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Suggested Citation:
A CONSIDERATION OF THE DEVELOPMENT AND CONSERVATION OF METAL-SKELETON BUILDINGS: 1884-1932

Lori Wynne Plavin

A THESIS

in

The Graduate Program in Historic Preservation

Presented to the Faculties of the University of Pennsylvania in Partial Fulfillment of the Requirements for the Degree of

MASTER OF SCIENCE

1991

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FINE ARTS
ACKNOWLEDGEMENTS

First I must express my gratitude to Dr. David DeLong, the Chairman of the Historic Preservation program, for the existence and character of the program here at the University of Pennsylvania. For all of their suggestions and encouragement, I thank Samuel Y. Harris, my Advisor, and David Hollenberg, my Reader. I am also indebted to both Dr. Roger Moss and Frank Matero for helping to determine the scope and direction of this thesis.

I wish to express my sincere gratitude to the conservators and engineers who were so generous with their time and resources: Dr. Alan Pense and William D. Michalerya, The Center for Advanced Technology for Large Structural Systems (ATLSS) at Lehigh University; Kimball Beasley, Wiss Janney Elstner Associates; Dr. Mario Salvadori, Weidlinger Associates; Raymond M. Pepi, Building Conservation Associates; Robert Silman, Robert Silman Associates; and finally Elizabeth English -- for her interest, suggestions, and her invaluable proof-reading.

I sincerely thank Victor Pepenelli, PSFS Building Manager, for his unflagging interest and assistance with my study of the PSFS Building. I am also grateful to Craig Thigpen, PSFS Building Architect-in-Residence; V. Chapman-Smith, Archivist; and Bea Jennifer, for their accessibility and aid the numerous times I called on them.

Finally, I must express my heartfelt gratitude to my parents, Jerry and Pearl Plavin and my siblings, Jody, Benjamin, and Matthew for being so patient and supportive, and to my future husband, Marcos Salganicoff, for his steadfast support and faith.
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INTRODUCTION

The metal-skeleton building is a recent development in the world of architecture relative to more traditional materials such as stone and wood and their systems. The year 1884 marks the erection of the Home Insurance Building in Chicago, considered by many to be the first skyscraper. Although the attribution of the title "First Skyscraper" has been a source of disagreement then as now, the building, designed by William LeBaron Jenney, was truly a landmark building in the history of metal-skeleton buildings -- completely fireproofed and the first to contain steel as a primary structural element. The Home Insurance Building heralded in an era of experimentation with new designs and materials and adaptation of the systems of other structural types (bridges, ships, railroads).

During the following decades many metal-skeleton buildings were designed and erected, their propagation slowing in the 'teens and late 1920s/early 1930s due to economic factors and world events. Many of the buildings built in the 1930s had been planned much earlier; new building was uncommon. Construction slowed almost to a stop in the 1930s and did not pick up again until after World War II.

The PSFS Building of Philadelphia, designed by Howe and Lescaze, was completed in 1932, one of the last buildings to be built in this era. Included, before the building was finished, in The International Style, the book and Museum of Modern Art exhibit by Henry Russell Hitchcock and Philip Johnson, the PSFS was seen to be a prototype of, if not a participant in, this previously European movement in America. The building had elements which anticipated the future movement of metal-skeleton buildings such as the articulation of columns (on two facades). Built with masonry cladding on shelf angles, without cavity walls or expansion joints, and with riveted connections, however, the systems of the building belonged to the earlier era of metal-skeleton buildings which is the subject of study in this thesis.

1 "Skyscrapers" are often defined as those buildings which contain a loadbearing fireproofed steel frame, are tall, and contain elevators. Since the definition of tall, and therefore use of the term "skyscraper," is relative to temporal and geographic factors, the more consistent term "steel-skeleton" is used in this study. The skyscraper may be considered a type of steel-skeleton building.

2 In using the term "metal skeleton," this author is referring to those buildings of metal (cast iron, wrought iron, and/or steel) -frame construction in which internal and external loads are transmitted through the frame to foundations in the ground. The metal-skeleton buildings discussed in this study are ten stories high or higher.

3 In the 1934 edition of the Chicago Daily News Almanac, it was revealed that building space vacant as of January 1933 was 21.3% in New York, 25.5% in Chicago, 31.5% in Philadelphia, and 38.1% in Detroit. The conclusion that was drawn from these figures by Robins Fleming, an engineer and author of many articles about steel-skeleton buildings in engineering magazines, was that: "It is hardly probable that more high buildings will be constructed until a marked percentage of these vacancies is filled."


The cladding of metal-skeleton buildings from 1884 to 1932, however, was with the dimension stone, cast stone, brick, and terra cotta of masonry load-bearing buildings, albeit used in a somewhat different manner. Many buildings from this era have survived to today, and are now over 50 years old. Consideration for the preservation of these historic structures is crucial not just from an aesthetic and cultural standpoint, but for human safety as well.

The effects of age, environment, and use on the materials and systems of metal-skeleton buildings, as combinations of lesser and better known elements, is a complex subject, and the problems and issues involved with the conservation of these buildings are considerably less explored than those of the traditional materials and building types. In order to understand these lesser and better known elements, knowledge of the development of the fundamental systems and the properties and deterioration mechanisms of the materials of these buildings is necessary.

In order to determine the areas of a building in need of conservation, a conservator (or architect, or engineer) needs methods of collecting and weighing relevant information. Buildings may be considered analogous to human beings in that humans sometimes suffer from enigmatic ailments which may be identified by a practiced professional in a physical examination. An examination of every possible hidden human ailment, however, would be costly, time-consuming, and most likely unnecessary. Doctors receive clues from patients' past health and treatment records, from family history, and from known and common human ailments and make decisions as to what should be looked for, where, and how. Tests may then be performed to further examine the pathology, tests which may or may not cause some harm in and of themselves.

Such an educated-guess driven physical examination is appropriate for a steel-skeleton building. Clues such as maintenance records of problems, complaints, and treatments of the building; physical history of similar structures and examples of failures; and anticipated deterioration of the building's materials and elements, in addition to other architecture-specific factors, would serve as the guideposts for assessment. These guideposts have been organized in this thesis into a design which proposes to direct the assessment of the conditions of a metal-skeleton building.

This program has been utilized for the study of the conditions of the PSFS Building, 59 years-old this year. This study, and the analysis of information which was uncovered, may be found in Chapter 4.
CHAPTER 1
NOTES ON THE HISTORY OF METAL-SKELETON BUILDINGS OF 1884-1932

"The technical innovations made or perfected by the Chicago architects are now so
common that, like all the great basic inventions on which our lives depend, they have
come to be regarded as natural things that have always existed."^5

Carl Condit

The era between 1884 and 1932 was one of innovation and proliferation for the skeleton building. Armed
with the empirical understanding of the strength of iron and steel, inspired by the implications of an
increasingly speedy elevator, and motivated by the need for efficient use of increasingly expensive land,
designers of Architecture in America created the soaring structures which quickly came to be identified as
the definitive American Architecture: metal-skeleton buildings.

Building in iron and steel would have been neither possible nor conceivable had not a number of key
developments taken place. The discovery of large iron ore deposits in the Mesabi Range and elsewhere,
the existence of the railroads to transport the ore, and the invention of techniques to mass-produce iron and
steel made the construction of iron and steel buildings possible^6. Furthermore, the skeleton itself would
not have become what it did without the development of fundamental systems such as connections,
foundations, and trusses in bridges decades before -- and the engineering insights associated with them.

That necessity is the mother of invention is especially true of the metal-skeleton building. As land prices
rose in major cities such as Chicago and New York, owners sought ways to increase their rentable area to
ground area ratio.

The first relatively tall office buildings in the United States were load bearing and, encouraged by the
invention of the elevator^7, owners built taller. This required very thick walls at the base to carry the

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^6 A concise yet detailed account of iron and steelmaking in America and the advent of cheap steel through the
developments of the Bessemer and Open Hearth processes was written by:
W. David Lewis, *Iron and Steel in America* (Greenville, Delaware:Eleurthian Mills-Hagley Foundation, Inc,
1976).
^7 Elevators in buildings came before the steel frame. The desire for height was, to a great extent, based on
economical considerations: the higher the building, the better the use of allotted area. Before the invention by Elisha
Otis, six floors was the maximum building height. No one wanted to walk higher. With the elevator came higher
buildings whose heights were restricted by building materials rather than building occupants.
The development of the passenger elevator took place over a twenty-year span. The first one was in the Crystal
Palace of 1853, built by Elisha Graves Otis. Otis Tufts built a "vertical-screw railway" in the 1859 Fifth Avenue Hotel.
The St. James Hotel boasted the first suspended steam elevator in 1866 and a water-balance elevator was placed in the
weight, which significantly decreased floor space (and therefore rentable space). Wrought and cast iron columns and beams were sometimes employed to reduce necessary wall depth. Masonry buildings reached as high as sixteen stories by the 1880s.

Architects and engineers rapidly realized the possibilities afforded by iron and steel, and experimented with improvement of the fundamental systems. Fireproofing of iron elements soon became standard. Heavy brick arches spanning wrought-iron beams were quickly replaced by various configurations of hollow tile in flat arches. Bolted connections, obligatory with the cast iron column, gave way to riveted connections soon after the advent of steel. Exterior masonry became clothing instead of structure in the minds of designers less than two years after steel made its first appearance in a skeleton building. To a great extent, the components used in the steel skeleton buildings of this era were in place by the turn of the century.

The history of early metal skeleton buildings has been examined from many vantage points. Historians, architects, and engineers have investigated and catalogued the influences and agendas of the pioneers, the evolution of specific technologies such as steel members and wind bracing, the development of the chosen modes of dress, and the progression of building in specific cities and subsequent building code modifications.

For the purpose of this study, examination of early metal-skeleton buildings' history comes in the form of investigation into the evolution of its fundamental systems -- frame, foundation, fireproofing, connections, and cladding -- as well as the history and basic properties of wrought iron, cast iron, and steel. Furthermore, since a catalogue which describes the technology of specific metal-skeleton buildings built in the United States during 1884-1932 has not yet been published, information of this sort has been collected and may be found in Appendix 1. As there were thousands of metal-skeleton buildings by the end of the period in question, this catalogue is but a small sampling.

Western Union Building in 1873. A vertical-cylindar hydraulic elevator was introduced into New York in 1878 and the first electric elevator was installed in Baltimore in 1887. Hydraulic elevators were the most popular type until the early 1890s when they were replaced by electric.

Robins Fleming. "Whence the Skyscraper?" Civil Engineering vol.4 no.10 (October 1934), 506.

The Tacoma Building (1886-1889) was designed by Holabird and Roche in Chicago. Two of the four facade walls were carried by spandrel beams.

Condit, Fleming, Hool, Mainstone, Mujica, Randall, Schuyler, Starrett and many others have published dense and informative investigations into many other aspects the development of the steel-skeleton.
1.1 BEFORE THE SKELETON

More than a century of experimentation and achievement preceded the first built attempt in the United States at skeleton construction\(^\text{10}\), William LeBaron Jenney's Home Insurance Building. It is remarkable that the designers of the day came so far in so short a period of time -- the very first iron structure, the cast iron Coalbrookdale Bridge which spans the Severn River in England, was built in 1779 (and is still extant!).

The technology of metal bridges played a fundamental role in the development of the technology of metal-skeleton buildings. In addition to the first primary structural use of iron and steel, bridges also contributed bolting and riveting connections, trusses (from which wind bracing borrowed), and foundation technology. Indeed, many of the pioneering structural engineers of buildings were first bridge engineers.

Industrial structures were the first buildings to utilize the iron frame's superior strength, ductility, and response to stresses. Advances in understanding of the properties of the materials lead to the first successful use of cast iron beams and columns in a seven-story cotton mill in Manchester, England in 1801. By the 1820s-1830s, cast iron was being used as structural columns in theatres, markets, and institutional structures.

In America, a number of firsts in iron bridges occurred in the 1830s and 1840s. The first iron bridge, Dunlop's Creek Bridge, was built from 1836-1839 in Brownsville PA. The first iron truss bridge, the Frankford Bridge over the Erie Canal, was built in 1840. In 1945, the first iron railroad bridge in the United States, the Pennsylvania & Reading Railroad Bridge of Manayunk PA, was built.

In 1847, Daniel Badger's Architectural Iron Works were established in New York, NY. James Bogardus' Iron Foundry was built in the same city in 1848-1849. The 1855 shot tower of the McCullough Shot and Lead Co. of New York by James Bogardus was a precursor to modern curtain wall buildings and the cast iron beams which spanned the load-bearing iron posts carried the entire load of the brick exterior.

In France, the warehouse of the St. Ouen Docks in Paris was built between 1864 and 1865 -- the first multistory fireproof building in Europe (and possibly the world).\(^\text{11}\) The chocolate factory of Menier at Noisiel-sur-Marne, designed by Architect Saulnier in 1873, is thought to have been the first iron skeleton

\(^{10}\) The following is a brief chronological list of early uses of iron and steel, predominantly in America.

The three-story building had an iron roof and sat atop four masonry piers in the River Marne.¹²

France may have given birth to the iron skeleton, but it was the pioneering designers of the United States who raised the child.

¹² A brief description of the structure explains how advanced this design is: Four longitudinal box girders and two end cross-girders support each floor, the exterior hollow multi-colored brick walls, and two interior rows of columns. Vertical and horizontal members were of an unequal-flanged H-section, with the smaller flange facing out. J. Deforth, "The Originator of the Skeleton Type of High Buildings," *Engineering News* (5 January 1893).
In 1881, George B. Post used iron skeleton construction in the court walls of the Produce Exchange building. In that same year, an iron skeleton was used by Joseph M. Wilson in the remodeling of the Broad Street Station.

Cast iron facades were used extensively in the United States during the 1850s, 1860s, and early 1870s. Wrought iron had been rolled in America since 1853, introduced by Peter Cooper in Trenton, New Jersey, and first rolled for use in the floors of New York's Cooper Union Building. In 1860, a second company, the Phoenix Iron Co. of Pittsburgh began to roll wrought iron beams. Rolled wrought iron was first manufactured, however, primarily in Belgium and France. Wrought iron beams in floors and cast iron columns to carry the floor loads were used in masonry load-bearing buildings to save space -- allowing exterior walls to be required to bear only their own weight and thus be significantly thinner.

Cast iron columns were used extensively with wooden girders in the late 19th century. Initially, only small details were altered when floor beams and girders changed from wooden to iron and steel. Floor beams and girders were connected to columns by being bolted to lugs (projecting stubs which were cast with the column) and sitting on brackets.

Skeleton construction was achieved when free-standing walls were replaced with a veneer of hollow clay tiles or brick, which was carried as panels at each floor by spandrel girders and secured with hooks to the frame. The first office building which had such construction was Chicago's Tacoma building (Holabird and Roche), begun in 1886. Exterior walls rested on the bottom flanges of spandrel girders or angles affixed to them, and were secured to columns by bent rods.

The development of an understanding of the forces within framed structures began with the first published studies in the 1850s. The 1860s saw the beginnings of graphic statics, which developed in the following decades. The earliest designers understood that the structure of a skeleton building is by nature indeterminate, in other words, there are more unknown quantities than independent equations regarding distribution of loads to joints and members. In order to be able to solve equations and design a building which would withstand the worst conditions, assumptions were made, erring on the conservative side.

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16 "Tall Buildings in Chicago," The Railroad Gazette (30 October 1891), 759-762.
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16 "Tall Buildings in Chicago," The Railroad Gazette (30 October 1891), 759-762.
Members were consistently oversized, systems made stronger and heavier than necessary, and redundancy built into the structure (so that the failure of one member could not bring the entire structure down). The problem of static indeterminacy, in fact, is so complex that it was not solved until the advent of the computer.

1.2 METAL-SKELETON BUILDINGS: 1884-1932

In the period 1884-1932, the metal-skeleton developed from a rectangular building with cast iron columns, bolted connections, "floating" foundations, and free-standing heavy masonry walls, to complex forms completely reliant on a riveted steel frame, and supported by piles and/or caissons extending deep into the ground. Many factors went into its development: greater understanding of and trust in the material steel, the desire for increasing height, comfort (of tenants and pedestrians), application of bridge engineering to foundations and wind bracing, building code restrictions, and aesthetics.

As architects and engineers came to understand and take advantage of the forces they were working with, so too did legislatures. Recognition of the problems caused by huge buildings on streets inspired increasing legislation and restriction. Whereas in 1910 twelve cities had height ordinances, by 1917 this number had jumped to 50.

In 1916, for example, the New York Building Zone Resolution became law. The city was divided into use, height, and area districts; the height of a prospective building was restricted to 3/4 to 2-1/2 times street width (street width consideration limited to 250 feet), depending on which height district the site was in. In order to build higher, setbacks were and are used - the proportion of setback to increased height dependant on the district, although unlimited height may be attempted when building on 25% of the site. This law, and similar ones which followed in other cities, were extremely important in regards to the future form of the metal-skeleton building.

Chicago height-limitation ordinances changed rapidly. In 1893, a height limitation of 130 feet was imposed - this was doubled in 1902 to 260 feet but then reduced in 1910 to 200 feet. The April 6, 1923 ordinance saw a limitation of 264 feet and the allowance for set back towers to reach higher.

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18 A building on a "floating" foundation was carried on surface crust without disturbance to or penetration into the watery clay beneath.
The evolution of the metal skeleton building is an amalgam of developments of individual systems. Most of the systems had already found close to final form for this era by the turn of the century. The following is a brief description of the development of each major system -- columns and connections, exterior walls, fireproofing, floor systems, foundations, roofing, and wind bracing.

1.21 Connections and Columns

Riveting, bolting, and welding were the ways through which horizontal and vertical members were connected to themselves and each other. Bolts, then without ways to control and monitor degrees of tightening, were most commonly used as primary connective element in the 1880s. The use of rivets, however, was already in practice in bridges by the time buildings came along and rivets soon replaced bolts. By the turn of the century, bolts were generally relegated to areas needing lower strength and rivets in areas with greater requirements. It was this configuration, rivets as primary connecting element aided by bolts in the secondary position, which predominated throughout the rest of the era.

Bolting fell out of favor due to the tendency of the nut to work loose, but continued to be used where little vibration was anticipated. The degree of initial tightness was also difficult to control with bolting since it was done by hand and without a gauge.

Rivets were made of low-carbon steel and consisted of a half of a sphere on a shaft before construction. During construction, the shaft of a red-hot rivet would be run through aligned holes in the members to be connected and the unformed end would be formed by a pneumatic or hydraulic riveter. The resulting second head would usually also be hemispherical, otherwise it would be flat or countersunk.
Welding had been used to a very limited extent in construction of steel-skeleton buildings towards the end of the era, but was still considered to be in the experimental stages and was generally used for spot welding rather than whole structures.\textsuperscript{22}

The first and second most common types of welding processes used in structural fabrication and erection were the electric arc\textsuperscript{23} and oxyacetylene\textsuperscript{24} welding processes, respectively. Welds were of four types: butt (members’ edges beveled and gap filled by weld), fillet (weld at angle between horizontal and vertical element), lap (weld at end of one member and top or bottom surface of another of two overlapping elements), and rivet. The rivet weld takes the lap weld one more step by further connecting the bottom lap through welded plugs in holes drilled into the top piece.\textsuperscript{25}

I-beams were used as beams and girders. Due to the angled inner part of the flanges (see below for explanation), only shear (web) connections were possible unless the beam was connected through brackets above and below.

Cast-iron, cast in a cylindrical shape, preceded steel and wrought-iron for use as column. Cast iron had been used for many decades before the commercial appearance of steel and it was with cast iron that wood and stone were be replaced in the earliest structures using iron.

\textsuperscript{22} Whitney Clark Huntington. \textit{Building Construction} (New York: John Wiley & Sons, 1929) 291.

\textsuperscript{23} An electric arc would come from an electrode of a metallic wire (in metallic-arc welding) or a carbon rod (carbon-arc welding) held and directed by a worker. The arc would heat the metal of the members to be joined alone or with a metallic rod for extra weld metal.

\textsuperscript{24} Oxyacetylene welding is a process which burns oxygen and acetylene gas to heat surfaces and uses an additional metal rod as well.

\textsuperscript{25} Huntington. \textit{Building Construction}, p. 295.
Among other factors, the brittle nature of cast iron and the difficulty with accessibility rendered riveted connections impossible and favored bolted connections. Horizontal connections to columns were made either at collars which encompassed columns and were bolted to them, or on brackets which would be cast along with columns.

Owing to the relative crudity of production and erection methods, the columns of the early skeleton buildings were often shimmed at vertical connections in an effort to assure straightness and flush connection with horizontal elements. In anticipation of this, holes were often made larger than necessary so that bolts and rivets could be fit through.

Columns were generally manufactured in one- or two-story lengths. To make building-height columns, then, these elements would be joined together (spliced). The splice was commonly made two feet above the floor line so as to not interfere with connections to horizontals.

From the turn of the century, the ends of each of columns to be joined would be milled so that one would bear directly on another without point loading or necessitating shimming. Plates would be riveted to the splice. If the columns to be joined were not of the same width, filler plates would be added to the lesser vertical and sometimes at the horizontal interface as well. The plates were intended to take bending stress to provide lateral rigidity but not to transfer load.

In general, the most common connecting panels for wrought iron and steel columns and girders were fillets, angle brackets, and split beams or structural tees. Angle bracket connections consisted of two angles.


26 The obligatory use of bolts was but one of the ways in which cast iron was at a disadvantage to steel. Other problems included potentially deadly hidden flaws in the casting, and the sudden, catastrophic nature of its failure. It was soon superseded by steel and, for a time, wrought iron, which possessed none of these problems. Cast iron continued to be used, albeit decreasingly, until the collapse in 1904 of the Darlington Apartment House in New York during construction.


At this point steel had almost completely taken the place of cast iron and with this collapse came the end of popular use of cast iron as a primary structural element.

27 Huntington, Building Construction, 298.
bolted or riveted to flanges of beams or girders and columns. This is a relatively flexible joint as the angles are flexible in and of themselves.

The split beam or structural tee connection is one through which forces are transferred from the flanges of a horizontal member to a flange of a column by two T-shaped members, the heads of which are connected to the column flange. These connections are less flexible than the angles since the T's are more rigid.

Before the process for rolling wide-flange I-beams (or H-beams) was introduced, some of the more utilized types of wrought-iron and steel columns were the Phoenix, the Keystone octagonal, latticed angle, channel and lattice, plate and angle, Z-bar, Gray, Larimer columns.

The Z-bar (or Strobel) column was invented by Charles L. Strobel for use in the Kansas City Bridge in 1886. It consists of four z-shaped bars which could be connected through riveting to web beams in various configurations to form an approximate "I" shape and could be made into a box shape through use of cover plates. Its first use in a building was the Cleveland Society for Savings Building in Cleveland, Ohio by Burnham & Root.


The typical connection was with plates sitting between Z-bar columns and girders, all riveted through at the girders' lower flanges; sometimes the upper flange would be held through small angles as well. Cast iron blocks were sometimes used sitting on post plates below smaller girders to level upper flanges.\(^{28}\)

Z-bar columns were among the most successful in receiving loads axially and were also at an advantage for having only 2 rows of rivets, but were at a disadvantage for fireproofing - they could not achieve a compact fit. By 1891, the riveted Z-bar column was the most commonly used steel column in Chicago.\(^{29}\) In New York,

\(^{28}\) "Tall Buildings in Chicago," 761.

\(^{29}\) Corydon T. Purdy, "The Steel Skeleton Type of High Buildings II," Engineering News (12 December 1891), 560.
however, Phoenix columns were used over Z-bar columns ten to one.30

The Phoenix column was patented in Germany in 1862 and was used extensively from the 1870s to the 1920s here in the United States. The Phoenix columns consist of arcs with flanges which are connected at the flanges to form a cylinder. The most common Phoenix column consisted of four such segments. Filler plates were sometimes added at the webs to increase rigidity, expand the cross-sectional area, and act as girder connection. These were called cross-pintle connections. Angles were riveted to these plates and/or to the column webs and a plate would be placed over them.31

Plate and angle columns were also extensively used in skeleton buildings as the elements involved were simple to manufacture and therefore available at all mills. They would simply be riveted together to form "I" shapes and boxes but would require a lot of riveting.

FIGURE 6: Phoenix Column
SOURCE: Birkmire. 23.

FIGURE 7: Example of Connection to Phoenix Column.
SOURCE: Birkmire. 57.

FIGURE 8: Plate and Angle Columns.
SOURCE: Birkmire. 23.

FIGURE 9: Example of Connection to Plate and Angle Column.
SOURCE: Birkmire. 58.


This was a rebuttal to Mr. Purdy's article II on the Steel Skeleton Type of High Buildings. Incidentally, Milliken Brothers published a book on Phoenix Columns.

The Larimer steel column was patented by J. M. Larimer in 1891 and manufactured by Jones and Laughlins Co., Limited. It consists of two I-beams bent at right angles at mid-web and riveted together at this bend with a small I-beam filler between. When a stronger column was required, channels and a web plate would be placed between the bent I-beams. Only one row of rivets was necessary in this column. The Larimer column connects to I-beam flanges at angles riveted to I-beam flanges or a solid octagonal collarplate which is fit around the column with its inner edge bent down to receive girders. These were only occasionally the chosen column for buildings.

The Gray Column was patented by J. H. Gray of Chicago in 1892. It is made up of four T-shapes made of angles which are connected by three-sided channel plates whose flanges connect to T-webs.\(^3\)

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\(^3\) "Wind Bracing and Column Construction for Buildings," *Engineering News* (7 June 1894), 475.
The Keystone Octagonal consisted of four "bent channels" with angled flanges which connect to form an octagonal with four flanges. It was only occasionally used.

Around the turn of the century, an American, Henry Grey, invented a process for rolling I-beams in proportions which had previously been thought impossible. The Grey process of rolling allowed the relative depth of web to flange to be reduced, producing "Broad Flange Beams" which were, before World War I, rolled primarily in Belgium and Luxembourg.

Wide flange "special" and "girder" I-beams became available due to the Grey universal beam mill and were listed in the 1907 Bethlehem Steel Company catalogue. Steel wide-flange I-beams had been rolled in Germany for several years before Bethlehem introduced it to America.

When the top flanges of a connected I-shaped beam and girder would have to be level, the beam's top flange would be cut back to accommodate the girder flange (coped).

Although I-shaped beams had been rolled in wrought iron and steel long before the Grey process, the technology of rolling was such that the inner portion of flanges would have to be angled so as to be assured of being able to remove the roller. The methods used would leave an uneven surface. This explains the reason for the shape of what is now known as the American Standard shape of I-beam.

By the mid-1920s, the Larimer, the Keystone octagonal, and the Grey column had gone the way of the Phoenix and Z-bar columns -- out of use. The built-up channel column and the H-shaped rolled column were still in use at this time, however.

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36 Fleming, "Whence?" 506.
Until 1900, allowable loads were not specified by ASTM and were instead published in mill catalogues. The AISC did not have published specification requirements until 1923.38

1.22 Corrosion Protection

There seems to have been little interest in the causes of corrosion of metals with their earliest uses. Papers published in France in 1819 and 1830 discussed corrosion as an electrochemical phenomenon, perhaps the first hypotheses of their kind. Experiments between 1834 and 1840 provided evidence of a connection between chemical action and electrical currents.

Experimentation into corrosion and corrosion protection waned, and until 1908 the view was generally held that corrosion was due to the presence of acid, particularly carbonic acid and hydrogen peroxide. In 1908-1910, experiments were performed which established that iron may be corroded by nobler metals and preserved by a baser one, although this concept was apparently understood as early as 1824.

The potentially corrosive effect of variations in oxygen concentration were discovered as early as 1830 but were more widely recognized when published in 1916. 1931-1939 saw research published in the action of salts in corroding metals.39

Some of the substances used as pigment in coatings acted as inhibitors of either the anode or cathode. Research into these types of coatings was published in 1910. These coatings offer protection even without a continuous coat. Moisture-barrier coatings, however, relied on the total separation of metal from the atmosphere. "Corrosion-fatigue" was observed during 1914, and extensive research began into this type of deterioration in 1926.40

Among the most commonly utilized pigments in coatings, red lead is considered an "active pigment" since it is an inhibitor, neutralizing film acids, insolublizing sulfates and chlorides, and rendering water non-corrosive. Iron oxide, which may come in red, ochre, and black, aids corrosion resistance through its inertness and impermeability. Iron oxide was used to separate the metal from the mechanism. Carbon


In addition to listing steel specification stresses, lists of the sizes of beams, columns, and joists before standard rollings were utilized are provided in painstaking detail.


40 Evans, *Introduction to Metallic Corrosion.* xxi.
black worked in much the same way. The oils used with these pigments, often a combination of raw and cooked linseed oil, were found to dry with time, leaving behind a thin, flaking layer of pigment.

1.23 Exterior Walls

Although the word "curtain" seems to imply something which is hung from the top rather than supported from the bottom, the "curtain walls" of early skeleton buildings were usually directly supported on spandrel beams (or on angles attached to these beams) and secured to columns with bracket angles. The walls were further secured by anchoring them to masonry backing or the structure itself with ties such as painted or galvanized iron and steel wires. Bronze and copper ties were also used.41

Walls of buildings built between 1884 and 1932 were most often built of brick, terra cotta, and stone applied over a layer or two of backup masonry. This backup layer was usually hollow tile or second-rate brick. Within the first few years of metal-skeleton building, stone was found to be too heavy for most of the buildings' entire facades. Stone also lost favor as a cladding material due to the difficulty experienced in attaching stone to the skeleton.42 The lighter materials -- clay and sand-lime bricks, terra-cotta, and cast stone -- were often used, sometimes imitating stone.

Terra cotta was very popular from the 1880 through to the 1930s, first popularly utilized after the 1871 Chicago fire and losing favor due to machine made ceramic veneer and precast concrete.43 Webs or partitions were used to give compressive strength to structural blocks and decorative elements. Most terra cotta from the early steel skeleton buildings was 4" deep with a thickness of 1" to 1-1/4". Over time, glazes and coatings changed while forms stayed the same. Glazes were developed which could be glossy or matte, made of metal salts, which would fuse with the terra cotta during firing.

Terra cotta and its anchoring would be set first and then filled in with backup brick or some other masonry. It would also sometimes be filled with concrete or remain open and have weep holes. This concrete may experience movement, absorption, etc. different from the terra cotta. Concrete back filling was mainly used to protect the anchoring steel from corrosion.44

42 Freitag, Architectural Engineering, 92.
Anchoring was complex for terra cotta as cladding. Each terra cotta block would be anchored individually. The anchoring of terra cotta depended on the element. Spandrel panels, soffits, cornice sections, and lintels had projections (dowels) in the sides of the blocks which would be connected by hooks to structural steel. Steel angles would be employed with this hook and dowel system for larger and projecting elements.

The mortar used with these walls was usually Portland cement. The reason lime mortar ceased to be used is not clear, although the apparent failure of lime mortar in a fire may have had some impact. Also the perception that lime mortars were inferior to Portland in waterproofing no doubt came to bear.

None of the buildings in the study period were built with expansion joints as we know them today (in fact, these joints were not incorporated into standard building practice until the 1950s). Cavities in curtain walls were at first designed as they had been in masonry walls with a veneer, a cavity, and backup masonry. Corrosion, however, seemed to be enhanced by this configuration and the cavity wall was soon eliminated. Solid masonry (face and backup together) became the usual type of wall construction toward the turn of the century, and the metal was completely covered or encased in cement mortar.

The Tacoma Building of 1886-7 was the first building to reduce masonry to a curtain surrounding and supported by a frame (two walls were of this construction and two bore their own weight). The credit for the concept of masonry panels supported by spandrel beams at each floor below goes to Sam Loring, a manufacturer of terra cotta who had brought the idea to architects Holabird and Roche some years before. The "Chicago type" of construction grew from this breakthrough, which was followed, within three or four years, by a half-dozen similarly treated buildings.

Spandrel arrangements varied with almost every building. Whether they were channels facing each other, I-beams with or without cast-iron separators, or channels with one angle making a J-shaped beam, the wall would either rest on steel or be suspended/hung from it with anchors. In some cases, holes were punched

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45 Production of portland cement in the United States began in the 1860s, although it was patented in Great Britain in 1824 (by John Aspdin). In 1887, the synthetic material of primary importance was discovered as tricalcium silicate. Research into the composition of portland cement continued, and as the cement was utilized for a widening array of structural types, it was refined and made more uniform. It was not until after the 1930s that portland cements were manufactured which would harden rapidly and resist sulfates.


46 Smith, "Diagnosis of Nonstructural Problems," 218-222.


through the webs of I-beams for terra cotta anchor ties. Steel in the spandrel of a flush curtain wall would be continuous throughout the wall length.\textsuperscript{50}

In the 1920s and 1930s, metal cladding started to appear, most conspicuously on the 1931 Chrysler Building.

1.24 Fireproofing

In response to the Chicago fire of 1874, iron beams were first advocated as non-combustible replacements for wood floor construction. Tragic experience had educated architects and builders (not to mention insurance companies) as to their performance in high heat, and fireproofing of iron came to be recognized as a necessary feature of buildings with iron or steel incorporated into the structure. By 1880 the use of fireproof floors and fireproof columns had become well established for the best building construction.\textsuperscript{51}

By the turn of the century, concrete began to replace terra cotta as the predominant fireproofing material.

Acceptable fireproofing materials included brick, concrete, hollow tile (of which terra cotta is a type), metal lathe and plaster, and gypsum block. Brick and tile were backfilled with mortar. As designers were not sure of the exact fireproofing qualities of each\textsuperscript{52}, fireproofing of this era was often oversized.

\textsuperscript{50} Corydon T. Purdy, "The Steel Skeleton Type of High Buildings IV," \textit{Engineering News} (2 January 1892), 2.
\textsuperscript{52} Huntington, \textit{Building Construction}, 320.
Difficulty in applying protective masonry depended on a column's cross-section. A circular or other non-square section is much more problematic than the square. Cover plates were sometimes added to I- and H-shaped columns to span between flanges and create a square. Square sections also allowed simpler connections.

Of the various materials have been used to protect steel from fire, clay or terra cotta tile was the most commonly used. Brick walls were built around columns, but they were heavy, bulky, and expensive. Concrete was poured inside of hollow cast iron columns and later reinforced concrete was placed in direct contact with columns. Another technique lauded in the 1920s is gypsum hard wall plaster or cement plaster with metal lathe.\(^5\)

### 1.25 Flooring Systems/Trusses

The first buildings in which iron floor beams were used in this country were the Equitable Life Assurance Society, Cooper Union, the Herald Building, the Times Building, and the American Exchange Bank. Peter Cooper, commissioned to make the floors of Princeton University's Nassau Hall fireproof, did so with rails of wrought iron.\(^6\)

The earliest iron frame-supported flooring systems of this era consisted of brick arches spanning wrought iron I-beams from lower flange to lower flange. These arches would be leveled on top with concrete which contained wood nailing strips for wood flooring. The ceilings this system created were rows of curved

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\(^{5}\) A. W. Sinnamon, "Fireproofing of Structural Steel," *The Iron Age* (5 March 1925), 694-696.

arches which would be plastered over. This was a heavy system which left bottom flanges susceptible to fire, protected only by ceiling plaster.


Hollow fire-resistant clay tile\(^55\) was introduced as a building material in 1871, shortly after the Chicago fire.\(^56\) The flat tile arch soon replaced the heavier brick and concrete arch, allowing for flat ceilings below. Since these floors were framed into supporting members rather than simply bearing on them, they were often referred to as having "end construction" as opposed to "side construction" of brick arches.

The Montauk Building (Chicago) of 1881 and the Equitable Life Assurance Building (Denver CO) of 1872 both had tile arch floor systems. The lower flanges of the I-beams were unprotected in this system, except for by plaster. The hollow tile floor of the Home Insurance Building was the first flooring system which protected the beam soffits (with 1" of terra cotta).\(^57\) Until 1884, even with the use of clay tile, the lower flanges were still exposed. The Home Insurance Building boasted the first instance in which the beam's lower flanges were protected from fire with more than plastering. The depth of the tile arches depended on span and load. Maximum spans were furnished by manufacturers.


A number of tile arches came to be recognized by name: Pioneer Arch, Lee Arch, Johnson's Patent Flat Arch, and Guastevino Arch. The Pioneer Arch was so named because it was manufactured by the Pioneer Fireproofing Company of Chicago. In this arch, voids in the hollow-tile ran parallel to the I-beams which

\(^{55}\) Fire clay, which is subjected to a high pressure when moist and then molded by dies, becomes hollow tile through kiln burning after it dries. Fire clay which was mixed with sawdust or some other consumable material which burns when fired and creates pores is called "porous" clay tile or terra cotta.

\(^{56}\) Fleming, "Whence?" 506.

supported them. The voids in the hollow tile of the Lee Arch, patented in the 1890s, ran perpendicular to supporting beams. The Lee Arch was lighter than the Pioneer since it used porous terra cotta.


The Guastevino Arch has been likened to a concrete shell\(^5^8\) since 50% of the arch consisted of concrete -- the tiles could be considered aggregate. The first of 25 related patents was obtained by Raphael Guastevino Sr. in 1885, whose company, The Guastevino Fireproof Construction Company, was incorporated four years later. The arch is created by laying the first course in a quick-setting plaster of Paris (gypsum) to be used as a formwork for subsequent layers (usually three). Reinforcing bars, which may or may not have effected the strength and rigidity of the arches, were added later. The flat clay tiles were hard burnt and 6"x8" or 8"x12" and generally 3/4" thick. In 1914, Rumford acoustical tiles were incorporated into the vaults. These were improved upon with the Akoustolith acoustical tiles which began to be used in 1916. The arches were widely used in buildings of the study period and well afterwards as well.\(^5^9\)

Another arch, the Johnson's Patent Flat Arch, was made of a hard (non-porous) terra cotta with thinner webs and was very commonly used at the end of the 19th Century. This arch was of end construction.\(^6^0\) The Guastevino Tile Arch flooring system is a series of layers of thin tile made monolithic by cementing the tiles together. This method of flooring creates a vaulted ceiling below. Tie rods, connected though beam webs, were necessary with all of these flooring systems to take the horizontal thrust of the arches.

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\(^5^9\) Prudon, "Guastevino Tile Construction."

\(^6^0\) Freitag, *Architectural Engineering,* 60-61.
Corrugated Arches were connected sections of octagons, alternatively concave and convex, spanning from web to web at the bottom flange of floor I-beams. Concrete and wood nailers would fill the rest of the web space to the upper flange. The corrugated metal could also be an arched sinusoidal curve between floor beam and bottom flange.


**FIGURE 20:** Corrugated Metal Arch Flooring. SOURCE: Birkmire. *Skeleton Construction*. 1894. p. 82.
The brick and tile arch systems required short spans between floor beams to reduce floor thickness. The beam and concrete slab system used first in New York resulted in thinner floors and larger beam spans, with the added benefit of being able to create conduits in the floor when pouring the concrete. Gypsum with wood shavings also produced light fireproofed floors but were not often used.61

Wrought-iron and steel beams continued to be used, with steel rapidly becoming the most commonly used material. In 1917, Ewart S. Andrews stated: "By the present time, mild steel beams have entirely replaced wrought iron beams, although the latter still appear in some of the books on building construction."62

1.26 Foundations
As the metal-skeleton building first evolved in Chicago, the unique conditions of the soil63 had to be addressed and the science of foundations was begun and developed here.

Before the mid-1870s, heavy masonry buildings typically sat on continuous beds of concrete or stone, experiencing settlement problems which were sometimes profound64. The laying of foundations was not considered a science until 1873, when Frederick Baumann of Chicago published "The Art of Preparing Foundations for All Kinds of Buildings." Of particular interest was the chapter "The Method of Constructing Foundations on Isolated Piers," which suggested the use of pyramids of stone as individual footings beneath heavy buildings to create a more adaptable foundation.

The first isolated footings were in Chicago and of pyramidal dimension stone. Early iron buildings had masonry pier foundations which sat at or just below street level, resting on the hardened clay crust. The main (first) floors were reached by climbing steps. The cast-iron columns would sit on cast iron shoes which, in turn, would rest on the pyramidal piers. Pyramidal footings lost favor by 1886 as they took up a lot of valuable basement space.65

63 Chicago soil consists of a hardened blue clay crust which begins 12 to 14 feet from surface and is nine or ten feet thick. Through the next ninety feet the soil becomes clay of differing degrees of softness with some pockets of quicksand, very wet at the top and drying at it descends with course gravel and glacial boulders at the bottom. Hardpan, clay in the process of formation into rock, occurs at varying levels, usually around 55 feet below grade. Bedrock may be found about 100-125 feet below grade.
64 Such as the 24-inch differential settlement of the 1877 Chicago Government Post Office and Custom House which was on a 3-1/2 foot thick bed of concrete. It was demolished in 1895, eighteen years after it was built.
65 Randall, P. 18.
In 1878, the Montauk Block, by Burnham and Root, was designed with a new type of foundation fashioned to free basement space which had historically been taken over by the foundation pyramids. Stone piers were used in some places, but a shallow spread foundation of I-beams imbedded as a grillage in concrete transferred much of the load to the ground and the pyramids which were used were of reduced volume. The embedded iron rails increased the allowable compensation in the concrete. Large cast iron base plates sat between the concrete/iron base and the building's columns.66

This use of iron rails was a precedent to the grillage system used so pervasively later. This is called a "floating foundation" since the it was carried on the crust without disturbance of or penetration through to the watery clay below. It is also called a "shallow-spread foundation" since it extends beyond building lines (the 16-story Monadnock Block projected as much as eleven-feet beyond building lines.67

The shallow-spread or floating foundation was the typical foundation of the late 1880s to early 1890s. By the beginning of the 20th century, floating foundations were being replaced in popularity by deeper foundations. The floating foundation system proved inadequate to support the loads of higher (and therefore heavier) buildings in a stable manner. Also, the crust was being affected by movement in the plastic, moist clay layer beneath due to tunnels and shafts being dug into it. The crust, in reaction to a disrupted support and greater load above, would deflect and cause differential settlement of the building. The use of a "raft" foundation which distributed column loads evenly over a grid of timber beams, was also found to be impractical due to differential settlement.

One solution begun in the early 1890s was to drive piles -- long heavy shafts of wood -- deep into the clay layer, in some cases all the way to the hardpan. Pile foundations could be used only if the tops would always be under water to eliminate contact with free oxygen and reduce deterioration. The piles were grouped in sets below columns. Wood piles were first use in a building in 1883, under the river wall of the Hiram Sibley & Co. Warehouse.68

Piles rely either on friction at the skin, bearing on hardpan (if they are driven that deep), or both. Piles are driven in with a steam hammer, an action which causes vibrations and a disturbance in the clay layer. For these reasons, they were often not used beneath walls adjoining other buildings for fear of undermining them. Often caissons were sunk in their place.

67 Randall, P. 18.
68 Randall, P. 18.
Caissons, cylindrical concrete cylinders which belled at the end, were first used in the 1894 Chicago Stock Exchange Caissons, pneumatic. The which if change the well. Then, in the end, were sank 50 feet to bedrock to support the Manhattan Life Building, also in 1894.

The well of the open caisson, as opposed to the pneumatic, was dug by hand four feet at a time, dirt removed in a bucket. Wood tongue in groove planking with iron rings (lagging) lined the sides of the dug well. Then, at the bottom of the caisson, the shaft was widened to form a bell - hardpan bells being twice the diameter of those caissons to rock. The pneumatic caisson was a common type of bridge foundation and was brought to the building trades by Gen. William Sooy Smith, originally a bridge engineer, through the Manhattan Life Insurance Building. These were used when caissons sunk below ground water level.

Pneumatic caissons are dug under compressed air, thereby restricting water from surging in and avoiding a change in surrounding soil pressure. Above the compressed air chamber, steel or timber with steel rings would be placed at the perimeter of the hole to keep water and earth from entering (cofferdams).

If caissons were sunk to bedrock, the bedrock would be cleaned and stepped. The prepared caisson would then be rammed with concrete, and a brick pier built on tip. Later, caissons would become all concrete.

The disturbance of the plastic clay layer by the introduction of piles and caissons sometimes affected piles in other buildings. For instance, the concrete caisson construction of the Tribune Building in Chicago in 1903 caused the Hartford Building across the street to rise 1/4".

1.27 Roofing

Most of the flat roof construction during the period in question consisted of tile topped with concrete or concrete slabs. In one such system, used in many of the early skeleton buildings, T-irons supported on I-beams would support booktile at the flanges. Segmental tile arches would also be used. These would in turn be topped with concrete and built-up roofing.

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69 Randall, P. 18.
70 Steel caissons are concrete caissons whose shaft had to be lined with steel instead of steel-braced timber to enable the shafts to sink through difficult material such as quicksand.
73 "Development of Shallow and Deep Foundations," 561.
74 Freitag, Architectural Engineering, 164.
Built-up roofing consisted of several layers of felt cemented with asphalt and tar pitch. Saturated felts may have been asphalt-asbestos felt, asphalt-rag felt, or tar-rag felt. This roof was usually topped off with gravel or slag.\footnote{Huntington, Building Construction, 406.}

![Figure 21: Built-up Roofing on a Concrete Deck. SOURCE: Huntington. Building Construction. 1929. p. 407.](image)

The felts consisted half and half of paper and rag and, after saturation or coating, would be sprinkled with talc or sand in order to be stored and transported as a roll. Once unrolled onto the roof deck, each layer would receive an application of hot coal tar or asphalt and then the next layer would be unrolled on top.\footnote{Lyle Haack, formerly of Certainteed Corp., interview with author.}

Asphalt is a bitumen produced by refining petroleum. Tars are bitumens which yield pitches through distillation and are themselves produced by distillation of bitumens and organic materials.\footnote{Huntington, Building Construction, 406.}

The flashing of built-up roofing was usually achieved in one of two ways. Two strips of the many-ply felts would rest on the horizontal portion of L-shaped metal base flashing at the parapet, nailed to wood nailers in a concrete roof deck. A metal counterflashing would be inserted in a parapet joint above the metal base-flashing, lapping over the top of the base flashing.

The second type of flashing was called the Barnett system. This was canted up at the edge, the angle created by a strip of wood placed diagonally at the edge. The built-up felts follow the angle up, topped a
the angle's lower edge by three additional strips of tar and felt. These three strips would terminate inside of the parapet wall in a "flashing block.\textsuperscript{78}

Cinders were used at rooftops as fill in enclosed spaces or as aggregate in a lightweight concrete for heat insulation. Their most common use was as a base for built-up roofing: compacted and covered with a layer of cement.\textsuperscript{79}

Clay tile was sometimes used as a roofing material. They would always be nailed to wood sheathing or nailing strips, gypsum, porous terra cotta, or nailing concrete with copper or dipped galvanized steel nails.\textsuperscript{80}

Sheet-metal roofing was roofing of tin or terne plate\textsuperscript{81}, zinc, or lead. Flat seams, usually soldered, were used on flat roofs. The metal would be nailed to wood sheathing through metal cheats which would in turn be nailed to roofing.\textsuperscript{82}

1.28 Wind Bracing
The builders of early skeleton buildings recognized that wind had an effect on their buildings, and knew of wind bracing in tower and bridge construction, but the numbers were not available for specific calculations. Although intensively discussed and debated, the science of windbracing was an empirical one.

The effects of wind on skeleton buildings were not really understood until well after the end of the era in question. In 1931, the "First Progress Report of the Structural Division SubCommittee on Wind Bracing in Steel Buildings," was presented to the ASCE, Clyde T. Morris et al. citing lack of actual data on the relationship between wind forces and deflection of high steel buildings.\textsuperscript{83} Wind speed/pressure over periods of time had been measured at various heights, but wind gusts had been overlooked.

Masonry buildings and those using cast and wrought iron were too small and heavy to be affected by high winds. As these buildings grew higher, the ability of masonry walls to withstand lateral load came into

\textsuperscript{78} Huntington, \textit{Building Construction}, 391.
\textsuperscript{79} Lyle Haack, formerly of Certainteed Corp., interview with author.
\textsuperscript{80} Huntington, \textit{Building Construction}, 398-9.
\textsuperscript{81} Tin plate is manufactured by dipping sheet steel into tin, and terne plate by dipping sheet steel into tin and lead.
\textsuperscript{82} Huntington, \textit{Building Construction}, 398-401.
\textsuperscript{83} Clyde T. Morris et.al., "Wind Bracing in Tall Steel Buildings," \textit{Civil Engineering} vol.1 no.6 (March 1931), 481.
question. When skeleton buildings began rising, there was little precedent for wind bracing in buildings. Notice was taken of wind stresses and a need for a more rigid structure was recognized.

In the early skeleton buildings, lateral load was handled by the sheer heaviness of exterior cladding and by heavy hollow-tile partition walls which extended from floor to floor. Other typical features of building design aided wind resistance: column spacing was often 20-30 feet, hollow-tile wall partitions were heavy and often extended floor to floor, and window openings were usually less than half the wall area.

Many early metal-skeleton buildings were designed without wind bracing incorporated in the frame. In 1895, Joseph Freitag lamented: "there are buildings from ten to sixteen stories high in the City of Chicago, that possess absolutely no metallic sway-bracing, and others, scarcely better, where sway rods, as wind laterals, were attached to pins through lugs on cast columns, which lugs were of an ultimate strength of, perhaps, 25% of the rods." The greatest difference of opinion between engineers in 1892 was with the benefit of hollow tile walls and iron and steel rods as windbracing.

The question of appropriate wind bracing continued throughout the 20th century. According to Robins Fleming in his Engineering article, the biggest problem with buildings was with wind bracing in the 1920s.

In trying to calculate wind stress on individual members and on the building as a whole, theorists tended to choose between two assumptions. The cantilever method assumes elastic columns and rigid beams. The portal method leads more to a direct calculation of column and girder moments. It assumes that column bending is due to girder bending in reaction to lateral loading. According to this method, outer columns take half as much bending moment and shear as inner columns due to the number of girders connected.

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84 There were, however, a few precedents in iron-frame building, although these were not high buildings. The Hungerford Fish Market in London, was designed by Charles Fowler in 1835. In this structure, the roof frame was supported by cylindrical cast iron columns and braced with curving knee braces.

The Crystal Palace in New York of 1853 was the first building with a curtain wall of glass and the first light-framed building made rigid with wind bracing - the wind bracing was the first portal bracing in a building.


86 Freitag, Architectural Engineering, 136.


89 "Wind Design for 1,000 foot Tower Buildings." Engineering News-Record (19 February 1931)
As the need for bracing became increasingly acknowledged, wind resistance was often designed for by using triangular bracing in the vertical plane. One of the earliest forms of wind bracing was in the form of diagonals in tension which connected columns and girders in compression. This method necessitated complete enclosure, which meant permanent partitions (less attractive from a renting standpoint), and interfered with placement of doors and windows.

![Diagram of wind bracing types]


Wind bracing at the exterior was found to be most desirable: gusset-plated and/or bracketed connections, considered to be rigid, were by 1929 the most common form of wind bracing. This was sometimes augmented by horizontal bracing in some of the floor planes -- for narrow, high towers for instance. Also considered rigid by some were trusses which took the place of girders.

The concept of portal arch bracing was based on the portal frame of trussed bridges, the earliest version of which was developed by Corydon T. Purdy. Portal arch bracing consists of steel plates riveted together to form a solid, full bay, arch. This arch is riveted to the underside of the floor girder above, to the full breadth of columns and to the floor girder below at corners. This system was costly in labor, space, and materials but lent a high degree of rigidity to the structure. Versions of this system had been used in the Crystal Palace and for the frame up to the 28th floor of the 1913 Woolworth Building. As buildings rose higher, the popularity of portal arch bracing decreased in favor of diagonals, knee bracing, and other types of portal bracing.

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91 The 1926 Miami hurricane demonstrated the ability of floors to pass wind loads horizontally. Many of the buildings built around this time incorporated one or two floors with horizontal bracing as a sort of stabilizing diaphragm.

"Wind Design for 1,000 foot Tower Buildings."
Wind bents, groups of braced vertical panels in a single vertical plane, were also commonly used with a variety of the previously mentioned bracing types.

1.29 Windows

Window frames and sash were typically made of wood or metal. Wood types included white pine, sugar pine, redwood, cedar, and Douglas fir. Metal windows were and are rolled (solid), hollow, or metal-covered windows made of steel with or without copper, galvanized steel, nickel silver, cold-rolled copper or bronze. Metal covered windows would be of a non-resinous wood (such as pine) beneath sheet metal of temeplate, galvanized iron, cold-rolled copper or sheet bronze. 92

Window lintels were often formed by connecting an angle to a channel. This same angle would likely also serve to carry the weight of the masonry of the floor above. Window mullions were stiffened with iron connection to the beams above and below. 93

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92 Huntington, Building Construction, 429.
93 Purdy "Steel Skeleton Type of High Buildings IV," 2.
CHAPTER 2
NOTES ON THE CONSERVATION OF METAL-SKELETON BUILDINGS OF 1884-1932
Part 1: Causes of Failures in Buildings and Signs of Their Occurrence

The failure of a building, a system, or an element means, in the simplest terms, that that particular object has ceased to perform as it was designed and expected to. Failure, therefore, may denote corrosion or other types of deterioration, isolated fracture, or loosening of connections, for example, as well as total collapse.

The failure of steel-skeleton buildings may occur due to reasons such as faulty design details and/or construction, use of inappropriate materials, differential settlement of foundations, or through the deterioration of the materials of the exterior walls and corrosion of the skeleton. Usually, some of these faults work together, causing, enhancing, and accelerating each other. It is only through an understanding of each of these faults that one may begin to determine causes of manifested failure or to anticipate failure of specific systems.

2.1 DETERIORATION OF EXTERIOR MATERIALS
The metal-skeleton building is composed of primary structural elements as well as secondary elements such as roofing and cladding. Cast iron, one of the three metals most commonly used in metal skeletons, is brittle and fractures without yielding plastically. Cast iron, however, is present as a primary structural material in very few extant skeleton buildings built between 1884 and 1932. The other materials of the skeleton, steel and wrought iron, and therefore the skeleton itself, are well able to react elastically to movement, heavy dynamic and static loads, and lateral and vertical loads. They will yield plastically (barring significant corrosion) long before ultimate failure (fracture). For this ability to yield plastically, steel is called a ductile material.

The secondary systems, however, react quite differently to such forces -- elasticity is low (the materials are brittle) and ultimate failure occurs significantly earlier. While there was quite a bit of redundancy in the designs of the skeletons of these buildings, the margin for error and unanticipated complications was slim to none with regards to roofing and cladding. Cladding, therefore, experiences compressive stresses as it is restricted from moving by its connections to backup masonry and metal support. It is wont to move due to wind, corrosion, structural deformation, and dimensional changes caused by temperature and moisture fluctuations and the products of these fluctuations (frost, for instance).

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94 As will be explained later, in more detail, wrought iron is strong in tension, cast in compression and not at all in tension, and steel is strong in both tension and compression.
Cladding of this era was typically constructed of masonry materials of structural clay (brick and terra cotta), sand-lime brick, and stone (limestone, granite, and marble) with a Portland and/or lime-based cement as binder for mortar. The masonry materials used in the cladding systems are of the hard, brittle, porous variety and are strong in compression. Porous materials may generally be described as consisting of a crystalline aggregate with a sometimes non-crystalline binder. The binder is the constituent which is most susceptible to attacks by acids and other types of chemicals. Limestone, granite, marble, brick, and terra cotta are the masonry materials most commonly used in skeleton buildings of 1884-1932.

The most common and damaging non-dynamic failures of masonry, mortar, and roofing (as well as iron and steel) have been found to be due to water infiltration. Masonry and mortar deteriorates through the action of salt crystallization, freezing and thawing cycles, thermal expansion and contraction cycles, chemical attack, moisture expansion, differential movement of elements within a body, and differential movement of adjacent elements.

The crystallization of salts and frozen water within pores causes damage and destruction to these pores as the crystals are larger than the materials in solution and are relatively strong. Soluble salts may come from building materials themselves. Sulphur may exist in limestone, clay and marble due to the disintegration of pyrite and marcasite present in the rocks. Salts in masonry are also created by the reaction of acidic moisture with alkaline building elements.

Precipitation, usually in the form of rain and drizzle, often has a slightly acidic pH (between 3.0 & 5.8) due to carbon dioxide and sulfates from industrial pollution. Carbon dioxide occurs naturally and also through industrial sources. Sulfuric acid is created by the combustion of fuels containing sulphur. Water in the ground has hundreds of times more carbon dioxide than in the air due to micro-organisms. Carbonic acid results from the solution of carbon dioxide. Carbonic acid dissolves feldspars, kaolinite and calcite.

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95 Dimension stones are rough stones which may be dressed to a specific size. There exists other types of dimension stone, but granite, limestone and marble are the stones most applicable to this study. These three are each representative of a type of stone: igneous, sedimentary, and metamorphic.

Igneous stones are formed when molten rock near the center of the earth moves toward the surface and cools. Sedimentary stones are the results of thousands, perhaps millions, of years of accumulation of material which predominantly consists of organic or chemically precipitated grains of silica or calcite, cemented together by those minerals in solution and/or other minerals. Metamorphic stones are the result when great heat and pressure are applied to sedimentary stones over time.

The exterior of a building can be affected by temperature in a variety of ways. A change in temperature may bring a material into the temperature range in which deterioration mechanisms are most active. Dimensional changes -- expansion and contraction -- occur in materials in varying degrees. The depth of thermal expansion of a material depends on its conductivity.\textsuperscript{97} The conductivity of a stone depends on its minerals, porosity, saturation, and the temperature being applied.\textsuperscript{98} A conservator may perform tests to determine all of these factors.

Thermal changes occur daily and seasonally which cause changes in stone due to conductivity and thermal stresses induced by irregularities and anisotropy. Seasonal changes in temperature penetrate stone more deeply than daily changes.\textsuperscript{99} These thermal stresses initially occur at a microscopic level, within and at the boundaries of mineral grains, and result in irreversible fractures which increase permeability. Water in pores increases stresses relative to pore size: a large pore may allow volume without constraint while smaller pores encourage capillary action.

The composition of dimension stone determines the degree to which mechanisms of deterioration will be effective in walls -- pore structure, elemental composition, isotropy or anisotropy\textsuperscript{100}, bedding planes, and streaks of impurities. The same may be said of brick and terra-cotta, although they are manufactured rather than natural materials. The mechanisms of deterioration in masonry are often the same for each type considered here.

2.11 Faulty Design Details
The most common result of detailing errors which occur with exterior materials result in water infiltration.

Cladding systems were designed before the combined effects of thermal and ceramic expansion of the cladding were understood.\textsuperscript{101} The walls were built without proper expansion joints, horizontal and vertical, to adjust to volumetric changes.

Differential movements between the wall and the structure result in damage due to the lack of details to accommodate them. In addition to the lack of expansion allowance, the lateral movement of the building

\textsuperscript{97} The rate at which heat is conducted in millicalories per second through a 1-cm\textsuperscript{2} area down a temperature gradient of 1°C over 1-cm in length.


\textsuperscript{99} Robertson, "Physical Properties of Building Stone," 75.

\textsuperscript{100} A material is isotropic if its properties are the same in all directions.

will result in scratches which disrupt the protective coating of the metal skeleton. The presence of coating breaches in some coatings will accelerate the rate of corrosion of those areas, enhancing the reaction.

The cavity wall was eliminated early (see Chapter 1) and walls were most often designed to seal the building off from moisture (barrier walls), with weepholes sometimes provided at spandrels to allow condensed and infiltrated water to escape. The lack of an interior cavity eliminated control of temperature and, therefore, control of internal condensation\(^1\). Some buildings lacked flashing altogether.

The iron and steel supports and ties which are an integral part of the cladding system are directly affected by the deterioration of the materials they support as they are often invited to participate soon after this protective layer is breached. Wall ties were rarely galvanized before the 1930s;\(^2\) With the corrosion of these metals comes iron oxide (rust) which is about twice the size of the metal it had been. The metal elements which secured and were intimately confined by inelastic masonry expands and creates cracks and displacement which serve to admit further moisture.

Many of the cornices from this era are massive. The problems they encounter include poor design which places supporting metal close to and sometimes outside of the masonry. The horizontal ledge created by a cornice would often be covered with the same sort of built-up felt material used on the roof, but, since the deterioration of this covering is more likely to go unnoticed, water may infiltrate cornice elements undetected for long stretches of time. This has resulted in the detachment of pieces of stone or terra cotta from cornices.

Roofs of buildings of this era are typically drained with gutters located inside of the perimeter of the roof and interior downspouts. These downspouts were built into interior, usually permanent, walls. Obviously, then, any problem with a downspout would result in a problem with walls. Pipes which become clogged would be impossible to clear without destroying masonry.\(^3\) Furthermore, interior downspouts too close to the exterior wall are susceptible to freezing of standing water and bursting.

The parapets of buildings were often a couple of feet above the roof line. If the walls of parapets are restrained to a different degree than the rest of the wall below, they will expand and contract differently,

\(^1\) Although the cavity wall was suggested as early as 1850 (by A. J. Downing in The Architecture of Country Houses).


\(^3\) Smith, "Diagnosis," p 226.
causing shear stress at the interface. Masonry at shelf angles may be encouraged to ride off of these angles by the stresses induced.

Lintels and sills were also often problematically designed. Sills which do not project past the face of the wall encourage water damage to concentrated areas of masonry below. Lintels, which were most often formed by steel angles attached to the structure, were often not protected by flashing, allowing runoff water to come down and into contact with the lintel metal.

Design-related problems also occur at the roof level. Thermal movement may occur in the roof deck, inducing stresses at upper stories and at the parapet. Also, the concrete decking used as insulation in some roofs is usually a lightweight concrete with cinder fill. This is usually a loose concrete (not well bound with many voids and pores), and percolates water through to the surface below, delivering it as a slightly acidic liquid.

The lack of provision for movement, stress, and moisture control in cladding enhances the mechanisms of deterioration which these materials normally experience.

2.12 Limestone

Limestone is a sedimentary stone, composed primarily of calcium carbonate (calcite) or the double carbonate of calcium and magnesium (dolomite). The source of these minerals is either the calcareous remains of living organisms or precipitation of chemicals from solution. Fossils are often visible in the organically-derived limestone. Oolitic limestone, that which is formed from precipitation, is an agglomeration of rounded grains of calcite or aragonite (which are less than 2mm in diameter).

The permeability of limestone is higher at bedding planes, microcracks, and areas with intrinsically well-connected capillaries. The flow and absorption of moisture depends on the amount of effective, connected pores, their size, and their tortuosity (twisting and turning). The permeability of limestone is often relatively high; sedimentary stones are typically high in porosity and therefore have a better chance of being highly permeable than metamorphic or igneous stones.

107 Although porosity does not imply permeability. A stone may have many pores which are not well connected and therefore do not transfer moisture.
The deterioration of limestone occurs predominantly in the binding material, between fossilized shells or oolitic grains, leaving them in relief at the surface and easily removed. The calcite converts to gypsum on interaction with sulphur dioxide.

2.13 Granite
Commercially, almost all igneous rocks used in architecture are considered granite. True granite consists predominantly of silica with varying amounts of other minerals such as alkali feldspars, micas and hornblende. The grains in granite range in size from fine to very course. As it is an igneous stone, granite was a molten mass which cooled. The rate at which it cooled determined the coarseness of grain and composition. Courseness of grain relates to the degree of crystallization — the longer the cooling process, the larger the crystal.

Although granite is the typically the most weather-resistant of the stones considered here, may be jointed and layered (foliated) — properties which increase the possibilities of deterioration. It will spall in sheets near the surface due to thermal expansion and salt crystallization (salt fretting). Granites of medium or fine grain are the most likely to scale.

2.14 Marble
Commercially, marbles are considered to be all stones of a crystalline nature able to take a high polish, which are composed predominantly of calcite, dolomite, or serpentine. True marble is limestone or dolomite which has metamorphosed under high heat and pressure into a stone with interlocking crystals which are fine to very fine in size. The stone takes its color from impurities in the original limestone including talc, chlorite, amphiboles, pyroxenes, iron oxides, hydroxides, sulfides, and graphite.

When marble is attacked by acidic moisture, the binding material dissolves and leaves the stone friable (called sugaring). Gypsum crusts are often formed through redeposition in the presence of sulfates. These impermeable surface skins blister and exfoliate.

Marble may experience irreversible expansion due to a large number of thermal cycles. In very thin units of cladding, marble has been found to bow out in order to accommodate the increased volume.

108 Herz, "Geological Sources of Building Stone," 52.
109 Winkler, "Problems in the Deterioration of Stone."
2.15 Brick and Terra Cotta

Sand-lime bricks, sometimes referred to as calcium silicate bricks, are composed of damp sand and 5-10% hydrated lime. This mixture is pressed under 200 tons into exact and uniform shapes and then steamed at a pressure of 120-250 psi. These bricks are resistant to frost and fire, but are susceptible to salt crystallization. Sand-lime bricks have been found to have five to ten times the moisture expansion of terra cotta and two to five times that of limestone.

Structural clay products such as brick and terra cotta are composed of a combination of three types of materials. The first is hydrated clay, composed of silicon dioxide and aluminum dioxide. The bond is very weak producing a platelike and highly directional material. The second is a fluxing material, added to lower the firing temperature of the clay. The third constituent is an inert filler like quartz. Other materials are sometimes added to decrease plasticity and decrease shrinkage (such as sand) or which are combustible and will be consumed during firing (such as sawdust and ashes), creating a lighter, porous product. Terra cotta is made from fine clay and grog (a prefired clay, added to reduce shrinkage).

The technology for extruding clay into brick forms already existed by the time skeleton buildings were beginning to be built. This technique allows the use of a clay much stiffer than that which was used with hand molding. Pressed brick, also used in some skeleton building exteriors, is produced by pressing clay into a mold cavity. Pressed bricks have a higher porosity than extruded bricks.

The quality of firing - temperature, continuity, time spent in kiln - affects the hardness and porosity of bricks. Bricks exposed to higher temperatures will be harder and less porous than bricks fired at lower temperatures for the same amount of time. Bricks will become more homogeneous the longer they are fired. Naturally, the surface of the brick receives more direct heat and is the strongest and hardest part of a brick. After firing, bricks consist of crystals bonded together in a vitreous, noncrystalline matrix: strong in compression but brittle.

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113 Ashurst, *Brick, Terracotta and Earth,* 46.
116 Markow and Brach, "Ceramics as Construction Materials," 84.
Bricks experience irreversible expansion due to moisture absorption after firing. An older brick would be more stable as it is "seasoned" although this does not imply an increase in strength (in fact, seasoned bricks have been found to lose some compressive strength). Forty percent of moisture expansion will occur in the first three months, fifty percent after one year, and 100 percent after 60-100 years.\(^{117}\)

Bricks usually fail through delamination of the surface layer since it is harder and less porous than the center. The delamination of the surface eliminates the protection of the softer core of the brick.

Bricks which are restrained by the building behind it and by other panels above will react differently to thermal movement then less dependent wall such as parapets. Such walls will be freer to move and expand, causing it to change volume at a different rate then the more restrained panels. The brick may "ride off" of shelf angles at these places.

The color of bricks will naturally affect heat absorption. While both dark and light bricks absorb some heat, dark bricks have been found to reach 175\(^\circ\) F on sunny days.\(^{118}\)

Terra cotta and its anchoring would be set first and then filled in with backup brick or some other masonry. It would also sometimes be filled with concrete or remain open and have weep holes. This concrete may experience movement, absorption, etc. different from the terra cotta. Concrete back filling was mainly used to protect the anchoring steel from corrosion.\(^{119}\)

Incorrectly fired or mixed glazing will eventually result in spalling. The strength of terra cotta can be compromised by incorrect firing or cooling temperatures.

Terra cotta is, like most brick, not homogeneous. The exterior skin is denser and harder than the interior. Underfiring can cause the exterior to fail to form the protective outer layer. This is most often found in buff-colored brick.\(^{120}\) Terra cotta will continue to absorb moisture and expand for 2-3 years or longer. As the glaze does not expand, it goes into tension.\(^{121}\)

Deterioration of mortar joints significantly contributes to the failure of terra cotta, especially when it is glazed. The mortar originally used in the joints was typically harder than the terra cotta itself and has

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117 Kellermeyer and Chin, "Lessons Learned," 154.
120 Ashurst, Brick, Terracotta and Earth, 76.
121 Ashurst, Brick, Terracotta and Earth, 76.
proved to be unable to allow sufficient movement. Very strong mortar mixes often fostered separation of terra cotta from mortar, the terra cotta becoming the sacrificial material.

Bad maintenance practices frequently found with brick and terra cotta include abrasive cleaning and cleaning with alkaline solutions where, if they are absorbed, they become a source of salt formation.

2.16 Mortar

The production of portland cement is begun by mixing lime- and clay-bearing materials which are them made into clinker (which is primarily hydraulic calcium silicate) through calcination (the combination of free lime - CaO - through heat). The clinker is finely ground and sometimes combined with gypsum (to slow the setting rate) and other materials. The constituent elements of portland cement are predominantly silica, lime, and alumina with some magnesium, sulphur, and iron sometimes mixed in.

The deterioration which takes place in masonry often takes place in mortar as well. Lime-based mortars were rarely used in the building of exterior walls; portland cement was most often used as the binder in mortars as well as fireproofing and deck concrete. Portland cements are very strong and rather impermeable.

Mortar joints may erode, transfer salts to surrounding masonry, and may separate from surrounding masonry. Erosion of mortar joints could result from high winds, water, and compressive stress present in walls. Portland cement is deteriorated by soluble sulfates present in wet brick through a volume increase which results in pressure in the mortar.\(^{\text{122}}\) Despite its rather impermeable nature, portland cement has been found to pass soluble salts to surrounding masonry.

It has been found through research and experience that water enters a wall through gaps in mortar-masonry interfaces more than any other path. Mortar joints may open for a variety of reasons. The nature of portland cement is to shrink upon setting, so a joint may be breached at the outset. Also, the tendency of the windward side of a building to experience tensile stress was not anticipated and so not designed for and mortar joints often open at this facade.

The use of an extremely hard mortar or a brick with significantly low porosity will prevent the brick and mortar from achieving a solid bond. Unclean or frozen brick will also thwart a solid bond, and an

inappropriate aggregate mix may cause point loading to occur in a joint. Poor workmanship, such as joint slushing (where the joint is only filled at the visible edge), often causes stresses, open joints, and failure.

As mortar ages, the alkaline nature of the cement becomes neutralized through carbonation. It is the alkalinity which prevents rusting of embedded ties and shelf angles and when this protection is eliminated, the metal elements are susceptible.

2.17 Roofing
The constituent elements of roofing in the era in question may include tile, concrete, and wood, and always include felt and tar of some sort. Flashing failure is a major cause of deterioration in a building since the forces which the roof must sustain necessitate a strong, sound seal. The materials and fasteners of a roof may fail due to poor workmanship, thermal stress, or material deterioration.

Waterproof coverings may be compromised by differential thermal and moisture movement of a flat roof, standing water, U-V degradation of materials, and blistering from trapped water and air.

Roofing tar typically has a service life of 15-20 years (barring impact or other sorts of dynamic damage). U-V radiation, along with the extremes of weathering, serve to degrade the elements of the tar, causing them to become less and less elastic and self-healing.

Some buildings insulated the roof with a layer of concrete on top of the roof deck (beneath the felts). As a light concrete was desired, cinders would sometimes be used as aggregate. This cinder fill concrete was indeed light, but is apparently a weaker concrete -- nails would pull out more easily than with concrete containing aggregate of pebbles and sand. It also was apt to go to pieces from any moisture which would infiltrate, and allow water to percolate through.123

2.2 DETERIORATION OF SKELETON
The modes and mechanisms of deterioration of the exterior materials is relatively well understood. The tests which have been performed on masonry buildings have been used or adapted by engineers and architects for use on the cladding of metal-skeleton buildings, some of which have been published. The condition of the iron and steel beneath, however, has been found to be considerably more difficult to assess without destruction of surrounding material.

123 Lyle Haack. Interview with author.
The deterioration of the skeleton depends on the construction and nature of both the exterior materials and of the skeleton itself. Theoretically, a metal skeleton may fail through a variety of means including corrosion; failure of connections and member through shear, bending, and deflection; and combinations of the two.

It has been the experience of structural restoration engineers that failure will occur due to corrosion and rarely anything else. Indeed, all published accounts of other types of failure found by this author have occurred during construction, and studies of decades-old metal-skeleton buildings during demolition have revealed nothing but corrosion. It must be kept in mind, however, that the redundancy of the skeleton and the strength of masonry combined with the relative youth of these buildings may serve to mask significant inherent problems.

2.21 Description of Materials

Iron is found naturally only in combination with other elements, generally. In order to extract iron or "reduce" it, it is necessary to use a reducing agent - carbon. The resulting product is pig iron which consists of iron (91-94%), carbon (3-6%), Silicon (0.5-3%), phosphorus (0.04-2%), and sulphur (less than 0.055%)\(^2\). Carbon and heat were originally produced by burning wood, then charcoal, and now coke\(^\text{126}\) is used to produce the heat and the carbon necessary for reducing iron. Burning these materials provided the reducing carbon as well as heat.

Wrought iron contains a relatively small percentage of carbon (0.1%-0.4%). It is manufactured by processing melted pig iron in a reverberatory furnace. The carbon, silicon, phosphorus, and sulphur are eliminated through oxidation when they come in contact with the iron oxide which lines the hearth of the furnace. Slag remains in the iron.

Slag (approximately 3.0%) is worked into the iron which is not molten but not yet totally solidified. Through working the slag becomes threads within the metal, giving it a fibrous structure. Wrought is less

\(^{124}\)Until the middle ages, technology was such that the heat produced was sufficient to extract iron from ore but not to melt it. By the 15th century, higher heat allowed melting and casting of iron.

\(^{125}\)Until the Bessemer furnace, a furnace able to reach an iron-melting heat, was invented in the 1850s, iron was difficult to extrude from ore and was prohibitively expensive for building purposes. It was not until 1866, however, that the three individual patents for components of the furnace were controlled by the same group: The Pneumatic Steel Company. The invention of open hearth process of producing steel arrived in America soon after its invention in 1868 in Europe. With this process, economical steel was produced for the first time.

\(^{126}\)Coke is coal from which most of the gasses have been removed by heat. It burns intensely and with little smoke.
strong, but less brittle, ductile, and better in tension than cast iron. It was originally used in building as connecting materials, tie rods and cramps, for masonry and wood. It is corrosion and fatigue resistant.

Cast iron is cast from remelted pig iron and scrap iron (from previous castings) and does not differ too much in composition. Cast iron is, by the nature of its production, very high in carbon (3-4%) and therefore quite brittle. The compressive capability of cast iron, however, is very high, and has been used structurally as compressive members such as columns and arches. Cast iron is not ductile (brittle) with great compressive strength and the ability to absorb vibration. It is relatively corrosion-resistant.

Wrought iron and low carbon steel differ in process of manufacture rather than chemical composition. Mild (low carbon) steel contains less than 0.03% carbon, medium contains 0.30-0.60% carbon, and high-carbon steel may contain as much as 1.50% carbon. The greater the carbon content, the more strong, hard, brittle, and the less ductile the metal.127

Steel is made from iron ore by first processing ore, limestone, and coal (coke) in a blast furnace and creating molten iron. Molten steel is created with this molten iron and steel scraps by driving off excess carbon from the coal. This requires a very high heat -- producible in this country with the acid Bessemer processes or the acid or basic open-hearth processes.

Steel contains less carbon than cast and performs well in tension as well as compression. Mild steel, the steel most commonly used structurally, is ductile: it deforms and adjusts to load, totally failing after a significant amount of deformation (except in the case of fire on unprotected steel). Very low temperatures also reduce ductility of steel. Very little changed in the composition of steel until the 1960s.

2.22 Faulty Details

Laboratory testing and studies of construction failures have revealed areas of possible susceptibility of some members to corrosion and fracture, due to shape, temperature change, and material composition.

Lateral instability of beams with coped ends was studied and tested by the ASCE in 1988. They found that coping can "significantly reduce the lateral buckling strength." Experiments found that the degree of reduction of buckling-resistance capacity depended on cope length and depth, amount and character of applied load, span length. Restraining connections and adjacent spans were found to increase the capacity.

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127 Huntington, Building Construction, 35.
The effects of temperature-induced movement in iron and steel may be that the exterior and interior columns experience different temperatures and therefore different degrees of dimensional change. This difference will be absorbed predominantly by joint movement in a hinged frame and floor wracking in a rigid frame.\(^{128}\)

Failure in rivets and bolts may theoretically occur due to incomplete connections, fatigue cracking of steel in holes, or corrosion. Connections which are designed without provision for all forces, rotation, and movement will be subject problems when these are encountered.

Geometric details could affect the application and effectiveness of a coating. Coatings of the steel could be breached by the differential movement of masonry and skeleton scratching it. Furthermore, human error combined with complex surfaces and the inevitable occurrence of non-flush rivet and bolt heads renders impossible the total coverage of protective coatings of iron and steel. Liquid paint films applied to a sharp edged corner or angle will pull away from that edge upon drying, either significantly thinning or completely leaving that surface.\(^{129}\)

It was reported in 1892 that manufacturers of z-bars consistently had problems producing z-bars which were straight, implying that the z-bar columns had the same problem. It was also asserted that bracket holes rarely fit column holes exactly in these columns.\(^{130}\)

A possible problem with the Gray columns was identified in 1894 as eccentric loading. Unless the top of the column is truly rigidly bound together, the loads of girders are borne primarily by the T-shaped members of the column.\(^{131}\)

The nuts of bolted connections were prone to loosening with vibration, sometimes cracking interior plaster at areas of connection. "This was due to the play of bolts in the holes."\(^{132}\)

Areas of bad detailing in the skeleton include:

- Bracing one weak member by connecting it to another in a nontriangulated manner;\(^{133}\)


\(^{130}\)Milliken, "Steel Skeleton Buildings," 41.

\(^{131}\)"Wind Bracing and Column Construction for Buildings," *Engineering News* (7 June 1894), 475.


- Insufficient bracing of end-bays;\textsuperscript{134}
- Inadequate connection at ends of knee braces, with knee braces often possessing less than half of the strength of the members they are connecting;\textsuperscript{135}
- The strength of curved girders and connections at ends which experience a great deal of strain;\textsuperscript{136}
- Some configurations result in tension on rivet heads and some in excessive shear on the extreme rivets of a group;\textsuperscript{137}
- Beams which must act as cantilevers are detailed with end connections standard for simple beams. This commonly manifests itself in neglect of the bottom (compression) flange, providing only for tension at the top.\textsuperscript{138}
- Top (compression) flanges not braced against lateral deflection;\textsuperscript{139}

The expectation that walls which extended from floor to ceiling would act in shear to resist wind loads is sound if the walls were designed to transfer loads. That masonry can withstand compression rather well will be discussed later. Tension, however, is a different story. A "shear wall" which is not able to work in tension will crack at the diagonal perpendicular to the line of tension (at what is called the resultant of shear). The extent of cracking depends on the shape of the wall (ratio of height to width), the elasticity of the masonry and of the skeleton, and the amount of leeway afforded the wall.\textsuperscript{140}

\textbf{2.23 Deterioration: Types of Corrosion}

Cast iron, wrought iron, and steel may fail through corrosion, distortion, and fracture due to the presence of water and oxygen, differential settlement of foundations, insufficient details, unanticipated responses to stresses, and failure of protective measures such as coatings, cladding, and roofing materials.

The element iron has 26 positive neutrons in the nucleus and 26 negative electrons around it. The two outermost electrons are in a shell by themselves and are most easily given away; when they are shared with other iron atoms, iron metal is formed.\textsuperscript{141}

\begin{flushleft}
\footnotesize
\textsuperscript{134} Fleming. "Errors."
\textsuperscript{135} Fleming. "Errors."
\textsuperscript{136} Edward Godfrey, "Common Errors in Detailing Steelwork for Buildings," \textit{Engineering News-Record} vol.83 no.16 (October 16, 1919), 730.
\textsuperscript{137} Godfrey. "Common Errors."
\textsuperscript{138} Godfrey. "Common Errors."
\textsuperscript{139} Fleming. "Errors."
\textsuperscript{140} Kaminetsky. "Preventing Cracks," 212.
\textsuperscript{141} Giorgio Torracca. "Teaching Iron Technology to Conservation Architects." ICCROM.
\end{flushleft}
When iron corrodes, it does so in two stages through electrochemical corrosion. First, iron atoms lose the two outer electrons and become iron ions. This is called anodic dissolution (oxidation). Second, oxygen and water pick up the loose electrons and produce hydroxyl ions in what is called a cathodic reaction (reduction). The iron ion combines with the hydroxyl ions and form ferrous hydroxide which is oxidized to become ferric hydroxide or rust.\textsuperscript{142} Obviously, then, both water and oxygen are necessary for the corrosion of iron and steel.

Aside from its low tensile strength, the most serious flaws in cast iron are the unpredictable and hidden irregularities of cast members. Differential cooling and trapped air cause weaknesses in a cast member which may be perfect looking on the outside. Cast iron is more resistant to rusting than wrought iron or steel, although, due to the high percentage of carbon, graphite crystals may be formed. These crystals are easily cleaved and may result in microscopic cracks.\textsuperscript{143}

A cavity found behind the bracket cast with a cast-iron column apparently occurred due to iron contraction during cooling; material flowed away from behind the bracket after having set at the exterior. A comment by the editor of Engineering News at the end of the article pointed out that defects at the column/bracket interface had repeatedly been found.\textsuperscript{144}

Wrought iron was used as flooring as it is strong in tension. This is due to the fibrous nature of the material achieved through inclusion of minute threads of slag throughout the metal. Due to the small amount of carbon, a rust layer which forms on the surface of wrought iron will be compact; wrought iron is relatively corrosion resistant.

Steel is strong in both compression and tension. Steel will deform plastically long before ultimate failure, and performs elastically until a very high psi is reached. As mentioned previously, it is this elasticity which puts cladding without expansion joints in jeopardy. Of the three metals considered here, steel is the most susceptible to electrochemical corrosion.

The electrochemical corrosion of these metals comes in six forms: pitting; crevice; stress-corrosion cracking; intergranular corrosion; uniform corrosion; and galvanic corrosion. Given the redundancy of the structures considered here, it is not surprising that stress-corrosion cracking has not been witnessed by any


\textsuperscript{143}Torracca, "Teaching Iron Technology."

\textsuperscript{144}F. L. Martindale, "A Dangerous Spot in Cast-Iron Columns," Engineering News (12 December 1907), 643.
of the structural engineers interviewed. Connecting elements such as bolts and rivets, however, are often required to withstand enormous stress, so a discussion of this form of corrosion is appropriate here. Intergranular corrosion occurs when grain boundaries are more anodic than grain interiors and usually occurs in heat treated austentic (18% Cr, 8% Ni) stainless steels.

When a pit is formed in iron, the pit acts as an anode and the surrounding unpitted area as a cathode. A pit begins when a small area is exposed to oxygen and water (such as when protective coatings are scratched). Rust covers the anodic pit which is considerably smaller in area than the surrounding cathodic area, and grows rapidly.145

Crevice corrosion usually occurs in the presence of chloride ions, which come in contact with an area connected to a shielded area. It takes place where there is metal shielding like-metal, such as built-up members. This type of corrosion occurs when the shielded area has a lower oxygen content than that surrounding it and becomes the anode in a corrosion cell whose cathode exists just outside of the shielded area.146

If sufficient tensile stress is acting on an element which is subject to at least mildly corrosive conditions, stress corrosion cracking may result. One explanation for this type of corrosion is that on the surface of a material experiencing tensile stress and in contact with a corrosive element, an anode will be formed at an intercrystalline boundary with adjacent crystals becoming cathodic. Another is that stress may rupture a protective coating and uncover a chemically active area. A stress corrosion cracking failure causes brittle initial fractures.147

Uniform corrosion is a common form of corrosion which is due to corrosive conditions common to an entire surface of a metal element. Galvanic corrosion, on the other hand, is due to either direct contact of two dissimilar metals or contact through a medium such as water. Metals with different capacities to conduct electrolytes will result in galvanic corrosion of the less noble element. Also, one metal, subject to two very different temperatures can experience thermo-galvanic corrosion.148

146 J. Yahalom, "Corrosion of Iron and Steel."
148 J. Yahalom, "Corrosion of Iron and Steel."
This phenomenon is based on the propensity of an electric current to flow from positive to negative. The Galvanic Series listed below is but one of the possible orderings; metals react differently in different mediums. The medium for which this sequence is true is natural water.

**THE GALVANIC SERIES**

<table>
<thead>
<tr>
<th>Anode</th>
<th>Cathode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnesium, magnesium alloys</td>
<td></td>
</tr>
<tr>
<td>Zinc</td>
<td></td>
</tr>
<tr>
<td>Aluminum 1100</td>
<td></td>
</tr>
<tr>
<td>Cadmium</td>
<td></td>
</tr>
<tr>
<td>Aluminum 2024-T4f</td>
<td></td>
</tr>
<tr>
<td>Steel or Wrought Iron</td>
<td></td>
</tr>
<tr>
<td>Cast Iron</td>
<td></td>
</tr>
<tr>
<td>Chromium iron (active)</td>
<td></td>
</tr>
<tr>
<td>Type 304, 316 stainless (active)</td>
<td></td>
</tr>
<tr>
<td>Lead, Tin</td>
<td></td>
</tr>
<tr>
<td>Nickel (active)</td>
<td></td>
</tr>
<tr>
<td>Brass</td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td></td>
</tr>
<tr>
<td>Bronzes</td>
<td></td>
</tr>
<tr>
<td>Copper-Nickel alloys</td>
<td></td>
</tr>
<tr>
<td>Silver solder</td>
<td></td>
</tr>
<tr>
<td>Nickel (passive)</td>
<td></td>
</tr>
<tr>
<td>Chromium Iron (passive)</td>
<td></td>
</tr>
<tr>
<td>Type 304, 316 stainless (passive)</td>
<td></td>
</tr>
<tr>
<td>Silver</td>
<td></td>
</tr>
<tr>
<td>Titanium</td>
<td></td>
</tr>
<tr>
<td>Graphite</td>
<td></td>
</tr>
<tr>
<td>Gold</td>
<td></td>
</tr>
<tr>
<td>Platinum</td>
<td></td>
</tr>
</tbody>
</table>

Anode (least noble)  Cathode (most noble)

Corrosion is accelerated by the presence of sulphur dioxide and chloride salts in the environment. The sulphur dioxide is acidic and the chloride salts are highly conductive and aid the electrochemical corrosion.

### 2.3 SETTLEMENT OF FOUNDATIONS

Buildings are sometimes found to be out of plumb. Movement such as this is generally either caused by dynamic forces or settlement of some sort in the foundation. Documented foundation failures point to reasons such as rotting of wood piles, damage due to driving of adjacent foundation elements, and/or miscalculation of or change in the nature of bearing soils. Failures have also been found to be caused by faulty design, materials, and workmanship of foundation components.

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Changes in the character of soils may be due to water content changes or pressures from new adjacent construction. Foundation systems may also provide insufficiently for thermal changes and flooding.

2.4 THE MOST LIKELY SOURCES AND AREAS OF DETERIORATION AND CORROSION

Very little of the total assessment and restorative work which has been performed on these buildings has been published. It was therefore necessary to seek out the opinions of professionals active in the field -- usually the people with answers were structural engineers who had been involved in restorative work. These engineers were asked the question: "In your experience, where has corrosion been found most likely to occur?"

All of the professionals surveyed pointed to water damage as the most significant cause of deterioration in metal-skeleton buildings. The areas of likely water damage were also a concensus, namely, in the steel near the exterior and the roof through failed flashing, copings, and damp-proof membranes. Connections were also mentioned as typical problem areas.

Studies of buildings as they were being destroyed agree with these assertions and added some areas of likely water damage as well. Kitchens were found to be a source of moisture; in one case the degree of corrosion was such that webs of beams and girders were perforated in places. Soil pipes located near columns were also found to be a source. A brief description of some of these studies may be found in Appendix 3.

Moisture has also been found to attack through precipitation (especially if it is wind-driven), from the ground through capillary action, leaking plumbing, and interior condensation.

Masonry is likely to deteriorate where water is most likely to wash over a surface -- at chimneys, parapets, beneath windows, and at quoins and plinths. Areas which are protected from water deteriorate as dirt settles on them and the small amount of moisture which does land here solubilizes the chemicals, allowing them to enter masonry and become salts. Protected areas, however, have generally been found to deteriorate considerably less than more exposed ones. The orientation and surface geometry of a given masonry element are of great importance in determining what will fail as these factors dictate the pattern of water runoff.

Mortar deterioration has been found to occur most commonly toward higher parts of walls, at sill ends, corners, balconies, and behind pipes (where leaks may occur).
Leaking plumbing will admit water in areas where it can sit, both indoors and out. Capillary action allows ground moisture to travel through stone at building bases. This moisture usually contains ground salts which both occur naturally and are deposited for de-icing. The majority of these salts remain in the stone after evaporation, attracting further moisture penetration as they are hygroscopic.\textsuperscript{150} Moisture inside of the building, however, will attempt to migrate from the building due to a change in relative humidity from differences in temperature (warm to cool). Water vapor may find its dewpoint temperature within the cladding of the structure and then become a mechanism.

In addition to atmospheric and soil sources, salts may come from calcium chloride used to prevent mortar freezing while it set, portland cement itself, cleaning agents, and adjacent materials.

Low-pitch or flat roofs experience greater suction than steeper roofs and the most severe suction is generally around the perimeter and near leading corners of the windward face.\textsuperscript{151} Additionally, as previously mentioned, waterproof coverings may be compromised by differential thermal and moisture movement of a flat roof, standing water, U-V degradation of materials, and blistering from trapped water and air. This is often due to inadequate detailing at parapets and projections, inappropriate or lack of maintenance, mechanical damage, and age.

Mechanical systems in buildings of this era were more likely to be housed in a floor of the building or the basement rather than on the roof. When these systems were placed on the roof, the roof became more susceptible to water infiltration as the flashing at projections is more prone to have problems than perimeter flashing.\textsuperscript{152}

Vertical cracks at corners often occur very near the corner column, allowing moisture to the penetrate and possibly reach the column. There are various theories regarding the reason for the relative movement of the skeleton and masonry. It is the contention of at least one structural engineer\textsuperscript{153} that failures in masonry cladding in older skeleton buildings are attributable to a gradual buildup in cladding stresses. The buildup may take decades but some compressive stress begins almost immediately with structural clay: all structural clay products will absorb moisture and irreversibly expand just after being fired. Others point to the elastic shortening of steel columns due to loads added after a wall is built.\textsuperscript{154}

\textsuperscript{150}Winkler, "Problems in the Deterioration of Stone."
\textsuperscript{151}Keith J. Eaton, "Cladding and the Wind," \textit{Journal of the Structural Division}, American Society of Civil Engineers, 1043-1058.
\textsuperscript{152}Lyle Haack. Interview with author.
\textsuperscript{154}Jacob Feld, \textit{Construction Failure}, (New York:John Wiley & Sons, Inc., 1968), 193
Regardless of the reason, the differential movement of the two systems often results in cracks. One of the most common types of the crack is likely to occur at corners since the skeleton restrains all but the edge of the masonry, which is then allowed to respond to induced stresses more freely. One maintenance mistake is the cutting of vertical expansion joints in response to the manifestation of vertical cracks at far corners -- especially dangerous since this creates an almost free-standing vertical pier.\textsuperscript{155}

Shorter vertical cracks and diagonal cracks are often indicative of corroded steel anchors. Horizontal cracks, on the other hand, may be due to corroded supports.\textsuperscript{156} Horizontal cracks and displacement without concurrent ferrous staining may indicate the movement of masonry off of shelf angles.

Cracking of terra cotta at the top of blocks (and sometimes at the bottom of the block immediately above) has been found to correspond to corrosion of anchors. Corrosion of shelf angles has been found to manifest itself in separation from and spalling around the joint. Another serious defect which is possible in terra cotta is shear of the web from the panel face -- a defect which is not generally visibly detectable.\textsuperscript{157}

\textsuperscript{156} Prudon, "Architectural Terra Cotta," 35.
\textsuperscript{157} Prudon, "Architectural Terra Cotta," 35.
CHAPTER 3
NOTES ON THE CONSERVATION OF METAL-SKELETON BUILDINGS OF 1884-1932
Part 2: A Proposed Design for an Assessment of Conditions

"The first operation in any conservation process is to assess accurately the substance of the object to be safeguarded."

Paul Phillipot

"Many destructive and lamentable errors result from not having considered the material of the work of art in its duality of appearance and structure."

Cesare Brandi

In order to begin the conservation of a building, a conservator must learn as much as possible about the building's physical history, understand the deterioration and properties of the materials involved, and establish in his or her mind what is ultimately to be accomplished by the initiation of the process. The best-case program is that the study of a building of historical significance will result in the appropriate correction of any structural or architectural defects or failures found. Realistically, this is usually not the case; it is often decided to move toward one or the other direction.

This author has attempted to design the following guidelines for assessment of conditions with the necessary combination of regard for structure and architecture. As it was not the intention of the author to propose measures to remedy the pathologies found, and it therefore may be perceived that more "substance" has been attributed to the structural aspect of the program.

The purpose of this methodology is to identify the areas of a building which are possibly in danger of failing structurally, be it cladding or steel.

3.1 INVESTIGATION OF A BUILDING'S PHYSICAL HISTORY

3.11 The Original Building

Important pieces in information about the construction and structure of a building may be found in various archival documents. Theses references include architectural drawings, specifications, shop drawings, as-built drawings, design calculations, quality control reports on foundations, steel, and concrete, soil surveys, use information (for evidence of load changes), and newspaper and magazine reports about the building.

In the best of situations, an owner (or previous owner), building manager, or the original or current architectural firm will have access to such documentation. If this information is not available, locate files
of correspondence and accounting records which may reveal names and addresses of subcontractors with information.

When this is not the case, conduct research in historical agencies in the area of this and surrounding buildings. For buildings in Chicago, in addition to the information listed in APPENDIX 1, some bibliographical information may be found in Randall's, *History of Development of Building Construction in Chicago*. Since some of the buildings discussed in the books and magazines consulted were not included in APPENDIX 1, these texts should be reviewed. Finally, search records of newspaper and magazine articles published at or around the time of construction of the building.

Drawings which are found will be theoretical versions of what was actually built. When reviewing drawings, special attention should be paid to the "Notes to Erectors" which often delineates the ways in which specific areas may be somehow different than pictured.

Compare details to the faulty details listed above. Any areas possessing examples of these details should be noted as they may be sources of deterioration. The faulty details which were described in Chapter 2 is not an exhaustive list as engineers, architects, and sometimes erectors were sometimes creative with the common systems. Request that a structural engineer critically review the drawings looking for problematic situations.

### 3.12 Problems, Treatments, Alterations

Consult maintenance records in order to uncover previous surveys, problems, and treatments, who performed them, where, and with what materials. Contact organizations which would be able to augment and detail general information. Conduct interviews with building occupants such as long-time tenants and organizations mentioned in the maintenance records. Also conduct interviews with building personnel such as the manager, architect-in-residence, and head custodian. These interviews may yield information not documented. This word-of-mouth information should be considered secondary until it is corroborated by a primary source, such as the documents mentioned in 3.11.

Additionally, identify potential problem areas such as restaurants, kitchens, bathrooms, and areas of undamped vibratory movement (such as may be the case with a printing press).

### 3.13 Map Problems, Treatments, Alterations
Map the primary information found through Section 3.12 on simplified elevation drawings of the building. Chronology of changes should be apparent. Note patterns in type of change, elevation, height, and material.

3.2 VISUAL INVESTIGATION OF CONDITIONS

3.21 Map Exterior Materials
Map the materials which clad the building. Make note of the typical mechanisms and usual sources of deterioration of these materials (as described in Chapter 2).

3.22 Survey Conditions of Interior
Survey, if possible, the conditions of the interior of the building, paying close attention to areas identified in section 3.12. Record through writing, detail sketches, and photography discoloration/deterioration at or from the ceiling and near windows, and cracks. Note patterns. Note also the condition of the interior of the curtain wall.

3.23 Determine Degree of Settlement
Determine the alignment of horizontal and vertical elements and the plumbness of the building. Observe entrance at ground floor for evidence of change in altitude.

If the building is found to be out of plumb, enlist the services of appropriate professionals to identify the cause and determine whether movement has ceased. Have a geotechnician, for instance, review foundation drawings, original soil studies, behavior of adjacent structures, and current soil condition. Determine whether there are any vibrations, and if so, what their source is.

3.24 Survey Conditions of Exterior Walls
Using magnification when necessary, survey the conditions of the exterior of the building, paying close attention to the areas identified in sections 3.12 and 3.22. This may be done from adjacent buildings, from the ground, or from scaffolding on the building itself.

Note all cracks as well as whether they look seasoned (eroded edges or re-opened pointed crack) or fresh; are accompanied by discoloration, efflorescence, or spalling; or follow the line of mortar joints or run through masonry.

Displacement of elements is sometimes difficult to see in this type of building since observation will likely be from a distance. This condition will be visible in raking light and should be recorded in as much detail
as possible. Note the presence of discoloration or efflorescence at these areas, the degree of newness, and whether attempts have been made to seal accompanying cracks. Also note the presence of adjacent voids.

Record all previous repairs to determine their condition and the condition of surrounding materials.

Record failure in materials such as glaze failure and spalling in brick and terra cotta; and erosion, delaminating, spalling, pitting, and discoloration of natural stones.

Observe voids and open joints in all materials. Pay close attention to the joints themselves and record any apparent erosion, cracks, or evidence of separation from masonry.

Collect evidence of runoff patterns, rusting and efflorescence by recording the location, shape, and opacity of white, green, reddish-brown, and black discoloration.

3.25 Survey Conditions of Roof(s)
If it is possible to gain access to the roof(s) of the building, do so and record any blistering or other evidence of water infiltration (such as plant life), holes or tears, the system of drainage and its success, the condition of the flashing at the perimeter and at any projections, and the condition of the material itself.

Observe the parapet for water penetration, open joints, failure in coping stones or joints, any indication of recent movement, and trueness of plumb. Inspect flashing at perimeter and projections. Examine the roof at vertical surfaces such as dormers and roof substrate under patches.

3.26 Map Selected Findings -- Wall and Roof Conditions
On a blank copy of the same simple elevations used in previous maps, map the information collected in Sections 3.23 (Settlement of Building) and 3.24 (Conditions of Exterior Walls) and any information from Section 3.22 (Conditions of Interior) which had to do with the exterior wall. The chronology and the interior or exterior location of a condition should be readily understandable.

On a simple roof plan, map the findings of Section 3.25 (Conditions of Roof).

3.3 ANALYSIS OF FINDINGS
The information gathered so far will have identified areas with visible manifestations of failure, and may already have offered clues to their sources and suggested problem areas which have not yet manifested visible symptoms. In order to uncover these clues and hidden problems, the role of the environment
(pollution, wind load and direction), the inherent or created weakness of certain systems (faulty details, areas affected by deterioration or corrosion), and the properties of the materials (actual strength, elasticity, permeability), must be investigated.

3.31 The Role of the Environment
Chemicals in the atmosphere, such as sulfur dioxide and carbon dioxide, may very likely affect building materials, as was described in Chapter 2. Knowledge of the substances to which materials are subjected will aid in unraveling sources of deterioration. Information about wind and precipitation patterns will also be of help. Finally, knowledge of prevailing winds, freeze-thaw patterns, and comparison of this historical information with the history of maintenance of the building may reveal sources.

Contact the Environmental Protection Agency. The EPA is concerned with health and human safety and does not collect information on all air- and precipitation-borne chemicals which affect building materials (for instance, carbon dioxide levels are not measured). Some of their "criteria chemicals" for humans, however, are also criteria chemicals for buildings (such as Sulfur Dioxide).

Local climatological data is available from the U.S. Department of Commerce, dating back to 1949. Valuable information may be gotten from the annual meteorological data collected and analyzed; such as daily maximum and minimum temperatures averaged per month; amount and type of precipitation; and prevailing direction, speed, and direction of fastest wind. This information may be used to trace freeze-thaw cycles and evaluate the participation of wind in observed damage.

3.32 The Properties of Materials and Their Mechanisms
Questions having to do with the properties of materials may be answered through laboratory or in-situ testing. The following is a list of ASTM tests158 which will aid in establishing such factors as the sources of deterioration, the activity of cracks, the reasons for these cracks, the actual strength and composition of deteriorated materials, and to find and evaluate suspected corrosion.

As tests are often costly and problematic, they should only be utilized when they will yield necessary information which will lead to or confirm a source of deterioration, identify a mechanism, reveal the properties of materials and systems.

<table>
<thead>
<tr>
<th>Designation</th>
<th>Standard Method (Comments)</th>
</tr>
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The telltale signs of hidden rusting metal, such as bulging and ferrous discoloration, are generally responded to with the removal of masonry to access metal or with the decision to do nothing. Non-destructive methods of testing have not yet been developed expressly for use on metal-frame buildings, although methods have been developed to find rusting rebars in reinforced concrete. Some of the methods
which are in use today in other types of buildings may be adaptable for use in detecting the presence and degree of metal corrosion in metal-frame buildings.

**Radiography** involves a portable "source unit" and film on opposite sides of an examination area, the source unit exposing the film through pulses of radiation sent through the area. With this method, it is sometimes possible to view variations in porosity, inclusions, and discontinuities. This method, however, is not inexpensive and safety precautions must be taken.\(^{159}\)

To study roofing for entrapped water without breaking the surface of the roof, x-raying has been adapted. The layout of the roof, including location of projections and drains, is drawn, a grid laid over it and on the roof, and a neutron generator mounted on a cart moves over the surface counting the total number of hydrogen atoms present, apparently making adjustments for hydrogen-bearing roofing materials.\(^{160}\)

Another non-destructive technique for measuring degrees of damage to roofing reads the thermal changes in the roof. An infrered scanner, mounted on a helicopter flies over the building at various altitudes, temperature scanning the entire roof each time.\(^{161}\)

**Infra-Red Detection** produces thermal (heat) pictures form the invisible energy (electromagnetic waves) radiating from building materials. This method can be used to identify hidden voids and elements of structure. It is very sensitive to environmental conditions and expensive to buy although consultants exist.\(^{162}\)

The propagation of high-frequency sound waves, **Ultrasonics**, tests for concealed inconsistencies, voids, faults, and cracks. Although this method is successfully used in quality control of homogeneous materials such as metals, ceramics, and concrete, it has been found to be only marginally successful at building sites. This method is typically unable to discern multiple boundaries in close proximity.\(^{163}\)

**Microwave Analysis**, although still in its infancy, has apparently been used for the detection of voids, inconsistencies, faults, and the location of dense buried materials in Canada and the United States.


\(^{160}\) "A Nuclear 'Divining Rod'... for Pinpointing Roof Problems," *Technology & Conservation* (Fall 1976), 5.


\(^{162}\) Fidler, "Non-Destructive Surveying Techniques."

\(^{163}\) Fidler, "Non-Destructive Surveying Techniques."
Electrical signals which are sent into the material bounce back from each surface and are amplified for recording.\textsuperscript{164}

It is Magneto\textit{m}etry which is typically used to locate reinforcement steel buried in concrete, measuring the degree of disturbance to a large bent-bar magnet probe from elements within the area -- non-magnetic materials are transparent. This method is expensive, but the equipment is rentable.\textsuperscript{165}

Surveying through Fiber-Optics consists of optic fiber (cylindrical mirrors with near-total internal reflection and few leaks) in tubes or cables sent into voids and sending back pictures. It can be made to travel around bends and can go far from its lamp source. Endoscopes (flexible tubes more than six-feet long filled with optic fibers) and borescopes (fibre optic cable and a small diameter stainless steel pole with built-in optics) are two varieties of this type of testing.\textsuperscript{166} It is the borescope which has met with success in its limited use in buildings such as those considered here.

3.34 The Need of Further Investigation

As a last, but often necessary, resort, destructive investigation should be undertaken with the "Priority One" areas as they are described below.

The Priority One areas are areas which are in danger of detaching and harming surrounding people and buildings, which may be allowing significant water infiltration, and which are suspected of having lost their necessary structural integrity.\textsuperscript{167} Priority Two areas are areas of the exterior which seem to be cosmetically damaged but which may soon degenerate to Priority One or whose appearance impacts significantly on the architecture. Priority Three areas are those which will require testing to determine mechanisms of deterioration, but whose deterioration will not impact significantly on the structural or architectural soundness of the building.

3.35 Suggestions for Future Investigation

Skyscrapers and other metal-skeleton buildings are now being designed with the aid of computers. New technology allows architects and engineers to design a building and on it hypothetically test horizontal, vertical, lateral, and wind loads as well as other possible forces. A new development in the assessment of

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\textsuperscript{164} Fidler, "Non-Destructive Surveying Techniques." Fidler is researching this method further.

\textsuperscript{165} Fidler, "Non-Destructive Surveying Techniques."

\textsuperscript{166} Fidler, "Non-Destructive Surveying Techniques."

\textsuperscript{167} For instance, areas with bulging, cracking, stained masonry which are located above structural metal are of the first priority for testing to locate corrosion. Areas which appear to be considerably deteriorated due to compressive and tensile stresses and moisture related problems are also of the first priority.
bridge deterioration (specifically fatigue distress) has been achieved at the ATLSS Laboratory of Lehigh University using data collected in the field and evaluated by a database-run Knowledge-Based System. This system, the Bridge Fatigue Investigator (BFI) for metal girder bridges, identifies "connection details on the given bridge which are most susceptible to fatigue distress," based on knowledge of "distortion-induced fatigue situations," and recommends close observation of those details.\textsuperscript{168}

Computerization of the assessment process for metal-skeleton buildings may best be done with a database and may perhaps be developed as a dissertation topic for a structural engineer with a bent for conservation. Creation of a database which interacts with graphics programs such as AutoCAD\textsuperscript{169} and MicroStation\textsuperscript{170}, allowing identified areas and elements to be highlighted graphically for explanation to a client, may be the superior approach.

\begin{footnotesize}
\begin{itemize}
  \item \textsuperscript{168} ATLSS Brochure, Lehigh University.
  \item \textsuperscript{169} AutoCAD is made by AutoDesk Inc.
  \item 2320 Marinship Way, Sausalito, CA, 94965
  \item (415) 332-2344
  \item \textsuperscript{170} MicroStation is made by Intergraph Corporation
  \item 1 Madison Industrial Park, Huntsville, ALabama 35807
  \item (205) 722-2549
\end{itemize}
\end{footnotesize}
The focus of this chapter is on the conditions of both the exterior surfaces and steel skeleton of the 1932 PSFS Building located in Philadelphia, PA. An analysis of the findings follows the graphic representation of the conditions found.
4.1 A BIT OF HISTORY

The PSFS building at 12th and Market Streets in Philadelphia, PA is 59 years old, built in 1932\footnote{The building had its beginnings in 1926, with a commission from the Society to Mellor, Meigs & Howe, an architectural firm in which George Howe was a partner (made so shortly after his 30th birthday). Howe, assisted apparently to a small degree from Meigs, created a blocky building, which rose straight from the 3-storied banking room to the 15th floor and then rose further with setbacks. The Philadelphia Savings Fund Society was concerned with the attractiveness of the site for banking and had George Howe, still in partnership with Mellor and Meigs, design a small, temporary structure there. It was not until early in 1929 that the Society decided to go forward with a skyscraper and solicited proposals from George Howe, who had left Mellor, Meigs, and Howe, and also from Meigs, since he had participated in the 1926 design. According to William Jordy, Meigs's design was traditional while Howe's four alternate schemes were modern and Howe got the commission. In the second scheme proposed by Howe began the building which was to become the PSFS building. Dated March 20, 1929, this design preceded the Howe and Lescaze partnership by more than a month yet two aspects find similar counterparts in the final design. First is the slabline massing of the office tower, with columns rising on a series of trusses which bridge a banking space surrounded by columns. Second is the location of the elevator spine at the back of the slab, the site of the top half of the present T. With the collaboration of Howe and Lescaze came a combination of Howe's traditional education at Groton, Harvard, and the Ecole des Beaux Artes and Lescaze's more modern education in the Zurich Technische Hochshule. Lescaze was 10 years Howe's junior. Apparently, Howe was in search of first-hand contact with European modernism as he suggested the partnership. Howe brought the PSFS commission to the partnership at which time Lescaze took control of the design, as per their general partnership agreement. Howe had not only acquired the commission and started the design, but also had a Gentlemen's Agreement with James Willcox, the president of the Philadelphia Savings Fund Society, to produce a respectable building and not just publicity for himself. Willcox was, like Howe, familiar with tradition but open minded. All of the correspondence between Mr. Willcox or the Building Committee at PSFS and Howe & Lescaze was handled by Howe or an assistant. Lescaze was not invited into correspondence for two reasons. First, the partners' agreement was such that Howe was to be predominantly responsible for business and Lescaze for design. Second, according to a draftsman in the office during the commission, was President Willcox's intense dislike for Lescaze and corresponding respect for Howe. Nevertheless, according to their partnership agreement, Lescaze was responsible for control of the design. The December 2, 1929 rough preliminary sketch of the base is the first PSFS drawing by William Lescaze. This sketch shows the curvature of the base and an overhang where the final cantilever will be. At this point the architects were already studying the possibilities of banking on the second floor. 23 days later, a more detailed sketch included the curvature, the canopy, and more clearly the ribbon windows - horizontality was a feature in which the architects believed strongly. Two of the most distinctive features of the building were initially a source of disagreement between the architects and Mr. Willcox. The expression of the structure through articulation of columns on the exterior of two elevations was promoted by Mr. Willcox, and disclaimed by the architects, while Mr. Willcox had to be convinced to allow six-foot cantilevers on two facades.} by Howe & Lescaze with the participation of the PSFS president, James Willcox. This building was the second in the United States to be entirely air conditioned.\footnote{The first had been the 1928 21-story Milam Building in San Antonio.} The structural engineering firm was Purdy & Henderson. The steel was manufactured by the American Bridge Company, and erected by Karl Koch Erecting Co.
The PSFS Building has been recognized by Architectural Historians (including Henry Russell Hitchcock, Philip Johnson, Vincent Scully, William Jordy, and Robert Stern), famous architects (Paul Cret), and various architectural and historic preservation bodies as significant locally, nationally, and internationally. Commendations the building has received include:

- **Certified Historic Building.** Philadelphia Historical Commission, 1968.
- **Blue Ribbon Building Award.** Philadelphia Chapter, AIA, 1981.

The building sits at a corner and so has the potential to be abutted by other buildings at just two facades. The west facade has actually been joined from the sixth floor down to a building called 1234 Market Street. At the south sits the landscaped PSFS Plaza. This site had been occupied from 1812-1973 by a Friends Meeting House. Indeed, some of the maintenance records refer to the facade above the "Friends' Garden".

### 4.2 PHYSICAL DESCRIPTION OF THE BUILDING

#### 4.2.1 Dimensions and Massing

PSFS is a 36-story 491-foot high steel-frame building enclosing a volume of 8-million cubic feet and a floor area of 560,000. While the footprint of the building is rectangular, the tower of the building is in the shape of a unequal "T", with services such as elevators, stairs, flues, and duct shafts located in the head of the "T". The stem of the "T" contains the banking room and executive offices as well as most of the rentable office space. The tower is topped by observation decks (one of which has been taken over by Bell Telephone) and executive spaces. Portions of the north and east facade are cantilevered 6'-5" past the final column line\(^{173}\) and begin, at the sixth and third floors, respectively, with metal gutters.

#### 4.2.2 Materials

The building is clad with fossiliferous limestone, black and grey granite, and three varieties of sand-lime brick: grey, glazed (glossy) black, and unglazed (matte) black. Hollow tile serves as back-up masonry for the cladding and was also originally used as interior partition material. The interior spaces have been changed to suit the needs of tenants and most of these tile partition walls are no longer extant.

In addition to the serving as north elevation cladding of the third- and fourth-floor executive offices and cafeteria, limestone covers columns which project from the building on the grey-brick portion of the east and west facades. The triangular PSFS sign at the top of the building (on the roof above the 33rd floor) serves to both announce the building and cover rooftop mechanical systems.

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\(^{173}\) Incidentally, these cantilevers increased rentable space by 7,000 square feet.
The roof consists of Dex-O-Tex\(^{174}\) roof deck surfacing over the original roofing material (quarry tile on top of the structural concrete deck, which was topped with bituminous built-up felts). Coping for parapets are of limestone, black granite, as well as metal light boxes which are no longer in service for lumination purposes. Roofs shed water through drains which lead to interior pipes in the shaft wall.

Cast-in-place concrete serves as fireproofing for columns and trusses, the flooring is of concrete (according to the Building Manager, Victor Pepenelli, it is cinder-fill concrete). The building rests on caissons and its lower level includes an entrance to a subway substation.

This is a steel-skeleton building.

4.23 The Structure

Of the eleven-thousand tons of steel used in the building, 5,600 were used in the columns and 750 tons in the trusses. Trusses in the "third mezzanine" space between the second and third floors span the banking room on the second floor, carry the columns of the upper 30 stories of the building and allow for a 63-foot widthwise expanse in this space. The two lines of interior columns which help support the upper 30 stories of the tower begin at the top flange of the third floor mezzanine truss.

At the second floor, the first, northernmost truss is 12'-9" high, and the six following trusses are 4'-9" high. The flooring of the first level is carried by six 4' trusses, with the area between the northernmost columns spanned without a truss.

Due to the trusses of the first three floors, this area was considered by the designers to be rigid. Windbracing is provided in all of the upper stories by knee braces at every connection of column and girder. The exception to this is the k-bracing at the south elevation. Assuming a wind pressure of 30 pounds at the top of the building, the members and systems were designed to allow up to 0.002-times the height, or about 7" (0.035" per floor) total deflection.

Complicated framing was necessary to accommodate the rounded northeast corner faced in granite, limestone, and metal, as well as to permit the front corner shop windows to be carried several feet outside

\(^{174}\) The Dex-O-Tex system consists of a "slip sheet" on top of the substrate, a fabric reinforced waterproof latex membrane, topped with a neoprene-cement traffic surface which comes in eighteen colors.

DEX-O-TEX Product Description Sheet, (Roselle Park, NJ:Crossfield Products Corp). Information received from Jim LePond of S. S. Gill who performed the roof work.
the column lines. The system includes eliminating the corner column and cantilevering the floor and cladding support from the nearest columns. A 2'3" beam diagonally spans the corner, supported from the nearest north facade column by an inclined hanger and from the nearest east facade column by an angle and plate girder cantilevered 9'8" from the column line. The cantilevered girder carries channels which span this (the east) elevation then round the corner (supported by the 2'3" beam) to run along the north face in front of the first truss. At this facade, the system is supported by inclined beams which cantilever from the top chord of the truss behind the first.

These channels support granite and limestone panels at the third mezzanine level. Similar, although lighter, channels support the granite at the second floor, and a similar corner arrangement is used. The small roof over the show windows of the Market Street and 12th Street elevations is also supported by the second floor framing.

The limestone of the east and west facade exterior columns are carried on a shelf angle at the front of the column and at angles which also diagonally brace the outer flanges of these columns to the spandrels. The bracing is necessary since the spandrels between the columns are connected to these columns at the inner flange.

The brick cladding is supported on angles mortared into the backup hollow tile, which in turn sits on angles riveted to spandrels, a single wythe of hollow tile backing of a single wythe of face brick. Full and partial header courses also tie the brick back to the tile. This hollow tile appears to be the same tile which was originally used in interior partitions. In some cases, the wythe of brick has been reduced to accommodate bolt and rivet heads. As originally constructed, mortar was placed over the joints which contain angle flanges. Cracks and open joints have been covered with elastomer, in some cases on top of inserted mortar.

As originally designed, the masonry sat directly on the metal without benefit of flashing. As the building stands today, flashing is present only in the northeast and northwest corners of six floors, installed in 1989. The walls are solid rather than cavity walls, and hence have no weepholes (except for the granite which has weepholes at the east facade). Sills lap over half of the top course of brick.

The 6'5" cantilevered portions of the north and east facades necessitate special treatment of the framing. Floor beams cantilever over the girders of the front bent and are connected to a beam running perpendicular through the webs (flanges are coped). A bracket is connected above each floor beam to the flanges of both beams, and angles are connected vertically to this bracket. A continuous horizontal angle sits on top of and unites the vertical angles and connects back to the columns at the extreme ends.
The information just recounted was taken predominantly from American Bridge Company drawings\textsuperscript{175} and is therefore the theoretical version of what actually stands at the corner of 12th and Market Streets. It is necessary, therefore, to addend this information with relevant directions included on the drawings for erectors.

- "In order that the cantilever beams running over the top of the girder beams between columns 1-4 and 37-51 (the columns at the north and east cantilevers) may be set level, the girder beams between these columns have been dropped 1/4" and 3 shims 1/8" thick have been bolted to the top of the girder beam. The erector must take out or add shims, in order to make the cantilever beams level."

- "Steel in spandrels supporting stone on 12th Street and Market Street must be carefully set by the Erector and the stone contractor must exercise care in chasing and erection of the stone as no adjustment has been provided in the design of the steelwork."

- "Where beams are marked (-4) or (-5) (i.e. they are 4" or 5" below finished floor line) on plan "this figure must be held and the necessary shims used between bottom flange of beam and seat angle."

4.3 SUMMARY OF PREVIOUS PROBLEMS AND MAINTENANCE

As is obvious from the maps derived from the information located in the PSFS Archives,\textsuperscript{176} the files of the Building Manager, the correspondence between the original architects and various PSFS personnel, and contractors' own records, the PSFS Building has received a lot of attention to maintenance. Much of the maintenance is in quick response to problems which were noticed by alert building management or by tenants with leaks. To this day, the Building Manager keeps a close eye on the conditions of the roof and the interior walls as well as other aspects of maintenance.

The maintenance which has previously been performed on the building generally involve cracking of masonry at joints or through elements (usually brick, less frequently limestone and granite), opening of joints, deterioration of window caulking, and replacement of roofing materials. According to the Building Manager, much of this is preventative rather than reactive maintenance and so therefore may not be indicative of problems. Although the records of joints in limestone, granite, and brick being pointed (at

\textsuperscript{175} Other sources aided the interpretation of these drawings:
On the PSFS staff, Victor Peperelli, Building Manager, and Craig Thigpen, Architect-in-Residence.
References to the structure in maintenance and correspondence files.

\textsuperscript{176} APPENDIX 3 contains a description of available records which pertain to PSFS maintenance.
Maintenance records earlier than 1966 were not found in the building archives. Any earlier listed records would have come from correspondence files or contractors' records.
least at the outermost portion of joints) with elastomeric sealant rather than replacement mortar begin in 1969, earlier treatments are possible.

Waterproofing of the building is listed often in the 1980s, but unfortunately the location of these treatments were not specified. Earlier treatments, however, such as the 1967 brick and the 1969 limestone waterproofing, were described. Additionally, all or part of the limestone of the north facade was sandblasted in 1973.

In 1982 water pipes in the PSFS building suffered extensive damage, breaking and leaking in two separate instances. According to the current Building Manager, no signs of the flooding appeared on the exterior of the building.

The roofs of the PSFS Building, originally of quarry tile and built-up felt and bitumen, were replaced with Dex-O-Tex, a seamless neoprene deck system, from 1961 to 1964. Repairs to the roofs occurred intermittently afterward, with one scheduled to be undertaken soon at the only tear in the surfaces found in the conditions survey.

The maintenance records provide almost all of the information available about the condition of the interior of the building. In addition to this information, it should be noted that staining was witnessed by this author in the ceiling of the Executive Dining Room on the 33rd floor. The ceiling was not wet, however, and may not be a recent stain. No other interior damage was observed, although it should be noted that most of the building is occupied by private offices and was not accessible for observation.

One final item of interest found in the archives: photos taken during construction shows the cast-in-place fireproofing and the building of the exterior walls being built during the winter. As raising the building as quickly as possible was of importance, as it is with just about every other building of this scale, chemicals may have been added to help prevent the freezing of mortar and concrete. Also, since they were laid in the cold, perhaps freezing, weather, the bricks, tile, mortar, and concrete were at their smallest dimension, likely to increase in volume with the heat of subsequent springs and summers.

4.4 SUMMARY OF CONDITIONS OF EXTERIOR WALLS AND ROOF
The conditions of the exterior walls were surveyed from the ground and from adjacent or nearby buildings. The north and east elevations were surveyed from the ground and from the 23rd floor of the ARA Building at 11th and Market Streets. Portions of the east elevation were also surveyed from within the building itself. The west elevation was surveyed from the 6th and top-floor roofs of the connected 1234 Market
Street building. The south elevation was surveyed from the ground as well as from the building directly across the PSFS Plaza to the south.

The building was surveyed on sunny and partly cloudy days, with the amount of sun due to time of day dictating what time each elevation was observed (north and east in morning, south in afternoon, and west in late afternoon). Conditions which were less obvious were observed with magnification and with the aid of raking light to identify areas of subtle as well as marked bulging and displacement.

The general condition of the materials are as follows:

4.41 Limestone
The limestone which sheathes the exterior columns of the east and west facades was found to have cracked through some of the blocks with no related discoloration involved. The only spalling limestone observed is sheathing the first and fifth columns from the north on the west elevation (near the sixth floor roof). The spalls had been caulked, but had progressed and split the caulk.

Erosion of the limestone is evident on 100% of the surfaces seen, yet all but the 5th floor north elevation coping seems to be of minor circumstance. Staining of the limestone is marked beneath the north elevation cantilever, and bedding planes are evident in the columns.

4.42 Granite
The granite was found to be cracking at the bases and corners of panels (6% of east elevation panels and 12% of north elevation panels exhibit such cracking). In two places the granite was seen to be bulging. The condition of the material was excellent, however, with no erosion evident in either panels, basecourses, or coping stones.

4.43 Brick
As evidenced by the maintenance records and correspondence, the brick has experienced problems such as open joints and step- and through-brick cracking. The historical cracking and that which continues to occur is located predominantly at outside corners. Inside corners (i.e. the corners where the "T" goes from stem to top) exhibited no such cracking or signs of pathology.

177 See ILLUSTRATIONS which follow for exact locations and descriptions of conditions by elevation.
The brick was also seen to be mechanically damaged, stained in places, and experiencing horizontal displacement quite frequently at panels near the roofline. The mechanical damage occurs directly above and below mortar joints and across the faces of bricks with a sweeping appearance. As determined by degree of displacement, the most severe instances of shifting occur at the west elevation (particularly between the 4th and 5th column from the north), and at the southwest corner of the south facade. Horizontal displacement was also observed, to a much lesser degree, within the south elevation stretch of panel. These slight and marked areas of displacement occur at or very near areas which theoretically contain steel. They are also often at the level at which the parapet begins. Most of the deterioration at the south facade may be characterized as large, concentrated areas of open joints, black and white patches and streaks, and this subtle horizontal bulging.

With the exception of the streak extending from the penthouse at the south facade, black staining of brick generally corresponds to the location of window mullions and was observed on 90% of the brick spandrel areas. Brick delamination only afflicted header bricks. This "delamination" looks as if the glaze or paint had simply rubbed off. The delamination occurs independent of other visually observed pathologies, although they may be related.

The most significant horizontal caulking, corner step-caulking, and step-cracking occurred at the north elevation (Market Street facade).

Many of the areas of previous treatment were quite obvious. For instance, brick which was chosen to replace grey brick at the northeast and southeast corners of the tower was entirely distinct in color from the original. Due to the decision to repoint with black or white caulk, previously (and perhaps still) open joints were easily seen and recorded. The areas of most significant brick replacement occurred above the 24th floor at the northeast and northwest corners of the Market Street facade. Significant brick replacement also occurred at the easternmost portions of the 34th and 35th floors.

4.44 Roofs

Roofs were generally of excellent condition with well maintained coping joints and parapet- and projection-flashing. Over all of the roofs observed, only one 1/4" speck of algae was observed. The roof in the most disrepair is that which covers the 6th floor above the bank entrance and connects to 1234 Market Street. Here, the surface is irregular and has ponding and unsealed drains. Mortar in the parapet in this roof is deteriorating in spots. Of all the coping materials -- limestone, granite, and metal (the lightboxes) -- the metal lightbox coping seems to have the greatest amount of difficulty, having separated in places from the brick on the outer face of parapets.
4.5 ANALYSIS OF FINDINGS AND CONCLUSIONS

The analysis of the pathologies found in the PSFS Building will take the form of conjecture followed by recommended testing procedures to determine sources and causes. It will be necessary to perform tests on the building as well as on elements taken from the building.

The horizontal displacement of panels of brick may be caused by rusting and expansion of steel members beneath, compressive and tensile stresses in highly restrained brick, differential movement of restrained and less-restrained panels (such as at the parapet) causing the less restrained brick to "ride off" of the shelf angle, or a combination of these. The facts that the roofs are and seem to have always been well maintained, and that no ferrous discoloration was observed may point to low rather than high amounts of water penetrating. It also suggests that the bulging and displacement were due to differential movement rather than water penetration.

The building was windbraced assuming the vertical cantilever principle: deflection is theoretically taken in columns while the horizontal elements remain planar. The fact that the building is working in this manner is evidenced by the locations of the cracks and bulging: at or near horizontally-restraining steel elements. Further evidence is the lack of cracking at inner corners.

That there are two (and perhaps more) explanations suggests the need for further investigation into the areas beneath and into the nature of the bricks themselves. ASTM E518: Flexural Bond Strength of Masonry, E519: Diagonal Tension in Masonry Assemblages, monitoring of cracks for movement, and strain testing is suggested. As the cause of the displacement may not be rusting, non-destructive investigation in the widest gaps using the fibre optic boroscope may shed light on the reason for this movement. It may be necessary, however, to remove the brick in the most severely affected areas.

Almost all of the observed pathology of the west elevation occurred above the line of shade caused by the 1234 Market Street building. The effect of thermal changes may figure heavily in the problems with the elevations experiencing strong sun: East, South, and West.

The location of the granite cracking points to difficulty with the angle supports. Indeed, the message to erectors on the American Bridge Company drawings warned of a need for "care in chasing and erection of the stone as no adjustment has been provided in the design of the steelwork." According to the maintenance records, the granite was repaired in 1974. If it is the case that the cracks have not been redressed since that time, then they may be thought of as stable since no reopening was noted.
The two areas of displacement (one spall and one two-panel bulge) should be investigated, however. The spall may be removed and the cause searched for. The removal of the panels, however, may be problematic and a boroscope may be sent in.

The cracking of the north elevation cantilever corners should be monitored for movement. The difference between the changes in lintels with flashing and those without should be noted over time as these changes will help to identify the specific effects of lack of flashing in these areas.

The staining of brick and limestone does not appear to contain rust, and while the black staining of the brick and limestone are likely due to pollution, these products should be analyzed to determine the chemicals of which they are made and the degree to which they are affecting the building materials beneath. Samples of the white staining at the south elevation should be taken and analyzed as well. The staining of the exterior materials may be detrimental to the building only from an aesthetic standpoint but could also be indicative of more serious deterioration.

While the analysis of the products of deterioration involves simply sending samples to a testing laboratory, the degree to which these mechanisms are affecting masonry depends on a number of factors. First is the propensity of the building material to react with the product. Second is the permeance of the masonry elements (ASTM test E514: Water Permeance of Masonry), and third is the permeance of the wall itself (ASTM test E 547: Water Penetration of Exterior Windows, Curtain Walls, and Doors by Cyclic Static Air Pressure Differential).

According to a source\(^{178}\) at the Environmental Protection Agency, fuel is required to be low in sulfur in Philadelphia. The monitoring site located closest to the PSFS Building registers the highest sulfur dioxide reading in the Philadelphia area, but is still fully half of the EPA standard of 80 micrograms/meter\(^3\). According to the EPA, levels have always been low in Philadelphia.

Another aesthetic problem which may have greater implications is the method of repointing. One of the functions of mortar is to allow the passage of water vapor at joints causes water vapor to travel through bricks and limestone. The use of black sealant on white limestone and light brick is historically incorrect and jarring to the eye. Similarly, the replacement of brick with brick of a different color imprints a patchy building surface on the mind's eye.

\(^{178}\) The person contacted was Michael Giuranna.
4.6 ILLUSTRATIONS
The following thirteen pages contain illustrations of the materials, history of maintenance, and conditions of the exterior facade and roofs of the PSFS Building, organized by facade.

4.61 Materials
Representation is of the typical materials. New replacement brick, of colors different from the original brick is shown in the conditions section.

4.62 History of Maintenance
These illustrations include maintenance performed as well as significant events which could be attributed to a specific area. Due to the often general nature of descriptions of maintenance (eg: "Waterproofing work was performed"), much of the Maintenance information did not lend itself to diagramatic translation. The written description of maintenance records, outlined in Appendix 3, should be consulted in addition to the illustrations should any questions arise.

4.63 Conditions
Conditions shown are solely those observed by the author with the naked eye and through binoculars.
KEY

Black Brick (Matte)
Black Brick (Glazed)
Grey Brick
Black Granite
Grey Granite
Limestone
Metal

PSFS BUILDING
Materials
SOUTH ELEVATION
PSFS BUILDING

Conditions

WEST ELEVATION
KEY

Black Granite

Limestone

Metal

Dex-O-Tex

PSFS BUILDING
Roof Materials and Conditions
4.7 PHOTOGRAPHS

Most of the photographs were taken from buildings proximate to the PSFS Building with magnification. The photographs were taken from the sites at which the elevations were surveyed. The North and East Elevations were photographed from the 19th floor of the ARA Building at 11th and Market Streets (through colored glass) as well as from the ground; the South Elevation was photographed from the 12th floor of the bank building at 12th and Chestnut (through colored glass) and from the ground; and the West Elevation was photographed from the 6th floor roof of the PSFS Building and from the top floor roof of the adjacent 1234 Market Street Building.
PHOTOGRAPH #1: North Elevation, 31st Through 33rd Floors

PHOTOGRAPH #2: North Elevation, 29th Through 31st Floors
PHOTOGRAPH #3: North Elevation, 2nd Through 4th Floors

PHOTOGRAPH #4: North Elevation, Street Level
PHOTOGRAPH #5: North Elevation, 3rd Through 8th Floors
PHOTOGRAPH #6: Northeast Corner, 30th Through 32nd Floors

PHOTOGRAPH #7: East Elevation at North End, 31st and 32nd Floors
PHOTOGRAPH #8: East Elevation in Raking Light, 31st and 32nd Floors
PHOTOGRAPH #9: East Elevation, 34th and 35th Floors

PHOTOGRAPH #10: Northeast Corner, 34th Floor
PHOTOGRAPH #11: East Elevation, 20th floor

PHOTOGRAPH #12: East Elevation, South End
PHOTOGRAPH #13: East Elevation, 2nd Mezzanine Through 4th Floor
PHOTOGRAPH #14: South Elevation at East Corner, 32nd Through 34th Floors

PHOTOGRAPH #15: South Elevation, 13th Floor
PHOTOGRAPH #16: West Elevation, 32nd and 33rd Floors

PHOTOGRAPH #17: West Elevation, 23rd Floor
PHOTOGRAPH #18: West Elevation, 33rd Floor

PHOTOGRAPH #19: West Elevation, 33rd Floor
PHOTOGRAPH #20: South Elevation, 33rd and 34th Floor

PHOTOGRAPH #21: South Elevation at West End, Ground Level
PHOTOGRAPH #24: West Elevation at 6th Floor Roof

PHOTOGRAPH #25: Northwest Corner, 7th Floor
PHOTOGRAPH #26: West Elevation

PHOTOGRAPH #27: South Elevation
PHOTOGRAPH #28: 33rd Floor Roof

PHOTOGRAPH #29: 33rd Floor Roof
CHAPTER 5

Conclusions

"The buildings familiar to us have stood up to the assaults of nature so well that they look immortal; it takes an earthquake or a hurricane to make us realize that total structural failures are due almost exclusively to dynamic forces, that is, forces changing rapidly with time."\(^{179}\)

Mario Salvadori

The original thesis of this document was that the chances of catastrophic failure of metal-frame buildings of 1884-1932 due to hidden defects were higher than suspected. This was, however, not supported by literature or the architects and engineers interviewed\(^{180}\). Their contention is that the structures of this era were designed with enough redundancy to make up for inherent or developed defects. Additionally, catastrophic failures in buildings of this type were found to have occurred only during their construction.

The problems which have been found to exist -- faulty details and the properties and deterioration tendencies of constituent elements and materials -- contribute to failure which is less than total-structural, but failure nonetheless. The action of chemicals (e.g. acids, salts); water penetration and withdrawal; differential movement of cladding and surrounding elements due to thermal changes, expansion of materials, foundation movement and lateral loads; and human error serve to damage exterior materials and roofing and the metal structure immediately beneath. Most of the experts interviewed have had a significant amount of experience with the structure at the exterior of these buildings. Considerably less investigation further into the structure has been performed.

It was one of the original goals of this thesis to establish a methodology to identify the specific areas of a building which are most likely to fail. The scope of this problem is far larger than was anticipated and the preceeding document only scratches the surface. The contention that total structural failures are due to


\(180\) Other interviews which have not been mentioned previously included:
- Dr. Alan Pense and William D. Michalerya of the Center for Advanced Technology for Large Structural Systems (ATLSS) at Lehigh University were interviewed in November, 1990;
- Paul Byard of Byard and Platt Architects by phone in October, 1990.
- John Loss, of A EPIC (an architecture and engineering performance center at the University of Maryland) was interview by phone in December of 1990.
- Dr. Theodore Prudon of the Ehrenkrantz Group was interviewed by phone in February of 1991.
- Kimball Beasley of Wiss Janey Elstner Associates was interviewed in February, 1991.
- Lyle Haack, formerly of Certainteed Corporation (a roofing contractor), was interview by phone in March of 1991.
- Dr. Mario Salvadori of Weidlinger Associates in April of 1991.
dynamic forces such as earthquakes is based on the experience of the architects and engineers who have observed the conditions of 50+ year-old structures first hand. Yet we also understand that nothing is meant to last forever and that we can only hope to delay "the inevitable". It seems logical, then, that the deterioration associated with age will someday take a metal-frame building, the redundancy somehow finally not enough. Given their relative youth and redundancy, the elements and systems of these buildings may have not yet reached the point of yield, and so have not alerted us to this possibility and its potential location.

Economics may have more significant effects on metal-skeleton buildings of this era as the buildings grow older and the repercussions of these effects may be profound. The vacancies of the 1930s implied little new construction. The implications today of high vacancies are, in addition to little new construction, that some buildings will empty completely, maintenance will be deferred or performed in a temporary manner, and problems will be ignored.

Considerably more study is needed of the actions of the elements and systems of the metal-frame buildings of this era over time. This may take the form of investigation into the status of actual buildings either as they are or during their demolition. Simulations may also be performed, although care should be taken to make the tests as accurate as possible -- taking the effects of non-structural elements on the skeleton into account.

The catalogue of which APPENDIX 1 is comprised also scratches the surface of an area which needs considerably more attention. The seventy-five or so buildings listed in the APPENDIX is but a representative sampling of the thousands of buildings which stood by the end of 1932.
APPENDIX 1

Systems Used from 1884 to 1932, Chronologically by Building

The following list of buildings represents the more frequently discussed steel-skeleton buildings -- buildings which were built by famous architects, provided innovative designs, or were well executed examples of a mode of steel-skeleton architecture. It is not an exhaustive list of all steel-skeleton buildings built in the United States between 1884 and 1932, but represents buildings which were discussed by architects and engineers at the time of their creation, or architectural historians afterwards.

Some of the buildings discussed have been demolished but are included as requisite to any dialogue of the evolution of the steel-skeleton building. The following list denotes demolished buildings by including a DEMOLITION category. The lack of such a category in the description of a building, however, does not necessarily mean that that building has not been demolished, rather, no information had been found to indicate demolition.

N/A (not available) indicates lack of information rather than lack of a certain feature. If, for instance, a building was known to have no windbracing, "None" would follow the colon after WIND BRACING, and if information had not been found regarding WIND BRACING, N/A would follow the colon.

Most of the information listed is taken from accounts of buildings' erection. Subsequent changes to the buildings, therefore, are often not described.

1884-85 Home Insurance Building, Chicago IL\textsuperscript{181,182,183}
William LeBaron Jenney, Architect

DIMENSIONS/MASSING: Originally ten stories in height, this building was later increased to twelve.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: This building was the first iron and steel-framed curtain-wall building. The framing system consisted of cylindrical cast-iron columns on individual


\textsuperscript{182} A rather interesting account of how steel first came to be used in this building appears in Starrett pg. 27: "When the framework had reached the sixth floor, a letter came to Mr. Jenney from the Carnegie-Phipps Steel Company of Pittsburgh. It stated that they now were rolling Bessemer steel beams and asked permission to substitute these for wrought-iron beams on the remaining floors. Jenney agreed, and the resultant shipment was the first ever made of structural steel in the modern sense. The columns continued to be cast iron, however, since plates and angles of steel, of which the later steel columns were built up, had not yet been rolled."

footings, box columns of wrought iron in built-up sections at the exterior, and steel I-beams spanning these columns from the sixth floor upward. Columns were cast with projecting shelf brackets and filled with concrete. Wrought iron beams were connected loosely by a single bolt through holes larger than bolt shafts to allow for difficulties during erection. The beams were pulled tight to columns by means of a 1" wrought iron rod bent into the top flange of the girder and threaded through the column's adjacent flange, bolted by a nut placed inside the column. Cast iron lintels, which rested on (not bolted or riveted to) columns, supported spandrel walls between piers. The frame supported most of the load, but was aided by the presence of party walls and granite piers at the base. The brick fireproofing was designed by Peter B. Wight.

WIND BRACING: None

FOUNDATION: N/A

EXTERIOR MATERIALS: N/A

DEMOLITION: It was demolished in 1931.

1885-86 Rookery Building, Chicago IL\textsuperscript{184,185,186,187}

Burnham & Root, Architects

DIMENSIONS/MASSING: Eleven stories high, this building is a combination of cast iron, wrought iron, and steel.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: The skeleton is formed by cast iron columns, external wrought iron spandrel beams, and internal steel beams which spanned the columns, supporting the floors and party walls. No columns are located in exterior walls.

WIND BRACING: N/A

FOUNDATION: The foundations were the first of the concrete and steel grillage design. "...two courses of railroad steel, laid at right angles to each other and embedded in concrete, with steel I-beams embedded in concrete, with steel I-beams crossing the upper courses."

EXTERIOR MATERIALS: The exterior is covered with marble and terra cotta.

1886-1889 Tacoma Building, Chicago IL\textsuperscript{188,189}

Holabird and Roche

\textsuperscript{184} Condit, \textit{The Chicago School, 1875-1925}.
\textsuperscript{186} Contemporary written descriptions and illustrations may be found in the July 1888 \textit{Inland Architect}, on page 7 of a 1892 \textit{Chicago Times} article entitled "Chicago and Its Resources Twenty Years After (1871-1891)," the 1887 \textit{Commercial and Architectural Chicago} by G. W. Orear.
\textsuperscript{188} Condit, \textit{The Chicago School, 1875-1925}, 117-118.
\textsuperscript{189} Fleming. "A Half-Century of the Skyscraper."
Carl Seiffert, Engineer / Purdy & Henderson, Engineers

DIMENSIONS/MASSING: The building was L-shaped.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: The skeleton consisted of cast iron columns, wrought iron for larger beams, and Bessemer steel for smaller beams; load was carried by this frame and but also brick walls. The frame was the first to be constructed with riveting (speed and efficiency of construction improved). Cladding was supported at each floor by spandrel beams and cast iron lintels connected to cast iron columns.

WIND BRACING: N/A

FOUNDATION: The treatment of the foundation for this building was unique for its time; the subsoil was tested using 50-foot borings, revealing some areas of soft clay and water which were stabilized by excavating the water and clay and filling under pressure with concrete. Eighteen-inch thick concrete columns, reinforced with I-beams, floated the building.

EXTERIOR MATERIALS: Brick and terra cotta

DEMOLITION: The Tacoma Building was demolished in 1929 to make room for a much taller structure.

1888-1889 Third Chamber of Commerce Building, Chicago IL

Edward Baumann and Harris W. Huell, Architects

Although some of the load was transferred to masonry piers, the structure of this building carried a significant percentage. It was demolished in 1928.

1889 Tower Building, New York NY

Bradford L. Gilbert

DIMENSIONS/MASSING: This steel and iron skeleton, the first in New York, was built because the owner wanted as much space as possible from the 21-1/2 foot building front (and 39-1/2 foot rear). The building was ten stories with a basement and a cellar, 129' high.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: Columns were of cast iron. The walls and floors were carried on the steel frame.

WIND BRACING: N/A

FOUNDATION: N/A

EXTERIOR MATERIALS: N/A

DEMOLITION: N/A

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190 There are different Engineering firms credited for this building: Condit, The Chicago School, 1875-1925. Pp. 117-118. credits Seiffert and Starrett, P. 33. credits Purdy & Henderson.


INTRODUCTION

The metal-skeleton building is a recent development in the world of architecture relative to more traditional materials such as stone and wood and their systems. The year 1884 marks the erection of the Home Insurance Building in Chicago, considered by many to be the first skyscraper. Although the attribution of the title "First Skyscraper" has been a source of disagreement then as now, the building, designed by William LeBaron Jenney, was truly a landmark building in the history of metal-skeleton buildings -- completely fireproofed and the first to contain steel as a primary structural element. The Home Insurance Building heralded in an era of experimentation with new designs and materials and adaptation of the systems of other structural types (bridges, ships, railroads).

During the following decades many metal-skeleton buildings were designed and erected, their propagation slowing in the 'teens and late 1920s/early 1930s due to economic factors and world events. Many of the buildings built in the 1930s had been planned much earlier; new building was uncommon. Construction slowed almost to a stop in the 1930s and did not pick up again until after World War II.  

The PSFS Building of Philadelphia, designed by Howe and Lescaze, was completed in 1932, one of the last buildings to be built in this era. Included, before the building was finished, in The International Style, the book and Museum of Modern Art exhibit by Henry Russell Hitchcock and Philip Johnson, the PSFS was seen to be a prototype of, if not a participant in, this previously European movement in America. The building had elements which anticipated the future movement of metal-skeleton buildings such as the articulation of columns (on two facades). Built with masonry cladding on shelf angles, without cavity walls or expansion joints, and with riveted connections, however, the systems of the building belonged to the earlier era of metal-skeleton buildings which is the subject of study in this thesis.

1 "Skyscrapers" are often defined as those buildings which contain a loadbearing fireproofed steel frame, are tall, and contain elevators. Since the definition of tall, and therefore use of the term "skyscraper," is relative to temporal and geographic factors, the more consistent term "steel-skeleton" is used in this study. The skyscraper may be considered a type of steel-skeleton building.

2 In using the term "metal skeleton," this author is referring to those buildings of metal (cast iron, wrought iron, and/or steel) -frame construction in which internal and external loads are transmitted through the frame to foundations in the ground. The metal-skeleton buildings discussed in this study are ten stories high or higher.

3 In the 1934 edition of the Chicago Daily News Almanac, it was revealed that building space vacant as of January 1933 was 21.3% in New York, 25.5% in Chicago, 31.5% in Philadelphia, and 38.1% in Detroit. The conclusion that was drawn from these figures by Robins Fleming, an engineer and author of many articles about steel-skeleton buildings in engineering magazines, was that: "It is hardly probable that more high buildings will be constructed until a marked percentage of these vacancies is filled."


The cladding of metal-skeleton buildings from 1884 to 1932, however, was with the dimension stone, cast stone, brick, and terra cotta of masonry load-bearing buildings, albeit used in a somewhat different manner. Many buildings from this era have survived to today, and are now over 50 years old. Consideration for the preservation of these historic structures is crucial not just from an aesthetic and cultural standpoint, but for human safety as well.

The effects of age, environment, and use on the materials and systems of metal-skeleton buildings, as combinations of lesser and better known elements, is a complex subject, and the problems and issues involved with the conservation of these buildings are considerably less explored than those of the traditional materials and building types. In order to understand these lesser and better known elements, knowledge of the development of the fundamental systems and the properties and deterioration mechanisms of the materials of these buildings is necessary.

In order to determine the areas of a building in need of conservation, a conservator (or architect, or engineer) needs methods of collecting and weighing relevant information. Buildings may be considered analogous to human beings in that humans sometimes suffer from enigmatic ailments which may be identified by a practiced professional in a physical examination. An examination of every possible hidden human ailment, however, would be costly, time-consuming, and most likely unnecessary. Doctors receive clues from patients' past health and treatment records, from family history, and from known and common human ailments and make decisions as to what should be looked for, where, and how. Tests may then be performed to further examine the pathology, tests which may or may not cause some harm in and of themselves.

Such an educated-guess driven physical examination is appropriate for a steel-skeleton building. Clues such as maintenance records of problems, complaints, and treatments of the building; physical history of similar structures and examples of failures; and anticipated deterioration of the building's materials and elements, in addition to other architecture-specific factors, would serve as the guideposts for assessment. These guideposts have been organized in this thesis into a design which proposes to direct the assessment of the conditions of a metal-skeleton building.

This program has been utilized for the study of the conditions of the PSFS Building, 59 years-old this year. This study, and the analysis of information which was uncovered, may be found in Chapter 4.
CHAPTER 1
NOTES ON THE HISTORY OF METAL-SKELETON BUILDINGS OF 1884-1932

"The technical innovations made or perfected by the Chicago architects are now so common that, like all the great basic inventions on which our lives depend, they have come to be regarded as natural things that have always existed."^5

Carl Condit

The era between 1884 and 1932 was one of innovation and proliferation for the skeleton building. Armed with the empirical understanding of the strength of iron and steel, inspired by the implications of an increasingly speedy elevator, and motivated by the need for efficient use of increasingly expensive land, designers of Architecture in America created the soaring structures which quickly came to be identified as the definitive American Architecture: metal-skeleton buildings.

Building in iron and steel would have been neither possible nor conceivable had not a number of key developments taken place. The discovery of large iron ore deposits in the Mesabi Range and elsewhere, the existence of the railroads to transport the ore, and the invention of techniques to mass-produce iron and steel made the construction of iron and steel buildings possible^6. Furthermore, the skeleton itself would not have become what it did without the development of fundamental systems such as connections, foundations, and trusses in bridges decades before -- and the engineering insights associated with them.

That necessity is the mother of invention is especially true of the metal-skeleton building. As land prices rose in major cities such as Chicago and New York, owners sought ways to increase their rentable area to ground area ratio.

The first relatively tall office buildings in the United States were load bearing and, encouraged by the invention of the elevator^7, owners built taller. This required very thick walls at the base to carry the

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^6 A concise yet detailed account of iron and steelmaking in America and the advent of cheap steel through the developments of the Bessemer and Open Hearth processes was written by: W. David Lewis, *Iron and Steel in America* (Greenville, Delaware:Eleurthian Mills-Hagley Foundation, Inc, 1976).
^7 Elevators in buildings came before the steel frame. The desire for height was, to a great extent, based on economical considerations: the higher the building, the better the use of allotted area. Before the invention by Elisha Otis, six floors was the maximum building height. No one wanted to walk higher. With the elevator came higher buildings whose heights were restricted by building materials rather than building occupants.

The development of the passenger elevator took place over a twenty-year span. The first one was in the Crystal Palace of 1853, built by Elisha Graves Otis. Otis Tufts built a "vertical-screw railway" in the 1859 Fifth Avenue Hotel. The St. James Hotel boasted the first suspended steam elevator in 1866 and a water-balance elevator was placed in the
weight, which significantly decreased floor space (and therefore rentable space). Wrought and cast iron columns and beams were sometimes employed to reduce necessary wall depth. Masonry buildings reached as high as sixteen stories by the 1880s.

Architects and engineers rapidly realized the possibilities afforded by iron and steel, and experimented with improvement of the fundamental systems. Fireproofing of iron elements soon became standard. Heavy brick arches spanning wrought-iron beams were quickly replaced by various configurations of hollow tile in flat arches. Bolted connections, obligatory with the cast iron column, gave way to riveted connections soon after the advent of steel. Exterior masonry became clothing instead of structure in the minds of designers less than two years after steel made its first appearance in a skeleton building\(^8\). To a great extent, the components used in the steel skeleton buildings of this era were in place by the turn of the century.

The history of early metal skeleton buildings has been examined from many vantage points. Historians, architects, and engineers have investigated and catalogued the influences and agendas of the pioneers, the evolution of specific technologies such as steel members and wind bracing, the development of the chosen modes of dress, and the progression of building in specific cities and subsequent building code modifications.

For the purpose of this study, examination of early metal-skeleton buildings' history comes in the form of investigation into the evolution of its fundamental systems -- frame, foundation, fireproofing, connections, and cladding -- as well as the history and basic properties of wrought iron, cast iron, and steel. Furthermore, since a catalogue which describes the technology of specific metal-skeleton buildings built in the United States during 1884-1932 has not yet been published\(^9\), information of this sort has been collected and may be found in Appendix 1. As there were thousands of metal-skeleton buildings by the end of the period in question, this catalogue is but a small sampling.

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Western Union Building in 1873. A vertical-cylindar hydraulic elevator was introduced into New York in 1878 and the first electric elevator was installed in Baltimore in 1887. Hydraulic elevators were the most popular type until the early 1890s when they were replaced by electric.

Robins Fleming. "Whence the Skyscraper?" Civil Engineering vol.4 no.10 (October 1934), 506.

\(^8\) The Tacoma Building (1886-1889) was designed by Holabird and Roche in Chicago. Two of the four facade walls were carried by spandrel beams.

\(^9\) Condit, Fleming, Hool, Mainstone, Mujica, Randall, Schuyler, Starrett and many others have published dense and informative investigations into many other aspects the development of the steel-skeleton.
1.1 BEFORE THE SKELETON

More than a century of experimentation and achievement preceded the first built attempt in the United States at skeleton construction\(^{10}\), William LeBaron Jenney's Home Insurance Building. It is remarkable that the designers of the day came so far in so short a period of time -- the very first iron structure, the cast iron Coalbrookdale Bridge which spans the Severn River in England, was built in 1779 (and is still extant!).

The technology of metal bridges played a fundamental role in the development of the technology of metal-skeleton buildings. In addition to the first primary structural use of iron and steel, bridges also contributed bolting and riveting connections, trusses (from which wind bracing borrowed), and foundation technology. Indeed, many of the pioneering structural engineers of buildings were first bridge engineers.

Industrial structures were the first buildings to utilize the iron frame's superior strength, ductility, and response to stresses. Advances in understanding of the properties of the materials lead to the first successful use of cast iron beams and columns in a seven-story cotton mill in Manchester, England in 1801. By the 1820s-1830s, cast iron was being used as structural columns in theatres, markets, and institutional structures.

In America, a number of firsts in iron bridges occurred in the 1830s and 1840s. The first iron bridge, Dunlop's Creek Bridge, was built from 1836-1839 in Brownsville PA. The first iron truss bridge, the Frankford Bridge over the Erie Canal, was built in 1840. In 1945, the first iron railroad bridge in the United States, the Pennsylvania & Reading Railroad Bridge of Manayunk PA, was built.

In 1847, Daniel Badger's Architectural Iron Works were established in New York, NY. James Bogardus' Iron Foundry was built in the same city in 1848-1849. The 1855 shot tower of the McCullough Shot and Lead Co. of New York by James Bogardus was a precursor to modern curtain wall buildings and the cast iron beams which spanned the load-bearing iron posts carried the entire load of the brick exterior.

In France, the warehouse of the St. Ouen Docks in Paris was built between 1864 and 1865 -- the first multistory fireproof building in Europe (and possibly the world).\(^{11}\) The chocolate factory of Menier at Noisiel-sur-Marne, designed by Architect Saulnier in 1873, is thought to have been the first iron skeleton

\(^{10}\) The following is a brief chronological list of early uses of iron and steel, predominantly in America.

building ever built. The three-story building had an iron roof and sat atop four masonry piers in the River Marne.\^12


France may have given birth to the iron skeleton, but it was the pioneering designers of the United States who raised the child.

\^12 A brief description of the structure explains how advanced this design is: Four longitudinal box girders and two end cross-girders support each floor, the exterior hollow multi-colored brick walls, and two interior rows of columns. Vertical and horizontal members were of an unequal-flanged H-section, with the smaller flange facing out. J. Deforth, "The Originator of the Skeleton Type of High Buildings." *Engineering News* (5 January 1893).
In 1881, George B. Post used iron skeleton construction in the court walls of the Produce Exchange building. In that same year, an iron skeleton was used by Joseph M. Wilson in the remodeling of the Broad Street Station.

Cast iron facades were used extensively in the United States during the 1850s, 1860s, and early 1870s. Wrought iron had been rolled in America since 1853, introduced by Peter Cooper in Trenton, New Jersey, and first rolled for use in the floors of New York's Cooper Union Building. In 1860, a second company, the Phoenix Iron Co. of Pittsburgh began to roll wrought iron beams. Rolled wrought iron was first manufactured, however, primarily in Belgium and France. Wrought iron beams in floors and cast iron columns to carry the floor loads were used in masonry load-bearing buildings to save space -- allowing exterior walls to be required to bear only their own weight and thus be significantly thinner.

Cast iron columns were used extensively with wooden girders in the late 19th century. Initially, only small details were altered when floor beams and girders changed from wooden to iron and steel. Floor beams and girders were connected to columns by being bolted to lugs (projecting stubs which were cast with the column) and sitting on brackets.

Skeleton construction was achieved when free-standing walls were replaced with a veneer of hollow clay tiles or brick, which was carried as panels at each floor by spandrel girders and secured with hooks to the frame. The first office building which had such construction was Chicago's Tacoma building (Holabird and Roche), begun in 1886. Exterior walls rested on the bottom flanges of spandrel girders or angles affixed to them, and were secured to columns by bent rods.

The development of an understanding of the forces within framed structures began with the first published studies in the 1850s. The 1860s saw the beginnings of graphic statics, which developed in the following decades. The earliest designers understood that the structure of a skeleton building is by nature indeterminate, in other words, there are more unknown quantities than independent equations regarding distribution of loads to joints and members. In order to be able to solve equations and design a building which would withstand the worst conditions, assumptions were made, erring on the conservative side.

Carl Seiffert, Engineer / Purdy & Henderson, Engineers

DIMENSIONS/MASSING: The building was L-shaped.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: The skeleton consisted of cast iron columns, wrought iron for larger beams, and Bessemer steel for smaller beams; load was carried by this frame and but also brick walls. The frame was the first to be constructed with riveting (speed and efficiency of construction improved). Cladding was supported at each floor by spandrel beams and cast iron lintels connected to cast iron columns.

WIND BRACING: N/A

FOUNDATION: The treatment of the foundation for this building was unique for its time; the subsoil was tested using 50-foot borings, revealing some areas of soft clay and water which were stabilized by excavating the water and clay and filling under pressure with concrete. Eighteen-inch thick concrete columns, reinforced with I-beams, floated the building.

EXTERIOR MATERIALS: Brick and terra cotta

DEMOLITION: The Tacoma Building was demolished in 1929 to make room for a much taller structure.

1888-1889 Third Chamber of Commerce Building, Chicago IL

Edward Baumann and Harris W. Huell, Architects

Although some of the load was transferred to masonry piers, the structure of this building carried a significant percentage. It was demolished in 1928.

1889 Tower Building, New York NY

Bradford L. Gilbert

DIMENSIONS/MASSING: This steel and iron skeleton, the first in New York, was built because the owner wanted as much space as possible from the 21-1/2 foot building front (and 39-1/2 foot rear). The building was ten stories with a basement and a cellar, 129' high.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: Columns were of cast iron. The walls and floors were carried on the steel frame.

WIND BRACING: N/A

FOUNDATION: N/A

EXTERIOR MATERIALS: N/A

DEMOLITION: N/A

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190 There are different Engineering firms credited for this building: Condit, *The Chicago School, 1875-1925.* Pp. 117-118. credits Seiffert and Starrett, P. 33. credits Purdy & Henderson.


1889-90  Second Rand McNally Building, Chicago, IL

Burnham and Root (Edward Shankland), Architects
Wade and Purdy, Engineers
Theodore Starrett, Steelwork Designer

DIMENSIONS/MASSING: This building was the first steel-framed building, rising as a rectangular prism to ten stories.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: The columns were made rigid through their creation as four z-angles riveted to a central plate. This was the first use of these columns, commonly called z-bar columns, and the first large structure in which steel is used throughout.

WIND BRACING: N/A
FOUNDATION: N/A
EXTERIOR MATERIALS: This building also had the first all terra-cotta street frontage.
DEMOLITION: The building was demolished in 1911.

1889-1890  Second Leiter Building (aka Seigel, Cooper & Company Building aka Sears, Roebuck & Co.), Chicago, IL

William LeBaron Jenney

DIMENSIONS/MASSING: A rectangular building which extends 402 feet in length, eight stories in height, and 57,900 square feet in area. The building's story heights reach sixteen feet.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: The skeleton consists of steel and wrought iron. This was the first building without support from walls and the first to use steel columns throughout. Within the skeleton, tile arch flooring and tile partitions define the space.

WIND BRACING: There is no wind bracing in this structure.
FOUNDATION: Spread foundations consist of beams on a sixteen inch grillage of concrete.
EXTERIOR MATERIALS: A heavy veneer cladding of white Maine granite and/or Bedford stone at the exterior.

1889-1890  Pulitzer (World) Building, New York NY

George B. Post

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196 Freitag, Architectural Engineering, 227.
197 Starrett, Skyscrapers, 34.
198 Fleming, "A Half-Century of the Skyscraper."
Steel frame but also bearing walls. Sixteen stories and 309' tall.

1890 Masonic Temple, New York NY
Burnham & Root
21 stories on floating spread foundations.

1890-91 Fair Store Building (aka Montgomery Ward), Chicago, IL\textsuperscript{199,200,201,202}
William LeBaron Jenney and William B. Mundie
Louis E. Ritter, Engineer
DIMENSIONS/MASSING: Three buildings completed in 1891 came from the partnership of Jenney and Mundie of which this is the first and largest. Originally nine stories with one basement, two stories were added later, resulting in an area of 55,000 square feet and rectangular plan.
FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: The steel and wrought iron frame is made of a series of built-up box columns and deep I-beams with concrete flooring which rests on tile arches spanning the joists. The steel columns, fireproofed with terra cotta tile, are z-bar columns with single covers. Connections between columns, beams, and girders are bolted with gusset plates and brackets.
WIND BRACING: N/A
FOUNDATION: The original foundation of this building was concrete raft reinforced with beams and rails, and was replaced in 1923 and 1924 with caissons to rock at the north wall and caissons to hardpan elsewhere.
EXTERIOR MATERIALS: N/A

1890-91 Manhattan Building, Chicago, IL\textsuperscript{203,204}
William LeBaron Jenney, Architect
Louis E. Ritter, Frame Designer
DIMENSIONS/MASSING: A twelve-story rectangular prism, flanked by two nine story wings, was increased to sixteen stories a few years after completion, creating a square area of 10,040 at 196' 10" in height.
FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: The columns are of cast iron and many of the beams and girders are wrought iron. Steel was used in the main girders and joists and to the channels

\textsuperscript{199} Freitag, Architectural Engineering, 227.
\textsuperscript{200} Condit, The Chicago School, 1875-1925, 89-91.
\textsuperscript{201} Randall, History of Development of Building Construction in Chicago, 127.
\textsuperscript{202} Condit, American Building, 127.
\textsuperscript{203} Condit, The Chicago School, 1875-1925, 91-92.
\textsuperscript{204} Freitag, Architectural Engineering, 227.
used for the spandrel beams. Above the first floor, deep girders are connected to columns with diagonals riveted to the depth of the girder web. Girders are doubled in some places at the first and second floors. The vertical load of one of the peripheral lines of columns is carried by the adjacent line of columns through the use of cantilevers. The partition and floor systems are built of tile.

WIND BRACING: This building was the first in the United States with a fully wind-braced iron and steel frame. Diagonal (rod) and portal bracing resist the wind. An additional recognition of wind-induced shear and bending at the basement level comes in the form of columns connected by double wrought iron diagonal rods tensioned with turnbuckles.

FOUNDATION: The foundation is of spread concrete footings reinforced with steel rails.

EXTERIOR MATERIALS: White terra-cotta tile covers the building.

1890-1891 Wainwright Building, St. Louis Missouri

Adler and Sullivan

DIMENSIONS/MASSING: The ten-story Wainwright building is the first iron and steel-framed building designed by this firm. The footprint is rectangular, but the building rises in a U-shape above the ground floor. Fireproofing is achieved by terra-cotta tile. Cladding is carried on spandrel shelf angles.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: N/A

WIND BRACING: The steel frame is riveted and wind-braced

FOUNDATION: The foundation is of reinforced concrete raft footings.

EXTERIOR MATERIALS: N/A

1891 Wyandotte Building, Columbus OH

D. H. Burnham & Co., Architects

DIMENSIONS/MASSING: The building is 620-1/2x62'11" in ground plan and 150' and eleven stories plus an attic high.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: The exterior wall girders are extra-strong plate girders with rigid column connections. Columns are Gray columns in two-story lengths with joints at alternating stories. Columns are connected by vertical splice plates, no cap plates were used.

WIND BRACING: The rigid exterior column to girder connection and large wall girders are meant to act as wind bracing. No other system is utilized.

FOUNDATION: N/A

EXTERIOR MATERIALS: N/A

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1891  Ludington Building, Chicago IL
William LeBaron Jenney
This is a steel frame building, eight stories high and designed to accommodate eight more. The foundation is a spread foundation with footings continuous over almost the entire lot. 207

1891  Pontiac Building, Chicago IL208,209
Holabird and Roche
DIMENSIONS/MASSING: The square foot area of the fourteen story building is 5,340, reaching a height of 174'6".
FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: The Pontiac Building is a steel frame building with z-bar columns and tile partition and floor systems.
WIND BRACING: Wind bracing is achieved through the use of the interior cross walls as shear walls.
FOUNDATION: The foundations are spread foundations with beam grillages.
EXTERIOR MATERIALS: The building is clad in brick and terra cotta.

1891-1892  Unity Hotel (aka Unity Building aka American Bond and Mortgage Company Building aka 127 N. Dearborn Street Building), Chicago IL210,211,212,213
Clinton J. Warren, Architect
DIMENSIONS/MASSING: The is an eighteen-story, 210 foot building.
FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: The frame consists of cast-iron columns with wrought iron girders and floor beams. This was one of the last buildings to use cast-iron columns. The floor and wall systems at the interior are of tile. Trapezoidal frames carry the banks of projecting windows (oriel).
WIND BRACING: Wind bracing diagonals at the end bays are of wrought iron.
FOUNDATION: The foundation is a system of beams and concrete. A substantial lean of the south wall over the alley was recorded. Foundations were replaced in 1912, 1927, and 1940, the first two times due to uneven settlement and the last for a subway. In 1912, caissons to rock were put in at the south and west walls, the southwest corner, one to the north and two to the east; in 1927 the six remaining under the south wall to the east were replaced; and in 1940, the four under the west wall were replaced.

208 Freitag, Architectural Engineering, 227.
210 Freitag, Architectural Engineering, 227.
211 Condit, The Chicago School, 1875-1925, 151-152.
EXTERIOR MATERIALS: N/A

1891-1892  Garrick (aka Schiller aka Dearborn) Theater, Chicago IL

Adler and Sullivan
William Sooy Smith, Foundation Engineer

DIMENSIONS/MASSING: This building had a seventeen-story central tower with two nine-story wings and a fourteen story wing at the stem of the T.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: The braced framing for this T-shaped, building is complex. Steel columns and beams carry the office space and iron ribs, hangers, and two story-deep steel trusses support the vaulted theater ceiling and the floors above. Four 93-foot Phoenix columns carry the walls rising from the rigging loft above the stage.

WIND BRACING: N/A

FOUNDATION: The foundations of this building consist of concrete columns resting on a grid of oak timbers, all supported by 700-800 50-foot oak piles driven to hardpan -- a precursor to caissons. Cantilevered footings carry party walls.

EXTERIOR MATERIALS: Exterior cladding was of terra cotta and brick.

DEMOLITION: The building was demolished, after a lengthy fight, in 1961.

1891-1892  Havemeyer Building, New York, NY

George B. Post

DIMENSIONS/MASSING: The steel frame of this fifteen story, 180 foot building stops just short of being completely load bearing. Although most of the interior and wind loads were carried by the frame, windows and exterior walls were carried by these walls.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: Wrought-iron riveted columns and steel beams, fireproofed throughout. Heavy anchors secured to the column at the lower floor levels were built into the masonry as it was placed. Windows have cast iron lintels. All beams and channel-bars are mild steel.

WIND BRACING: N/A

FOUNDATION: Columns have cast-iron base plates, connected through bolts.

EXTERIOR MATERIALS: Indiana limestone covers the first four stories above which light grey brick and terra cotta cover the building.

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216 Skeleton Construction in Buildings, 109-139.
1892    
Venetian Building
Wind bracing and provision against elastic action.

1892    Great Northern Hotel, Chicago IL\(^\text{217}\)
Burnham and Root
This building was the first hotel building to follow the structural innovations of commercial architecture. It was a fourteen-story L-shaped building with a steel and iron frame. The building was demolished in 1940.

1892    Ashland Block, Chicago IL\(^\text{218,219}\)
Burnham and Root
Sixteen stories high, the steel and wrought-iron frame was surrounded by brick and terra cotta. This building was demolished in 1949 for a bus terminal.

1892    Masonic Temple (aka Capitol Building), Chicago IL\(^\text{220,221}\)
Burnham and Root
DIMENSIONS/MASSING: At twenty-two stories and 272'10" high, the Masonic Temple was the highest building in the world when it was built. The building was U-shaped in plan.
FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: Steel was the sole structural material.
WIND BRACING: It was windbraced with wrought iron rods diagonally spanning one or two stories, depending on the level.
FOUNDATION: Foundations were of spread footings with four courses of steel rails.
EXTERIOR MATERIALS: N/A
DEMOLITION: It was demolished in 1939.

1892-1893    Majestic Hotel, Chicago IL\(^\text{222}\)
D. H. Burnham and Company
The Majestic Hotel along with the adjacent Great Northern Hotel and the 1895-1896 Great Northern Theater Building, created a U-shaped footprint which covered an entire city block. This building was demolished in 1961.

\(^{218}\) Condit, The Chicago School, 1875-1925, 102-103.
\(^{220}\) Condit, The Chicago School, 1875-1925, 103-104.
\(^{221}\) Fleming, "A Half-Century of the Skyscraper."
1892-1893  Isabella Building, Chicago IL.223,224
William LeBaron Jenney

DIMENSIONS/MASSING: Eleven stories and 166' high (11 stories and 110 feet w/basement according to Randall-p.127)

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: At the main facade, the framing of the second through seventh floors includes piers which are continuous from the second floor belt course. The tile floor and wall systems connect to Z-bar columns which rest on the foundations.

WIND BRACING: This steel-framed building is notable structurally for its use of knee braces (rods) between columns and girders, perhaps the first wind bracing of its kind in the United States.

FOUNDATION: The foundation system is of rails and beams on 16" of concrete.

EXTERIOR MATERIALS: N/A

1892-1893  Association Building aka Central YMCA Building, Chicago IL.225,226
William LeBaron Jenney

DIMENSIONS/MASSING: Sixteen stories and 251 feet high to the tower, this building is L-shaped in plan, with the front facade 54 feet long and the length of the L 184 feet.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: It is structurally similar to the Isabella Building, with Z-bar columns, tile wall and floor systems, and rods as wind bracing.

WIND BRACING: Knee braces (rods) between columns and girders act as wind bracing.

FOUNDATION: The foundations are a systems of beams on 16" of concrete.

EXTERIOR MATERIALS: N/A

1893  Meyer Building, Chicago IL.227
Adler and Sullivan

Brick-faced steel-frame building seven stories high on spread foundations.

1893-1894  Chicago Stock Exchange Building (aka 30 N. LaSalle Street), Chicago IL.228,229,230
Adler and Sullivan (F. L. Wright)

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223 Freitag, Architectural Engineering, 227.
224 Condit, The Chicago School, 1875-1925 93.
225 Freitag, Architectural Engineering 227.
226 Condit, The Chicago School, 1875-1925 93.
228 Freitag, Architectural Engineering 227.
229 Condit, The Chicago School, 1875-1925 129.
William Sooy Smith, Engineer

DIMENSIONS/MASSING: The fire-proof, steel-framed thirteen-story building stands 173-feet high with 18,000 square feet of area.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: It has Z-bar columns and tile partitions. The floor system is a combination of tile and concrete arches.

WIND BRACING: Completely without wind bracing.

FOUNDATION: The building boasts one of the first caisson foundations: reinforced concrete footings rest on timber piles driven 55 feet to hardpan at all but the west line of columns, which have cylindrical concrete piers sitting on hardpan.

EXTERIOR MATERIALS: The exterior cladding is of buff-colored terra cotta with white enamel brick in the interior court.

1893-1895 Marquette Building, Chicago IL231,232,233,234
Holabird and Roche, Architects
Purdy and Henderson, Structural Engineers

DIMENSIONS/MASSING: This building is a sixteen-story, 207-foot high, E-shaped structure. There is 24,190 square feet of area within the building. The dimensions are 113’x140’ to 190’. An addition was built in 1905.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: Entirely steel frame which consists of Z-bar columns in two-story heights to stagger the joints.

WIND BRACING: Tile floor and partition systems and rods are used as wind bracing.

FOUNDATION: Steel beams and concrete make up the foundation. Unequal settlement was anticipated with a hydraulic apparatus at the west party wall. Each support includes a cast steel shoe resting on six plates which rest on two heavy iron castings (also called a "split shoe") which are identical halves. The foot of distance between the halves allows for a hydraulic apparatus, with four uniformly moving lifts, which raises and lowers the upper plates. Lifts were originally to be operated by a pump operated by one or two men. In 1940 caissons to hardpan were built under the east wall.

EXTERIOR MATERIALS: A veneer of dark red brick covers the frame with terra cotta base, cornice, and detailing.

1893-1894 Old Colony Building, Chicago IL235,236,237,238,239,240

231 Freitag, Architectural Engineering 26, 227.
234 "Recent Chicago Tall Buildings," Engineering News vol.34 no.16 (17 October 1895), 250.
Holabird and Roche, Architects
Corydon T. Purdy, Structural Engineer
General Sooy Smith, Designer of South Wall Caissons

DIMENSIONS/MASSING: It is a seventeen-story, 213-foot high building and is 386 feet wide.
FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: It has a frame which consists of Z-bar columns and wrought iron Phoenix columns and steel girders and beams. Tile floor and mackolite partition systems establish the interior. All columns were entirely surrounded with a three-inch hollow tile wall which at the exterior columns was covered on three sides with 13 inches of solid brick.
WIND BRACING: Portal wind bracing is used in this building, a unique feature at the time. Portal bracing is achieved by attaching the depth of the main girder to the column using a deep fillet - resulting in a rigid frame.
FOUNDATION: Caissons resting on hardpan at the south and west facades carry that part of the load due to settlement and the construction of a subway, respectively. The south caissons were added during construction and are located beneath the second line of columns; the load of the first line of columns is transferred to the second through cantilevers. The west facade caissons were added years after the building's completion and are located underneath concrete footings.
EXTERIOR MATERIALS: The exterior is covered by blue Bedford stone on the first four stories and by "Philadelphia white" brick above.

1893-1894 Manhattan Life Insurance Building, New York NY

Kimball and Thompson, Architects
Messrs. Charles Sooysmith & Co., Foundation Engineer

DIMENSIONS/MASSING: Sixteen-stories and 242-feet high, this building occupies a 67x123-foot lot. A tower terminating in a dome increases the height to 348 feet. The front of the building supports its own weight.
FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: Cladding is carried on the three non-load bearing facades by steel girders. Partitions are of hollow-tile blocks. Single-plate, double-plate, box and

238 "Special Structural Details of the Old Colony Building, Chicago IL," Engineering News (December 21, 1893), 486-488.
243 Skeleton Construction in Buildings, 206-223.
lattice-truss girders are used in the building to carry different loads. The single plate girders are generally used to support floor beams and as small wall girders. These wall girders have stiffeners at their ends and at intermediate places. Double-plate and box girders support larger walls; all double-plate girders have "stay plates" riveted to and covering flanges. Box girders are either built up from two webs, angles, and cover plates, or have single webs and are bolted together with separators between. Cast iron columns are present in the lower stories and generally throughout the interior of the building. Steel Z-bar columns are used throughout the building. Where a steel column starts upon one of cast-iron, the foot of the steel column is reinforced by plates and angles and riveted to a wrought-steel plate, which latter is bolted to the flange of the cast-iron column with one-inch bolts. Trusses support the recessed front at the fifteenth floor. Also, an arcade at the fifteenth and sixteenth floors requires arches of heavy angles and latticing connected at the ends by bolting. The entire arcade framework is covered with copper.

WIND BRACING: N/A

FOUNDATION: Foundations are of fifteen steel caissons on rock.

EXTERIOR MATERIALS: The entrance facade is clad in limestone, the facade opposite in light-colored brick and terra cotta, and the side walls are of brick.

1893-1895 Carnegie Office Building, Pittsburgh PA

F. H. Kindl, Structural Engineer

DIMENSIONS/MASSING: This U-shaped building is 238 feet high with an interior court of 30x60 feet wide.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: The columns are z-bar columns in two story lengths, fireproofed with brick. All steel work was riveted - both in shop and on site. Fireproofing between beams consist of 12" terra cotta arches whose webs are perpendicular to beam webs.

WIND BRACING: N/A

FOUNDATION: The steel frame rests on a foundation of steel beams which in turn rest on shale (commonly found at certain depths in Pittsburgh). Between the beams is rammed concrete, "about 6 ins. of concrete being used underneath the lower course to level up the beams and give them a uniform bearing."

EXTERIOR MATERIALS: The first two floor of the facade is clad with "Portage Entry" sandstone, and the floors above with red brick and terra cotta; the court is clad entirely with white glazed pressed brick.

1893-1894 American Tract Society Building, New York NY

R. H. Robertson, Architect

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244 "Carnegie Office Building," Engineering News (11 January 1894), 34.
DIMENSIONS/MASSING: 307-feet tall at its highest point, the majority of this building rises to a height between 249 and 261 feet. Above the first floor a 16'9" light court creates a U-shaped floor plan.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: Columns and cantilevers are bolted to the cast iron base. Lines of box girders at the 6th, 10th, 14th, and 18th floors support the weight of masonry above. All beams, connections (both riveted and bolted), rods, girders, angles, tees and channels, built-up sections, columns, cantilevers, and the smoke flue are of mild steel. Floor beam separators are of cast iron. Columns are fireproofed with four inches of brick, floors are flat firebrick arches of "end construction."

WIND BRACING: Windbracing is achieved through a combination of the base size, the heavy floor connections, the lattice girders and the lines of box girders.

FOUNDATION: Twenty-foot foundation piles of American spruce are driven to a depth of from 10 to 25 feet into fine red sand (which extends at this spot down 36 feet below the curb line to a 7-8 foot layer of clay, then fine sand, then bedrock), spaced 19" center to center, their heads cut off at 36' below the curb line; 18" of concrete is rammed around the heads. Column bases sit on cast iron shoes which sit of 10" granite blocks on brick foundation piers. Parts of the two non-street facades are carried on cantilevers.

EXTERIOR MATERIALS: The granite facade of the first through fifth floors is self-supporting, terra cotta above is carried on the lattice girders.

1894? Huck & Young Building, Chicago

Henry Ives Cobb, Architect

DIMENSIONS/MASSING: The beam/column connections were given special attention in this seven-story building due to its unusual footprint: trapezoidal with a large rectangular air shaft in the center.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: Larimer columns are connected to beams through riveting.

WIND BRACING: N/A

FOUNDATION: N/A

EXTERIOR MATERIALS: N/A

1890, 1894-1895 Reliance Building, Chicago

Charles B. Atwood for D. H. Burnham and Company

Edward C. Shankland, Structural Engineer

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247 Freitag, Architectural Engineering, 228.
249 Fleming, "A Half-Century of the Skyscraper."
250 "Recent Chicago Tall Buildings," 250.
DIMENSIONS/MASSING: The building is 200 feet and fourteen or fifteen stories high, with 4,675 square feet of area and is 55'x85' in ground plan. Four stories were erected in 1890. As the leases of the tenants of the first floor and basement stipulated that future building was not to interfere with them, the upper three stories were torn down and a temporary roof was placed over them and the adjoining sidewalks while construction took place.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: The frame is of steel. The webs of the spandrel girders are either solid or trussed. The load of the floor slabs, which are of a porous tile arch system, are carried by joists and girders to columns. Wall partitions are similarly of a porous tile system. The columns, which are Gray columns, are in two-story heights, their joints are staggered in alternate floors.

WIND BRACING: Wind bracing includes 24-inch-deep spandrel plate girders rigidly bolted through the web depth to Gray columns as well as two-story Gray columns which provide staggered joints.

FOUNDATION: Steel beams and concrete.

EXTERIOR MATERIALS: The treatment of the facade is notable for its visibly obvious inability to resist wind and bear load; the first curtain wall structure which gives the appearance of a "dematerialized skin." The horizontally proportioned "Chicago Window" made its first appearance in this building and this is the first building to use terra cotta as the sole curtain wall material.

1894-1895  Guaranty Building aka Prudential Building, Buffalo, NY
Adler and Sullivan (George Grant Elmslie)
The plan of this thirteen-story building is the form of a U. The frame is a braced steel frame.

1894-1895  American Surety Building (aka Bank of Tokyo), New York NY251,252
Bruce Price
DIMENSIONS/MASSING: The first non-loadbearing steel-skeleton building in Manhattan, it is also thought to be the first free-standing tower building. The American Surety building rose 303 feet to reach twenty stories. Originally only seven bays wide, the Broadway elevation was expanded to eleven bays in 1920.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: The frame was braced and riveted.

WIND BRACING: N/A

FOUNDATION: N/A

EXTERIOR MATERIALS: The cladding of the structure is of Maine granite.

1895-1899 St. Paul Building, New York NY

George B. Post

DIMENSIONS/MASSING: This building is 313-feet tall and 25 stories.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: This structure consists of two-story staggered box columns, I-beams at the floors, and portal bracing at some panels; box columns consist of 2 heavy steel channels set back to back riveted together at their flanges through two plates. Floor beams rest on brackets riveted to column sides and contain hollow tile. Cladding is carried by floor beams cantilevered past the column line. The St. Paul replaced the Masonic Temple as the highest building.

WIND BRACING: The floor beams cantilevered past the column line to carry cladding also have gusset plates above and below for wind bracing. Wind bracing is also achieved through portal frames on each floor and vertical diagonal bracing between the columns of the fifth and sixth floors. Steel work was coated with graphite paint (with linseed oil).

FOUNDATION: N/A

EXTERIOR MATERIALS: The building is faced entirely with yellow Indiana limestone.

1895 Studebaker Building aka Brunswick Building

Solon S. Beman

This steel-frame building was the first to use steel as spandrel panels. Large areas of glass are notable as the predominant facade treatment.

1896 Morton Building aka 638 S. Dearborn Street, Chicago IL

Jenney and Mundie

Eleven stories on spread foundations.

1896 New York Life Insurance Building, New York NY

Cass Gilbert

Copper roof and cast bronze lantern in the tower.

1896-1897 Gillender Building, New York NY

Berg & Clair, Architects

Post & McCord (Henry Post), Steelwork Designer

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254 Starrett, Skyscrapers, 65.
Stephens & O’Rourke, Foundation Designers

DIMENSIONS/MASSING: On a lot of 8’x75’, this building was nineteen stories and 300 feet high with one basement. Three of the nineteen stories formed a tower.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: The frame is of steel-cage construction with four columns which go to the seventeenth story and eight which reach the top of the nineteenth. The frame was one bay wide at the small ends.

WIND BRACING: Columns were connected by transverse bracketed box girders and in the rear by lattice trusses.

FOUNDATION: The soil beneath the building consists of a deep stratum of quicksand extending to hardpan and pneumatic caissons of yellow pine with steel cutting edges were support the building on the hardpan. Above the pine, successive piers of concrete and brick sit beneath the steel foundation grillage, leveled off under the grillage I-beams with a foot of concrete.

EXTERIOR MATERIALS: The first four floors are faced with granite, the next 10 with limestone, and the remaining with terra cotta. Tower walls were clad in brick with terra cotta with the upper part sheathed in sheet copper.

DEMOLITION: The building was taken down in 1910 for a larger building. Steelwork was taken apart by cutting out the rivets and keeping the steel members intact.

1896-1897  Mercantile Building, New York NY

Stephens & O’Rourke, Foundation Engineers

This twelve-story structure has nine timber and five steel caissons, sunk to rock and leveled with a two foot bed of concrete.

1896-1899  Park Row Building, New York NY257,258

R. H. Robertson, Architect (A. Pavli)

Nathaniel Roberts, Steelwork Designer

DIMENSIONS/MASSING: At 33 stories, this office building was the world’s tallest until the Singer Building of 1908.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: Columns are of differential lengths, relative to each other, and are square, rectangular, or double square box columns, flanged at every story near the floor beams for support of surrounding masonry. Floor beams are composed of two I-beams with full beam-height cast-iron separators five feet apart, bolted to the beams. Box and lattice girders connect

columns at the walls. Cast iron is the material of the lintels and sills. The main roof over the 25th story is flat and designed to carry a 10,000 gallon water tank. The 27th-story roof has "angle-iron trusses six-feet apart with T-iron purlins 12-1/2" center to center." All beams, connections (rivets and bolts), cantilevers, and columns are of medium steel. Floors are terra cotta arches of end construction with cinder cement on top. Specifications provided that all finished surfaces must be protected with which lead and talow, all surfaces inaccessible after assembly were treated with read lead and oil or asphaltic or graphite paint - three coats on all portions surrounded by masonry.

WIND BRACING: Horizontal diagonal floor members and vertical diagonals at some panels, along with the lateral stiffness afforded by the box and lattice girders, provide wind bracing.

FOUNDATION: The foundations of this irregularly shaped building include American spruce piles driven to a depth of about 20 feet.

EXTERIOR MATERIALS: The building is clad with granite from the first through the third story, then with buff Indiana limestone on two facades to the sixth story sills; the remainder of the building is clad with buff brick, terra cotta, and stone. The sills, mullions, and lintels are of cast iron.

1897 Astor Hotel (second half of Waldorf-Astoria Hotel), New York NY

H. J. Hordenbergh, Architect
Purdy & Henderson, Structural steel designer

Built to connect with the already standing Waldorf Hotel, the building's site is 98'9"x335' with four light courts at the back. Design features such as a ballroom, a second ballroom and a banqueting room necessitate special structural considerations: trusses at east and west ends free the rooms from column which would otherwise support the floors above. The ballroom ceiling is at the fourth floor, and the lower chords of the trusses are built into this floor. The trusses are trapezoidal and 51'3" deep (incorporated into the structure), the upper chord occurring at the eighth floor. Similarly, the second ballroom truss begins at the second floor and extends to the fourth floor. The banqueting room acquires a clear span through the use of heavy box girders. Gusset plates and knee bracing as vertical diagonals, riveted horizontal diagonals at some of the floors, and portal framing at some panels, provide rigidity and wind bracing. All of the main structural members are of mild steel painted once before erection and twice after with graphite paint (33% graphite, 20% iron oxide). Columns, which are different sizes in various places, are fireproofed with brick.

1897 Commercial Cable Company Building, New York NY

George Edward Harding & Gooch

1898  Gage Group, Chicago IL
Holabird and Roche
Louis Sullivan

1898  Williams Building, Chicago IL
Holabird and Roche

1899-1900  McClurg Building (aka Ayer aka Crown aka 218 Wabash Ave), Chicago IL
Holabird and Roche
Nine stories and a basement

1899, 1904, 1906, 1927  Carson, Pirie, Scott Store (aka Schlessinger & Mayer), Chicago IL\textsuperscript{261}
Louis Sullivan, Hill & Woltersdorf, D. H. Burnham and Company (Burnham Bros.?)
DIMENSIONS/MASSING: This rectangular building, five units built in four stages, is nine stories at the 1899 (Sullivan) portion of the structure, twelve at the 1904 portion, and twelve at the 1906 (Sullivan and the Hill & Woltersdorf building originally called the Thomas Church building). A sixteen story addition was built in 1927 (D.H. Burnham and Company/Burnham Bros.).
FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: The structure consists of an iron and steel skeleton; the cast iron columns of the 1904 structure may be the last use of this element in a tall office building.
WIND BRACING: N/A
FOUNDATION: The building is supported by 50-foot wood piles under the earliest portion and concrete caissons beneath the rest.
EXTERIOR MATERIALS: N/A

1902  Farmers' Bank Building, Pittsburgh PA\textsuperscript{262}
Alden & Harlow, Architects
George A. Fuller Company (Corydon T. Purdy), Foundation Designer
R. B. Woodworth, Steelwork Designer

DIMENSIONS/MASSING: This building stands on a lot of 80x140 feet, occupying the entire area with the exception of two light courts at the rear. It is 24 stories and 327 feet high with an attic and a deep basement additional.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: The beams, columns, windbracing, and foundation grillage is of steel; the columns have cast iron footings. The cladding and all of the floors above street level are supported on the steel frame, but the basement walls of the facades which do not front the street, the bank vault, and the smokestack are self supporting.

WIND BRACING: Wind bracing is provided for with cross-bracing transverse to the building and knee brackets at the connections of all interior columns to transverse floor girders and at some exterior panels. Steel box columns are make of C- or L-angles and web and cover plates, the heavier made of eight C-angles, three web plates, and two cover plates. Although the columns were made in two-story lengths, the joints were not staggered.

FOUNDATION: The soil beneath the building is that of an old river bed - clay, sand, gravel, and boulders.

EXTERIOR MATERIALS: The exterior is clad with marble from the first through the fourth stories and with brick and terra cotta above.

1904-1905  Chicago Garment Center, Chicago IL
William LeBaron Jenney
A ten-story steel-framed building.

1904, 1909  Republic Building, Chicago IL
Holabird and Roche
Originally twelve stories with two basements, the building was increased to nineteen stories in 1909. It is a steel frame on concrete caissons.

1906-1908  City Investing Building (aka Bensenson Building), New York NY
Francis H. Kimball, Architect
Messrs. Welskopf & Stern, Structural Engineers
DIMENSIONS/MASSING: An unusually shaped building due to site considerations, the City Investing Building has light shafts as recesses at the front of the building. The building rises in steps: 25 stories in the main building with a small tower at one corner and another reaching 32 stories or about 400 feet. The first two stories are both 22-feet high, the rest are 14. A through-building arcade, three-stories high, has one opening which is a large arched portal.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: "The structural features of the building do not vary from ordinary practice," but are unique in places due to their magnitude. Columns are spaced 22 feet on center connected at the exterior and in the main girders by twin I-beam floor girders which are connected by I-beams; a rectangular grid except for the radial grid at the elevators. The two story arcade is braced above.

WIND BRACING: N/A

FOUNDATION: Built adjoining to and at the same time as an older part of the Singer Building, foundations were difficult; the column footings extended to the basement 30 feet below the ground, the load traveling to hardpan through compressed-air concrete caissons for interior columns. The wall columns rest on grillages cantilevered from adjacent footings.

EXTERIOR MATERIALS: Cladding is of white stone on the first six stories and then with white brick with terra cotta.

1906-1908 Singer Building, New York NY264,265

Ernest Flagg, Architect

Boiler & Flagg, Consulting Engineers

DIMENSIONS/MASSING: At 47 stories and 614 feet, it was the tallest building in the world - for one year. The twelve-story building is L-shaped. It is a combination of new structure with two previously existing buildings.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: Terra-cotta tile acts as fireproofing of steel columns as well as flooring topped by concrete. Steel columns are made up of double channels, enlarged when needed with flat plates.

WIND BRACING: The tower is wind-braced by treating each of the corners as separate towers and bracing them on all four sides with cross-diagonal struts. Elevator shafts are also windbraced, but there is no horizontal floor bracing.

FOUNDATION: Concrete footings sunk to 90 feet below street level to bedrock receive loads from columns with cast iron footings (or "shoes") and steel I-beam grillage.

EXTERIOR MATERIALS: The building is covered with terra-cotta cladding and bands of floor-to-ceiling windows.

1908 Chicago Athletic Association Building266

264 Schueller, The Vertical Building Structure.
Richard E. Schmidt, Garden & Martin, Architects

DIMENSIONS/MASSING: Annexed to an older 10-story masonry structure with which it shares a basement, the building has 12 stories with 3 basements. It is 48 feet wide and 80 feet in length.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: One of the masonry basement walls of the older structure was taken down and loads were transferred to new steel columns. Wall columns are spaced 18’6” o.c. and are built up from channels with flanges facing outward and coverplates riveted to flanges; there are no interior columns. Plate girders span columns in the wall and across the width at the three pairs of wall columns there. Girders are connected to columns through angles at webs and brackets at flanges with both bolted and riveted connections. I-beams span the girders. The inner web angles are connected to angled gusset plates which connect to angle brackets on the I-beam stringers. The outer web angles carry triangular gussets which hold shelf beams for exterior masonry.

WIND BRACING: N/A

FOUNDATION: N/A

EXTERIOR MATERIALS: N/A

1908-1909  LaSalle Hotel, New York NY267

Holabird & Roche, Architects

Purdy & Henderson, Consulting Engineers

DIMENSIONS/MASSING: 160’x175’ and 260’ high with two basements.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: Roof and floors are of hollow tile blocks. A curved mansard roof on two facades starts at the nineteenth floor and has a framing of small beams and tee bars to carry the ornamental roofing tile of the main banquet hall. The basements have concrete walls and floors, reinforced in the walls by vertical I-beams. Box columns are built up with channels and coverplates; the columns below the foyer trusses are heavier than the rest. Between columns are plate girders and paired or singular I-beams. Steel is Bessemer medium steel. Girders are attached to columns through large gusset plates. Arch trusses span the nineteenth floor banquet hall and carry the roof and are connected by two lines of stiffening trusses spanning the 20 feet between.

WIND BRACING: Assumed to be through the connections of girders and columns due to the length of the building’s sides.

FOUNDATION: Columns rest in cast iron shoes. The foundation of 89 cylindrical concrete caissons extend to bedrock, reaching an average of 108’ below the curb line. Foundation piers and columns are asymmetrical due to interior design.

EXTERIOR MATERIALS: Stone to the fourth floor, brick with terra cotta above.

267“LaSalle Hotel,” Engineering News (3 December 1908), 609-611.
1909 Metropolitan Life Insurance Tower, New York NY

Napoleon LeBrun & Sons

DIMENSIONS/MASSING: This building robbed the Singer Building of the "Tallest Building" title, and held it for four years. It stands 50 stories and 675 feet tall.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS:

WIND BRACING: N/A

FOUNDATION: N/A

EXTERIOR MATERIALS: N/A

1909-1910 Liberty Tower, New York NY

Henry Ives Cobb

This 33-story building is clad in terra cotta with a steep pyramidal copper-clad roof.

1910-1913 Woolworth Building, New York NY

Cass Gilbert, Architect

Gunvald Aus Co., Consulting Engineer

DIMENSIONS/MASSING: The Woolworth Building stands 55 stories and 761 feet tall (with two basements), the tallest building in the world for 17 years. It sits on a 152'x196' plot and is U-shaped in plan with two 60'x110' wings and a 35'x96' interior court from the fourth floor to the 50th with setbacks at the 40th and 47th floors. The 51st through 55th floors make up a 105'-high pyramid with an observation gallery on top. The main portion of the building is 30 stories. Shops in the basement include barber's shop, dining room, and cafe.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: The basement and first story floors have 5" thick concrete floors with corrugated steel reinforcing rods, and all above are of a hollow tile construction topped with cement (at offices) and "Perraggo" (at corridors). A safe deposit vault in the basement necessitated two-foot thick walls with railroad ties. Field and shop connections were specified to be only machine-driven rivets; in some special cases, hand-driven rivets and turned bolts may have been used where machine-driven rivets were impracticable. Smaller column at upper stories are built up from pairs of rolled channels or of built latticed channels. All others are box columns of two built channels with at least one thickness of coverplate. Lower stories' heavier columns have an additional center web. Columns in

268 Schueller, The Vertical Building Structure.
269 Dolkart, Forging a Metropolis, 45.
270 Schueller, The Vertical Building Structure.
271 Condit, American Building, 98.
the four stories of the tower with portal bracing have "full length vertical ribs projecting from the faces of the cover plates to receive the field-riveted connections to the webs of the portal girders, which extend the full depth of the story [and] one thickness of the cover plate on each face projecting beyond one of the flanges of the built-up channel to provide similar connections for the double portal girders in the opposite planes." Corrosion protection of steel members were specified as one coat of red paint (red lead and linseed oil) painted on rust-, scale-, and dirt-free steel before shipping. Surfaces inaccessible after erection were to be given two coats. Field rivets were to be painted first before a general second coat, of a different shade of red (red lead, linseed oil, and lampblack), was applied. Finally, two coats of R.I.W. paint at and below the ground floor and one above were to be applied.

WIND BRACING: The frame boasted portal arches as wind bracing up to the 28th floor, above which knee braces are riveted above and below primary transverse girders at column. The portal arches are full deck, solid web single and double plate girders and are on the entrance facade. On the opposite facade, full-story triangular struts form trusses. The tower is designed to have independent stability against wind pressure - the inclined pyramidal members transfer lateral load through gusset plate connections between the four interior columns and floor beams to the 47th floor. At this point the load is transferred horizontally through the floor connection to the exterior.

FOUNDATION: 116 concrete pneumatic caissons, reaching an average of 122 feet below curb level, rest on bedrock. Columns have cast steel pedestals.

EXTERIOR MATERIALS: The cladding of the first three floors is granite and limestone; above the third floor, glazed terra-cotta sheathes the building. All exterior materials are backed up with red brick. The sloping roofs are of copper and the flat roofs are of red quarry tile. Windows are of copper kelemein and plate glass.

1912 L. C. Smith Building (aka Smith Tower), Seattle Washington

Gaggin & Gaggin, Architects
Balcom & Darrow, Steel Engineers
Chr. J. Jepperson, Consulting Foundation Engineer

DIMENSIONS/MASSING: At 42 stories and 461 feet, this was the highest office building outside of New York when it was built. The 21-story main building is topped by a 12 story tower with a peak that is an additional 9 stories.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: N/A
WIND BRACING: N/A

FOUNDATION: Borings showed the substrata to be of sand, clay, and volcanic pumice at quite variable levels. More than 1,276 piles were used with footings which consisted of crossed I-beams resting on a slab of concrete.

EXTERIOR MATERIALS: N/A

1913 Orpheum Theatre, New York NY
First rigid-frame construction in steel in the US

1913-1914 Continental & Commercial National Bank Co.274
D.H. Burnham & Co., Architects
DIMENSIONS/MASSING: 324’x166’ feet with an interior light court of 154’x57’ which begins at the fifth floor. With twenty stories and three basements, the building rises 260 feet above curb level.
FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: One of the concrete retaining walls (without steel reinforcement) in the basement has I-beams embedded erratically. Some interior columns are carried by heavy girders resting on columns and piers, although none of the girders cantilever. These girders are used beneath the basement, below the bank vaults, and at the fourth floor to span the columnless banking floor below. These girders are built up, some with single and some with double webs. H-section built-up columns consist of web plate and four angles. The lower sections are of very heavy construction, both bolts and rivets are used in connections. Floors are of I-beams of double channels and also plate girders and double I-beams. Spandrel girders are I-beams and are connected to channels on the outer side which carry the exterior masonry.
WIND BRACING: Horizontal wind bracing is present as diagonals in the fourth and sixth floors. Vertically, wind bracing is through gusset plate and corner angles at spandrel beams and at girder-to-column connections on two facades and the light courts; X-bracing is also used in some panels - particularly adjacent to each side of the large banking space.
FOUNDATION: 160 concrete caissons extend to bedrock 96’ to 104’ below the curb level. Column bases rest directly on a steel grillage.
EXTERIOR MATERIALS: Eight exterior columns are encased in granite (with concrete between steel and stone) and form a loggia. The roof is sheathed with tile covered with concrete and an exterior waterproofing material.

1915 Equitable Building, New York NY275,276,277

275Dolkart. Forging a Metropolis, 30.
Graham, Anderson, Probst & White, Architects
Joachim G. Giaver, Structural Engineer

DIMENSIONS/MASSING: This H-shaped building is forty stories tall with three basements, rising 537 feet without a setback (its creation of a lightless canyon made obvious the need for a setback requirement in New York, NY- made into law in 1916). The building sits on a plot 159’x308’ and contains 1,250,000 square feet of space. Above the seventh floor the plan is H-shaped due to large light courts. It was deemed Heaviest Building in the World by Engineering News in 1914.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: The structure is quite regular: columns run from footings to roof and no trusses (other than for lateral loads) are present. Floor framing is of end-construction hollow tile arches spanning I-beams. Simple I-beams consist of four angles and a web plate; I-beams with covers have web reinforcing - there are 13 types of columns in all which are variations on these two with three widths of coverplates and three web depths.

WIND BRACING: On the two longitudinal building fronts, windbracing is through top and bottom spandrel girder connections as well as web connections to columns. The transverse direction has eight planes of windbracing which consist of girders and gussets/kneebraces, and diagonal girder bracing of different depths. The two-story entrances are framed by columns reinforced with auxiliary columns with diagonal windbracing between them. Horizontal diagonal windbracing is used on the twenty-third floor.

FOUNDATION: N/A

EXTERIOR MATERIALS: N/A

1922-1925 Chicago Tribune Tower, Chicago\textsuperscript{278}

Raymond Hood

DIMENSIONS/MASSING: Thirty-four stories high this building has the first of seven basements at street level with a 110’ steel flagpole. An octagonal tower rising to the 34th floor from the 25th floor at which point there is a floor-height truss. The ceiling of the entrance lobby on the first floor extends to the third floor; a printing plant is located in the basement and offices begin at the fourth floor.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: Flying buttresses from the 25th floor required 450’ columns. Due to the entrance lobby, heavy girders at the fourth floor allow upper level column loads to travel to the outer edges of the lobby and the print room. "At the third, fourth, and fifth floors, changes in walls and chamfered corners of the building cause a shifting of many columns, some of them diagonally, while there is also a change in the spacing of the front columns. These conditions

\textsuperscript{276}Tauranac. Essential New York, 163-164, 144-146.
\textsuperscript{277}"Equitable Building," Engineering News vol.71 No.17 (23 April 1914), 112-114
\textsuperscript{278}A 34-Story Steel-Frame Tower Building in Chicago," Engineering News vol.94 no.21 (21 May 1925), 848-850.
necessitated a complicated girder arrangement, and in order to avoid beveled connections on the webs, the diagonal girders across the corners were set on top of their supporting girders instead of being framed between them." None of the columns continue through the 25th floor. Girders and I-beams carry concrete floor slabs, some of the girders being concealed in partition walls. Interior fire towers instead of exterior fire escapes were placed for the first time in Chicago.

WIND BRACING: Wind bracing rigidity is provided through the vertical diagonal bracing of the east and west ends of elevator shafts at the building's center, in addition to bracketed connections or gussets at almost all lines of columns. Knee bracing at the top-most portion of the tower and horizontal bracing in the floor also serve as wind bracing.

FOUNDATION: N/A
EXTERIOR MATERIALS: N/A

1923-1926 New York Telephone Company (Barclay-Vesey Building), New York NY
MacKenzie, Voorhees & Gmelin; Ralph Walker, Architect in Charge

1926-1927 American Insurance Union Building, Columbus OH

DIMENSIONS/MASSING: This is a 20-story building with a 47-story tower, 555-1/2' above the curb line. A tunnel connects the basement to that of the adjacent Deshler Hotel which also leased several floors of the American Insurance Union Building as an annex when it was built. There is a theatre on the first floor and a convention hall on the second which had a bridge connection to the hotel. The theatre's roof is at the fifth-floor level, a rectangular space enclosed by one corner of the building and two wings of the building. Entrance archways are three-stories high.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: Columns are encased in metal lathe and two-inches of concrete for fireproofing. The second-floor framing is suspended from third-floor girders. Typical end connections of floor beams are top and bottom shelf angles, riveted against column flange. H-beam columns are used, the ones in the lower floors having cover plates. Floors typically have I-beams except for where there are girders over open spaces at the third floor and are both concrete slab and "slab and joist" construction. Slabs are used in the tower and are supported at four sides; slab and joist is used in the wings.

WIND BRACING: N/A

FOUNDATION: Concrete pneumatic caissons extend 100 feet to hardpan and are capped with reinforced concrete.

EXTERIOR MATERIALS: Terra cotta cladding which has vertical reveals

1926-1927    Graybar Building, New York NY\textsuperscript{280}  
Sloan & Robertson, Architects  
H. G. Balcom, Steel Engineer  

DIMENSIONS/MASSING: Thirty-stories high with railroad tracks running below, this was the world's largest office building in square footage when it was built. It adjoins the Grand Central Terminal.  

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: The railroad track framing consists of I-beam stringers connected to plate girders width run transverse to the tracks between columns; track steel framing is completely independent of building's columns to avoid transferring vibrations: all building steelwork is at least eight inches from railroad steelwork. Building steelwork at railroad level required special steelwork to handle lateral loads. North-south bracing consists of double girders of two web plates, four angles, and double lacing bars top and bottom - spanning, on average, 20 feet. East-west bracing is placed at right angles to railroad tracks. Built-up box columns here are spliced only at floor levels and are quite long and heavy - the heaviest consisting of two web plates, four angles, and two coverplates. Three of these columns were assembled with field riveting from two separate pieces due to their weight. Three sides of the building's exterior columns are supported on cantilever girders or trusses at the second and third floors. The trusses allow a change in the column centers by diagonally supporting the columns' bend and include billets, gusset plates, hangers and small angles within the triangular corner truss. Connections of girders to columns necessitated splicing of the girder webplate. Flooring systems are different at different levels: office floors have a four-inch cinder-concrete slab covered by three inches of fill and one inch of finish, the mezzanine and second floors have four-inch concrete slabs designed for twice the live load as office floors, and the ground floor has an eight-inch cinder concrete slab as fire break between the building and the tracks. Stone concrete was used below the ground floor.  

WIND BRACING: Wind load is taken care of through the shear volume of the structure, and through angles riveted to tops and bottoms of columns and beams.  

FOUNDATION: Column bases have wing plates. Vibration mats of asbestos, sheet lead, and galvanized iron sit between concrete footings and the iron grillage beams.  

EXTERIOR MATERIALS: The exterior is of broad flat surfaces of buff face brick and spandrels of dark brick with the first three stories of buff Indiana limestone.

1928-1929    Daily News Building, Chicago IL\textsuperscript{281,282}  

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\textsuperscript{282} Fleming, "A Half Century of the Skyscraper."
Irving Chanin
FRAME FOUNDATION: Wind are around opposite The newspaper's support were.

DIMENSIONS/MASSING: A corner of the main 26-story building and all of the two four-story wings were built over the track space of Union Station. This is the first large building to be built on air rights.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: Trusses, cantilever girders, and hangers support columns and transfer loads to accessible parts of the ground. The first six floors house the newspaper's departments; the second holds the printing press. Floors are of I-beam framing and concrete. The east side of the building was made to be removable for attractiveness in leasing. Girders are present generally at the first and second floors but also at some upper floors with framing suspended from them by hangers. Shallower girders are pin connected to the ends of the cantilever girders and pin connected at opposite ends to the next row of columns. Concrete platforms and floor slabs of the track level are separated from the building's columns and beams by a cushion of clay in addition to asphaltic packing around columns at the floor slabs. Vibrations from the second floor printing presses are eliminated as they are mounted on and connected to a foot thick slab of reinforced concrete which rests on a three-inch layer of prepared cork which in turn rests on the floor. They are not connected to the frame of the main floor.

WIND BRACING: Pin connections of girders and columns act as rigid connections.

FOUNDATION: Concrete caissons extend 100 feet below Chicago city datum to rock below the 26-story tower, and 60 feet to hardpan below the wings.

EXTERIOR MATERIALS: The roof's siding and the window frames are made of chrome nickel iron.

1928-1931 Irving Trust Company Building (now The Bank of New York), New York NY
Voorhees Gmelin & Walker; Ralph Walker, partner in charge
This building rises 654 feet, set back in subtle steps. It is clad entirely in white limestone.

1928-1929 Chanin Tower Building, New York NY
Sloan & Robertson, Architects
Ball & Snyder, Structural Designer

DIMENSIONS/MASSING: 626 feet and 56 stories high, this building is L-shaped. The first setback occurs at the 15th floor, then four successive setbacks between the 16th and 27th floors, the tower climbs without further setbacks from the 28th to the 56th floors. Part of the first floor was built to be used as a bus terminal.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: Heaviest columns are built-up box columns with four angles, two web plates, two reinforcing plates, and two cover plates. There is a private theatre on

283“Structural Features of the 626-foot Chanin Building,” Engineering News vol.102 no.19 (9 May 1929), 740-743.
the 49th and 50th floors. The second and mezzanine floors are designed so as to be removable: "all column connections in the second and mezzanine floors for girders which may be subsequently omitted have been designed so that they can be removed without resorting to flame cutting. The first floor bus terminal includes a bus turntable carried at the center by a column from the basement and framed between surrounding columns. A 34-foot truss spans the third and fourth floors above this turntable, carrying the second floor from an H-section at its midpoint.

**WIND BRACING:** Transverse wind-bracing connection is made by T-shaped, column-width stubs of two standard beams with their flanges shop riveted to columns and their webs field riveted to the flanges of beams which are sandwiched between the stubs. A web angle is added to take vertical shear.

Longitudinally, the wind-bracing connection is made up of the stub of two channels with flanges shop-riveted to columns and with webs field riveted to beams - again web angles were added to take vertical shear. Also, sway bracing of channels in three lower-story bents and two upper story bents secure the building against torsional wind stress action about the transverse neutral axis. Spandrels are braced with top and bottom angles. The removeable second and mezzanine floors required heavier windbracing at the first and third floors by way of double girders.

**FOUNDATION:** Foundations rest on bedrock with grillage, steel shoe, and wing plates at bases of heaviest columns.

**EXTERIOR MATERIALS:** N/A

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1929  
**New York Central Building (aka Helmsley Building)**

Warren & Wetmore, Architects

The Helmsley Building straddles Park Avenue and sits atop Grand Central Station, rising 35-stories. Since it is built above railroad tracks the foundation had to be built on stilts - steel columns lined with lead and asbestos. Where tracks and columns meet, four inches of compressed cork sits between.

1929-1930  
**Lincoln Building, New York NY**\(^{284}\)

Hurlbut & van Vleck, Architects

**DIMENSIONS/MASSING:** 53-stories high, the first 33 stories are without setback. Additionally, a 27-story arm extends from the main building. The building is on a plot of 160'x66', and becomes H-shaped in plan above the sixth story.

**FRAME MATERIALS, CONSTITUENTS, CONNECTIONS:** There are six one-story A-frame trusses over the first floor entrance arcade (which is a 22-foot wide hallway). Deep reveals necessitated plates to be used on spandrel beams. At the 53rd floor, pointed brick and terra cotta arches are carried on curved

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steel angles. Heavy reinforcing of tower columns through cover plates and web plates or angles is necessary due to high loads. The flange cover plates for these columns consist of solid billets which were shop-riveted cold. Columns and column bases were rolled.  

WIND BRACING: Wind connections are predominantly of "the usual split-girder type," connections having been selected based on the "Fleming portal method".  

FOUNDATION: Some of the wall columns are centered over foundation piers but some are cantilevered. Column bases have wing plate billets and "the edges of the wing-plate billets were machined so the loads could be transmitted by direct bearing instead of through rivets." Bases sit on I-beam grillages.

EXTERIOR MATERIALS: N/A

1929-1930 Bank of Manhattan Building
H. Craig Severance with Yasuo Matsui, Architects
Purdy & Henderson Co., Consulting Engineers
Moran & Proctor, Foundation Engineers
DIMENSIONS/MASSING: This 72-story building rises 900 feet through setbacks to a pyramidal roof. It sits on a 150'x200' plot. The main banking room is in the second floor.  

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: Architectural considerations restricted the size of the spandrel beams. Sloping rafters form the pyramid and serve as continuous ties through connecting steel straps. Wind-load bearing elements were riveted and "as is customary in a wind analysis, rivet stresses were increased. Knees braces and diagonals are made of one angle and one plate separated by washers to provide for rivet connections. Eight tower columns rest on four trapezoidal trusses at the fifth floor (bottom of trusses are at the third story floor level. The banking room is at the second floor - thirty foot high trussed columns have double bends at mitered joints. In the exterior walls a single I-beam carries wall, wind, and floor loads.

WIND BRACING: Due to the small spandrel beams and the symmetrical, regular window treatment, window bracing is achieved through an irregular system of knee braces and diagonals. Bracing is also achieved through closely set columns and deep field riveted web connections. The third floor has horizontal wind bracing.

FOUNDATION: Temporary foundations were built which were able to support 25 stories so that demolition of the previous building and construction could be executed. Permanent foundations include 69 caissons to rock and 27 footings consisting of groups of steel tubes

EXTERIOR MATERIALS: N/A

1930 Chrysler Building
William Van Alen
77 stories and 1,048 feet high, this building was the world's highest until the Empire State Building was built the next year. The finials, gargoyles, spire, and "radiator caps" are all of stainless steel.

1928-31  Empire State Building, New York, NY285
Shreve, Lamb, and Harmon

DIMENSIONS/MASSING: Originally 86 stories and 1,100 feet, the Empire State Building was equipped with a zeppelin mooring mast in 1929, bringing it to 102 stories and 1,250 feet. The mooring mast is a cyliner 25' in diameter and 200' high. A B-25 airplane crashed into the building at the 79th floor in 1943.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: Floors are cinder concrete arches topped by cinder concrete. There are three basic types of columns: rolled steel I-beams with or without flange-covering plates slightly wider than flanges, rolled steel I-beams with flange-covering plates a great deal wider than flanges, and box columns made of heavy rolled-steel I-beams with two flange covering plates, two plate webs, and four angles. Larger rivets (1-1/8") connect elements of the built-up columns. Almost all main column lines are continuous; setbacks do not require offset columns. Exterior columns are fireproofed with four inches of brick, the basement and lower story interior columns are fireproofed with cinder concrete, and all others are protected with two-inch terra cotta blocks. Steel was shop painted with iron oxide and linseed oil and painted after erection with an alkali-reistant asphaltum paint.

WIND BRACING: Knee braces at interior adjacent to elevator shafts and special column connections using the wide-cover plated I-beams connected to floor I-beams through web and flange connections. Cast aluminum wings buttress the mooring mass against the wind.

FOUNDATION: Concrete caissons extend to bedrock.

EXTERIOR MATERIALS: The mullions are of steel.

1930  Daily News Building, New York NY286
Howells & Hood

This 37 story building terminates with a flat top, an extension of the tower. Unbroken verticality is created with strips of white brick alternating with bands of windows which have red and black brick spandrels. The steel columns are located at every other white brick strip, the other strips concealing pipes, conduits, and ducts. The newspaper's printing presses are located on the first nine floors.

1930-1931  McGraw-Hill Building (aka 326 West 42nd St), New York NY287,288

285 "The Empire State Building," Architectural Forum, (August 1930), 241-246; (January 1931), 4-7; (February 1931), 229-233.
286 Tauranac, Essential New York, 163-164.
287 "COLOR Built into Skyscraper," Construction Methods (June 1932), 32-37.
288 "COLOR Built into Skyscraper Part II," Construction Methods (July, 1932) 40-45.
Raymond Hood, Godley & Fouilhoux, Architects
Lockwood-Greene, Engineers

DIMENSIONS/MASSING: This 34-story 488-foot high building adheres to the setback requirements of New York in an extremely geometric and regular fashion. Setbacks occur at the seventh, eleventh, sixteenth, and thirty-second floors. The main tower of the building starts at the sixteenth floor, and is 90'x130' in plan to the thirty-second floor, reducing to 69-1/2'x130' at that level. Story heights are 12 feet in the tower and as high as 15'-10" at the sixth and eighth floors. Printing presses were housed inside the building for the first few years of its existence.

FRAME MATERIALS, CONSTITUENTS, CONNECTIONS: Cinder concrete floor slabs, reinforced with wire mesh, are carried by I-beams with riveted connections. Extra heavy floor slabs were provided for the floors which were expected to carry printing presses. Columns were fabricated and erected in two-story lengths (not staggered), flange and web angle connections affixed to them in the shop. Steel trusses support the penthouse above the 33rd-floor conference room which has no interior columns.

WIND BRACING: Heavy windbracing was used.

FOUNDATION: I-beam grillage on concrete caissons

EXTERIOR MATERIALS: Window bands with light green painted steel sashes alternate with bands of sea-green glazed terra cotta at spandrels, and reveal the steel skeleton in places. Columns on the exterior are covered with sheet steel. Piers and mullions are then painted green-black. The store fronts, building entrances, and lobby are finished with polychrome enameled steel with bronze and chromium.

1929-32 PSFS Building, Philadelphia, PA
Howe and Lescaze

See Chapter 4
APPENDIX 2
Summaries of Selected Case Studies
Structural Assessments of Metal-Skeleton Buildings During Demolition
Foundation Settlements

In published reports about the conditions of buildings at the time of their demolition, the "excellence of the metals" is revealed. Corrosion was found, however, to some degree in all of the buildings for which such studies were published: the Mail Express Building\(^\text{289}\) (twenty-nine years old), the Gillender Building\(^\text{290}\) (fourteen years old), and the Tower Building\(^\text{291}\) (twenty-five years old) in New York, the Home Insurance Building\(^\text{292}\) (fourty-eight years old), the State Bank in Chicago\(^\text{293}\), and the Tacoma Building\(^\text{294}\) (fourty-years old) in Chicago. The Tower Building consisted of cast-iron columns and wrought iron floors; the Tacoma of cast-iron columns and steel floors\(^\text{295}\); the Home Insurance Building of cast iron, wrought iron, and steel; and the remaining consisted of steel.

Corrosion of the Tower and the Gillender Buildings was found in the form of slight pitting at roof beams. Corrosion in the Tower Building was discovered at the top of the building -- the angles supporting the tile of the roof construction were found to have an "appreciable amount of scale". At one possible source of infiltration, lime mortar used at the parapet had deteriorated to the point that bricks were easily removed. Rust was also found in decreasing amounts on beams and girders farther down, although the foundation grillage showed an "appreciable amount of surface rusting."

The roof of the State Bank of Chicago Building (a brick load-bearing building with interior steel) was tiled, laid in cement and connected with wires to metal sheeting. At the time of the study, much of the cement had disappeared and corroded wires were common. Tiles attached to severely corroded wires broke away

\(\text{289}\) F. J. T. Stewart, "Dissecting a Twenty-nine-Year-Old Steel-Skeleton Buildings," *Safety Engineering* vol.41 no.2 (February 1921), 57-58.


Maximillian Toch, "The Condition of the Steel of the Gillender Building; A Final Report," *Engineering News* vol.66 no.7 (17 August 1911), 204-205.


\(\text{293}\) "Chicago Building Obsolescent After 40 Years," *Engineering News-Record* (December 26, 1929), 1003-1004.


\(\text{295}\) Tests by the AISC on the floor beams revealed them to be steel, not wrought iron as had been believed.

"Chicago Building Obsolescent," 1003.
and exposed the underlayers. Leaks in this area and at the dormers (of which there was 50) occurred throughout the life of the building, resulting in the corrosion of steel roof beams. Maintenance was slim to none in the last decade of the life of this building as the Bank intended to tear the building down for ten years before it was actually demolished.

The Gillender Building was found to have a number of rivets largely corroded and corrosion was also found at voids in the interface between the brick and mortar and the steel, although there were only two or three examples of "bad rust pitting". Uniform corrosion occured at the southeast and northeast corners, where moisture had come through walls.

The frame of the Tower Building showed no rust of the wrought-iron beams, but the columns experienced corrosion in some discrete areas, most significantly at the bolted connection to the windbracing diagonals. According to excited surveyors, corrosion of the Home Insurance Building occured only below a leaking tank in what would have been steel.

More recently, restoration architects and engineers had a chance to observe the steel of the Carnegie Hall, Daily News Building, and the Woolworth Building. Although Carnegie Hall is not a high-rise metal-skeleton building, the manefestation of rusting shelf angles is applicable: although it was not known whether or where there were shelf angles, a rythmic consistent arching in the brickwork along perfect horizontals revealed them in their corroding state.296

The structural engineering aspects of the Daily News Building was performed by Wiss, Janney, Elstner Associates297. Corrosion of the roof beams was found by them; the roof system included a cinder-fill concrete roof slab as insulation below a built-up felt and coal tar roof. Their deduction was that moisture had penetrated the tar and percolated through the typically very porous cinder-fill concrete, becoming slightly acidic this way. After making its way through the concrete roof deck, the moisture attacked steel. This path of corrosion has been seen by this firm, which has performed over a thousand such surveys, quite commonly with cinder-fill concrete roof slabs.

The restoration of the Woolworth building, also performed in part by Wiss, Janney, Estner, was expensive and as thorough as possible. The restorers uncovered thousands of steel frame members, a degree of investigation which has yet to be matched. A great deal of corrosion was found in the steel incorporated into the cladding, with two or three beams completely gone but the remarkable redundancy of the structure

296 Bob Silman. Interview with author, September 1990.
297 Kimball Beasley, interviewed by the author in March of 1991, was on the team which surveyed the building.
coupled with the strength of the terra cotta cladding held the building together. Water infiltration was determined to be due to extremely high compressive forces in the terra cotta cladding which was cracking and spalling due to the absence of expansion joints and the non-expansion of the skeleton beneath. Enhancing the problem was the thermal incompatibility of the glaze with the terra cotta: these two elements worked to admit moisture and corrode steel.298

When the New York Times Building was altered in 1894, wrought-iron beams that had been encased in solid brick walls were found to be corroded "to the point of utter worthlessness."299

"In a building wrecked in 1914 in Chicago, about twenty years after it was constructed, the floor joists and girders had tile fireproofing, and an effort had been made to have a continuous covering of mortar on the steel; the paint was practically intact. The columns, encased with tile with vacant spaces along the metal, showed some rust along these air spaces. At one column, due to a leaking soil pipe, the corrosion was serious, the weight of rust indicating a loss of about 1/16" of metal. The foundation contained unpainted grillage beams encased in Portland cement concrete. When removed they showed not deterioration whatever. In another building, where there had been a restaurant kitchen for a number of years, examination disclosed that water percolated through to the beams and girders. The corrosion was very serious, the webs of beams and plate girders being perforated in a number of places. Incidental to some shoring operations a number of column bases were exposed in a 16-story building. The columns were encased in hollow tile fireproofing. Considerable rust was found on the steel."300

When the Tacoma Building was demolished in 1929, the wrecker, W. J. Newman discovered that the building leaned 11-3/4 inches out of plumb to the east.301

A study of settlements in buildings conducted by Skempton and MacDonald in 1956, collecting existing data on ninety-eight mill and office buildings.302 As defined in this paper, the greatest differential settlement in a building is the difference between the maximum settlement and the minimum. The Fair Store and Central YMCA buildings of Chicago were found to have settled a maximum of 1.38" and 2.69", respectively. The Home Insurance Building of Chicago settled 4" at maximum with a greatest differential

298 Kimball Beasley, March 1990 interview.
300 Burt, "Growth of Steel Frame Buildings," 682.
301 Condit, The Chicago School, 1875-1925, 117.
of 0.75". The Old Colony Building, also of Chicago, was found to have sustained functional and architectural damage and to have settled a maximum of 5.1".
APPENDIX 3
Records Pertaining to PSFS Building Maintenance

Staff
The Building Manager is currently Victor J. Pepenelli; the archivist, V. Chapman-Smith; the architect, Craig Thigpen. Until 1988, the building had its own Construction Staff. The decision was made to replace this non-union staff with outside contractors, against the wishes of the building management. It is the contention of Mr. Pepenelli, however, that the elimination of an in-house construction staff will not negatively impact the maintenance of the structure.

Exterior Materials
1934 Condition of window caulking studied. Hairline cracks and separation from brickwork was found.
1966 Cracks and open joints in brickwork on the east side of the 34th, 35th, and 36th levels (at the head of the "T") were investigated. At the 34th floor, the inside edge of the metal light box which serves as the coping was found to have separated from the brick below. This was thought, by United Engineers and Contractors, to be due to the differential temperatures experienced between the inside and outside faces of the parapet. At the 35th and 36th levels, horizontal cracks were found near the top courses along with vertical cracks which extended from the horizontal cracks to the area of the cantilevered floor beam. This was thought to be due to deflection of the floor beam. Cracks were mortared with the outermost portion of the joint sealed with Thiokol, an elastomeric sealant.
1967 Step- and through brick-cracking and displacement of exterior brick at the northeast corner of the "upper stories", accompanied by rusting steel hangers (which support spandrels) was found to be more severe at the north side than the east side of the corner. Backup tile was not cracked, however. United Engineers and Contractors blamed the thin covering of structural steel (sometimes less than 1 brick wythe) and recommended replacement of brick, after scraping and painting steel (with Rustoleum), with an "impermeable and non-absorptive brick", waterproofing of brick with silicone waterproofing six months to a year after replacement, and reinforcement of cement mortar with "additives for elasticity, tenacious bond, and resistance to water intrusion (Acryl 60 and several others suggested).
1968-1969 Joints of brickwork above north elevation board room windows cut out and repointed with a Portland cement/Acryl-60 mixture, and with Pecora Polysulfide sealant where "elastic material is required" (Ev-Air-Tight Calking Company)
1969 Two coats of W-2 Super Toch Waterproofing applied to limestone panels at 4th and 5th floors between columns 4 and 81, and the panel on the third floor between columns 80 and 81. (William Watts)

- Limestone and Granite repointed (where necessary). (Ev-Air Tight)

1969-1970 "Removed cracked bricks to find the source of pressure, corrected condition, and replaced with new bricks on the northeast and southeast side of the building."

Lintels pointed, repainted, and caulked. (William Watts)

1970 Windows from sixth floor to the third mezzanine floor recaulked with Thiokol caulking. (William Watts)

1971-1972 South wall: extended westernmost vertical expansion joint, "re(did) all expansion joint on the east side that tie into the granite," cut out and pointed necessary adjacent brick.

North wall: Cut out and repointed 34th to 36th level joints on east side. Pointing for both was specified to be Portland cement (1 part), sand (2-1/2 parts), and water plus Acryl-60 (3 parts water to 1 of Acryl-60). (William Watts)

1973 Matte brick of south elevation waterproofed with two coats of a 5% silicone solution. (William Watts)

- Sandblasted "north face of building," cut out and recaulked limestone with Thiokol caulking. (William Watts)

1974 Granite facing on Market Street repaired. (Cleveland Marble Mosaic Co.)

- Installed black-faced brick on south end of west wall. (1234 Associates)

- Damage to the plate glass of the Lerner's Store occurred due to a windstorm. Ten panes of glass were installed, some because of the windstorm, and an aluminum (tubes and beads) sill and lintel system replaced the old wood sill and lintel system. Tubes were anchored to marble's base and stainless steel overhead. Work was performed by the Russell Glass Company.

1975 Damage to the plate glass of the Lerner's Store occurred due to a PSFS night cleaning lady running her car through the window. Two panes of glass, an 80-inch divisional bar, and ten feet of sash molding were replaced by the Russell Glass Company.

1976 Engineering services provided in connection with 34th and 35th floor brick parapet deterioration. (Kling Lindquist, Inc.)

Concrete removed from columns on 34th floor (?) (Jack Donnelly Co., Inc.)

Cut out and relaid brickwork, cut out "plaster on beams for angle irons." (Perhaps at 29th and 30th floors due to stairwell removal). (William Watts)

1978 Repaired exterior walls with Black Thiokol Chemcalk. Location and reason not described. (Ev-Air-Tight)

1982 Storm windows furnished and installed. (Lasco Industries)

1982 Repairs to exterior wall. Location and purpose not described. (Ev-Air-Tight)

1983 Exterior wall and capstone at the corner and north face of the west wing repaired. Brick pointed and replaced as necessary. Location and purpose not described. (Ev-Air-Tight)

1984 Waterproofing work performed. Location, material, and purpose not described. (William Watts)

1985 Waterproofing work performed. Location, material, and purpose not described. (Western Waterproofing)

- Selected joints at the northeast corner of the tower raked out, cleaned, and caulked. (William Watts)

- At the south and west elevations' corner, all the perimeter window frames, sash and sills were cut out and recaulked masonry to metal and metal to glass. All deteriorated openings of masonry joint and cracks in brickwork were sealed. (Western Waterproofing)

1986-1987 Windows cut out and reglazed at five windows-widths of the entire northeast corner, seven window-widths at the corners of the north faces of the east and west elevations, and the four remaining windows across down the entire north face. Also, the northwest corner of each window was cut out and reglazed, metal to glass (like the northeast corner), and the perimeter of each window was cut around and caulked metal to masonry.

1987 Southwest corner receives 6 expansion joints from the fifth floor to the base. Joints were cut 1/2" wide and 4" deep, cleaned with solvent and sealer. Specification called for a sealant of Tremco 'Dymonic' or Pecora 'Dynatrol-2.' Spalled brick, such as brick at the second floor level, was removed and replaced. (A & R Engineering)

1988 West Wall renovation. Location and purpose not described. (Western Waterproofing)
Defective caulking cut out and area recaulked at third floor roof. (Western Waterproofing Company)

1989
Under "Heating Repairs" in the "1989 Engineering Budget Proposals", the need for the continued replacement of expansion joints is expressed: "Most of the expansion joints in the building are original equipment and cannot be repaired. Planned replacement for this year would require the purchase of 12 units."

$40,000 worth of building facade replacements recommended and approved due to "recent heavy rains [which] have apparently completed the erosion of portions of the building face and roof allowing heavy penetration into tenanted areas."

$36,000 allocated to fund a "major window replacement project." A memo written three days before this allocation explained that there were approximately 150 broken windows in the building.

Western Waterproofing received authorization to proceed with masonry and brick repairs to the northwest corner from the 32nd floor to the 26th, inclusive. "The work area is approximately one window in width on the north elevation and one window in width on the east elevation at the corner." Repairs included brick removal (three courses above each window at lintel angle), flashing installation (membrane flashing at the angle turned up the terra-cotta block 6"-8" and attached, with weep holes provided), and repointing (after cutting out joints to a depth of one-half inch).

1990
Repairs performed including repointing open joints in brickwork, cutting out caulking in expansion joints, cutting and repointing 20th & 21st floors, cutting out expansion joints from the 22nd floor down, repairing caulking around windows, and caulking expansion joints and skylight. (Western Waterproofing)

1990-1993
Replacement of seal strips and eroded joints. Location and purpose not described. (Tower Maintenance Service Company)

Interior - Selected information
Restaurants are located at the fourth and twenty-second floors; kitchen in the 33rd floor.

1982
A pipe burst on the fifth floor pipe, releasing approximately 25,000 gallons of water and resulting in damage to interiors of elevators and the third and fourth floor elevator lobby. Elevators were repaired by the United Elevator Co. and other repairs were executed by J. B. Evrell Co. and John A. Donahue & Son, Inc.
Pipes on the third and fourth floor were replaced due to leaking which was detected by workmen. Damage to 3rd and 4th floors repaired (Donahue)

A pipe on the 18th floor (suite 1840) broke causing water to infiltrate portions of all the floors below, down to the sub-basement which flooded. The areas most affected were in suites directly under this suite, particularly at the 10th, 11th, and 14th floors.

Design changes in wind brace at column 18. (A & R Engineering Co., Inc.)

1984 Replacement of piping on the 25th floor which feeds water to floors 18 through 25.

1986 Fourth floor restaurant dishwasher exhaust system was replaced as it was leaking into the corridor and private dining room and dripping through ceiling. (Ernest D. Menold)

1989 Damaged ceiling patched on the 31st floor. Reason not described. (R. Stone)

1989-1991 Replacement of horizontal piping housed in five floors completed or projected to be completed.

1990 Plumbing renovations in the 31st and 32nd floors.

? - 1991 Asbestos is present in the building and has been removed in areas. Asbestos burial certificates are on file as late as January 1991.

Roofs

1961-1964 Roofing of a seamless application of Dex-O-Tex Weatherwear installed by S. S. Gill Company of Philadelphia. Original roofs overlaid with 1/4" neoprene deck system (Dex-O-Tex); heaved quarry tile and tile surrounding drains were removed. (S.S. Gill)

1962 Bell Telephone Company informed that roofs which have traffic on them cannot be bonded; that roofing installer's guarantee is voided if roof is pierced; and therefore that regarding the anchoring of 34 equipment posts for platforms, Bell takes responsibility if the roof is pierced and that platforms may be anchored to structural steel or steel supporting tower - pending approval by Purdy & Henderson. Thiokol Sealing Compound is suggested by S.S. Gill to be used between Weatherwear and posts if piercing is deemed necessary.

1969 The following areas were repointed with Portland cement (1 part), sand (2-1/2 parts), and water plus Acryl-60 (3 parts water to 1 of Acryl-60); third and fourth floors at east side parapet wall, sixth floor at west side parapet wall, 33rd floor at lightbox seams of east and north sides and parapet walls, 34th floor and main solarium roof parapet walls and lightboxes on the east side, 36th floor main tower and lower porch parapet walls. (William Watts, Inc.)
1971-1972 Recaulked granite coping joints at west side of 36th floor roof over south elevation. (William Watts)

1975 Repaired cooling tower deck and deck over solarium with Dex-O-Tex. (S.S. Gill)

1977 John Calvitti Company hired to replace cooling towers, also to clean and repaint existing and new structural steel (only that which relates to the cooling towers and the roof sign). This secondary work was carried out by a sub-contractor, Metalweld Inc. who power-tool cleaned, primed, and painted (3x) the steel.

1978 PSFS roof sign replaced. (Simpson Sign Co.)

1979 Installed new "S.I.S." roof on Bell Telephone space on 36th floor. (Savory Roofers)

1982 Dex-O-Tex installed. Location not described. (S.S. Gill)

1983 New Dex-O-Tex covering installed on 36th floor roof after removal and underlayment work. (S.S. Gill)

1984 Dex-O-Tex flashing replaced on 34th floor cooling tower deck. (S.S. Gill)

1987 Roofing and roofing fabric removed and replaced (with double layered fiberglass mesh with two coats of roofing membrane) at lower deck area over the main dining room (which dining room?). Water had penetrated roofing through holes at perimeter of area, possibly trapped there for years. Deteriorated coping stone caulking and metal was cut out, recaulked, and primed; holes in the terra-cotta coping were patched and joints spot pointed where necessary. These voids were allowing water to penetrate. The parapet wall was repointed in small isolated areas on the interior of the east facade, the north facade, and the interior of the west facade. Repairs were made to the interior section of the parapet walls. (Western Waterproofing, perhaps others)

1989 Repair and replacement of Dex-O-Tex roof system below sign, on antenna tower roof, on Solarium roof, and around Solarium. (S.S. Gill)

**West Facade Interface with 1234 Market Street**

1973 Bracing between columns 29 and 46 replaced. (George Ewing Company)

1974-1976 Problems due to differential air pressure between the PSFS and 1234 Market buildings at their connection led to the replacement of doors with revolving doors on the banking floor by International Steel Corporation, and the installation of an additional set of swing doors on the third floor.
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