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# HISTORY OF BUILDING FOUNDATIONS IN CHICAGO

A REPORT OF AN INVESTIGATION
CONDUCTED BY
THE ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS
IN COOPERATION WITH
THE WESTERN SOCIETY OF ENGINEERS
AND
THE ILLINOIS SECTION
AMERICAN SOCIETY OF CIVIL ENGINEERS

BY
RALPH B. PECK

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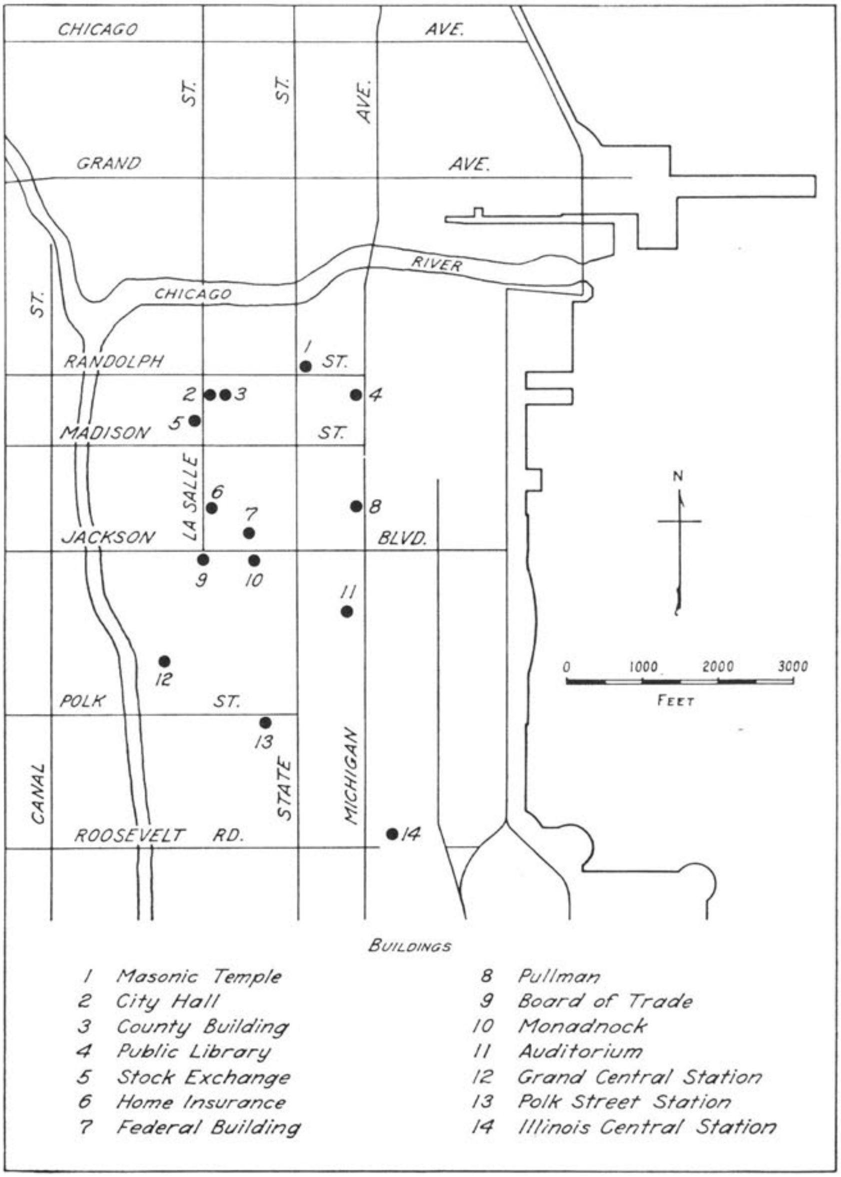


Fig. 1. Map Showing Location of Buildings in and near Loop Area

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## ABSTRACT

The history of foundation engineering in Chicago is of more than local significance because many present-day practices stem from the experiences of Chicago engineers during the period from 1871 to 1915. As these engineers improved upon their invention the skyscraper, the necessity for providing adequate foundations beneath the new structures in spite of unfavorable subsoil conditions led different engineers to different expedients. The success or failure of these attempts is of interest even to the engineer of today.

In 1873, Frederick Baumann enunciated the principles of his "Method of Isolated Piers," probably the first statement in this country of a rational procedure for proportioning footings. Many Chicago structures designed according to these principles were eminently successful. As building heights and weights increased, settlements grew apace, but the movements were anticipated and were considered normal by most architects and engineers.

By 1890, a few engineers recognized the possibility of using long piles to provide less yielding support. A slow trend to pile foundations began, but it was cut short by the development of piers constructed in shafts excavated by the so-called "Chicago caisson" method. By 1900, the transition to deep foundations was virtually complete, and accounts of the activities of Chicago foundation engineers almost disappeared from contemporary literature.

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# HISTORY OF BUILDING FOUNDATIONS IN CHICAGO

## I. Introduction

### *Scope of Study*

The history of building foundations in Chicago between 1871, the year of the great fire, and 1915 epitomizes the development of foundation engineering throughout the world. Within less than half a century, and within the confines of the small area known as the Loop, the art of constructing building foundations grew to maturity by a process of trial, error, and correction. Seldom in any field of engineering has so much experience been concentrated in so little time and space.

Many factors worked together to produce this unique experience. The most important, undoubtedly, was the presence of a deep bed of compressible clay which underlies the Loop, and without which no foundation problems would have arisen.

Of almost equal importance, however, was the rapid growth of the city. At the time of the great fire, on October 9, 1871, the population was 300,000. By 1880 it was 500,000; by 1890, 1,100,000; and by 1900, 1,700,000.

The phenomenal growth of the city after the fire was accompanied by the continual construction of new and larger buildings. The progressive settlement of these structures on the soft clay bed became apparent, but the pace of new construction afforded little opportunity to observe the behavior of one structure before designing the next. Therefore, different architects and engineers diagnosed the difficulties differently, and many variations in foundation practice were introduced. These variations constituted full-scale experiments in the field of foundation engineering.

The final factor which made the Chicago foundation experience unique was that the period of phenomenal growth of the city was coincident with the transition from the traditional wall-bearing structure to the modern skeleton-frame building. Differential settlement became a matter of prime importance because it led to distortion of the masonry and of the structural framework and introduced supplementary stresses which were difficult to consider in the design. The quest for an unyielding foundation for the new skyscraper had an important influence on the history of Chicago foundations.

A scientific study of the records of the settlements of the structures built in Chicago during this period is a promising field for research in soil mechanics and foundation engineering. However, even a non-technical history of the developments provides the practicing engineer of today with a valuable background, and helps him develop an insight into present foundation practice. It is the purpose of this bulletin to present such a history. Although the subject-matter is likely to be of particular interest to Chicago engineers, it should be of some significance to the foundation engineer everywhere. In addition, the non-technical history presented herein will serve as a framework for a more detailed, scientific study of the records of individual buildings.

*Acknowledgments*

This bulletin represents part of the work of the Joint Committee on Soil Mechanics and Foundations of the Western Society of Engineers, the Illinois Section of the American Society of Civil Engineers, and the Engineering Experiment Station of the University of Illinois.

The personnel of the Committee consists of FRANK A. RANDALL, Chairman; RALPH B. PECK, Secretary and Editor; FREDERICK W. REICHERT, Associate Editor; A. E. CUMMINGS; V. O. MCCLURG; P. C. RUTLEDGE; C. P. SIESS; and K. TERZAGHI.

The assistance of many Chicago engineers in locating information pertinent to this study is gratefully acknowledged by the committee.

## II. Soil Conditions

*Original Topography*

The general nature of the soil deposit in the Loop area at the present time is shown in Fig. 2, which represents the summary of a number of boring logs. All elevations refer to Chicago City Datum (El. 579.94 M.S.L.) which corresponds roughly to the level of Lake Michigan. The site of the city was originally swampy and low-lying ground, and the earliest buildings experienced foundation troubles due to the unstable nature of the wet, silty soil. Furthermore, because of the low elevation, the area could not be drained adequately. The early

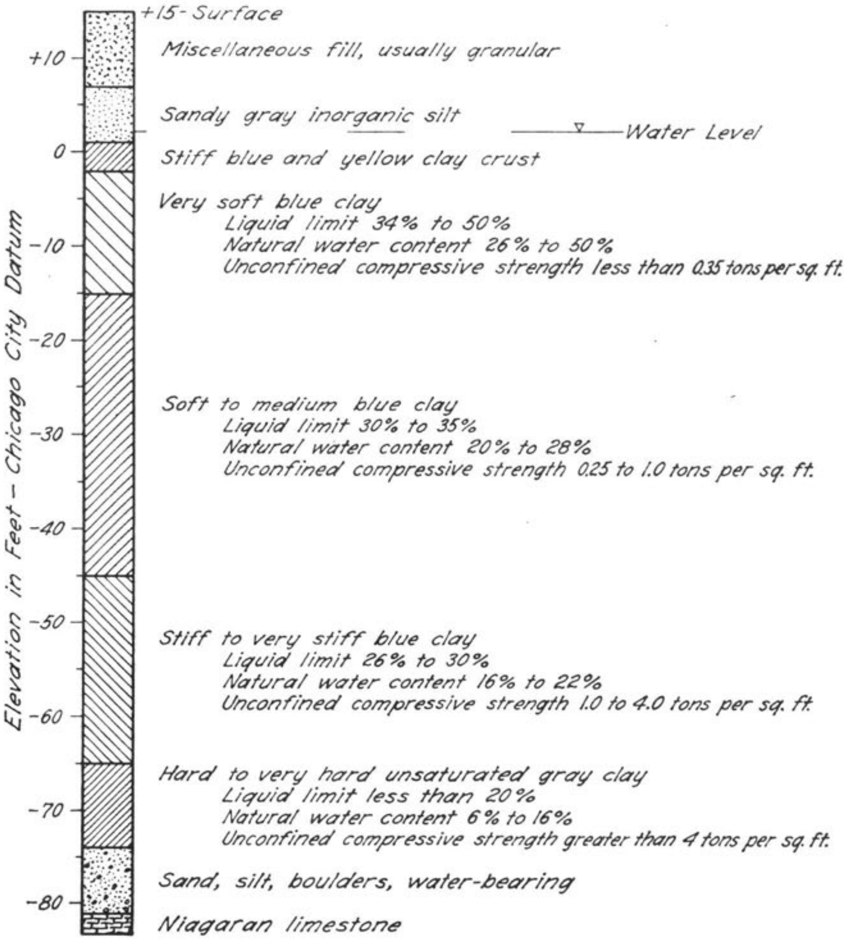



Fig. 2. Typical Soil Conditions in Loop Area

conditions were described in 1883 by John M. Van Osdel, Chicago's first architect, who arrived in the city in 1837. At that time, he states,

"From the Fort [on the south side of the river, just west of Michigan Avenue] . . . south on Michigan Avenue, the surface of the ground was . . . about nine or ten feet above the surface of the lake. [At this time, the elevation of the lake and river was probably about + 3 feet, C.C.D.]. The surface drainage was from Michigan Avenue west to the river, and from State Street west was nearly a level plain, elevated some two or three feet above the river [i.e., at elevation + 5 or + 6]. The topography of the north division was similar, the surface declining from Rush Street toward the west. The surface-water cut large gullies in the soil, known as sloughs; three of these sloughs opened into the main river. One at State Street was about sixty feet wide at the mouth, and extended in a southwesterly direction to the site of the present Tremont House [S.E. corner Dearborn and Lake Streets]. Another had its outlet between Clark and LaSalle Streets, and extended across Lake Street. The third and most formidable one was on the north side, near Franklin Street, being eighty feet wide at the river, and extending north through the Kingsbury and Newberry tracts to Chicago Avenue. In 1838 . . . the depth of water in the slough was sufficient to float . . [a] . . scow."(1)*

*Raising the Grade*

The progressive nature of the young city was demonstrated by the decision, in 1855, to raise the grade of the entire area. According to Van Osdel,

"The grade established by the city . . . made it necessary to build stone walls around each block to retain the filling of the streets . . . . Mr. James Brown, of Boston, an expert in raising buildings, contracted with J. D. Jennings to raise his store on the northeast corner of Dearborn and Randolph Streets. This was done in 1857, and was the first brick building raised to the new grade. An entire block of heavy buildings on the north side of Lake Street, extending from Clark to LaSalle Street, was raised simultaneously. This was accomplished in 1859. The raising-business extended through seven years, from 1857 to 1864."(2)

After the fire of 1871, the grades were raised once more, and debris from the fire was used for much of the filling. These final grades,

* The parenthesized numbers throughout the bulletin refer to Appendix B.

which refer to the sidewalk level at the building line, were El. + 15.0 on Michigan Ave., El. + 14.5 on Wabash, and El. + 14.0 in all other parts of the south division, making a level grade from State St. west to the river.

*Subsoil Conditions*

On account of the raising of the grade, the upper eight feet of soil indicated in Fig. 2 consist of miscellaneous fill. Beneath the fill is commonly found a gray, lake-bottom silt of variable quality, but usually loose and compressible. It has a thickness of about six feet. Approximately at datum is a crust of partially oxidized blue and yellow clay which acquired its stiffness by desiccation during a temporary low-water stage of the geological forerunner of Lake Michigan. Although the strength and thickness of this crust vary, the layer is one of the most important features of the Chicago subsoil, because it is the only material of high quality at shallow depth. Most of the early skyscrapers were founded upon it, and the crust undoubtedly served to spread the loads from their footings before the pressure was transmitted to the soft clay beneath.

The soft clay deposit beneath the oxidized crust was the principal seat of settlement of the early buildings. It extends to El. − 40 or − 50. Beneath it the clay becomes stiffer, and hard dry clay is found in some localities at El. − 60 to − 70. Bedrock is encountered at elevations between − 80 and − 120. The hard clay is an extremely variable deposit. In places it is missing altogether. It may be underlain or replaced by waterbearing sand, silt, or boulders, or it may extend to the bedrock.

Within the area bounded by Roosevelt Road on the south, Canal Street on the west, Division Street on the north, and Lake Michigan on the east, the subsoil conditions are represented with reasonable accuracy by Fig. 2. Actually, the subsoil contains many local variations which must be taken into account in design and construction. In this general survey, however, the preceding information is sufficient for an understanding of the principal foundation problems.

## III. Foundation Practice Immediately After the Great Fire (1871-1878)

*Primitive Practices*

The buildings erected after the fire of 1871 were different in no important respects from those constructed during the previous two decades. The driving urge in the reconstruction period was to restore the city to its former condition. Indeed, when Van Osdel observed the approach of the flames, he buried his building plans and records, and after the conflagration many structures were rebuilt according to the exact plans of their predecessors. Most of these structures were from three to six stories in height, with bearing walls and few interior columns. The foundations consisted of dimension stone footings with their bases from three to five feet above the surface of the stiff clay crust. The width of the footings varied in a general way with the number of stories in the building, but almost without exception there was no attempt to proportion the width to obtain a uniform soil pressure under all parts of a structure.

Information regarding these foundations comes largely from the observations of men who examined them while the buildings were being demolished. For example, in 1910 E. C. Shankland wrote:

"The load per square foot on the soil under these buildings is often very great, and averages much greater than those under buildings erected later. There are buildings of this type where the pressure on the soil from the dead weight of the buildings is from 14,000 to 15,000 pounds per square foot.

"These excessive loads caused very great and very uneven settlement, but the buildings being of brick and wood could withstand all distortion produced by the great variation in settlement, — variations which would not be allowed in the more recent steel frame buildings.

"Then, too, the settlement was not noticed, because the street grades varied so much. Only a few years ago it was common to have steps in the sidewalk, caused by the different grades of adjoining buildings, and several such sets of steps would be found in the same block. Where the street varied in height several feet in the same block, the settlement of the buildings, however great it might be, would attract little attention."(3)

*The Contribution of Frederick Baumann*

The settlement of the buildings and the distortion and cracking of the structures did, however, attract the attention of at least one Chicago architect, Frederick Baumann. For a number of years he had observed the behavior of the buildings in the Loop area, and also experimented with possible improvements in his own practice. In 1873 he published his conclusions in a pamphlet entitled "The Art of Preparing Foundations for All Kinds of Buildings, with Particular Illustration of the 'Method of Isolated Piers' as Followed in Chicago." This pamphlet of 38 pages, written in clear and forceful language, is undoubtedly the first statement made in the United States of principles for the scientific design of foundations. It had a far-reaching influence upon the future development of Chicago foundations.

Baumann stated two principles which should govern the design of footings. First, "the areas of base must be in due proportion to the superincumbent loads"; second, "the centers of these areas of base must coincide with the axes of their loads." He added that these "principles are self-evident, well known, and often loosely mentioned, yet so seldom observed."

For the use of the architect he summarized his principles into a set of three rules:

"First Rule.—Resolve the building, upon its ground plan of the lower story, into isolated parts, and independently apportion to each its proper share of foundation.

"Second Rule.—Estimate the weights of all those (really and ideally) isolated parts, in order to apportion to each its due share of foundation.

"Third Rule.—Determine, upon the ground section, centers . . . of all . . . parts, which in upright section will be the axes . . . of these parts, and place the . . . bases so that the centers of their areas of contact will coincide with the first centers. . . . Observation of this rule is of the utmost importance, for upon it will depend the perpendicularity of all the walls and corners of the structure. . . . There will . . . be no particular need of any anchors, except for temporary use, while in the contrary case the strongest and best applied anchors will not suffice to preserve the *exact* normal position of the walls and corners."[4]

Baumann claimed no originality for these rules, which he grouped together as the "Method of Isolated Piers." Rather, it was the extent to which he carried the application of the rules that was original and that influenced the work of later architects so strongly. Since the buildings of Baumann's time were wall-bearing structures, continuous footings were the rule, and the guiding principle was to obtain all the bearing area possible. In contrast, he advocated "a principle which makes isolated piers the rule in all cases, and continuous foundations

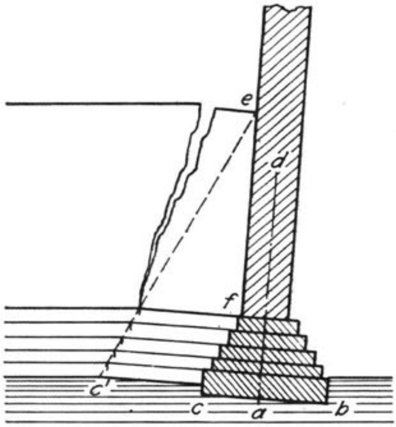



FIG. 3. APPLICATION OF METHOD OF ISOLATED PIERS TO OUTER WALL AND ABUTTING DWARF-WALL

the exception, where, for instance, piers of uniform weights are so close to each other that the bases will interconnect."

As an example of the consequences of failure to follow his principles, Baumann considered the pier of an outer wall and an abutting dwarf-wall (Fig. 3). His discussion was as follows:

"If, as the old method would suggest, in order to furnish 'all the bearing possible,' the dwarf-wall is connected with the pier at its line of intersection, *ef*, the pier will be thrust outward and the dwarf-wall crack as indicated. The cause may readily be found. Construct the axis, *da*, of the pier, and see whether it coincides with the center of area occupied by the base of the pier. Were the dwarf-wall *not connected* at *ef* and $ab = ac$, i.e., were the construction made in accordance with the 'method of isolated piers,' there would be no thrust against the pier. But the usual old random mode of 'all the bearing possible' extends the area of base insidely to *c'*, and thereby shifts the axis of the pier *off the center* toward the outer edge of the supporting base, *bc'*, which causes the ground to be pressed into an inclined surface and, consequently, the pier to be thrust outward. Were the base of the dwarf-wall made so narrow as to cause a settling of the dwarf-wall equal to that of the pier, it would at first sight appear as though then the wall might be connected. Yet this is, nevertheless, forbidden by the circumstance that the base of the dwarf-wall would receive *all* its load before the pier would, say, one-fifth part of it."(5)

He concluded that the axis of the load should "always strike a little way *inward* from the center of the area of the base, in order to make sure that it shall not be toward the *outside*," because inward inclination is resisted by the floor beams. Further, he recommended that the dwarf-wall should be built independently from the outer pier or wall, with perhaps a clear space of four inches to be walled up afterward. In case certain foundations would receive their load more quickly than others in the same structure, he suggested pre-loading the latter with pig iron so that all foundations would settle at the same rate.

Additional examples discussed in detail the common types of defects in Chicago buildings due to differential settlement, and in a convincing manner each failure was ascribed to a deviation from the strict application of the method of isolated piers. These examples, explaining for the first time the cause of well-known defects, made a considerable impression on Chicago architects. However, the full importance of Baumann's work was not felt for five or ten years after its publication. The last example presented in the pamphlet was a critical discussion of the foundation of the new Federal Building, then under construction. According to Baumann, the mat foundation of this structure violated every principle, and would prove unsatisfactory. The complete and prompt failure of the foundation greatly increased the reputation of the method of isolated piers, and influenced the design of foundations for at least two decades.

Engineers of today have an understanding of the manner in which stresses are transmitted through the subsoil from individual footings, and are aware that the compression of a deep bed of clay is not appreciably altered, as Baumann believed, by minor details in the arrangement of the footings. This understanding has been obtained largely from a study of the theory of elasticity, which was, at the time of Baumann's pamphlet, in its infancy. Indeed, the method of isolated piers antedates the theory of Boussinesq, now the basis for settlement computations, by more than a decade. Hence, Baumann's work must be regarded as an important forward step. It concentrated the attention of Chicago architects and engineers on the rational design of foundations and introduced conservative values for allowable soil pressures. In this connection, Baumann states that the most suitable bearing capacity is "twenty pounds to the square inch [2880 lb. per sq. ft.]. . . . Such proportionate load will compress the hardpan [now known as the blue and yellow clay crust] to the extent of about one inch during construction of the building, and about one-half of an inch during the next six months."(6)

Compared to the customary loads of 14,000 to 15,000 pounds per square foot, mentioned previously, Baumann's practice was indeed conservative. With the publication of his pamphlet, Chicago foundation design became recognized as an engineering problem.

## IV. Era of Dimension Stone Footings (Before 1874)

### *Description of Stone Footings*

Until about 1874 the most common construction material for footings was hard limestone quarried at Lemont, a few miles west of Chicago. This stone was even-bedded, about eight to twenty inches thick. If the material was cut into large slabs of rectangular shape, it was known as dimension stone. According to Baumann, there "can be no better material in the whole world than this dimension stone." Footings were built up in layers (see Fig. 4a), with a mortar between the joints of "two parts of roofing gravel and one of fresh cement." The offsets were generally made somewhat less than the thickness of the stone. If the footing rested on sand, it was bedded on "a thin layer of gravel or broken stone, rammed into the surface, and grouted with liquid cement-mortar."

Smaller, irregularly shaped pieces of the same stone were laid up into rubble stone piers. (Fig. 4b). The offsets were generally four inches for each foot of height. Both dimension stone and rubble stone footings were used commonly in construction. The choice between the two types was generally a matter of economy. Rubble stone was usually cheaper for narrow bases, and dimension stone for wider ones.

Concrete, made of natural cements and not reinforced, was not yet considered a reliable material. It was used by some builders for constructing mat formations, but as will be discussed subsequently, these early mats met with spectacular failure.

### *Polk Street Station*

Figure 5 shows two cross-sections through the foundations of the Chicago and Western Indiana Railroad Station, now known as the

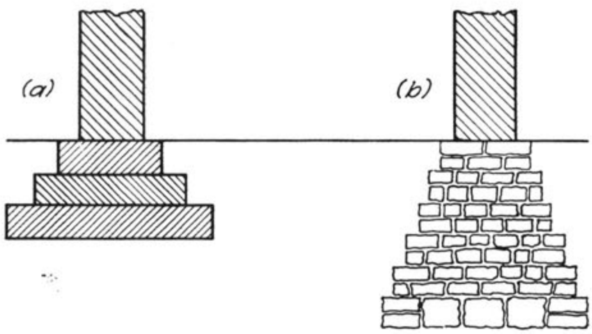



Fig. 4. (a) Typical Footing of Dimension Stone; (b) Rubble Stone Pier

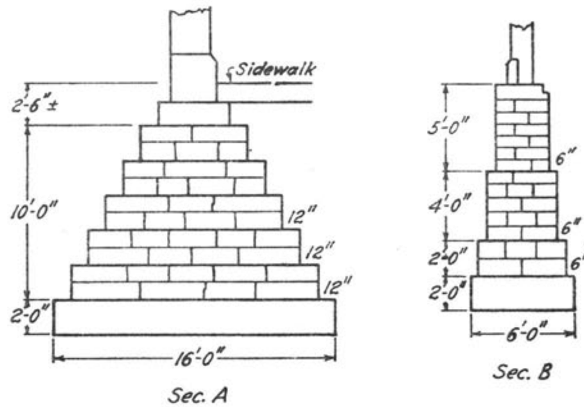



FIG. 5. SECTIONS THROUGH FOUNDATIONS OF POLK STREET STATION (1883)

Polk Street Station, on Polk St. at the foot of Dearborn St. Section A shows the foundation for the base of the tower, 170 feet high, and Section B for the three-story part of the structure. The Polk Street Station, which was completed in 1883, was one of the last important buildings now in existence in which masonry footings were used. However, in 1885 the Continental National Bank Building and the Home Insurance Building were completed, both with dimension stone footings. The former, located at 208 S. LaSalle St., was demolished in 1912, and the latter in 1931.

### *Home Insurance Building*

The Home Insurance Building, on the northeast corner of LaSalle and Adams Streets, is now generally recognized as the first structure embodying the principle of skeleton construction. The procedure in constructing its footings was probably representative of the best practice. According to its architect, W. L. B. Jenney, the top of the blue and yellow clay crust, known at that time as the hardpan, "is used for the bottom of the masonry foundations, care being taken not to remove any of the hard pan.

"The system of foundations adopted is what is known as that of independent piers, each basement pier and each interior column having its independent foundation. . . . [Weights] on each separate foundation were carefully calculated, it being of the greatest importance that the load per square foot of footing course should be uniform over the entire building, otherwise the settlement would be unequal. . . .

"It is not easy to decide in advance as to the exact permanent load on the floors of the building. This, however, is of much importance in calculating the foundation of the interior columns which as a rule are made disproportionally large, and give trouble by not settling so much as the outside walls. In the Home Insurance Building there was added to the weight of the material actually used in the construction of the building a further weight of eighteen pounds per square foot for the average permanent load on the floors, the building being solely for office purposes. Borings were made in some twenty places over the site [to a depth of twenty feet], and the thickness of hard pan [five to six feet] was found sufficiently uniform to allow of a uniform weight of two tons per square foot to be used as the permanent load on the foundations. . . . "(7)

Figure 6 shows a section through one of the exterior piers. Jenney's account continues:

"The alternation of rubble and dimension stone is for economy. Rubble can be laid directly on undressed dimension stone, while if large dimension stone are placed, the one directly upon the other, it is necessary to dress the surface in order to obtain an even bearing. The offsets on dimension stone can be made much greater than on rubble stone, and also the large stone serve as a bond to the pier, — so that at least each alternate course should be dimension stone, and in the instances where the weights are excessive, every course must be dimension. This must be done in order by many large offsets to obtain the necessary surface of concrete without disturbing the hard pan which is the best foundation this locality offers, every inch of whose thickness should be preserved."(8)

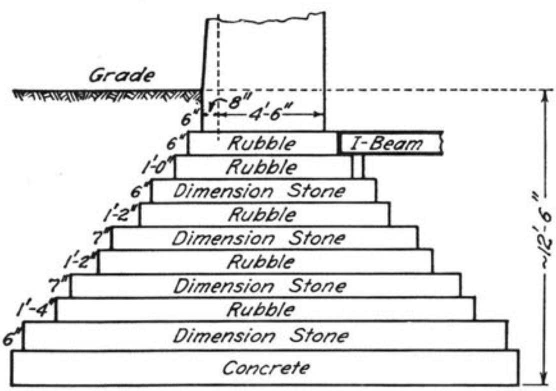



FIG. 6. SECTION THROUGH EXTERIOR PIER OF HOME INSURANCE BUILDING

## V. Grillage Footings (1878-1894)

### *Drawbacks of Stone Piers*

Mr. Jenney's description of the foundations for the Home Insurance Building suggests the impasse which designers of office buildings seemed to be approaching. Under heavy loads, the footings had to be of dimension stone rather than rubble masonry to spread the load adequately without having to cut into the stiff clay crust, but even in the nine-story Home Insurance Building the piers, in order to attain the required width, occupied the full height of the basement. The weight of the piers themselves was at least as great as that of an additional story of the superstructure. Furthermore, as the buildings became taller the demand for basement space increased, but the greater volume of the piers reduced its availability.

### *Timber Grillages*

The combination of the factors just mentioned appeared to set a limit to the height of structures which could be built on spread foundations. The first solutions of the problem were made by S. S. Beman in the Pullman Building, built in 1884 and still standing at 79 E. Adams St., and by W. W. Boyington in the Board of Trade, built in 1885 at 141 W. Jackson Blvd. In both these buildings the dimension stone piers rested on timber grillages probably consisting of two layers of 12-by-12-inch oak timbers. The members of the upper layer were placed at right angles to those of the lower. The offset between the lowest stone course and the edge of the timbers was made as great as two feet, whereas with dimension stone an offset was commonly restricted to one foot. Hence the timber grillage permitted use of a somewhat smaller stone pier within the basement. Use of timbers was, of course, restricted to elevations below the water table or to a distance of two or three feet above the stiff clay crust. Consequently, the timber grillages did not solve the problem completely.

### *Rail Grillages*

A more far-reaching solution was developed by John Wellborn Root, junior partner of the young firm of Burnham and Root. In 1878 this firm was commissioned to design a 10-story office building at 64 W. Monroe St., known as the Montauk Block. The structure, which was completed in 1882, was the first tall building to be designed by the partners, and to it they brought the genius which led to their undisputed leadership during the next decade. The history of the solution of the footing problem has been related by Harriet Monroe, from whose writings the following paragraphs are quoted.

"In the planning, it was found that stone piers, of the size necessary for supporting a heavy column of fireproof vaults, would seriously obstruct, not only the basement, but also the first story. Mr. Owin F. Aldis, one of the owners, mentioned this objection to Root, and told him that he must make room somehow for the dynamos. 'A day or two later,' Mr. Aldis reports, 'he said to me: "I believe we could make the piers smaller without loss of strength by buying old steel rails, which would be cheap, and laying them row on row, with concrete around them to prevent rust." He made preliminary calculations then and there, and decided that it would be feasible. . . . '

"In the Montauk Block, the new foundation was used merely as a temporary expedient, with no thought of extending the system to other buildings. But after the Insurance Exchange had been built in the old way, the firm found that there was scarcely room enough in its stone-obstructed basement for necessary machinery. Resolving not to be caught in that way again, they studied various expedients for gaining space without digging deep into the earth, which the conditions of our soil make inexpedient. The old Montauk experiment recurred to their minds as the most available plan, and accordingly they determined to use steel-rail-and-concrete experiments throughout under the tall buildings then in the office — the Rialto, the Phoenix, and the Rookery."(9)

The Rookery Building, still standing at 209 S. LaSalle St., was completed in 1886. It was the first structure to be supported entirely on rail grillages, and during the next five years most of the spread footings were of this type. In 1891, the north half of the Monadnock Block, the heaviest office building in Chicago, was completed on such a foundation. It still stands on the southwest corner of Dearborn St. and Jackson Blvd. Figure 7 shows a cross-section through one of the footings of this building.

The rails used in the grillages were commonly of a section weighing 75 pounds per yard. At a unit stress of 16,000 pounds per square inch, each rail was capable of resisting a moment of 12,500 foot-pounds. The rails in each course were designed as if they were uniformly loaded cantilever beams with a length equal to the length of the projection beyond the overlying course. The offset was taken as three feet (sometimes less), and the number of rails per course calculated. Since the height of each course was only 4¾ inches, the new footings

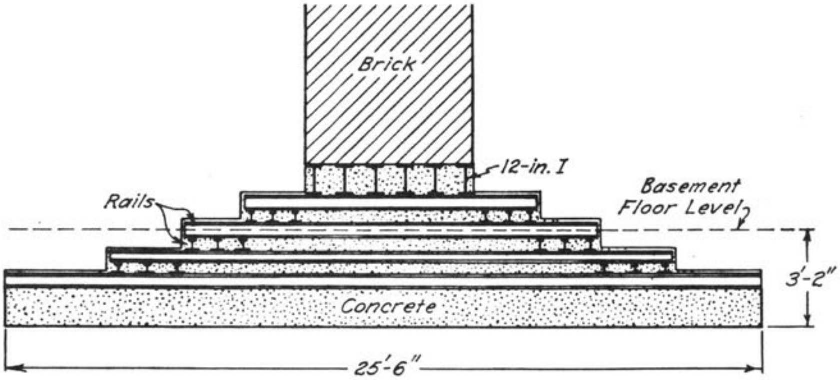



FIG. 7. SECTION THROUGH RAIL-GRILLAGE FOOTING OF MONADNOCK BLOCK

possessed a great superiority over their dimension-stone predecessors, because the basement space was very slightly obstructed. The distance from the clay surface to the base of the column on a dimension stone pier 16.5 feet square would be about 8 feet, whereas that for a rail grillage footing of the same base area would be about 3½ ft. The space between the rails was filled with cement grout to prevent rusting, and the whole grillage was bedded on a layer of concrete generally about one foot thick. The grout and concrete were not considered in the calculations as adding to the strength of the footing.

The rail-grillage footings saved both weight and basement space. They also possessed the advantage that they could be constructed more quickly than piers and, since heavy cranes were no longer required to handle stone blocks, could be installed during the winter under protection of tarpaulins. In the early 1890's, the speed of construction became a matter of considerable importance.

*I-Beam Grillages*

Root's invention of the rail-grillage footing made possible continued progress in the development of the tall building. By 1886, the office building had grown to 13 stories, and by 1892 to 20 stories. In 1888, the steel rails were replaced by I-beams in the grillage for the Tacoma Building, designed by the new firm of Holabird and Roche. The greater efficiency of the I-beams in resisting bending moments caused the new type of grillage to be widely adopted, and to remain the dominant type of spread footing until the introduction of reinforced concrete footings in the early 1900's.

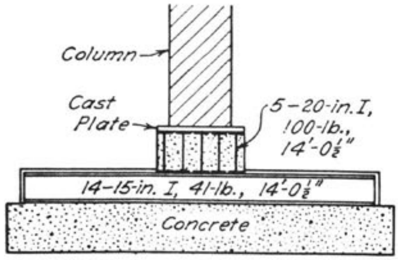



FIG. 8. SECTION THROUGH I-BEAM FOOTING OF MARQUETTE BUILDING

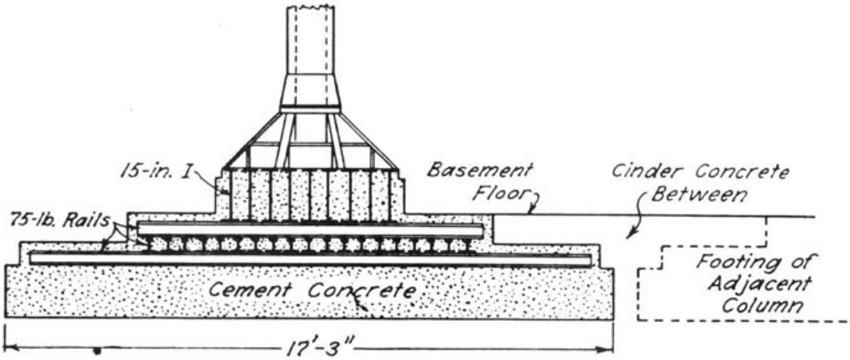



FIG. 9. SECTION THROUGH RAIL AND I-BEAM GRILLAGE OF THE FAIR STORE

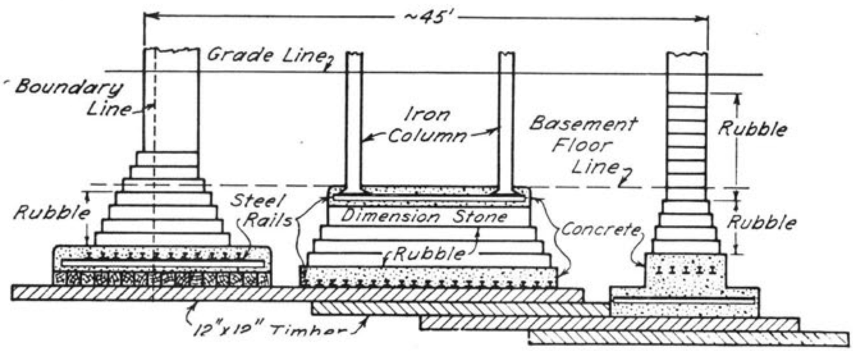



FIG. 10. SECTION THROUGH COMBINED FOOTINGS OF AUDITORIUM

A typical I-beam grillage under a single column in the Marquette Building, constructed in 1895 at 140 S. Dearborn St., is shown in Fig. 8. Although the depth of such footings was somewhat greater than that of rail grillages, the quantity of steel was considerably less.

Various combinations of the spread-footing types were used to suit the particular needs of the structures. In the Fair Store, located between State and Dearborn Streets north of Adams St., Jenney combined the rail and I-beam grillages as shown in Fig. 9. In the Auditorium, under construction in 1887, Adler and Sullivan combined rails, I-beams, dimension stone, rubble masonry, timber, and concrete. Some features of these footings are shown in Fig. 10.

*Cantilever Footings*

One of the principal advantages of the I-beam grillage footing is the ease with which the load from two or more columns can be transmitted to a single footing. Before the use of I-beams, the load from exterior wall columns had to be supported by footings laid out with their centers of gravity directly below the columns. As a consequence the footings projected beyond the building line. When the wall of a new building was constructed adjacent to that of an older one, it was necessary to underpin the old wall with new party-footings common to both walls. This operation was expensive, and in some instances not feasible.

In the Auditorium, a few lightly loaded columns adjacent to the Studebaker Building were supported on beams cantilevered from footings about four feet inside the building line. One of these footings is shown in Fig. 11. This appears to be one of the earliest uses of the cantilever footing. More extensive use of the principle is reported by Mr. Adler to have been made in the Chicago Edison's Building on Adams St. Construction of this building was begun at about the same time as the Auditorium, but details of the foundation are not known.

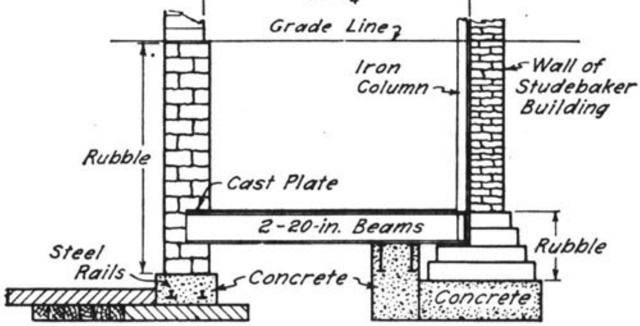



FIG. 11. SECTION THROUGH CANTILEVER FOOTING OF AUDITORIUM

The first large-scale use of the cantilever footing was made in 1890 by Burnham and Root in the Rand McNally Building located between Adams and Quincy Streets west of LaSalle St. At almost the same time, Jenney used cantilever footings to support the walls of the Manhattan Building, still standing at 431 S. Dearborn St. Figure 12 shows a cantilever footing used to support the south wall of the Old Colony Building, constructed in 1894 at 407 S. Dearborn St. This footing was underpinned a few years later because of excessive settlement (see page 58).

In the design of all of the structures on grillage footings, the architects and engineers complied strictly with the principles laid down by Frederick Baumann. Combined and cantilever footings were carefully proportioned so that the centroids of the footings were coincident with the resultants of the column loads. The amount of live load which should be taken into account when the footings were proportioned for equal settlement was a matter of some controversy. It was agreed by the foremost architects and engineers that only a small fraction of the nominal live load should be considered. For office buildings and stores, many designers considered only the dead load of the structure. A few included a floor load of five pounds per square foot, and the maximum value which seems to have been used was 18 pounds per square foot, by Jenney in the Home Insurance Building. In the Fair Store, the same architect later used the conservative value of 2880 pounds per square foot in proportioning the footing areas, with no allowance for live load.

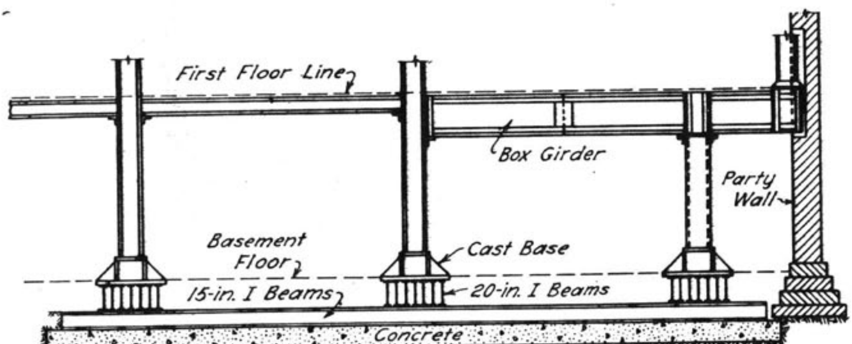



FIG. 12. CANTILEVER FOOTING SUPPORTING SOUTH WALL OF OLD COLONY BUILDING

## VI. The Public Buildings, 1871-1894

### *Federal Building*

The development and popularity of spread footing foundations in Chicago were due not only to the impact of Baumann's treatise on Chicago builders, but also in large measure to the fate of three monumental public buildings, two of which were founded on concrete mats and the third on piles.

The first of these was the Federal Building, in the block bounded by Jackson, Clark, Adams and Dearborn Streets. This structure was founded on a continuous bed of plain concrete 3½ or 4 feet in thickness, spread upon the surface of the stiff clay crust. The exterior of the structure consisted of a series of masonry piers of unequal weight, with fairly large openings between. In the interior were many lightly loaded columns, and several piers carrying loads of 380 tons or more. It was assumed that the concrete would act as a rigid base which would spread the loads uniformly to the underlying clay.

In "The Art of Preparing Foundations" Baumann commented upon this foundation, which was then under construction. His first observation was that "any masonry is essentially a yielding mass, through which the loads act, in proportion to their weights, compressing the ground beneath, forcing the masonry to accommodate itself accordingly." Thus, he recognized the fallacy of the fundamental assumption of the designer that the mat would remain rigid. In discussing the foundation of the outer wall, he presented the cross-section (Fig. 13). According to his method of isolated piers,

"The axis *da* is shifted off the center of its base; the clay beneath will consequently be compressed . . . with a tendency to thrust the wall out of its perpendicular line. This tendency need, however, not become reality, because of the very probable rupture of the bed of concrete, as indicated in [the figure]. Had this wall an independent central base, as dictated by the 'method of isolated piers,' no possible contingency could ever arise.

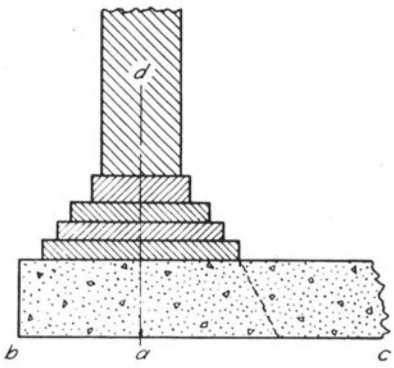



Fig. 13. Section Through Portion of Mat Foundation of Federal Building

"Considering the large inequality of the weights of the piers of the outside walls, the heavier piers will sink down, in some measure, proportionate to the weight of pier and size of base upon the clay, such as it may assume for itself, while the little piers will almost wholly retain their original levels."(10)

Baumann's judgment was more than justified. By December, 1885, six years after completion, repairs to the building due to the unequal settlement amounted to $94,000. The mat was said to have broken up when it had experienced a settlement of about 14 inches. In 1896, the building had to be demolished.

*City Hall*

In 1882, another mat foundation of similar construction was built to serve as the base for the new City Hall, which occupied the west half of the block bounded by LaSalle, Randolph, Clark, and Washington Streets, the site of the present City Hall. Even during the construction of the building, the settlement became noticeable. In 1891, Mr. D. C. Cregier recalled that "when we came to put in the floors, it had settled in some portions seven inches and a quarter."(11) By the time of its removal, the structure had settled differentially at least 14 inches.

Chicago engineers and architects derived considerable satisfaction from the fact that the architects of these two structures were Easterners. With Baumann's forecast to emphasize the merit of their own local methods, they dismissed mat foundations from consideration, believing them inherently unsuited to the local conditions. Even after the introduction of steel beams into foundations, so that mats of sufficient rigidity and strength became feasible, only one building of any consequence, the 14-story Owings or Bedford Building, built in 1890 at 203 S. Dearborn St., was constructed on a foundation of this type before the turn of the century.

*County Building*

The east half of the block bounded by LaSalle, Randolph, Clark, and Washington Streets was occupied by the County Building, completed in 1885. The superstructure of this building was the counterpart of the City Hall on the west half of the block. The foundation, however, consisted of footings supported by short piles. The character of the piling is not exactly known, but all records agree that the length of piling was 30 feet and that the tops were cut off at about city datum. One record, which may be unreliable, states that after the thirty-foot piles were driven, twenty-foot piles were driven on top of them without providing a substantial connection. It is certain that the piles did not penetrate to the bottom of the soft clay. Mr. Cregier reported that the piles were "so thick that when they drove one down where they wanted it, the next one that was driven down drove up the first one, and they had to keep driving right along; they were a good many months at it."[(12)]

By 1891, the County Building had experienced a differential settlement of 18 inches, and was in worse condition than the City Hall. The failure of the foundation demonstrated the inability of short piles to support heavy loads without excessive settlement. However, the statements of Chicago engineers at the time leave no doubt that the failure was ascribed to the mere fact that the structure had a pile foundation, and that no mental distinction was made between short friction piles and long point-bearing piles. Since this foundation also was designed by an Eastern architect, the local engineers were more than ever inclined to use and to refine their own specialty, the foundation of isolated spread footings.

Hence, from the time of the great fire until 1890, the spread foundation was the dominant type in Chicago, and many architects had dismissed the thought that any other type was worthy of consideration. The behavior of the public buildings in the early 1880's merely added to their conviction.

## VII. The Problem of Settlement

*Introduction*

In retrospect it seems obvious that one important characteristic which the three public buildings had in common was the extreme variation in the distribution of the weight of each building over the total area covered by the structure. The excessive differential settlement of the structures was attributed solely to the use of a foundation type believed to be unsuited to the local conditions. Yet, in the period between 1883 and 1887, three equally monumental buildings were constructed on spread footings, with equally poor results. These structures were the Polk Street Station (1883), the Board of Trade (1885), and the Auditorium (1889). The unsatisfactory behavior of the first two was attributed to the belief that their Eastern architects, although wisely using spread footings, did not fulfil the requirements of the method of isolated piers. The Auditorium, however, was designed by one of the ablest Chicago architectural firms, and the requirements of the method were meticulously satisfied. Its subsidence began a discussion among Chicago engineers which was not resolved for two decades. Details of the controversy are given in Chapter X (pages 56–60).

*Polk Street Station*

The Polk Street Station, Fig. 14, contains a brick tower, originally 170 feet high and 21 feet square at the base. Adjacent to the tower the structure was only two stories high, whereas beyond the two-story sections the height was three stories. The foundation plan of that portion of the structure facing Polk Street is shown in Fig. 15a. All the walls, including those of the tower, are supported by continuous rubble stone footings. Interior columns, which support only the floors and roof, are founded on individual spread footings. The tower footing extends to the clay surface at city datum, whereas the wall and column footings rest on silt or clay at approximately El. + 1.00.

The weight of the original tower, including the foundation, was about 1860 tons, and the area of the tower footing was 1200 square feet. Hence the unit soil pressure under the tower was 3100 pounds per square foot. The pressure under the smaller footings was approximately the same. Therefore, it appears that the structure was designed for a moderate soil pressure. It is also apparent that the tower footing and the footings for the adjacent walls were not separated from each other and that the method of isolated piers, as such, was not used.

In 1897 Mr. Artingstall stated that, to his knowledge, the tower had twice been cut away from the main building in order to allow it to settle and not wreck the building. In 1899 a set of levels was taken along the front of the building which indicated that the tower had settled about 8 inches, whereas the two-story building had settled less than one inch.

In 1943 a series of differential levels was made along the originally horizontal stone base course. The results, as shown in Fig. 15b, indicate a differential settlement of $7\frac{5}{8}$ inches between the tower and the main building; most of the settlement is concentrated in the main building within a few feet of the tower. The top of the present tower is some 45 feet lower than the original, because of the destruction of the original roof by fire.

The failure of the foundation of the Polk Street Station was well known, and was magnified by ignorance. Even Frederick Baumann, who was usually conservative and reliable in his statements, wrote that "the Polk Street Railroad Depot stands upon ground which had been softened by extinct water courses," and that [1898] the "central tower . . . has sunk more than a foot below where it ought to stand, and the whole fine building is, in view of this fact, little better than a wreck."[13]

FIG. 14. POLK STREET STATION, SHOWING THE ORIGINAL TOWER

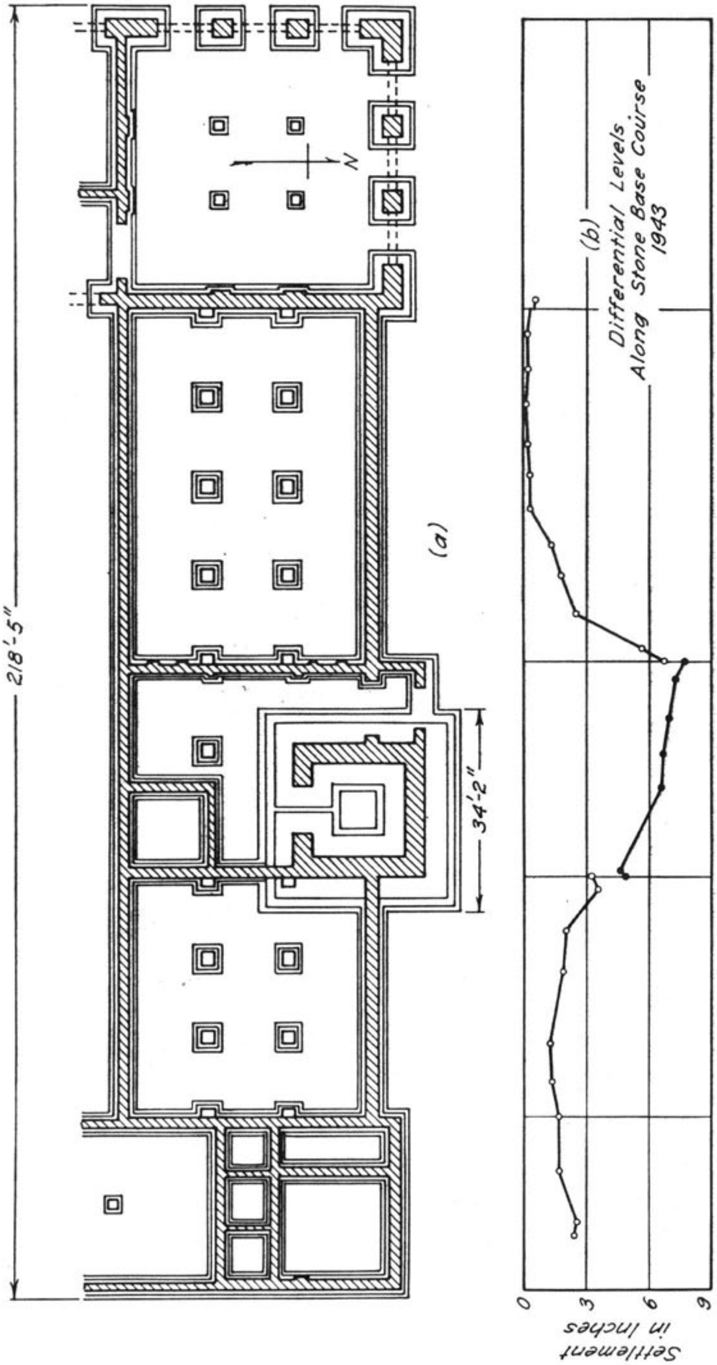



FIG. 15. FOUNDATION PLAN OF FRONT PORTION OF POLK STREET STATION, WITH DIFFERENTIAL LEVELS ALONG STONE BASE COURSE OF NORTH WALL (1943)

*Old Board of Trade*

The Board of Trade Building is shown in Fig. 16. It was located on the site of the present structure of the same name, between Sherman and LaSalle Streets on the south side of Jackson Blvd. The front portion of the structure was 240 feet high. It contained the trading hall, a large room without interior columns. At the middle of the front wall, on Jackson Blvd., rose a tower 32 feet square to a height of 303 feet. The lower 225 feet of the tower were of granite masonry, whereas the upper 78 feet consisted of a cast-iron lantern. The rear of the building, 160 feet high, contained offices.

The total weight of the structure was 69,700,000 pounds, of which 53,800,000 pounds were carried by the wall footings. The foundation appears to have consisted of individual masonry piers resting on timber

FIG. 16. BOARD OF TRADE BUILDING, SHOWING ORIGINAL TOWER

grillages at the clay surface. The average load of the structure over the entire building area, not considering the reduction in load due to the basement excavation, was only 1780 pounds per square foot. However, the average soil pressure under the wall footings was 6900 pounds per square foot, and the values of pressure actually ranged from 5680 to 8800 pounds per square foot. On the other hand, the soil pressure beneath some of the interior columns was as small as 2060 pounds per square foot.

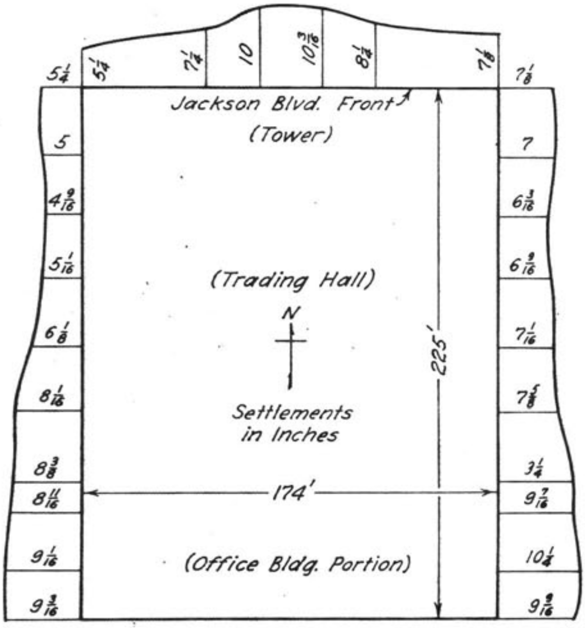



FIG. 17. SETTLEMENT OF BOARD OF TRADE FROM 1884 TO 1889

Within five years after the structure was completed, its settlement had become so alarming that the owners retained General William Sooy Smith, one of the foremost foundation engineers of the day and a resident of the suburb of Maywood, to study the problem. At this time (1889) the maximum settlement had reached 10¼ inches. Figure 17 shows the results of Sooy Smith's levels on the outer walls.

In November, 1893, Sooy Smith made a report stating that the uneven settlement demanded prompt and costly repair. He proposed that deep masonry piers should be constructed to hard foundation at a cost of $150,000. In February, 1894, a popular account stated:

"Levels taken for five years show that the building has settled at the rate of one-sixteenth of an inch a month, the settlement [of the building proper] amounting in the whole to eight inches. . . . The northwest corner has settled most and is now almost entirely separate from the rest of the structure, there being a crack ten inches wide between it and the partition wall. . . . The heavy weight of the tower has caused another depression, greater still than that of the north wall."(14)

The owners did not follow Sooy Smith's recommendation to underpin the building, but in the interest of safety the cast iron lantern was removed from the tower in 1895, and a system of steel tie rods was installed to hold the walls together.

After the removal of the lantern, the structure stood until 1929, when it was removed and the present Board of Trade Building erected. During this entire period, level readings were taken periodically and the condition of the structure was closely observed. At the time of its destruction, the maximum settlement was 21 inches.

*Auditorium*

The settlement of the Board of Trade was public knowledge, and was almost universally ascribed to the failure of its Eastern architect to use a constant and conservative value for the soil pressure. Of the Auditorium, however, it could hardly be said that the best Chicago practice was unobserved. Hence a history of this structure is of more than usual interest to the student of Chicago foundations.

The Auditorium (Fig. 18), upon which construction started in August, 1887, was designed to combine the facilities of a hotel, an office building, and a theater. The structure is roughly rectangular, extending 160 feet along Wabash Ave. and Michigan Ave. and 360 feet along Congress St. The portion fronting on Wabash Ave. and partly on Congress St. comprises the office building. The Michigan Ave. front and most of the rest of the Congress St. face is the hotel. The entire area enclosed by these three faces is occupied by the theater, with its stage toward Michigan Ave. and its balconies toward Wabash Ave. Above the theater is a large banquet hall. The theater entrance is located in a 19-story tower at about one quarter of the distance from Wabash Ave. to Michigan Ave. The rest of the structure is 10 stories.

The building consists of exterior and interior masonry bearing walls which support most of the floor and roof loads. Within the theater itself there are no columns except those which support the floor.

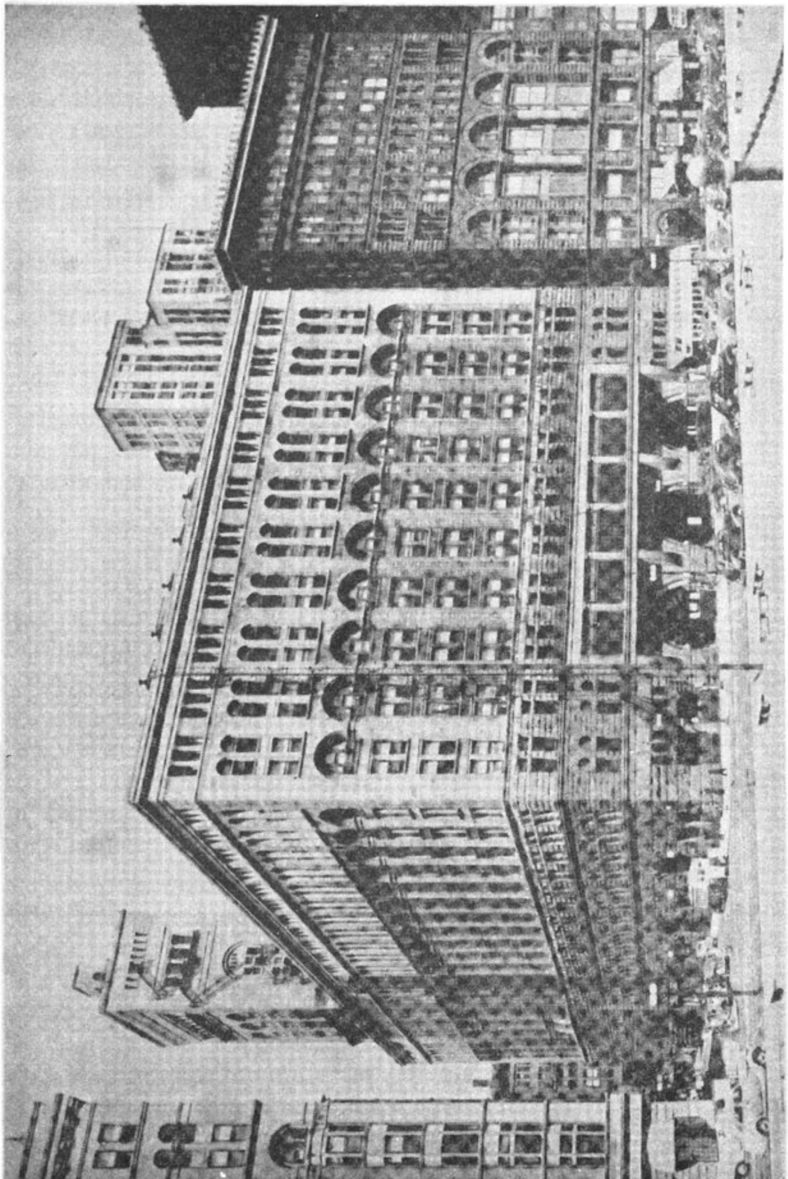


Fig. 18. Auditorium

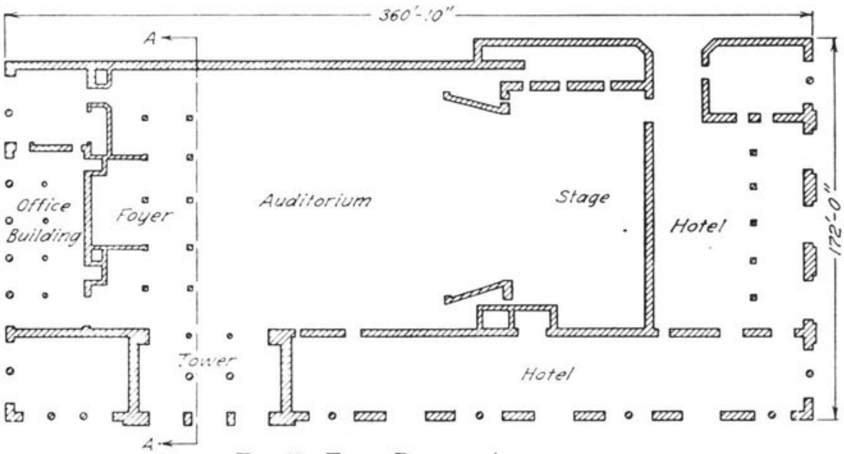



FIG. 19. FLOOR PLAN OF AUDITORIUM

The banquet hall and roof are carried by wrought iron trusses resting upon the masonry walls. The foyer at the rear of the theater contains a number of columns which support the balconies, and the interior loads of the office building, hotel, and tower are carried by cast iron columns and steel or iron floor beams. The bearing walls are continuous along the back of the building, parallel to Congress St., and for the most part in the interior. The fronts on Michigan Ave., Congress St., and Wabash Ave., however, consist of separate piers and columns in the lower stories. The general arrangement is shown in Fig. 19.

A study of Fig. 19 shows that the distribution of load over the building area is extremely non-uniform. Under the tower the concentration of load is very great. On the other hand, under the theater floor the weight of material excavated for the basement is greater than the applied building loads. Furthermore, the requirements of head room in the basement, particularly below the stage, made it necessary to establish the footings below the top of the desiccated clay crust. All these factors suggested to Adler and Sullivan, the architects, that the foundations must be designed with great care. Mr. Adler was himself an engineer of considerable skill, and he retained General Sooy Smith as consultant on foundations.

Sooy Smith made a series of borings at the site of the structure, and conducted a series of load tests. The results of these tests have not been located, but it is known that the areas of the test plates were varied and that tests were made at different elevations in the upper clay strata in order to study the effects of these factors upon the probable settlement of the footings. On the basis of the tests it was decided to locate the base of the tower footing at El. − 5 and of the others at El. − 4, and to proportion all the footings for a unit load of 4500 pounds per square foot including an allowance for live load. The intensity of dead load beneath the footings was approximately 4100 pounds per square foot.

All footings consisted of 2 layers of 12-inch timbers laid at right angles to each other in prepared beds of gravel. So great was Sooy Smith's concern lest the water level might drop below the level of the timbers that he interconnected all the gravel beds and established a free connection to the water of Lake Michigan, which at that time was only a short distance across Michigan Avenue.

Above the timbers was placed a stepped grillage of railroad rails, steel beams, or both, embedded in concrete. On top of the grillage were placed dimension stone or rubble piers. The foundation of the tower was one large footing approximately 100 by 67 feet. It is shown in cross-section in Fig. 20.

The footings were proportioned with great care for the same soil pressure. Many of the footings were combined in order to satisfy the condition of concentricity of loads. Furthermore, since it was anticipated that the 10-story part of the structure would be completed before the tower reached its full height of 19 stories, Baumann's suggestion of pre-loading was adopted. The bricks to be used for construction of the entire tower, supplemented by loads of pig iron, were placed on the tower footing at such a rate that when the entire building reached the height of 10 stories, the full weight of the tower rested upon its footing.

Thus, in every respect, the foundations represented the best practice. The amount of settlement expected is reflected in the fact that the entire building was set two inches above grade. However, Sooy Smith and Adler took additional precautions to minimize the effects of such differential settlements as might occur. In order to avoid separation of the tower from the adjoining parts of the structure, such as had already become apparent in the Polk Street Station and the Board of Trade, Sooy Smith tied the tower footing to the adjoining wall footings by a series of 15-inch I-beams, which are clearly shown in Fig. 20. Furthermore, it was feared that several lightly loaded columns which carried loads from only one story would not settle as much as the rest of the structure, and screwjacks with a run of six inches were inserted at the top of these columns to allow for adjustment in the future.

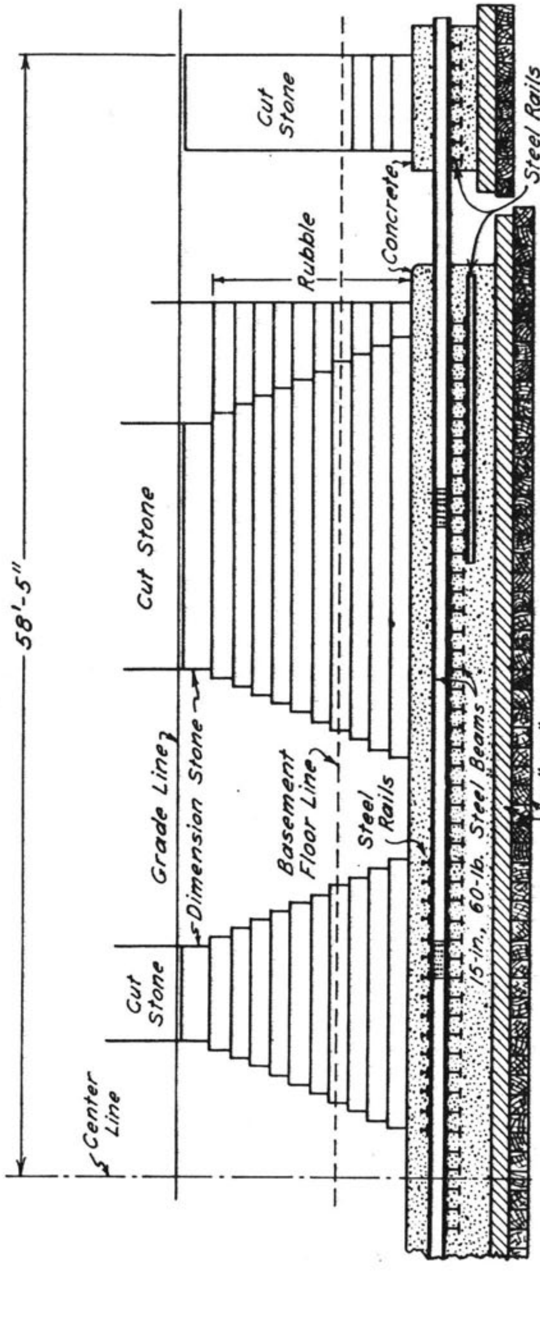



FIG. 20. TOWER FOUNDATION OF AUDITORIUM

The care with which Dankmar Adler considered the foundations for the Auditorium was representative of the design of the entire building. The artistry of Sullivan and the engineering skill of Adler produced what has generally been regarded as a masterpiece of architecture. The theater, with perfect acoustics, was the largest of its time. The decision to hold the World's Columbian Exposition of 1893 in Chicago was strongly influenced by the fact that the city possessed this remarkable building.

Yet Adler and Sooy Smith were compelled to watch the settlement of this structure grow within two years to seven inches, and in five years to eighteen. The tower did not separate from the rest of the structure, but the distortion of the frame was very great and on several occasions the safety of the building was a matter of litigation.

Fortunately, continuous settlement levels have been taken since the construction of the structure. A curve showing the progress of settlement at the point of maximum subsidence is shown in Fig. 21. Figure 22 shows a profile of the foyer floor in 1942.

*Other Buildings*

The full significance of the Auditorium's settlement was not felt until about 1895. In the meantime, many other large buildings were constructed on spread footings, with a considerable degree of success. Table 1 is a list which includes all downtown structures nine stories or higher, except the Auditorium and the Board of Trade, which were built on spread footings between the years 1884 and 1895.

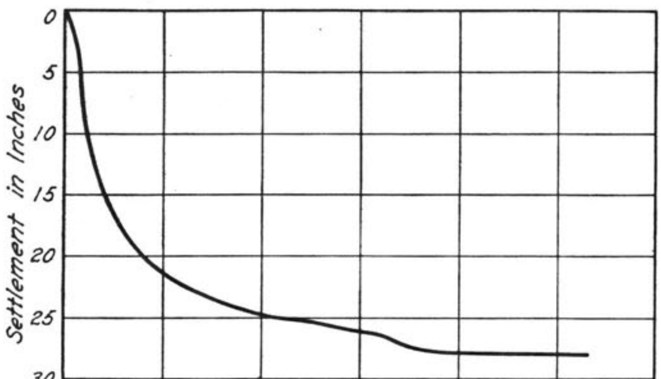



FIG. 21. TIME-SETTLEMENT CURVE FOR TOWER OF AUDITORIUM

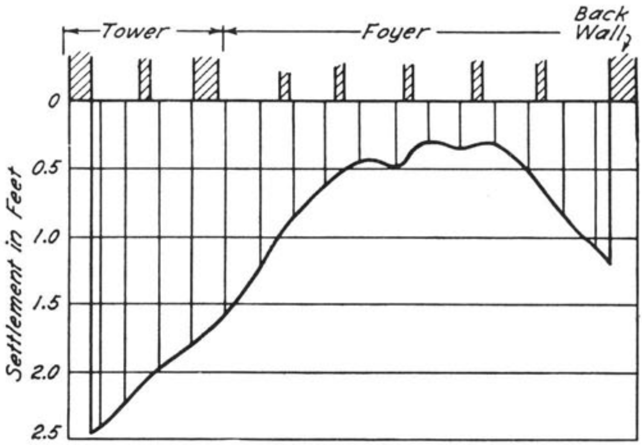



FIG. 22. PROFILE OF FOYER FLOOR IN AUDITORIUM (1942)

TABLE 1

BUILDINGS ON SPREAD FOOTINGS, NINE STORIES OR HIGHER, 1884-1895

The asterisk indicates that the structure was still in use in 1940, approximately 50 years after construction.

| Date | Name | Stories | Location | Architect |
|---|---|---|---|---|
| 1884 | Calumet | 9 | 111-17 S. LaSalle | Burnham & Root |
| | Mallers | 12 | 224-26 S. LaSalle | John J. Flanders |
| | Pullman* | 10 | 79 E. Adams | S. S. Beman |
| | Goff | 9 | 230 S. LaSalle | S. V. Shipman |
| | Counselman | 9 | N.W. cor., S. LaSalle & W. Jackson | Burnham & Root |
| 1885 | Chicago Opera House Block | 10 | S.W. cor., N. Clark & W. Washington | Cobb & Frost |
| | Continental Nat'l Bank | 9 | 208 S. LaSalle | Burnham & Root |
| | Royal Insurance | 12 | 160 W. Jackson | W. W. Boyington |
| | Home Insurance | 9 | N.E. cor., S. LaSalle & W. Adams | W. L. B. Jenney |
| 1886 | Rialto* | 9 | 132-48 W. VanBuren | Burnham & Root |
| | Union Bank | 9 | 21-29 N. Dearborn | |
| | Mercantile* | 9 | 305 W. Adams | Bauer & Hill |
| | Rookery* | 11 | 209 S. LaSalle | Burnham & Root |
| | Austin (Western Union)* | 11 | 111 W. Jackson | Burnham & Root |
| | Adams Express | 11 | 109-19 S. Dearborn | Geo. H. Edbrooke |
| | Bd. of Trade Hotel (Atlantic)* | 9 | 319-21 S. LaSalle | |
| 1887 | Como | 9 | 443 S. Dearborn | John M. Van Osdel |
| 1889 | Tacoma | 13 | N.E. cor., N. LaSalle & W. Madison | Holabird & Roche |
| 1890 | Chamber of Commerce | 13 | S.E. cor., N. LaSalle & W. Washington | Edward Baumann, Harris Huehl |
| | Rand McNally | 10 | W. Adams west of S. LaSalle | Burnham & Root |
| | Manhattan* | 16 | 431 S. Dearborn | W. L. B. Jenney |
| | Monon* | 13 | 436-44 S. Dearborn | John M. Van Osdel |
| | Bedford (Owings) (Mat)* | 14 | 203 S. Dearborn | H. I. Cobb & Frost |
| | Caxton* | 12 | 508 S. Dearborn | Holabird & Roche |
| 1891 | Monadnock (North)* | 16 | 53 W. Jackson | Burnham & Root |
| | 125 S. Market St.* | 10 | 125 S. Market | |
| | Virginia Hotel | 10 | N.W. cor., N. Rush & E. Ohio | Clinton J. Warren |
| | Pontiac* | 14 | N.W. cor., S. Dearborn & W. Harrison | Holabird & Roche |

TABLE 1 (CONCLUDED)

BUILDINGS ON SPREAD FOOTINGS, NINE STORIES OR HIGHER, 1884-1895

The asterisk indicates that the structure was still in use in 1940, approximately 50 years after construction.

| Date | Name | Stories | Location | Architect |
|---|---|---|---|---|
| 1892 | Venetian* | 13 | 15 E. Washington | Holabird & Roche |
| | Woman's Temple | 13 | 102-16 S. LaSalle | Burnham & Root |
| | Great Northern Hotel* | 16 | 237 S. Dearborn | Burnham & Root |
| | Fair Store* | 9 | S. State, W. Adams & S. Dearborn | Jenney & Mundie |
| | Unity* | 16 | 127 N. Dearborn | Clinton J. Warren |
| | Isabella* | 11 | 21 E. VanBuren | Jenney & Mundie |
| | Chicago Title & Trust* | 17 | 69 W. Washington | Henry I. Cobb |
| | Ashland Block* | 16 | 155 N. Clark | D. H. Burnham |
| | City Hall Sq. Hotel (Kedzie Bldg.)* | 9 | 87-91 W. Randolph | Edmund R. Krause |
| | Terminals* | 14 | 537 S. Dearborn | J. M. Van Osdel & Co. |
| | Boyce* | 12 | 30 N. Dearborn | Henry I. Cobb |
| | Marshall Field & Co. (So.)* | 9 | N. Wabash & E. Washington | D. H. Burnham |
| | Masonic Temple* (Capitol) | 21 | N.E. cor., N. State & E. Randolph | Burnham & Root |
| 1893 | Teutonic* | 10 | 179 W. Washington | Handy & Cady |
| | Congress Hotel* | 10 | 504 S. Michigan | Clinton J. Warren |
| | Central Y.M.C.A.* | 16 | 19 S. LaSalle | Jenney & Mundie |
| | Watson | 9 | 15-19 N. LaSalle | |
| | Monadnock (South)* | 17 | 53 W. Jackson | Holabird & Roche |
| | Columbus Memorial* | 14 | 31 N. State | W. W. Boyington |
| | Chicago Athletic Club* | 10 | 12 S. Michigan | Henry I. Cobb |
| | Hartford* | 14 | 8 S. Dearborn | Henry I. Cobb |
| | Lees* | 12 | 15-23 S. Wells | James Gamble Rogers |
| | Security* | 14 | 189 W. Madison | Clinton J. Warren |
| | Majestic Hotel* | 17 | 29 W. Quincy | D. H. Burnham |
| | VanBuren* | 10 | 210-14 W. VanBuren | |
| 1894 | Old Colony* | 17 | 407 S. Dearborn | Holabird & Roche |
| | Champlain | 15 | N.W. cor., N. State & W. Madison | Holabird & Roche |
| | Chemical Bank (Iroquois) | 9 | 21-23 N. LaSalle | Burnham & Root |
| | LaSalle-Monroe* (New York Life) | 12 | 37-43 S. LaSalle | Jenney & Mundie |

The fact that 38 of the 57 structures listed were still in service in 1940 is convincing evidence that the buildings served their purpose well. Furthermore, with one exception, there is no record of structural damage to any of them as a result of settlement under their own weight, such as occurred in the Polk Street Station, the Board of Trade, or the Auditorium. It is also worth noting that all these buildings exerted a relatively uniform load on the ground. None of them contained either a high tower with adjacent lower sections, or heavy load-bearing walls combined with lightly loaded interior columns. After 1885, almost every building listed was of skeleton construction and had a fairly uniform column spacing.

On the other hand, it should not be assumed that the structures did not settle or that Chicago engineers were ignorant of the settlement. In fact, it was the practice at least as early as 1884 to set the buildings above grade such a distance as would, in the judgment of the

TABLE 2
ALLOWANCES FOR SETTLEMENT

| Date | Building | Allowance inches | Architect |
|---|---|---|---|
| 1885 | Home Insurance | 2½ | W. L. B. Jenney |
| 1889 | Auditorium | 2½ | Adler & Sullivan |
| 1891 | Monadnock (North) | 8 | Burnham & Root |
| 1892 | Capitol | 8 | Burnham & Root |
| 1892 | Great Northern Hotel | 9 | Burnham & Root |
| 1892 | Fair Store | 4½ | Jenney & Mundie |
| 1894 | New York Life | 4½ | Jenney & Mundie |
| 1896 | Atwood | 6½ | Holabird & Roche |

engineers, cause the structure to be at grade after settlement. As experience disclosed the progressive settlement of the buildings, the allowance for settlement became greater. A chronological table (Table 2) showing the allowance for several structures is informative of the manner in which the importance of the settlement problem grew in the minds of the designers.

The actual settlement of a few of these structures is known in some detail, and fragmentary information exists about others. Mr. Jenney kept records of the settlements of his structures during the construction period. The maximum settlement of the Home Insurance Building at the time of completion was 2¼ inches, and the greatest differential settlement was 11/16 inch. There is no record of subsequent levels, but in February, 1889, Jenney wrote: "experience has taught that foundations calculated to carry 3500 to 4000 pounds per square foot . . . will settle four to five inches."(15) Since the soil pressure used for designing the Home Insurance Building was 4000 pounds per square foot, his statement suggests that after five years the Home Insurance Building may have settled that amount. The Fair Store, probably designed for 16 stories with a soil pressure of 3500 pounds per square foot and actually constructed with 9 stories at a pressure of 2850 pounds per square foot, settled a maximum of 1⅜ inches during its first four years. The Central Y.M.C.A., built in 1893 by Jenney, settled 2 11/16 inches during its construction period.

The 16-story Monadnock Block (north half) is one of the heaviest structures in Chicago. Although built in 1891, it was of wall-bearing construction. The average footing pressure was 3750 pounds per square foot, and the average pressure over the gross area of the structure was 3300 pounds per square foot. The area of the structure between building lines is a rectangle 66 feet wide and 398 feet long. On the basis of

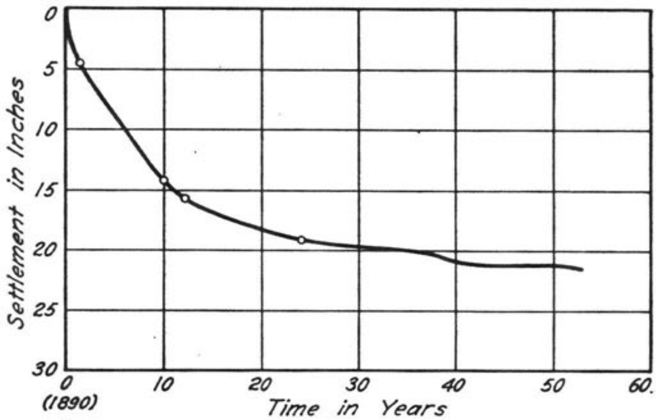



FIG. 23. TIME-SETTLEMENT CURVE FOR NORTH HALF OF MONADNOCK BLOCK

various surveys made from time to time, Mr. V. O. McClurg has reconstructed the settlement record shown in Fig. 23. The differential settlement of the structure in 1900 was of the order of 3 inches. Figure 24 shows a profile along the east side of the building, taken at that time. The profile extends through the south half of the building, built one year after the north half was constructed.

The Masonic Temple (Capitol Building), erected in 1892, was the first 21-story building in the world. It was rectangular in plan, 195 by 132 feet between building lines, and was designed for a soil pressure of 3200 pounds per square foot. In contrast to the heavy Monadnock Block, the Masonic Temple was of skeleton construction and exerted a load of only 1600 pounds per square foot over the gross area of the structure. Figure 25 shows time-settlement curves corresponding to two points in the building from the start of construction until 1913, twenty-two years afterward. The maximum settlement was ap-

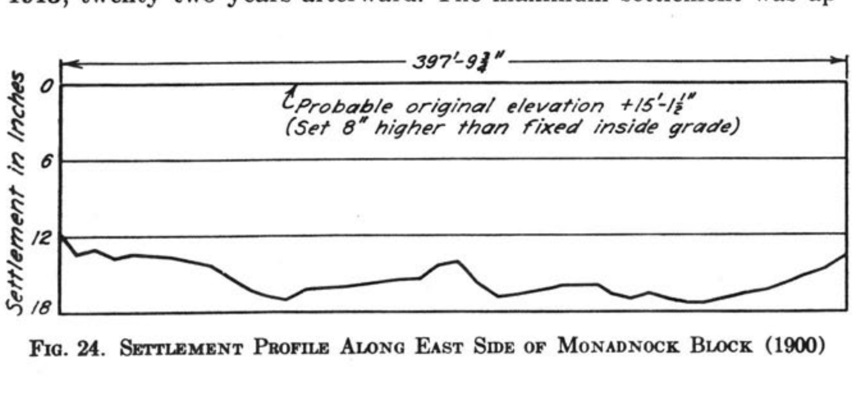
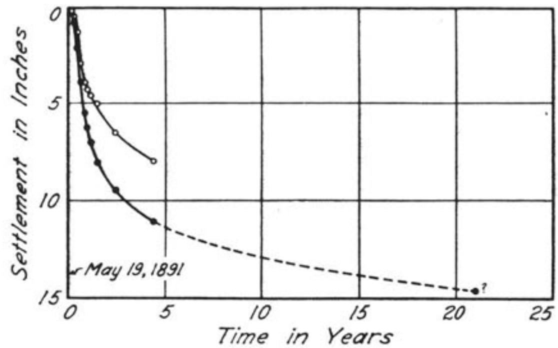



FIG. 24. SETTLEMENT PROFILE ALONG EAST SIDE OF MONADNOCK BLOCK (1900)

proximately one foot, and the greatest differential settlement was 7½ inches. Curves of equal settlement are shown in Fig. 26. They correspond to the year 1913. Settlement during the construction period was approximately 2½ inches.

The Great Northern Hotel, 16 stories, built of skeleton construction in 1892, settled between 9 and 10 inches during the first year after



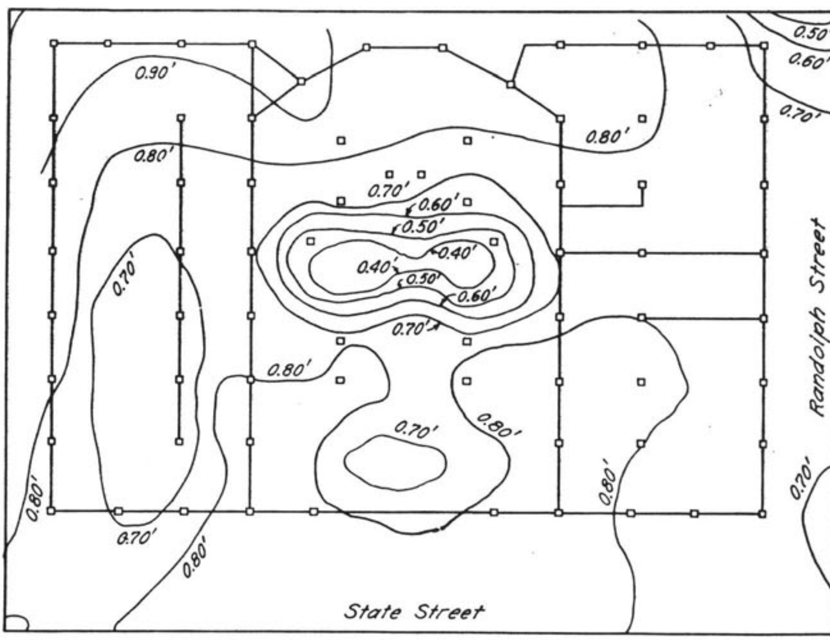




FIG. 25 (ABOVE). TIME-SETTLEMENT CURVES FOR MASONIC TEMPLE

FIG. 26. CURVES OF EQUAL SETTLEMENT FOR MASONIC TEMPLE (1913)

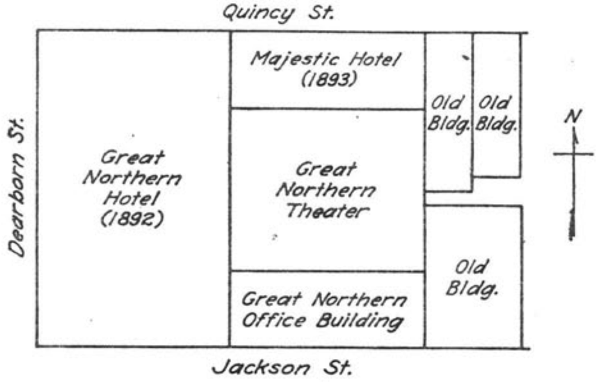



FIG. 27. LOCATION OF BUILDINGS, GREAT NORTHERN GROUP

construction. After this period three additions were constructed — the Great Northern Office Building, the Majestic Hotel, and the Great Northern Theater. The mutual relation of the four parts of the structure is shown in Fig. 27. One commentary on the new construction gives an interesting picture of the complacency with which Chicago engineers of this period regarded differential settlements:

"The new additional structures stand between the original hotel, which is of nearly equal weight . . ., and two other old style buildings which came to their permanent bearings many years since. Yet the new part fills the whole intermediate space, and it has been required to provide for the necessary settlement of the new building while regarding the safety and avoidance of disturbance of two classes of contiguous buildings. When it is understood that the estimated settlement of the new structure was nine inches, the difficulty in doing this can be readily appreciated. As a matter of fact, the Jackson street addition has settled nine inches and the Quincy street addition has settled six inches. But the former now has its full weight, while the latter has not yet attained its full weight, and the construction has been slower. The theater which stands between is therefore three inches lower on the south than on the north side, but as its whole construction is sufficiently elastic, nothing has to be feared while waiting for the north side to go down three inches more."[16]

During 1894, the Old Colony Building, a 17-story steel-frame structure, was completed. It was designed for a soil pressure of 3200 pounds per square foot. The average load over the gross area of the building was about 2500 pounds per square foot. The average settlement over its nine-month construction period was 4.2 inches, and the maximum value 5.1 inches. This settlement was considered quite normal.

Indeed, by 1895 most engineers and architects in Chicago felt themselves masters of their foundation problems. They accepted the idea that a certain amount of distortion of the building frames due to differential settlement was inevitable and, if anticipated, was not harmful. They did not consider it worth their while to investigate the possibility of less yielding foundations. As a matter of fact, the architect who contemplated a deep foundation for an office building would probably have failed to find any business, because Chicago business men were of a particularly utilitarian mind. Competition was keen among the architects to produce serviceable buildings at the lowest cost, and the expense of deep foundations seemed prohibitive and unnecessary.

## VIII. Rise of the Long-Pile Foundation (1883-1903)

### *Earliest Uses of Piles*

It is generally believed that pile foundations were first used in Chicago beneath the grain elevators along the waterfront. The earliest of these was built in 1848 on the northwest corner of Wells and S. Water Street (now W. Wacker Drive). In 1857, the first elevator constructed of 2-by-4 staves was erected, and from that date until the advent of reinforced concrete every elevator built in the city was of that type. All these structures were supported on long wood piles, loaded to about 20 tons per pile. The success of the foundations appears to have had little influence on the architects who constructed the tall buildings of a generation later, possibly because the construction of elevators was in the hands of a few specialists who did not engage in ordinary building construction. Furthermore, the apprenticeship of the skyscraper architects was usually in smaller buildings on spread footings, and as structures grew taller they were regarded merely as a development from the small structures.

The first use of piles beneath a conventional building was probably under the Sibley Warehouse, still in existence on the north bank of the Chicago River, on the east side of Clark St. Construction was started in 1883. This structure was of nine stories, each designed for a live load of 500 pounds per square foot. Only the river-front wall, 240 feet long, was supported on 30-ft. oak piles. The rest was carried on footings and masonry piers which, according to a contemporary account, "seem to nearly cover the whole area." The piles did not entirely prevent settlement or lateral movement of the river-front wall as the channel of the river was deepened from time to time, and the structure was tied together at an early date by iron tie-rods. In 1945, extensive alterations were made to the foundation along the river front. Systematic levels and alignment surveys have been made on the building for many years.

The first complete long-pile foundation under a building is that of the Grand Central Station, on the southwest corner of Harrison and Wells Streets, known formerly as the Wisconsin Central Station and as the Northern Pacific Station. It consists of a masonry tower, 27 feet square and 236 feet high, at one corner of the building, and adjacent portions only 8 and 5 stories in height. The piles are all about 50 feet long and loaded to 25 tons. This structure, built in 1890 by S. S. Beman, is still in use. A careful examination shows no signs of structural distress due to differential settlement, and the heavy tower and adjacent lighter portions are still perfectly bonded together.

The second long-pile foundation was that of the German (Garrick) Theater, built by Adler and Sullivan in 1892 at 64 W. Randolph St. The different parts of this structure range from

"a height of four stories for certain small portions of the structure to thirteen stories for the greater part of the same and from this to seventeen stories for the tower. . . . Borings made upon the ground show that the characteristic soft Chicago mud attains a depth here of from forty-two to forty-eight feet below the cellar floor, and that below this is found the well-known tunnel clay, so hard that it was impossible to bore through it with the ordinary boring tool used. Fifty-foot piles were driven through this soft mud until, as in the case of the Northern Pacific Station, their points strike the tunnel clay. Here they were merely given a sufficient number of blows to make sure that their points had penetrated the hard clay. . . . The heads of these piles are cut off at a uniform level of about three feet below . . . water line, and are then covered by a grillage of oak timbers running crosswise of each other and both layers drift-bolted into the heads of the piles. Upon this is formed a foundation of concrete and I-beams, of which the outer parts act as cantalevers [*sic*] for carrying the parts of the new enclosing walls, which are erected in immediate contact with the old party walls of the adjacent buildings."(17)

In itself, the foundation of the German Theater was an outstanding success. However, because of damage to adjacent structures due to the pile driving, the construction was followed by litigation.

In 1892 and 1893, three structures on long piles were completed. These were the Illinois Central Station, east of Michigan Avenue at Twelfth Street, Bradford L. Gilbert, architect; the Newberry Library, 60 W. Walton Street, Henry Ives Cobb, architect; and the Medinah Temple, northwest corner of Wells and Jackson, with Beers, Clay and Dutton as architects. Figure 28 shows a cross-section through one of the pile footings of the Illinois Central Station which is representative of the practice at this time.

In discussing this foundation, Mr. C. J. Mitchell, Assistant Civil Engineer for the Illinois Central Railroad, stated:

"Piles varied from 11 to 16 inches in diameter at the butt end, and were from 40 to 60 feet in length, averaging about 51 feet. . . . A cast iron cap was used in driving. . . . The drivers used, three in number, were of the usual pattern of drop hammer, the weights of which were

2800, 3200, and 3800 pounds respectively. . . . The fall of the hammer at the last blow was usually 35 to 40 feet, . . . [the] penetration under the last blow averaged about 3 inches, though a large number went less than 1½ inches. . . .

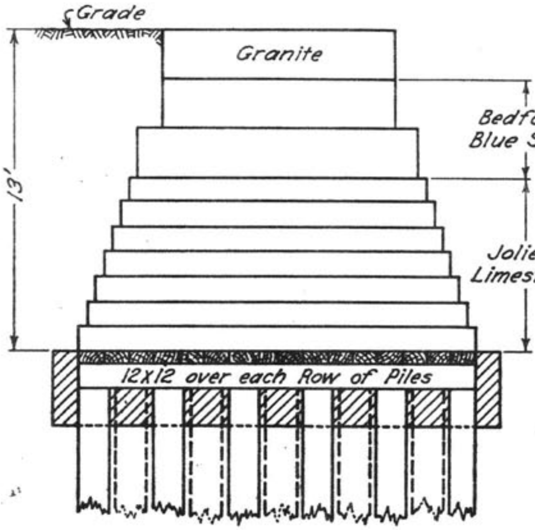



Fig. 28. Pile Footing of Illinois Central Station

"After the piles had been driven, the tops were sawed off to a uniform height of 3 feet below datum in order that all timber should be below low water. . . . After the piles were cut off, the earth was excavated 18 inches below their tops and rich Portland cement concrete was tamped in even with the tops of the piles. Oak caps 12 x 12 inches were fastened on by a drift bolt in the center of each pile, and the space between the timbers was filled with concrete; on top of this came the masonry work."(18)

During pile driving, it was noted that piles previously driven were lifted as much as four inches. No mention is made of any redriving. Hence, the information given by Mr. Mitchell indicates that the piles were not driven to a particularly resistant layer and that the foundation did not attain present-day standards. Nevertheless, the structure, which consists of a 13-story tower, a 9-story office section, and a 3-story station structure, has not been damaged by settlement.

*Pile Cut-off at Great Depth*

In 1893, General Sooy Smith introduced a new conception in the design of the pile foundations for the Public Library on Michigan Avenue between Washington and Randolph Streets. For several years General Sooy Smith had expressed his fear that a deep system of sewers or the construction of a subway would lower the water table and expose the tops of wooden piles cut off only one or two feet below datum. In connection with the Auditorium, this concern was reflected by his provision for direct transmission of water from Lake Michigan to the gravel pockets around the timber grillages. In the Public Library, it led to the adoption of a pile cut-off twelve feet below datum. A cross-section through one of the bearing-wall foundations is shown in Fig. 29.

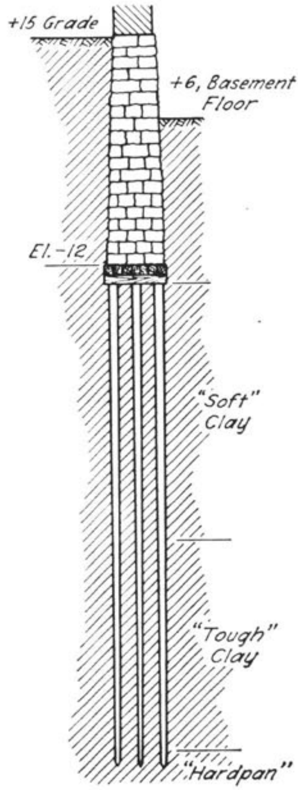


FIG. 29. BEARING-WALL FOUNDATION FOR PUBLIC LIBRARY

"The piles were driven [in the bottom of a sheeted trench] by a steam hammer . . . made by the Vulcan Iron Works; weight 4500 lbs.; fall, 42 ins., making 54 blows per minute. The last 20 feet were driven with a follower of oak. It was found that it required 48 to 64 blows to drive the last foot with the follower, and as the ratio of blows without follower to blows with follower is as one to two, it may be estimated that it would have required from 24 to 32 blows of the above hammer to drive the last foot directly, without follower. . . .

"The piles were driven $2\frac{1}{2}$ feet between centers . . . deemed to be as close as they can be driven with ease. They were about 54 ft. long and were driven about $52\frac{1}{2}$ ft. They had an average diameter of 13 in. . . . The heads of the piles, after being sawed off were 27 ft. below the street grade, and the tips were about 80 ft. below the same

[El. — 65]. They were driven about 27 ft. in soft, plastic clay, 23 ft. in tough, compact clay, and 2 ft. in hardpan."[19]

A load test was made on a group of four of the piles by Mr. N. E. Weydert, Superintendent of Buildings for the City. A platform seven feet square was constructed and placed on four piles. It was then loaded with pig iron to a height of 38 feet, subjecting each pile to a load of 50.7 tons. The load acted for eleven days, without producing measurable settlement. The design load was taken as 30 tons per pile.

Similar pile foundations were constructed by General Sooy Smith in 1894 for the Stock Exchange, still standing at the southwest corner of LaSalle and Washington Streets, and in 1897 for the Post Office, located between Clark, Dearborn and Adams Streets and Jackson Blvd. In the Stock Exchange, 30-ton piles were driven at three-foot centers and cut off at El. — 16′-10″; in the Post Office, piles were driven at 3½-foot centers and cut off at El. — 13′-8″. With a single-acting hammer weighing 4400 pounds, the average penetration per blow under the last 200 blows was less than one-half inch.

These foundations were practically unyielding and entirely satisfactory. However, Sooy Smith's fears of lowering the water table by drainage were based upon his failure to recognize the ability of the pervious sand and silt layer overlying the clay to furnish water more rapidly than it could be removed through the less pervious clay by any sewer or subway structure. Therefore, pile cut-off one or two feet below datum became the accepted practice, and no subsequent pile foundations were cut off at low level. In 1903 the LaSalle Street Station, located on the south side of VanBuren St. between LaSalle and Sherman Streets, was constructed, with E. C. and R. M. Shankland as engineers. It rests on 50-foot piles cut off just below datum. Hence, in this structure, the earlier practice became re-established; however, stone piers, such as were used in the Illinois Central Station, were superseded by grillages of I-beams and concrete.

A number of pile foundations have been constructed in the Loop, but as column loads grew heavier, piers to hard clay or bedrock became more popular. Piles are still the predominant foundation type for buildings north of the Chicago River, where a number of 15- to 25-story apartment houses have been built. In order to avoid cut-off at datum, concrete piles have been used extensively in this area.

## IX. The "Chicago Caisson" to Hardpan

*Limitations of Pile Foundations*

In the congested Loop district, the pile foundation was not without its disadvantages. The vibrations due to the pile driving were injurious to adjacent structures, particularly if these were of old construction and founded on the silt layer, because under vibration the silt tended to compact. Furthermore, even newer structures were damaged by the heave caused by displacement of the soil by the piles.

*Foundations for Stock Exchange*

The litigation associated with the construction of the German Theater has already been mentioned. In 1894 the owners of the new Herald Building, adjacent to the side of the Stock Exchange, obtained an injunction preventing the driving of piles for the foundations of the wall of the Stock Exchange nearest their structure. To overcome the difficulty, General Sooy Smith introduced a line of cylindrical piers to replace the piles. These piers were the first to be constructed in shafts excavated by the so-called "Chicago caisson method." The term "caisson" was not used by Sooy Smith but was incorrectly introduced at a later date by construction men. Nevertheless, the term has persisted, and became accepted in Chicago to describe foundation piers of this type.

The Stock Exchange caissons were the outgrowth of several years' thought and experience on the part of Sooy Smith. The forerunner of the caissons was a group of wells sunk beneath the stage of the Auditorium in 1887 to house hydraulic cylinders for raising and lowering part of the stage. The procedure is best described in the General's own words in 1892.

"I sank these wells after the adjacent walls of the building were built. Some of them went to a depth of 24 feet below the footings of the foundations and were only four and one-half feet from them. The weights resting on the soil amounted to . . . 4320 pounds per square foot. . . .

"Extraordinary precautions were taken to prevent the movement of the earth around the walls, as such movement might have caused serious settlements of the walls. Strong steel rings were used, and tongued and grooved sheathing was driven outside of these rings, and kept well in advance of the excavation as this proceeded. We got the wells down without the slipping of a spoonful of earth outside of them, and this without the difficulty anticipated."[20]

In 1893, Sooy Smith prepared plans and estimates for underpinning the Board of Trade Building by an extension of this method, but the scheme was rejected by the owners in favor of dismantling part of the tower. Hence, the Stock Exchange represented the first full-scale trial of the method. According to a contemporary account:

"The clay at this point is as soft as has been encountered in any part of the city. The conditions were such that pile foundations seemed especially desirable, yet it was quite out of the question to drive piles so close to the Herald Building as would have been necessary in supporting the building wholly upon piles. The foundation plan finally adopted was that shown in [Fig. 30], all footings resting on pile

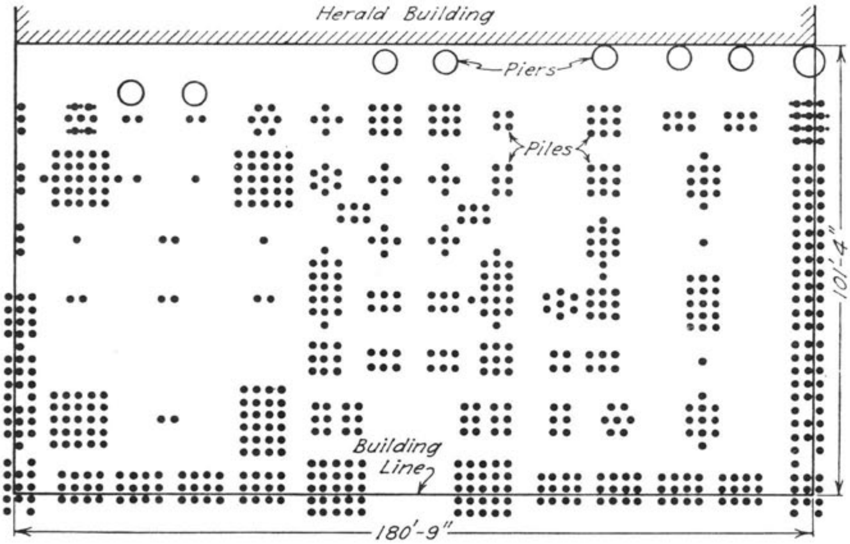



FIG. 30. FOUNDATION PLAN OF STOCK EXCHANGE

foundations except those near the Herald Building. These rest on foundations made by excavating wells down to the hard clay and filling the same with concrete. In making the excavations, the sides of the well were supported by oak sheathing held in place by steel rings, the sheathing being put in place as fast as the excavation progressed. These concrete foundations vary in diameter from 5 ft., to 6 ft. 4 in., increased at the base to 6 ft. 6 in. and 8 ft."[21]

*Later Applications*

The next use of the caissons was for underpinning the south wall of the Old Colony Building in 1896, three years after its erection. The footings for this wall had proven inadequate and excessive settlement occurred. The success of the operation, which was supervised by Sooy Smith, established the fact that the well method of construction was admirably suited for underpinning operations.

The first use of caissons under an entire new building probably occurred in 1899 at the Methodist Book Concern, now known as the Stop and Shop Warehouse at 12-14 W. Washington St. Within the next few years, many buildings were constructed on Chicago caisson foundations. Some 250 separate piers were constructed for the Cook County Hospital on Harrison St. between Wood and Lincoln Streets in 1912, and for the first time load tests were made to establish the bearing capacity of the hardpan at a building site. On the basis of the tests, the design load of 13,300 pounds per square foot at the bottom of the caissons was permitted.

## X. The Controversy over Shallow and Deep Foundations

Before 1890, serious consideration had never been given to the use of deep foundations in Chicago. By 1892, the settlement of six prominent buildings on shallow foundations reached the values given in Table 3.

Of these buildings, only the Auditorium had been designed by Chicago engineers and architects. Dankmar Adler and his consultant on foundations, Sooy Smith, remained in Chicago, where they could not but observe the settlement of their structure. Further, Sooy Smith was at the same time observing the settlement of the Board of Trade in order to recommend remedial measures. Hence it is not surprising that these two men should have been the first to conclude that spread foundations above the soft clay did not represent sound engineering and should be abandoned. In June, 1891, Mr. Adler wrote:

"Neither the timber and concrete foundations of the Board of Trade and the Pullman buildings, nor the rail and concrete foundations of the Rialto, Phoenix and Rookery buildings, nor the timber, concrete, rail and I-beam foundations of the Auditorium, nor the concrete and I-beam foundations of the Tacoma and later buildings are the last word. . . . We should take into consideration the brilliant success of pile foundations as used under most trying conditions as supports for our grain elevators and as the substructure of the Northern Pacific Railway station."[22]

In October, 1892, General Sooy Smith, addressing the engineering students of the University of Illinois, said:

"It is the common practice of Chicago architects to load the soil at the rate of 3000 pounds per square foot. . . . Experience with heavy buildings shows that in the course of months and years they . . .

Table 3

Approximate Settlement of Buildings in 1892

| Building | Age | Maximum Settlement | Differential Settlement |
|---|---|---|---|
| Post Office* | 13 yrs. | 14″ | . . . |
| Polk Street Station | 9 yrs. | 8″ (?) | . . . |
| Board of Trade | 8 yrs. | 14½″ | 7¼″ |
| City Hall* | 7 yrs. | . . . | 14″ |
| County Building† | 7 yrs. | . . . | 18″ |
| Auditorium | 5 yrs. | 17⅜″ | 17″ |

* Mat.
† Short Piles.

continue to settle when the soil is not loaded to exceed the limit above stated. Experience also shows that while the initial settlements under a given load may be uniform throughout the area covered by a building, the progressive ones may eventually so differ as to cause serious cracks and demoralization in the structure. . . . [We] must, if practicable, secure an unyielding foundation. . . . Wherever it is practicable, the foundations of heavy buildings should rest upon the rock or upon the hard-pan immediately overlying it. . . . [Piles] can be driven . . . down to the rock, or into the hard-pan immediately overlying it. . . . And in cases in which the rock is within easy reach by wells, say, at a depth not exceeding 60 feet, they may be sunk to the rock and a pillar or column of rubble masonry or concrete may be carried up to the level of the basement or sub-basement floor.

"Careful estimates show that these foundations will cost less than those which are now generally employed; namely, platforms of steel and concrete, resting on compressible soil."(23)

Excerpts from Sooy Smith's speech were printed in Chicago papers; the reaction of the designers of office buildings was swift and unfavorable. Mr. Jenney, designer of the Home Insurance Building, responded:

"As to the deep piling . . . recommended by the General, . . . it is unnecessary in my estimation, and would be only a waste of money. The great high buildings put up on foundations supported by piers at datum are proving highly satisfactory. For instance, the Home Insurance Building has settled so uniformly that the greatest variation throughout is only three-fourths of an inch. . . . The present method of putting up buildings, if carefully and scientifically followed out, leaves nothing to be desired. Gen. Sooy Smith's ideas are above scientific criticism, but I am afraid it would be hard to persuade capitalists to pay the extra money to put them in practice. Nothing but an Eiffel tower would demand them."(24)

Mr. D. H. Perkins, manager for D. H. Burnham, whose works included the Rialto, Phoenix, Rookery and other buildings, remarked,

"I do not like to criticise so great an authority as Gen. Sooy Smith at a moment's notice. . . . As to the piling principle we do not use it and all our buildings stand on separate column footings which rest on the blue clay. We have not found that piles are necessary and our buildings have not suffered for lack of them."(25)

Evidently the architects and engineers involved in the controversy felt that there was no middle ground. Adler and Sooy Smith stood almost alone in 1892. Adler's belief in the lesson to be learned from the Northern Pacific Station was evidently not shared by Mr. Corydon T. Purdy, who remarked four months after Adler's article:

"If we could drive piles to bear upon a real hard pan or solid rock we could put a greater load per square foot over the area covered, than we can with the spread foundation. . . . Some claim that this can be done, but its practicability has yet to be demonstrated.

"We believe that the secret of equal settlements is very largely in the proper distribution of . . . loads. . . . I have yet to learn of a case where reasonable care was exercised to secure the proper proportions that settled unevenly enough to reveal the fact in the construction."(26)

The statement that the practicability of pile foundations had not been demonstrated was challenged by Mr. H. B. Herr, who drove the piles for the Northern Pacific Station. He rejoined:

"We have pounded down a good many piles for foundation work and other purposes. . . . I am well satisfied that if you drive a pile until it reaches the hard clay anywhere in this city, that is the best you can do for foundation support, and I believe it can be done anywhere in the city."(27)

Before 1900, Adler and Smith had demonstrated the practicability of both pile and pier foundations. Indeed, after 1892 there is no record that either man was ever again associated with a spread foundation for a building of any importance in Chicago. Mr. Purdy's confidence in the ability to proportion footings for equal settlement must have been shaken by the necessity for having Sooy Smith underpin the south wall of his Old Colony Building only three years after construction. In fact, by 1900 there was a slow trend toward the deeper foundations. By that time, the settlement even of some office buildings had become unpleasantly great. Table 4 lists the settlement of a few of the structures.

Hence, evidence in favor of deep foundations began to accumulate, and one by one the architectural firms began to adopt them. Adler and Sullivan built their first deep foundation in 1891. The firms of D. H. Burnham (successor to Burnham and Root) and Holabird and Roche

TABLE 4

APPROXIMATE SETTLEMENT OF BUILDINGS IN 1900

| Building | Age | Maximum Settlement | Differential Settlement |
|---|---|---|---|
| Board of Trade | 16 | 18″ | 9″ |
| Auditorium | 13 | 23½″ | 23″ |
| Monadnock | 9 | 14″ | ... |
| Masonic Temple | 8 | 8″ | ... |
| Great Northern Hotel | 6 | 10″ | ... |
| Old Colony* | 6 | 5″ | ... |

* South wall underpinned.

began their transition in 1896 and 1897, respectively. Mr. Jenney, the strongest supporter and probably the most successful user of the spread footing, did not alter his methods until 1904.

After 1904, contemporary accounts of Chicago foundation practice almost disappeared from engineering literature. Indeed, in 1904, an event occurred which made any future argument strictly academic. At that time the Chicago Tunnel Company began the construction of small freight tunnels along the principal streets of the Loop. The digging of the tunnels, about nine feet high and six feet wide and located fifty feet below the ground surface, caused the settlement of many structures and initiated a widespread need for underpinning. From that date, the possibility of settlement due to adjacent excavation could not be ignored, and very few new buildings were set on spread footings.

The transition from spread to deep foundations is illustrated by Fig. 31, which shows the height of the buildings erected during any one year and the number of buildings on spread footings, piles, or caissons. Only buildings of six stories or more are considered. The slow transition between 1890 and 1900 is significant, for during this period the average building height did not increase. The rapid change to almost no spread footings after 1905 is very likely the result of the combined influence of settlements due to excavation and of increased height of buildings.

Thus, the controversy which was so active in the decade from 1890 to 1900 resolved itself. The superior merits of deep foundations and the disadvantages of spread footings gradually forced themselves upon the attention of Chicago foundation engineers and architects, and nullified all arguments to the contrary.

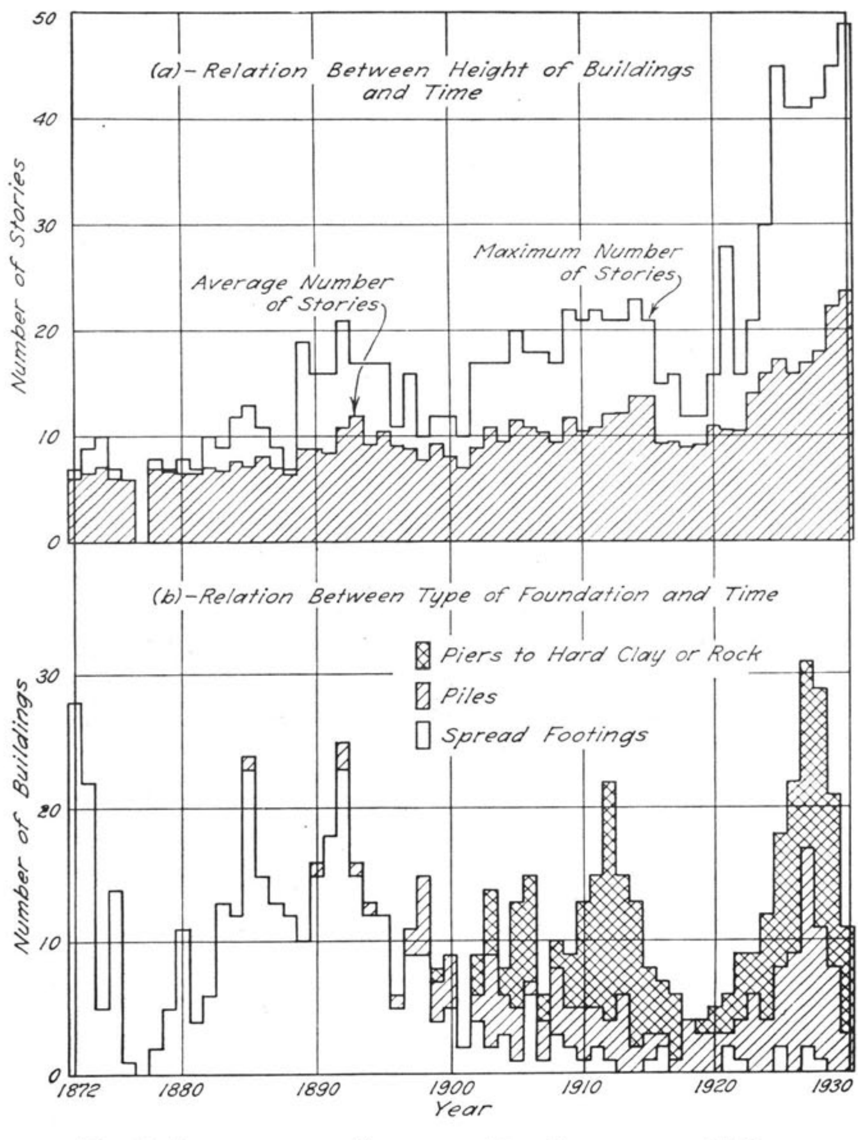



FIG. 31. TRANSITION FROM SHALLOW TO DEEP FOUNDATIONS. (a) RELATION BETWEEN HEIGHT OF BUILDINGS AND TIME; (b) RELATION BETWEEN TYPE OF FOUNDATION AND TIME

## APPENDIX A

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## APPENDIX B

### NOTES

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4. *Op. cit.,* p. 7.
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13. *Inland Architect,* Dec. 1898.
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22. *Inland Architect,* June 1891, p. 58.
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