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MECHANICAL PROPERTIES OF BRICK MASONRY WITH DIFFERENT TYPES OF BONDS

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ABSTRACT

In this research the influence of the type of bonds on mechanical properties of brick masonry is investigated experimentally and analytically. For this purpose English bond style and French bond style were chosen and specimens of each type were constructed to be subjected to compression load. Lower strength of French bond type specimen 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 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. Analytical model were constructed using finite element method (FEM) to estimate elastic modulus of brick masonry. French 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 can be obtained. These curves are important since they will permit to estimate the masonry characteristics from properties of its basic components (brick and mortar). Analytical formulation with good accuracy will permit to perform appropriate dynamic response simulation. In the elastic range these properties are crucial for the calculation of the period of vibration and therefore for simulation of the earthquake response of structures. In addition non-destructive Schmidt hammer test was performed on actual masonry structure and properties of masonry walls were estimated based on experimental compression test and analytical FEM results.

INTRODUCTION

In Japan some historical masonry structures still remain and efforts are done to preserve them. Analytical estimation of their dynamic characteristics depends on accurate determination of their mechanical properties in especial elastic modulus. In this research the influence of the type of bonds on the elastic properties of brick masonry and on their maximum strength are investigated experimentally. For this purpose English bond style and French bond style were chosen and 3 specimens of each type were constructed to be subjected to compression load.

Important difference was observed for ultimate strength between French type and English Type. It is believed that lower strength of French 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. However in case of elastic modulus the difference is small.

Analytical model were constructed using finite element method (FEM) to estimate the elastic modulus of brick masonry. French bond type specimen shows a slight decrease for elastic modulus.

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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.

Experimental and analytical results are used in combination with non-destructive Schmidt hammer test on actual building to estimate elastic modulus of its walls. Schmidt hammer test was performed separately for mortar joints and brick units. Accurate analytical formulation permits to perform appropriate dynamic response simulation. In the elastic range these properties are crucial for calculation of period of vibration and therefore for simulation of the earthquake response of structures.

COMPRESSION TESTS

Test specimens and load compression test setup can be observed in Figure 1. The brick units were commercial bricks that are usually sold at supermarkets or DIY stores. The mortar was cement sand mortar whit a ratio of 1 to 4; that is 1 part of cement for 4 parts of sand. The thickness of mortar was 1 cm. Nominal dimensions of specimens were 41 cm of height, 49 cm of width and 21 cm of thickness. For each bond type 3 specimens were constructed and they were called F-1, F-2 and F-3 for French bond; and U-1, U-2 and U-3 for English type bond.

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.

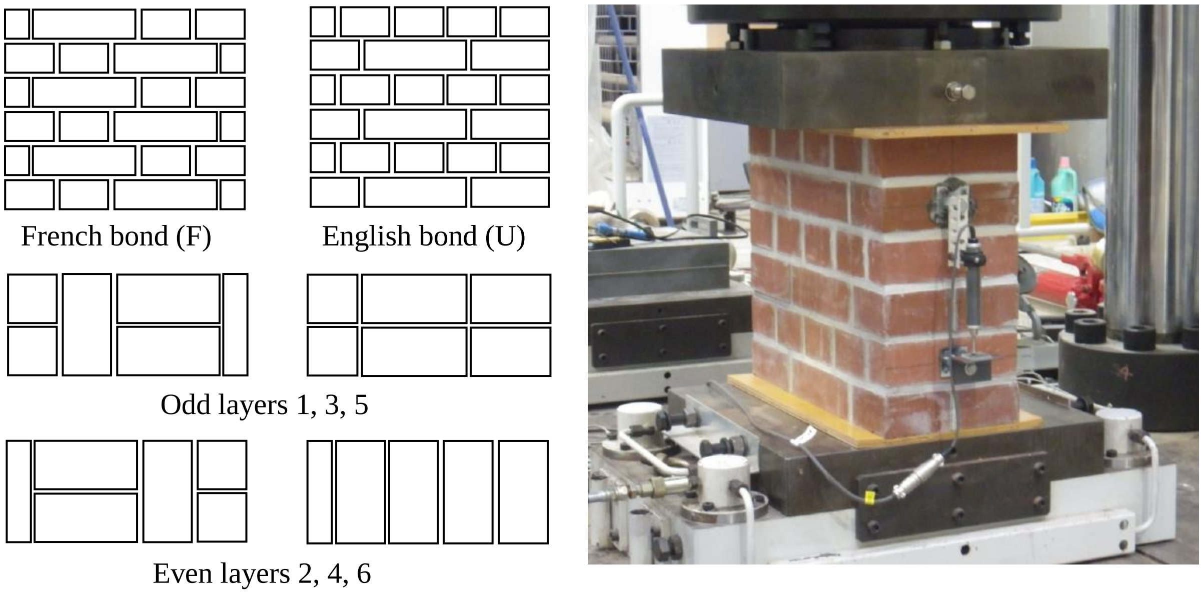


Figure 1. Test specimens and compression test setup

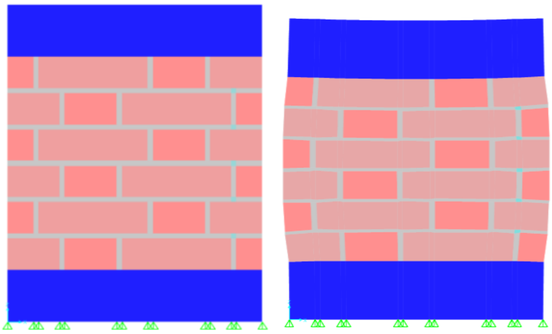
Test results are presented in Table 1 and it can be observed that French bond type specimen has a lower strength than English bond type specimen. Results for specimens F-1 and U-1 were discarded since lower value of strengths were due to inappropriate capping. The thickness of capping was increased for other specimens and more reliable results were obtained. It is believed that lower strength of French 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 French type specimens and it is believed that these joints have great influence on failure pattern.

Table 1. Compression test results

Bond Type	Test Specimen	Maximum Load (KN)	Maximum Stress (N/mm^2)	Maximum Average Stress (N/mm^2)
French	F-1	397.6	3.84	29.295 (F-1 not included)
	F-2	2486.5	23.93	
	F-3	3602.4	34.66	
English	U-1	2136.7	20.76	43.355 (U-1 not included)
	U-2	4574.3	44.36	
	U-3	4358.2	42.35	

FINITE ELEMENT MODEL OF COMPRESSION TEST SPECIMEN

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 Figure 2. This figure shows the French 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 are shown in Table 2.



Undeformed Deformed

Figure 2. FEM model

Table 2. 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 3. French 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 3. Estimation of elastic properties of masonry from FEM analysis

Bond Type	Elastic Modulus (N/mm^2)	Lateral Strain	Poisson Ratio
French	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 French bond type are shown in Figure 3. 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.

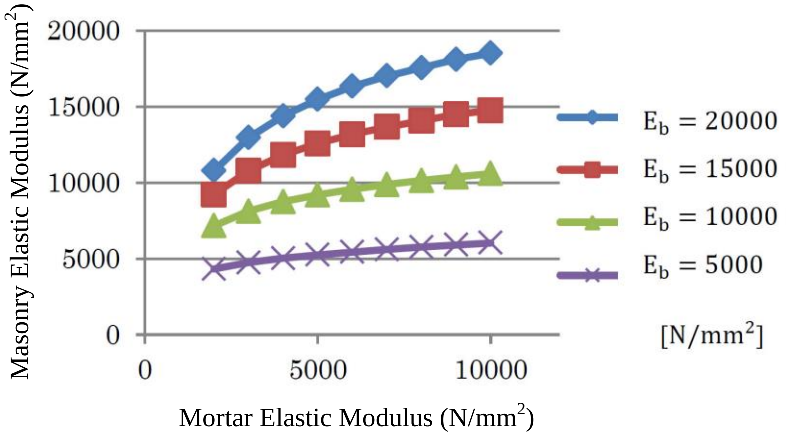


Figure 3. Relationship between masonry elastic ,modulus and mortar and brick modulus

NON-DESTRUCTIVE TEST

Schmidt hammer test was performed at a historical masonry building located at Ani town in Akita, Japan. A view of the building is show in Figure 4, where wall of west façade was selected to perform series of hammer rebound test.

Figure 4. Masonry building (Ani Ijinkan, Akita, Japan)

Schmidt hammer test was performed at 21 points for brick and also at 21 point for mortar. Scheme for determination of points of measurements are show in Figure 5. Lower layer, intermediate layer and upper layer with 7 point per layer were selected for measurements. Measurements at brick units were performed at central point of selected unit as detail is shown in Figure 6 (a). For bond mortar corner between horizontal bond and vertical bond was selected as point of measurement which is show in Figure 6 (b).

Figure 5. Determination of point of measurement for Schmidt hammer test

6 (a) Measurement at brick unit

6 (b) Measurement at mortar bond

Figure 6. Details of Schmidt hammer test

From Schmidt hammer test strength of brick units and mortar were estimated and results are show in Table 4. As it can be observed, mortar presents lower strength in comparison with brick units. It was expected that lower layer could present higher values due to confinement effect of the compression stress however large variance of results do not permit to observe that tendency. On the other hand, lower layers are more subjected to weathering and therefore their surface could present not so good conditions for rebound tests.

Table 4. Strength values from Schmidt hammer test (N/mm^2)

Point of Measurement	Lower layer	Intermediate Layer	Upper layer
Brick ①	21.44	20.14	25.55
Brick ②	28.48	28.48	31.57
Brick ③	31.57	34.8	31.57
Brick ④	39.93	34.8	30.01
Brick ⑤	22.77	39.93	28.48
Brick ⑥	30.01	28.48	34.8
Brick ⑦	31.57	24.14	25.55
Mortar ①	4.73	7.63	5.39
Mortar ②	4.11	9.32	7.63
Mortar ③	6.1	5.39	4.73
Mortar ④	4.11	6.1	6.1
Mortar ⑤	5.39	8.45	9.32
Mortar ⑥	9.32	7.63	6.1
Mortar ⑦	8.45	4.73	7.63

Using strength estimated from results of Schmidt hammer test, elastic modulus for brick and mortar were estimated considering that modulus is 500 time the strength which is a simple relation to relate masonry strength and masonry modulus. Then for simplicity values of brick strength are considered between 25 N/mm^2 and 35 N/mm^2, then it can be considered that elastic modulus between 13000 N/mm^2 and 17000 N/mm^2. For mortar if strength is considered between 4 N/mm^2 and 9 N/mm^2, then elastic modulus will be between 2000 N/mm^2 and 4500 N/mm^2. Then, for example if brick modulus is considered as 15000 N/mm^2, then masonry elastic modulus can be estimated from curves that were obtained in FEM analysis. This is shown in Figure 7, where elastic modulus is estimated between 9000 N/mm^2 and 12000 N/mm^2.

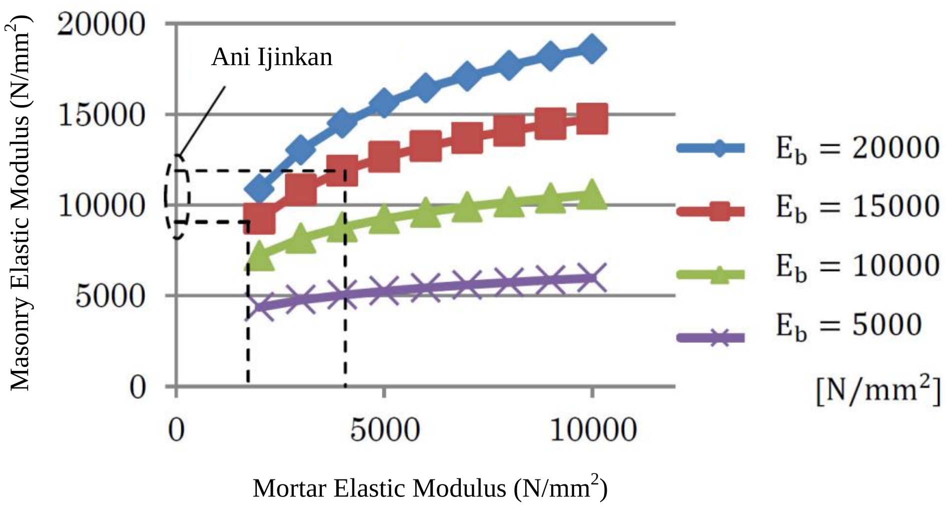


Figure 7. Estimation of masonry elastic modulus for Ani Ijinkan

CONCLUSIONS

In this research two type of masonry bonds (English bond and French bond) were used to investigate its influence on mechanical properties of brick masonry. Larger volume of bond mortar in French bond type specimen produces lower strength in comparison of English style bond since mortar have lower resistance than brick units. On the other hand French style bond produces larger volume of vertical bond mortar that crosses the total height of specimens conducing to a failure at lower strength.

Analytical model were constructed using finite element method (FEM) to estimate elastic modulus of brick masonry. French 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. Then application of these results to estimate elastic modulus for an existing building was performed. Properties of bricks and mortar were estimated from in-situ non-destructive test using Schmidt hammer. Experimental test and in-situ no-destructive test combined with FEM analysis provided a valuable basis for the evaluation of mechanical properties of masonry structures.

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