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Study on Flexural Behaviour of Reinforced Stone Masonry Beam with Openings

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Abstract

The rejuvenation of historical buildings has gradually become the focus of attention and research. Transverse openings are provided in stone masonry beam to accommodate utility ducts and pipes such as air conditioning, electricity, telephone, and computer network. This paper presents a study aimed at investigating the flexural behaviour of different shape and size openings in reinforced stone masonry beam.

Keywords: *Reinforced Stone Masonry Beam, Openings, Flexural Behaviour.*

1. Introduction

The transverse openings in the masonry beams in buildings are necessary for the passage of service ducts and piping in order to minimize the story height and to attain economic requirements. Usually these utility pipes and ducts are placed at the soffit of the beam and covered by suspended ceiling for aesthetical purpose. It creating a dead space. providing service ducts at the bottom of the beam, the floor to floor height increases and also the overall height of the building increases.

Beam depth is one of the factors to decide the overall height and floor to floor height of the building. For small buildings, the savings thus achieved may not be significant compared to the overall cost. But for high-rise buildings, any saving in storey height multiplied by the number of storey can represent a substantial saving in total height and hence a reduction in the cost also.

2. Classification of Openings

Openings in a beam may be of different shapes and sizes. Although numerous types are possible, circular and rectangular types are most common shapes. Circular opening accommodate services pipes like plumbing and electrical supply. While rectangular openings in beam accommodate air conditioning pipes. In order to reduce the stress concentration around rectangular openings the corners are rounded off thereby improving the cracking behaviour of beam in service.

With regard to the size of openings they may be classified as small or large openings without any definition. Circular opening considered as large when its diameter exceeds 0.25 times the depth of the beam. Some authors considered as classifying the small or larger openings lying in the structural response of the beam. While other criterion says that classification of small or larger opening depends on the loading on the beam.

3. Reinforced Stone Masonry Beam

The reinforcement of masonry structures is one of the most frequently used practices in restoration of historical buildings in the purpose to enhance the resistance. It can be performed using steel bars, rings and/or composite materials in the beginning. FRP were used for the reinforcement of structures. FRP consist of high strength fibers embedded in a resin matrix. The fibers are usually Carbon (CFRP), Glass (GFRP) or Aramid (AFRP). They are available in sheets, strips, tendons, reinforcing bars. They are used either as an internal reinforcement method or as an external strengthening method for reinforced stone beam members.

4. Finite Element Program

The numerical analysis herein is a three dimensional-nonlinear finite element analysis of the experimental set-up by the means of the commercial FE program ANSYS 16.2.

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4.1 Details of the Model

The geometric models shown in Fig. 1. The objective of this section is to develop a finite element (FE) model in order to predict the structural behaviour of stone masonry structure reinforced with GFRP. The material properties used for the analysis shown previously in Table 1.

Table.1 Material properties

Material	f_c (MPa)	f_t (MPa)	E (GPa)	μ
Lime stone	8.1 ± 0.4	4.1 ± 0.1	17 ± 0.5	0.2
Mortar	6.2 ± 0.3	1.8 ± 0.2	1.2 ± 0.1	0.3
GFRP	-	97.2	6 ± 0.2	0.3

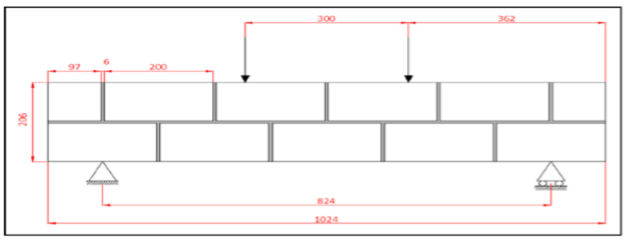

Fig.2 Masonry beam geometry. (Dimensions are in mm) (fayala, 2016).

4.2 Boundary Conditions

The numerical analysis herein is a three dimensional-nonlinear finite element analysis of the experimental set-up by the means of the commercial FE program ANSYS 16.2. Fig. 2 shows a typical three dimensional solid model containing the geometry and boundary conditions. The beam was already overturned and the deflection due to the weight wasn't recorded. During analysis, a vertical displacement is imposed at the upper side of the beam. The model is supported and restrained from out of the loading plan translation, using support (roller) lines. Full bond is assumed between GFRP and masonry.

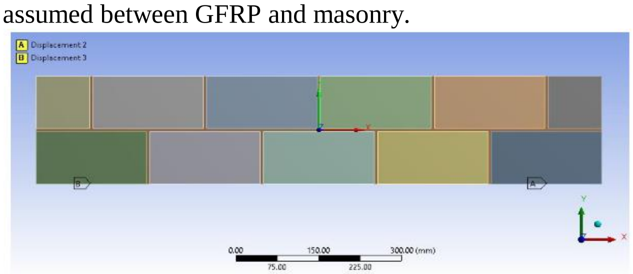

Fig 2. Geometrical conditions in reinforced stone beam

5. Flexural Behaviour of Masonry Beam with Circular Openings

Six models were used to study the structural behaviour of beams. The details of model shown in table 2. Openings are provided at the Centre of the masonry beam. Fig 3 shows the geometrical modeling of the structure.

Table 2. Details of Models

Model	Diameter(mm)	Specifications
O C M 50	50	Opening-circular-middle
O C M 70	70	Opening-circular-middle
O C M 90	90	Opening-circular-middle
O C M 110	110	Opening-circular-middle
O C M 130	130	Opening-circular-middle
O C M 150	150	Opening-circular-middle

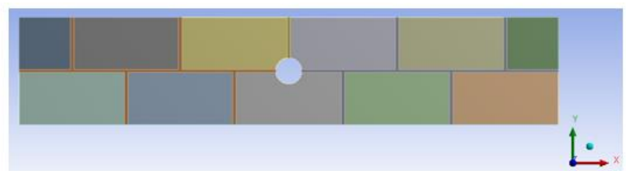

Fig. 3 Geometry of the Beam

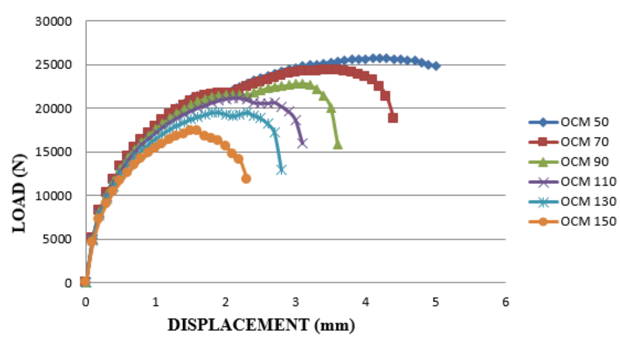

Fig 4. Load Displacement Curve for Circular Openings

In order to investigate the load carrying capacity and deflections of beams with opening, Load – deflection curves of the beams were studied. Figure 4 show the effects of changes in diameter of opening for different beams.

The peak load for OCM 50 is 25715 N, OCM 70 is 24333 N, OCM 90 is 22842 N, OCM 110 is 20671 N, OCM 130 is 19552 N, OCM 150 is 17344 N. The increase of the diameter of opening in beams with opening causes the decrease in the load capacity.

6. Flexural Behaviour of Masonry Beam with Square Openings

6.1 Geometric Modelling

Six models were used to study the flexural behaviour of beams. The details of model shown in table 3. Openings are provided at the centre of the masonry beam. Fig 5 shows the geometrical modeling of the structure.

Table 3. Details of Models

Model	Dimensions (mm)	Specifications
O S M 50	50	Opening –square -middle
O S M 70	70	Opening –square -middle
O S M 90	90	Opening –square -middle
O S M 110	110	Opening –square -middle
O S M 130	130	Opening –square -middle
O S M 150	150	Opening –square -middle

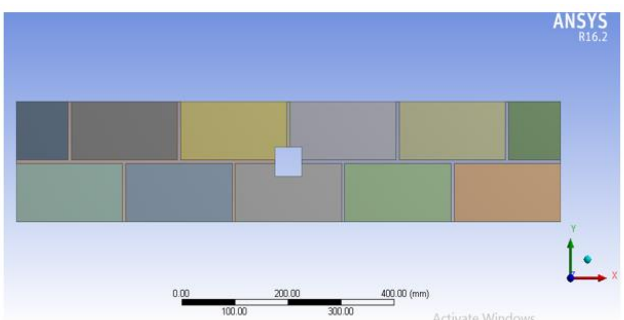

Fig. 5 Geometry of the Beam

A 3D nonlinear numerical model using the finite element commercial package, ANSYS, has been developed to predict the flexural load capacity of stone masonry beams. The effect of square opening sizes of 50, 70, 90,110, 130, 150 mm was studied. The load displacement curves for different square openings are shown in fig. 6.

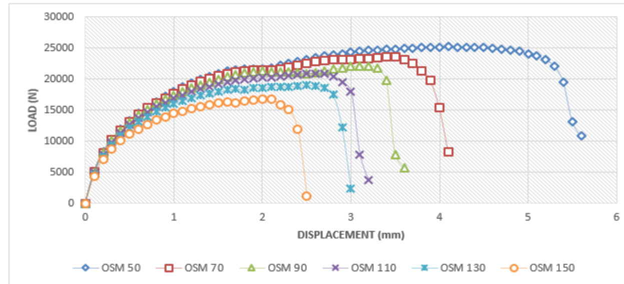

Fig 6. Load Displacement Curve for Square Openings

The increase in the size of opening in beams causes the decrease in the load capacity. The peak load for OSM 50 is 25189 N, OSM 70 is 23564 N, OSM 90 is 22071 N, OSM 110 is 20892 N, OSM 130 is 18951 N, OSM 150 is 16589 N. The increase of the diameter of opening in beams with opening causes the decrease in the load capacity

7. Flexural Behaviour of Masonry Beam with Rectangular Openings

The details of models were used to study the flexural behaviour of beams are shown in table 4. Openings are provided at the Centre of the masonry beam. Fig 7. shows the geometrical modeling of the structure.

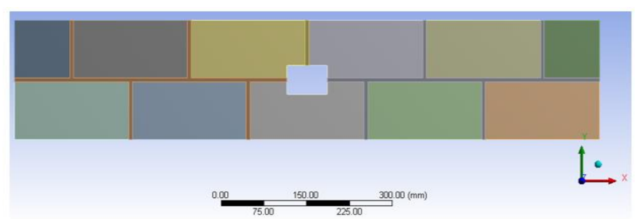

Fig.7 Geometry of the Beam

Table 4. Details of Models

Model	Aspect Ratio	Specifications
ORM 50:70	.71	opening –rectangular- middle
ORM 50:90	.55	opening –rectangular- middle
ORM 50:110	.45	opening –rectangular- middle
ORM 50:130	.38	opening –rectangular- middle
ORM 50:150	.33	opening –rectangular- middle
ORM 150:50	3	opening –rectangular- middle

ANSYS, has been developed to predict the flexural load capacity of stone masonry beams. The effect of rectangular opening with different aspect ratio was studied. The load displacement curves for different rectangular openings are shown in fig. 8.

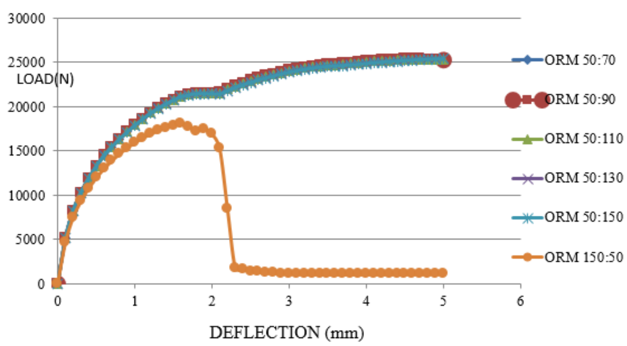

Fig 8. Load Displacement Curve for Rectangular Openings

The effects of different sizes rectangular opening on deflection can be illustrated by the load vs. deflection curve. The aspect ratio of openings plays an important role in the choosing the openings. The peak load for ORM 50:70 is 25462 N, ORM 50:90 is 25390 N, ORM 50:110 is 25325 N, ORM 50:130 is 25318 N, ORM 50:150 is 25266 N, ORM 150:50 is 18064 N. The increase of the aspect ratio of opening in beams causes the decrease in the load capacity.

8. Conclusions

A 3D nonlinear numerical model using the finite element commercial package, ANSYS, has been developed to predict the flexural load capacity of the stone masonry beam. Openings in a beam reduces the ultimate load capacity of the beam. Generally, the shape of large square openings gives a higher reduction in structural capacity compared to large circular openings as the sharp corners are subjected to large stress concentration.

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