Wind-bracing Systems and the Materials of Chicago School (Architecture) at the End of 19th Century

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Abstract. As an important node of architecture history, the Chicago School created a precedent of High-rise building and using of steel frame. Through a series of analysis and investigation of famous 19th Century construction work in Chicago, explored the technology breakthrough of Chicago School structure and construction, and the relationship between wind-bracing system and materials.

Introduction

The British political economist Thomas Malthus agued in “An Essay on the Principle of Population, 1798”: Food, Fuel, Fiber and Building materials are four main physical factor of limiting population growth. In the past 200 years, the food crisis eased by fertilizer technology; the oil discovery brought a new fuel revolution; textile industry production was large-scale by machinery factory and the first of Chicago School (Architecture) construction material innovation improved the people’s living conditions at the end of 19th Century.

The Chicago Fire caused huge casualties and economic losses in 1871 October 8th, on the other hand which became a booster for the modern architecture development. And as the Midwest and Great Lakes Regional Commercial Center, Chicago’s population soaring, therefore, fast reconstruction was referred to the headline of social problems. In order to build the residence that it can accommodate more people in limited urban area, functionalism first, the concept of High-rise Building was proposed. The first Chicago School (Architecture) was born in this background. The concept of Chicago School (Architecture) is first proposed in the book of “The Rise of the Skyscraper: The Genius of Chicago Architecture from the Great Fire to Louis Sullivan.” written by Karl Condit who was Northwestern University scholar in 1952 published. The book described that Chicago School’s rise, facing the challenge and how to lead the trend of world architecture. Subsequent decades, books and literatures about Chicago School (Architecture) have emerged continuously.

Steel and Frame

As an important part of reasons of rise of Chicago School of Architecture, steel frame and its technology was the core of architecture technology innovation. As the main material of architecture, iron and steel was first used in bridge construction. The first iron bridge of the world is Severn River Bridge near Coalbrookdale, built in 1779. It a semi-circular arch, which was 40 feet tall and the span of its single arch, was 100 feet 6 inches. It was originally designed by Thomas Farnolls Pritchard (1723-1777) and built by Abraham Darby III. The combination
of its reserves of coal, iron ore and the proximity of the busy River Severn made Coalbrookdale the cradle of the Industrial Revolution in Britain. The industrial revolution brought the Machine Production, and it made steel become the most basic industrial materials, the traditional process had already cannot satisfy the needs of development of industry and technology. The British Henry Bessemer made the steelmaking technology breakthrough by Bessemer converter; it met the demand of iron quality for industrial production at that time.

![Bessemer Converter](Image:Bessemer converter. jpg)

Figure 1. Bessemer Converter.

The successful application in bridge construction made cast iron widely using in architecture materials. Although the iron had a huge advantage in construction industry at that time, it still had some problems in the installation and manufacturing, so that it cannot be a stable frame with sufficient wind and load. Along with this disadvantage, cast iron needs more stone to use in the building foundation, and the structure brought space must be sacrificed at the bottom. At the end of 19th Century, steel frame structure was widely used in Chicago architecture design. The steel frame building because of its unique stiffness and toughness, wind-resistance and load capacity is more effective than iron frame. This advanced technique led to two changes after 1895, one is build span increased from its precious, another is reducing the rate of masonry using in the building.

The first publicized use of steel in building construction in the Home Insurance Building in 1885 to the definitive pronouncement by Engineering Record in 1895 that cast iron “could not be recommended” for structural purposes. (Leslie 2013) The carbon content of steel is similar to wrought iron, but the balance ration of its internal strength and toughness is more cautious. Though continuously striking or converter process, wrought iron is generated. With high strength and excellent process ability, steel can made engineers need not rely on auxiliary masonry shear wall to against gravity and lateral load. Be free from masonry wall entirely, steel framework can meet the wind-resistance demand, and completely liberate the bondage of lighting and space. Before the end of 19th Century, the proportion of wind load factors in High-rise building design was rarely considered. Because the weight of stone can bear a part of wind load. However, with building skeleton light weighting, the nature of building height increased and cast iron link unreliable, in 1880s Chicago High-rise building designers began to pay attention to solve the wind-bracing structural system. Such as Home Insurance Building and Rookery Building, which used the angle between two buildings to keep each other’s wind forcing.
There were three main problems in High-rise building construction. First of all, because buildings were built ever higher and higher in proportion to their foundation, the vertical cantilevers must be effectively distributed with lateral loads over building’s surface entirely. Therefore, High-rise Buildings had serious problem. Because their surface area increasing, exposed wall gathered much of lateral loads, so that building’s cantilever was increased, wind can be more easily leveraging foundation at the bottom. The lighter and higher wall reduced wind-resistance of the skyscrapers, while providing more focus points of wind power. Secondly, the internal pressure caused by this resistance is very large. If one building’s beam or column is too slim, or the connection points are too weak, in the theory, this building will be destroyed from the foundation by shear. The bottom layer is required with spacious and open space; it will inevitably lead to a series of problems. Engineers have to find an appropriate way to guide the wind power and reduce the effect of building surface by wind. Bending showed extra challenge. Under the wind action on the building face, internal columns on the leeward side of structural frame would be compressed, while those on the windward side would be stretched. These lead to more complex engineering work and load calculation. Finally, the wind load was brought from unpredictable direction, it increasing the pressure between members. Effective beam-column design includes detailed analysis, complex load distribution and materials properties, which is not exist before 19th Century.

The structure problem is not only in theory, but it also exists in the actual work of installation process. In 1879 December, the wind load could not be carried on, accident of Tay Bridge in Scotland, which caused by structure defects. Subsequent investigation found that the accident was due to the unreasonable structure design and installing improperly. The geometry diagonal brace design of this bridge brought great tensile load, and support members made of cast iron. These members were assembled by bolt placed in the hole, and the installation was not perfect. With the time passage, the repeated load tension work made the connection gasket loose, after a violent storm, Tay Bridge was collapsed. The excess movement produced by the tension and looseness of structure members, created additional dynamic load in cast iron rod, which eventually led to the structural collapse. This accident shows that structural connection points
not only require certain strength, but also compactness. Because the relaxation will lead to the risk of accident and dynamic load, and work in entire structural frame and final vicious spiral.

Wind load is still very important factor for many building's section and shape. 100 years ago, many architects and engineers were out of superstition for the experience method. There is a certain proportion of the building facades and basal area, it can avoid the threat of wind load. Edward Shankland (1856-1924), who participated in the planning and operation many Chicago buildings 100 years ago. He believes that the building height is not more than four to six times as long as basal area, it does not require special structural design. At that time, for other experts, the proportion of 3:1 is safe. In order to avoid the limitation of original experience, engineers and architects have to find ways to resist wind load in the new light steel frame.

Wind-bracing System

Although the similar tragedy as Scotland Tay Bridge did not occur in Chicago, there is anxiety and depression whenever the engineer met the wind and lateral load variables; they were unable to accurately calculate it. The engineers did not bring the variables into the laboratory analysis, the construction industry had to rely on estimation and speculation and put them into an estimated loading, which is seriously uncertain. Until 1885, Chicago's engineers developed a calculation method to determine the strength of wind loads. For example, 60 miles per hour, so it would be 18 pounds per square feet at building lateral load. In 1890, New York and Chicago introduced the data into the local building code, while the same period in Boston and Philadelphia had no evaluation system of wind load. The skyscrapers in the four cities, who survived in storm, low internal wind load assessment buildings which had a huge security risk and internal structure need higher stiffness to resist more wind load pressure. After 1890, the internal wind framework is a very important part of process in Chicago commercial buildings construction. The framework consisted of three types initially, in order to cope with complicated and changeable climatic conditions, which developed into a more efficient system. These include wind structure system: rod or sway bracing, knee braces, and portal frames.

Note: Resource by: Thomas Leslie, Chicago Skyscraper 1871-1934

Figure 3. Method of Wind-bracing.

In these wind resisting frame system, the rod and sway system are the most close to the bridge structure. A diagonal tension bar is arranged in building frame and connected at the intersection of beam and column. This metal support triangle frame can ensure that any possible tension by wind and the forged steel tensile strength can be used to resist lateral wind
loads. Rod-sway system was economic and practical wind resistant structural system, but in another hand it expensed much architectural space, also made the overall planning of architectural space narrow. Rod-sway system firstly is used in Manhattan Building Chicago which designed by engineer Le Baron Jenney in 1890. This building was ever tallest building in the world, but is located in the narrow area between Dearborn Street and Plymouth Avenue which made its ratio of length to width exceed all previous theoretical ratio limitation. Application of Rod-sway system met the needs of wind load resistance, at the same time, made lightweight construction need not too much masonry support. In addition, Venetian Building and Masonic Temple is also famous work used rod-sway system. The two buildings had long and narrow rectangular foundation, while the ration of foundation to elevation could deal with challenges of wind load. But engineers still used the rod-sway system to give an additional wind bracing.

Note: Resource by: Thomas Leslie, Chicago Skyscraper 1871-1934
Figure 6. Method of Wind-bracing.

The knee bracing system is a kind of structural system which can replace rod-sway system, which shorter diagonal members were placed between columns and girders to triangulate their connection. The design strategy came from the hull of deck and the keel of connection. When the lateral load strikes, this system can make the bending kinetic energy load transfer to another component, it effectively used multiple angles components to resist a single direction load. However, this system increases quantity of material, and makes the structure heavier.

The famous example of portal frame is Old Colony Building designed by Holabird and Roche, a 17 story high-rise building. As Manhattan Building mentioned previously, it is located in a narrow area between Dearborn Street and Plymouth Street. Engineer Corydon Purdy, originally planned to use tie rod system, but after the conflict with steel suppliers, wrought iron replaced steel, Purdy was forced to change structural style. He designed a set of elliptical iron arched portal frame system which connected to the columns and girders, and used improved iron mesh to reinforce each structural connecting point. Portal system provided sufficient
strength, but it occupied too much space and reduced the height of ceiling, which reflected the drawbacks of this system. In the mid of 1890s, Chicago construction industry consensus was, knee system and portal system improved the wind resistant structures, but because they were occupying a huge space, which led to the low lifting frame, and due to the additional process of manufacture and installation, resulting in the cost was not efficiency.

**Conclusion**

In 1890s, Chicago construction industry has made many attempts to wind resistant structural system in High-rise buildings. Rod-sway, keen and portal systems have contributed to the prosperity. From the experience with no evaluation system, to gradually having a specific numerical calculation method, the pioneers met the dual requirements of building material light weight and the height breakthrough. Meanwhile, it also avoids the risk of wind load caused by the weight loss and building height rising. This is the intelligence crystallize of local architects and engineers in Chicago 100 years ago. Although nowadays, there are many limitations, it still cannot be denied its historical value. This history has witnessed the origin of contemporary high-rise building structure, but also laid the foundation for the subsequent development of building structure.

**References**


