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Analysis of Framed Buildings Having Arbitrary Wall Panels

Calcul des ossatures en portique à voiles raidisseurs

Berechnung von Rahmentragwerken mit Schubwänden

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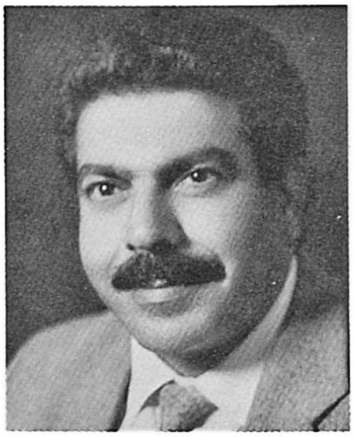

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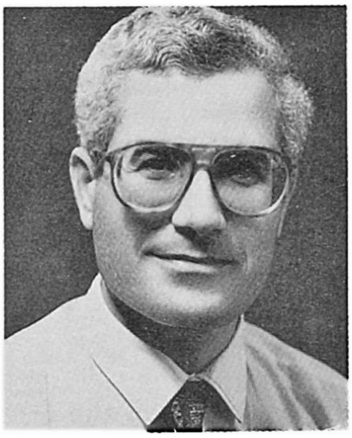

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SUMMARY

The direct stiffness method is employed to analyze framed buildings having arbitrary wall panels as structural elements modeled by finite elements. A computer program is developed to handle the mathematical formulations, solution of equations and calculation of joint displacements and member-end forces. Example problem is presented to demonstrate the effect of wall panel configuration on the stiffness of the structure.

RÉSUMÉ

Basé sur la méthode des éléments finis, un logiciel pour ordinateur a été élaboré en vue de calculer les ossatures en portiques comportant des voiles raidisseurs de position arbitraire. La résolution du système d'équations des éléments porteurs fournit les déplacements des noeuds et les efforts intérieurs. L'article présente un exemple qui montre l'influence de la disposition des voiles sur la rigidité de l'ouvrage.

ZUSAMMENFASSUNG

Für die Berechnung von Rahmentragwerken mit beliebiger Stellung aussteifender Wände wurde ein Computerprogramm entwickelt, das auf der Methode der Finiten Elemente basiert (Weggrössenverfahren). Aus der Lösung des Gleichungssystems der Tragelemente ermittelt es die Knotenverschiebungen und Schnittkräfte. Das vorgestellte Beispiel zeigt den Einfluss der Wandanordnung auf die Bauwerkssteifigkeit.

1. INTRODUCTION

The majority of multistorey buildings are commonly used for housing, offices, and other public or commercial facilities. The classical structural system consists of frames including column and beam elements. Such buildings have slabs, shear walls, and wall panels or partitions which have been constructed to satisfy functional requirements. Designer tend to consider the infill panels as nonstructural elements loaded on the beam elements and hence treat the frames as conventional ones; a practice is adapted, but it is far from reality.

Recently, there has been an increasing recognition among structural engineers that wall panels are no longer considered as nonstructural elements, but they affect the structural characteristics of the building and may alter the structural behavior by increasing the stiffness of the structural system. This fact stimulated researchers to develop methods of analysis which simulate the actual behavior by incorporating the wall panels as structural elements. Each method is recognized by the manner of modeling the panels.

The concept of equivalent truss member to idealize the panels is used by one group of investigators [1,2,3] while another group modeled the panel by finite elements [4,5]. The third group focused on either experimental evidence [6] or rationalized the design approach [7]. The literature survey on these methods could be found in Ref.5.

This paper presents the two-dimensional analysis of framed buildings having arbitrary wall panels aiming at studying the effect of such panels to improve the stiffness of the structure in general and to minimize the lateral drift in particular. In addition to that, selection of arbitrary wall panels is sought amongst various configurations to optimize the structural behavior of the entire building. The study presented herein is a continuation of previous studies [8,9]. The structural system consists of three media, namely: the superstructure, the substructure and the supporting soil medium. For the superstructure, the stiffness method is employed to model the beam and column elements. The wall panels are modeled by plane stress finite elements. The substructure is modeled by uniaxial finite elements. The soil is modeled by elastic half space where the stiffness matrix is obtained by the inversion of the soil flexibility matrix.

2. METHOD OF ANALYSIS

The direct stiffness method is utilized to develop the overall governing matrix equation in the form:

$$[K]\{D\} = \{Q\} \qquad (1)$$

where

[K] is the overall structural stiffness matrix,
{D} is the vector of unknown joint displacements, and
{Q} is the vector of joint loads.

2.1 Stiffness Matrices

The governing matrix equation of a framed member can be written in the form [10]

$$[k]\{d\} = \{q\} \qquad (2)$$

where

[k] = the global stiffness matrix of the member;
{d} = the member-end displacements, and
{q} = the member-end components.

The stiffness matrix of the soil medium as modeled by elastic half space can be obtained by inversion of the soil flexibility matrix which takes the form

$$[F] = [f_{ij}] \tag{3}$$

$$f_{ij} = \frac{1-\mu^2}{\mu\ E\ x_{ij}};\quad i \neq j \quad and \quad f_{ij} = \frac{2(1-\mu^2)}{\pi a E} C_{ij};\quad i = j \tag{4}$$

$$C_{ij} = ln[\alpha + \sqrt{1+\alpha^2}] + \alpha\ ln[\beta + \sqrt{1+\beta^2}] \tag{5}$$

$$\alpha = \frac{a}{b}; \beta = \frac{b}{a} \tag{6}$$

where a, b are the length and width of loaded element of soil, respectively.
E, μ are the modulus of elasticity and Poisson's ratio of soil, respectively.
$x_{ij} = x_j - x_i$
x_i = distance of node i from the origin of global coordinates.

The soil stiffness matrix is then obtained as

$$[S] = [F]^{-1} \tag{7}$$

The finite element technique is used to model the raft foundation of footings by using uniaxial bending elements. The wall panel is divided into a group of plane stress rectangular finite elements [11]. The stiffness matrix of the element can be written as:

$$[K] \;=\; a\ b\ t \int_{\xi=0}^{\xi=1} \int_{\eta=0}^{\eta=1} [B]^T\ [C]\ [B]\ d\xi\ d\eta \tag{8}$$

where

[B] = strain-displacement matrix; [C] = stress-strain matrix; a,b,t are the length, width and thickness of element, respectively and $\xi = x/a$; $\eta = y/b$

The stiffness matrix of the panel is formulated and condensed to correspond only to the four corners of the panel. Then the condensed matrix is partitioned into a system of (2x2) submatrices. Using equilibrium conditions and compatibility requirements, the contributing stiffnesses from wall panels, raft foundation, and soil are added to the appropriate joint positions to assemble the overall stiffness matrix.

2.2 Load Vector

Each joint is subjected to the resultant of external horizontal, vertical actions and moments to form the joint load vector [Q] of Eqn.1. The external loads can be either gravity loads, live loads and the wind or the equivalent seismic horizontal forces.

2.3 Solution of Equilibrium Equations

The governing matrix equation as given by Eqn.1 is solved by elimination techniques which proved to be more efficient, versatile and reliable because the stiffness matrix of the entire structure is always a positive definite matrix which enables the application of elimination technique in purely, sequential process without pivoting especially for a banded stiffness matrix. The whole process is applied within the computer program. Once, the unknown vector of joint displacements is established, the internal member-end forces can be obtained by back-substitution of individual stiffness matrix equation of members.

3. COMPUTER PROGRAM

A Computer program is developed and written by FORTRAN-77 to handle the mathematical formulations, numerical solution and calculations of joint displacements, soil pressure, and member-end tractions. The main segment reads the input data, assembles the load vector and prints the output results while a group of subroutines are used to perform the stiffness matrices of structural elements, wall panels, raft foundation and soil; solve for unknowns joint displacements; calculate the member-end tractions. The input data are the material properties, joint loads, x- and y-coordinates of the joints, dimensions of various elements, joint numbers, and control parameters. The output results are the soil pressure at the contact interface, joint displacements, and member-end forces,

4. APPLICATION

A 12-storey framed building as shown in Fig.1 is chosen to demonstrate the method of analysis. The columns have a cross section of 0.5 x 0.5m for the first two levels. The section decreases by 0.05m every two levels. All beams have cross section of 0.25 x 0.60m. The raft thickness is 0.7m. The thickness of concrete wall panel is 0.25m. Loads and properties: Dead Load $= 15kN/m'$ + dead weight of panels; Live Load $= 12kN/m'$; Lateral Load $= 100kN/floor$; Ec $= 25 \times 10^6 kN/m^2$; $\mu_c = 0.17$; Es$= 5 \times 10^4 kN/m^2$; $\mu_s = 0.40$

Six cases of wall panel configurations as shown in Fig.2 has been considered. Only one parameter is selected for comparison among these cases and that is the horizontal floor displacements as shown in Table 1.

5. CONCLUSIONS

The two-dimensional analysis of framed buildings having arbitrary walls as structural elements has been presented which simulates the actual behaviour of the structure. Other conclusions may be drawn from this study:

a. Wall panels should be treated as structural elements increasing the stiffness of the structure upon which the floor drift is decreased.

Floor No.	Height m	Horizontal Floor Displacement for Various Cases, mm					
		1	2	3	4	5	6
1	4.5	0.29	0.22	0.13	0.11	0.11	0.08
2	7.5	0.93	0.41	0.20	0.16	0.15	0.42
3	10.5	1.61	0.64	0.27	0.23	0.23	0.73
4	13.5	2.17	0.55	0.28	0.29	0.30	1.00
5	16.5	2.25	0.30	0.29	0.38	0.45	1.17
6	19.5	0.76	0.23	0.33	0.52	0.67	1.42
7	22.5	2.00	1.76	1.86	0.83	1.11	2.22
8	25.5	6.54	6.20	6.28	1.21	1.67	3.27
9	28.5	11.60	11.10	11.20	1.93	2.53	3.88
10	31.5	16.50	15.90	15.90	5.89	3.01	4.93
11	34.5	21.60	20.90	20.90	10.40	3.73	5.76
12	37.5	26.60	25.80	25.90	15.80	4.72	7.10

Table 1. Horizontal Displacements at Floor Levels.

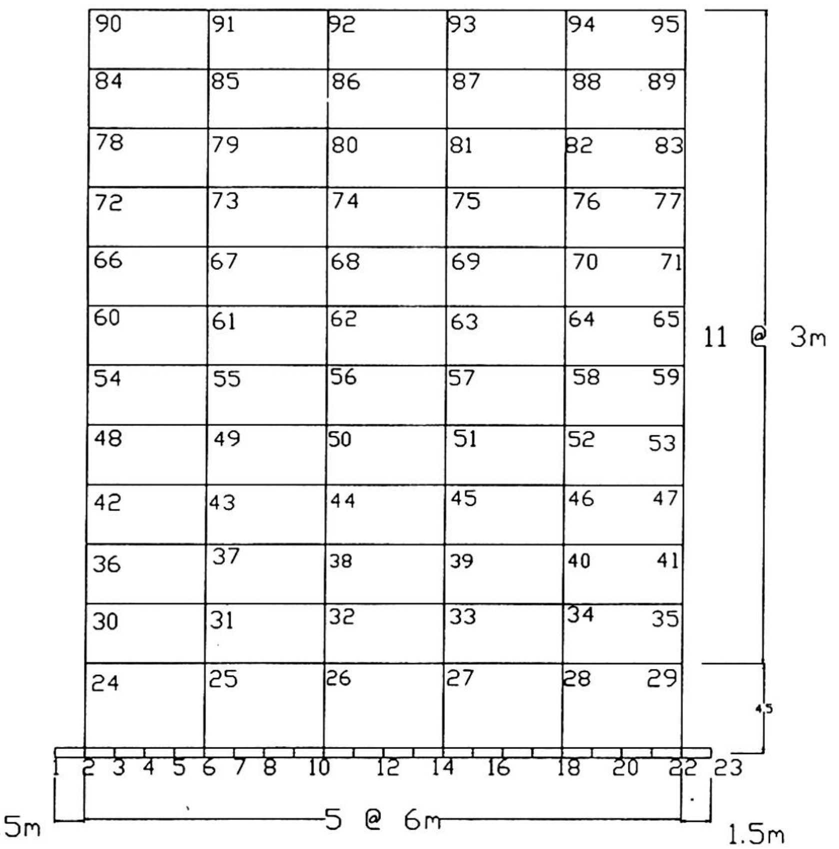

Fig.1. Geometry and Nodal Numbering

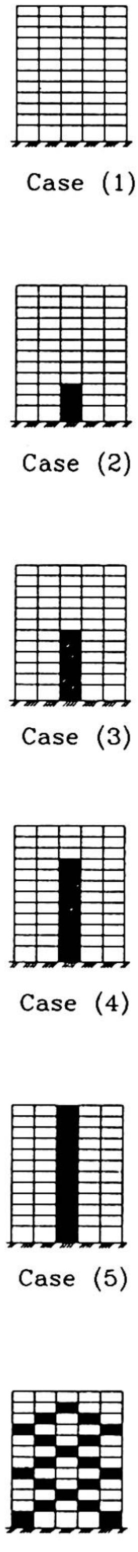

Fig.2. Panel Configurations

b. Wall panels forming a full shear wall is the best selection among all configurations. The shorter the shear wall is formed, the effect in enhancing the stiffness is reduced as can be observed in cases 3, 4, and 5.

c. Configuration of case 6 may be considered as shear wall equivalent, but on the account of using nearly twice the number of wall panels.

d. The presented method of analysis can be applied to concrete as well as to steel structures with concrete or metallic sandwich panels.

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