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Trends in Creative Design

Tendances de l'évolution de la conception créatrice du projet

Entwicklungstendenzen im kreativen Entwurf

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SUMMARY
Changes in standard rolled sections, improvement in connections and fabrication practices are reviewed. Effect of the emerging design methodology and of limited availability of skilled field labor on development of novel structural systems and forms are discussed. Recommendations to meet these changing conditions are made with examples where such recommendations have been implemented.

RESUME
Le rapport présente les innovations dans le domaine des profilés laminés, les perfectionnements concernant les assemblages et les procédés de fabrication. On considère l'influence d'une nouvelle méthodologie du projet et d'une limitation du personnel de chantier qualifié sur le développement de systèmes et de formes structurales nouvelles. Des recommendations sont faites pour tenir compte de ces conditions changeantes et des exemples appliquant les dites recommendations sont présentés.

ZUSAMMENFASSUNG
Im Bericht werden Neuerungen auf dem Gebiet der Walzprofile, die Weiterentwicklung von Verbindungen und Fabrikationsverfahren behandelt. Der Einfluss einer neuen Methodik des Entwurfs und der Bemessung und derjenige der beschränkten Anzahl erfahrener Monteure auf die Entwicklung neuartiger Tragsysteme und Bauformen wird besprochen. Der Autor zeigt in Form von Empfehlungen, wie man diesen wechselnden Bedingungen begegnen kann, mit entsprechenden Anwendungsbeispielen.

1. INTRODUCTION

This paper is an overview of new standards in rolled sections, computerized fabrication and changing field workmanship in structural steel in U.S.A. and the impact that these changing conditions have on engineering considerations and design. The overview is based on the author's own observations and conclusions of this impact; other engineers might put emphasis on different factors than his. Projects cited as examples have been designed by this author; the philosophy of his design was based on above conclusions.

2. THE MOST SIGNIFICANT FACTORS IN THE PRESENT TREND

2.1 Standards

As of September 1978 most standard structural shapes, particularly the wide flanges and H-piles, will change. There will be dimensional changes and larger number of different weight shapes. Range of capacities will not change, though the dimensional changes in some sections will result in improved bending properties. The change in dimensions has primarily been introduced to enable the rolling mills to produce a larger number of different weight shapes without interrupting production to change rolls.

There is no change in properties of steel which still remain in the 36,000-90,000 psi yield (with ultimate strength range of 50,000-130,000 psi), with most commonly used being in the 36,000-50,000 psi yield range. Weathering steel has the same properties as in the past 10 years but its use is being more widely accepted.

Welding of thicker shapes and plates is commonplace and the industry knows how to cope with lamellar tearing. Friction type bolted connections, Fig. 1, are used extensively, including galvanized bolts. Painting is unconditionally per-

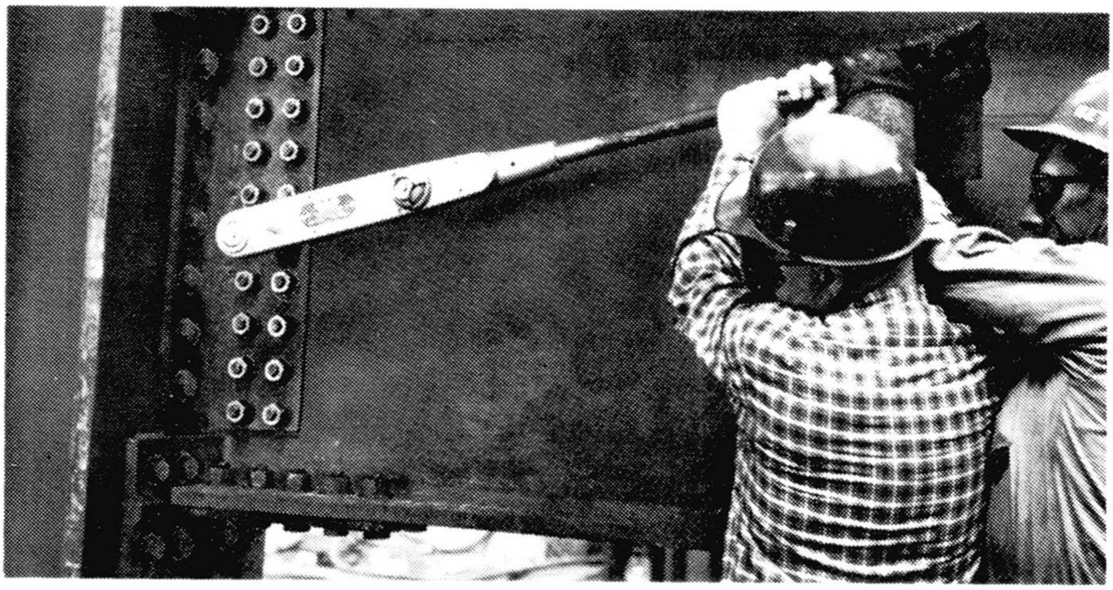


Fig. 1

mitted on bearing type connections. Since 1976, most of the allowable stresses in bolted connections have been increased.

2.2. Fabrication

In shop fabrication computer plays an important role. Fabrication drawings are drawn by computer-tracers, Fig. 2, saving time and improving accuracy. In the

Fig. 2

shop, of interest is the numerical control burning and drilling equipment, Fig. 3. This type of equipment proved to be not only cost saving, but of high degree of accuracy. Because of the accuracy of drilling holes, most of the old reamed assembled operations can be eliminated.

2.3 Mass Production

2.3.1 Light Gage Sheet Metal Structures and Components

Light gage, cold formed steel structural components have been, in the opinion of the author, of the most significant contribution to innovations and creativity in engineering design and structures in the last 20 years. Advantages are numerous: light weight, simplicity of erection, as well as the speed of erection. Field and shop errors are minimized as compared to fabricated structural steel.

2.3.2 Building Systems

The prefabricated metal industry - considerable user of light gage components - has been growing by leaps and bounds in the last 10 years. Prefabricated buildings are not used only for the industrial and agricultural purposes (Fig. 4) but in recreational, business and other private and public sectors (Fig. 5). Multi-span and large spans are easily accommodated. Most systems consist of light structural steel rigid frames with light gage purlins and enclosures (Fig. 6). These buildings are erected rapidly, with significant cost savings.

The most appealing aspect is reliability of initial construction cost estimates - a problem in custom-made type of construction.

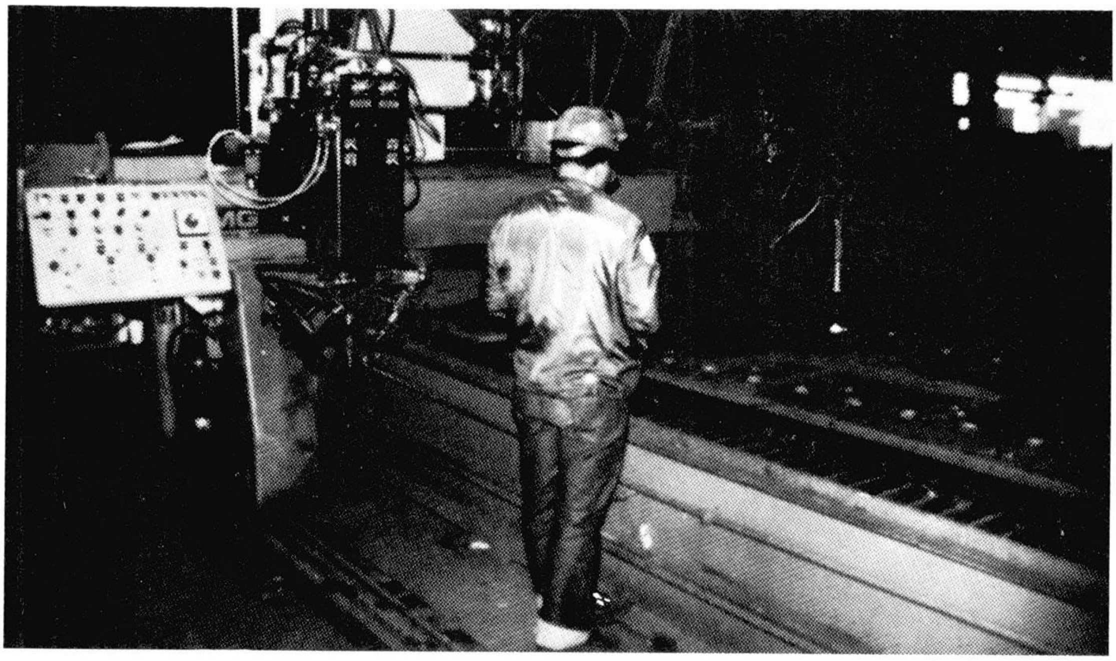


Fig. 3

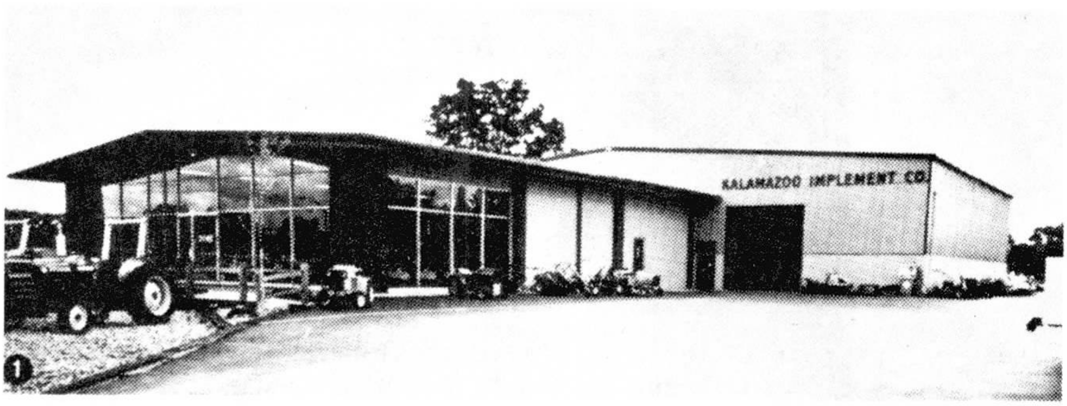


Fig. 4

Fig. 5

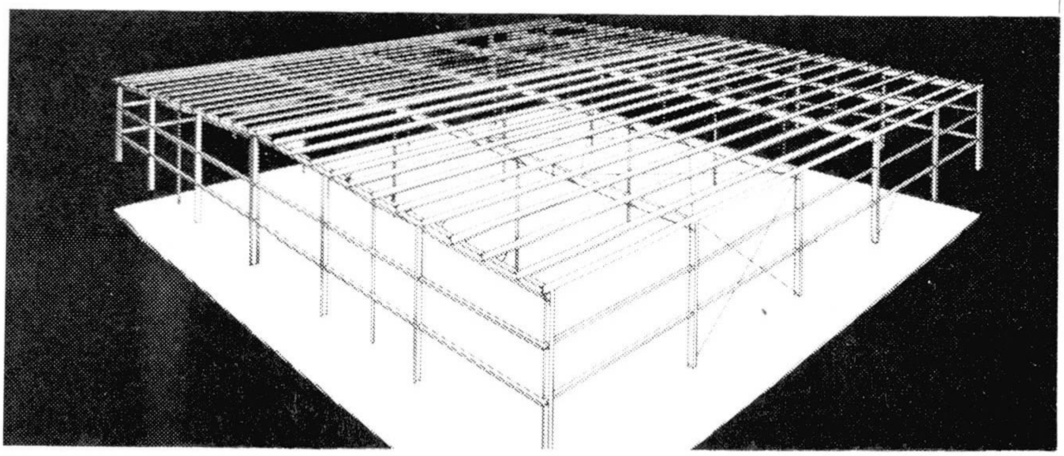


Fig. 6

3. METHODOLOGY OF DESIGN AND FIELD LABOR

All the previous factors in 2.1, 2.2 and 2.3, affect engineer's thinking and his considerations in the design philosophy. When standard sections change, for some time he no longer can use an instinctive evaluation of member sizes. This forces him to stop and think for a few minutes in search of the right size section. In turn, the brief pause gives him an opportunity to innovate. Similarly, he has the opportunity to innovate as changes occur in connections, or when his design has to compete with mass-produced structures. However, the most significant factors that affect today's designing philosophy are, in the opinion of this author, the emerging and the rapidly improving methodology of design and the sliding skill of field labor and its high cost. These two factors not only demand complete review of traditional philosophy of engineering approach, of structural systems and of their aesthetic forms, but make it imperative to develop novel systems and forms which are compatible with these new conditions. Indeed, the impact of these two conditions in U.S. has been considerable and innovations in structural systems and forms abound. The computers and the ensuing expansion in design methodology offer unlimited possibilities in selecting structural systems of any complexity designed to any degree of accuracy desired. These steps could compensate for the poorer field workmanship, for the use of lesser skilled laborers and for the higher cost of materials. In other words, selection of proper structural systems and proper design methodology could accommodate optimum relationship between the cost of labor, material and duration of construction time. Accordingly, from his experience, the author came to the conclusion that four major factors should be of prime consideration in the development of structural system:

3. (a). Increase in the permissible tolerance of error in the field.

3. (b). Reliance on the "statistical average strength" of connections rather than on the strength of individual connections.

3. (c). Simplicity of erection of the structural system.

3. (d). Predicting or "crystalballing" construction problems which might occur due to specific local conditions in workmanship and labor mentality.

The above four items merit some discussion.

3. (a). As engineering design methodology has been developing in the past few years and as consequently the structural members became thinner through sophisticated design, engineers tended to specify smaller and tighter tolerances in the field, demanding greater accuracy of field construction. This was contrary to the labor trend which has been deteriorating. Thus, the number of field problems, work stoppages and extra costs have been increasing rapidly, with the result that by using more economical structural components the final construction cost was higher than by using a heavier conventional structural system. To avoid field problems, and therefore to achieve a real economy, the contractor must be allowed a larger margin of error than in traditional conventonal structural systems.

3. (b). A new way of thinking is also required with regard to connections: In the traditional engineering approach, strength of a structure with N-connections depends theoretically on the strength of each connection; i.e. if one connection collapses, it is considered that the entire structure is inadequate. For example, if a welded truss with 50 welded connections has one broken weld, the truss would be (and should be) condemned. However, in my proposal, if the N-connections in a truss could be divided into localized groups of M-connections

each, and the strength of the truss would thus depend on the "statistical average" strength of M-connections in each group rather than on the individual strength of each connection, such dependence would permit a greater margin of error in the field.

3. (c). Consideration of Items 3. (a) and 3. (b) above could result in more complex structural analysis because such an analysis should take into account plastic deformation and slippage of joints, as well as relative rigid body movements of components of a structure. With the available methodology today, such a complex and sophisticated structural design should not prove a great impediment in design time or cost. The higher cost of engineering design will be but a fraction of the cost savings in the field labor due to the increased margin of permissible error. It is also obvious that Items 3. (a) and 3. (b) would contribute to a structure that could be erected easily and simply. For the purpose of this presentation, we shall define the term "simple" as a process not requiring stringent tolerances, extremely high labor skills, or thorough planning. A simply erected structure does not have to consist of a simple structural system or of simple components; as a matter of fact, it could be a very complex-looking structural system, requiring an extremely sophisticated structural analysis, as long as its erection procedure is simple.

3. (d). Structural systems utilizing considerations 3. (a), 3. (b), and 3. (c) require a certain modification in construction techniques and sequences. It is true that in many cases of such structural systems, a certain amount of construction planning is done during the design stage. Nevertheless, cases abound where problems arise during construction because of non-conventionality of the system. These problems are due to lack of previous experience, or unskilled labor or improper planning. These problems cause delays which increase construction cost. Field labor is apt to continue in inertia of past experience and work is more reliable when it consists of repeatable familiar steps. If, however, a joint in a steel frame is different from the one in the past experience, the chances are that a construction error would be committed in the field.

To insure the success of a relatively unconventional structural system, the designer must evaluate all the possible pitfalls on a particular site, with a particular contractor and with a particular labor force prior to completion of his design and to include those factors in his design so as to avoid such pitfalls. This evaluation the author termed "Crystalballing".

4. EXAMPLES

Following few projects illustrate application of engineering philosophy expounded previously:

4.1 Light Gage Hypar hangars (Fig. 7)

This project reflects 3. (a), 3. (b), 3. (c), i.e., large permissible field errors, statistical average strength and simplicity in field erection. The engineering design procedure, however, was complex, and included not only vigorous mathematical analysis but extensive laboratory testing.

The hangar covers an area of 285,000 square feet and contains close to 600,000 square feet of floor space, which includes office and service floors suspended from the roof. The roof consists of two 230-foot cantilevers Figure 8. The cantilevers are constructed out of prefabricated light gage metal hyperbolic paraboloid (hypar) shells connected together on the ground, and lifted up into place. The hypar cantilevers support moving cranes. The structure has been designed to resist earthquakes of Zone 3. Measured static deflections were of

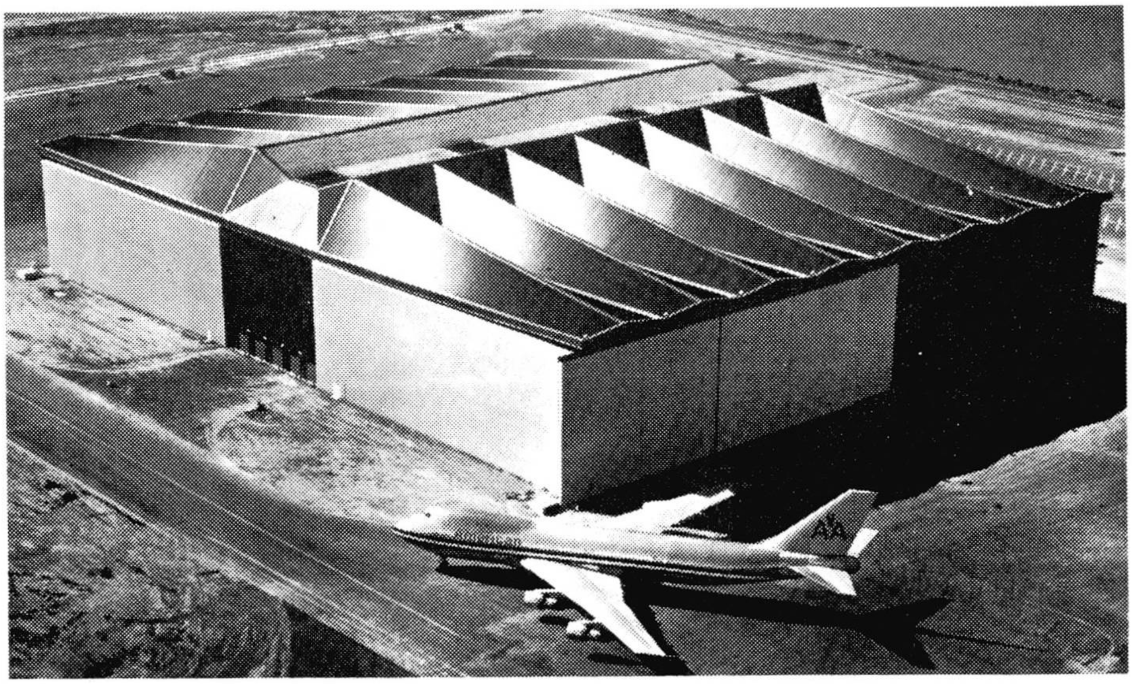


Fig. 7

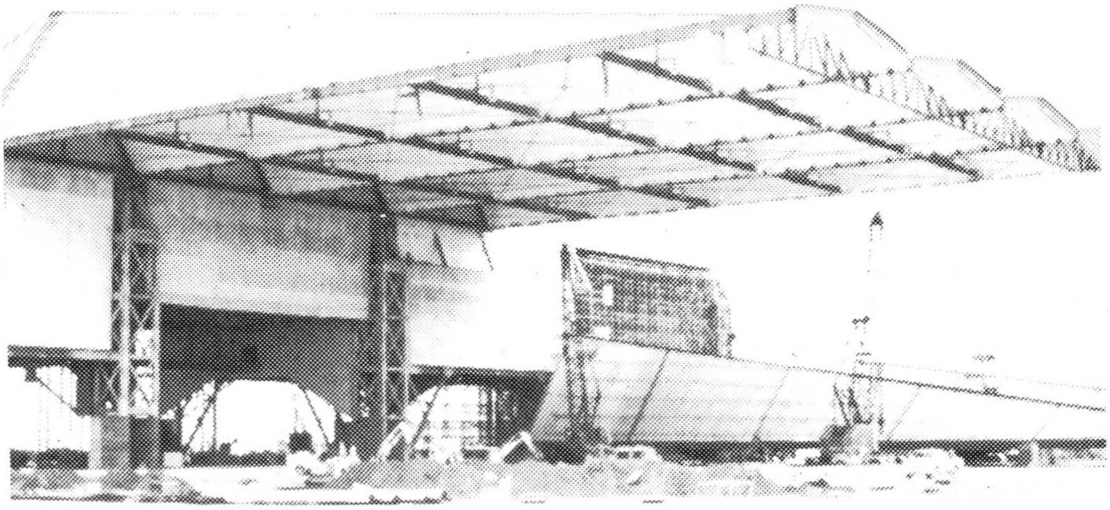


Fig. 8

very small magnitude (a fraction of deflections of a steel roof cantilever of the same span). The hypar cantilever weighs only 9 pounds per square foot, as compared to 35 pounds per square foot for steel trusses of the same span, and as compared to 100 pounds per square foot for a concrete shell of the same span.

The light gage shell consists of stock light gage deck strips commonly used for office floors, and hence, required no skilled labor for fabrication. All shell elements have been connected to form one hypar leaf 60 feet wide and 230 feet long. Connection between individual deck strips and between the deck strips and the surrounding steel border frames, which outline each prefabricated shell element, were only through tack welding. Thus, the strength between adjoining shell elements depends on the "statistical average" strength of the multitude of tack welds within and around a shell element, rather than on an individual tack weld.

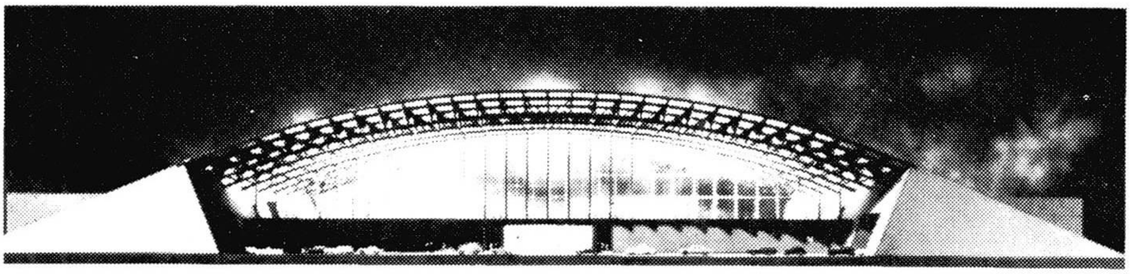
When each hypar leaf has been connected and erected, it was post-tensioned with high strength steel wires. This post-tensioning imparted continuity and homogeneity to the hypar, in addition to the beneficial effect it had on shear distribution within the hypar. The system was erected rapidly, with very little skilled labor and permitted relatively large errors in the field.

4.2 365 ft. x 315 ft Space Frame (Fig. 9)

This project reflects 3. (c) and 3. (d). i.e., field simplicity and "crystal-balling". Because of the nature of the bracing design, the erection of this space frame required relatively little scaffolding.

The latticed system is orthogonal in plan. The bracing was achieved through a series of butterfly elements which cantilever for 31 1/2 feet at each end of the space frame.

All the steel elements of the space frame were fabricated in Canada in a plant near Toronto and shipped across border to Niagara Falls, U.S.A. where the project is located. Predicting possible problems which could arise due to geography, human and construction practice differences between Canadian fabricators and American field erectors, was one of the most important factors in construction of this project. At the initial stages of construction it was necessary to evaluate the contractors, shop operations and prevailing field labor, as well as other field conditions, and on this basis to predict technical problems that could arise in the field. It was surprising how long the list of possible problems, which were specific to the prevailing conditions of field labor, came to be. The success of this method was outstanding; in spite of the technical complexity of the project, there were no field difficulties and the construction proceeded smoothly and on schedule.



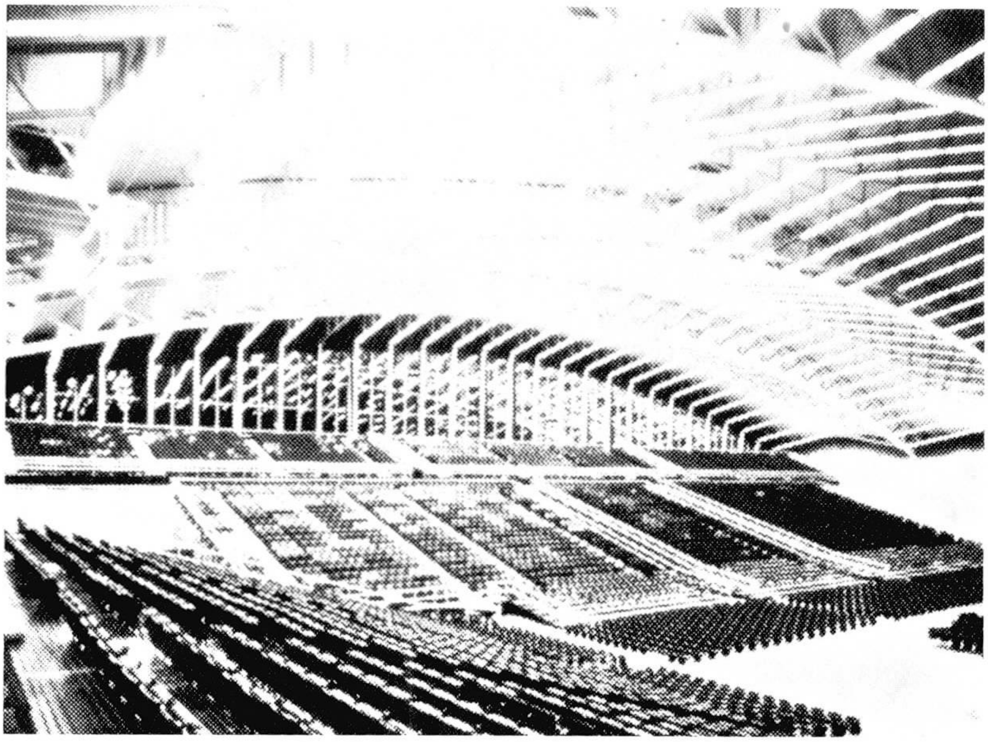


Fig. 9

4.3 Sculptured Space Frame (Fig. 10)

This project is interesting insofar as it demonstrates today's design methodology. The space frame consists of 1,373 members framing into 362 joints, is 125 ft. by 120 ft. x 60 ft., and each member measures exactly 10'. It is supported by three legs. Structural analysis was carried out for 19 different load conditions.

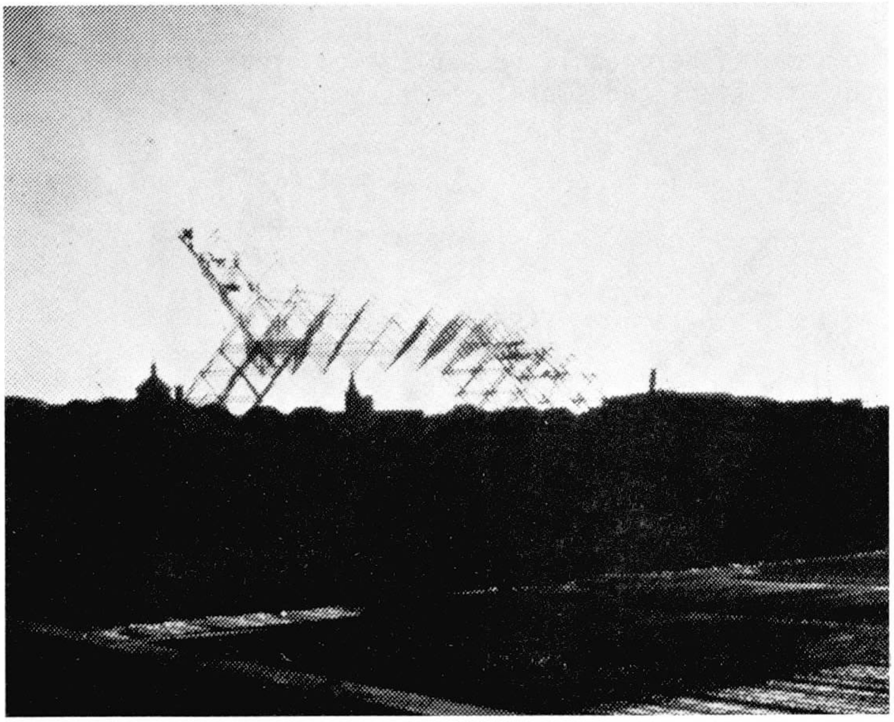


Fig. 10

4.4 Molecular Bridge (Fig. 11)

This project illustrates that new form of structural system, drastically different from traditional concepts, could be developed in order to be compatible with new materials and with untrained labor. The material is cardboard paper. Truck is a real, conventional truck.

On the average, paper is not lighter than concrete in the same proportion as it is weaker in strength. A similar bridge constructed out of solid paper beams, girders and deck would have weighed almost as much as a concrete bridge; thus, its dead weight would have been several times the design live load. The bridge is 32 feet long, 10 feet wide, and 4 feet deep. The "molecules", with approximately 4 foot lateral dimensions, are made out of paper. The molecules, pyramidal in shape, are interconnected to form the bridge. They were formed by folding fiber (cardboard). The deck on top of the "molecules" consisted of thin walled tubes sandwiched between the flat membrane sheets. The tubular deck assembly distributed stresses under concentrated truck wheel loads. Because of the "molecular" shell structure, the bridge weighed only 9,000 pounds for a designed concentrated load of 18,000 pounds. When the bridge was erected by connecting all the prefabricated molecules, it was lifted by helicopter and was dropped into place. It was subjected to tests and to service loads for long periods of time, exhibiting excellent performance both in durability and deflections.

Each face of the pyramidal "molecule" had a large surface area and faces of adjacent molecules were always in contact with each other. Since the contact surfaces were large, they permitted a "statistical averaging" of connection strength. In this case, the faces of adjacent pyramids were connected to each other by glue. It was not the strength per square inch of the gluing surfaces that was important, but the average strength throughout the whole contact surface. This bridge is a good example of simplicity of erection, a large permissible margin of error in the field, and statistical averaging strength of connections. Its structure is non-conventional and, therefore, is complex; its analysis has to go beyond elastic deformations and requires sophisticated methodology of design.

The concept presented here could be applied to other materials such as plastic, gunited mortar, or light gage metal sheet.

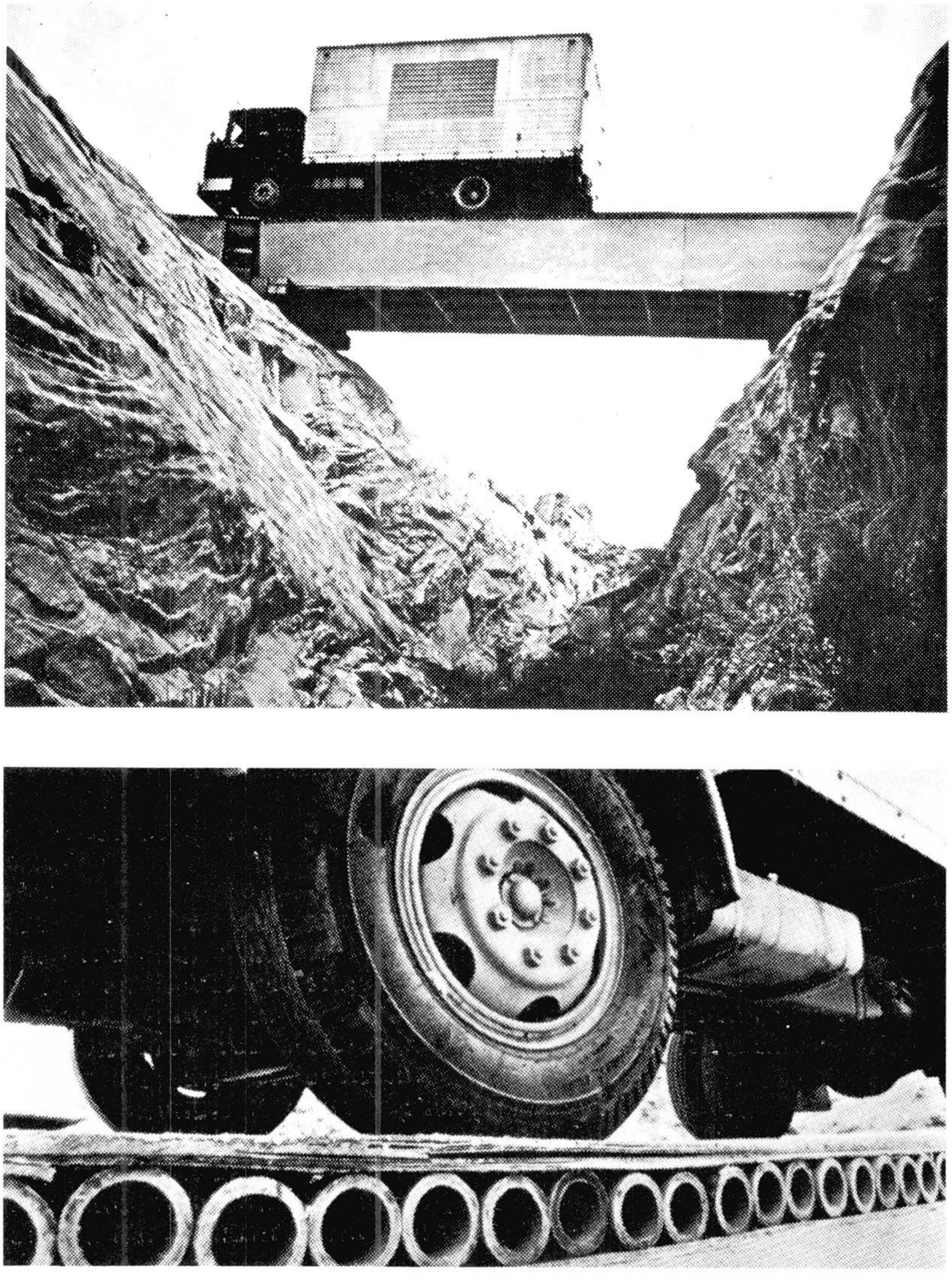


Fig. 11

4.5 30 Story Elephant (Fig. 12)

This elephantine structure contains several floors of activities inside its body. The project illustrates flexibility of steel and of engineering methodology. Load carrying structure is not the "bone skeleton", as is customary, but rather the skin. Exterior of the elephant is a space frame. The geometry of the frame was obtained by feeding photographs of the animal exterior anatomy into computers. Advantage of this solution is in more usable space inside the "elephant" and in not having costly art work in simulating the exterior countours of the skin.

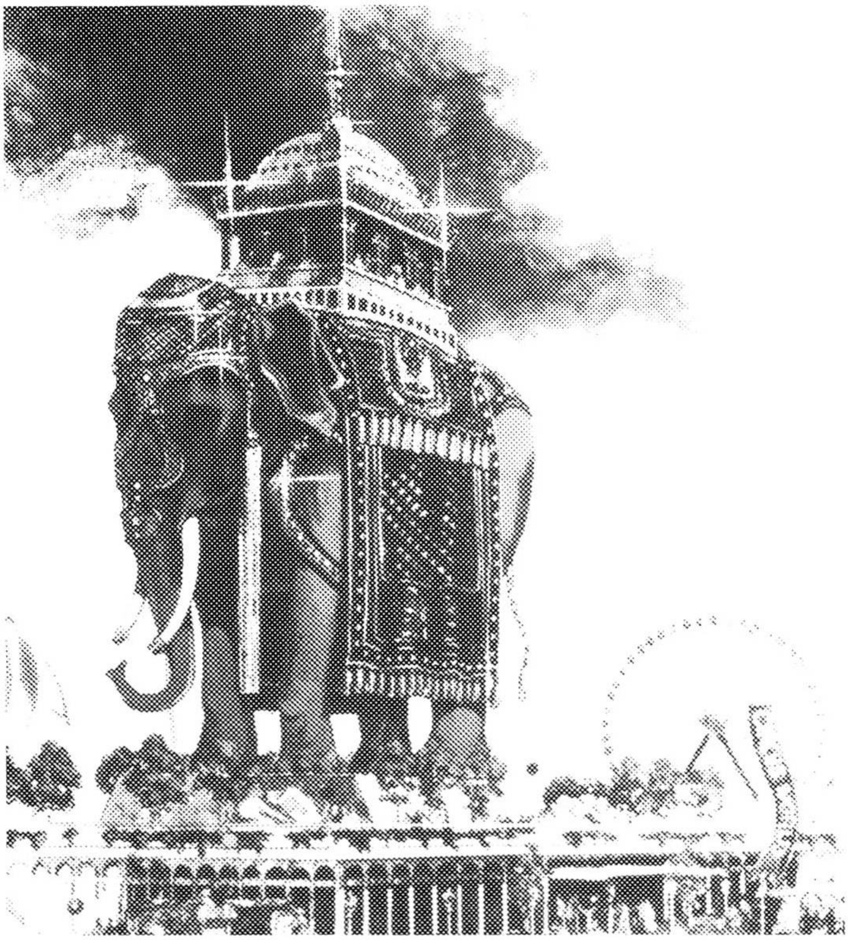
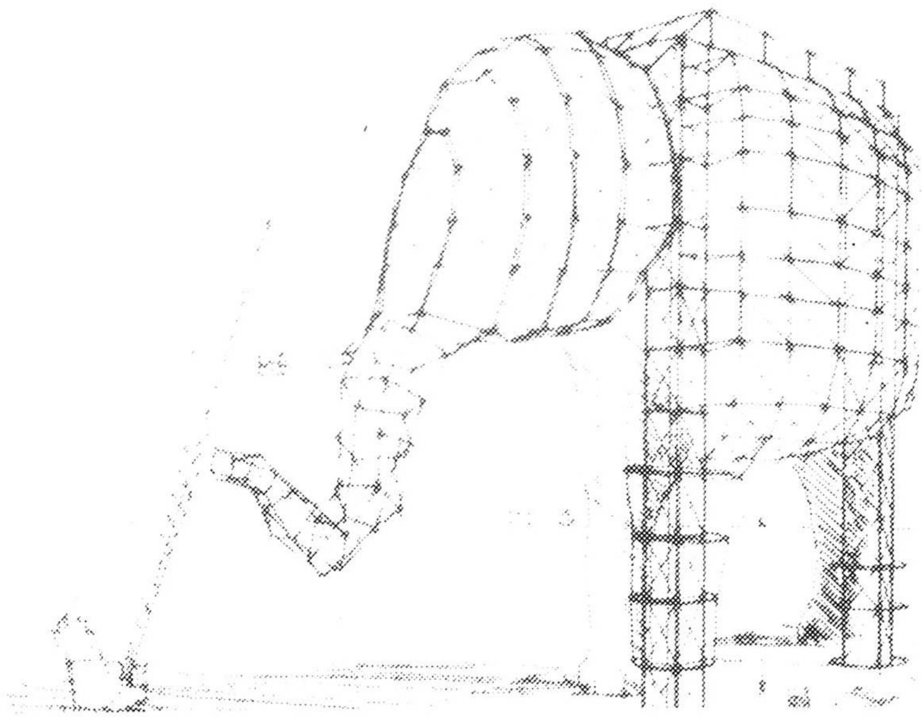


Fig. 12



4.6 Tension Structures

Any trend towards economy and changing forms of structures includes cables and tension structures.

Fig. 13.1 shows a suspension bridge wtihout stiffening deck and without guys. Loads are resisted by three dimensional dampened cable nets.

Fig. 13.2 shows a large regular passenger aerial tramway within busy section of New York City.

Fig. 13.3 shows a proposed solution for Panama crossing instead of a canal. Ships are lifted and transported under suspension mats between Pacific and Atlantic coasts.

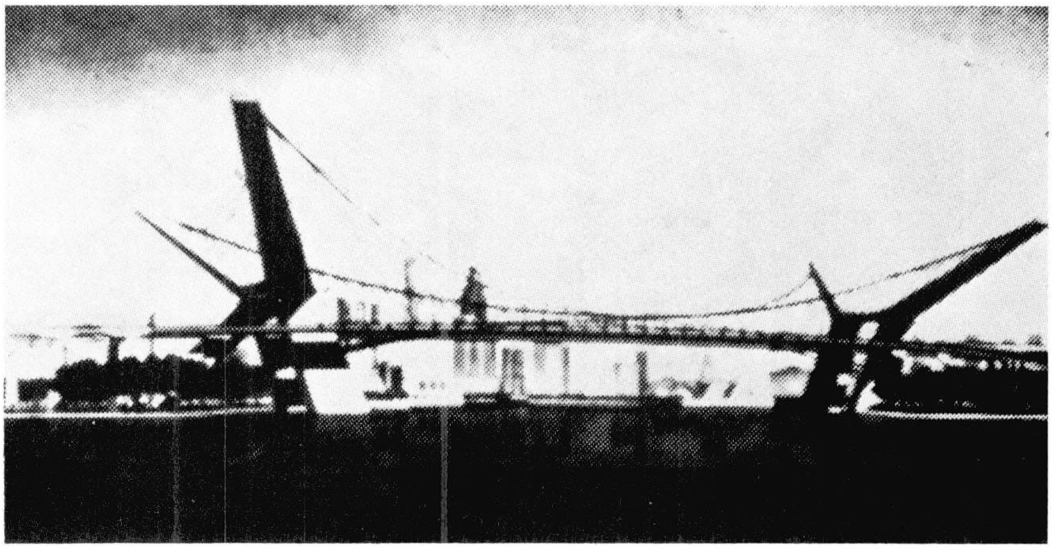


Fig. 13.1

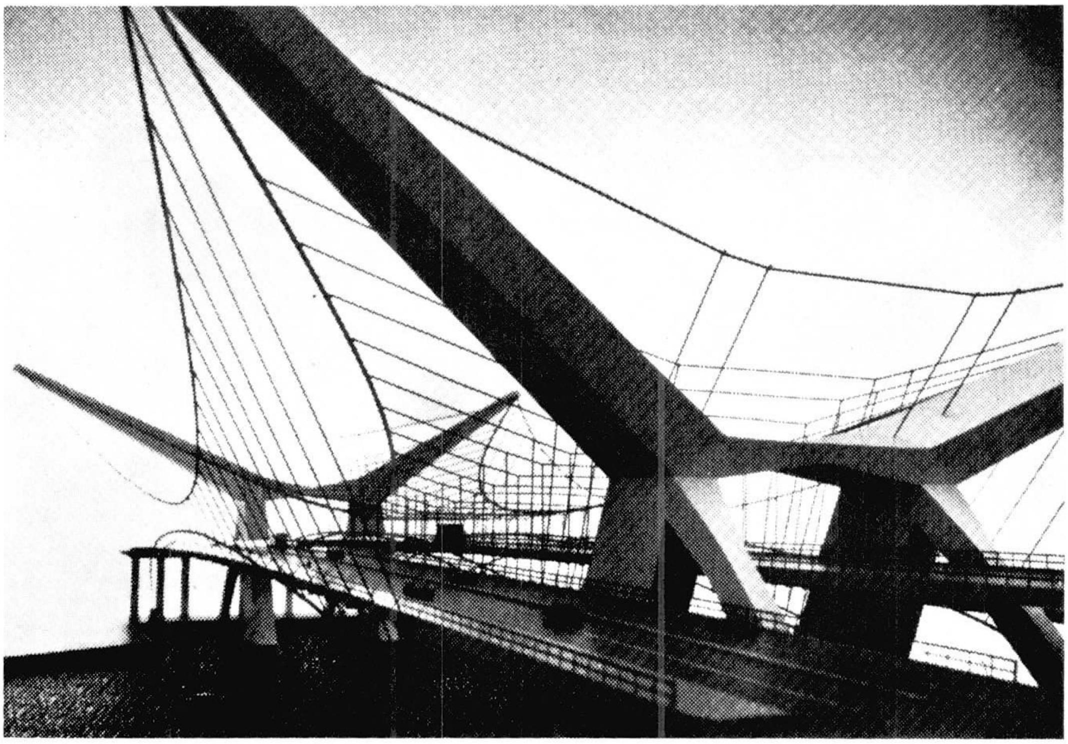
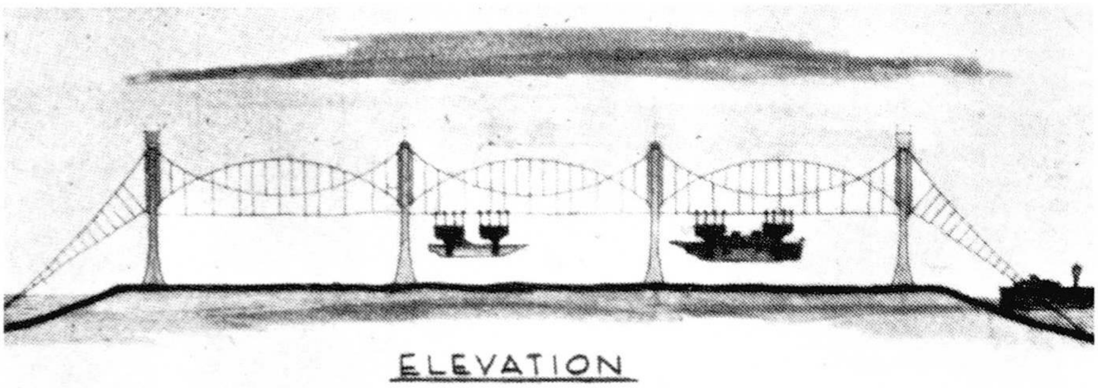


Fig. 13.2

Fig. 13.3



5. CONCLUSIONS

The rapidly changing conditions of technology, rising standards of living throughout the world, disruption in traditional relative costs of raw materials and need for evermore structures, impel the engineering profession to meet these conditions realistically. In the field of structural engineering this means that more efficient and more economic structural systems, compatible with available materials, skills and labor conditions, have to be devised. This calls for new methods of design and new forms of such systems. Our profession can meet this challenge. This paper attempts to demonstrate an effort towards this goal.

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