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Light Gage Space Structures with Prestressing

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LIGHT GAGE SPACE STRUCTURES WITH PRESTRESSING

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by

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SUMMARY

Use of conventionally interconnected light gage metal panels in a complete structural system presents two difficulties: 1) buckling out of plane of a panel, and 2) continuity (i.e. resistance to bending and shear) through the junction of light gage panels. This paper presents economical techniques to cope with these difficulties. The techniques have been developed and used by the author in several successfully constructed projects.

I. INTRODUCTION

Light gage metal as a principal component of structural systems has been widely used for the last 2-3 decades. The knowledge of its behaviour and of the design theory has vastly advanced since the 1950's when this author was working at Cornell on the research of light gage structures.

II. ENGINEERING ASPECTS

Evolution towards lightness in structural steel and concrete led to the development of three dimensional systems, space trusses and shells. Cables and fabric also create successful three dimensional structures.

In concrete, prestressing had been introduced, among other purposes, to provide tensile strength continuity in a material that cracks easily under tensile stress.

Light gage metal could advantageously be used for three dimensional membrane structures if two of its disadvantageous characteristics are overcome:

1) Sheet buckling perpendicular to its plane,
2) continuity through connections.

Obviously, the intent is to provide for the above within economical reason as compared to three dimensional structures in steel or concrete. For example, providing sheet buckling resistance through steel stiffeners specifically designed and fabricated for a project will be very expensive; similarly, providing mechanical connections or controlled welding at junction of individual light gage membrane panel components will also prove to be costly.

Fortunately, there are, as demonstrated by this writer, simple and economical means of solving both problems. This paper discusses the practical and theoretical means of solving them with examples of constructed projects developed and designed by this writer.

Specifically, sheet buckling could be avoided by proper utilization of "hat" sections or by attaching (gluing) cheap plastic (or similar) honeycombed panels to the light gage metal. Tension continuity could be accomplished with the use of tack welds at connection of individual light gage component panels and prestressing the assembly with high strength stands. It will be found that compressive continuity is relatively easy and economical to achieve with conventional connection details.

Details of each of the above solutions are discussed in the following:

III. BUCKLING

Buckling, of course, is the most adverse type of failure since it rarely offers load redistribution and, therefore, collapse could occur suddenly. It is this shortcoming that limits application of light gage metal to be used as a principal structural component. Limitation of a conventional metal deck, for example, as to span length is dictated by buckling of the web. A deeper metal deck could cover larger spans with little increase in metal thickness in the top and the bottom flanges. However, to prevent buckling of the web, thickness of the material in the web would increase the weight of the deck tremendously, making it uncompetitive with other types of floor construction.

Fortunately, lateral force necessary to prevent out of plane buckling of a panel is very small - it could be less than 1% of the buckling in-plane force. For example, buckling of a 14 WF steel column could be prevented by a taut piano wire attached horizontally at mid-height of the column.

The requirement of a small force to eliminate buckling means that the method of its connection to the panel does not have to be very accurate, as long as there is assurance that some lateral force will be exerted.

This simple requirement makes it possible to prevent buckling very economically. This writer developed a metal deck 48 inches deep that could span 60 feet for parking garage loads as shown in Fig. 1.

A honeycombed plastic panel, costing a few cents per sq.ft., is glued to the web. The glue does not have to be applied carefully with any engineering precision. As long as the plastic panel is glued to the steel web at any random points, sufficient lateral force will be applied to prevent buckling. The thickness of the

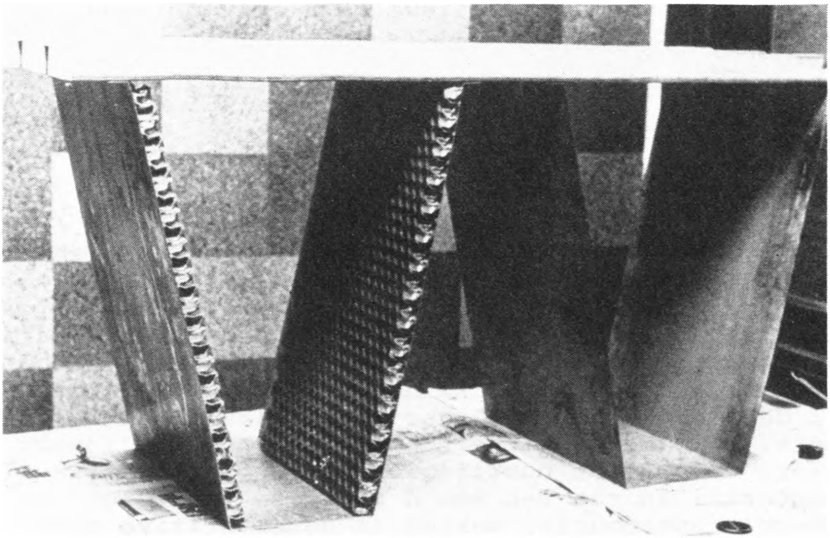

Fig. 1

metal in the web is minimal. In the example shown total steel requirement in a garage deck is 4 lbs./sq.ft. as compared to over 12 lbs. in a conventional structural steel floor system.

As another and a more far-reaching application of this principle is in replacing pick-up girders in tall buildings as shown in Fig. 2.

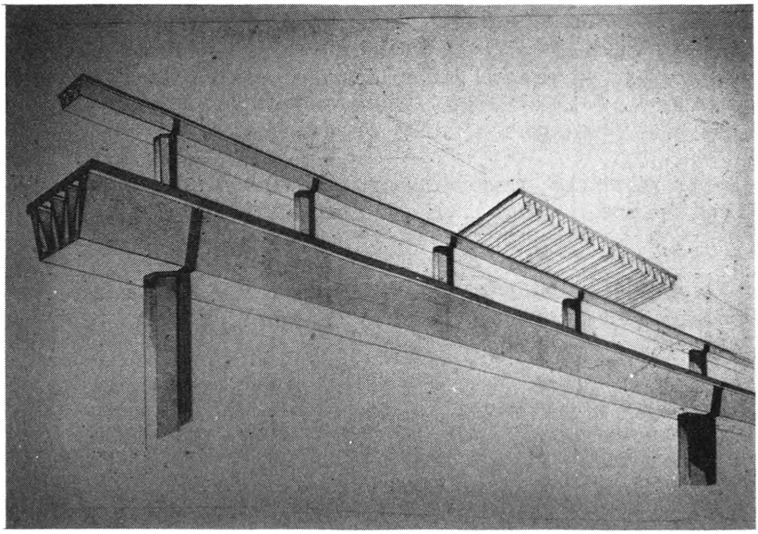

Fig. 2

In conventional plate girders, most of the weight of steel is in the web. In the example shown, the web, which consists of a number of light gage membranes is prevented from buckling through plastic panels glued to the sheet metal. The entire pick-up girder assembly is much lighter and much more economical than a conventional plate girder.

IV. PRESTRESSING

Prestressing in certain structural systems can create an integral continuous structure from a series of light gage panels joined together by tack welds. This will particularly be true in membrane shell structures. The most important function of prestressing is to impart bending moment and shear resistance at the junction of the individual light gage panels. In the opinion of this writer there is no need for controlled welding at the junction of light gage panels to transmit compression. In another paper, published sometime ago, this writer describes what he calls a "statistical average strength". According to this theory, strength of a structure under certain configuration of components could be made to be dependent on the average strength of some of its components and connections, rather than on the strength of individual components and connections. In other words, strength of a chain, with a certain configuration of the links, does not necessarily have to depend on the strength of the weakest link.

Also, under certain geometry of the shell and the pre-stressing strands, buckling of the shell could be prevented.

Figs. 3,4 and 5 show airplane hangars for the giant 747 airplane constructed in Los Angles and San Francisco.

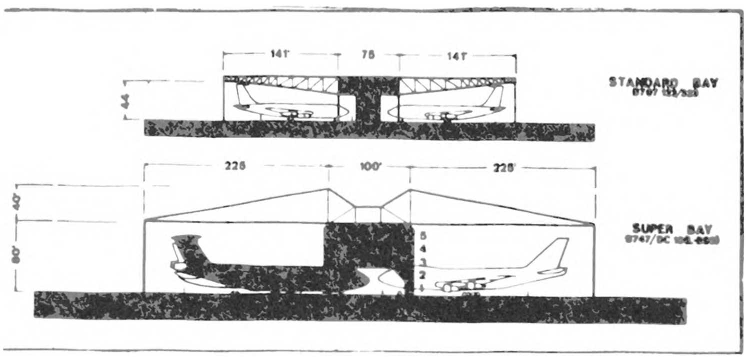

Fig. 3

Fig. 4

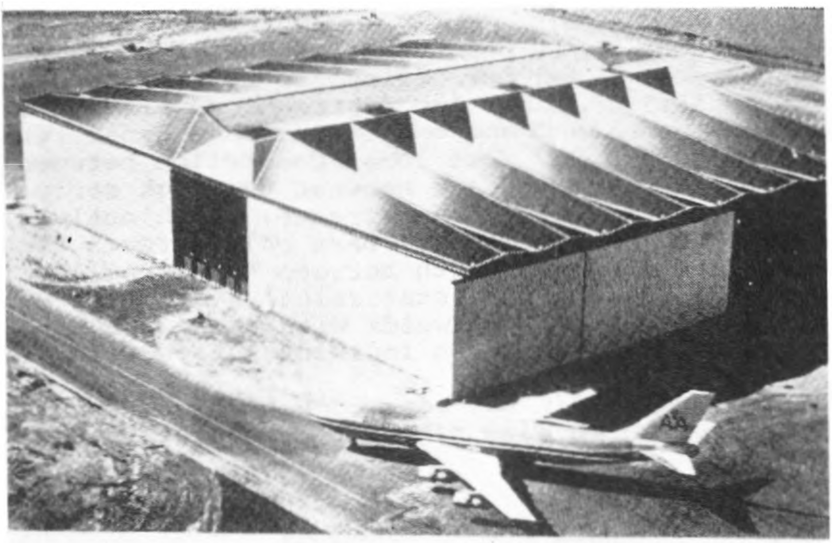

Fig. 5

The hangars have 230 ft. cantilevers, each equivalent to 500 ft. simple span. In the more common hangars with a steel structural system, steel trusses carry load, while the metal deck covers trusses and protects the building against weather. In this case, the trusses were dispensed with completely. The metal deck serves as the entire structural system. This is achieved through preplanned geometric warping and addition of prestressing cables. Thus, the metal deck replaced steel trusses. Cost saving was considerable: instead of 35 lbs. of steel per sq. ft. for steel trusses, the cantilevers weigh only 9 lbs./sq.ft.

This project reflects large permissible field errors, "statistical average strength" and simplicity in field erection.

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 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 very small magnitude (a fraction of deflections of a steel roof cantilever 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, Fig. 6.

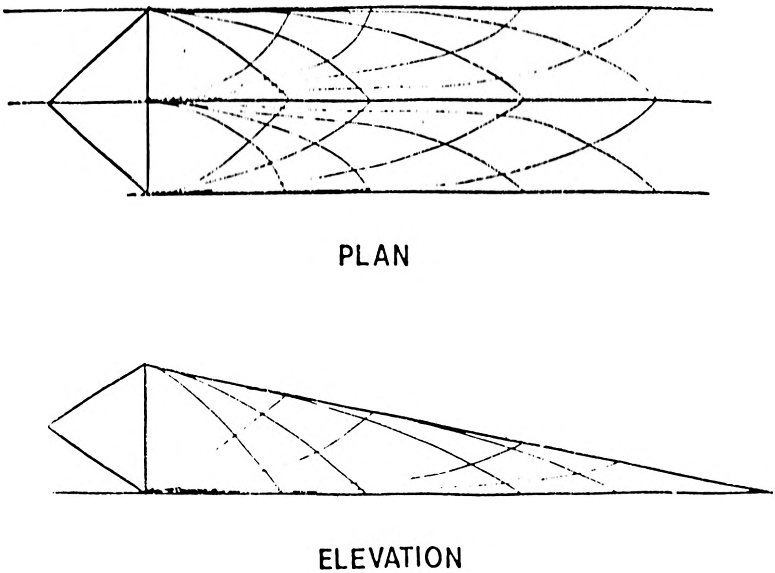

Fig. 6

This post-tensioning imparted continuity and homogeneity to the hypar, as well as bending moment and shear resistance at junction of individual light gage panels. The system was erected rapidly, with very little skilled labor and permitted relatively large errors in the field.

After the success of this system in the American Airlines hangars I have extended its use to the entire exterior shell of the structure, consisting of roof and supporting walls. This is shown in Fig. 7 for a stadium and in Fig. 8 for a 1,000 ft. span submarine construction cover.

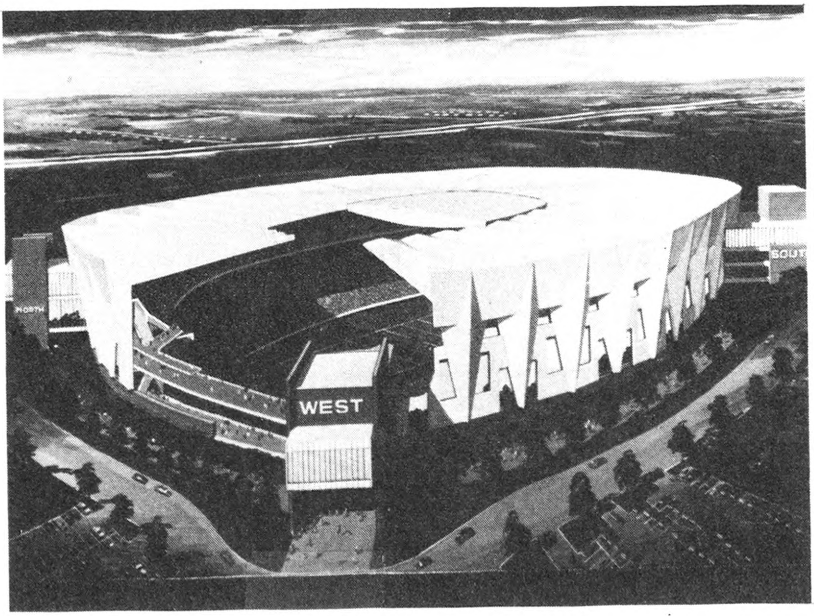

Fig.7

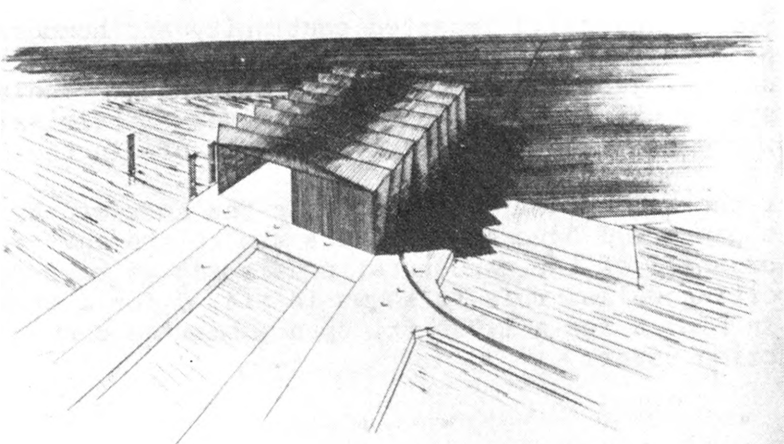

Fig. 8

It will be noted again that light gage shell structures are not sensitive to deflection and could carry heavy concentrated crane loads.

V. CONCLUSIONS

It is hoped that this presentation, with the examples cited, will point to the two not yet fully utilized advantages of light gage structures. Both potentials have been realized through imaginative addition of other materials than light gage steel. These two potential uses are a) reinforcement of light gage panels against buckling, and b) the imparting of continuity through interconnected light gage panels. The first could be achieved economically through readily available plastic or similar panels glued to the light gage panels, while the second, through the use of high strength cables.