Chapter 11

Reinforced Rat-trap bond Masonry infilled RC frames with Vertical Reinforcement (GRTIV)

11.1 Introduction:

In this study the behavior of grouted rat-trap bond masonry with vertical reinforcement is studied. The behavior is compared with bare RC frame, plain masonry infilled RC frame, GRTI and GRTIH. The table no.11.1 shows the nomenclature of the models studied. Fig.11.1 shows the typical descritized model.

<table>
<thead>
<tr>
<th>Sr No</th>
<th>Model No</th>
<th>Aspect Ratio</th>
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<tbody>
<tr>
<td>1</td>
<td>GRTIV4023</td>
<td>1.23</td>
</tr>
<tr>
<td>2</td>
<td>GRTIV 4523</td>
<td>1.41</td>
</tr>
<tr>
<td>3</td>
<td>GRTIV 5023</td>
<td>1.60</td>
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</tbody>
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Fig.11.1: Typical Descritized Model

11.2 Natural frequency:

Ten modal frequencies are captured. It is observed that the natural frequency has increased as the aspect ration increases. The variation in the natural frequency with the aspect ratio is shown in the fig.11.2 and the typical mode shapes are shown in fig11.3.
**Reinforced Rat-trap bond masonry infilled RC frames with Vertical Reinforcement**

Fig. 11.3: Mode Shapes of Reinforced rat-trap Bond Masonry infilled RC frames

Aspect Ratio 1.60, with horizontal and vertical reinforcement
11.3 Stiffness:

The behavior of the frames under the earthquake induced lateral excitation is studied. The typical deflection contours are presented in fig.11.4. The variation of components of deflection for different aspect ratio is presented in Fig. 11.5.

11.3.1 Deflection:

Load case 1: Grouted rat-trap bond masonry infilled RC frames with vertical reinforcement showed an improved resistance towards the lateral sway. The X-component of deflection reduces as aspect ratio increases and reduction varies from 18.34% to 31.48%. In case of Y-component the reduction varies from 10.79% to 19.42%. The Z-component of deflection is almost negligible.

When compared to bare RC frame the X-component of deflection reduces and the reduction varies from 72.23% to 75.07%. The increase in deflection in the Y-component varies from 4.18% to 18.29%.

When compared to plain masonry infilled RC frame the deflection has reduced in all the three components. In the X-component the reduction in deflection varies from 23.91% to 29.79%. Similarly in case of Y-component the reduction varies from 8.55% to 9.31%.

It is observed that, the deflection has reduced in all the three components and the higher reduction is observed in case of X-component and it varies from 6.38% to 8.24% when compared with GRTI.

When compared to GRTIH, marginal reduction in deflection is observed in the X-component and it varies from 2% to 2.3%. In other two components it is negligible.

Load case 2: In this case the X-component of deflection reduces and the reduction varies from 18.15% to 31.27%. Reduction is also noticed in the Y-component. The Z-component of deflection is almost negligible.

When compared to bare RC frame, the deflection has reduced in X-component and the reduction varies from 72.21% to 74.99%. In case of the Y-component of deflection has reduced and the reduction varies from 4.46% to 18.59%. Higher reduction is noticed in case of the frames with aspect ratio 1.23.
Reinforced Rat-trap bond masonry infilled RC frames with Vertical Reinforcement

Fig. 11.4 Deflection Contours of Reinforced rat-trap Bond Masonry infilled RC frames
When compared to plain masonry infilled RC frame, it is observed that the deflection reduces in all the three components. The reduction in deflection in X-component varies from 23.97% to 29.06% and in case of Y-component the reduction is around 9%.

When compared to GRTI, the deflection has reduced in all the three components and the reduction varies from 6.59% to 8.04% in the X-component. The reduction in the Y-component varies from 2.33% to 3.10%.

When compared to GRTIH, the reduction of deflection in the X-component varies from 2.0 to 2.51% and the reduction varies from 1.18% to 1.3% in case of Y-component.

The maximum X-component of deflection in all the load cases is located at the top right hand corner and the maximum deflection in the Y-component is located at top floor left column.

Load case 3: In this case the maximum deflection is noticed in the X-component. The deflection varies from 0.020 to 15.062 mm. In case of Y-component the deflections are less than 2.5 mm and the deflection in Z-component is almost negligible. The deflection has increased when compared to load case 1 and load case 2 to a larger extent.
When compared to bare RC frame, the deflection has reduced predominantly in the X-component and it varies from 75.82% to 78.41%. Marginal variation is noticed in the Y-component.

When compared to plain masonry infilled RC frame, the deflection has reduced in all the three components and the deflection varies from 26.05% to 31.52% in the X-component and 11.22% to 12.46% in the Y-component.

When compared to GRTI, the reduction in deflection is noticed in all the three components. The reduction in X-component varies from 7.19% to 8.99% and it varies from 3.70% to 4.30% in the Y-component.

When compared to GRTIH, marginal reduction is observed in X and Y-components. The reduction in X-component of deflection varies from 2.19% to 2.89% and reduction varies from 1.26% to 1.51% in case of Y-component.

11.4: Stresses

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

11.4.1 Normal stresses:

The typical contours and the variation of stresses is shown in figure 11.6, 11.7 and 11.8.

Load case 1:

a) RC frame: The stresses vary from 1.13 to 2.80 N/mm². In case of X-component the stresses decreased and decrease varies from 3.92% to 13.57%. 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.

b) Masonry: Stresses vary from 0.048 to 0.945 N/mm². The stresses are higher in the X-component. The stresses are almost negligible in the Z-component.

When compared to bare RC frame, the stresses in the frame have reduced in the X-component and reduction varies from 60.61% to 70.14%. The frame stresses have increased in the Y and Z-component.

When compared with plain masonry infilled RC frame, it is observed that the stresses in the frame have reduced in all the three components. A higher reduction was observed in the X-component and it varies from 18.48% to 19.60%. In case of the masonry stresses, higher increase is observed in the Y-component and the increase varies
Reinforced Rat-trap bond masonry infilled RC frames with Vertical Reinforcement

from 115% to 122%. In the X-component the increase in masonry stresses varies from 21.68% to 25.37%.

When compared with GRTI, the stresses in the frame decrease in all the three components. The reduction in stresses in the X-component varies from 4.11% to 5.09%. The masonry stresses have increased in all the three components. Higher increase is noticed in case of Y-component and it varies from 21.83% to 23.44%. In the X-component the increase in stress varies from 5.20% to 16.66%.

When compared to GRTI, the reduction in the stresses of the frame is observed in all the three components. The reduction in the Y-component varies from 1.92% to 2.60% which is higher when compared to other two components. The masonry stresses have increased in the X-component and the increase varies from 4.88% to 6.08%. The variation is almost negligible in case of other two components.

Load case 2:

a) RC frame: In this case the stresses vary from 1.71 to 11.50 N/mm². In this case also the stresses in the Y-component are higher. The stresses reduce as the aspect ratio increases.

b) Masonry: The stresses vary from 0.073 to 0.750 N/mm². The masonry stresses are higher in case of Y-component.

When compared to bare RC frame, the stresses in the X-component decrease and the percentage decrease varies from 60.76% to 70.14%. In case of the Y-component of stresses the increase varies from 26.51% to 37.93%.

When compared to plain masonry infilled RC frame the stresses in the frame have reduced in all the three components. The higher reduction is observed in case of X-component and it varies from 18.40% to 19.51%. Masonry stresses have increased in the Y-component and increase varies from 112% to 114%. Masonry stresses of X-component have increased and the percentage increase varies from 21.60% to 25.74%.

When compared to GRTI, the stresses in the frame have reduced in all the three components. Higher reduction is observed in the X-component and it varies from 4% to 4.92%. Increase in masonry stresses is noticed in all the three components and in case of Y-component the increase varies from 21.92% to 23.55.
Reinforced Rat-trap bond masonry infilled RC frames with Vertical Reinforcement

When compared to GRTIH, the stresses in the frame have reduced and the reduction in the X-component varies from 1.92% to 2.1%. The masonry stresses have increased in the Y-component and the increase varies from 5.03% to 6.23%.

Fig. 11.6: Normal Stress Contours of Reinforced rat-trap Bond Masonry infilled RC frames (X-Component)
Reinforced Rat-trap bond masonry infilled RC frames with Vertical 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 Vertical Reinforcement

Fig. 11.7: Normal Stress Contours of Reinforced rat-trap Bond Masonry infilled RC frames (Y-Component)

147
Load case 3:

a) RC frame: In this case stresses vary from 4.580 to 32.100 N/mm². In this case also Y-component stresses are higher. In all the three components the stresses reduce as the aspect ratio increases.

b) Masonry: The stresses in the masonry are predominant in the Y-component and they vary from 1.57 to 2.09 N/mm².

When compared to bare RC frame the stresses in the frame reduce in the X-component and the reduction varies from 65.84% to 74%. In the other two components the stresses have increased.

When compared to plain masonry infilled RC frame the stresses in the frame have decreased in all the three components. Higher decrease is observed in case of X-component and the decrease varies from 21.27% to 22.44%. The stresses in masonry have increased and the percentage increase is higher in case of Y-component and the increase varies from 1.06 to 1.09 times.
When compared to GRTI, the stresses in the frame have reduced in all the three components. The maximum reduction is noticed in case of X-component and it varies from 4.83% to 5.28%. In the other two components the reduction is less than 2%. The masonry stresses have increased in all the three components. It is noticed that the increase in stresses are higher in the Y-component and it varies from 20.76% to 22.94%.

When compared to GRTIH the stresses in the frame have reduced in all the three components. The reduction varies from 2.47% to 2.63% in the X-component and it is less than 1% in the other two components. The masonry stresses have increased and the higher increase is observed in case of Y-component and it varies from 4.66% to 6.09%.

The normal stresses are maximum in the bottom right hand corner, whereas the normal stresses are maximum in the masonry in the bottom panel in the X-component for all load cases.

11.4.2 Principal stresses:

The typical contours and the variation of stresses is shown in figure 11.9, 1.10 and 11.11.

Load case 1:

a) RC frame: The stresses vary from 0.767 to 7.680 N/mm². The maximum stresses are noticed in the 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.

b) Masonry: The stresses vary from 0.012 to 0.558 N/mm². The second and third principal stresses in the masonry are almost negligible. The masonry stresses are higher in case of the first principal stresses.

When compared to bare RC frame, the principal stresses decrease in the first principal plane and second principal plane and the stresses increase in the third principal plane. A decrease of 19.4% is observed in case of first principal stress for aspect ratio 1.23.

When compared to plain masonry infilled RC frame, the principal stresses decrease in all the three planes. The maximum reduction is observed in the second principal stresses and it varies from 12.06% to 17.25%. Similarly it is noticed that the
Reinforced Rat-trap bond masonry infilled RC frames with Vertical Reinforcement

Stresses in the masonry have increased in all the three planes. The increase in first principal stress varies from 83.33% to 91.75%.

Variation is also observed when the stresses are compared with GRTI. The stresses in the frame have reduced in the first principal plane and second principal plane. The predominant stress reduction is noticed in second principal plane and the reduction varies from 3.8% to 5.5%.

When compared to GRTIH, marginal variation is noticed in all the three planes. These stresses have reduced in all the planes and predominant reduction is noticed in the second principal stress and it varies from 1.92% to 2.60%. The stresses in the masonry have also varied and the stresses in first principal plane have increased and increase in stresses varies from 4.88% to 6.08%.

Load case 2:

a) RC frame: The stresses vary from 1.16 to 7.6 N/mm². Higher stresses in the frame are observed in the first principal plane.

b) Masonry: The stresses are higher in the first principal plane. The masonry stresses are almost negligible in the second principal plane and third principal plane.

When compared to bare RC frame, the variation is almost similar to the variation observed in load case 1. The stresses have decreased in all the three planes.

When compared to plain masonry infilled RC frame, the stresses in the frame have reduced in all the three planes and the reduction in the second principal plane varies from 12.50% to 16.95%. The masonry stresses have also increased in the first principal plane, the increase in masonry stresses varies from 83.37% to 91.17%.

When compared to GRTI, the stresses in the frame have reduced in the first principal plane and second principal plane, whereas increase is observed in case of the third principal plane. The stresses in the second principal plane decrease and it varies from 3.78% to 5.0%. The decrease is lower in case of frames with aspect ratio 1.41 and it is higher with other two aspect ratios. The masonry stresses have increased and the percentage increase in the first principal plane varies from 19.16% to 21.40%.

Variation is also observed when the stresses are compared with GRTIH. The stresses have reduced in the frame in all the three principal planes. The maximum reduction is noticed in the second principal stress and it varies from 2.13% to 2.53%. The
Reinforced Rat-trap bond masonry infilled RC frames with Vertical Reinforcement

Masonry stresses increase predominantly in the first principal plane and the increase varies from 4.90% to 6%.

Fig. 11.9: Principal Stress Contours of Reinforced rat-trap Bond Masonry infilled RC frames (1st Principal Stress)

(a) infilled RC frame (IFF)  
(b) Masonry (MS)  
Aspect Ratio: 1.23, Masonry with Vertical Reinforcement
Reinforced Rat-trap bond masonry infilled RC frames with Vertical 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 Vertical Reinforcement

Fig. 11.10: Principal Stress Contours of Reinforced rat-trap Bond Masonry infilled RC frames (2nd Principal Stress)
Load case 3:

a) RC frame: The principal stresses vary from 3.12 to 32.000 N/mm$^2$. The stresses have increased when compared to load case 1 and load case 2. The masonry stresses vary from 0.041 to 2.350 N/mm$^2$.

b) Masonry: Higher stresses are observed in the first principal plane. The stresses reduce as the aspect ratio increases.

When compared to bare RC frame the stresses in the frame have reduced in the first principal plane and second principal plane, whereas they have increased in third principal plane. In the first principal stress the decrease in stress varies from 15.03% to 30.5% whereas in case of second principal stress, the decrease varies from 39.21% to 61.93%.

When compared to plain masonry infilled RC frame the stresses in the frame have reduced in all the three planes. The reduction in the first principal and second principal stress varies from 9.34% to 19.59%. The masonry stresses have increased in all the three principal planes. The increase in the first principal stress varies from 76.92% to 86.50%.

When compared to GRTI marginal reduction in the stresses of the frame is noticed in the first principal and second principal planes. The masonry stresses have increased in
all the three principal planes and the predominant increase is noticed in the first principal stress and it varies from 17.94% to 20.51%.

When compared to GRTIH the stresses in the frame have reduced in all the three principal planes. The higher reduction is noticed in case of second principal stress and it varies from 2.34% to 2.95%. The stresses in the masonry have increased marginally. Higher increase is noticed in case of first principal stress and the increase varies from 4.54% to 5.85%.

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

11.4.3. Shear stresses:

The typical contours and the variation of stresses is shown in figure 11.12, 11.13 & 11.14.

Load case 1:

a) RC frame: The stresses in the frame vary from 0.067 to 1.110 N/mm². Higher stresses were observed in the XY plane. The stresses reduce as the aspect ratio increase in all the three planes.

b) Masonry: The masonry stresses are almost negligible in YZ and XZ planes. In case of XY plane the stresses vary from 0.213 to 0.239 N/mm².

When compared to bare RC frame the stresses in the frame have reduced in the XY plane and XZ plane and stresses increase in the YZ plane.

When compared to plain masonry infilled RC frame the stresses in the frame have shown mixed response in case of frames with aspect ratio the decrease in stresses is around 16.52%, whereas in case of aspect ratio 1.41 the increase in stress is around 18%. The marginal variation is observed in case of frames with aspect ratio 1.60. The increase in frame stresses is about 50% in case of the YZ plane. The masonry stresses also have increased in all the three planes. The stresses in the masonry have increased predominantly in the XY plane and vary from 29.80% to 35%.

When compared to GRTI the stresses in the frame have reduced in all the three planes, but the reduction is higher in XY plane and it varies from 62.1% to 65.6%. In case of the masonry stresses increase is observed in all the three principal planes. The percentage increase varies from 10.93% to 12.78% in case of the XY plane.
Reinforced Rat-trap bond masonry infilled RC frames with Vertical Reinforcement

When compared to GRTIH the stresses in the frame have increased in the XY and XZ planes. Marginal increase is noticed in these two planes. The masonry stresses have increased in the XY plane and it varies from 2.44% to 3.95%.

Fig. 11.12: Shear Stress Contours of Reinforced rat-trap Bond Masonry infilled RC frames (XY-Plane)
Reinforced Rat-trap bond masonry infilled RC frames with Vertical 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 Vertical Reinforcement

Fig. 11.13: Shear Stress Contours of Reinforced rat-trap Bond Masonry infilled RC frames (YZ-Plane)

156
Reinforced Rat-trap bond masonry infilled RC frames with Vertical Reinforcement

**Load case 2:**

*a) RC frame:* The shear stresses in the frame vary from 0.001 to 1.670 N/mm². The stresses are higher in case of frames with aspect ratio 1.41 in the XY plane.

*b) Masonry:* The stresses were increased when compared to load case 1. The masonry stresses in the XY plane vary from 0.324 to 0.362 N/mm². The stresses in the other two planes are almost negligible.

When compared to bare RC frame the stresses in the frame have reduced in case of XY and XZ planes and they have increased in the YZ plane.

When compared to plain masonry infilled RC frame the stresses in the frame have increased in XY and YZ plane and they have reduced in the XZ plane. The masonry stresses have also increased in all the three planes.

When compared to GRTI the stresses in the frame have increased in all the three planes. Higher increase is noticed in YZ plane and it varies from 62.77% to 73.19%. The masonry stresses also have increased in XY and YZ plane; they have reduced in the XZ plane. The increase in masonry stresses in XY plane varies from 11.34% to 12.42%.

When compared to GRTIH the stresses in the frame have increased in all the three principal planes correspondingly the masonry stresses also have increased. The increase in masonry stresses in the XY plane varies from 2.38% to 3.7%.

**Load case 3:**

*a) RC frame:* The stresses in the frame vary from 0.270 to 4.570 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.

*b) Masonry:* The masonry stresses vary from 0.009 to 1.010 N/mm². The stresses are higher in XY plane. The stresses are almost negligible in XZ and YZ planes.

When compared to bare RC frame the stresses in the XY and XZ planes have reduced and the stresses in the YZ plane have increased. The stresses in the YZ plane have increased as the aspect ratio increased whereas; in case of the XY plane shear stresses have reduced as the aspect ratio increases.

When compared to plain masonry infilled RC frame the stresses in the XY and YZ plane have increased. Higher increase is noticed in case of YZ-component and it varies
Reinforced Rat-trap bond masonry infilled RC frames with Vertical Reinforcement

from 42.65% to 45.80%. The stresses have decreased in the XZ plane and the decrease percentage varies from 10.26% to 15.6%. When compared with the masonry stresses, the stresses have increased in all the three components. The increase in stresses in XY plane varies from 25.07% to 30.99%.

The variation is also observed when the behavior is compared with GRTI. The stresses in the frame have increased in all the planes. Higher increase is noticed in case of YZ plane and it varies from 61.18% to 70.56%. The masonry stresses have increased in XY plane and YZ plane. The masonry stresses have increased in XY and YZ planes.

When compared with GRTIH the stresses in the frame have reduced in the YZ plane and the reduction varies from 0.85% to 1.3%. In other two planes the stresses have marginally increased. The masonry stresses have also increased. The percentage increase in the XY plane varies from 1.96% to 3.80%.

The maximum shear stress in the XY plane is located at the bottom right hand corner in the frame and the maximum stresses in the masonry are located in the bottom panel for all load cases.

Fig. 11.14
Maximum shear Stress
11.5 Acceleration:

The acceleration contours are shown in fig 11.15 and the variation of acceleration is shown in Fig. 11.16.

Load case 1: The acceleration varies from 0.017 to 8.743 m/sec². In all the three planes the acceleration varies in accordance with the aspect ratios. As the aspect ratio 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 bare RC frames the acceleration has increased in all the three components. When compared with plain masonry infilled RC frames the acceleration has increased in all the three components and the increase varies from 2.25% to 31.16%. When compared with GRTI the acceleration has increased and the increase varies from 0.49% to 6.66%. When compared with GRTIH in this case also the acceleration has increased in all the three components.

Load case 2: The acceleration varies from 0.026 to 13.248 m/sec². 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 increase in all the three components. Similar increase in acceleration is noticed when compared with plain masonry infilled RC frames. When compared with GRTI and GRTIH the increase in acceleration is noticed in all the three components. Higher increase in acceleration is noticed in the Y-component.

Load case 3: The acceleration varies from 0.072 to 36.824 m/sec². These values are higher when compared with 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 decreased and the decrease percentage in the X component varies from 1.149% to 3.495% whereas the acceleration is increased in the Y and Z component. When compared with plain masonry infilled RC frames the acceleration has reduced in X component whereas it is increased in Y and Z component. Similar observation is noticed when compared with GRTI and GRTIH.
Reinforced Rat-trap bond masonry infilled RC frames with Vertical Reinforcement

MX : Maximum acceleration;  MN = Minimum acceleration

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

Aspect Ratio: 1.23, Masonry with Vertical Reinforcement

Fig. 11.16: Acceleration Contours of Reinforced rat-trap Bond Masonry infilled RC frames
Reinforced Rat-trap bond masonry infilled RC frames with Vertical Reinforcement

11.6 Summary

- The presence of infill has further reduced the structural drift marginally, while increasing the strength and stiffness, in comparison with horizontally reinforced infilled RC frame as the reinforcement is taken inside the beams in all the floors.

- Infill walls when present in the structure have brought down the principal and normal stresses in the RC members while increasing the additional reserve strength in the members of the frame. Stresses have concentrated in the lower panels normally around the periphery, while reducing towards the center. The stresses are localized in nature.

- The masonry stresses have marginally increased due to the composite action indicating a better structural response to the earthquake excitations.

- Due to the increase in stiffness there is an increase in the acceleration along the Y-component while it has reduced in the X-component.