APPENDIX B:
LOAD ESTIMATION USING TRUSS ANALOGY METHOD

B.1 STRENGTH OF FRAME

B.1.(a) Tensile Cracking Strength of Windward Column :

\[ f_{ct} \] = Tensile strength of column concrete = 3.75 N/mm
\[ A_e = \text{Equivalent area} = A_c + (m - 1)A_{st} \]
\[ m = \frac{E_s}{E_c} = \frac{2.00 \times 10^5}{0.25 \times 10^5} = 8.00 \]
\[ A_{st} = \text{Area of reinforcement} = 865.875 \text{ mm}^2 \]
\[ A_e = 100 \times 200 + (8 - 1) \times 865.875 = 2606.1 \times 10^4 \text{ mm}^2 \]

Dead load of the structure on bottom storey of windward column = 5.111 kN.
Load for inception of first crack
\[ = A_e f_{ct} = 2.6061 \times 10^4 \times 3.75 = 97.729 \text{ kN} \]
Total upward force required for cracking = 97.729 + 5.111 = 102.840 kN
Force acting in the bottom storey of windward column = 2.839 H
Corresponding Equivalent Load, \( H = \frac{102.840}{2.839} = 36.224 \) kN
Base Shear = 36.224 X 3 = 108.672 kN

B.1.(b). Ultimate Tensile failure of Windward Column :

At the time of ultimate tensile failure, the entire concrete area of windward column was cracked. Hence effect of concrete is ignored.
\[ A_{st} = 865.875 \text{ mm}^2 \]
\[ f_y = 471 \text{ N/mm} \]
Tensile load to cause yielding of steel = 865.875 \times 471
\[ = 407.827 \text{kN} \]
Dead load on the column = 5.111 kN
Total load to cause yielding of steel = 407.827 + 5.111
\[ = 412.938 \text{kN} \]
Force acting in the first storey column = 2.839 H
Corresponding Equivalent Load \( H = \frac{412.93S}{2.839} = 145.452 kN \).

Base Shear \( = 145.452 \times 3 = 436.356 kN \)

**B.1.(c). Crushing strength of leeward column:**

Crushing Strength of leeward column
\[ = 0.4 f_{ck} A_c X 1.5 + 0.67 f_y A_{sc} X 1.15 \]

Cube Compressive Strength of concrete = 48.2 N/mm

Crushing Strength of concrete = \( 0.4 \times 48.2 \times (20000 - 865.875) \times 1.5 + 0.67 \times 471 \times 865.875 \times 1.15 = 867.590 kN \)

The dead load of the structure is to be subtracted from the crushing strength of concrete.

Net crushing strength of column concrete = 867.590 - 5.111 = 862.479 kN

Force acting in the leeward column of first storey = 1.743 \( H \)

Equivalent wind load, \( H = \frac{862.479}{1.743} = 494.824 kN \)

Base Shear = 494.824 \( \times 3 = 1484.472 kN \)

**B.2. STRENGTH OF BEAMS**

**B.2.(a) Cracking Strength of beams**:

Cracking Strength of beam concrete = \( A_c f_{ct} + (m - 1) A_s f_y \)

\[
A_c = \text{Area of concrete} = 100 \times 150 = 1.5 \times 10^4 \text{ mm} \\
f_{ct} = \text{Split tensile strength} = 3.23 N/mm \\
m = \frac{E_s}{E_c} = \frac{2 \times 10^5}{0.20 \times 10^5} = 10.00 \\
A_s = \text{Area of steel} = 288.625 \text{ mm} 
\]

Cracking strength = \( 1.5 \times 10^4 \times 3.11 + (10-1) \times 288.625 \times 3.11 = 54.729 kN \)

Force in beam 1 (left bay) = 0.332 \( H \)

Corresponding wind load = \( \frac{54.729}{0.332} = 164.846 kN \)

Force in beam 1 (Right bay) = 1.043 \( H \)

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Corresponding wind load = $\frac{54.729}{1.043} = 52.473$ kN
Base Shear = $52.473 \times 3 = 157.419$ kN

B.2.(b) Ultimate Tensile failure of beams:

Tensile load to cause yield of steel = $A_s t f_y$

$f_y$ = Yield stress of steel = 471 N/mm$^2$

$A_s t$ = Area of steel = 288.625 mm$^2$

Tensile load to cause yield = $288.625 \times 471$

= 135.942 kN

Force component in beam 1 (left bay) = $0.332 H$

Corresponding wind load = $\frac{135.942}{0.332} = 409.464$ kN

Base Shear = $409.464 \times 3 = 1228.392$ kN

Force in beam 1 (Right bay) = 1.043 H
Corresponding wind load = $\frac{135.942}{1.043} = 130.337$ kN

Base Shear = $130.337 \times 3 = 391.011$ kN

B.3. STRENGTH OF INFILL

Stafford Smith [7] recommended a parameter $\lambda h$ for calculating the strength of brick infill.

Parameter $\lambda = \sqrt{\frac{E_m t \sin^2 \theta}{4 E_c I_c h'}}$

The properties of the material of the infilled frame are obtained from experimental results.

$E_m = 0.630 \times 10^4$ N/mm$^2$, $E_c = 0.250 \times 10^5$ N/mm$^2$, $f_m = 3.38$ N/mm$^2$

Equivalent M.I = $96.3662 \times 10^6$ mm$^4$.

$\lambda = \frac{0.630 \times 10^4 \times 100 \times \sin 68.04^o}{4 \times 0.25 \times 10^5 \times 96.3662 \times 10^6 \times 675} = 0.003079$

Non-dimensional parameter = $\lambda h = 0.003079 \times 750 = 2.3093$
Panel ratio = $l' : h' = 1000 : 675 = 1.481 : 1$
Based on $\lambda h = 2.3093$ and panel ratio $1.481:1$ the different modes of failure of infill will now be considered.

B.3.(a) Shearing Strength of Brickwork:

The shearing strength of brickwork is calculated using the design curves given by Smith [7]. The following empirical relationship has been obtained by Govindan [44] using the design curves taking $\mu = 0.6$.

\[
\frac{R_s}{f_s h t} = 1.85 \left[ \frac{l'/h'}{h} \right]^{0.6} \left[ \lambda h \right]^{-0.05} \sqrt{f_s h_t}
\]

\[
\frac{R_s}{f_s h t} = 1.85 \left[ \frac{1000}{675} \right]^{0.6} [2.3093]^{-0.05} \sqrt{1000/675}
\]

\[
= 1.85 \times 1.2660 \times 0.9503 = 2.2257
\]

\[
f_s = 0.112 N/mm^2 \text{ as per IS 1905-1987 [55]}
\]

\[
R_s = 2.2257 \times 0.112 \times 750 \times 100
\]

\[
= 18690 N = 18.690 kN
\]

Force Component in Panel 1 (left bay) = 1.571H

Corresponding equivalent wind load = 18.690

\[
\frac{18.690}{1.571} = 11.897 kN
\]

Base shear = 11.897X3 = 35.691 kN

Force Component in Panel 1' (right bay) = 1.967H

Corresponding equivalent wind load = 18.690

\[
\frac{18.690}{1.967} = 9.502 kN
\]

Base Shear = 9.502X3 = 28.506 kN

B.3.(b) Diagonal Cracking Strength of brickwork:

Similar to shear strength of brickwork, the following empirical relationship can be used to predict the tensile strength of brickwork.

\[
\frac{R_t}{f_t h t} = 3.1 \left[ \frac{l'/h'}{h} \right]^{0.06} \left[ \lambda h \right]^{-0.11(l'/h')}^{0.47}
\]

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\[
\frac{R_t}{f_t \cdot ht} = 3.1 \left[ \frac{1000}{675} \right]^{0.56} \left[ 2.3093 \right]^{-0.14} (1000/ht)^{0.47}
\]

Assume \( f'_t = 0.07 \) N/mm\(^2\)

\( R_t = 4.088 \times 0.070 \times 750 \times 100 = 21462 \) N = 21.462 kN

**Force Component in Panel 1 (left panel)**

\[ 1.571H \]

**Corresponding equivalent wind load,** \( H = \frac{21.462}{1.571} = 13.670kN \)

**Base Shear** = \( 13.670 \times 3 = 41.010 \) kN

**Force Component in Panel 1’ (right panel)**

\[ 1.967H \]

**Corresponding equivalent wind load,** \( H = \frac{21.462}{1.967} = 10.911kN \)

**Base Shear** = \( 10.911 \times 3 = 32.733 \) kN

**B.3.(c) Crushing Strength of Brickwork**:

Generally, crushing takes place in the corner region of the infill. Smith [7] has recommended the following appropriate formula taking \( \mu = 0.6 \).

\[
\frac{R_c}{f'_m \cdot ht} = \frac{\pi \cdot S_{cc} \cdot \theta}{2 \lambda h} = \frac{\pi \cdot sec 34.02^\circ}{2 \times 2.3093} = 0.821
\]

\( R_c = 0.821f'_m \cdot ht = 0.821 \times 3.38 \times 750 \times 100 = 208124 \) N = 208.124 KN.

**Force Component in Panel 1 (left panel)**

\[ 1.571H \]

**Corresponding equivalent wind load,** \( H = \frac{208.124}{1.571} = 132.479kN \)

**Base Shear** = \( 132.479 \times 3 = 397.437 \) kN

**Force Component in Panel 1’ (right panel)**

\[ 1.967H \]

**Corresponding equivalent wind load,** \( H = \frac{208.124}{1.967} = 105.808kN \)

**Base Shear** = \( 105.808 \times 3 = 317.424 \) kN

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Table. B.1 Strength of Columns (Base Shear)

<table>
<thead>
<tr>
<th>Storey Level</th>
<th>Windward Column</th>
<th>Middle Column</th>
<th>Leeward Column</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>First Cracking</td>
<td>Ultimate Tensile</td>
<td>First Cracking</td>
</tr>
<tr>
<td></td>
<td>Strength in kN</td>
<td>Strength in kN</td>
<td>Strength in kN</td>
</tr>
<tr>
<td>1</td>
<td>108.672</td>
<td>436.356</td>
<td>408.771</td>
</tr>
<tr>
<td>2</td>
<td>140.691</td>
<td>412.338</td>
<td>865.494</td>
</tr>
<tr>
<td>3</td>
<td>197.970</td>
<td>785.640</td>
<td>734.280</td>
</tr>
<tr>
<td>4</td>
<td>375.210</td>
<td>876.132</td>
<td>1880.514</td>
</tr>
<tr>
<td>5</td>
<td>645.348</td>
<td>1518.237</td>
<td>1182.189</td>
</tr>
</tbody>
</table>

Table. B.2 Strength of Beams (Base Shear)

<table>
<thead>
<tr>
<th>Storey Level</th>
<th>Left bay</th>
<th>Right bay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cracking Strength in kN</td>
<td>Ultimate Tensile Strength in kN</td>
</tr>
<tr>
<td>1</td>
<td>494.538</td>
<td>1228.392</td>
</tr>
<tr>
<td>2</td>
<td>171.564</td>
<td>426.150</td>
</tr>
<tr>
<td>3</td>
<td>1292.811</td>
<td>3211.227</td>
</tr>
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<td>4</td>
<td>326.982</td>
<td>585.724</td>
</tr>
<tr>
<td>5</td>
<td>443.694</td>
<td>794.787</td>
</tr>
</tbody>
</table>

B.4. ULTIMATE LOAD CARRYING CAPACITY

Using the above procedure the strength of columns, beams and brick panels in all the storeys and both the bays were calculated and are given in Tables B.1. to B.3. The tensile cracking of column and shear and diagonal cracking of infill will not initiate the final collapse of the structure. From the analysis of strength of frame and strength of infill the ultimate failure load works out to H = 137.446 kN and the corresponding base shear is 412.338 kN.
Table. B.3 Strength of Infills (Base Shear)

<table>
<thead>
<tr>
<th>Storey Level</th>
<th>Left bay</th>
<th>Right bay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shearing Strength in kN</td>
<td>Diagonal Cracking Strength in kN</td>
</tr>
<tr>
<td>1</td>
<td>35.691</td>
<td>41.010</td>
</tr>
<tr>
<td>2</td>
<td>51.660</td>
<td>63.909</td>
</tr>
<tr>
<td>3</td>
<td>43.008</td>
<td>54.703</td>
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<tr>
<td>4</td>
<td>98.342</td>
<td>127.446</td>
</tr>
<tr>
<td>5</td>
<td>71.143</td>
<td>94.373</td>
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</tbody>
</table>