Chapter 10

Reinforced Rat-trap Bond Masonry infilled RC frames with Horizontal Reinforcement (GRTIH):

10.1 Introduction:

As the literature reports that the reinforcement in the masonry can alter the total dynamic behavior of the frame in this study the behavior of reinforced rat-trap bond masonry infilled RC frames with horizontal reinforcement is studied. The behavior is compared with bare RC frame, plain masonry infilled RC frame and GRTI. Table no.10.1 shows the nomenclature of the models studied. Fig.10.1 shows the typical discretized model.

Table 10.1

<table>
<thead>
<tr>
<th>Sr No</th>
<th>Model No</th>
<th>Aspect Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GRTIH4023</td>
<td>1.23</td>
</tr>
<tr>
<td>2</td>
<td>GRTIH 4523</td>
<td>1.41</td>
</tr>
<tr>
<td>3</td>
<td>GRTIH 5023</td>
<td>1.60</td>
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</tbody>
</table>

Fig.10.1 : Typical Discretized Model

10.2 Natural frequency:

Ten modal frequencies are captured. It is observed that the natural frequency of frame with aspect ratio 1.60 has increased by 19.39% when compared with natural frequency of frames with aspect ratio 1.23. The variation in the natural frequency with the aspect ratio is shown in the fig.10.2 and the typical mode shapes are shown in fig.10.3.

Fig.10.2: Natural frequency
Reinforced Rat-trap Bond Masonry infilled RC frames with Horizontal Reinforcement

Mode 1

Mode 2

Mode 3

Mode 4

Mode 5

Mode 6

Aspect Ratio 1.60

Fig. 10.3: Mode shapes of Reinforced rat-trap Bond Masonry infilled RC frames
10.3 Stiffness:

The effect of lateral earthquake excitation on stiffness is studied. The typical deflection contours are presented in fig.10.4. The variation of components of deflection for difference aspect ratio is presented in Fig. 10.5.

10.3.1 Deflection:

Load case 1: GRTIH shows additional resistance towards the lateral sway. The X-component of deflection reduces as the aspect ratio increases and the reduction varies from 18.08% to 31.50%. In case of Y-component the reduction varies from 10.67% to 19.92% the Z-component of deflection is insignificant.

When compared to bare RC frame the X-component of deflection reduces and the reduction varies from 71.66% to 74.56%. In case of Y-component increase in deflection is noticed and the increase varies from 4.65% to 25%.

When compared to plain masonry infilled RC frame the deflection reduces from 7.56% to 28.36% in X and Y components of deflection. Higher reduction is noticed in case of X-component and it varies from 22.34% to 28.36% as the aspect ratio increases.

When compared to GRTI the deflections in all the three components have reduced and the reduction is higher in case of the X-component and it varies from 4.45% to 6.36%. The variation in deflection is almost negligible in Z-component.

Load case 2: In this case the X-component of deflection reduces and reduction varies from 17.90% to 30.92%. The Z-component of deflection is almost negligible.

When compared to bare RC frame the deflection has reduced in accordance with the variation in aspect ratio and it varies from 71.64% to 74.35% in the X-component. In the other two components the increase in deflection is observed except for the frame with aspect ratio 1.23 and 1.60, where the reduction is observed in the Z-component which is about 15%.

When compared to plain masonry infilled RC frame the deflection has reduced in all the three components and the reduction varies from 7.38% to 27.23%. When compared to GRTI deflection has reduced but the percentage of reduction is less and it varies from 1.69% to 5.67% in the X and Y-components.
Reinforced Rat-trap Bond masonry infilled RC frames with Horizontal Reinforcement

Zone 4

Zone 5

Kobe

MX : Maximum deflection; MN = Minimum deflection

(a) X- Component  (b) Y- Component

Aspect Ratio: 1.23, Masonry with Horizontal Reinforcement

Fig. 10.4: Deflection Contours of Reinforced rat-trap Bond Masonry infilled RC frames
**Load case 3:** In this case maximum deflection is noticed in the X-component. The deflection increases from 10.29 to 15.40 mm as the aspect ratio decreases. In case of Y-component the deflections are less than 2.5 mm and the deflection in Z-component is insignificant.

When compared to bare RC frame the reduction in the X-component is predominant and it varies from 75.28\% to 77.75\%.

When compared to plain masonry infilled RC frame the reduction in X-component of deflection is observed in all the three components and it varies from 10.09\% to 29.48\%.

When compared to GRTI reduction is observed in all the three components and since X and Y-components are predominant the reduction varies from 2.46\% to 6.28\%.

Maximum deflection in the X-component is located at the top right hand corner, whereas the maximum deflection in the Y-component is located in the top floor left column for all load cases.
10.4 Stresses:

The variation of the stresses for different aspect ratios and load cases is studied.

10.4.1 Normal Stresses:

The typical contours and the variation of stresses is shown in figure 10.6, 10.7 and 10.8.

Load case 1:

a) RC frame: The stresses vary from 1.13 to 7.64 N/mm². In case of the X-component the stresses have decreased and decrease varies from 3.50% to 12.98%. The Y-components of stresses are higher when compared to X-component and the stresses reduced as the aspect ratio increased. The Z-components of stresses are less than 1.5 N/mm².

a) Masonry: Stresses are higher in the Y-component and they varied from 0.367 to 0.465 N/mm². The stresses in the X and Z-components are insignificant.

When compared to bare RC frame the stresses in the frame decrease in the X-component and the decrease varies from 59.73% to 69.61%. In the other two components the increase in stresses is noticed and the increase varies from 27.51% to 40.21%.

When compared to plain masonry infilled RC frame the stresses have reduced in all the three components and the higher reduction is observed in case of X-component and it varies from 16.67% to 17.63%. In case of the masonry stresses have increased and the higher increase is noticed in case of Y-component. The stresses have almost doubled. The stresses in the Z-component have increased by about 50%.

When compared to GRTI the stresses in the frame have reduced and the reduction varies from 0.131% to 2.745%. The highest reduction is noticed in case of X-component, which is around 2.3%. The masonry stresses have also increased and the higher increase is noticed in case of Y-component and it varies from 15.96% to 16.13%.

Load case 2:

a) RC frame: In this case the stresses vary from 1.74 to 11.6 N/mm². In this load case also the stresses in the Y-component are higher. The stresses have reduced as the aspect ratio increases from 12.6 to 23.10% in the Y component.

b) Masonry: The stresses vary from 0.069 to 0.60 N/mm². Masonry stresses in the Y-component are higher. The stresses in the Z-component are almost negligible.
Reinforced Rat-trap Bond masonry infilled RC frames with Horizontal Reinforcement

Zone 4

Zone 5

Kobe

MX : Maximum stress; MN = Minimum stress

(a) infilled RC frame (IFF) (b) Masonry (MS)

Aspect Ratio: 1.23, Masonry with Horizontal Reinforcement

Fig. 10.6: Normal Stress Contours of Reinforced rat-trap Bond Masonry infilled RC frames (X-Component)
Reinforced Rat-trap Bond masonry infilled RC frames with Horizontal Reinforcement

Zone 4

Zone 5

Kobe

MX : Maximum stress; MN = Minimum stress

(a) infilled RC frame (IFF) (b) Masonry (MS)

Aspect Ratio: 1.23, Masonry with Horizontal Reinforcement

Fig. 10.7: Normal Stress Contours of Reinforced rat-trap Bond Masonry infilled RC frames (Y-Component)
When compared to bare RC frame as in case of load case 1 the stresses in the frame have reduced and the reduction varies from 60% to 69.50%. The stresses in the frame have increased in the other two components and the increase varies from 27.37% to 40.26%.

In comparison with plain masonry infilled RC frame it is observed that the stresses in the frame have reduced in all the three components and the reduction varies from 4.91% to 17.76%. The masonry stresses have increased in all the three components. And the increase is almost 100% in case of the Y-component. In case of X-component the increase in masonry stresses vary from 11.88% to 19.00%.

In comparison with GRTI predominant reduction in stresses of the frame is noticed only in case of X-component and it is around 2.5%. The masonry stresses have also increased and the increase is higher in case of Y-component and it varies from 15.95% to 16.31%.

Load case 3:

a) RC frame: The stresses vary from 4.6 to 32.3 N/mm² in this case also the stresses in the Y-component are higher. In all the three components the stresses have reduced as the aspect ratio increases and the reduction varies from 14.46% to 25.53% in the Y-component.

b) Masonry: The stresses are higher when compared to load case 1 and load case and they increases from 0.195 to 1.970 N/mm².

The maximum normal stress in the X-component is located at bottom right corner, whereas the maximum stress in the masonry is located in the ground floor infill panel at the left corner in all load cases for all load cases.

When compared to bare RC frame the stresses have decreased in the X-component and decrease varies from 64.92% to 73.34%. In the other two components the stresses have increased and the increase varies from 10.18% to 22.24%.

When compared to plain masonry infilled RC frame the stresses in the frame have reduced predominantly in the X-component and it varies from 19.14% to 20.47%. The reduction in the other two components varies from 7.71% to 11.32% In case of the masonry stresses the increase in stresses is noticed in all the three components. The
increase in stresses is higher in case of Y-component and it is almost 100% when compared to plain masonry infilled RC frame.

When compared to GRTI the stresses in the frame have decrease in all the three components and the higher decrease is noticed in case of the X-component, which is around 2.5%. The masonry stresses have increased in all the three components and the increase is higher in case of Y-component and increase is about 15%.

![Graphs showing stresses in different components](image)

**Fig. 10.8**
Maximum Normal Stress

**10.4.2 Principal Stresses:**

The typical contours and the variation of stresses is shown in figure 10.9, 10.10 & 10.11.

**Load case 1:**

*a) RC frame:* The stresses vary from 0.773 to 7.71 N/mm². The maximum stresses are noticed in first principal stress. The reduction in the first principal stress is noticed as the aspect ratio increases. The similar reduction is also noticed in the second principal and the third principal stress. In case of second principal and third principal stress, the stresses vary from 0.773 to 1.92 N/mm². In case of the second principal stress the negligible stress difference is noticed for aspect ratio 1.41 and 1.61.
Reinforced Rat-trap Bond masonry infilled RC frames with Horizontal Reinforcement

a) Masonry: Stresses vary from 0.010 to 0.526 N/mm$^2$. The second and third principal stresses in the masonry are almost negligible. The masonry stresses are higher in case of the first principal stress and they increase from 0.430 to 0.526 N/mm$^2$.

Fig. 10.9: Principal Stress Contours of Reinforced rat-trap Bond Masonry infilled RC frames (1$^\text{st}$ Principal Stress)

MX : Maximum stress; MN = Minimum stress
(a) infilled RC frame (IFF) (b) Masonry (MS)
Aspect Ratio: 1.23, Masonry with Horizontal Reinforcement
Reinforced Rat-trap Bond masonry infilled RC frames with Horizontal Reinforcement

(a) infilled RC frame (IFF)                  (b) Masonry (MS)

Aspect Ratio: 1.23, Masonry with Horizontal Reinforcement

Fig. 10.10: Principal Stress Contours of Reinforced rat-trap Bond Masonry infilled RC frames
            (2nd Principal Stress)
When compared to bare RC frame the decrease in principal stresses in frames is noticed in first principal and second principal stress and it varies from 1.60% to 55.140%. The higher decrease is noticed in case of the second principal stress and it varies from 27.78% to 55.14%. Similar decrease is also noticed in case of the third principal stresses.

When compared to plain masonry infilled RC frame the reduction in principal stresses is noticed in first, second and third principal planes. The reduction varies from 1.942% to 15.044%. The reduction is higher in the third principal plane and it varies from 11.42% to 15.04%. The increase in masonry stresses is noticed and the higher increase is noticed in case of the third principal stress. In case of the masonry stress in the first principal plane the increase varies from 74.79% to 80.75% and the increase is about 50% in case of the second principal stress.

When compared to GRTI the stresses in the frame decrease in the first and second principal planes and decrease is about 2% in case of the second principal stress. Increase in stress is noticed in case of the third principal stress. Masonry stresses have increased in all the three planes. Higher increase is noticed in case of the first principal stress, and it varies from 13.45% to 14.59%.

**Load case 2:**

a) **RC frame**: The stresses vary from 1.170 to 11.700 N/mm$^2$. Higher stresses in the frame are observed in the first principal plane.

b) **Masonry**: The stresses are higher in the first principal plane and the stresses increase from 0.652 to 0.797 N/mm$^2$ as the aspect ratio decreases. The masonry stresses in the second and third planes are almost negligible.

When compared to bare RC frame the stresses have reduced and the reduction varies from 1.92% to 55.23% in the first two principal planes. Higher reduction is observed in the second principal plane. The stresses have increased in third principal plane, but the values are almost negligible.

When compared to plain masonry infilled RC frame the stresses in the frame have reduced in all the three principal strains and the reduction varies from 1.92% to 14.91%. The reduction is higher in case of the second principal stress. Increase in masonry stresses is observed in this comparison. Higher increase in masonry stresses is noticed in third
principal plane but the stresses are negligible. The dominant stresses are in the first principal plane and the increase in the stress is in the range of 74.79% to 80.31%.

When compared to GRTI the frame stresses have increased and the increase is marginal in the first two planes, whereas in the third principal plane, the marginal increase is noticed in the stresses. In case of the masonry stresses, the stresses are increased and higher increase is noticed in case of the first principal stress and it varies from 13.5% to 14.51%.

**Load case 3:**

*a) RC frame:* The principal stresses in the frame vary from 1.170 to 11.700 N/mm². The stresses have increased when compared to load case 1 and load case 2. The stresses have decreased as the aspect ratio increases.

*b) Masonry:* The stresses vary from 0.012 to 0.79 N/mm². Higher stresses are observed in the first principal plane. The increase in aspect ratio as resulted in the decrease of stresses.

When compared to bare RC frame the stresses in the frame have reduced in the first and second principal planes and the reduction varies from 14.41% to 60.77%. The stresses have increased in the third principal plane and the increase varies from 5.97% to 32.35%.

When compared to plain masonry infilled RC frame the stresses in the frame have reduced in all the three planes. Higher reduction is noticed in case of second principal stress and the decrease varies from 12.96% to 17.14%. The masonry stresses have increased in all the three principal planes, the stresses in the Z-component are almost negligible. The masonry stresses in the first principal plane have increased predominantly and the increase varies from 69.23% to 76.19%.

When compared to GRTI the stresses in the frame have decreased in the first and second principal plane whereas they have increased in the third principal plane. Higher decrease in stresses is observed in case of the second principal stress and it varies from 1.98% to 2.98%. The stresses in the frame have increased in all the three planes. The increase in the first principal stress varies from 12.82% to 13.82%.
Reinforced Rat-trap Bond masonry infilled RC frames with Horizontal Reinforcement

The maximum first principal stress is located at bottom right corner at support, whereas the maximum stress in the masonry is located at bottom left corner in the ground floor panel in all load cases.

![Graphs showing principal stress distributions](image)

(a) 1st Principal Stress  
(b) 2nd Principal Stress  
(c) 3rd Principal Stress

**Fig. 10.11 Maximum Principal Stress**

10.4.3 Shear Stress

The typical contours and the variation of stresses is shown in figure 10.12, 10.13 & 10.14.

**Load Case 1:**

a) *RC frame:* The stresses vary from 0.065 to 1.08 N/mm². Higher stresses are observed in the XY plane. The stresses in the frame for aspect ratio 1.41 have increased in comparison with the stresses of aspect ratio 1.23 in the XY plane.

b) *Masonry:* The stresses are almost negligible in YZ and XZ planes. In case of XY plane the stresses increase from 0.206 to 0.230 N/mm².
When compared to bare RC frame the XY plane stresses in the frame have reduced and the reduction varies up to 45.85%. The increase in stress is noticed in case of YZ plane.

When compared to plain masonry infilled RC frame the stresses in the XY plane have decreased for aspect ratio 1.23 and they have increased for the aspect ratios. The stresses in the YZ plane have increased and the increase varies from 47.47% to 51.35%. The stresses in the XZ plane reduce and the reduction varies from 10.20% to 13.71%. The masonry stresses have increased predominantly in the YZ plane but the stresses are almost negligible. The increase in the stresses in the XY plane varies from 25.61% to 29.94%.

Shear stresses have increased in XY and YZ planes when compared with GRTI. Higher increase is noticed in case of YZ plane and it varies from 62.2% to 67.16%. The masonry stresses have also increased and the increase is about 100% in case of the stresses along YZ plane but they are insignificant.

**Load case 2:**

a) **RC frame**: Shear stresses vary from 0.099 to 1.490 N/mm². The stresses are higher in case of frames with aspect ratio 1.41 in the XY plane. When compared with load case 1 the stresses have increased by 33%.

b) **Masonry**: Stresses in the XY plane vary from 1.390 to 1.490 N/mm². The stresses in the other two planes are almost insignificant.

When compared to bare RC frame the stresses in the frame have decreased in the XY and XZ planes, but they have increased in the YZ plane varies from 26.18% to 54.54%. The reduction in the XY plane varies up to 45.42%.

When compared to plain masonry infilled RC frame the stresses in the frame have increased in the XY and YZ plane, whereas they have decreased when compared to stresses in the XZ plane. Predominant increase is noticed in case of the YZ plane and it varies from 47.65% to 51.78%. The masonry stresses in the XY plane have increased, and the increase varies from 25.70% to 29.85%.

When compared to GRTI the stresses in the frame have increased in all the three planes and the variation in the YZ plane is from 62.96% to 75.28%. The masonry stresses have also increased and the increase in XY plane varies from 7.5% to 8.7%.
Reinforced Rat-trap Bond masonry infilled RC frames with Horizontal Reinforcement

Zone 4

Zone 5

Kobe

MX: Maximum stress; MN = Minimum stress

(a) infilled RC frame (IFF)  (b) Masonry (MS)

Aspect Ratio: 1.23, Masonry with Horizontal Reinforcement

Fig. 10.12: Shear Stress Contours of Reinforced rat-trap Bond Masonry infilled RC frames (XY-Plane)
Reinforced Rat-trap Bond masonry infilled RC frames with Horizontal Reinforcement

(a) infilled RC frame (IFF)  
(b) Masonry (MS)

Aspect Ratio: 1.23, Masonry with Horizontal Reinforcement

Fig. 10.13: Shear Stress Contours of Reinforced rat-trap Bond Masonry infilled RC frames (YZ-Plane)

MX : Maximum stress;  MN = Minimum stress
Load case 3:

a) RC frame: The stresses increases from 0.264 to 4.140 N/mm² which are higher when compared to the other two load cases. Higher stresses are observed in the XY plane. The stresses decrease as the aspect ratio increases, except in the case of aspect ratio 1.41, where the increase in stress is noticed.

b) Masonry: Stresses increases from 0.008 to 0.973 N/mm². The stresses are higher in XY plane. The stresses are insignificant in XZ and YZ planes.

The maximum shear stress is located at bottom right hand corner in the frame, whereas the maximum shear stress in the masonry is located at bottom right hand corner of the ground floor infilled panel in XY plane in all load cases.

When compared to bare RC frame the stresses in the frame decrease in XY plane and XZ plane, whereas the increase in the YZ plane. Higher increase is noticed in case of YZ plane. The masonry stresses also increase and the increase varies from 21.47% to 26.20% in the XY plane.

When compared to plain masonry infilled RC frame the stresses in the frame increased in XY and YZ planes and the increase is predominant in YZ plane and it varies from 44.07% to 47.74%. The stresses in the frame reduce in the XZ plane. The reduction remains...
Reinforced Rat-trap Bond masonry infilled RC frames with Horizontal Reinforcement

varies from 10.75% to 15.92%. The stresses in the masonry have been increased in all the three planes. The increase in masonry stress in the XY plane varies from 21.47 to 26.2%.

When compared to GRTI the stresses in the frame have increased in XY and YZ planes. Higher increase is noticed in case of YZ plane, where the increase varies from 62.57 to 72.83%. The masonry stresses also have increased in the XY and YZ planes. The stresses in the XY plane have increased and the increase varies from 6.70% to 8.26%.

10.5 Acceleration:

The acceleration contours and variation of acceleration is shown in Fig. 10.15 and 10.16.

Load case 1: The acceleration increases from 0.015 to 8.735 m/sec\(^2\). In all the three planes the acceleration varies in accordance with the aspect ratios. As the AR increases the acceleration increases in Y and Z-components, whereas, it reduces in case of the X-component. The acceleration in the Z-component is almost negligible.

When compared to CBF the acceleration has increased in all the three components. In the X-component the increase in acceleration is varies from 11.68% to 13.94%. Substantial increase in acceleration is noticed in case of the Y-component where, the increase is about 3.5 times.

When compared to EBI the increase in acceleration is observed and it is higher in case of the Y component and it varies from 21.60% to 28.65%. The increase in acceleration in the X component is around 2.5%.

In comparison with GRTI it is observed that, the acceleration has increased and the increase in acceleration along the Y component is predominant, it varies from 3.42% to 4.05%.

Load Case 2: The acceleration increases from 0.025 to 13.236 m/sec\(^2\). In this case also the acceleration in Y and Z-component has increased as the aspect ratio increases. But again the reduction is observed in case of X-component, where the acceleration is higher.

When compared to bare RC frames the acceleration has increased in all the three components. Higher increase is noticed in case of Y and Z-components, which is around 300%. The increase in acceleration along the X-component varies from 11.70% to 13.51%.
Reinforced Rat-trap Bond masonry infilled RC frames with Horizontal Reinforcement

When compared to plain masonry infilled RC frame the acceleration has increased and it varies from 1.75% to 23.64%.

When compared with GRTI it is observed that, the acceleration has increased in the first two components and it varies from 0.4% to 4.04%.

Fig. 10.15: Acceleration Contours of Reinforced rat-trap Bond Masonry infilled RC frames
Load case 3: The acceleration increases from 0.069 to 36.872 m/sec\(^2\). These values are higher when compared to load case 1 and load case 2. In case of the X component the acceleration reduces as the aspect ratio increases, whereas in case of Y and Z component it is vice versa.

When compared to bare RC frames the acceleration has increased in Y and Z-components whereas it has decreased in the X component.

When compared to plain masonry infilled RC frames the acceleration has increase in the Y and Z component, whereas it has marginally reduced in the X component. The increase in acceleration in the Y component varies from 18.31% to 25.12%.

When compared to GRTI again it is observed that, the acceleration have marginally increased in the Y component but the difference is very much minimum.

10.6 Summary

- The presence of steel has substantially altered the dynamic behavior of the masonry infilled RC frames.
• Presence of reinforced infill strongly influences the structural response. The trend is favourable for designing an effective bracing system for lateral loads.

• Stiffness of the system has increased substantially as is demonstrated by reduction in lateral sway. Both frame and reinforced infill have contributed for the increase in stiffness.

• Strength of RC frames with reinforced masonry infill has increased in good measure as can be seen from considerable decrease in stresses in comparison to infilled RC frames with plain masonry/grouted masonry without reinforcement. This is an indication of better participation of infill with stresses getting distributed well across the frame and infill.

• Although reinforcing with steel has increased the stresses in the masonry infill the stress values are high in the ground floor panel and are around the periphery of the infill and diminish rapidly towards the center.

• The acceleration in members of the RC frame with reinforced infill has reduced in the lateral direction due to the increase in stiffness of the system.