STRESS STATE ANALYSIS OF FRAMED-WALL-BEAM IN COMPOSITE-MASONRY BUILDING SUPPORTED ON FRAME AT FIRST STORY

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1. ABSTRACT

Based upon the experiments of model walls and analyses by FEM the transmitting process of internal forces in the composite walls supported on frame was studied. The effects of various numbers of RC confined columns in the composite wall to sustain and transmit vertical forces to the supporting beam were discussed. The inner arch action of wall and the stress state of supporting beam were analyzed. The important factors influencing on the internal force distribution in the wall had been studied and on this basis, a simplified formula for calculating the vertical force on the top face of the supporting beam was proposed.

2. INTRODUCTION

Owing to the complication in stress state of supporting beam and the beam itself is the principal bearing element of the building structure the method of calculation of the wall beam had been studied by many workers. In the early of 1952 Wood proposed "A tentative design method for the composite action of heavily loaded brick panel walls supported on reinforced concrete beams"(1-3). Prof. Gemoquking of former soviet Union treated the wall beam as a beam on elastic foundation(4). All these works demonstrated that there exists arch action in the wall beam and by which the internal forces are to be

Keywords: Composite masonry wall; Wall beam; Confined Column.

* Supported by CNNSF and Doctoral Program Fund for Special Discipline.
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transferred to concentrate near the supports, resulting a decrease of the vertical force on
the supporting beam. In China a large number of simple supported wall beams had been
tested and theoretically analyzed by many institute workers since 1970s and published in
«Design Code for Masonry Structures (GBJ 3-88)», it is however helpful only in the
case for simple supported wall beams.

The investigations for composite masonry wall building supported on frame-shear struc­
ture at the first storey began by the end of 1980s. The so-called composite masonry
wall is made of RC beam and columns arounding the perimeters and in the middle of
brick/block masonry, they are so tightly combined to each other and would hardly
break till collapse. The RC beam and column are called confined beam and confined col­
umn, which as a part or member of the single wall structural element, is used not only
to restrain the brick/block masonry, but also act as a part of wall element to resist the
vertical and horizontal loading actions. Due to actions of the confined columns and con­
fined beams, the stress state of the wall would be changed. Especially, a part of verti­
cal load will be directly transmitted through the confined columns to the frame columns
at the supprots. In addition to inner arch action of the wall the confined columns would
likely decrease the sustained load of the supporting beam. The beam with masonry and
light frame being constructed by confined columns and confined beams is called frame
wall beam. The stress state of this framed wall beam is studied.

3 STUDY ON THE BEARING STATE OF SUPPORTING BEAM

3.1 Analysis for Transmission of Bearing Load in Frame Supported Composite Wall of
8 Storeys

A 8-storey frame supported composite weightless wall under uniformly distributed ver­
tical load on the roof the wall was analyszed by FEM in order to understand the force
transmission of the wall (Fig. 1). The percentage of distribution of vertical force sus­
tained by confined columns and masonry at the site of each floor was calculated and the

result was listed in Tab. 1. The percentage of stiffness of columns and masonry was al­
so tabulated. It is obviously shown that at the site of ceiling on the 8the floor, the ver­
tical load distribution could roughly be estimated according to their area occupied and re-
distribution was made through the one storey height, the vertical load sustained by two
side and one central confined columns was then increased and by the masonry (includ-
ing two middle-side confined columns) decreased. After transmission of 8th to 5th floor
the percentage of distribution of vertical load between confined columns and the mason-
ry tends to be stabilized and would be basically distributed according to their stiffness.
At the site of the second floor a sudden change of distribution occurred by the arch ac-
tion of the masonry wall which plays a sole role for showing the effective height of the
wall beam at one storey above the beam.

Tab. 1 The bearing state of a 8-storey frame supported composite wall

<table>
<thead>
<tr>
<th>Location of Sections</th>
<th>Side and Central Confined Col.</th>
<th>middle side col. and masonry</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>stiffness/%</td>
<td>vertical force/%</td>
</tr>
<tr>
<td>at ceiling of 8th floor</td>
<td>54.6</td>
<td>11.9</td>
</tr>
<tr>
<td>at 8th floor</td>
<td>54.6</td>
<td>38.9</td>
</tr>
<tr>
<td>at 6th floor</td>
<td>54.6</td>
<td>47.3</td>
</tr>
<tr>
<td>at 5th floor</td>
<td>54.6</td>
<td>51.6</td>
</tr>
<tr>
<td>at 4th floor</td>
<td>54.6</td>
<td>45.4</td>
</tr>
<tr>
<td>at 3rd floor</td>
<td>47.9</td>
<td>53.4</td>
</tr>
<tr>
<td>at 2nd floor</td>
<td>47.9</td>
<td>65.5</td>
</tr>
</tbody>
</table>

3.2 The Action of The Confined Columns in Bearing of Vertical Load

All of 4 storeys frame supported composite walls without confined column, with two
side columns, two side and one central columns and five confined columns were respec-
tively calculated by FEM to understand the actions of confined column in sustaining
vertical force. The results are summarized in Tab. 2.

Tab. 2 Distribution of vertical load between confined
columns and masonry (%)

<table>
<thead>
<tr>
<th>Number of Conf. Col. at 2nd and 3rd floor</th>
<th>Number of Conf. Col. at 4th floor</th>
<th>Location of Section</th>
<th>Distribution rate %</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>No</td>
<td>at 4th floor</td>
<td>12</td>
</tr>
<tr>
<td>No</td>
<td>No</td>
<td>at 3rd floor</td>
<td>14</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>at 4th floor</td>
<td>34</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>at 3rd floor</td>
<td>46</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>at 2nd floor</td>
<td>64</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>at 4th floor</td>
<td>48</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>at 3rd floor</td>
<td>60</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>at 2nd floor</td>
<td>78</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>at 4th floor</td>
<td>44</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>at 3rd floor</td>
<td>56</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>at 2nd floor</td>
<td>76</td>
</tr>
</tbody>
</table>

From Tab. 2 it is shown that in the case of wall with two side confined columns 33% of
the vertical load would by directly transmitted to the supporting columns; if the central
confined column was set, then 47% of vertical load would be sustained by confined columns. If there are five confined columns in the wall, it would increase the load on beam, due to the sustained load of the two middle-side columns is transmitted to the beam. The fact is: the more confined columns, the more confined action to the masonry and the more shear resistance and ductility of the wall should therefore be produced, it is rather important for masonry building in the seismic zone.

3.3 The Effect of Horizontal Load on Distribution Rate Between Confined Columns and Masonry

If the stress state of the wall is within or a litter over of the elastic stage, the horizontal load would produce only a little change on the distribution rate between confined columns and masonry. But the bearing percentage of masonry would be increased if the wall was seriously cracked. From Tab. 3 it is shown that the distribution rate between confined columns and masonry have been changed to 1–3% when the horizontal load is 100kN (corresponded to an earthquake intensity of 8), but the percentage of masonry would be increase to 5–15% when the horizontal load is 200kN (corresponded to an earthquake intensity of 9) and the wall had been in a serious cracked state.

<table>
<thead>
<tr>
<th>Number of confined columns in 2 and 3 storey</th>
<th>Number of confined columns in 4th storey</th>
<th>Location of Sections</th>
<th>Hori. Loading kN</th>
<th>Distribution Rate %</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>No</td>
<td>at 4th floor</td>
<td>100kN corresponding to intensity of 8</td>
<td>Confined Coln.</td>
</tr>
<tr>
<td>No</td>
<td>No</td>
<td>at 3rd floor</td>
<td></td>
<td>12.44</td>
</tr>
<tr>
<td>No</td>
<td>No</td>
<td>at 2nd floor</td>
<td></td>
<td>15.89</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>at 4th floor</td>
<td></td>
<td>35.13</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>at 3rd floor</td>
<td></td>
<td>34.43</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>at 2nd floor</td>
<td></td>
<td>48.34</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>at 4th floor</td>
<td></td>
<td>65.0</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>at 3rd floor</td>
<td></td>
<td>47.77</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>at 3rd floor</td>
<td></td>
<td>63.1</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>at 3rd floor</td>
<td>200kN corresponding to intensity of 9</td>
<td>74.95</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>at 4th floor</td>
<td></td>
<td>27.38</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>at 3rd floor</td>
<td></td>
<td>35.17</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>at 2nd floor</td>
<td></td>
<td>50.91</td>
</tr>
</tbody>
</table>

The experiment of the 1/2 scale 4-storey composite masonry wall supported on frame at first floor had also shown that the distribution rate between columns and masonry was not changed or only a little change when the wall was cracked (7). The comparison of FEM with test results had been made in (8), it was shown that the maximum and average discrepancies of lateral bearing capacity and of distribution rate of vertical load are 13% and 7% and 13.4% and 11.1% respectively.

3.4 The Bearing State of Framed Wall Beam

The FEM showed that there are non-uniformly distributed vertical and horizontal forces acted on the top face of the framed wall beam (supporting beam), and showed the result of composite actions between framed wall and supporting beam. The horizontal forces are in the state of self-equilibrium, if only vertical load is acted. Due to these horizontal forces the axial tension or compression force would be produced in the beam
and it would make the beam to be in the state of eccentric tension or compression (Fig. 2 and Fig. 3). This supporting beam is a part of wall beam, so it is differed from the bent beam. The calculated results by FEM showed that the chief portion of the normal stresses in the beam sections are produced by the bending moment, and only a small portion of normal stress by axial force (not more than 20\% in the general case).

![Graphs showing shear stresses distribution at top face of the supporting beam](image)

(a) under vertical loading only (b) under combined horizontal and vertical loadings

**Fig. 2** Shear stresses distribution at top face of the supporting beam

![Graphs showing normal strain distributions on cross sections of the supporting beam](image)

(a) Normal Strain Distributions on the cross sections of the supporting beam under vertical load (Locations of section were shown in Fig. 1)
4. THE SIMPLIFIED FORMULA FOR CALCULATING THE PERCENTAGE OF VERTICAL LOAD SUSTAINED BY SUPPORTING BEAM

4.1 Some Main Factors to Effect the Bearing State of Supporting Beam

From paragraph 2 and 3, it is seen that the confined columns to take a part of the bearing load basically distributed according to their stiffness.

The arch action in the wall beam is due to the flexibility of the supporting beam. If the stiffness of the beam approaches to infinitive, then the arch action would be approaching to zero, in another words, the arch action of the wall beam is inversely proportion to the stiffness of the beam. The rate of vertical load sustained by supporting beam would be increased from 24.8% to 28.6% if the cross section of beam was changed from 550 X 300 to 700 X 350. Of course, the increasing of the span length of the beam would lead to decrease the load of the beam.
The effect of opening to the distribution rate of vertical load between confined columns and masonry is small, but the opening will effect the shear force of the beam at the nearer side of the opening.

The effect of the frame columns to the loading state of the beam is rather insignificant, as the cross section of frame column is changed from $400 \times 400$ to $600 \times 600$, the percentage of vertical load sustained by the supporting beam is increased from 22% to 22.8%.

4.2 The Simplified Formula
Based on a large number of numerical calculation for various frame supporting composite walls, an empirical formula for distribution rate of vertical load is proposed as follows:

$$Q_{beam} = 1 - Q_{columns}$$

$$Q_{columns} = 0.52 + 0.5 \frac{E_i A_i}{\Sigma E_i A_i} - 0.21 \times 10^{-3} E_i I_c$$

Where $E_i A_i$ —— axial stiffness of confined column, located on the site of frame column ($E_i$ in MPa, $A_i$ in $m^2$);

$\Sigma E_i A_i$ —— total axial stiffness of the composite wall, including all the confined columns and masonry;

$E_i I_c$ —— Bending stiffness of the reinforced concrete supporting beam ($E_i$ in MPa, $I_c$ in $m^4$).

A comparison of the results by above formula with FEM and wall test was made (8), the maximum and average discrepancies are 9.3% and 1.94% respectively.

In the case of composite masonry wall supported on first two storeys the above proposed formula may also be applied.

5. Conclusion
a. In the composite wall the confined columns and beams would act as a part of the wall element to resist both the vertical and horizontal loading actions, by which a part of vertical forces would be directly transmitted through confined columns to the corresponding supporting frame columns.

b. Taking account of the arch action of the wall and the confined columns on the supporting frame columns only about 1/3 of the total vertical load actually exists on the beam.

c. An empirical formula for calculating the vertical load existed on supporting beam in percentage of total vertical load is proposed.

REFERENCES


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