Determining initial damage state of confined masonry wall

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Abstract. A masonry wall can withstand the compressive, tensile, and shear forces, besides that, a masonry wall can add rigidity to the building structure. The stiffness contributed by the masonry wall can influence the stiffness of the global structure. The contribution of stiffness to masonry walls is linear until the walls are damaged. The linear limit of the behaviour of masonry infill reinforced concrete portal can be used as the first criterion of damage (damage state). This study aims to determine the limit criteria for damage to reinforced concrete masonry wall buildings. The types of bricks used are normal bricks, Z bricks, Z hook bricks. The portal structure of masonry infill reinforced concrete was analyzed using the stiffness approach in the matrix formulation, where the wall stiffness was assumed to be a strut. The strut stiffness is determined based on the masonry panel shear test. The amount of lateral deformation on the portal when the internal shear force on the strut element reaches the wall shear strength limit is used as a limit for the linear behaviour of the masonry-filled reinforced concrete portal.

1. Introduction
The masonry reinforced concrete portal can withstand compressive, tensile, shear forces and has rigidity. Rigidity is influenced by the quality of the material and adhesive. Stiffness is also influenced by the binding properties of the elements. This characteristic has resulted in some old buildings still standing firmly today [1–4]. Perfect rigidity makes the building more stable, safe, strong against force. Good rigidity will increase the strength of the building [3,5–8].

The behaviour of masonry infill reinforced concrete portals in receiving lateral loads until it collapses can be illustrated in Figure 1. Figure 1 is a linear behaviour in which the lateral deformation is proportional to the increase in load. After the load reaches a certain capacity, the behaviour of the masonry-filled reinforced concrete portal becomes non-linear. The starting point of the non-linear behaviour can be assumed as the beginning of damage to the masonry-filled reinforced concrete portal. This is characterized by an increase in lateral deformation that is not proportional to the increase in load. After the peak load, the deformation increases significantly along with the increasing load which causes the masonry-filled reinforced concrete portal to collapse.
Figure 1 illustrates the use of infilled frames to increase capacity, strength, and improve post-peak load performance in masonry reinforced concrete portals. Considering the contribution of infill walls in improving the behaviour of brick-filled reinforced concrete portals as mentioned above, this study proposes the use of various types of bricks (normal bricks, Z, and Z hooks) numbered Intellectual Property rights HKI P00201507718 [9]. The use of various types of bricks as shown in Figure 2 and Figure 3 is intended to determine the linear elastic limit of the various bricks.

![Figure 1. Capacity curve Dawe and Seah](image)

2. Experimental and Method

2.1. Modeling of masonry as reinforced concrete portal filling

The infill wall contribution is modeled as a strut element. A brick wall is considered a single homogeneous element into a new unit which increases the rigidity. Struts modeling is very applicable and makes it easy to analyze the behavior that occurs [2,10–12] so this research uses struts analysis.

Struts analysis requires several parameters, namely the parameters on the portal and the wall infill elements. Parameters on the portal consist of force, deformation, portal height, portal width, portal diagonal length, contact length, and struts (contact) width. Some of these parameters can be described as in Figure 4.

![Figure 2. Type Z Bricks Design](image)

![Figure 3. Type Z Hook Bricks Design](image)
Determination of the $bw$ value

Determination of the $bw$ value, the result of the different mean values of $bw$, namely:

$bw$ as written in [13]:

$$bw = 0.175(\lambda h) - 0.4 \, dw$$

(1)

$bw$ as written in [14]:

$$bw = 0.16(\lambda h) - 0.3 \, dw$$

(2)

$bw$ as written in [15]:

$$bw = 0.33 \, dw$$

(3)

$bw$ as written in [1]:

$$bw = 0.25 \, dw$$

(4)

The stiffness parameter $\lambda h$

$$\lambda h = h \sqrt{\frac{Em \cdot Sin2\theta}{Ec \cdot Ie \cdot hn}}$$

(5)

The parameters of the portal filling elements are useful for constructing the stiffness matrix, viz. element area, element length, modulus of elasticity, moment inertia, wall thickness. The modulus of elasticity of concrete ($Ec$) and brick ($Em$) can be found using the formula $Ec = 4700 \sqrt{f'c}$ and $Em = 700 \frac{s}{d} 1000 \, \text{fm}$ [14].

Determine the value of stiffness using a matrix formula. The stiffness is affected by portal elements and brick wall elements. The portal element uses a beam stiffness matrix and the brick wall elements use a struts matrix element. The two matrices have different orders, so the order of the matrices must be equalized so that they can be operationalized. The following Figure 5 are the beam and struts matrices with equalized orders.
2.2. Method

The research method used is destructive by using several samples to determine the instrument [3,16,17]. From the test results, the initial damage and total collapse were calculated. The results from the laboratory as shown in Figure 6 are processed using a matrix analysis procedure to determine the resulting internal force and deviation. The calculation results of several brick designs are then compared and concluded.

Calculate the forces and deformations during the initial breakdown of various bricks using the stiffness matrix operation. Global matrix for calculating global deformation. Global deformation can determine the deformation of elements. The deformation value of the struts element results in the amount of internal force. The value of the internal force obtained is compared with the value of the shear capacity of the laboratory specimen. After obtaining the value of the internal force equal to the shear capacity of the test object, the deformation due to the internal force is used as the boundary for global linear behavior. The value of the linear behavior boundary deformation is used as the basis for determining the magnitude of the acting lateral force. The lateral force capable of moving the extent of the deformation is called the stiffness value

![Figure 6. Shear Stress Test](image)

The results of the analysis during the shear test showed that there was a fault direction that cut the brick, cut the diagonal, and horizontal spacing and there was no loose bond between the bricks and the spaces. This incident is influenced by the adhesion and bonds between the bricks. High attachment and bonding will make the object more stable. The stable condition of objects will increase the ability to withstand forces that affect stiffness, global structural strength. So that the stronger the adhesion and
binding strength of the brick design, the higher the shear stress value of the brick panels. Stress is sought by testing the panel shear in the laboratory using the test object. The stress is calculated from the laboratory shear test as shown in Figure 6, using the formula [17–20].

\[ T = \frac{0.707 P}{w z} \frac{mn}{\pi} \]  

(6)

The value of the internal shear force on the struts element can be found by the stiffness of one strut [14]

\[ k_s = \gamma_s \frac{AmE_m}{dm} \cos^2 \theta \]  

(7)

3. Result and Discussion

3.1. Analysis Result of Reinforced Concrete Portal Filling Various Bricks

The results of the analysis of the test object in the laboratory, when the shear test took place, there were several existing shear damage models, namely

1. 70% suffered horizontal damage in the horizontal spacing direction with 40% cracking range
2. 20% suffered horizontal damage in the horizontal spacing with 10% crack spacing.
3. 10% experienced a diagonal crack by cutting the brick body.

From the results above, it can be concluded that there is a need for reinforcement in the direction of horizontal spacing. Increasing the reinforcement of horizontal spacing will increase the shear strength.

The value of the shear capacitance of the test object is used as a limit for linear behavior. This value is a guideline to be achieved using the strut element matrix operation by entering the deformation value. After obtaining the same force results, the force and deformation are considered as limits of linear behavior. Research conducted by researchers using a wall-size of 3x3 m using a normal brick design, Z, Z hooks, 10 MPa of concrete quality after the analysis of the matrix operation was carried out according to the method and by taking into account the existing parameters, resulting in the elastic behavior limit values as shown in Table 1 and Table 2.

| Brick Design | Matrix formulation (N) | Crisafulli (N) |
|--------------|------------------------|---------------|
| Z hook       | 6363,0                 | 3862,784      |
| Z            | 2121,0                 | 1850,176      |
| Ordinary     | 1979,6                 | 1820,748      |

Table 2. Global stiffness and deformation values in normal bricks, Z, Z hooks

| Design  | Global Stiffness (N) | Deformation (mm) |
|---------|----------------------|------------------|
| Z hook  | 131876,358           | 0,577            |
| Z       | 90623,401            | 0,401            |
| Ordinary| 85932,487            | 0,381            |

3.2. Comparison

Based on the result in Table 2, the Z hook brick design has better elastic limits; stiffness is better; better deformation; strength is better; better voltage than other designs. Then the hook brick is superior.
Results of several force-deformation relationship curves from several studies. Prayuda using a column size of 15x15 cm with a concrete quality of 15 MPa produces a force value of 15,000-20000 N with deformation of 0.4-0.6 mm. The capacity curve from the results of the research for several bricks is as follows in Figure 7.

Sri Prafanti's research on the 3rd-floor building by applying bricks in several countries as shown in Figure 8, obtained a force magnitude of 250-2000 kN with deformation of about 0.05-0.1 m [22]

4. Conclusion
Based on the form of shear damage that occurs, it can be concluded that there is a need for reinforcement in the direction of horizontal spacing. Increasing the reinforcement of horizontal spacing will increase the shear strength. Horizontal spacing has the function of attaching between bricks. This new brick design can increase the bond area. The area of the tie area, especially on the head layer. This can increase the shear strength. The wider the bond area, the greater the shear strength. The Z hook brick design has better elastic limits, better stiffness, better deformation, better strength, and better stress when compared to other designs. Hook bricks are superior to other types of bricks tested in this study.

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