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Influence of bond types on brick masonry strength

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ABSTRACT

Influence of bond types on mechanical properties of brick masonry is investigated experimentally by compression tests. English bond style and Flemish bond style were chosen and 6 specimens of each type were constructed and subjected to compression loads. For each type of bond, joint mortar of 15.02 N/mm^2 (3 specimens) and 8.86 N/mm^2 (3 specimens) were used. Lower strength of Flemish bond type specimens was obtained and it is believed that this is due to larger volume of mortar used in this type of bond. Since strength of mortar presents lower values than strength of brick units, it is reasonable that combination of bricks of larger strength with cement mortar of lower strength produce specimens of lower strength when larger volume of mortar is used. This difference is more remarkable for joint mortar of lower strength.

1. INTRODUCTION

Historical brick masonry structures were constructed using different types of bonds where more representative styles are Flemish bond and English bond. In this research these two kinds of brick arrangements are studied experimentally to evaluate possible differences in their mechanical behavior.

In Japan only few masonry structures remain as cultural heritages and efforts are done for restoration and conservation of this kind of buildings. For example in Akita prefecture, in the north part of Japan, an old masonry building that was the house of a German engineer who worked in local mining at Ani village is conserved as local heritage (see Fig. 1). This building has English bond style and was reconstructed in year 1879 and was destroyed by fire and reconstructed in year 1956.

Important difference was observed for ultimate strength between Flemish type and English Type. It is believed that lower strength of Flemish bond type specimen is due to larger volume of mortar used in this type of bond. Since strength of mortar presents lower values than brick units it is reasonable that combination of bricks of larger strength with cement mortar of lower strength produce specimens of lower strength when larger volume of mortar is used.

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Fig. 1 Masonry building (Ani Ijinkan, Akita, Japan)

Analytical model were constructed using finite element method (FEM) to estimate the elastic modulus of brick masonry. Flemish bond type specimen shows a slight decrease for elastic modulus. Using FEM modelling, curves to estimate masonry properties for different combinations of brick properties and mortar properties were obtained. These curves are important since they will permit to estimate the masonry characteristics from properties of its basic components (brick and mortar). Then parametric curves to estimate elastic modulus of masonry walls were obtained for different combination of elastic modulus of brick and mortar.

2. COMPRESSION TESTS

Test specimens with nominal dimensions of 41 cm of height, 49 cm of width and 21 cm of thickness were prepared using 2 types of bonds as is shown in Fig. 2. Brick units were commercial bricks that are usually sold at supermarkets or DIY stores. Two kinds of mortars were used to fabric masonry specimens. Mortar of 15.02 N/mm^2 of strength (identified here as mortar B) and mortar of 8.86 N/mm^2 (called here mortar C) were used. The thickness of mortar was 1 cm. For each bond type 6 specimens were constructed (3 with mortar B and 3 with mortar C). Flemish type bond is identified with letter F and therefore specimens with mortar B were called BF specimens and specimens with mortar C were called CF specimens. In the case of English bond this type is identify by letter U and specimens were called as BU and CU for mortar B and mortar C respectively. In Table 1 denomination of test specimens are summarized.

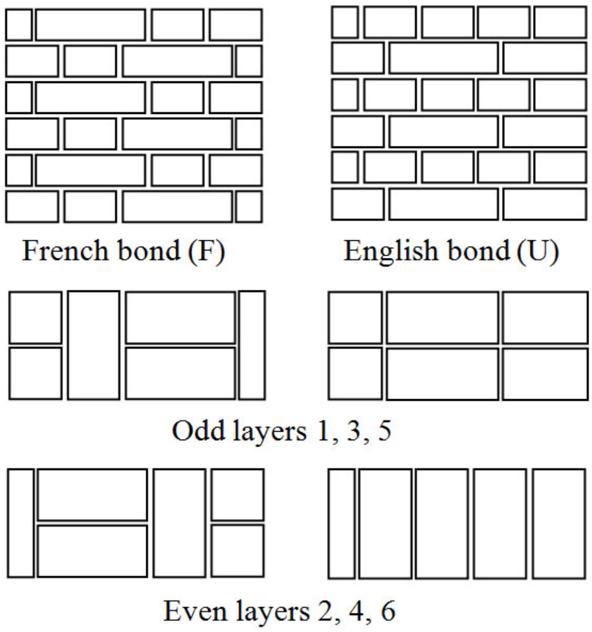


Fig. 2 Test specimens layout

Table 1 Denomination of test specimens

Mortar (strength)	Flemish style specimens	English style specimens
B (15.02 N/mm^2)	BF-1, BF-2, BF-3	BU-1, BU-2, BU-3
C (8.86 N/mm^2)	CF-1, CF-2, CF-3	CU-1, CU-2, CU-3

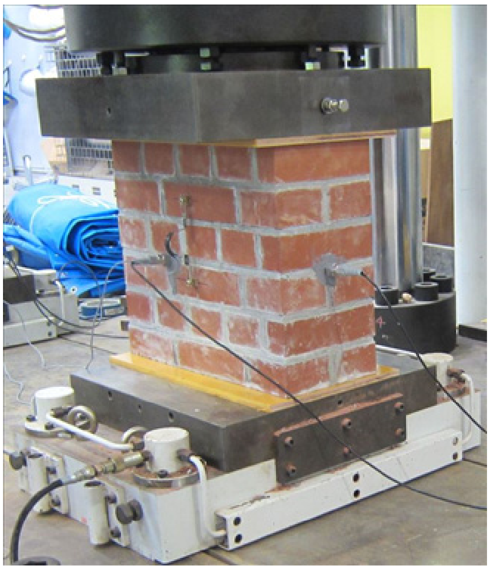


Fig. 3 Test specimen and compression test setup

Tests were performed at structural testing laboratory of Akita Prefectural University using a compression machine with 5000 kN of capacity. Load was applied according to Japanese Industrial Standard (JIS) with a load stress velocity between 5 to 10 N/cm^2/s. General compression test setup is shown in Fig. 3.

Test result for specimens with mortar B and C are shown in Table 2 and Table 3 respectively.

Table 2 Compression test results for specimens with mortar B

Specimen	Maximum Load (kN)	Strength (N/mm^2)	Average strength (N/mm^2)	Young Modulus (N/mm^2)	Average Young Modulus (N/mm^2)
BF-1	4129	40.37	41.18	23722	21612
BF-2	4154	40.45		19824	
BF-3	4378	42.72		21318	
BU-1	4288	41.67	42.24	18178	18067
BU-2	4250	41.39		17159	
BU-3	4466	43.67		18864	

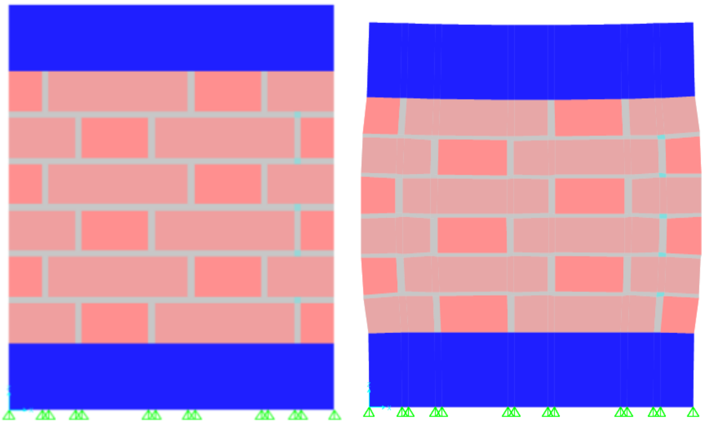
Table 3 Compression test results for specimens with mortar C

Specimen	Maximum Load (kN)	Strength (N/mm^2)	Average strength (N/mm^2)	Young Modulus (N/mm^2)	Average Young Modulus (N/mm^2)
CF-1	3410	33.34	30.57	16178	14974
CF-2	3172	31.02		18276	
CF-3	2815	27.35		10470	
CU-1	3497	34.05	34.52	15388	16097
CU-2	3751	36.45		23108	
CU-3	3402	33.07		9796	

It is believed that lower strength of Flemish bond type specimen is due to larger volume of mortar used in this type of bond. Since strength of mortar presents lower values than brick units it is reasonable that combination of bricks of larger strength with cement mortar of lower strength produce specimens of lower strength when larger volume of mortar is used. On the other hand, portions of vertical joints that passes all layers presents larger volume for Flemish type specimens and it is believed that these joints have great influence on failure pattern.

3. FINITE ELEMENT MODEL

Analytical model were constructed using finite element method (FEM) to estimate the elastic modulus of brick masonry. Analytical model considers brick units and mortar materials separately as is shown in Fig. 4. This figure shows the Flemish type bond and also the deformed shape when model is subjected to compression load is shown. To transmit appropriately the compression loads, steel plates at top and bottom of model were considered. Material properties of brick units and mortar that were used for preliminary analysis are shown in Table 4.



Undeformed Deformed

Fig. 4. FEM model

Table 4. Material properties for FEM analysis

Material	Compression Strength (N/mm^2)	Elastic Modulus (N/mm^2)
Brick Unit	20	15000
Mortar	6.7	5000

Results of analysis are presented in Table 5. Flemish bond type specimen shows a slight decrease for elastic modulus. Then from analysis it can be observed that type of bond has a slight influence in elastic range.

Table 5. Estimation of elastic properties of masonry from FEM analysis

Bond Type	Elastic Modulus (N/mm^2)	Lateral Strain	Poisson Ratio
Flemish	12577.0	0.845×10^{-2}	0.2109
English	12634.3	0.803×10^{-2}	0.2093

Using FEM modelling, curves to estimate masonry properties for different combinations of brick properties and mortar properties were obtained. These curves are important since they will permit to estimate the masonry characteristics from properties of its basic components (brick and mortar). To construct these curves brick elastic modulus (E_b) of 5000, 10000, 15000 and 20000 N/mm^2 was considered. For mortar elastic modulus of 2000, 3000, 4000, 5000, 6000, 7000, 8000, 9000 and 10000 N/mm^2 was considered. Typical curves for Flemish bond type are shown in Fig. 5. It can be observed that the relation is no lineal as expected. In especial for mortar of low elastic modulus the masonry shows a great decrease in its elastic properties.

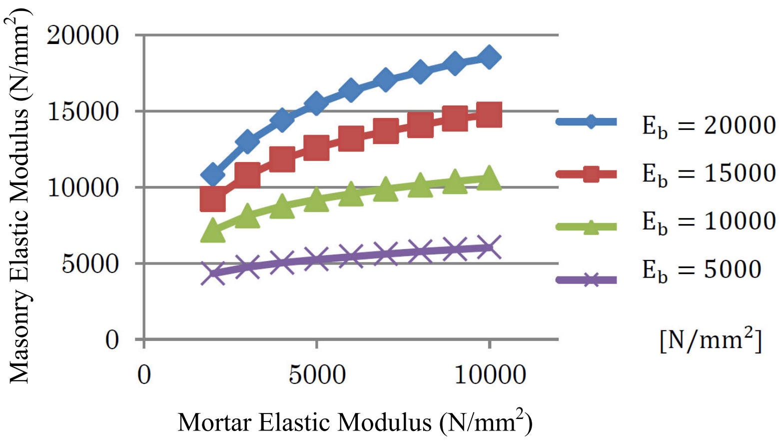


Fig. 5. Relationship between masonry elastic modulus and mortar and brick modulus

4. CONCLUSIONS

In this research two type of masonry bonds (English bond and Flemish bond) were used to investigate their influence on mechanical properties of brick masonry walls. Larger volume of bond mortar in Flemish bond type specimen produces lower strength in comparison to English style bond since mortar have lower resistance than brick units. On the other hand Flemish style bond produces larger volume of vertical bond mortar that crosses the total height of specimens conducing to a failure at lower strength.
Analytical models were constructed using finite element method (FEM) to estimate elastic modulus of brick masonry. Flemish bond type specimen shows a slight decrease for elastic modulus. Using these analytical models, curves to estimate masonry properties for different combinations of brick properties and mortar properties were obtained.

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