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Steel Framed Tier Buildings in American Design Practice

Les méthodes américaines d'étude des ossatures métalliques pour bâtiments à étages multiples

Amerikanische Berechnungsmethoden für Stahlskelettbauten

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Building design is one of the many fields in which a civil engineer may choose to use his talents. The design of tiered building frames in America, commonly referred to as skyscrapers, is an area for endeavor and accomplishment that has peculiarities and requirements worthy of note. There are more and different considerations involved in the tiered frames than there are in the types of buildings from which this class grew. Complexities have multiplied as the demands for enlarged and finer accommodations have increased from year to year. How the structural engineer performs, and how he obtains the desired results of his efforts, is perhaps of interest.

In the United States of America, the organization to perform this work generally follows a pattern which has developed in a clime of an expanding economy and rapid change. Since the introduction of steel construction, there has been a growing tendency boldly to accept new concepts and to disregard or even to discard that which has been done before. The engineer has lived in, and adjusted himself to this atmosphere. He has acquired a flexibility and has participated in, and contributed to, the advances that have marked the age in which we live.

The engineer in the United States usually practises as an independent private professional, often in association with one or more partners. He maintains an office and draughting room where a staff of engineers, technicians and draughtsmen produce the structural plans and specifications for the various projects for which he is responsible. He depends upon professional fees for his expenses and personal income. The plans finally prepared under his direction are complete and illustrate the whole structural design. These plans are used to obtain a permit to build from the local building department or authority, They also permit competing steel fabricators to estimate and bid for the job of detailing, making and erecting the work.

Design is a creative art. It cannot be taught, for textbooks only give the tools to be used. Each basic concept must originate in the mind of one man, the designing engineer. The art must be learned by those who have aptitude and imagination, and who have acquired technical training coupled with a knowledge of available materials and local builders' capabilities. Of utmost importance, in the field under discussion, is the will on the part of the designers to cooperate with others. The modern big building is a most complicated machine. The support of the structure, although vital, is not the only feature that contributes to the successful functioning of the building.

In a sense, the practice of structural design is the same and has the same basic requirements as any other art. The musician, before he can perform in public, or the painter, before he can produce a good picture, must work to acquire a knowledge of his tools and the technique of their use. If these artists try and fail, they may get popular sympathy but it is not so with the structural engineer. Once charged with the responsibility for a project, he must reach a safe conclusion within a reasonable time. This calls for vision based on experience, and he cannot rely wholly upon what he or someone else has done previously. No two buildings are alike, though some may be similar.

Now, how are the structures under discussion conceived and planned? A team is needed ... a team of experts who should actively participate in the earliest phases of planning. A period of several months may be allowed for the development of studies. Frequent consultation with the owners must be maintained so that they may be completely satisfied that what is being planned will adequately meet their needs. It must be emphasized that worthwhile ideas can be most advantageously contributed only before too many vital or irrevocable decisions have been made. Belated thinking by the experts is to be avoided.

The captain and coordinator of the team is the Architect who decides the scope, function and appearance desired. The team includes a number of specialists; various mechanical engineers who dictate the organs, nerves and vascular system required, and the structural engineer who must conceive a suitable skeleton. It is somewhat like creating a human body which throughout its life or span of existance must serve, labor and resist the ravages of time and of the elements. It is in the early stages of the coordinated planning that the structural engineer may most successfully show his ingenuity.

The conception that evolves from this preliminary work is the true design and requires the broadest skill and knowledge. It demands the imaginative, creative thinking which would be fruitless as an afterthought when the work of planning has progressed to a more advanced stage.

The structural designer must acquaint himself with the magnitude of the proposed building, the site conditions, the approach to and the exposure of the property. He must also consider the nature of the ground on which the building is to rest and the possibility of obtaining a suitable foundation. Tall towers should have a firm, unyielding base and narrow structures may even require anchorage to prevent overturning due to horizontal forces. Schemes for the framing of typical floor panels must be studied and compared for suitability and cost. The floors not only carry the dead and live loads to the columns, they have to be capable of acting as stiff horizontal diaphrams to distribute the wind or seismic shears to the braced bents. Great care must be used so that all live and dead loads are included in the calculations and that local laws are not violated. He must exercise to a great extent the ability to think in three dimensions. Such ability is a vital characteristic of the real engineer. He must decide the number and position of the supports or columns at the various levels, providing for the large or uninterrupted spaces deemed essential by the Architect. This may involve girder or truss transfers of columns. Often the trusses exceed in magnitude, if not in span length, the heaviest bridge work.

A major consideration in this planning phase is that, simultaneously, the structural engineer must devise and incorporate a system for bracing a high structure to withstand horizontal forces such as wind or earthquake. Except in a very sketchy way, as a sort of mental guide, figures or computations are not involved, but at the same time, the size of the members that will eventually be required must be made clear so that the other experts may make allowances in their planning. The number, speed and heights of elevator banks to service the building must be determined by one of the experts, and provision must be made for the type and space requirements of ventilating or air conditioning ducts and equipment. All this, in the early stages, is done in a freehand manner. An active exchange of ideas must be maintained among members of the team either in meetings or by means of sketches. Herein is demanded a sympathetic cooperation so that all of the ultimate demands of the project are clearly illuminated. The real designer of the steel structure must be sure that he has not neglected any basic factors needed for complete design. He may use some pilot figures, but mainly he and his confreres rely on judgement.

Neglect of a major factor is not to be tolerated. Not too long ago, plans for a high building in a foreign land were issued for bidding by contractors in numerous countries. In all respects they seemed complete, but no provision to withstand the strong winds of the locality had been incorporated. Nor was it possible to add strength and stiffness without utterly preventing the intended use of the building. The plans were useless.

The structural designer must be very intimately aware of what shapes and sizes can reasonably be obtained and handled for each particular job. He must know how they can be connected and to what extent he may employ riveting, bolting or welding. For high buildings of the class under discussion, welding, as a means of connecting members of the frames together, has not been used to a great extent in the United States. In almost every steel structure, however, some places can be found where welding is employed. Practically all of the work done in the fabricating shop is riveted.

For field connections, ordinary bolts serve only for the minor filling-in pieces. Riveting has long been the most favored method in general use, but for nearly all of the recent projects, the so called high-tension bolts are being substituted for rivets. Properly installed with calibrated power wrenches, they provide a most satisfactory substition and a saving in cost.

It is well, if in his earlier training, the engineer has had a few years of detailing, making shop drawings of actual pieces and thus learning to solve the small problems that arise with infinite variety on every job.

The growth of the large and high framed building has been most notable in the United States where the unstinting use of steel has been of less economic importance than in other countries. The industry has contributed, over the years, by developing and making available, the desired shapes in a variety of quantities and qualities.

In tiered buildings, the space between ceiling and floor must be kept to a minimum. The depth of the horizontal framing establishes the story heights. The cost of extending stairs, walls, piping, elevators and ducts must be balanced against the cost of using the shallower beams or girders in the floors. The demand for wider and wider open spaces dictates an ever increasing spacing of columns and shallower beams, or the design of beams that can be punctured for the passage of horizontal ventilating ducts and pipes. While this sort of thing often requires what might be by itself regarded as an extravagant use of metal, it effects an overall saving in the building cubage and cost.

As the demand for larger and higher buildings has increased, year by year, the manufacturers have marketed heavier and heavier rollings. Very sizable projects are accomplished today by using plain rolled sections. However, the bigger and more spectacular creations of modern times have required columns with immense load carrying capacity, and of sizes far in excess of even rolled column shapes with ordinary cover plate reinforcement. The design of the heavy columns for the lower parts of multi-story buildings requires study in each case. It is not just a simple matter of getting a cross section of so much area. The scheme of wind bracing is as much a governing consideration as is the load in the design of the cross section of the column. If the plan is of a long narrow building, the wind may be a major problem in one direction only. If the plan is of a tower approximately square, moment connections may be needed to all faces of a column. The magnitude of the maximum moments will require a detail that lends to a grading or modification up through the frame without abrupt change of type. Strength is not the only requirement. Stiffness must be obtained so that tenants are never conscious of way in slender towers.

The frame should be rigid so that damage is not done to stiff partitions, or to column encasements and fireproofing in the finished building. Knee braces are generally stiffer and more economical than are moment connections, but they are architecturally objectionable as a rule.

For satisfactory results on slender towers, assuming prescribed wind pressure, the sway should be limited to .002 of the height as a maximum. It must be borne in mind that more modern and lighter construction does not contribute the stiffening benefits of the old fashioned, heavier masonry walls and floors. Total dependence for rigidity is upon the steel frame alone and judgement often dictates the use of a drift factor of .0015 in the design computations.

Examples from three monumental buildings nearing simultaneous completion in New York City serve to illustrate various treatments of the problems.

Case I

This is a sixty story office building with forty column shafts for the full height arranged in four lines of ten supports on each line. Obviously, with this rectangular plan, the major wind problem is in the relatively narrow bents

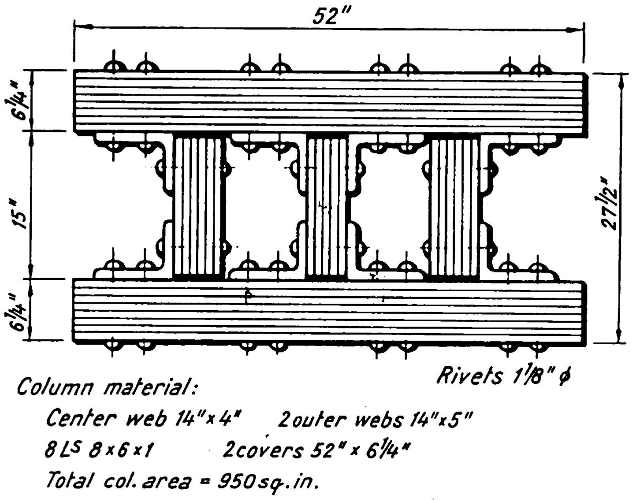

Fig. 1.

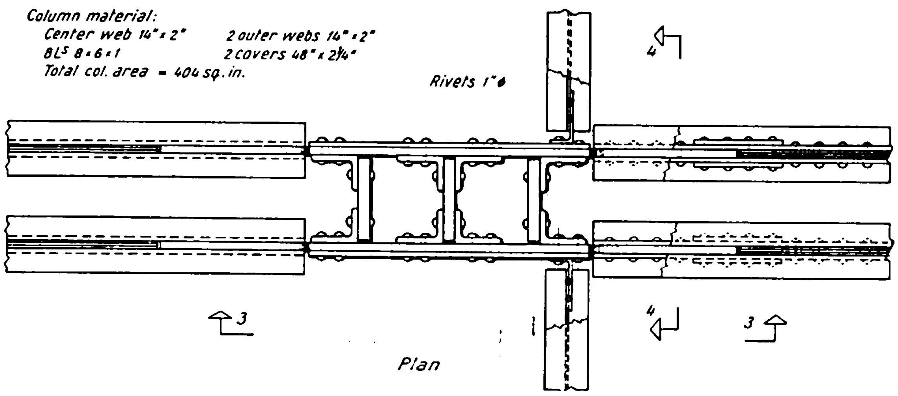

Fig. 2.

of four columns. These bents are twenty-nine feet apart and the columns are spaced from thirty-one to forty-five feet apart. The interior columns carry as much as eleven hundred square feet of floor at each level. Fig. 1 shows the cross section of the maximum column shaft used with an area of 950 square inches of steel. Note that the shape of the column, twice as deep as it is wide, represents an ideal solution for making a compression member to be strong in bending about one axis. Figs. 2, 3 and 4 show a typical detail for moment connections in an upper story. They illustrate how certain of the laminated cover plates were extended as gussets to engage the floor girders which are

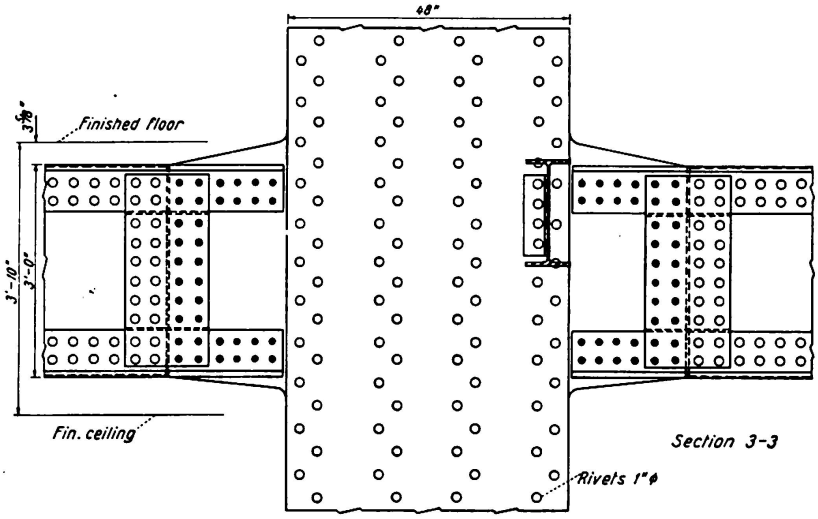

Fig. 3.

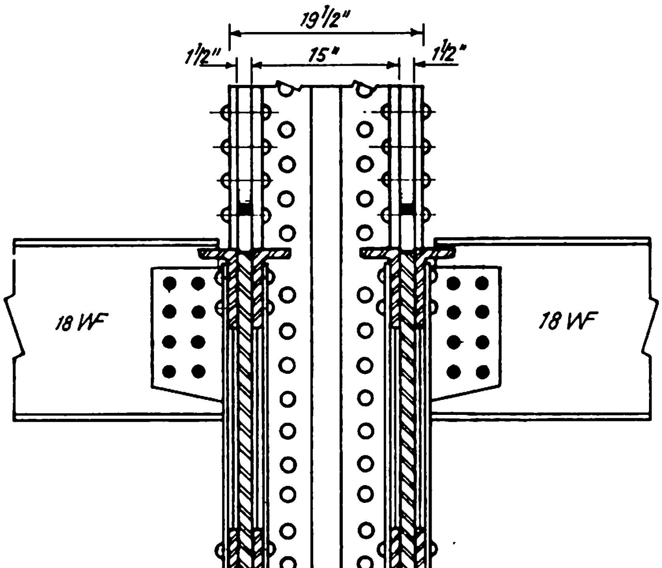

Fig. 4.

36 inches deep for the normal 12′–7″ stories and 48 inches deep where the stories are higher.

The lesser wind problem in the long direction of the structure was taken care of by using double angle knee braces along the two interior column lines. This bracing is encased and hidden by the partitions enclosing the elevators, stairs, shafts and utility rooms.

Case II

This is a relatively square fifty three story tower and the wind pressure in each direction is approximately the same. Figs. 5, 6 and 7 show a typical interior condition where moment connections were required on all four faces

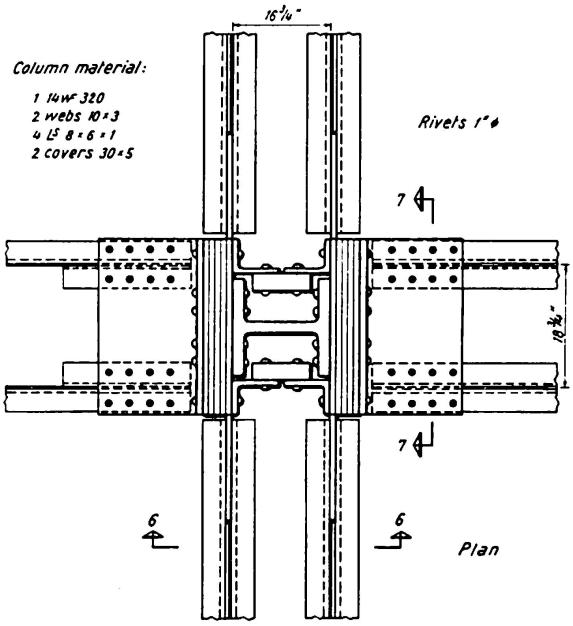

Fig. 5.

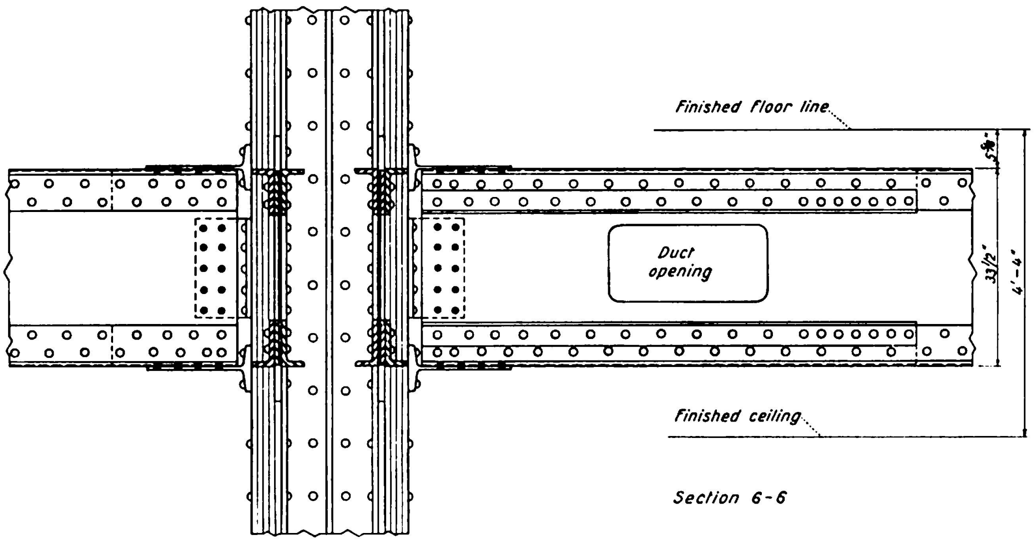

Fig. 6.

of the column. The spans varied from twenty to forty feet and rectangular openings in the girder webs allowed the horizontal ventilating ducts to be kept within the 33 inch depth of steel girders.

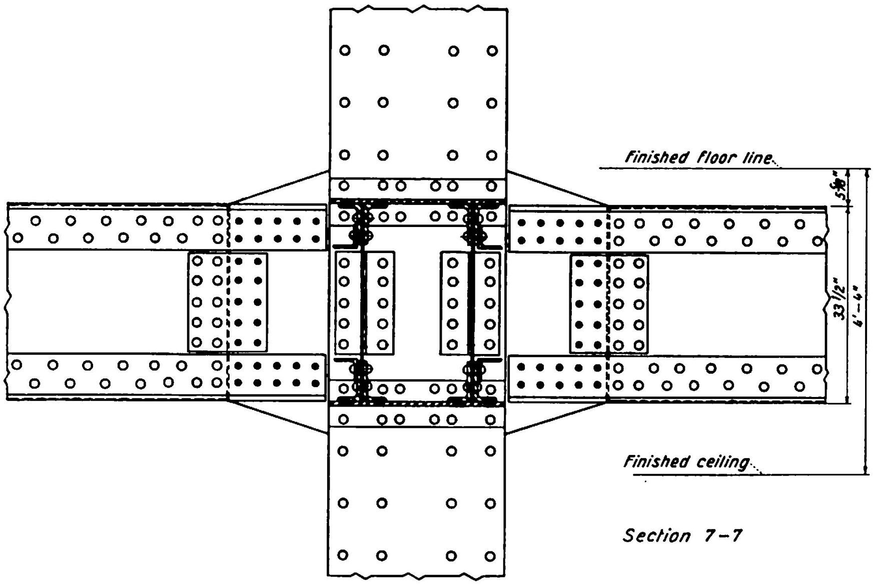

Fig. 7.

Case III

This is a forty-three story tower 167′ × 147′ in plan. Here the wind treatment is kept entirely within the 42′ × 109′ central core area and no moment connections of the surrounding office floor framing were required. The core is a braced tower by virtue of a system of interdependent trusses and knee braces in both directions. This bracing is economical of steel and is acceptable architecturally as it is entirely hidden and fireproved by enclosure walls and partitions. The floor area outside of the core is supported by simple beam and girder framing. Since these members were free of any wind stress considerations, filler beams were 16″ deep and girders 21″ deep on approximately 28 ft. spans. Air conditioning ducts diverge from large vertical distribution shafts in the core and pass under the structural framing to properly located diffusers. A cross section through the typical floor construction would reveal a 1″ cement topping on $3^1/_2$″ lightweight fill; a 5″ lightweight concrete mesh reinforced slab supported on structural steel members encased in concrete; 8″ deep air conditioning ducts and 3″ of ceiling construction. The total dimension from finished floor to finished ceiling is 3′—5″. The architects set the clear ceiling height at 8′—10″ and a typical story height of 12′—3″ resulted.

Fig. 8 shows the typical tower framing plan. Figs. 9 and 10 are cross section diagrams of the tower framing. Fig. 11 is a cut-away perspective of the skeleton of this tower.

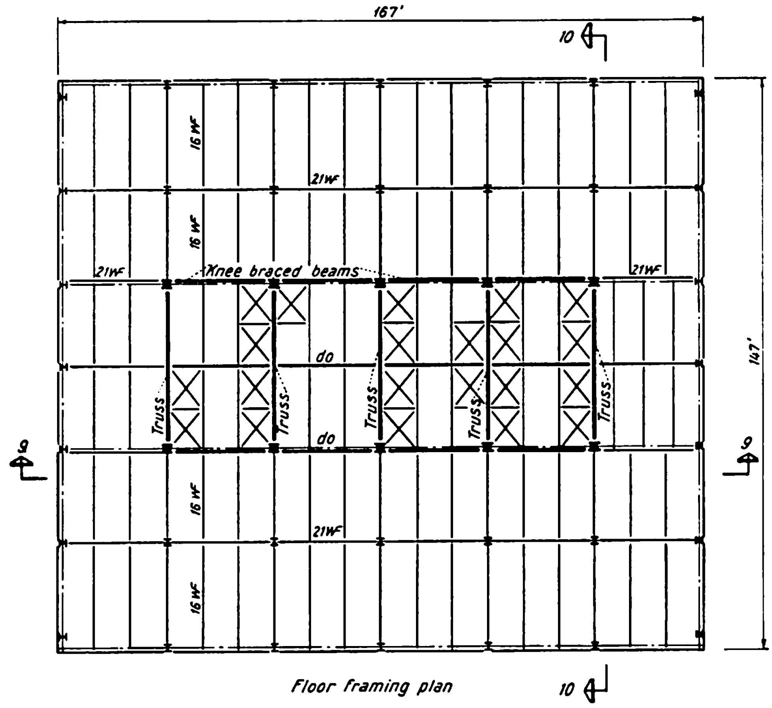

Fig. 8.

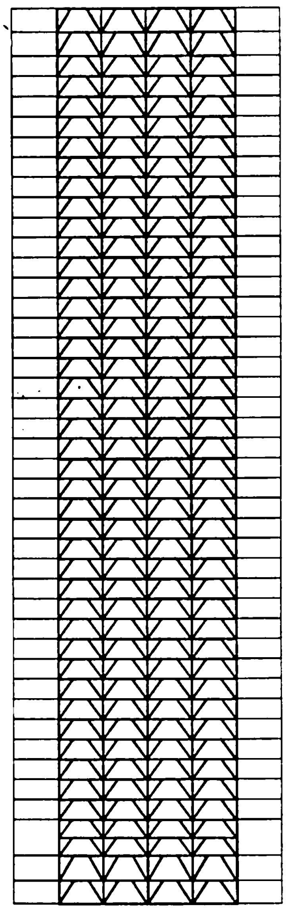

Fig. 9.

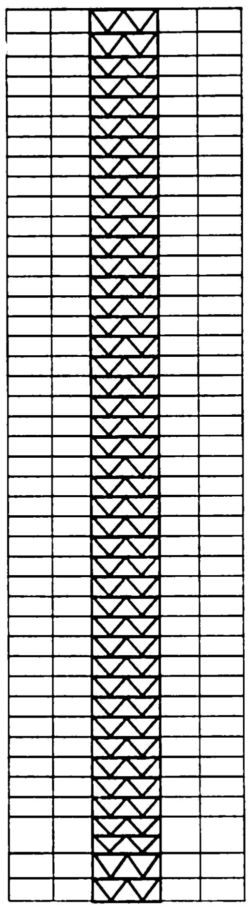

Fig. 10.

These three examples serve to illustrate the variety there is to the solutions that are to be found in answer to problems common to all buildings that tower above the ground; buildings that in a sense are vertical cantilevers that must withstand dynamic horizontal forces. There is no preferable form of wind bracing. The engineer must devise a scheme that he considers best suited for the particular problem at hand. He may decide that only certain selected bents are to withstand the shear. He may decide to use moment connections or cross braced panels or combinations of the two that will be proportioned to act in concret.

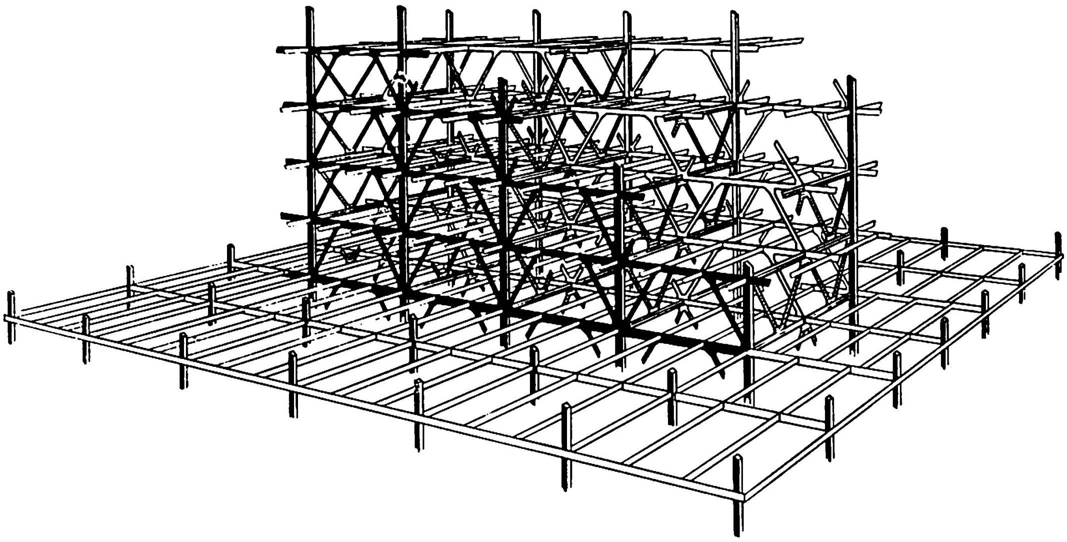

Fig. 11.

Once a project is started, as little time as possible is allowed for exhaustive study or involved comparison of various schemes. A firm sure hand must map the course to be followed. A tiered building is designed from the top down but, of course, will be built from the bottom up. Where high buildings are planned, the land values are likewise high, and the planners are urged to speed their work so that a return on investment will start at the earliest possible date. Usually high towers are planned for areas already congested, and the land selected is being currently put to some commercial use. There is no advantage to starting to excavate before the foundations are designed. The column loads and locations must be determined accurately to permit the commencement of work at the site.

A most important feature of the steel design is the column schedule. It has been found generally most advantageous and economical to splice all columns at every second story in order to reduce the number of pieces and thus the milling and splicing. Every third story has been tried in some few instances, but after consideration, it has been discarded as a practice. It piles too much material on the deck if three tiers of beams are to be sorted after delivery. On the other hand, such considerations as an abrupt increment of load, as an occasional high story, or exceptionally heavy weight of pieces may dictate the use of one story column shafts. This was the case in the lower stories of the structure cited in Case I, where the lifting capacity of the heaviest derrick equipment obtainable forced the designing engineer to limit the lengths of the shafts to be handled during erection.

It is impossible to describe herein all the items involved in the design of tiered buildings. The engineer must delineate the comprehensive scheme, largely imaginative in the early stages, and this must be followed up by the more detailed work of computing and draughting. Led by the structural engineer, his staff of technicians produce plans and schedules which complete the steel design. The structural steel contractor to whom the fabrication is awarded must then make shop details of every piece, and these details must be submitted to the engineer for his corrections and final approval. This is an important part of the engineers work and needs thoughtful care. Besides being a check upon the accuracy of the contractor's interpretation of the design, it furnishes the engineer a final opportunity to appraise his own work.

Participating in the design of a modern skyscraper is a rewarding experience. Looking up at a completed building, one cannot be but proud of man's accomplishment and especially of the part played by the Engineer in such an achievement.

In 1890, the poet, Rudyard Kipling wrote about the ancient subject of art. One verse referred to the building of the Tower of Babel.

"They builded a tower to shiver the sky and wrench the stars apart,
Till the Devil grunted behind the bricks: 'It's striking, but is it art?'
The stone was dropped by the quarry side, and the idle derrick swung,
While each man talked of the aims of art, and each in an alien tongue."

Thus the first attempt of men to attain a structural height was a failure due to their inability to cooperate. We are learning by experience. May we work together in harmony and with understanding.

Summary

This paper on the Practice of Design in the United States is more philosophic than scientific. The technical aspects of the subject are too well known, varied and intricate to receive more than passing reference. Taking for granted that the readers are schooled in the fundamentals, herein are treated the pertinent points that particularly apply to high buildings and to the role of the engineer in his handling of the problems involved. Engineers are regarded as men who compute. Attention is not generally paid to the extent to which they have first to conceive what they will figure. By generating original ideas and conforming to the laws of nature within the boundaries of economy, the

designer displasy his genius. The high steel structure requires, in full measure, the best efforts of the profession in the practice of design as an art.

Résumé

Cet article, qui traite de l'étude des immeubles à étages multiples aux Etats-Unis, est plus philosophique que scientifique. Les aspects techniques du sujet sont trop connus, trop variés et trop complexes pour recevoir plus qu'une mention au passage. Les lecteurs, que nous supposons instruits des notions de base, trouveront traitées ici les questions les plus importantes relatives particulièrement aux immeubles élevés et au rôle de l'ingénieur dans la façon de résoudre les problèmes que cela implique. On considère les ingénieurs comme des personnes qui font des calculs. On oublie trop souvent jusqu'à quel point ils doivent concevoir d'abord ce qu'ils calculeront ensuite. C'est en émettant des idées originales et en les conformant aux lois de la nature dans les limites de l'économie que l'auteur d'un projet montre son génie. Les ossatures élevées en acier exigent que l'on applique à leur étude toutes les ressources de la technique et de l'art de l'ingénieur.

Zusammenfassung

Dieser Bericht über statische Berechnungen in den Vereinigten Staaten von Amerika ist mehr philosophisch als wissenschaftlich. Die technischen Aspekte sind zu gut bekannt, zu verschiedenartig und zu kompliziert und können daher nur am Rande erwähnt werden. Unter der Voraussetzung, daß die Leser mit den Grundlagen vertraut sind, werden in diesem Bericht die Schwierigkeiten behandelt, die besonders bei der Berechnung von Hochhäusern auftreten und die Rolle des Ingenieurs bei der Handhabung der verschiedenen Probleme. Ingenieure werden als Männer betrachtet, die Berechnungen aufstellen. Im allgemeinen wird der Tatsache viel zu wenig Aufmerksamkeit gewidmet, wie weit sie zuerst gestalten müssen, was sie anschließend berechnen. Bei der Schöpfung von neuen Ideen und deren Anpassung an die Naturgesetze, in den Grenzen der Wirtschaftlichkeit, zeigt der Entwerfer seinen Genius. Die statischen Berechnungen von Stahlkonstruktionen für Hochhäuser sind zur Kunst geworden und erfordern im höchsten Maße die größten Anstrengungen des Ingenieurberufes.