건설에서의 복합재료
-설계된 구조물을 사용한 건설 I-

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COMPOSITES IN CONSTRUCTION
- CONSTRUCTION WITH DESIGNED STRUCTURES I -

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Key Words : concept optimization, simple method, quasi-isotropic constant, correction factor, folded plate theory.

ABSTRACT

Almost all buildings/infrastructures made of composite materials are fabricated without proper design. Unlike airplane or automobile parts, prototype test is impossible. One cannot destroy 10 story buildings or 100-meter long bridges. People try to build 100-story buildings or several thousand meter long bridges. In order to realize "composites in construction", the following subjects must be studied in detail, for his design: Concept optimization, Simple method of analysis, Folded plate theory, Size effects in failure, and Critical frequency. Unlike the design procedure with conventional materials, his design should include material design, selection of manufacturing methods, and quality control methods, in addition to the fabrication method.

1. Introduction

The educational background of the majority of the construction engineers is the bachelor's degree. Even the engineers with higher degrees have very much difficulty in design/ analysis, with acceptable accuracy, of buildings/infrastructures made of, even, conventional materials. Buildings/bridges by the reinforced concrete/steel are three-dimensional structures made of composite materials, such as cement, steel bars, etc.

However, the engineers can design/analyze such structures by considering them made of one-dimensional beams/columns. But, they are protected by codes and specifications. Almost all buildings/infrastructures made of composite materials are fabricated without proper design. Unlike airplane or automobile parts, prototype test is impossible. One cannot destroy 10 story buildings or 100-meter long bridges. People try to build 100-story building or several thousand meter long bridges. In order to realize "composites in construction", the following subjects must be studied in detail.

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2. Concept Optimization

Throughout long history of human civilization, four basic concepts of structural construction have evolved and developed. These concepts, namely, beam and column, masonry arch, wooden truss, and modern steel truss and frame, were made possible by available construction materials and applicable technical knowledge of each age.

Modern materials engineering has produced numerous new structural materials, and the science of mathematical calculation and others related with structural analysis, and construction have reached near its zenith. It is necessary to develop or to redefine the new concept (or concepts) suitable for new materials. The senior author wished to call this the fifth basic concept of structures [1]. One calls it an advanced composite when controlled placement of reinforcements with optimum shape, amount, and direction, according to "accurate" analysis result, is made. This indicates that a composite material must be treated as a structure.

Compared with metals, composites have higher specific strength and higher specific modulus. Generally speaking composites are corrosionless.

Regardless of the advantages of composites over the conventional materials, composite application in the field of large size structures is still in the cradle. The author believed that there have been three major problems delaying the civil structures application of the advanced composites.
These are:

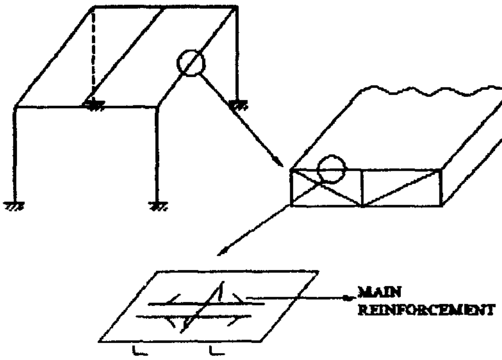
1. Theories are too difficult for ordinary engineers. The most of the engineers in the design offices and fields have theoretical background of undergraduate level.
2. There was no comprehensive text/reference book available for structural engineers.
3. There has been a "prejudice" on the cost of composites.

The senior author has developed enough number of simple but accurate formulars for the ordinary engineers and published a book on composite structures for civil and architectural engineering.

Now that price structure of materials shows a sign of coming down, and efficient manufacturing methods are evolving day-by-day, design method plays great role in cutting price down. There are several civil structures, designed with composites, more economical than other material construction. Improper design with concept based on other material is largely responsible for higher cost of the structures. It is necessary to do design optimization based on the new structural concept, which the author has called the Fifth Basic Concept of Structures.

Very large portion of civil structures can be analyzed by considering them as frameworks of one-dimensional elements. Composite materials are, generally, strong in tension. When an element is designed based on tension load, it will have thin section, which is weak against any loading type other than in-plane on –axis tension load. This requires the section modulus increase by means of employing thin walled sections. The thin panels of such section are weak against the loads normal to these panels. The longitudinal stringers are added between transverse diaphragms to take care of such loads. The diaphragms transmit the loads from stringers to the walls of the beams by means of in-plane shear.

'A' TYPICAL BRIDGE FRAME



TOTAL SECTION: BEHAVES LIKE A FOLDED PLATE SHELL

Fig. 1 Typical bridge or building frame

Even when the frames are analyzed as one-dimensional beams and columns, these one-dimensional elements are three dimensional structures made of thin walls, which are called as folded plates (shells). Thus, the analysis of structures made of composite materials, becomes that of folded plates, both prismatic or non-prismatic.

3. Simple Method of Analysis of Certain Composite Laminated Primary Structures for Civil Construction.

This subject is given in full detail in Article 7.9 in senior authors book[1]. Many laminates with certain orientations have decreasing values of B_{16}, B_{26}, D_{16} and D_{26} as the number of plies increases. Such laminates can be solved by the same equation for the special orthotropic laminates. Some of such laminates are as follows :

$$[AB]_r,\ A=-B.$$
$$[ABBAAB]_r,\ A=-B.$$
$$[ABBCAAB]_r,\ C=0^\circ,\ or\ 90^\circ,\ A=-B.$$

If the quasi-isotropic constants are used, the equations for the isotropic plates can be used. Use of some coefficients representing the anisotropy of the laminate, which the senior author called as the correction factor, can produce "exact" values for laminates with such configuration. The most of the structures for civil construction requires many layers of plies even though the ratio of the thickness to the length is small so that the effect of transverse shear deformation can be neglected. At the preliminary design stage, the orientations of laminae in a laminate are not known. This fact discourages the most of engineers from the beginning.

Use of the quasi-isotropic constants gives a guideline toward a simple and accurate analysis.

One can calculate the quasi-isotropic constants and, using the isotropic plate theory, obtain $w_{mn}^{(iso)}$, $\omega_{n}^{(iso)}$ and $N_{cr}^{(iso)}$, where $w_{mn}^{(iso)}$ is the m-nth term of deflection expressed in Fourier series, and $\omega_{n}^{(iso)}$ and $N_{cr}^{(iso)}$ are the natural frequency of vibration and the critical buckling load, respectively. Then, the exact values of such quantities are

$$w_{mn} = w_{mn}^{(iso)} / FRC^2,$$
$$(\omega_n)^2 = (\omega_n^{(iso)})^2 \cdot FRC^2,$$
$$N_{xcr} = N_{xcr}^{(iso)} \cdot FRC^2.$$

where FRC is the correction factor[5].

One may try to obtain some orientations other than $[AB]_r$, $[ABBAAB]_r$, $[ABBCAAB]_r$, etc, which satisfy above conditions.

4. Folded Plate Theory

Composite materials are, generally, strong in tension. When an element is designed based on tension load, it will have a thin section, which is weak against any loading type other than in-plane on-axis tension load. This requires the section modulus to be increased by means of joining thin-walled plates or sandwich panels. Even the one-dimensional element, after the frame is analyzed, requires additional study by the methods explained for thin-walled sections. The thin panels of such sections are weak against the loads normal to these panels. The longitudinal stringers are added between transverse diaphragms to take care of such loads. The diaphragms transmit the loads from stringers to the walls of the beam by means of in-plane shear. Any curved surface can be considered as continuations of certain types of triangular plates. Therefore, the theory of nonprismatic folded plates can be applied to any type of shell structures [7,8,9].

Any three-dimensional structural configuration can be approximately represented with good accuracy by nonprismatic folded plates, which is composed of sectorial plates. Any sectorial plate problem with both in and normal to the plane forces can be solved by the finite difference method, finite element method and others. The problem then reduces to that of boundaries of two adjoining sectors. Each sector may be inclined. Kim, D.H.[8,9,10] worked on this problem by finite difference and influence coefficient methods. The joint forces and displacements at the n th fold line can be transformed to a system common to both adjoining plates [1, pp406-408].

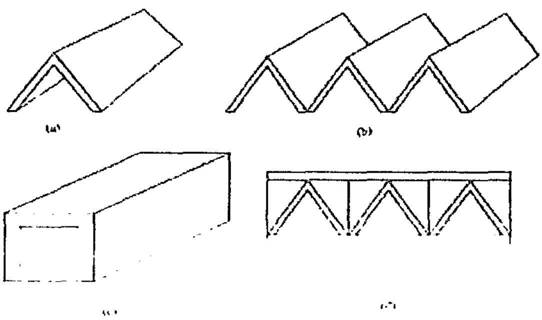


Fig 2. Prismatic Folded Plate Structures

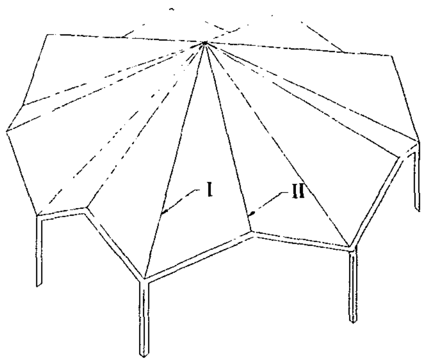
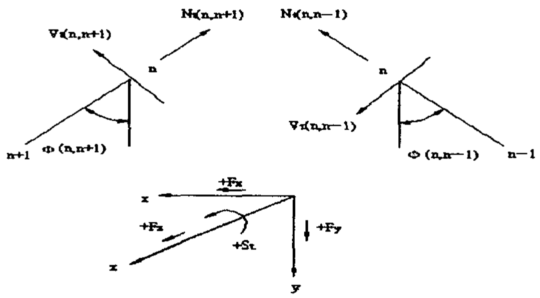
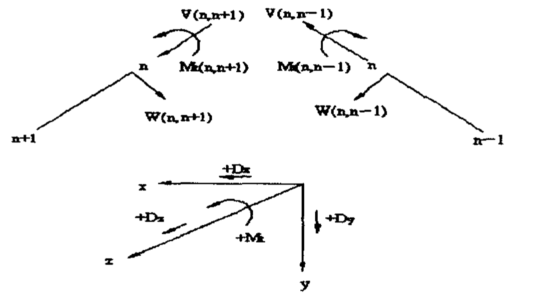


Fig 3. Nonprismatic Folded Plate Structures



Forces



Displacements

Fig. 4 Notations and sign conventions at the upper fold lines

The types of the joint compatibility and joint equilibrium conditions depend on which dependent variables are chosen. If the transverse bending moment, M_t, and the three displacement components, u, v and w, are taken as unknowns, it is necessary to satisfy the slope compatibility condition and the three force equilibrium conditions at each fold as follows.

$$S_{t(n,n+1)} - S_{t(n,n+1)} = 0,$$
$$F_{xy(n,n+1)} + F_{xy(n,n-1)} = 0$$
$$F_{x(n,n+1)} + F_{x(n,n-1)} = 0$$
$$F_{y(n,n+1)} + F_{y(n,n-1)} = 0$$

where $F_{xy} = \tau_{r\theta} h = N_n$.

Since these 'force' expressions are to be written in terms of displacements, the compatibility conditions are automatically satisfied. At each fold line, these conditions must be satisfied when the governing differential equations are integrated.

If the finite difference method is used to integrate the differential equations, some elaborate work is necessary. A method of solving such a problem was reported by the senior author. The process of calculation is straightforward. A very high degree of accuracy can be obtained by this method [8,9].

With the method of analysis as mentioned above available the problem is reduced to solving a plate, either prismatic or non-prismatic with arbitrary elastic boundary conditions.

5. Conclusion

In this paper, concept optimization, simple method of analysis and folded plate theory are briefly explained in order to help engineers to design safe and sound, and yet, economical structures. Unlike airplane or automobile parts, prototype tests for buildings and bridges are impossible. Nevertheless, almost all buildings / infrastructures made of composite materials are fabricated without proper design. Design/analysis of such structure is simply too difficult for most of the engineers.

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