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Autor(en): **Brunner, Lewis**

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Selection of Structural Materials for High Rise Buildings in USA

Choix des matériaux pour les bâtiments-tours aux USA

Auswahl von Konstruktionsmaterialien für Hochhäuser in den USA

Lewis BRUNNER
Vice Pres., Marketing
American Inst. of Steel Constr.
Chicago, IL, USA

Lew Brunner has been directly involved in the design and construction of bridges and buildings using steel for 40 years. Having held various engineering, sales and marketing positions with United States Steel Corporation, he is now marketing activities of AISC and its 400 fabricator members throughout the USA. He holds a BSCE degree from Wiedner-PMC University.

SUMMARY

This paper describes the planning and contractural methods used to build high rise buildings in the United States. It briefly traces the evolution of the material decision-making process over the past 100 years since the steel frame was introduced. The current position of the steel in the competitive market is described along with the tools and techniques the industry employs to increase market share.

RÉSUMÉ

Cet article décrit les méthodes de planification et le processus de décision utilisés dans la construction de bâtiments-tours aux Etats-Unis. L'évolution du choix des matériaux durant ces 100 dernières années, époque correspondant à l'introduction des charpentes métalliques, est brièvement montrée. La place de l'acier dans ce marché est décrite, ainsi que les moyens et techniques que cette industrie utilise pour accroître sa part du marché.

ZUSAMMENFASSUNG

Dieser Beitrag beschreibt die in den USA bei Hochhäusern angewandten Planungs- und Vertragsmethoden. Er verfolgt die Entwicklung des Auswahlverfahrens bei Materialien in den letzten 100 Jahren – seit Einführung des Stahlskeletts. Sowohl die gegenwärtige Lage von Stahl auf dem Konkurrenzmarkt wird beschrieben wie auch Mittel und Techniken, welche von der Industrie eingesetzt werden, um den Marktanteil zu vergrössern.

BACKGROUND

The year 1985 is significant in the history of structural steel construction for high-rise buildings. It was exactly 100 years ago that the Home Federal Insurance Building was completed in Chicago. That 10-story structure was the first multi-story office building to be supported by a steel frame.

Located at LaSalle and Monroe Streets in Chicago, the Home Federal Insurance Building was a culmination of a dream by the renowned engineer William Le Baron Jenney. He came home one evening and noticed that his wife had placed a very heavy bible on top of a wire frame rectangular bird cage. Jenney was immediately struck by the fact that the light wire structure could support such a heavy load. This relatively insignificant incident sparked the idea in Jenney's mind that a similar system could be used to resist the floor loads of multi-level buildings. He applied the theory successfully by using steel members to frame the Home Federal Office Building, a project he was designing at the time.

This demonstration opened the door to the era of vertical growth in office buildings and the expanded use of structural steel. It's interesting to note that two blocks from the Home Federal site, the Monodnock Building was under construction at the same time. At 16 stories, it was to be the world's tallest masonry wall bearing building. With six-foot thick walls, it still holds that record. So, within two blocks of each other, two monuments were erected -- one to the end of an era and the other the start of an era.

The period that followed was a time of great excitement as cities began to grow vertically in ways not thought of before. In six short years, Jenney's creation was dwarfed by the 20-story Masonic Temple in Chicago and by 1909 heights had reached 50 stories in New York. Skylines continued to change rapidly, both in Chicago and New York. A great plateau was reached in 1931 with the completion of the 102-story Empire State Building in New York. This American phenomenon, the skyscraper, emanated from the minds of imaginative architects and was supported by industrialists who produced an array of new steels in a variety of shapes for the ever expanding market. As a structural material, steel led the way in the dynamic expansion of the nation. It stood virtually unchallenged until after World War II.

During a 50 year period improvements and refinements in structural design developed rapidly. Steel strengths increased and production methods improved. Consolidation of rolling practices by producing mills evolved into a series of standard rolled structural shapes. The early 20's saw the establishment of codes and standards for steel construction and fabricating under the leadership of the American Institute of Steel Construction (AISC), which brought steel framing for high-rise buildings to a common yet sophisticated level by the early 1950's.

GROWTH OF COMPETITION

The period before the 1950's was clearly dominated by structural steel in the high-rise office building market. With a few exceptions, all structures 10 stories and taller were automatically steel framed. However, the hold on that market began to deteriorate in the mid-50's and the dominance of the material came under heavy attack by concrete. Three major developments brought pressure to bear on the hold steel had on the high-rise market. First, improved concrete strengths were developed through research. Secondly, steel shortages began to re-occur. Brought initially by the Korean War, these shortages were intensified by lengthy steel strikes and the threats of strikes that followed. These last two events forced designers to look elsewhere for materials to ensure completion of their projects. With improved materials and opportunities created by the steel industry's inability to deliver, the

concrete industry began to invade the high-rise building and long-span bridge market. The dominance by structural steel in buildings taller than 10 stories began to deteriorate.

Recognizing the magnitude of the opportunity, the cement industry expanded their research and put into the field some 250 trained engineers to work with architects and engineers on specific projects. Their main purpose was to convert steel-framed structures to concrete and educate designers about the latest practices of reinforced concrete design. The combination of shortages, improved awareness, free support and technical advice resulted in the construction of concrete buildings to heights never attempted before. The educational process reached beyond the design level. It impacted contractors and subcontractors as well. New methods for placement of concrete and new techniques for handling and finishing the materials were developed in the competitive market place by contractors interested in expanding their share of the construction market.

The invasion of this private sanctuary by the concrete industry did not go unnoticed. The steel industry fought back with an array of new high strength structural steels with yield strengths of 50 ksi. Weathering steel was introduced and revolutionary fastening techniques made riveting in the shop and in the field obsolete by the late 1950's. Rapid strides in bolting and welding reduced costs and shortened construction time. New, more efficient shapes were produced by the rolling mills -- standard flooring and roof joists were developed and used. Improved fire protection materials were developed that reduced cost and field application time. Out of intensive research by the steel industry new possibilities emerged and architects were introduced to exposed steel. Mill producers and fabricators alike encouraged the development of composite structural and floor systems. They pressed the advantages of power and communication distribution through steel cellular flooring. Millions of dollars and a vast amount of time were spent on research, advertising promotion and education by all segments of the steel industry to combat the invasion of concrete. This effort resulted in better, lighter weight, lower cost high-rise structures that would allow the Empire State Building to be built today with a fraction of the amount of steel used in 1931. Improvements in design and materials serve the owner and occupant more efficiently. As a result, we arrive at the present era in which we find intense competition between the two materials as a framing solution for high-rise office buildings up to 80 stories tall.

Even though steel no longer can claim the high-rise office building market for its own, the erosion that started in the 1950's and continued for a number of years has stopped. We are pleased to report that a balance in the use of the two competing materials seems to have been reached. The market share has remained constant over the past five years and the steel industry is working very hard to maintain that level and increase its share through coordinated technical, promotional and marketing activities by all segments of the steel producing and fabricating industry.

According to the latest AISC statistics, structural steel accounts for 44% of all types of building frames and 56% of office building construction. The office building segment includes both high-rise and low-rise offices. In 1984 302 million square feet of office structures of all types were placed under contract. Although no attempt has been made to identify or separate this number by building height, we estimate steel accounted for more than 56% of the 10 to 80 story market segment.

METHODS OF BUILDING IN USA

The rapid changes in materials and their use have been taking place the past 35 years. More recently, there have been other changes that have had a profound effect on the material decision processes in America. There has been a reduction in the number of owner occupied office buildings and a corresponding increase in the position of the speculative builder/developer. This shift has intensified the importance of the financial aspects of construction projects. The office building market continues to be a very appealing area for investment despite over capacity in many large cities. It has also spawned a host of new specialists whose interest is money-related rather than design or material related.

At the present there are four methods for the planning and construction of high-rise office buildings. These are Traditional, Fast Track, Scope and Design Build. The Traditional method has been used in the United States for many years and is still in use. It involves the creation of a set of completed design drawings and construction documents prepared by the architect. Lump sum bids are taken from general contractors for completion of the project in accordance with the documents. In addition to the Traditional system, new methods have been developed in recent years to shorten the construction period. These are Fast Track and Scope. Under these two methods, subcontracts are awarded for major segments of the building during the design process. Both allow certain work to be performed on major segments of the project before completion of final plans and specifications. Successfully applied, these methods shrink construction time, which in turn reduces the cost of the construction loan and generates income through earlier occupancy. The disadvantage of Fast Track and Scope lies in the fact that the investor is not sure of the total cost of the project until much of the work has been completed. Also, cost can vary because of agreements made with incomplete plans and insufficient understanding between all parties. Changes during construction are also more frequent. Design Build, if performed properly, can satisfy both problems of price control and a shortened construction period. Under this system, the owner and a single responsible contractor agree on price and schedule before design or the expenditure of any funds.

When one takes into account the nature of the high-rise building construction business in the USA, one becomes aware of the many influences involved in the material selection process. Although all of the four methods require the services of the same design professionals and tradesmen, their importance varies depending on the way the project is managed.

In the case of the Traditional method, the owner normally retains an architect who evaluates the owner's present and future needs and recommends solutions through the creation of preliminary plans and specifications. Modifications are made in concert with the owner as he evaluates the architect's ideas and reviews preliminary cost estimates. After agreement is reached, final working designs are prepared and lump sum bids are taken from general contractors. Included in the final plan are the designs of major items such as foundations, structure, heating, ventilation, exterior finish, etc. All items are completely designed and specified to leave no room for misunderstandings by the contractor. Under the Traditional method, the selection of framing material is left to the architect and the structural engineer, who is selected by the architect.

If the bid received from the general contractor is satisfactory to the owner, contracts are made and the general contractor then has the responsibility to award subcontracts, supervise performance, establish schedules, coordinate all trades and complete the work on time and within the budgets. The exception is when the owner has a preference due to past experience or expertise in these matters. Some developers and owners, because of the nature of their business,

can make such judgments. However, in most instances the design professionals retained by the owner are the decision makers.

In the Traditional style, primary control for all systems rests with the architect and engineer. Material change or interference with this selection process does not usually occur unless the general contract bids exceed the budget. Therefore, in order for the steel industry to maintain market position, it is necessary that architects and structural engineers be kept abreast of the latest developments in our industry, including availability and price and improvements in material fabrication and design. In our country, the responsibility for the distribution of information resulting from technical and market research has been assigned to industry groups such as the American Institute of Steel Construction (AISC) and the American Iron and Steel Institute (AISI). This information reaches engineers and architects through printed matter, advertising, national and local meetings and seminars plus direct contact by Institute staff representatives. Current data on material availability and price is supplied by the producing mill representatives and local fabricators. That data is usually tailored to meet the needs of the designers for a specific project and is offered for evaluation during the early planning stages. It is not uncommon for the mill staff to prepare a special steel framing layout that fits the specific architectural requirements of building size shape and interior arrangement. The structural engineer has the best thinking of the steel industry as far as layout is concerned backed up by local pricing.

In the case of Fast Track and Scope methods, the material decision making process changes because of the introduction of the construction manager or other practicing professional business person acting on behalf of the owner. With few exceptions, his task is to supervise all aspects of the project starting with the design. He sees that it is completed within the allotted time frame at the lowest possible cost. Under such an arrangement the construction manager not only negotiates and supervises sub-contracts, he also plays a major role in choosing the architects, engineers and contractors that make up the building team. Systems and materials are investigated early in the planning stage by the team with constant pressure for maximum economy from the construction manager. Final selection is usually made cooperatively by the construction manager and the owner or developer. Since this process is common for speculative buildings, little consideration is given to life cycle costing and therefore the short term cash flow aspects of the project became paramount. It is obvious that the decision making authority of the architect and engineer is considerably reduced under this arrangement. In an effort to have products chosen for the project, promotional focus shifts to the construction manager and owner. Under these conditions, price becomes more important than aesthetic, structural performance and life cycle performance considerations.

Scope is nothing more than a modification of Fast Track, because control is in the hands of the owner representative and construction begins prior to the completion of designs. In this case the architect and engineer prepare partial designs under the supervision of a construction manager. The documents are advanced to a stage of completion that allows firm unit prices to be agreed upon between the major subcontractors and the construction manager/ owner. This method ensures better control over final construction cost.

Fast Track and Scope construction accomplish the same thing -- a rapid or reduced construction schedule. Both involve site work prior to the completion of the final design. The difference is largely in the area of contractual arrangements between the principals. However, in both systems, firm unit prices are agreed upon by the owner or owner's representative and the subcontractors before final documents are complete. In both instance the manager exercises a great deal of control in the material decision process.

The fourth type of contractual arrangement is known as Design Build. In this method, the owner outlines his overall space and functional requirements, then enters into a contract with a company to provide a facility that will meet his needs. This company is known as the Design Build company. Under such arrangements, the contracting company has broad latitude to design and furnish a facility that satisfies the requirements within the agreed upon fixed price and specified time at a particular location. The contractor has responsibility for overall design of the structure and material selection. In most instances, firms offering Design Build service usually restrict their operations to a set of rather rigid standards and operate in a narrow band of the construction spectrum. In most instances the design build firm has full time architectural and engineering staff personnel along with cost estimating and construction supervisory capability. It is common practice for such a company to perform much of its own work or deal with established subcontractors with whom they have done business in the past. This type of organization has the highest degree of sophistication in the area of total construction with maximum control in the choice of materials. The existence of Design Build is quite common in small office low-rise building construction, but is rare in the high-rise office building segment.

ADVANTAGES OF STEEL

Despite the fact that the methods for planning and building high rise buildings in America have changed, the primary reasons for selecting structural steel remain the same. These include:

> Strength - Speed of construction - Lighweight-Quality - Flexibility of design and construction - Cost - Technical support - Economy - Long span capability - Off site fabrication - All weather construction - Easy modification - Ease of design

All these characteristics are beneficial, in some degree, to all members of the building team, according to a 1984 survey by Engineering News-Record in which all disciplines involved in planning and building construction responded. These values were recognized as synonymous with structural steel.

It is widely recognized that the quality of steel is predictable, consistent, and measurable. Few other materials are, or even can be, produced and fabricated under such closely controlled conditions as structural steel -- from the raw materials to finished assemblies. Structural steel is produced and tested to rigid specifications established by the American Iron and Steel Institute (AISI), and each step documented. Consequently, the chemistry, strength, connections, dimensions and other details are precisely known and easily verified -- before the material is delivered. Furthermore, environmental factors at the site -- hot, wet, cold or dry -- don't affect the quality or installation of structural steel.

Research into problems and opportunities involving structural steel is being conducted continuously under grants and programs by AISC and AISI. The results of the research are furnished to architects and engineers through revised specifications, the AISC Engineering Journal (which is distributed world wide), trade publications and flyers, national and local seminars, advertising, mailers and by direct contact by AISC and producing mill field representatives scattered strategically across the nation. Because of the long standing established practice of research and information distribution the Institute and its producers enjoy a high degree of credibility in the eyes of practicing professionals. The AISC Manual of Steel Construction, first printed in 1929, is in its Eighth Edition and is regarded as the unquestioned standard of the industry by all major regulatory agencies and code bodies.

The concern of the industry goes beyond the technical aspects of the material itself. We must continually remind those who build high-rise office buildings of the other, less apparent, values of steel over concrete construction. Because of this we address the needs of the owner, developer and investor. Typically, the owner/developer's goal is to match investment objectives to desired return ratios through examination of a building's particular characteristics. The closer the owner/developer can come to pin-pointing specific criteria that will translate into the desired return, the closer he will come to realizing investment objectives. This is why a consideration of the frame can be so important to the owner/developer -- knowledge of how various framing systems affect space efficiency can lead to more accurate and more favorable return ratios.

A lighter weight frame, larger spans and fewer columns result in reduced foundation cost. Costs are all affected positively by a reduction in construction time. The time saved can be easily translated into dollars saved because the interest rates for construction loans are considerably higher than long term mortgage rates. Therefore, a savings of a few months or days construction time for a very large project can offset price differences for building components.

For example, interest on a $50 million construction loads at only 12% is more than one-half million dollars per month, which is nearly $17,000 per day or $700 per hour. The shortening of the schedule also permits earlier occupancy, improving the income schedule. On large projects structural steel can save up to four months over concrete construction. These are direct first cost items that all members of the building team can appreciate. More subtle advantages of steel framing are less apparent but may be more valuable to the owner or investor in the long run. The most important advantage to all members of the building team is the feature of flexibility -- not the flexibility of individual members, but flexibility in terms of options open to all those involved. Adjustments can be made to accommodate changing demands during design and construction, as well as during the entire life of the structure. These options include:

Flexibility of design

Flexibility during construction -- that is the ease in which modifications can be made to members in place that must be changed

Flexibility in scheduling

Flexibility within finish space because of smaller and fewer columns

Flexibility to accommodate a wide variety of tenant requirements, including increased loads Flexibility for major modifications such as horizontal and vertical expansion

All these advantages can be translated to improved return on investment for developers and present and future owners.

The steel industry continues to remind all those involved in the planning and building of high-rise buildings of the direct and indirect benefits of structural steel through direct and indirect means. The business aspects of building have become more dominant, the methodology more complicated and the competition more intense than it was in Jenney's day. However, the fundamental values of strength, reliability and flexibility of steel that brought his dream to reality still exist and continue to make it the preferred structural material for today's modern skyscrapers in the United States.

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