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## Performance of Framed-Tube Structures under Vertical Forces

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### Summary

This paper reports the summary of a simplified analysis of framed-tube structures subjected to vertical forces.

### 1. Introduction

The framed-tube structure consists of a closely spaced exterior columns tied at each floor level by spandrel beams to produce a system of four orthogonal rigidly jointed frame panels forming a rectangular tube system (see fig 1(a)). The most significant framed-tube structure are the 110-storey twin towers for the World Trade Centre in New York, USA. The analysis of framed-tube structures supported on rigid and elastic bases and subjected to lateral wind load were considered in two papers<sup>1,2</sup>. By replacing the discrete structure by an equivalent orthotropic tube (see fig 1(b)), and making simplifying assumptions regarding the stress distribution in the substitute structure simple closed solutions were obtained. In addition to the lateral load, the framed-tube structure is subjected to vertical forces due to the dead load of the structure and the imposed load acting on the floor areas.

### 2. Method of analysis

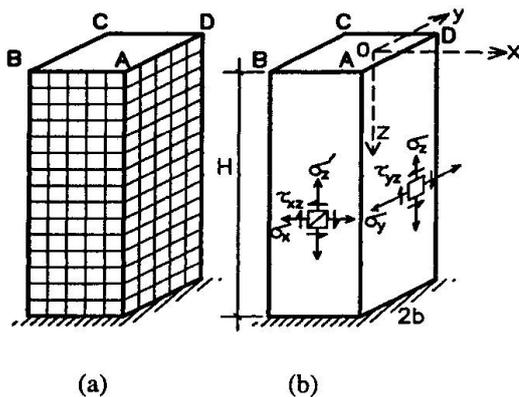
Detailed analysis of a framed-tube structure of rectangular cross-section, subjected to vertical forces, is given in Reference 3. In this paper a framed-tube of square section, of side  $2b$ , is considered (see fig 2). The vertical force caused due to the weight of the structure itself may be considered as a uniform force  $\rho_s$  per unit volume of the equivalent tube structure. The weight of the floor system and the imposed load acting on the floor areas are transferred equally to the four panels at every floor level, which for the panel AD may be expressed as

$$\rho = \rho_f \left[ 1 - \left( \frac{y}{b} \right)^2 \right] \quad (1)$$

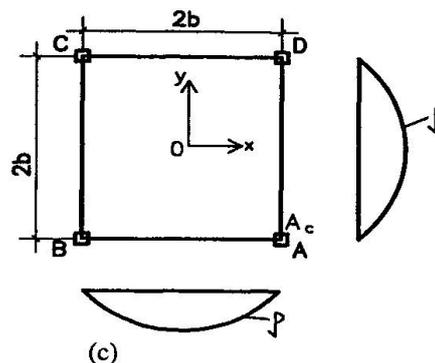
where  $\rho_f$  is a constant term independent of the height coordinate  $z$ .

The simplest approximation which may be made for the symmetrical distribution of vertical stress  $\sigma_z$  in the panel AD may be expressed as

$$\sigma_z = f_1 + \left( \frac{y}{b} \right)^2 f_2 \quad (2)$$



(a) (b)  
Fig 1 Framed tube (a) real and  
(b) substitute structure



(c)  
Fig 2 Vertical forces  
due to floor load

in which  $f_1$  and  $f_2$  are functions of the height coordinate  $z$  only.

By considering the condition of vertical force equilibrium at any level  $z$  the function  $f_1$  is given as

$$f_1 = -\frac{W}{A} - \frac{3n+2}{3(n+2)} f_2 \quad (3)$$

in which  $W$  is the total vertical force at that level, given by

$$W = 4tz \left[ \frac{4}{3} b \rho_f + \left( 2b + \frac{A_c}{t} \right) \rho_s \right] \quad (4)$$

$n = A_c/bt$ ,  $A$  is the area of the equivalent tube section, given by  $A = 8bt + 4A_c$ ,  $t$  is the thickness of the equivalent tube and  $A_c$  is the area of the corner column.

By applying the laws of equilibrium and the principle of least work the function  $f_2$  is determined as

$$f_2 = \frac{\rho_f \sinh m_2 H \xi}{m_2 \cosh m_2 H} \quad (5)$$

in which  $m_2$  is constant and  $\xi = z/H$ .

The distribution of vertical stress in each panel may be expressed as

$$\sigma_z = -\frac{W}{A} - \left[ \frac{3n+2}{3(n+2)} - \left( \frac{y}{b} \right)^2 \right] f_2 \quad (6)$$

The normal stress  $\sigma_y (= \sigma_x)$  and shear stress  $\tau_{yz} (= \tau_{xz})$  may also be found. The results from the substitute continuum system must then be transferred into the real discrete structure to give shears, and thus moments, and axial forces in beams and columns.

## References

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