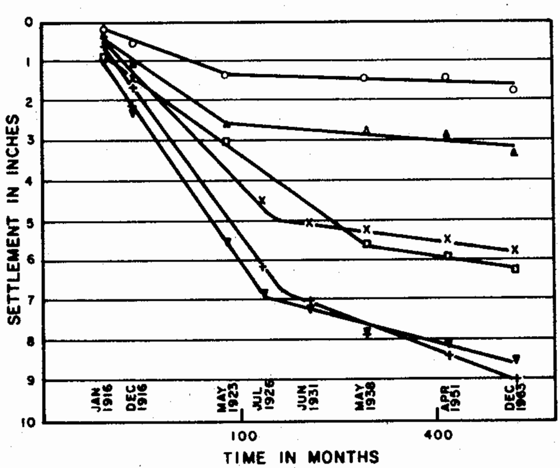

Figure 21. Time rate of settlement plotted using square root of time method.

Ironically, had Freeman's proposed foundation for the New Technology been adopted, building settlements would have been even greater than those which occurred, although differential settlement may have been less.

Freeman called his proposal a "floating foundation" only because of the rigidity of the structural concrete foundation girders. His design was not a "floating foundation" as defined in foundation engineering practice today

His plan had no basement. The ground floor was to be 4 to 5 ft. above street grade. Thus, the average net stress on the underlying clay stratum would have been even greater than that for the existing structure which has a basement.

KARL TERZAGHI COMES TO MIT

The unexpected settlements made all those involved with the design process aware of the failure of existing technology in civil engineering. Many phenomena involving the behavior of soils, earth structures and foundations were not understood.

Starting in 1925, MIT would develop a new technology called soil mechanics.

In the spring of 1925, an Austrian engineer named Karl Terzaghi, Figure 22, Professor of Civil Engineering at Robert College in Constantinople (Istanbul), Turkey, published a lengthy book in German titled Erdbaumechanik (Soil Mechanics). A result of seven years of patient experimentation in a primitive laboratory, his book established the theoretical principles of soil mechanics accepted today.

Dr. Terzaghi was 42 years old at the time, his reputation was limited and his career had reached a turning point.

Professor Charles M. Spofford, '93,* Head of the Civil and

*MIT's first staff roster in 1865 included John B. Henck, Professor of Civil and Topographic Engineering. He was succeeded by George L. Vose in 1882 until George F. Swain,'77, became Hayward Professor of Civil Engineering and department head in 1887. Swain, possibly the finest teacher-engineer of civil engineering the country has produced, held the post of department head for twenty-two years until 1909. One of Swain's outstanding students, Charles M. Spofford, '93, left his position at Brooklyn Polytechnic Institute in 1909 to assume the Hayward Professorship. He became department head in 1911, serving until 1933.

Figure 22. Karl Terzaghi, circa 1925.

Sanitary Engineering Department at MIT and partner in the firm of Fay, Spofford and Thorndike, had heard of Terzaghi's research work, and also learned that he was to have a year's leave of absence from Robert College. At his recommendation, President Samuel Stratton invited Terzaghi to come to MIT, offering him the position of Lecturer on Foundations and Soil Mechanics and Research Associate at a salary of $2,000.

We can only assume that Stratton invited Terzaghi not only to teach but to evaluate the subsidence of the main buildings.

He is known to have written a report for the Institute concerning settlement of the New Technology, although the authors have been unable to locate a copy. Ordinarily, we would surmise that he would use his theory of consolidation, a diffusion process based on a Laplace equation, to explain the slow dissipation of pore water pressure in the clay and the resulting time-settlement curves, and thus provide some assurance that the majority of settlement had taken place. However, we find that Terzaghi in his years at MIT did not fully understand the cause of settlement.

In the spring of the year following Terzaghi's arrival at MIT, President Stratton asked him to investigate underground conditions for expansion north of the main buildings. His report dated October 13, 1926 includes some interesting observations.

He concluded that the "...test borings confirmed all the statements contained in Professor W. O. Crosby's* original report... (July 1913) except for the statements concerning the character of the blue clay...experience has shown that the blue clay did not behave as expected." (25, p.2).

He performed soil tests to determine if the clay contained "excess water" and to determine the ultimate settlement of the clay without any other loads acting on it, and finally the "ultimate bearing capacity...the load under which the clay starts to flow like a viscous liquid." For his one-dimensional compression tests, he used samples of clay which had been mixed with water into "the viscous liquid state". Undisturbed samples were used for "cube tests" to determine the bearing capacity.

Terzaghi determined that the natural water content of the clay increases with depth, meaning that "the percentage of excess water increases considerably with depth," and assumed that "consolidation is still going on, as a geological process."

He concluded that unequal settlement of the MIT buildings was due to three different causes:

"(a) The gradual consolidation of the clay deposit, which is a geological process, hardly affected by the presence of the buildings.

(b) The volume change (loss of water) due to the added weight of the buildings.

(c) Lateral flow of the clay, produced by the weight of the buildings.

Of the three causes, (a) and (b) seem to be of minor importance compared to (c), because the low degree of permeability of the clay prevents the volume change from proceeding with speed. Hence the settlements are essentially due to lateral flow, at fairly constant water content." (25, p. 9).

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*Professor Crosby died on December 31, 1925.

Several years later, in an ASCE paper published in 1929, he made the following statement: "...the extreme slowness of consolidation of typical clays is illustrated by the following observation. In 1915, a building of the Massachusetts Institute of Technology was erected ... The pressure exerted by the building on the clay amounts to approximately 1500 lb. per sq. ft. In 1926, a test boring was made next to the heaviest section of the building. Physical examination of the drill samples disclosed the fact that the consolidation of the clay deposit had hardly started." (26, p.278).

In fact, primary consolidation was nearly complete by 1930.

FREEMAN SUPPORTS TERZAGHI

Terzaghi's appointment attracted Freeman's attention. He obtained a copy of Erdbaumechanik which, in spite of his limited knowledge of the German language, he believed to be the most outstanding work published on the topic.

In the fall of 1925, Freeman invited Terzaghi to his home in Providence for the weekend, to become acquainted with his work. They talked for hours and got along famously. Freeman was convinced that Terzaghi was one of the brightest engineers he had met. In a letter to his good friend former MIT President Henry Pritchett he stated, "He (Terzaghi) seems to combine practical experience with a facility in mathematical analysis that is hard to find among American professors in engineering." (12).

Thereafter, he ordered more copies of Terzaghi's book and sent them to various professors, including Hardy Cross at the University of Illinois, and practicing engineers for their opinions. He made use of his personal contacts to check out Terzaghi's professional and academic reputation.

Once Freeman had convinced himself of the value of Terzaghi's ideas and abilities, he became a strong and influential supporter.

Freeman worked hard to expose the engineering community to Terzaghi's ideas. He used his influence as past president of the ASCE to arrange for Terzaghi to lecture before the civil engineering societies in Boston and New York.

TERZAGHI ESTABLISHES SOIL MECHANICS IN THE U.S.

Terzaghi needed all the help he could get. His contemporaries were confused by some of the terminology he used. Some influential engineers were insulted by Terzaghi when they sought clarification.

In November and December of 1925, Engineering News Record published eight papers he authored on the physical properties of clay and sand, and related topics. Some of his concepts were viewed with skepticism, in particular his ideas concerning capillary pressure in clay caused by surface tension during drying. Nevertheless, these papers were to establish Terzaghi's reputation.

President Stratton had asked Freeman to evaluate Terzaghi and his work, to determine if he should be asked to stay at MIT permanently. Terzaghi had made a bad impression on Stratton, who considered him a prima-donna. Freeman lobbied on Terzaghi's behalf and counseled him on how to work with the MIT faculty and administration.

In January 1926, he wrote Stratton recommending strongly that Terzaghi be retained at the Institute and that he be provided with the apparatus and space he needed for a laboratory. Professor Spofford supported the recommendation.

President Stratton accepted the recommendation, telling Freeman "I have long ago come to the conclusion that we can put up with eccentricities (of prima-donnas) in the case of real genius, but it isn't worthwhile with ordinary men. I can assure you that it is my intention to give Dr. Terzaghi an opportunity to demonstrate whether or not he is a genius."

Terzaghi's assistant during his first year at MIT, was Glennon Gilboy, '25. Gilboy would receive his Sc.D. degree in 1928 and serve on the civil engineering faculty teaching soil mechanics until 1937.

A year later, a young Austrian engineer named Arthur Casagrande joined Gilboy in assisting Terzaghi. Casagrande had arrived in the United States in April 1926, and shortly thereafter met Terzaghi in Cambridge. Terzaghi asked him to become his private assistant for the summer, working on his consulting projects in Washington, DC. By December, Terzaghi had arranged for Casagrande to be employed by the Bureau of Public Roads, serving as his assistant at MIT. Casagrande remained until 1932, during which time he made major contributions to our understanding of soil behavior and the development of laboratory testing equipment and procedures.

With Freeman's assistance Terzaghi's ideas were gradually accepted in the academic community and by practicing engineers. He became the revered father of soil mechanics.

MIT established and then expanded the laboratory facilities Terzaghi needed. He was promoted to the rank of full professor in 1928, just three years after his arrival. When he left to return to Austria in 1929, a vigorous research program had been established at MIT, providing a rational basis for evaluating the behavior of soil in relation to foundation engineering and earthwork problems

Indeed, the New Technology in Cambridge had served as a laboratory for the development of a new technology called soil mechanics.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the encouragement and support provided by Helen Slotkin, the Institute Archivist and the staff at the Institute Archives and Special Collections, where the John R. Freeman papers are held. Mr. Warren Seamens, Director of the MIT museum was extremely helpful in identifying applicable material for our research and supplied most of the photographs presented herein.

We thank Professor T. William Lambe for making available records of settlement of the MIT buildings and related information.

If further acknowledgement is due, it is hereby gratefully presumed.

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