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Performance of Large Composite Columns

Comportement de poteaux mixtes massifs

Verhalten grosser Verbundstützen

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SUMMARY

The instrumentation of one of four large composite columns that make up the main structural system for a tall building is described. The results of the project indicate that the axial loads in the columns can be accurately measured and good correlation obtained with analysis if factors such as shrinkage, creep, and changes in construction loads are incorporated into the calculations. The forces measured were significantly below those specified in design, but were well within the range expected.

RÉSUMÉ

L'article décrit les instruments de mesure montés sur l'un des quatre poteaux mixtes massifs qui forment la structure porteuse principale d'une maison haute. Les résultats de ce projet montrent que les charges axiales peuvent être mesurées de façon précise et qu'il y a un bon accord avec l'analyse si on tient compte du fluage, du retrait et des variations des charges de construction dans les calculs. Les forces mesurées ont été nettement inférieures aux forces prévues lors de la conception, mais l'écart réel a été bien en deçà de l'écart prévu.

ZUSAMMENFASSUNG

Die Messinstrumente an einer der vier grossen Verbundstützen, des Haupttragsystems eines Hochhauses, werden hier beschrieben. Die Ergebnisse zeigen, dass man die Axialkräfte mit guter Genauigkeit messen kann und dass eine gute Uebereinstimmung mit den gerechneten Werten existiert, wenn Einfluesse wie Schwinden, Kriechen und Veränderungen der äusseren Lasten berücksichtigt werden. Die beobachteten Kräfte sind erheblich kleiner als die Bemessungswerte.

1. INTRODUCTION

In the past 10 years a large number of buildings have been erected in the United States utilizing composite or mixed systems [1], and many of the tall structures currently under design or construction utilize such systems. Mixed systems present both economic and technical advantages over all steel or all concrete buildings, particularly as the number of stories increases. However the design of critical members in such structures, particularly the connections, is still done quite conservatively because of the dearth of experimental or field data on the performance of such structures.

This paper reports the result of an instrumentation project and accompanying analytical studies conducted on a large composite column and its connections at the 19th-floor of a 57-sory building, the Norwest Center in Minneapolis. The objects of the study were:

(1) To trace the construction loads on the large corner composite columns, and to compare the measured and predicted axial response of the column.

(2) To determine the force transfer mechanisms between the composite columns and one of the beams forming part of a Vierendeel truss. The main purpose was not to verify whether the magnitude of the design loads was correct but to confirm the load transfer mechanisms envisioned in the design.

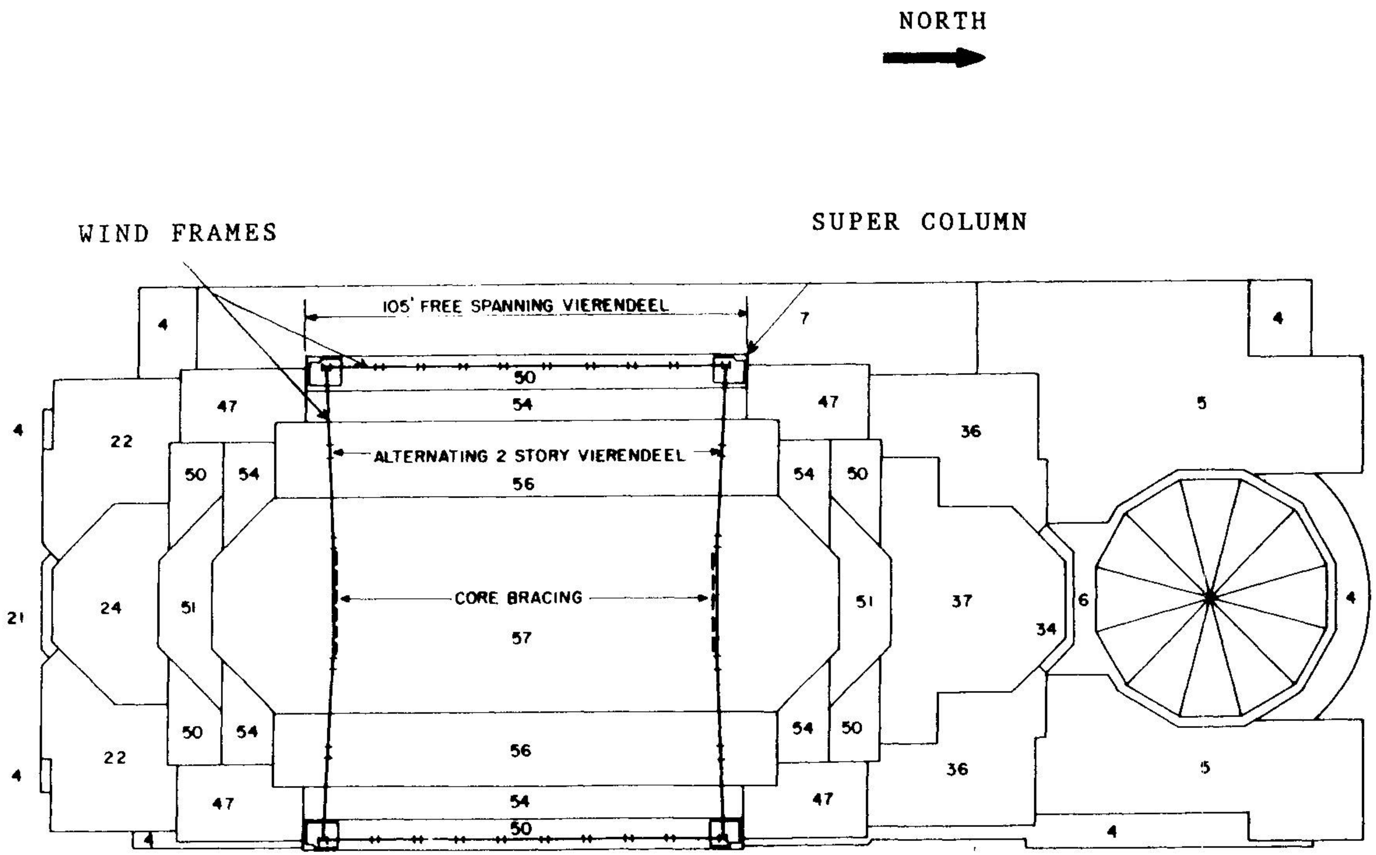
(3) To make some dynamic measurements on the building under ambient vibrations to help determine its principal natural frequencies and dynamic characteristics.

2. THE NORWEST CENTER

The Norwest Center building is more or less rectangular in shape, at the base, but has a number of setbacks and recesses at different levels along the height of the building (Fig. 1). The building extends 235 m. above ground level and has four basement levels below. The most striking characteristic of the building is the attempt to concentrate all the lateral load resistance in the middle third of the building by use of braced frames in the short direction and rigid trusses in the long direction. This decision was due mainly to the large number of setbacks in the building, and the necessity to tie the interior core with the perimeter frames for optimal lateral resistance.

The structural design of the building is such that the advantages of steel and steel-concrete mixed sub-systems have been maximized. Steel is the major material used in the framing systems. The shorter sections of the building which do not go all the way up to 57 stories, utilize conventional steel frames to carry the vertical loads. The use of steel resulted in more free space within the building as well as less gravity load to be transferred to the columns and the foundation due to lesser weight of steel vis-a-vis concrete on a per-square-foot basis. On the other hand the higher axial stiffness, greater mass and better damping properties of concrete in the composite columns has been utilized to provide the lateral load resisting system.

There are four huge composite columns located at the corners of the central, almost square portion of the building. Figure 2 shows the size of these



NOTE : NUMBERS REFER TO THE FLOOR LEVELS AT WHICH SETBACKS OCCUR.

Figure 1 .- Plan view of the Norwest Center.

columns, varying from 4470 mm. by 2514 mm. at the foundation level to 1448 mm. by 1676 mm. at the 47th floor level. At the 47th floor level the composite column ends while only the steel section goes up.

The column is heavily reinforced with 413 MPa bars and high-strength Dywidag bars. At the floor of interest, i.e. 19th, there are three separate reinforcement cages covering the three zones bounded by the faces of the column and two steel beams (Figure 3). These cages contain twenty-nine 44 mm. and fifteen 32 mm. bars. Between these steel beams and the beams immediately above and below, there are Dywidag bar cages. These were attached by welding small pieces of angles to the beam flanges, and then welding the Dywidag bars to the angles.

The two super-columns along the wider face of the building are connected by 105' free spanning steel Vierendeel trusses. The Vierendeel trusses are five stories high, up to the 42nd floor, and there is a single seven-and-a-half story high truss up to the 50th floor. The Vierendeel trussses are connected at the midheight of levels 7, 12, 17, 22, 27, 32, 37 and 42 by connections designed to transfer only horizontal shear during the erection, but turn into moment connections when the concreting of the corner columns had reached up to the next level of hinge connections. This system forms the lateral load resisting system along the North-South direction of the building. Along the shorter dimension of the building (East-West), the super columns are connected by alternating two-story Vierendeel having steel bracing in the middle span.

3. INSTRUMENTATION

The main objective of this study was to verify the mechanism of the transfer of forces to the composite super-columns. Hence it was decided to instrument one of these columns immediately above and below one of its connections with the beam of the Vierendeel truss. The instruments were intended to determine the variations in strain during the construction in the composite column and connection region. Due to the economical limitations of the project and the physical constraints of the site, it was decided to use a mixture of electrical resistance strain gages and dial gages for measuring strains around the moment resisting connection of the super-column.

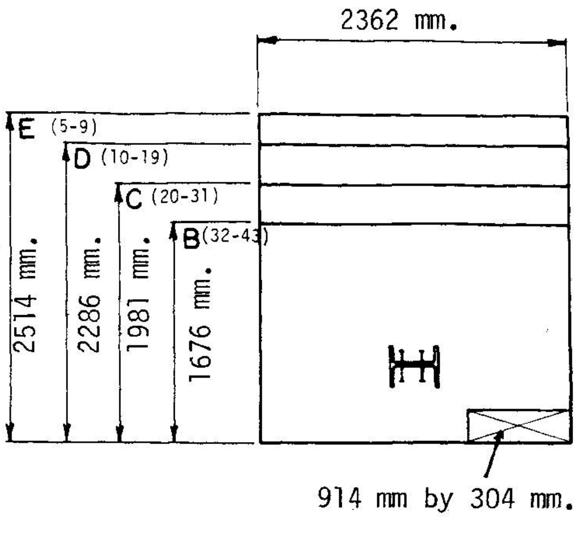


Figure 2 - Column size with height

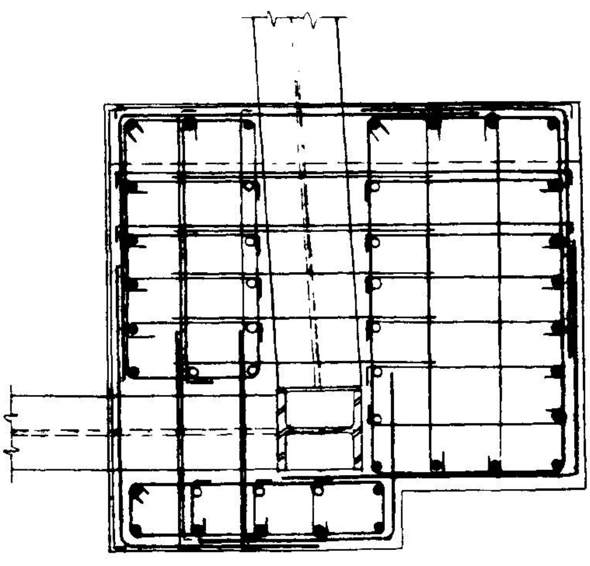


Figure 3 - Typical column detail

Unlike most experimental research studies which are done under laboratory conditions, this project required the installation of the instrumentation to be done in-situ, during the routine construction process and with as little impact as possible on the construction work. At the same time the instruments had to survive the exposure to the varying weather conditions, which at times was very cold, windy and wet. Also the concreting and vibration to be done during the pouring of the column posed a major threat to the survival of the strain gages.

4. RESULTS

A typical variation of the axial strain in the column plotted vs. time is shown in Figure 4. As can be seen, there are some local fluctuations due mostly to temperature effects since the temperatures during construction ranged from +35C to -30C. While most of the instruments had internal temperature compensation, all the gages seemed to show the same local fluctuations pointing to some unknown but constant source of electrical noise. Thus an averaging technique was used to remove this fluctuations and a best fit line (also shown in Fig. 4) calculated. The axial strains measured in the column varied from 225 to 350 microstrain in a concrete with an average cylinder strength of about 60 Mpa.

In addition to the experimental study, two analytical studies were carried concurrently. One aimed at determining the effect of creep and shrinkage on the column shortening, while the other intended to analyze the structure as the actual construction loads were applied. The former study utilized the procedures proposed by Fintel [2], while the latter utilized the commercially available program ADINA. The results obtained from these studies indicted that the measured strain were very close to those predicted. These studies implied a large amount of effort, since tracking the construction sequence and loads was imperative to a successful model.

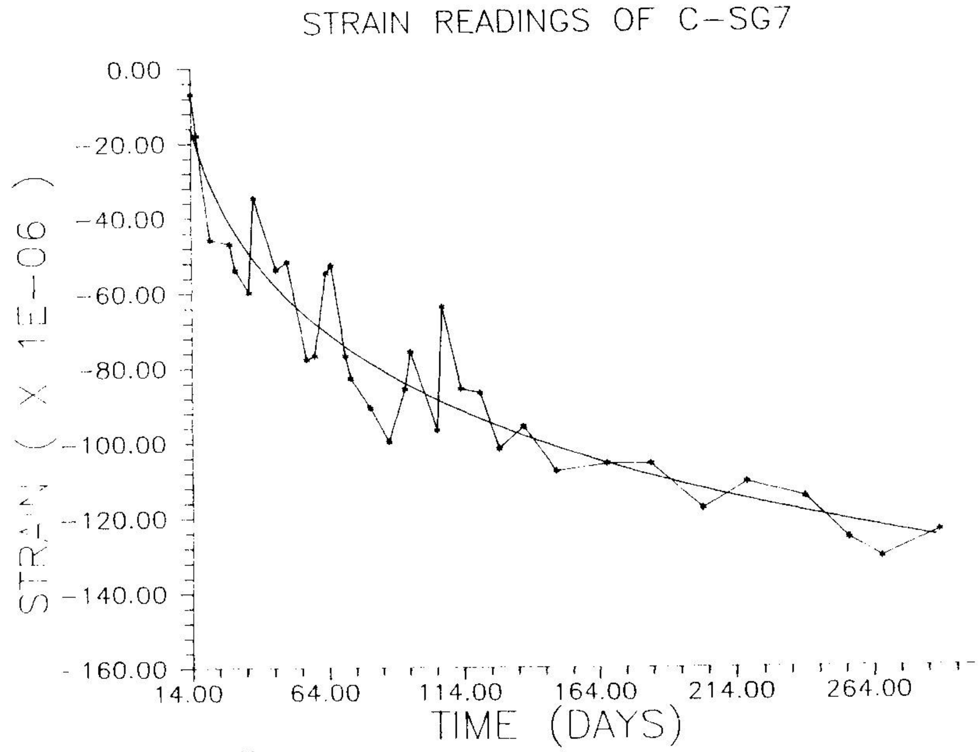


Figure 4 - Typical axial strain measurement.

Utilizing similar data obtained from strain gages in the beams framing into the column, the following conclusions were reached:

(a) The five story Vierendeel truss acts like one deep 29 m. long beam, transferring moments, shear and axial load to the super columns, which provide close to fully rigid rotational and translational restraint.

(b) The axial force in the beam, at the location of strain gages, is negligible. The stresses therefore are mainly due to flexure.

(c) The shear forces in the spandrel beam members of the truss vary at different levels of the five story high truss. The shear forces in the beams are minimum at the top and bottom story of the truss and maximum at the middle story.

(d) The bending moment in the spandrel beams in each bay is more or less linear, changing from negative moment at the end closer to the nearest super column, to positive moment at the other end.

(e) At the location of the strain gages on the steel spandrel beam, the moment due to gravity load is negative.

To determine the dynamic characteristics of the building, a low level accelerometer attached to a Fast-Fourier Transform (FFT) analyzer were used. Typical data from these studies showed a first natural frequency was about 0.196 Hz. in the short direction and about 0.204 Hz. in the long direction. The results show a structure substantially more stiff than predicted by the three-dimensional finite element analysis carried out by the designer. This is not surprising since the measurements were taken under constant NW winds with speeds between 10 mph. and 15 mph., a relatively low level of vibration.

5. CONCLUSIONS

The results obtained indicate that:

(a) It is possible to determine the axial forces and moments acting on large composite columns by using external dial gages and internal strain gages.
(b) Much care must be exercised when reducing the data, as both creep and shrinkage of the concrete and changes in temperature must be properly incorporated into the data reduction.
(c) Tracking of the actual construction loads is imperative. Calculations based on design loads or on assumed loads cannot, in general, provide good correlations to measurements.
(d) The data must be acquired from the very beginning of the construction phase so as to obtain an initial baseline for the readings.
(e) The construction loads are significantly lower than those assumed in design. This is true in the global sense, i.e., for main members such as the super-columns.

6. REFERENCES

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