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EFFECT OF BRICK TYPES ON COMPRESSIVE STRENGTH OF MASONRY PRISMS

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ABSTRACT

This study investigates brick types and masonry prisms under compressive loading according to ASTM C1314–14 as the basic parameters for evaluating lateral resistance of masonry infill walls and to compare compressive strength amongst various brick types. The lateral resistance capacity of a masonry infill wall model depends on the compressive strength of the masonry prism, and the lateral deformation of a masonry infill wall model depends on the strain at the maximum stress of the masonry prism. A masonry prism is an assemblage made of representative units (clay brick, hollow brick, lightweight block, etc), mortar and grout. In this research, eight types of brick are considered which are hollow brick, lightweight block and six types of clay brick. From the test results, the ductile behavior of a masonry prism under compressive loading means that it undergoes further deformation. The masonry prisms made of solid clay brick show the best performance with the largest average compressive stress of 10.8 MPa and largest cumulative energy dissipation of 444 kN/mm, but their behavior is non-ductile. The compressive stress of lightweight block is the weakest with the average compressive stress of 2.62 MPa. The compressive strengths of masonry prisms made of all clay brick types are higher than the compressive stresses of those made of hollow brick and lightweight block.

Keywords: Compressive stress; Effect of brick type; Masonry prism

1. INTRODUCTION

In recent years, many earthquake events occurred and were recognized in Thailand. The earthquake events that caused damages to the building structures in Thailand occurred during the December 13, 2006 earthquake with a magnitude of 5.1 on the Richter scale and its epicenter was in Chiang Mai province, and during the May 16, 2007 earthquake with a magnitude of 5.4 in Richter scale and its epicenter was in Laos PDR and the latest, during the May 5, 2014 earthquake with a magnitude of 6.3 in Richter scale and its epicenter was in Chiang Rai province. It is not only the force due to earthquakes, but also the force due to other disasters, such as tsunamis, storms and floods, which exert lateral forces acting on the structure of a building. Many researches propose that a masonry infill wall enhances the lateral resistance of a building significantly (Mehrabi et al., 1996; FEMA 306, 1998; Mostafaei & Kabeyasawa, 2004; Crisafulli & Carr, 2007; Foytong et al., 2013). Masonry infill walls are widely modeled as a diagonal strut as shown in Figure 1. The lateral resistance capacity of the masonry infill wall model depends on the compressive stress of the masonry prism, and the lateral deformation of the masonry infill wall model, which depends on the strain at the maximum stress of

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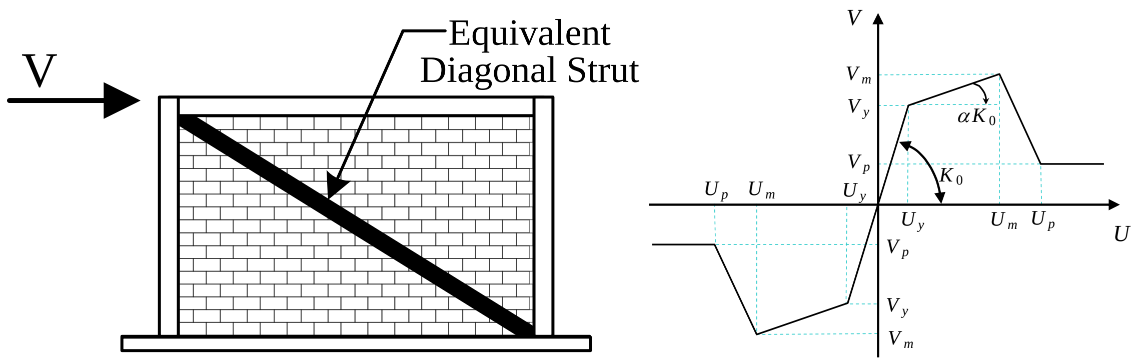
masonry prism. The compressive strength is a measure in relation to the compressive stress, which indicates the failure of the material under compressive loading.



(a) Equivalent diagonal strut (b) Strength envelope for masonry infill walls

Figure 1 Equivalent diagonal strut and strength envelope for masonry infill wall models (Mostafaei & Kabeyasawa, 2004)

This research investigates the compressive stress of brick and masonry prisms according to the American Society for Testing and Materials ASTM C1314–14 Standard (ASTM, 2014) as the basic parameters for evaluating the lateral resistance of a masonry infill wall and to compare the compressive strength amongst various brick types.

2. BRICK AND MASONRY PRISM SPECIMENS

2.1. Brick

This study investigated brick, masonry prisms and mortar under compressive loading to compare the compressive strength between various brick types (ASTM, 2014). Eight types of brick, which are widely used in Thailand, are investigated. They are hollow brick, lightweight block and six types of clay brick as shown in Figure 2. Three specimens of each brick type are tested. The average dimensions of brick specimens are shown in Table 1. The six types of clay brick configurations are different because of local manufacturing techniques.

2.2. Masonry Prism

The masonry prism specimens of each brick type are constructed and tested according to ASTM C1314–14 Standard (ASTM, 2014). A masonry prism specimen has to be longer than 100 mm and is built of a minimum of two units high. A ratio of height to thickness (h_p/t_p) is between 1.3 and 5.0. Three specimens are constructed for each brick type, except **HB** and **LWB,** those types have only two specimens, because data were lost during the tests. The dimensions of the masonry prism specimens are expressed in Table 2.

Two kinds of bricklaying mortar are used. Portland Cement Type 1 is used for the clay brick and hollow brick specimen with an average compressive stress of 8.23 MPa, and lightweight block bricklaying mortar is used for the lightweight block specimen with an average compressive stress of 17.78 MPa. After bricklaying, the specimens were wrapped for 7 days. For the plastering mortar, Portland Cement Type 1 is used for the clay brick and hollow brick specimen, and lightweight block plastering mortar is used for the lightweight block. The preparation procedures of masonry prism specimens are described in Figure 3.

(a) Hollow brick, **HB** (b) Lightweight block, **LWB** (c) Clay brick 1, **CB1**

(d) Clay brick 2, **CB2** (e) Clay brick 3, **CB3** (f) Clay brick 4, **CB4**

(g) Clay brick 5, **CB5** (h) Clay brick 6, **CB6**

Figure 2 Eight types of brick specimens

Table 1 Average dimensions and average compressive stress of brick specimens

Type	Length (cm)	Width (cm)	Height (cm)	Area (cm^2)	Max Force (kN)	Stress (MPa)
HB	38.9	6.5	19.0	253.7	120.8	4.76
LWB	60.0	7.5	20.0	449.1	117.9	2.62
CB1	13.9	6.0	5.5	83.8	122.9	14.65
CB2	15.1	6.6	7.0	100.1	168.7	16.85
CB3	13.3	6.4	2.8	85.0	249.8	29.37
CB4	13.4	5.6	6.0	74.3	155.7	20.94
CB5	16.9	6.0	8.5	102.2	133.6	13.08
CB6	23.2	6.4	12.0	148.6	132.0	8.90

Table 2 Average dimensions of masonry prism specimens

Type	Length (cm)	Height, h_p (cm)	Thickness, t_p (cm)	h_p / t_p	Area (cm^2)
HB	40.2	39.9	8.59	4.64	345.6
LWB	40.7	40.4	9.37	4.31	381.1
CB1	45.4	34.1	7.80	4.37	354.4
CB2	49.4	37.7	8.93	4.23	440.7
CB3	44.3	23.8	8.51	2.79	377.1
CB4	45.4	36.7	7.58	4.84	344.1
CB5	56.7	39.2	8.54	4.60	483.7
CB6	49.4	39.1	8.24	4.75	407.0

(a) Wrapping (b) Glossing (c) Masonry prism specimens

Figure 3 Preparing masonry prism specimens

3. SETUP OF SPECIMENS

Brick specimens and masonry prism specimens are tested under compressive loading by a Shimadzu universal testing machine with a capacity of 3,000 kN. The specimen setup for masonry prism is shown in Figure 4. All specimens for both the brick and masonry prisms are capped by sulfur before testing. The compression load was transferred to the specimen by rigid beams. Two linear variable differential transformers (LVDT) were set to measure the deformation of the masonry prism specimens. During the test, the compression force and deformation were recorded.

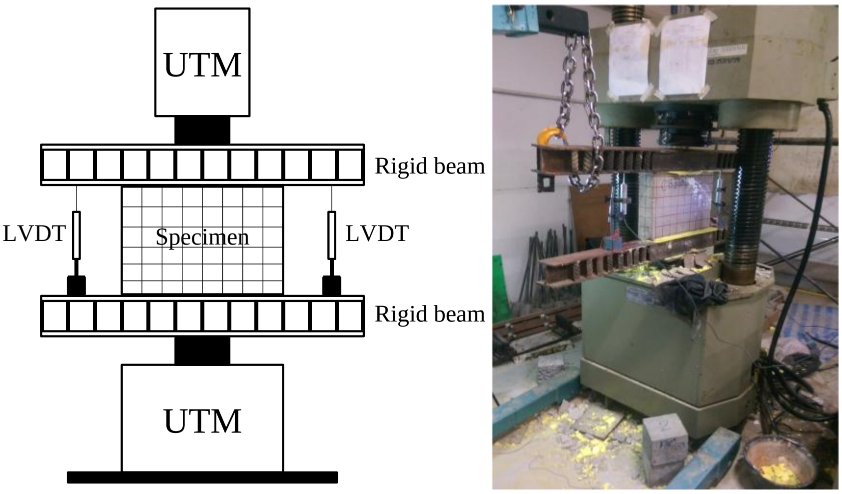


Figure 4 Setup for masonry prism specimens

4. EXPERIMENTAL RESULTS

4.1. Compressive Strength of Brick

The average maximum compressive loading and average maximum stress of each brick type are shown in Table 1. **CB3**, a solid clay brick without holes, shows the largest compressive stress of 29.37 MPa. The compressive stress of **LWB** is the least stress with a rating of 2.62 MPa. The clay brick strength ratings were sorted from the highest to the lowest as follows: **CB3**, **CB4**, **CB2**, **CB1**, **CB5** and **CB6** with the compressive stresses of 29.4 MPa, 20.9 MPa, 16.8 MPa, 14.6 MPa, 13.1 MPa and 8.90 MPa, respectively. The compressive strength of the clay bricks depends on the number of holes in an area and the forming quality. The compressive strengths of all types of clay brick are higher than the compressive strength of the hollow brick and lightweight block, respectively.

4.2. Compressive Strength of Masonry Prism

According to the ASTM C1314–14 Standard (ASTM, 2014), the compressive forces on prisms are corrected due to the height-to-thickness ratio. The correction factors for the masonry prism specimens are shown in Table 3. Three specimens are investigated for each brick type, except for **HB** and **LWB** there are only two specimens because data were lost during the test. The stress-strain relationship for all masonry prisms under compressive loading are shown in Figure 5. The maximum compressive force, maximum compressive stress and strain at the maximum stress of the masonry prism for each brick type are listed in Table 4. The distribution of maximum stress and strain at the maximum stress of all masonry prisms is described in Figure 6.

Table 3 Height to thickness correction factors for masonry prism compressive strength (ASTM, 2014)

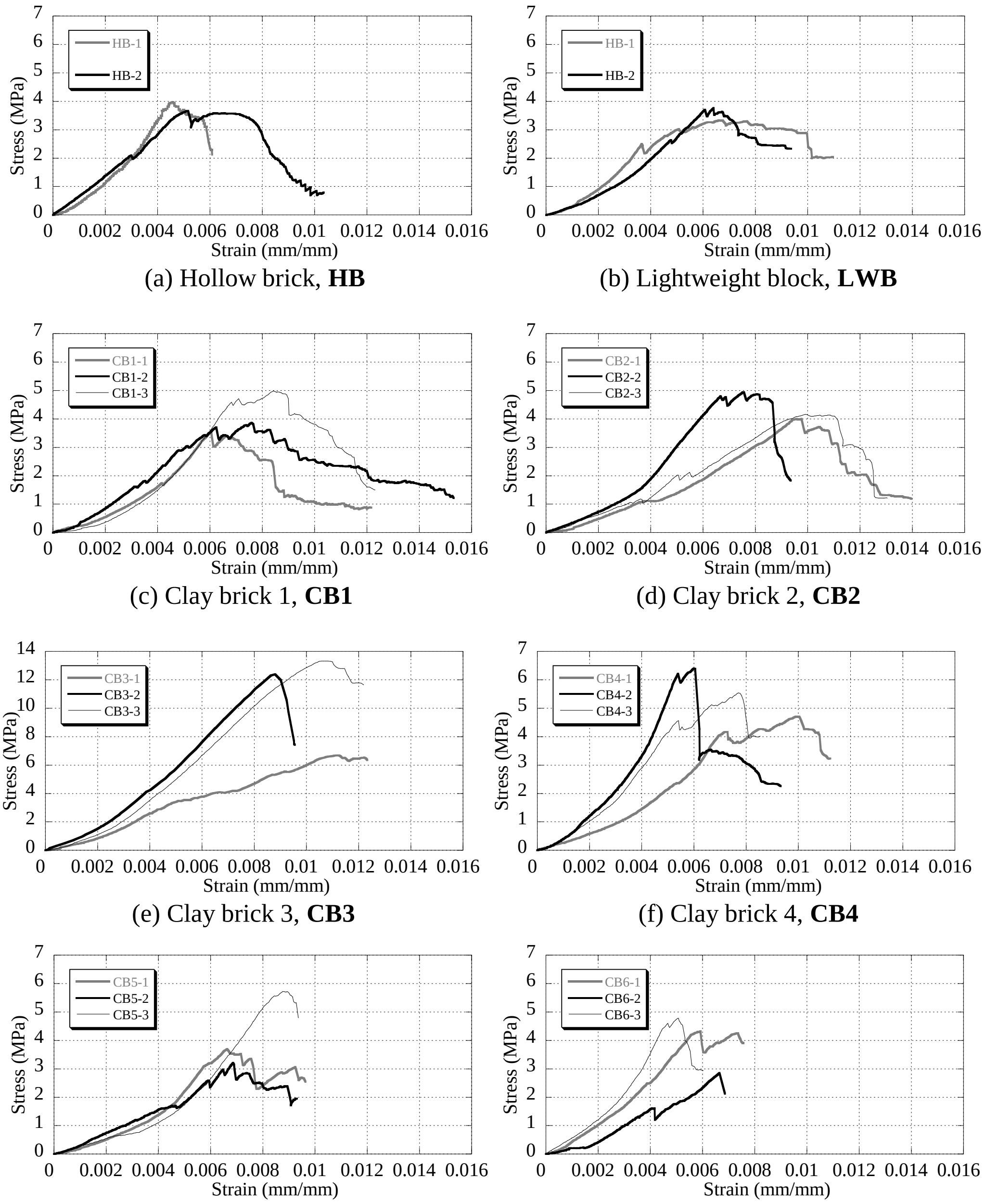
h_p / t_p	1.3	1.5	2.0	2.5	3.0	4.0	5.0
Correction Factor	0.75	0.86	1.00	1.04	1.07	1.15	1.22

Table 4 Average compressive stress, strain and energy dissipation of masonry prism

Type	P_{max} (kN)	σ_{max} (MPa)	ε at σ_{max} (mm/mm)	Cum. Energy Dissipation at σ_{max} (N/mm)
HB	131.6	3.81	0.00490	115.2
LWB	135.3	3.55	0.00651	169.0
CB1	146.1	4.12	0.00708	162.6
CB2	192.6	4.37	0.00902	281.2
CB3	405.2	10.80	0.01024	444.2
CB4	191.0	5.55	0.00791	249.7
CB5	203.6	4.21	0.00742	225.8
CB6	162.2	3.98	0.00588	153.7

The stress-strain relationships of the masonry prism for the same brick type start with the similar trend of initial slope. After cracking of the materials in the masonry prism, the material properties are different. The stress behavior of each masonry prism is ductile, after the peak stress of masonry prism undergoes further deformation. Except for **CB3**, the maximum stress of **CB3** was the largest at about 10.80 MPa, thus the masonry prisms of **CB3** failed after the peak stress.

The trend of maximum compressive strength of masonry prism and brick is similar. The maximum compressive stress is in the masonry prism made of **CB3** with the compressive stress of 10.80 MPa. The minimum compressive stress is the masonry prism made of **LWB** with the maximum compressive stress of 3.55 MPa. The strength of each masonry prism was sorted from maximum to minimum, based on masonry prisms made of **CB3**, **CB4**, **CB2**, **CB5**, **CB1**, **CB6**, **HB** and **LWB** with the compressive stresses of 10.80 MPa, 5.55 MPa, 4.37 MPa, 4.21 MPa, 4.12 MPa, 3.98 MPa, 3.81 MPa and 3.55 MPa, respectively. The compressive strengths of masonry prisms made of all clay brick types are still larger than the compressive strengths of masonry prisms made of hollow brick and lightweight block. However, the different stresses of the masonry prisms are not large as those of the brick types, due to the effects of brick type and manufacturing techniques.



(a) Hollow brick, **HB**

(b) Lightweight block, **LWB**

(c) Clay brick 1, **CB1**

(d) Clay brick 2, **CB2**

(e) Clay brick 3, **CB3**

(f) Clay brick 4, **CB4**

(g) Clay brick 5, **CB5**

(h) Clay brick 6, **CB6**

Figure 5 Stress-strain relationship for masonry prisms for each brick type

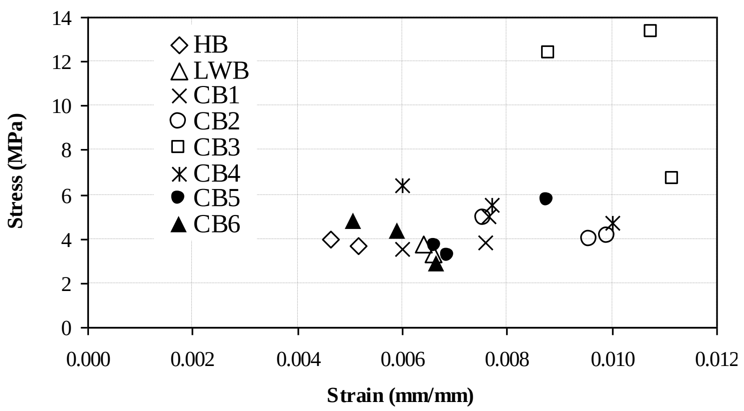


Figure 6 The maximum stress and strain relationship of masonry prism for each brick type

Strains at the maximum stress of the masonry prisms made of the same brick type are diffuse. Strains of masonry prisms made of mostly clay brick types are larger than the strain of masonry prisms made of hollow brick and lightweight block. The cumulative energy dissipation at the maximum stress for all masonry prism specimens is also shown in Table 4. The maximum cumulative energy dissipation of masonry prisms made of **CB3** is still largest at 444.2 kN/mm. The maximum cumulative energy dissipation of masonry prisms made of **LWB** is larger than those of **CB1** and **CB6**.

5. CONCLUSION

This research investigates the compressive stress of brick and masonry prisms according to ASTM C1314–14 Standard as the basic parameters for evaluating lateral resistance of masonry infill walls and to compare the compressive strength between various brick types. Findings in this research can be summarized as follows:

1. A solid clay brick shows the maximum compressive stress of 29.37 MPa. The compressive stress of **LWB** is the minimum stress of 2.62 MPa. The compressive strength of clay bricks depends on the number of holes in an area and the forming quality. The compressive stresses of all types of clay brick are higher than the compressive stresses of hollow brick and lightweight block.
2. The stress-strain curves of masonry prisms for the same brick type start with a similar trend of an initial slope. After the peak stress, the behavior of the masonry prism is ductile that undergoes further deformation.
3. The masonry prism made of solid clay brick shows maximum compressive stress of 10.80 MPa. The minimum compressive stress is masonry prism made of lightweight block with the compressive stress of 3.55 MPa. The maximum stress-strain of masonry prisms made of clay brick are larger than those made of hollow brick and lightweight block. The masonry prisms made of solid clay brick, **CB3**, display the best performance with the largest stress and largest cumulative energy dissipation, but their behavior is non-ductile.

6. ACKNOWLEDGEMENT

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