

STRUCTURAL ANALYSIS FOR A 40-STORY BUILDING

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SUMMARY

NASTRAN was chosen as the principal analytical tool for structural analysis of the Illinois Center Plaza Hotel Building in Chicago, Illinois. The building is a 40-story, reinforced concrete structure utilizing a monolithic slab-column system. The displacements, member stresses, and foundation loads due to wind load, live load, and dead load were obtained through a series of NASTRAN runs. These analyses and the input technique are described in this paper.

INTRODUCTION

The demands of a prosperous economy, combined with advancements in material technology, have created a high-rise building boom all over the world. In most cases, these buildings have complicated structural configurations for the purpose of accommodating the multiple functions required. The traditional structural analysis of buildings has been limited to simplified methods, such as plane frame or truss analysis. These methods often lead to erroneous results. To improve solution accuracy, manual iteration has been used at the expense of higher computation and labor costs. Occasionally, model testing techniques have been employed. However, the measured results did not necessarily yield better accuracy. They are more generally accepted as an indication to insure the conservatism of the designer.

In the last few years, the finite element method has gained wide recognition in this field. Unfortunately, most of the finite element programs available do not have the capabilities necessary to analyze a theoretically desirable model of a large building. They are either insufficient in capacity, or lacking essential finite elements. The emergence of the NASTRAN program has served to alleviate these shortcomings.

The Illinois Center Plaza Hotel is located near Lake Michigan in downtown Chicago. It is a 40-story reinforced concrete building which includes 1,000 guest rooms, several restaurants, parking facilities, and large conference rooms and ballrooms. The structural system of the building is the unique slab-column system, in which, the thin floor slabs are poured monolithically with the columns. There are no drop panels or haunches at the slab-column junctions. The savings in construction costs associated with this simplification makes the slab-column system a very competitive one in comparison to the conventional beam-column-slab system. However, more analytical work is necessary to insure an adequate design of this type

of system. The stress concentrations at the junctions, and the interaction between the slab and column become a necessary part of the analysis.

The hotel building is symmetrical about its short axis (X-axis) as shown in Figure 1. Therefore, only one-half of the structure was analyzed. The mathematical model representing this half building consisted of 1718 GRID points; 5000 CBAR elements, with maximum nodal difference of 81; and 3600 concentrated forces and moments. NASTRAN was chosen for this application on the basis of solution accuracy, problem capacity, and multiple constraint and restart capabilities. The analysis and results are described herein.

SLAB-COLUMN INTERACTION ANALYSIS

Structurally, the slabs of a high-rise building have two functions. They support the live and dead load and transfer them to the columns and footings. On the other hand, they also resist shear forces due to wind pressure on the building.

The models used in this analysis are shown in Figures 2 and 3. The model in Figure 2 consists of 777 GRID points, 124 CBAR's, 618 CQUAD2's, and one CTRIA2. CBAR elements were used to represent columns, while CQUAD2 and CTRIA2 elements were used to represent floor slab and shear walls. Because the point of inflection of a column is approximately midway between two floor slabs, the length of the columns were taken to be half of the floor height. The model shown in Figure 3 is similar to the first one, with 152 GRID points and 234 CBAR's. The columns are the same as in the first model, whereas, the slabs are represented by an equivalent beam system. The equivalent beams are fictitious beams with the slab thickness as their depth, and the reduced slab width as their width. The amount of width reduction is determined by the means of the displacement analysis which is described in the following paragraphs. In the case of the shear walls, the total cross section was considered to be effective in formulating the replacement CBAR elements.

Since the inplane rigidity of the slab is relatively stiff, the lateral displacements of the column ends which are not connected to slabs are tied together with multiple constraints. This constraining condition yields a more realistic distribution of shearing force among the columns.

The slab-column model was analyzed with three loading conditions; live load, dead load, and wind load. The individual results were also combined in accordance with local building codes. The live load and dead load analysis determined the related bending and shearing stresses, as well as displacements of the slab. It also provided the distribution of column loads. In the wind load analysis, the total accumulation of wind load was applied at the top of the model, and the wind load of the particular story was applied at the slab level. This resulted in the computation of shearing displacement of the particular story, and the shearing and bending stresses in slabs and columns due to wind load. By inspection of the stress variation across the width of the slab, an initial width was determined for the equivalent beams in the beam-column model.

Then, the same wind load was applied to obtain the shearing displacement. The width of the beams was varied to search for a configuration which provided the same displacement as the slab-column model. These two models are displacement compatible models. Obviously, the motivation for this is strictly economical. In this investigation, the size of the problem was reduced by 80%. Yet, it still provided a reasonably reliable wind stress analysis.

SPACE FRAME BUILDING STRUCTURE ANALYSIS

Once the simple equivalent model was obtained through the analysis described in the previous paragraphs, the task of assembling the model for the whole building was a straight forward one. It resulted in the space frame shown in Figure 1. Because the building has one plane of symmetry, only half of the building was necessary for this model.

There were two NASTRAN runs in this analysis. The first one was to analyze the displacements and stresses due to live load, dead load, and wind load acting in the direction of the short axis of the building, with symmetrical boundary conditions at the grid points along the short axis. The second run was to analyze the displacements and stresses due to wind load acting along the direction of the long axis (Z-axis) of the building, with anti-symmetrical boundary conditions along the short axis.

The results showed that the building shortens about 3.6 centimeters under combined live and dead load. It also drifts 8.6 centimeters and 17.8 centimeters under wind load in the direction of long and short axis, respectively. The profiles of the drift of the building are shown in Figure 4. They all conform to Chicago building code. The amount of drift is considered to be an important criteria for design. It determines the natural frequencies of the building and, hence, the response of the building to wind loads. The stress results were used for design purposes such as determining reinforcing, sizing concrete sections, and required material strengths. The Single Point Constraint Forces at the base of the building were used for the design of the foundation system.

PREPROCESSOR

Since a large portion of the building layout was uniform, there was a great deal of repetition of the bulk data. In order to take advantage of this and simplify data preparation, a short preprocessor was written to generate bulk data cards from a few key cards. Essentially, the preprocessor was a collection of counters and bulk data Formats. The function of the counters was to repeat and extrapolate the data on key cards. The bulk data Formats were required to generate card images. Approximately 11,000 input card images were generated on magnetic tape from 1,500 cards input to the preprocessor program.

The operation of linking the preprocessor, storing and transferring data, as well as executing NASTRAN, were done on a CDC 6600 computer under the SCOPE 3.3 operating system. All together, seven SCOPE control cards were required for this entire operation. Therefore, the amount of data preparation work was minimal. It represented an approximate reduction of 86% when compared to all manual work.

CONCLUDING REMARKS

The slab column interaction analysis presented herein is believed to be the first of its kind in the field of high-rise building analysis. It bypassed the requirement of conventional assumptions and, therefore, provided more reliable results.

The average nodal difference in the building model was 41, with a maximum of 81 occurring at the transfer girder floor. However, the maximum nodal difference occurred only in a few elements. This made it ideal for the application of the active column approach utilized in NASTRAN. As a result, the solution times were competitive with some of the fastest finite element codes in the field.

In addition to being fast and accurate, the flexibility on NASTRAN's I/O routines and data management, coupled with a simple preprocessor, greatly reduced input time. This is essential in solving large structural problems. The current version of NASTRAN may not have the best elements being developed in research institutions, nevertheless, the present degree of sophistication is generally consistent with current procedures used in the design and construction of a high-rise building.

STRUCTURE OF THE HOTEL BUILDING

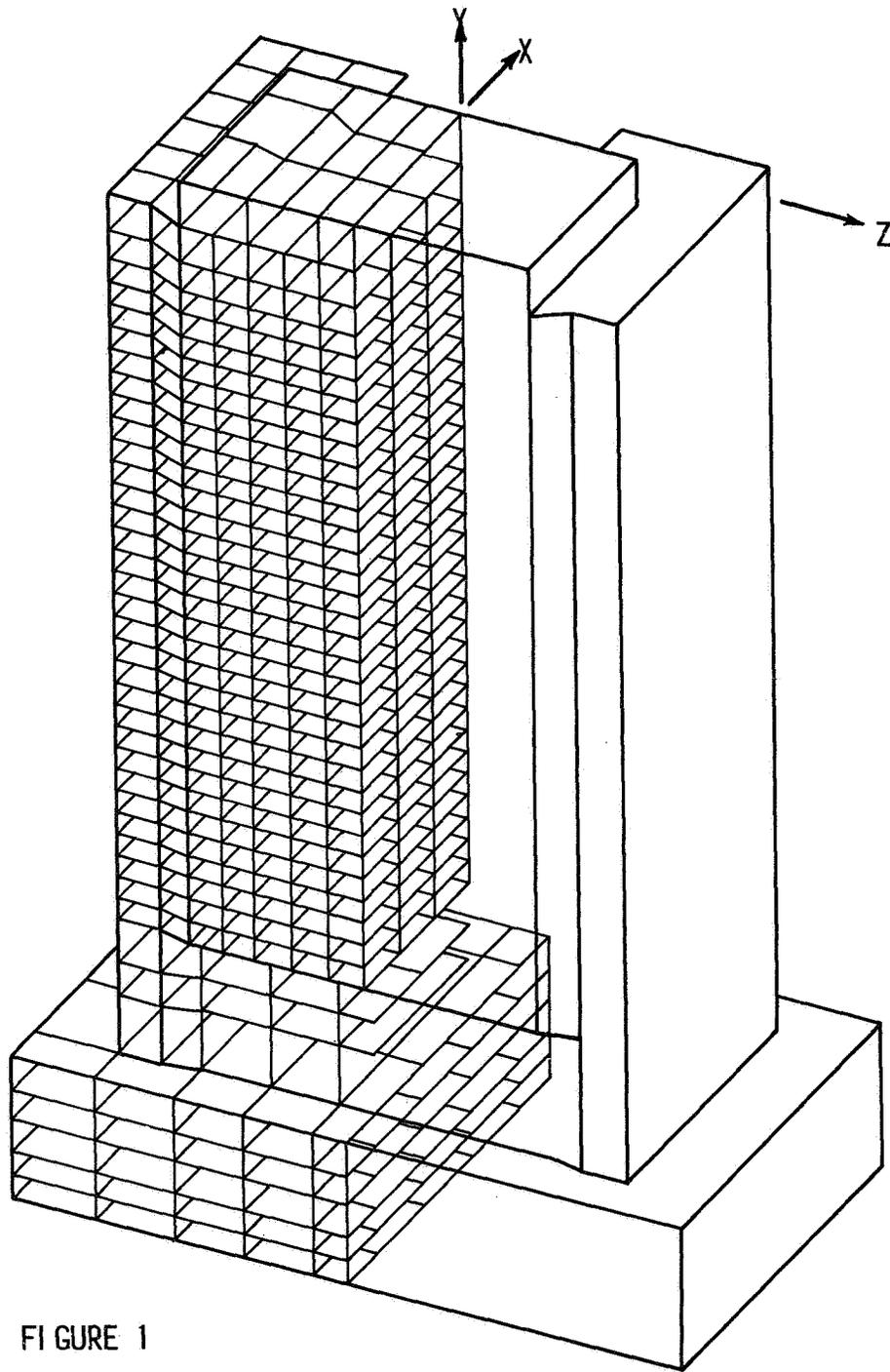


FIGURE 1

SLAB-COLUMN MODEL

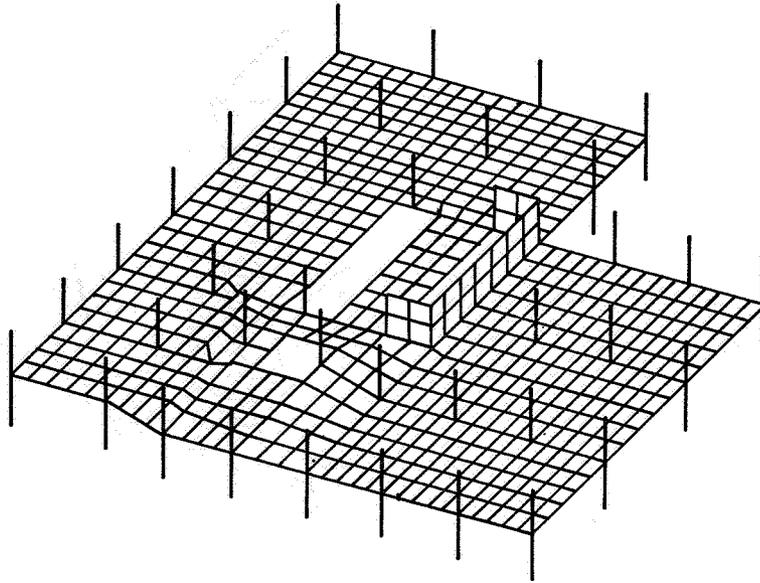


FIGURE 2

SLAB-BEAM-COLUMN MODEL

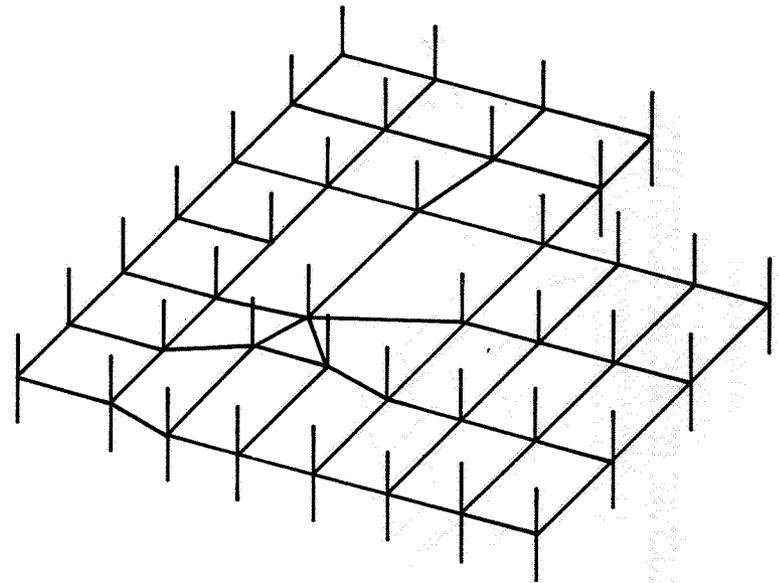


FIGURE 3

DRI FT OF THE BUI LDING

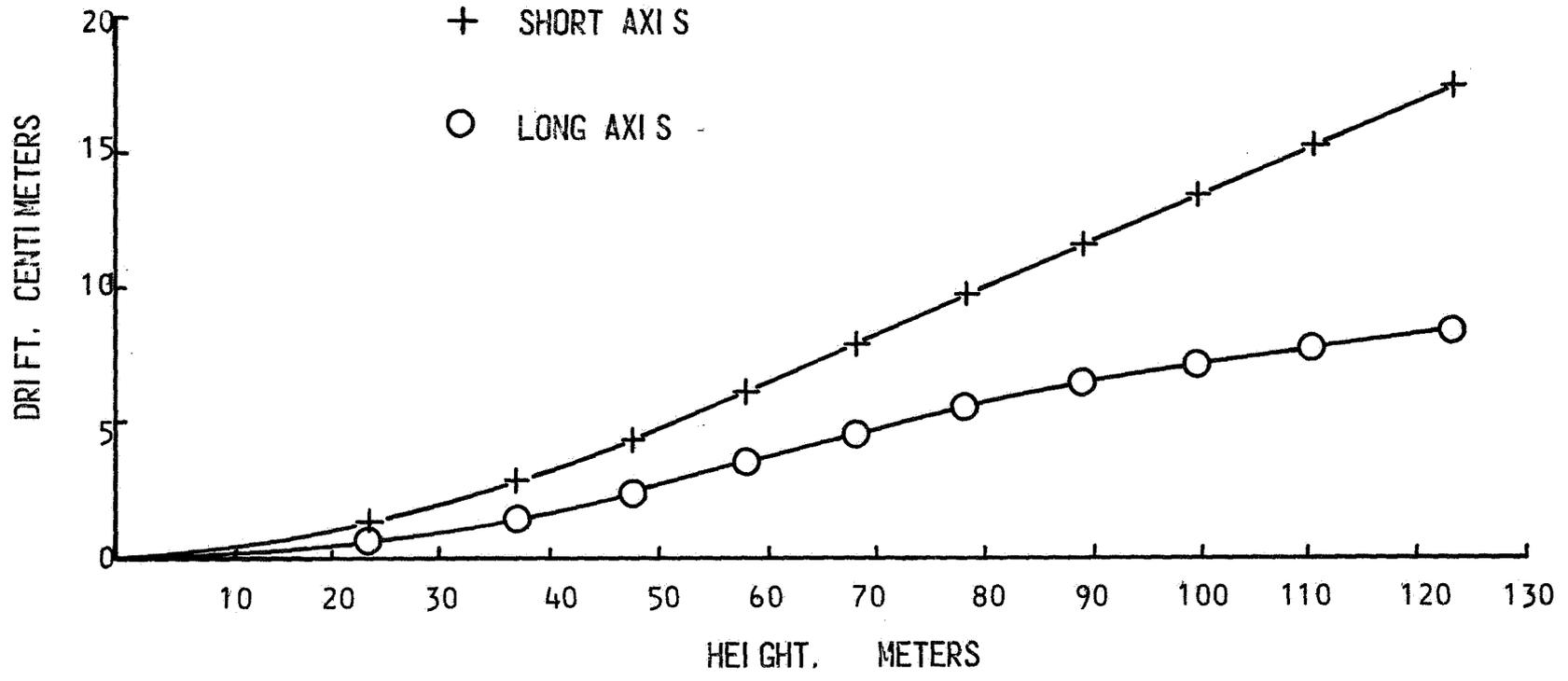


FIGURE 4