4th WORLD CONFERENCE ON EARTHQUAKE ENGINEERING SANTIAGO, CHILE

On behalf of the Executive Committee of the International Association for Earthquake Engineering (IAEE), the Indian Society of Earthquake Technology, invites Engineers and Scientists interested in the field of earthquake Engineering and Seismology to contribute papers to the 4th World Conference on Earthquake Engineering to be held at Santiago, Chile in January, 1969. The papers may be contributed on any of the themes given below :

Theme I : Earthquake Science and Analysis of Response of Structures to Earthquake Ground Motion.

a. Seismicity
b. Instrumentation and Ground Motion Measurements
c. Spectra and Soil Characteristics
d. Response Analysis
e. Research in Earthquake Engineering
f. Linear and Non-Linear Action of Structure

Theme II : Earthquake Resistant Design and Construction Practices.

a. Design Criteria and Codes of Practice
b. Observation of Performance in Earthquakes
c. Materials of Construction for Earthquake-Resistance
d. Design of Low-Rise and High-Rise Buildings
e. Design Considerations in Other Types of Structures
f. Foundations ond Soil-structure Interaction.

All accepted papers will be printed and distributed prior to the opening of the Conference. The tentative dates for submitting the abstracts and full papers are as follows :

Abstract — January 1, 1968.

Full Paper — June 1, 1968.

Those interested can send their papers for the Conference through the Secretary, Indian Society of Earthquake Technology, School of Research and Training in Earthquake Engineering, University of Roorkee, Roorkee, U.P, or to the Executive Committee of the I.A.E.E. on the following address :

Secretary General,
International Association for Earthquake Engineering,
C/O International Institute of Seismology and Earthquake Engineering,
Building Research Institute,
4-Chome, Hyakunin-Cho, Shinjuku-Ku,
Tokyo, Japan.

The exact dates of the conference and other details would be communicated to the members of the Society as soon as the same are received from the I.A.E.E.

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SEISMIC DESIGN OF TALL BUILDINGS-USE OF SHEARWALLS

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Synopsis

The importance of shearwalls or shear panels to increase the lateral stiffness of tall buildings is well known. However, the structural and aesthetic requirements as considered by the engineer and the architect are quite often contrary to each other, and a shear-wall may be entirely absent where it is most needed. Thus the usual design methods assuming a uniform and systematic distribution of shear-walls in each storey are rather impractical A unified method capable of incorporating the stiffness of shear-walls and other stiffening elements like floor slabs and cladding, at their actual location is needed for a realistic analysis of practical shear-wall buildings. In the following pages an attempt is made to present outline of a similar method.

Introduction

Recently there has been a considerable increase in the number of tall buildings, both residential and commercial, because of certain advantages of 'circulation', 'land utilization' and 'planned development' etc. Structural frames of steel or reinforced concrete are generally used and are quite efficient where the lateral forces like wind loads or seismic actions are insignificant. However, in a highly seismic zone due consideration for lateral forces is necessary.

The inherent weakness of structural frames under lateral loads[1], can be easily removed by inserting shear-wall or shear-panels in the building at suitable locations. The advantages of shear-walls as primary lateral load resisting elements for seismic structures was first recognised by Benjamin and Williams[2] of Stanford University in 1948. Since then many workers in U S.A., U.K., U S.S.R., aud Japan have tried to present a theoretical or experimental solution to the problem with varying success. However, a generalised comprehensive solution has not been presented so far.

Previous Work

The utility of shear-walls in tall buildings can not be over emphasised. However, the usual objections to the use of shear-walls in a building frame are, that:

(1) Theoretical analysis of shear-panels and their stiffness factors for various boundary conditions are not adequately known.

(2) Very often the architect may not provide a shear-wall where it is most needed or he may pryvide openings in it to weaken it considerably.

Most of the research workers have treated the shear-wall building as a cantilever and their analysis suffers from excessive idealization. For example Martin Schulz[3] has analysed a multistorey shear-wall with a row of identical openings in each storey, by considering it as a pair of beams with elastic connections. A second degree differential equations of the form.

$$\frac{\partial^2 N}{\partial x^2} - \alpha^2 N = \beta M \tag{1}$$

is obtained where

N = The shear force in connecting beams at each story.

M = Bending moment in the shear-walls.

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1, 2, 3, ... Refer the serial number of references given at the end.

α,β=Constants, depending on the elastic properties of shear-walls and connections. The solution obtained is of the form,

$$N = A \cosh \alpha x + B \sinh \alpha x + \frac{\beta}{\alpha^2} M_o + \frac{\beta}{\alpha^4} M_o'' \tag{2}$$

Other workers like Eriksson[4] and Beck[5] adopt similar procedure with some modifications.

The limitations of this procedure are obvious. Apart from the question of considering a 3-dimensional structure as a one dimensional element, it is assumed that all the openings are similar and uniformly spaced. Thus for a normal building with unsymmetrial walls and openings the theory is not applicable.

New Techniques for Isolated Shear Panels

The governing equations for the shear-wall problem in the simplest form are:

$$\left.\begin{aligned}
&\frac{\partial \sigma_x}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} = 0 \\
&\frac{\partial \tau_{xy}}{\partial x} + \nu \frac{\partial \sigma_x}{\partial y} + E \frac{\partial^2 v}{\partial y^2} = Pg \\
&\frac{\partial u}{\partial x} + \nu \frac{\partial v}{\partial y} - \frac{(1-\nu^2)}{E} \sigma_x = 0 \\
&\frac{\partial \sigma}{\partial x} + \frac{\partial u}{\partial y} - \frac{2(1+\nu)}{E} \tau_{xy} = 0
\end{aligned}\right\} \tag{3}$$

Where σ_x and τ_{xy} are the direct and shear stresses and u, v are the displacements in x and y directions. Exact solution of these partial differential equations with practical boundary conditions is nearly impossible to achieve. Classical methods like 'conformal mapping techniques' and 'Galerkin' or 'Kantorovich' methods have been tried without much success. Hences a search was made for new methods and various mathematical and semi-equivalent methods tried. Finally the following two methods, termed as 'Line Solution' and 'Grid Analysis' were developed for general application.

Line Solution Techniques

Details of the Line solution techniques has been presented earlier[6,7]. Briefly speaking it is a semi-exact mathematical method for the solution of linear partial differential equations with constant coefficients, having two-point boundary conditions. The 'n'th order governing partial differential equation of any two-dimensional structure is rendered unidirectional by dividing the structure into a number of strips by a series of 'm' lines parallel to, say the 'x' axis, and replacing all the y-derivatives with their finite difference equivalents. This gives a set of 'm' ordinary differential equation of 'n' th order which in turn are reduced to a set of 'mn' first order equations by the use of a new set of variables as:

$$\frac{d F_{k,j}}{dx} F_{k,j+1} \quad (k = o, 1, 2, \ldots m - 1;\ j = o, 1, 2, \ldots n - 2) \tag{4}$$

In matrix form the set may be represented as:

$$\frac{d F}{d x} = \underline{A}\ \underline{F} + \underline{B} \tag{5}$$

Where $\underline{A}$ is a square matrix of size (mn × mn) and $\underline{F}$ and $\underline{B}$ are conformable column matrices. This matrix differential equation is solved by 'matrix progression' method and standard computer programmes are made available.

Grid Analysis

This is an equivalent method [8,9] for the solution of general plane-stress problems and and consists of replacing the actual 2-dimensional structure by a hypothetical structure with one dimensional elements, to form a grid work. Conditions of equilibrium and compatibility are approximately satisfied by specifying desired areas and moments of inertia to the members of this grid. However, this is the only approximation made in this analysis. The resulting grid is exactly solved by the stiffness method and a standard programme for the Ferranti Pegasus computer has been developed. The accuracy of thc results obtainable by this method is comparable to any of the so called exact methods.

A Generalized Method of Analysis

The difficulties mentioned earlier have to be considered first and their successful solution would form the basis of the new theory. The problem will be studied in two stage i.e. the analysis of isolated single storey shear-walls and the analysis of general multistorey, multi-bay shear-wall buildings.

Analysis of Single Storey Shear-walls

A detailed study of this stage of the problem has been successfully done using these methods. Briefly speaking the following cases were considered:—

a. A shear-wall on a rigid base, under a uniform lateral load.

b. A shear-wall on an elastic base under a uniform lateral load.

c. A shear-wall with an opening on a rigid base under a uniform load.

d. A shear-wall with an opening on a elastic base under a [illegible]orm lateral load.

Line Solution and grid analysis techniques were used for all [illegible]ases though numerical results could be obtained for case 'a' only in the case of Line Solutio[illegible]

Grid analysis, however. was much more successful and ve[illegible] lose agreement with experimental results could be obtained in all the cases. Extensive computer programmes were developed for the computation. Necessary tables and graphs have now to be prepared for the stiffness factors and stress concentration ratios for various shapes and sizes of the shear-walls and openings with different boundary conditions. It will take considerable time on the computer but no further thinking is needed for this. These tables and graphs should be so prepared that for any shear-panel the designer should be able to know the equivalent stiffness and expected maximum stress and its location in the panel.

Analysis of Multistorey Buldings

This stage of the problem is more difficult and merits an extensive treatment. The following steps are suggested to obtain the solution. Actually this should form the basis of a completely new theory for the design of tall buildings.

A. The whole buiding is treated as a 3-dimensional structure and all the wind load at a certain floor level is to be taken by all the shear-walls anywhere on that floor in the proper direction. Fig. 1. shows a typical random positioning of the shear-walls in a certain bay of a multistorey building.

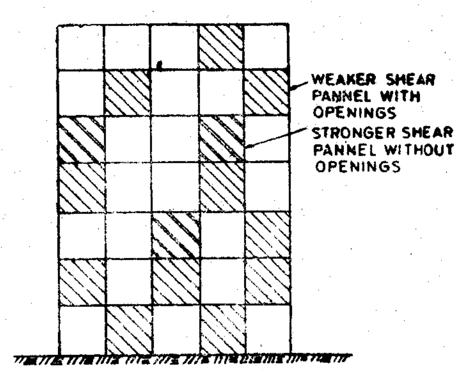

Fig. 1 A Typical Frame with Shearwalls

B. Usually there will be some frames more stiff than others i.e. having more number of, or stiffer shearwalls at a certain level than the others (Fig. 2). Naturally in a continuous structure, such frames should take more wind load compared to the weaker frames, and some transfer of wind load is necessary.

C. This shifting of wind loads from weaker frames to tronger frames is allowed by providing elastic connections between these frames. The transfer takes place through floor slabs acting as horizontal shear-panels. Their stiffness is calculated and substituted as the stiffness of spring connections between the frames (Fig. 3).

D. Analysis of the whole building can be finally done on a large computer, as a series of frames having various stiff panels at different locations (generally represented as an inclined member of equivalent stiffness) and the adjacent frames jioned together by elastic links, (Fig. 4) having the equivalent properties of the floor slabs. The computer time will depend on the number of stories in the building and the number of bays in both directions. For a 9 storey building with 3 and 4 bays in x and y directions, it will be about 1½ hour on Ferranti Pegasus II computer.

Secondary effects like the bending stiffness of roof slabs and cladding should also be considered in the final analysis. This is necessary for accurate prediction of displacements and stresses.

Elastic Properties of Connecting Links

If we consider a symmetrical shear-wall building having similar shear-wall in every storey and bay [3,8] where the overall stiffness of the frames if proportional to the wind load or seismic actions borne by them, it is clear that the individual deflection of each frame will be same and the connecting links shown in figure 4 will remain unstressed. Horizontal shear panels will be under stress only when there is some transfer to load due to unequal deflection of adjacent frames, and the net deflection of a shear panel will be equal to the extension

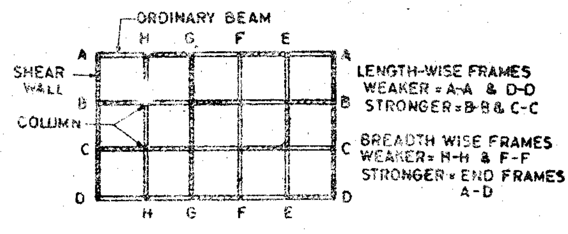

Fig. 2. A Typical Floor Plan Showing Weaker & Stronger Frames in Both Directions.

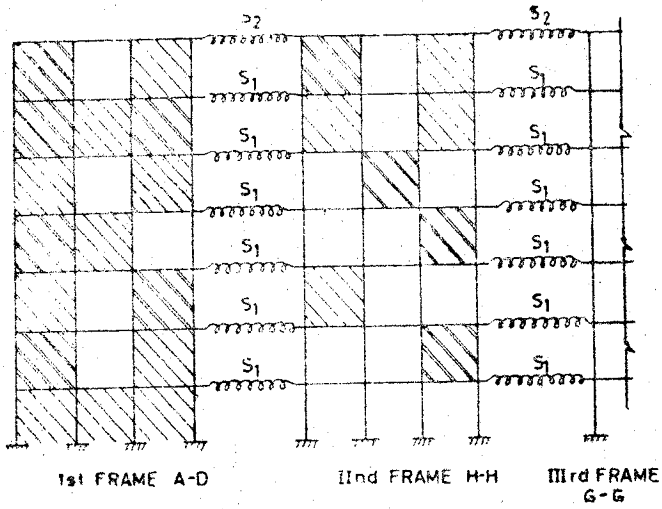

Fig. 3 Connection of Frames by Elastic Links.

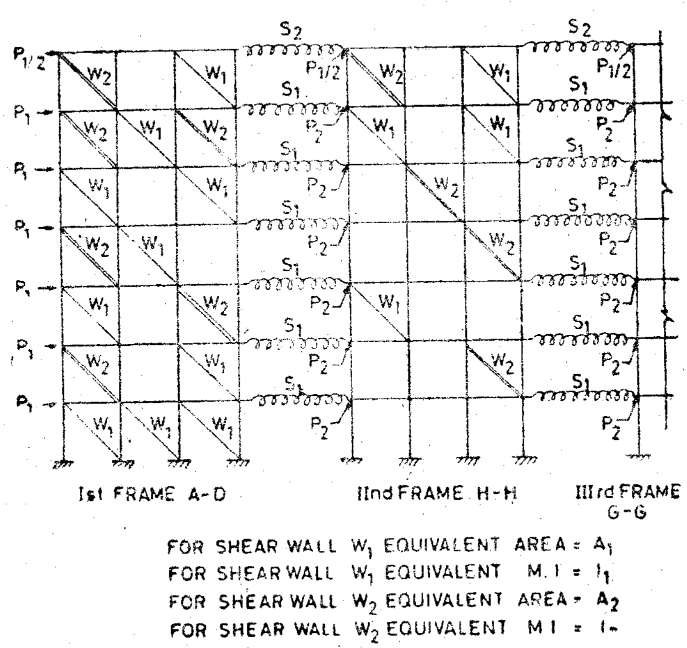

Fig. 4 Reduced Frames with Loading

of the equivalent connecting link. The equivalent area of these links can beound out from this consideration provided the deflection characteristics of the shear panels in question are known.

The moment of inertia of the elastic link could be assumed as zero or it will be hinged at both the ends. This is necessary as horizontal shear panels can not increase the overall stiffness of the building. Their job is only to produce an equitable distribution of horizontal forces.

Experimental work and Results

Experimental investigation for the analysis of single storey shear wall mentioned earlier was done by using 2 dimensional photo-elasticity. Araldite B was used for the models. To facilitate the experimental works quare shear-walls with or without centrally located square holes were used. The agreement between theory (grid analogy) and experiments was very good. As an example, the curves of shear stress for lines "N" and "P" are presented in Fig. 5 and 6. The case is that of a shear-wall with an opening resting on an elastic simply supported beam. These clearly show that the grid analogy technique is quite reliable for complex cases.

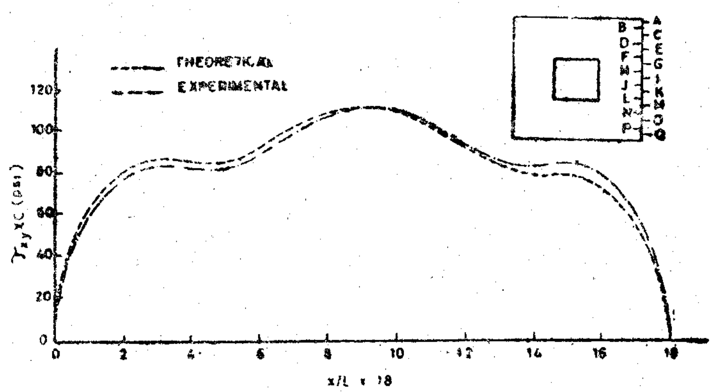

Fig. 5 Shearwall on Elastic Base, Shear Stresses At 'N'

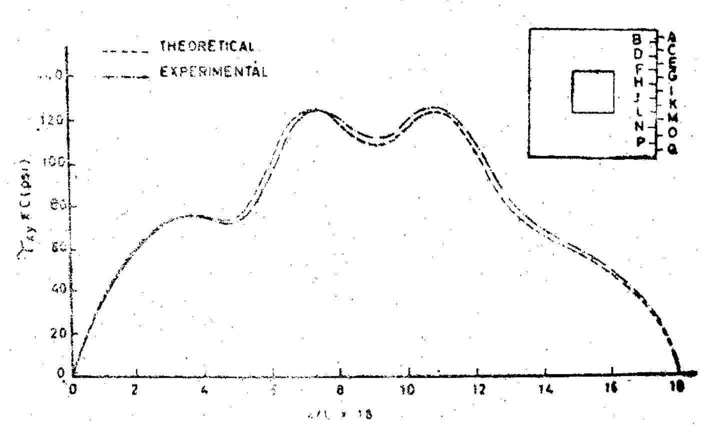

Fig. 6 Sheerwall on Elastic Base, Sheer Stresses At 'P'

Conclusion

The theory discussed in this paper has tremendous possibilities and extensive application in practical problems may be expected when the design curves and tables are made available. Preparation of the design curves is a time consuming process but once they are available, the actual analysis should not take much time on a fast computer. The grid analysis technique is quite suitable and its accuracy is demonstrated by the close agreement between experimental and theoretical results.

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