Analysis of Brick Masonry Wall using Applied Element Method

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Abstract. The Applied Element Method (AEM) is a versatile tool for structural analysis. Analysis is done by discretising the structure as in the case of Finite Element Method (FEM). In AEM, elements are connected by a set of normal and shear springs instead of nodes. AEM is extensively used for the analysis of brittle materials. Brick masonry wall can be effectively analyzed in the frame of AEM. The composite nature of masonry wall can be easily modelled using springs. The brick springs and mortar springs are assumed to be connected in series. The brick masonry wall is analyzed and failure load is determined for different loading cases. The results were used to find the best aspect ratio of brick to strengthen brick masonry wall.

1. Introduction

Brick masonry walls are commonly used in most of the buildings in India. Bricks of various materials and aspect ratio are available in the market. It will be of immense use if the best aspect ratio which provides maximum strength to the structure is known. Applied Element Method enables the analysis of brick masonry wall by appropriately considering its composite nature. The background to AEM is discussed by Kimiro Meguro in [1] and [2].

2. Methodology. The brick masonry wall is discretized along both length and height direction as shown in Fig. 1. In this paper a half brick is taken as an element. Springs are provided at every 5 mm distance. Springs those accommodate mortar joints are treated as ‘joint springs’. Stiffness of joint spring depends upon the properties of mortar and brick. Hence, the simple stiffness formula has to be modified. For the joint springs, equivalent normal and shear stiffness is calculated by assuming that these springs are arranged in series [3] as shown in Fig. 2.
The equivalent stiffness of normal and shear springs, $K_{neq}$ and $K_{seq}$, are defined as follows:-

\[
\frac{1}{K_{neq}} = \frac{1}{K_{nb}} + \frac{1}{K_{nm}} + \frac{1}{K_{nb}} \quad \text{and} \quad \frac{1}{K_{seq}} = \frac{1}{K_{sb}} + \frac{1}{K_{sm}} + \frac{1}{K_{sb}}
\]

where,

$K_{neq}$ is the equivalent stiffness of normal spring, $K_{seq}$ is the equivalent stiffness of shear spring, $K_{nb}$ is the stiffness of normal spring (brick), $K_{sm}$ is the stiffness of shear spring (brick), $K_{nm}$ is the stiffness of normal spring (mortar), $K_{sm}$ is the stiffness of shear spring (mortar).

Since a half brick is treated as an element, two types of element connection occur in the length direction and three types of element connection occur in the height direction. These connections are indicated in Fig. 1.

2.1 Element connections along length. Two types of element connection occur along length. One is brick-to-brick connection and the other is brick-mortar-brick connection. They are shown in Fig. 3.
In element connection 1, top and bottom springs represent mortar and all the intermediate springs represent brick. Stiffness of brick springs and mortar springs are given by Eq. 2 and 3.

Stiffness of brick springs:
$$K_n = \frac{E_b \times 5 \times T}{L/2}$$

Stiffness of mortar springs:
$$K_n = \frac{E_m \times 5 \times T}{L/2}$$

Stiffness of mortar springs:
$$K_s = \frac{G_m \times 5 \times T}{L/2}$$

In element connection 2, top and bottom springs represent mortar whereas intermediate springs represent brick-mortar-brick joint. The stiffness of mortar springs and brick-mortar-brick springs are given by Eq. 4 and Eq. 5.

Stiffness of mortar springs:
$$K_n = \frac{E_m \times 5 \times T}{(L/2)+10}$$

Stiffness of brick-mortar-brick springs:
$$K_s = \frac{10E_mE_bT}{LE_m + 20E_b}$$

2.2 **Element connections along height.** Three types of element connections that occur in height direction are shown in Fig. 4.
For the left end element, leftmost spring has the property of mortar whereas the rightmost spring has the property of mortar in the case of right end element. The leftmost and rightmost springs are treated as brick-mortar joint in the case of middle element. All the interior springs are brick-mortar-brick joint for all the connections. The stiffness of mortar springs, brick-mortar springs and brick-mortar-brick springs are given by Eq. 6, Eq. 7 and Eq. 8.

Stiffness of mortar springs

\[ K_n = \frac{5E_m T}{D+10} \]

Stiffness of brick-mortar springs:

\[ K_n = \frac{5E_m E_b T}{(E_b(D/2+10)+(E_mD/2)} \]

Stiffness of brick-mortar-brick springs:

\[ K_n = \frac{5E_m E_b T}{10E_b+DE_m} \]

Since five types of element connections occur, five different types of local stiffness matrices will be obtained. The global stiffness matrix can be determined by appropriately assembling these five local stiffness matrices.

3. Validation. Brick Masonry wall with opening [4] is considered for validation. The wall is made of 12 bricks along length direction and 17 bricks along depth direction as shown in Fig. 5. The opening has a size of 0.75 m × 1.69 m. The size of the brick is 240 × 120 × 60 mm and thickness of mortar is 10 mm. The bottom layer of brick masonry is fixed. Uniform load of 0.3 MPa is applied on the top layer of brick.
The parameters used are:-

| Parameter                             | Value                |
|---------------------------------------|----------------------|
| Modulus of elasticity of brick        | 16700 N/mm²           | [4]                  |
| Modulus of rigidity of brick          | 7261 N/mm²            | [4]                  |
| Permissible compressive stress of brick | 15 N/mm²             | [5]                  |
| Permissible tensile stress of brick   | 2 N/mm²              | [4]                  |
| Permissible shear stress of brick     | 2 N/mm²              |                      |
| Modulus of elasticity of mortar       | 7900 N/mm²            | [4]                  |
| Modulus of rigidity of mortar         | 3292 N/mm²            |                      |
| Permissible compressive stress of mortar | 5 N/mm²              | [6]                  |
| Permissible tensile stress of mortar  | 0.116 N/mm²           | [7]                  |
| Permissible shear stress of mortar    | 0.116 N/mm²           |                      |

The load-displacement curve obtained using Applied Element Method and by Bishnu Hari Pandey [17] are shown in Fig. 6. Displacement at the top left corner is considered.
Fig. 6 shows that the analysis by AEM can give the load-displacement curve with a maximum error of 20%.

3.1 **Determination of best Aspect Ratio.** To find the best aspect ratio which gives maximum strength to masonry, two cases of support condition and loading were considered for analysis. Aspect ratio represents the length to depth ratio of brick. 10 number of bricks were adopted along length and depth directions. Size of the brick used is 190 × 90 × 90 mm.

**Case 1.** In case 1, the lower part of the brick masonry is regarded to be fixed. Therefore, all the elements in the lower row are constrained in translation and rotation. Lateral load is applied at the top left end which is uniformly distributed along the top layer. The support conditions and loading of this case is shown in Fig 7.

![Fig. 7 Case 1: Support condition and loading](image)

The graph showing the relation between aspect ratio of brick and first cracking load of case 1 is shown in Fig. 8.

![Cracking Load vs Aspect Ratio](image)

Fig. 8 shows that the strength of brick masonry wall increases with increase in aspect ratio and thickness of brick.

**Case 2.** In case 2, the lower part of the brick masonry is regarded to be simply supported. Therefore, all the elements in the lower row are constrained in translation. Moreover, all the
elements at the left end are given horizontal support. Uniform lateral load was given at the right end. The support conditions and loading of this case are shown in Fig. 9.

![Fig. 9 Case 2: Support condition and loading](image)

The graph showing the relation between aspect ratio of brick and first cracking load of case 2 is shown in Fig. 10.

![Cracking Load vs Aspect ratio](image)

Fig. 10 shows that the strength of brick masonry wall will be a minimum for the aspect ratio 1.9 for this case of support and loading conditions. The strength increases as the aspect ratio increases or decreases from this value. The aspect ratio corresponding to the minimum strength of brick masonry varies with the number of bricks arranged in horizontal as well as vertical directions.

### 4. Conclusions

In this paper Applied Element Method was used for the analysis of Brick Masonry wall. From the study the following conclusions were arrived:-

- AEM could predict the load-deflection curve with less than 20% error.
- For the support and loading conditions shown in Fig. 7, the brick masonry wall can be strengthened by increasing the aspect ratio and thickness of brick.
If the brick masonry wall is supported and loaded as shown in Fig. 9, the wall will give minimum strength at an aspect ratio of 1.9.

References
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