Three dimensional Thin-open-section System Computer Program for sophisticated high-rise buildings and its applications in China

G.J. Wong
Chief, Programming-Electronic Computer Station
East China Architectural Design Institute (ECADI)
Shanghai, China

KEYWORDS

3D Computer Program, Thin-open-section System, Sophisticated High-rise Building

ABSTRACT

In the early 1980's, the configurations of high-rise buildings under design became more sophisticated, and then, our application softwares were found unable to yield acceptable results for structural design purposes. A new 3D thin-open-section system computer program was thus studied and developed, enabling high-rise buildings with shear walls curved in plan, unsymmetrically positioned and non-orthogonally intersected to be analysed integrally including torsional effects. The capability of simulating the construction sequence for the effect of differential shortening of vertical members under dead loads has raised its reliability and applicability. A plexiglass model of the Shanghai Telecommunication Tower Building was tested in laboratory, and a good agreement between the test results and the computed values by applying the program was obtained. A brief view of applications of the program with satisfaction to about 70 major high-rise buildings in Shanghai and other large cities in China will be given with some results of calculation presented graphically.

Le Programme de Calculateur Tridimensionnel de Système en Section Mince Ouverte pour les Immeubles de Grande-hauteur Compliqués et ses Applications en Chine

G.J.Wong

Institut de Projets de l'Architecture à l'Est de Chine

Mots-clés

le programme de calculateur tridimensionnel
le système en section mince ouverte
les immeubles de grande-hauteur compliqués

Sommaire

Au début des années 80, les configurations des immeubles de grande-hauteur dans nos projets sont devenues de plus en plus compliquées, et les softwares antérieurs dans notre paquet de programme ne peuvent plus donner des résultats acceptables aux projets de structure. Donc, un nouveau programme de calculateur de système en section mince ouverte tridimensionnel a été étudié et développé. Il permette aux immeubles de grande-hauteur avec des murs de cisaillement courbes, dissymétriques et non-orthogonales, dans le plan, d'être analysés spatialement en tenant compte des effets de torsion. Ses capacités d'assimilation des ordres de l'exécution des travaux pour les effets des contractions différentielles des membres verticaux sous les charges permanentes agrandissent ses sûretés et utilités. La maquette de la tour de Télécommunication de Shanghai a été expérimentée dans le laboratoire. Une bonne compatibilité a été trouvée entre le résultat du test et la valeur calculée par ce programme. Un bref exposé des applications du programme avec satisfaction dans la soixante dizaine des immeubles de grande-hauteur importants à Shanghai et en d'autres grandes villes de Chine sera donné et certains résultats de calcul seront aussi représentés par graphique.

1. Introduction

During this decade, a number of high-rise (HR) buildings, have to be erected. As HR buildings play an important role in the improvement of the environmental condition of the city, many creative concepts have been contributed by architects, and sketches of buildings with sophisticated configurations proposed. For such buildings, standard computer programs are inadequate in making analysis with acceptable results. Thus, a new purpose-written program has been developed and widely applied in practice with satisfaction.

2. Development of the program.

2.1 Special features and treatments. For HR buildings with sophisticated configuration, non-planar walls in various sections such as ∠, ᒣ, [or even curved shapes may appear; elevator wells are usually of partially closed ⊏ type; irregular setbacks are likely to occur; and structural arrangement is often asymmetrical. All these special features give complicated criteria to the development of the program. The approach taken has been still the discretization technique but with the introduction of thin-open-section elements to represent walls of irregular section. The discrete structure is composed of beams, columns and thin-open-section vertical elements with beams connected to them at points of support at each floor, from which stiff arms are provided to the respective shear centres (S.C.s) of the thin-open-sections. Stiff arms are also provided between relevant S.C.s at the floor levels, where the axes of some members through their S.C.s become out of alignment owing to the different locations of openings in walls above and below the floor.

2.2 Method of analysis. The stiffness matrices of thin-open-section elements have been developed by using Vlasov's (1) thin walled beam theory. Story height segments of such open-section-elements are represented by individual single columns located at their respective S.C.s with necessary transformation from C.G.s to S.C.s. Each node of such elements has to have an additional warping degree of freedom (Fig. 1). The element stiffness matrix $[K]$ in Eq. (1) of an open section element is, therefore, 14X14 in contrast to 12X12 for an ordinary element.

$$\{f\} = [K]\{\delta\} \qquad \text{Eq. (1)}$$

The additional warping matrix terms are as in expression (1).

$$\begin{array}{c|c|c|c|c} & (6) & (7) & (13) & (14) \\ \hline (6) & \overline{GJ}\ K\ SH & \overline{GJ}(CH-1) & -\overline{GJ}KSH & \overline{GJ}(CH-1) \\ (7) & & \overline{GJ}(l\,CH-\frac{SH}{k}) & -\overline{GJ}(CH-1) & \overline{GJ}(\frac{SH}{k}-l) \\ (13) & \text{symmetrical} & & \overline{GJ}\ K\ SH & -\overline{GJ}(CH-1) \\ (14) & & & & \overline{GJ}(l\,CH-\frac{SH}{k}) \end{array} \qquad (1)$$

in which, $\overline{GJ}=GJ\left[\frac{1}{2-2CH+kl\ SH}\right]$, $k=\left[\frac{GJ}{EI\omega}\right]^{1/2}$, SH=Sinh kl, CH=cosh kl.
To obtain the structure matrix, element matrices as well as force and displacement vectors are transformed from their local coordinates to the "global" coordinates, and Eq.(1) becomes

$$\{f\}_q=[k]_q\{\delta\}_q \qquad \text{Eq. (2)}$$

For beams $$[k]_q=[Q]^T[R]^T[T]^T[K][T][R][Q] \qquad \text{Eq. (3)}$$

For columns $$[K]_q=[Q]^T[T]^T[H]^T[K][H][T][Q] \qquad \text{Eq. (4)}$$

where $[T]$, $[H]$, $[R]$, $[Q]$ represent transformation matrices of coordinates, rigid arms, beams and stories respectively (2). The structure stiffness matrix is, then,

$$[K\ K]=\sum_{i=1}^{NM}[K]_{qi} \qquad \text{Eq. (5)}$$

where NM represents total number of members.

The seismic analysis is based on the Chinese Aseismic Design Code (3), in which a modal analysis procedure is required.

2.3 Consideration of the effect of construction sequences. For tall buildings the effects of differential elastic shortening of vertical members should be considered. Such differential shortenings due to most part of the dead load is not applied simultaneously but depends upon the construction sequences. Computer analysis has to be carried out for this particular load case in the way of "one story at a time". In solving the displacements at various floor levels with the variable matrix band width technique, a "re-elimination" approach is introduced to count for the "one story at a time" effect efficiently (Fig.2). In simulating the construction of the ith story on the constructed (i-1)th story, the stiffness matrices of members joinedat the (i-1)th floor are to be first revised, then the matrix terms in the shaded trapezoidal area are to be re-eliminated. The remaining part of the matrix terms of the (i-1)th story and downwards can be retained unchanged. In this way, the computer time required to carry out the "one story at a time" load case analysis can be greatly reduced.

3. Comparison of computed and model test results.

During the design of the 130m high Shanghai Long Distance Telecommunication Centre Building, a 12-story plaxiglass model of 600X900 mm in size

(Figs. 3 and 4) was tested, separately under uniform and triangular lateral loads, and a torque at the top of the model to verify the performance of the program. It can be seen from Figs. 5,6,7 that the computed results of the torsional deformations of the model and shear forces in the periphral columns under the torque load, and the shear lag effect under lateral loads are in good agreement with the corresponding values obtained from the model test.

4. Applications in structural design.

Since 1982, the program has been applied to structural design of more than 70 HR buildings in several big cities in China. Some of these buildings have quite confisticated configurations and the results obtained have been found satisfactory. The following are two of its applications by ECADI.

4.1 Hongqiao Guest Hotel.

It is 29-story, 95M high with curvi-triangular shape in plan (Fig. 8). The design seismic intensity is 7° MM scale. Due to the asymmetrical layout of the core walls, there exist slight amounts of translating and twisting displacements (U,V,θ) under dead load as seen in Fig.9. Fig.10 shows the U,V,θ values under seismic load in the (-Y) direction. The vertical stresses in thin-open-section elements of the core under seismic load in the (-Y) direction varies from max-compression along the (-Y) edge to max-tension at the (+Y) apex in a slightly curved shape (Fig.11).

4.2 Huating Guest Hotel, Shanghai.

It is 28-story, 90M high with "s" shape in plan. In view of the "S" shape and narrow long strip of floor slab, two aseismic, as well as expansion joints have been set to separate the structure into 3 independent units, the most sophisticated part of which is the tier end unit as seen in Figs. 12,13. The setbacks in the tier units are structurally irregular. This feature together with the curved plan have stressed the necessity of using this program. The cross walls, cut off along T, V, X grids at every 3 stories, cause abrupt changes in stiffness of the lateral resisting elements, which in turn induce shear redistribution among them. This phonomenon has been well reflected in the calculated results(Fig.14), and the unbalanced redistributed shears have been considered in designing the floor slabs.

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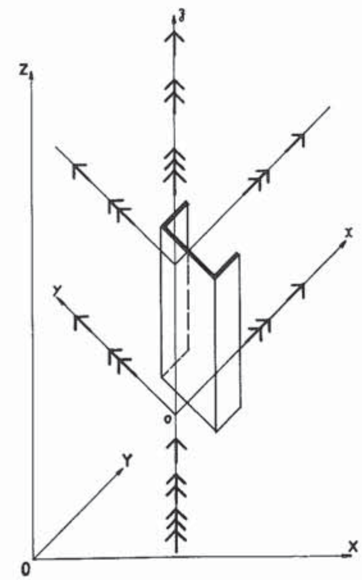

Fig. 1 A thin-open-section element with 7 degrees of freedom at each node. OX, OY, OZ: "global" axes, ox, oy, oz: element axes, ⟶ force, ⟶⟫ moment, ⟶⋙ bimoment.

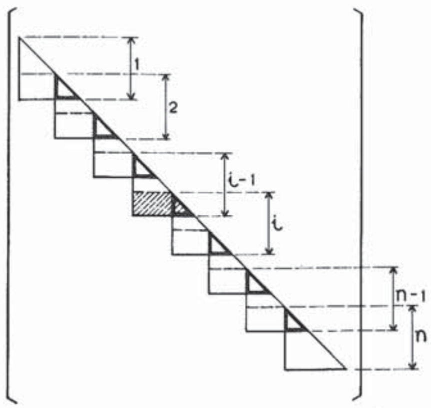

Fig. 2 Illustration of the "re-elimination"
1, 2, ... i-1, i, ... n-1, n numbers of stories.
◺ overlapping area of matrix terms of adjacent stories.
▨ area of matrix terms of (i-1)th story to be "re-eliminated".

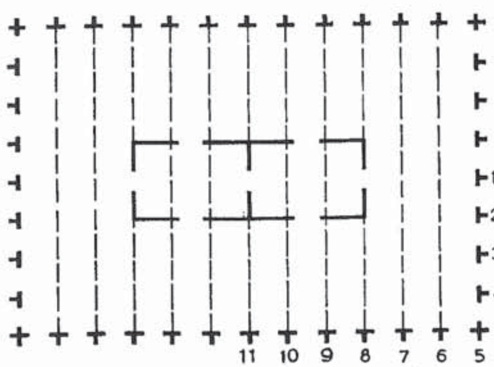

Fig. 3 Plan of a 12-story plexiglass model.
1, 2, 3, ... 10, 11 numbers of the peripheral columns

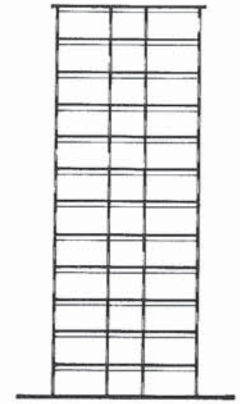

Fig. 4 Transverse section of the model.

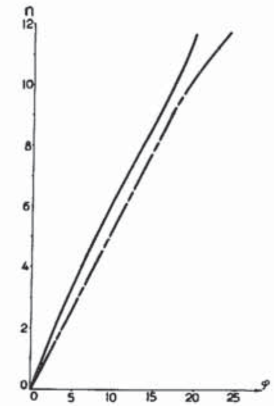

Fig. 5 Torsional deformation under a torque applied at the top
n: numbers of stories, ϕ torsional deformation in 10^{-5} rad.
——— from computed values,
—·—·— from experimental values.

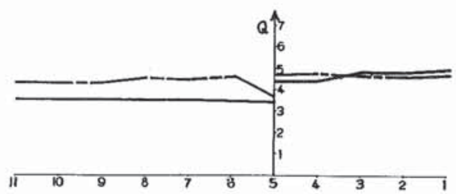

Fig. 6 Shear forces in peripheral columns in the directions parallel to the sides of the plan. Q: shear force in Kg.
1, 2, 3, ... 10, 11: numbers of the peripheral columns as in Fig. 3.

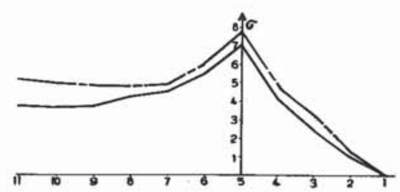

Fig. 7 Vertical stress in the columns under hori. loads.
σ: Vertical stress in Kg/cm^2.

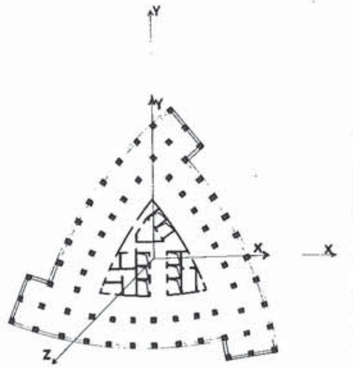

Fig. 8 Plan of Hongqiao Guest Hotel(HQGH). OX, OY, OZ: "Global" axes.

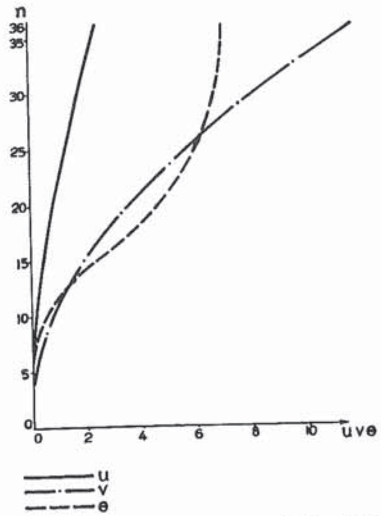

Fig. 9 Displacements of the HQGH under dead load.
u: displacements in the X direction(mm), v: displacements in the Y direction(mm), : rotational displacements about Z axis ($\times 10^{-5}$ rad). ——— from u values, —·—·— from v values, ------ from θ values.

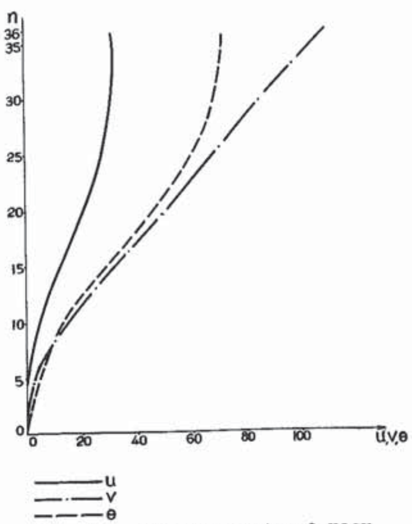

Fig. 10 Displacements of HQGH under seismic load in the (-Y) direction.
u in (mm); v in (mm);
θ in ($\times 10^{-5}$ rad).

Fig. 11 Vertical stresses in thin-open-section elements of the core of HQGH.
C compression; T tension.

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AT THE TIME OF PUBLICATION.

Fig. 12 Architectural model of Huating Guest Hotel (HTGH).

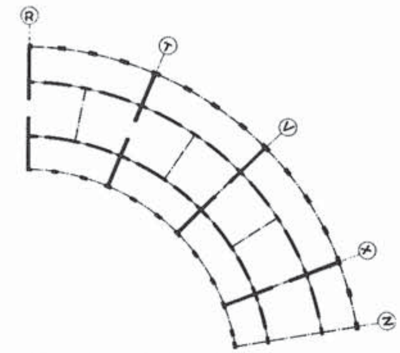

Fig. 13 Plan of the tier unit of HTGH.

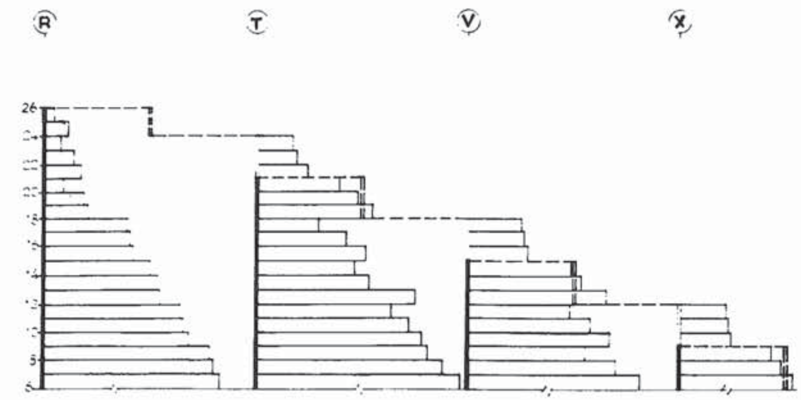

Fig. 14 Shear force redistributions among cross walls at setbacks of the tier unit under wind load.
▌: cross wall for whole width of building, ▯: cross wall for half width of building, ‖ : beam-column frame.