SUMMARY: 
In this study, the structural behaviour and the effect of strengthening for historic masonry walls with arch openings under horizontally cyclic loading are investigated by experiment. Results obtained from the three un-strengthened specimens show the initial crack occurred at a drift angle of approximately 2/1000. In addition to the specimen test, a method for evaluating the ultimate load of a brick wall with arch opening has been developed from a simplified model. Comparing the ultimate load evaluated and that obtained from test specimens, the difference is less than 6% for low or medium bearing and less than 9% for high bearing. Furthermore, a strengthening design is also developed for the strengthening method using 2 thin stainless steel straps imbedded into the intrados face of the arch. Finally, seismic assessment and strengthening design of masonry brick wall with arch openings is illustrated with the Li-Xian Building of Former Japanese Infantry 2nd Wing Camp.

Keywords: Historic Building, Brick Masonry Arch, Seismic Assessment, Strengthen, Drift Angle

1. INTRODUCTION

Arch is an important architectural element of masonry historic buildings in Taiwan. Due to the geometric characteristic of arch, the masonry wall with arch opening is easy to get damage during earthquake. Thus for the reservation of historic buildings, properly repairing the earthquake damage and improving the seismic resistant ability of masonry wall with brick arch are worth to be investigated. From four practical strengthening methods in previous study, only 1 strengthening method is compared in this study. 2 thin stainless steel straps (10mm x 1mm) are imbedded into the intrados face of the brick arch. The arch subjected to vertical loads is also compared. The main purpose of this study is to understand the improvement of ultimate strength and seismic performance of historic brick arch strengthened with proposed methods. The results obtained in this study will provide architect useful information for planning and design retrofitting of historic buildings.

2. EXPERIMENTAL PROGRAM

2.1. Wall Specimens

Four arch specimens with thickness 1B were manufactured in Dutch bond (Figure 1). In order to simulate the bricks used in most historic buildings in Taiwan, all specimens use bricks with 23x11x6cm in size. The dimension of each of the specimen is 202cm in width and 239cm in height. The cement mortar used is 1:2 (cement: sand).

Table 1 lists the details of the specimens. WU1, WU2 and WU3 are un-reinforced specimens used for comparison the performance of specimens with different vertical loads. Specimens WS1, WR1 and
WR2 are strengthened, 2 thin stainless steel straps are imbedded into the intrados face of the arch. In these two specimens, WR1 and WR2 are strengthened after specimens WU1 and WU2 damaged, and used to compare the performance with un-reinforced specimens. During manufacturing the specimen, the cutting slot is filled with EPOXY mortar.

![Figure 1](image_url)

**Figure 1.** Brick arch specimen, 2 thin stainless steel straps are imbedded into the intrados face of the brick arch (specimens WS1, WR1 and WR2)

<table>
<thead>
<tr>
<th>Specimen</th>
<th>L×H×T(cm)</th>
<th>Strengthening method</th>
<th>Equipment Weight (kN)</th>
<th>Applied Vertical Load (kN)</th>
<th>Total Vertical Load (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WU1</td>
<td>239×203×23</td>
<td>Without strengthening</td>
<td>12.2</td>
<td>-</td>
<td>12.2</td>
</tr>
<tr>
<td>WU2</td>
<td>239×203×23</td>
<td>Without strengthening</td>
<td>12.2</td>
<td>59.0</td>
<td>71.2</td>
</tr>
<tr>
<td>WU3</td>
<td>239×203×23</td>
<td>Without strengthening</td>
<td>12.2</td>
<td>87.8</td>
<td>100.0</td>
</tr>
<tr>
<td>WS1</td>
<td>239×203×23</td>
<td>2 thin stainless steel straps (10mm x 1mm) are imbedded into the intrados face of the brick arch (Figure 1)</td>
<td>12.2</td>
<td>-</td>
<td>12.2</td>
</tr>
<tr>
<td>WR1</td>
<td>239×203×23</td>
<td>2 thin stainless steel straps (10mm x 1mm) are imbedded into the intrados face of the brick arch strengthened post WU1 damaged</td>
<td>12.2</td>
<td>-</td>
<td>12.2</td>
</tr>
<tr>
<td>WR2</td>
<td>239×203×23</td>
<td>2 thin stainless steel straps (10mm x 1mm) are imbedded into the intrados face of the brick arch strengthened post WU2 damaged</td>
<td>12.2</td>
<td>59.0</td>
<td>71.2</td>
</tr>
</tbody>
</table>
2.2 Material properties

gives the fundamental properties of the brick arch specimens. All the strengths are tested in lab. The materials are taken at the same time as specimens manufactured.

The value of elastic modulus $E_m$ is between 733MPa to 1534MPa according to the stress strain relationship of brick masonry specimens cut from a wall specimen (Chang, et al. 2010). Because this is obtained from a used wall specimen, for a new specimen the elastic modulus may be greater than 1534MPa. The average flexural strength $f_{mb}$ is 1.77Mpa. To simply the calculation, the material is assumed to be homogeneous. Based on Chen, et al. (2002) the limit elastic modulus $E_m$ is estimated as following:

$$ f_m' = 0.27 f_{bc}^{0.7} f_{mc}^{0.3} $$

$$ E_m = 138 f_m' $$

where

- $f_m'$ is the compression strength of masonry (MPa)
- $f_{bc}$ is the compression strength of brick (MPa)
- $f_{mc}$ is the compression strength of mortar (MPa)

Take specimen WU1 for example, $f_{bc} = 57.09\text{MPa}$, $f_{mc} = 28.04\text{MPa}$, $f_m' = 12.45\text{MPa}$, $E_m = 1718\text{MPa}$. For specimen WS1, $f_m' = 11.07\text{MPa}$, and $E_m = 1528\text{MPa}$.

Compare the Elastic Modulus of Masonry $E_m$ calculated from Eqn. 2.2 and the flexural test value (733MPa ~1534MPa) of the cut specimens, the calculated Elastic Modulus of Masonry $E_m$ is much close the maximum test value.

<table>
<thead>
<tr>
<th>Table 2 Tested material properties (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material properties</td>
</tr>
<tr>
<td>1 Compression strength of brick, $f_{bc}$</td>
</tr>
<tr>
<td>2 Compression strength of mortar, $f_{mc}$</td>
</tr>
<tr>
<td>3 Compression strength of Masonry, $f_m'$</td>
</tr>
<tr>
<td>4 Elastic Modulus of Masonry, $E_m$</td>
</tr>
</tbody>
</table>

2.3 Test setup

Figure 2 is the test setup designed for this study. The lower RC beam is fixed on the steel base by high strength bolt. The upper RC beam and the steel cap are bolted together with 10 bolts (D= 30mm). The end of the steel cap is connected to the actuator that is attached to the reaction wall. During test, the upper beam transmits the horizontal load to the top plane of the brick arch. The loading was measured by the load cell on the actuator, and the displacement was measured using a displacement transducer.

During test, the arch specimen was subject to an increasing cyclic lateral loads (Figure 2) which were controlled by the stroke of the actuator. The test is stopped as the specimen has been seriously damaged. Specimens WU2 and WR2 are simultaneously loaded with cyclic lateral load and a 59.0kN vertical load. Specimen WU3 is simultaneously loaded with cyclic lateral load and a 87.8kN vertical load. The mechanism of the vertical loading system is shown in Figure 3. The vertical load is amplified by the action of lever arm and pulleys.

2.4 Experiment Results

The maximum load obtained and its corresponding displacements are listed in Table 3. Based on the test results, we suggest that drift angle 2/1000 could be assigned as the initial damage point, and drift angle 4/1000 to be the ultimate performance point for historic building seismic assessment. In order to
compare in later section, we define the load ratio to the Maximum load of WU1 (un-reinforced specimen) as ultimate load ratio 1.0.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Loading Cycle</th>
<th>Loading Angle</th>
<th>Loading (kN)</th>
<th>Ultimate Load Ratio</th>
<th>Drift Angle</th>
<th>Loading (kN)</th>
<th>Ultimate Load Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Un-reinforced WU1</td>
<td>11</td>
<td>-2.20/1000</td>
<td>-105.4</td>
<td>0.60</td>
<td>2.13/1000</td>
<td>83.9</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>-3.13/1000</td>
<td>-123.1</td>
<td>0.70</td>
<td>2.73/1000</td>
<td>92.8</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>23</td>
<td>-6.24/1000</td>
<td>-175.8</td>
<td>1.00</td>
<td>5.53/1000</td>
<td>128.6</td>
<td>0.98</td>
</tr>
<tr>
<td>Un-reinforced WU2</td>
<td>8</td>
<td>-3.01/1000</td>
<td>-166.5</td>
<td>0.95</td>
<td>3.38/1000</td>
<td>122.2</td>
<td>0.93</td>
</tr>
<tr>
<td>w/ 59.0kN vertical load</td>
<td>13</td>
<td>-4.29/1000</td>
<td>-185.6</td>
<td>1.06</td>
<td>4.33/1000</td>
<td>132.0</td>
<td>1.00</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>-5.90/1000</td>
<td>-204.3</td>
<td>1.16</td>
<td>6.16/1000</td>
<td>146.3</td>
<td>1.11</td>
</tr>
<tr>
<td>Un-reinforced WU3</td>
<td>9</td>
<td>-2.40/1000</td>
<td>-190.2</td>
<td>1.08</td>
<td>2.45/1000</td>
<td>168.4</td>
<td>1.31</td>
</tr>
<tr>
<td>w/ 87.8kN vertical load</td>
<td>10</td>
<td>-2.88/1000</td>
<td>-197.4</td>
<td>1.12</td>
<td>2.79/1000</td>
<td>176.5</td>
<td>1.37</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>-4.66/1000</td>
<td>-209.9</td>
<td>1.19</td>
<td>3.68/1000</td>
<td>184.7</td>
<td>1.40</td>
</tr>
<tr>
<td>Post damage</td>
<td>12</td>
<td>-2.91/1000</td>
<td>-147.0</td>
<td>0.84</td>
<td>3.59/1000</td>
<td>101.9</td>
<td>0.77</td>
</tr>
<tr>
<td>Strengthened WR1</td>
<td>21</td>
<td>-5.77/1000</td>
<td>-223.3</td>
<td>1.27</td>
<td>6.39/1000</td>
<td>161.3</td>
<td>1.23</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>-6.86/1000</td>
<td>-229.7</td>
<td>1.31</td>
<td>7.73/1000</td>
<td>168.3</td>
<td>1.28</td>
</tr>
<tr>
<td>Post damage</td>
<td>9</td>
<td>-2.66/1000</td>
<td>-115.6</td>
<td>0.66</td>
<td>2.94/1000</td>
<td>110.4</td>
<td>0.84</td>
</tr>
<tr>
<td>Strengthened WR2</td>
<td>14</td>
<td>-4.52/1000</td>
<td>-152.7</td>
<td>0.87</td>
<td>4.76/1000</td>
<td>146.8</td>
<td>1.12</td>
</tr>
<tr>
<td>W/ 59.0kN vertical load</td>
<td>21</td>
<td>-6.68/1000</td>
<td>-185.7</td>
<td>1.06</td>
<td>8.40/1000</td>
<td>181.6</td>
<td>1.36</td>
</tr>
</tbody>
</table>
3. ESTIMATE OF ULTIMATE LOAD

The brick arch simplified as frame model, and take linear elastic structural analysis. Taking the specimen of this study as an example, refer to the experimental results, assume the initial crack section E start a $45^\circ$ crack to spandrel then change to be developed horizontally as shown in Figure 5. In the limit performance state, the crack almost completely throughout the specimen, so assume that the arch stress equal to the flexural strength of the masonry, the corresponding horizontal force is the horizontal ultimate load $P_u$.

The simplified frame model is shown in Figure 6. The section properties of the members are:

The moment of inertia of member $b$, $I_b = \frac{23 \times 59.5}{12} = 403,736 \text{ cm}^4$

The section area of member $c$, $A_c = 48 \times 23 + 23 \times 47 = 2185 \text{ cm}^2$

The neutral axis of member $c$, $y_c = \frac{47 \times 23 \times 59.5 + 23 \times 48 \times 24}{2185} = 41.56 \text{ cm}$

The moment of inertia of member $c$, $I_c = \frac{47 \times 23^3 + 47 \times 23 \times (59.5 - 41.56)^2 + 23 \times 48^3 - 23 \times 48 \times (41.56 - 24)^2}{12} = 947,957 \text{ cm}^4$

Height of the frame, $h = 173.25 \text{ cm}$

Length of the frame, $l = 180.12 \text{ cm}$

$k = I_b / I_c \times h / l = 0.4097$

![Figure 5. Assumed initial crack position of brick arch specimen (unit:cm)](image)

![Figure 6. Analysis model for brick arch specimen (unit:cm)](image)

The bending moment $M_c$, horizontal internal force $H_c$ and vertical internal force $V_c$ of joint C as shown in Figure 7 could be derived by elastic analysis:

\[ M_c = \frac{P_h}{2} (1 + 6k) - \frac{3k}{6(2 + k)} \frac{w l^2}{2} \]  

\[ H_c = \frac{P_h}{2} + \frac{w l^2}{4h(2 + k)} \]  

\[ V_c = \frac{3P_h k}{l(1 + 6k)} - \frac{w l}{2} \]
From Eqn. 3.1 to Eqn. 3.3, the distributed vertical load \( w \) should consider the self weight of member BC in Figure 7. Consider the actual corner of the brick arch having a bigger section, and observe the damage mode and development of specimen, the crack position is simplified as shown in Figure 5. The corresponding load could be estimated.

The cross section area \( A_E = 47 \times 23 + 23 \times 68.09 = 2647.07 \text{ cm}^2 \)

The neutral axis of the section \( y_E = \frac{47 \times 23^3 + 47 \times 23 \times (79.59 - 52.64)^2 + 23 \times 68.09^3}{2647.07} \text{ cm} \)

The moment of inertia \( I_E = \frac{47 \times 23^3}{12} + \frac{47 \times 23 \times (79.59 - 52.64)^2 + 23 \times 68.09^3}{12} \text{ cm}^4 \)

\[
\text{The maximum flexural tensile stress for section E as crack initially}

\[
f_E = \frac{M_c y_E + V_c \sqrt{I_E} - H_c \sqrt{I_E}}{A_E}
\]

Substitute Eqn. 3.1 into Eqn. 3.3 \( M_c, H_c, V_c \) into Eqn. 3.4, may derive the ultimate load \( P_u \) of the specimen cracked

\[
P_u = \frac{F_b + w(l/6 + (2 + k) y_E) - \frac{l}{2(2+k) I_E} + \frac{l}{4h(2+k) \sqrt{2A_E}}}{h \left( \frac{M_c}{2I_E} \frac{y_E}{2} + \frac{1}{1+6k} \frac{1}{1/2A_E} \right)}
\]

The comparison of estimated and experimental horizontal ultimate load of specimen WU1, WU2 and WU3 is shown in Table 3. The error is small than 9\%, and it is conservative for practical application. As the vertical load increases, the error increases, this simplified model for seismic assessment is a conservative method for vertical load.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>( l ) (cm)</th>
<th>( h ) (cm)</th>
<th>( k )</th>
<th>Vertical Load ( (kN) )</th>
<th>Distributed Load, ( w ) (N/cm)</th>
<th>Estimated Ultimate Load, ( P_u ) (kN)</th>
<th>Experimental Ultimate Load (kN)</th>
<th>Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WU1</td>
<td>180.12</td>
<td>173.25</td>
<td>0.4097</td>
<td>12.2</td>
<td>78.06</td>
<td>175.4</td>
<td>175.8</td>
<td>-0.23%</td>
</tr>
<tr>
<td>WU2</td>
<td>180.12</td>
<td>173.25</td>
<td>0.4097</td>
<td>71.2</td>
<td>273.68</td>
<td>192.9</td>
<td>204.3</td>
<td>-5.58%</td>
</tr>
<tr>
<td>WU3</td>
<td>180.12</td>
<td>173.25</td>
<td>0.4097</td>
<td>100.0</td>
<td>393.96</td>
<td>201.4</td>
<td>219.5</td>
<td>-8.25%</td>
</tr>
</tbody>
</table>

![Figure 7](Figure 7. Free body on joint C of brick arch specimen)
4. STRENGTHENING STRENGTH OF MASONRY ARCH

According to the previous study, in general, using stainless steel strap for strengthening has shown the improvement of earthquake-resistance. The performance and comparison for different strengthening method are concluded as follows:

Assume the strain of stainless steel $\varepsilon_S$ is consistent with the bonded brick arch strain $\varepsilon_m$.

$$\varepsilon_S = \varepsilon_m = \frac{F_b}{E_m}$$  \hspace{1cm} (4.1)

Assume the cross section area $A_S$, and calculate the tensile force at the crack section

$$T_S = E_S \varepsilon_S A_S$$  \hspace{1cm} (4.2)

Where $F_b$ is the flexural strength, and $E_m$ is the limit elastic modulus of brick masonry. $E_S$ is the elastic modulus of stainless steel. For $\varepsilon_S > \varepsilon_y$, $\varepsilon_S$ must be replaced by $\varepsilon_y$

$$T_S = E_S \varepsilon_y A_S$$  \hspace{1cm} (4.3)

Assess the horizontal ultimate load $P_u$ of the brick arch before strengthening, then estimate based on previous method. Analyze the required horizontal ultimate load $P_{req}$ if $P_{req} \leq P_u$, the brick arch need not strengthen; while $P_{req} > P_u$, the brick arch need to be strengthened.

Using 2 thin stainless steel straps (10mm x 1mm) imbedded into the intrados face of the brick arch, the flat stainless strips will supply a tensile force $T_S$ at the crack (Figure 8), due to the effect of this tensile force, the ultimate strength of the masonry arch will increase $\Delta P_u$. The strengthening design process is as follows:

Transfer $T_S$ to an equivalent moment $M_S$

$$M_S = T_S j_d$$  \hspace{1cm} (4.4)

Where $j_d$ is the distance of the centroid of stainless strip to the compression center of brick arch (Figure 8c). Conservatively assumed as

$$j_d = d - \frac{d_c}{3}$$  \hspace{1cm} (4.5)

where

$d$ is the distance of the centroid of stainless strip to the edge of the section

d$_c$ is the distance of the neutral axis to the edge of the section.

The incremental ultimate load $\Delta P_u$ could be derived from Eqn. 3.1

$$\Delta P_u = \frac{2}{h} \left[ \frac{(1 + 6k)}{3k} M_s + \frac{M_s^2}{6(2 + k)} \right]$$  \hspace{1cm} (4.6)

Add horizontal ultimate load $P_u$ and $\Delta P_u$ to be $P_u'$, and compare $P_u'$ with $P_{req}$, if $P_u'$ smaller than $P_{req}$ then enlarge $A_S$ until $P_u' = P_u + \Delta P_u \geq P_{req}$.

Taking specimen WS1 as an example, the limit elastic modulus of masonry

$$E_m = 138 f_{mc} = 138 \times 0.27 f_{bc}^{0.7} f_{mc}^{0.3} = 1528 MPa$$
Use 2-10mm*1mm flat stainless strips with 2mm diameter holes to increase the bond of the slot, the section area $A_S=(10-2)*1*2=16 \text{ mm}^2$. The modulus of stainless steel $E_s=193 \text{ GPa}$.

The maximum strain of masonry $\varepsilon_m=F_b/E_m=0.00116 >$ yield strain of stainless steel $\varepsilon_y=0.00106$, and $T_s=E_s*\varepsilon_y*A_S=F_y*A_S=205*16=3280\text{ N}$.

![Figure 8](image)

**Figure 8.** Free body on joint C of brick arch specimen

**Table 4** is the calculated results of $\Delta P_u$, $P_u'$, and ultimate Load Ratio. The estimated strengthened horizontal ultimate strength $P_u'=188.6\text{ kN}$, this value is smaller than the experimental ultimate load 198$kN$ of WS1 (4.75%). This underestimated value is due to the fact that the neutral axis may move toward compression area after initial crack, and $j_d$ may larger than the assumed value. Besides, the curved shape effect of the stainless strips is not calculated.

Compare the reinforced $P_u'$ and $P_{req}$, and check the cross section area. Suppose the required ultimate load ratio $R_u$ of specimen WU1 is 1.15

$$P_{req}=175.4\text{ kN} * 1.15=201.7\text{ kN}$$

then the stainless section should be enlarged to 16mm (width) * 1.5mm (thickness) as shown in **Table 4**.

<table>
<thead>
<tr>
<th>Reinforcement (W<em>T</em>number)</th>
<th>$j_d$ (cm)</th>
<th>$M_S$ (kN-cm)</th>
<th>$\Delta P_u$ (kN)</th>
<th>$P_u$ (kN)</th>
<th>$P_u'$ (kN)</th>
<th>Ultimate Load Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>10mm<em>1mm</em>2</td>
<td>77.03</td>
<td>252.7</td>
<td>13.2</td>
<td>175.4</td>
<td>188.6</td>
<td>1.08</td>
</tr>
<tr>
<td>16mm<em>1.5mm</em>2</td>
<td>77.03</td>
<td>663.2</td>
<td>26.5</td>
<td>175.4</td>
<td>201.9</td>
<td>1.15</td>
</tr>
</tbody>
</table>

4. STRENGTHENING DESIGN

Taking the southern 2F brick arch of Li-Xian Building as an example, assess the horizontal ultimate load of the 2F semicircle brick arch. Choose one unit of the Li-Xian Building 2F arches (**Figure 9**). Refer to the investigation report (Hsu, et al. 2008), the shear stress of this wall $F_{ve}=1.933 \text{ kgf/cm}^2$, $\xi=2.07$.

Base shear stress of this wall $F_{ve}/\xi=1.933/2.07=0.934 \text{ kgf/cm}^2$

The shear of brick column =0.934*50*109*9.81/1000=49.9 $\text{ kN}$
Equivalent horizontal external load = 2*49.9=99.8 kN

**Figure 10** shows the details of the column, based on the dimension of the arch and column section, the ultimate load $P_u$ could be estimated. **Table 5** lists the results, brick arch ultimate load $P_u=77.2kN <99.8kN$ (equivalent horizontal external load). The assessment result of Li-Xian Building southern 2F brick arch shows that the arches need to be strengthened under seismic code load.

**Figure 9.** The element size of Li-Xian Building

**Table 5** Estimated horizontal ultimate load of Li-Xian Building unit brick arch

<table>
<thead>
<tr>
<th>$I_b$ (cm$^4$)</th>
<th>$A_c$ (cm$^2$)</th>
<th>$y_c$ (cm)</th>
<th>$I_c$ (cm$^4$)</th>
<th>$l$ (cm)</th>
<th>$h$ (cm)</th>
<th>$k$</th>
<th>Vertical Distributed Load $w$ (N/cm)</th>
<th>Estimated horizontal ultimate load $P_u$ (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3,572.396</td>
<td>5.450</td>
<td>25</td>
<td>1,135,417</td>
<td>313</td>
<td>483</td>
<td>4.8552</td>
<td>751.45</td>
<td>77.2</td>
</tr>
</tbody>
</table>

Taking the southern 2F brick arch of Li-Xian Building for example, the strengthening design is as follows:

Using 3-16mm*1.5mm flat stainless strips with 2mm diameter hole to increase the bonding of the slot, the cross area, $A_s=(16-2)*1.5*3=63$ mm$^2$.

**Table 6** is the calculated results of the increment ultimate load $\Delta P_u$ and The strengthened horizontal ultimate strength $P'_u$. The strengthened horizontal ultimate strength $P'_u=101.1kN>98.8kN$, shows that the arches will not damage seriously after strengthening under seismic code load.

**Table 6** the strengthening design of Li-Xian Building

<table>
<thead>
<tr>
<th>Reinforcement (W<em>T</em>number)</th>
<th>$d$ (cm)</th>
<th>$M_S$ (kN-cm)</th>
<th>$\Delta P_u$ (kN)</th>
<th>$P_u$ (kN)</th>
<th>$P'_u$ (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16mm<em>1.5mm</em>3</td>
<td>77.03</td>
<td>994.8</td>
<td>23.9</td>
<td>77.2</td>
<td>101.1</td>
</tr>
</tbody>
</table>
6. CONCLUSIONS

According to the test of designed brick arch specimens, in general, using flat stainless steel strips for strengthening has shown the improvement of earthquake-resistance. Through the study, the following results can be used as the reference of the repair assessment applications for the historical buildings:

1. Based on the test results, we suggest that drift angle 2/1000 could be assigned as the initial damage point, and drift angle 4/1000 to be the ultimate performance point for historic building seismic assessment.

2. Comparing the ultimate load evaluated by the simplified method and that obtained from test specimens, the difference is less than 6% for low or medium bearing and less than 9% for high bearing.

3. The strengthened strength evaluated by this simplified method may be undervalued.

4. The results obtained in this study will provide architect useful information for planning and design retrofitting of historic buildings.

ACKNOWLEDGEMENTS

This study was supported by the National Science Council, Taiwan, (NSC95-2221-E-006-437 and NSC97-2221-E-006-199). The authors are grateful to this support.

REFERENCES


