Variability of Strength Properties of Lightweight Block Masonry and its Effect on Seismic Safety

Nikhil P. Zade[1], Pradip Sarkar[1*] and Robin Davis[2]

[1]Department of Civil Engineering, National Institute of Technology Rourkela, Odisha, India.

[2]Department of Civil Engineering, National Institute of Technology Calicut, Kerala, India.

nikhilzade648@gmail.com; sarkarp@nitrkl.ac.in; robin@nitc.ac.in

*Corresponding author, Email: sarkarp@nitrkl.ac.in

Abstract

Lightweight concrete block masonry such as Autoclave Aerated Concrete (AAC) and Cellular Lightweight Concrete (CLC) is becoming more popular in earthquake-resistant infilled reinforced concrete (RC) frame buildings due to its several advantages. As a result, a proper understanding of the strength properties of AAC and CLC block masonry is required for a probabilistic seismic assessment of such structures. The best-fitted probability density functions are proposed after laboratory tests are conducted to analyze the uncertainties associated with the two most important parameters that affect the resistance capacity of infilled brickwork. Furthermore, using the specified probability density functions, the in-plane seismic performances of typical RC frame buildings infilled with AAC and CLC block masonry are analyzed in a probabilistic framework It is observed that the assumption of the normal distribution can lead to an inaccurate assessment of the seismic risk of an RC frame building infilled with AAC and CLC block masonry in the absence of an appropriate uncertainty model. Due to their lower strength properties, lightweight block masonry was found to slightly enhance the seismic risk of the building when compared to traditional brick masonry, despite its low density.

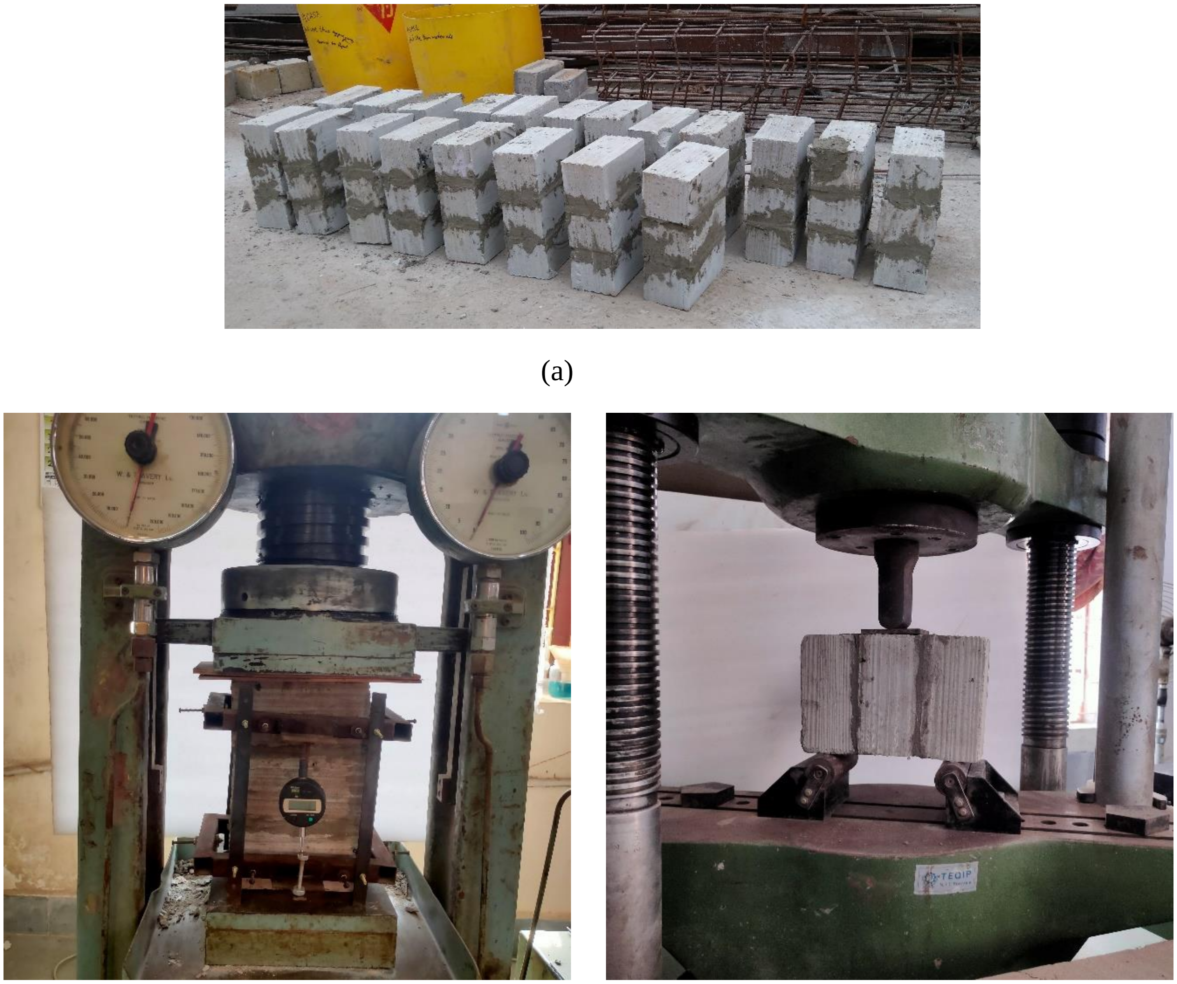
INTRODUCTION

Due to its numerous advantages over clay brick and eco-friendliness, the autoclave aerated concrete (AAC) and cellular lightweight concrete (CLC) block is growing in favor as an infill masonry material in the construction sector. The confidence of stakeholders to use more AAC and CLC blocks in the masonry building sector will rise as a result of strong research output on the performance of structures made of these blocks, which will also boost the conservation of natural resources. A thorough assessment of the literature, however, shows that there are few research on the performance of AAC and CLC block masonry infill structures.

The degree of uncertainty surrounding the material properties directly affects a structure's performance and safety. Despite the development of computer technology, structural analysis will be less accurate and satisfying if such uncertainties are ignored. These uncertainties for conventional materials have been thoroughly researched in published literature (Sahoo et al., 2020; Sahu et al., 2019; Kilinc et al., 2012). Similar studies on AAC and CLC block masonry uncertainty modelling, however, did not gain any research attention. The present study's objective is to assess the seismic performance of RC-framed buildings with AAC and CLC block infills while taking into account the inherent uncertainties in structural capacities and loading. The statistical analyses of the experimental data yield the probability distribution functions that are most appropriate for describing the uncertainties in the compressive and shear bond strengths of AAC and CLC block masonry. The strength parameters gained through experimentation and a commonly used backbone curve for masonry infill (Panagiotakos and Fardis, 1996) are used to create the nonlinear model of AAC and CLC block masonry needed for the structural analyses.

EXPERIMENTAL STUDY AND TEST OUTCOMES

For the experimental study, AAC and CLC with commercial availability are purchased. The current study takes into account the endorsement of ASTM C1314 (2018) and BS EN 1052-3 (2002) for the compressive and shear bond strength tests, respectively, of AAC and CLC block masonry. 20 stack bonded triplet specimens are prepared using commercially available ready-mixed AAC and CLC blocks for each compressive and shear strength test. Fig. 1 depicts the load-controlled testing frame used to test the triplets of AAC and CLC block masonry for compression and shear bond strength. The masonry triplet compressive strength is determined by dividing the peak load before failure by the cross-sectional area (f_m). Masonry specimens are tested for shear bond strength in accordance with BS EN 1052-3 (2002) without pre-compression. The total load before failure divided by twice the shear resistance area gives the shear bond strength (τ_{cr}) of the masonry triplets.



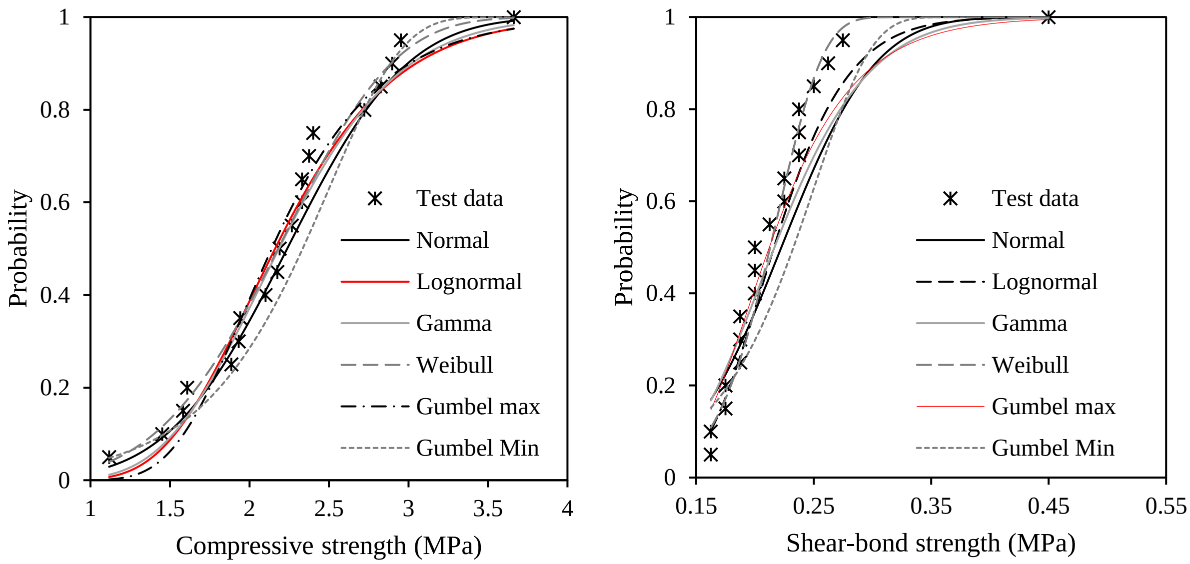
(a)

(b) (c)

Fig. 1: Experimental test setup: (a) Masonry triplets, (b) Compressive strength test and (c) Shear bond strength test

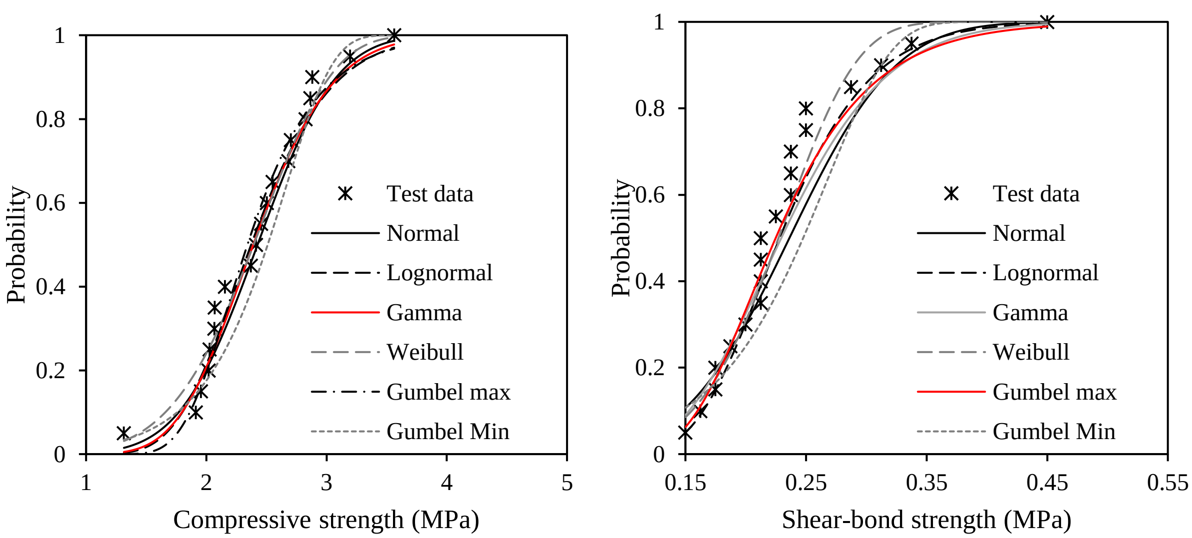
The statistical goodness-of-fit (GOF) tests are used to create probability distribution models from data on compressive and shear bond strength that were collected experimentally. The pre-determined two-point probability distribution models (normal, lognormal, gamma, weibull, gumbel max, and gumbel min) are used in this study because it has been suggested that these distributions are better at describing the strength characteristics of brittle materials (Sorrentino et al., 2016; Montazerolghaem, 2015). In the current investigation, three GOF tests—KS, AD, and CS—were utilised (Zade et al., 2022). Figs. 2-3 displays the cumulative distribution functions (CDF) for the test data for each of the chosen distribution models. Based on the minimal total statistics value, the best-fit distribution is chosen following the published literature (Zade et al., 2021). According to the outcomes of the GOF tests, the lognormal and gamma density functions, respectively, presents the variability in the compressive strength of the AAC and CLC masonry.

The Gumbel Maximum distribution, on the other hand, illustrates the variation in the shear strength of both masonry types.



(a) (b)

Fig. 2: CDF of AAC block triplet strength (a) compressive strength and (b) shear bond strength



(b) (b)

Fig. 3: CDF for CLC block triplets (a) compressive strength and (b) shear bond strength

SEISMIC PERFORMANCE EVALUATION

The seismic performance of the selected infilled RC frame is evaluated through the fragility curves, a probability-based seismic evaluation method (Vamvatsikos and Cornell, 2002) using incremental dynamic analysis (IDA). The fragility function shows the likelihood that the demand parameter (*D*) will surpass the chosen limit state capacity of the structure (*C)* at the intensity level selected (*IM*). According to Celik and Ellingwood (2010), it can be represented as follows in closed-form:

$$P(C \le D|IM) = \Phi\left(\frac{\ln(\hat{D}) - \ln(\hat{C})}{\sqrt{\beta_{D|IM}^2 + \beta_c^2 + \beta_m^2}}\right) \quad (1)$$

Where, $\hat{D}$ and $\hat{C}$ are the median demand and capacity, $\beta_{D|IM}$ β_c β_m are the dispersions in D (at a given IM), C, and structural model, respectively. More details of these variables and constants can be obtained from the published literature Bhosale et al. (2018). In the current study, a 230mm thick RC frame with an eight-storey, four-bay geometry is selected. The buildings are modelled and analysed using OpenSEES laboratory tool established by McKenna et al. (2016). The infill wall is modelled as a double-braced compression-only diagonal bracing that uses a compression-only backbone, according to Fardis (1996). Fig. 4 shows the details of the selected RC frame along with the backbone curve used for the modelling of the infill.

22 pairs (44 ground motions) of far-field ground motions from the California region were chosen in order to model seismic loading uncertainty. Using the variability of particular masonry materials as mentioned in Table 1, the uncertainty in the strength properties of the building masonry is modelled. The fragility curves obtained using the method outlined in the preceding section are shown in Fig. 5. Clay > Fly-ash > CLC > AAC is the observed sequence of increasing probability of failure for the non-integral frame. AAC infilled RC frames are found to function better than other infills due to their lower seismic weight. The order of increasing failure probability for the integral frame, however, was determined to be contrary to the designer's general perception.

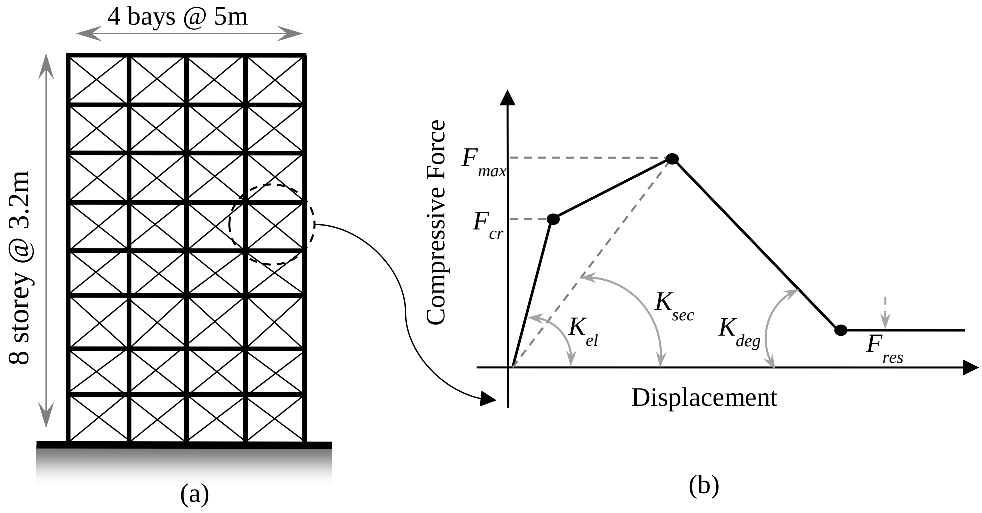
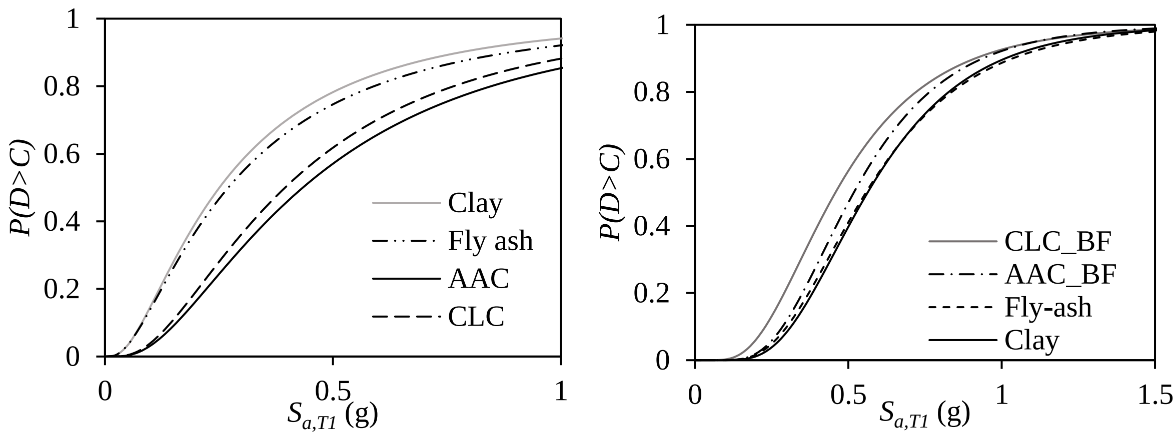


Fig. 4: (a) Geometry of selected building frame and (b) Backbone curve for the infill

Table 1. Uncertainty modelling of selected infill masonry

Infill	Parameters	Shape Parameter (MPa)	Scale Parameter (MPa)	Distribution	Reference
CLC	f_m	0.86	22.45	Gamma	Present study
		2.42	0.51	Normal	Assumed
	τ_{cr}	0.20	0.054	Gumbel max	Present study
		0.23	0.069	Normal	Assumed
AAC	f_m	0.77	0.27	Lognormal	Present study
		2.23	0.60	Normal	Assumed
	τcr	0.19	0.05	Gumbel max	Present study
		0.22	0.06	Normal	Assumed
Clay	f_m	5.32	0.80	Normal	Singhal and Rai, 2014
	τ_{cr}	0.43	0.10	Normal	
Fly-ash	f_m	3.90	0.58	Normal	Basha and Kaushik, 2015
	τ_{cr}	0.46	0.092	Normal	



(a) Non-integral frame (b) Integral frame

Fig. 5: Fragility curves for the 8S4B RC frame

SUMMARY AND CONCLUSIONS

Performing GOF tests on small sets of experimental data and taking into account the two-parameter probability distribution functions, the current work evaluates the variability in two crucial strength properties of AAC and CLC block masonry. Furthermore, using a probabilistic framework, this study evaluates the seismic performance of a typical AAC and CLC masonry infilled RC frame using fragility curves.

The Lognormal and Gamma density functions, respectively, represent the variability in the compressive strength of the AAC and CLC masonry, according to the results of the goodness of fit tests. Whereas, the variability in the shear strength of both the masonry is represented by Gumbel Maximum distribution. The fragility curves are obtained considering the infill as a non-integral frame (considering only the mass of the masonry). The better seismic performance of AAC infilled RC frame compared to traditional infill due to reduced seismic weight. As compared to clay and fly-ash brick masonry, the lightweight infilled RC frame buildings' seismic performance is marginally reduced due to its lower strength, and stiffness.

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