# NUMERICAL ANALYSIS OF RC SLAB STRENGHTENED WITH CFRP STRIPS, MILD STEEL LAMINATES, CARBON FIBRE ROD UNDER GRADUALLY APPLIED LOAD AND IMPACT LOAD

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**Abstract -** Reinforced concrete slab is an essential component in all kind of structures. They are subjected to impact loads from accidental mishaps like falling of construction equipment, rocks and boulders which are not considered in structural design. But current advancements in computational techniques make it possible to obtain the response of slabs subjected to impact load.

This study aims to investigate the behaviour of RC slab strengthened with Carbon fibre-reinforced polymer (CFRP) strips, mild steel laminates and carbon fibre rod through a numerical simulation using ANSYS Workbench.

In the preliminary stage of study, a three-dimensional (3D) finite element (FE) model is developed to simulate the response of strengthened reinforced concrete (RC) slabs under gradually applied load and then the load deformation diagram and stiffness of the slab is evaluated in this study. In next phase, the response of strengthened RC slab shall be evaluated under an impact load.

In final phase of study, an optimal configuration of slab is obtained in accordance with the stiffness of the strengthened slabs. It can thus be concluded that the developed FE model could be used as a platform to predict the behaviour of reinforced concrete slabs when strengthened with CFRP strips, mild steel laminates and carbon fibre rod.

**Keywords:** *Impact load, Gradually applied load, CFRP, Mild steel, Carbon fibre rod, Finite element model, ANSYS*

## 1.INTRODUCTION

Concrete is still being considered and used in the construction of structures for public and defense establishments. Extreme loadings in the form of explosion, projectile impact, landslip, wind loading and ground vibrations by earthquake are usually common. Short duration loadings with high strain rate such as impact induce an impulsive effect on the structure and may damage a structure or its components beyond repair.

Reinforced concrete (RC) slabs are essential components in all kind of buildings. They are subjected to impact loadings due to accidental mishaps such as falling of objects from upper floor and falling of construction equipments, rocks, boulders etc. Under impact loading, the performance of RC slabs differs from that under static loading owing to the strain rate effect and inertial effect. The general problem of impact is extremely complex. Impact loading causes large displacements, material non-linearity, elastic and plastic instability, post-buckling strength, coulomb friction and material behaviour under high strain rates in concrete structures.

Impact loads are not considered in the structural design that is, the structure is not designed for such impulsive loadings and understanding of the structural response under such loadings are incomplete. But current advancements in computational techniques makes it possible to obtain response of slabs subjected to impact load. Finite element methods can provide an effective solution for analysing such impact loading problems.

## 2. OBJECTIVE

- To find deformation and stiffness of conventional RC slab under gradually applied load and impact load
- To find deformation and stiffness of RC slab externally strengthened with CFRP strips and mild steel laminates under gradually applied load and impact load
- To find deformation and stiffness of RC slab internally strengthened with carbon fibre rods under gradually applied load and impact load
- To compare models using contour plots and tabulation of results

## 3. METHODOLOGY

The whole project is divided into sequential steps. The following flow chart represents the methodology of the work:

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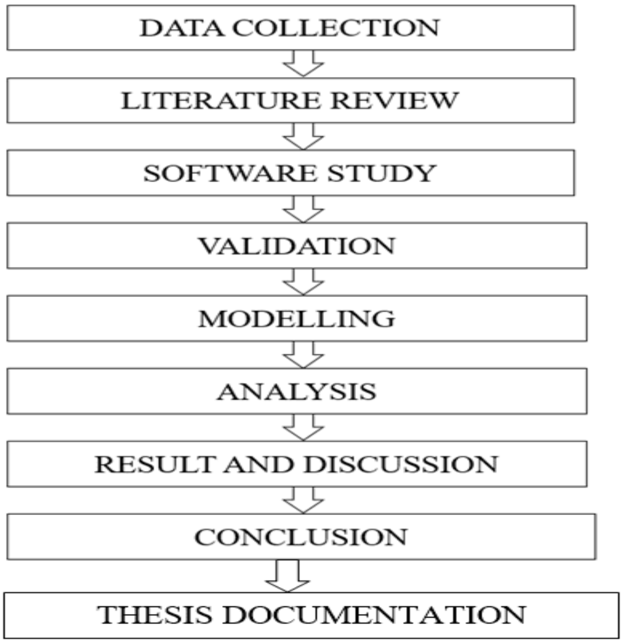


## 4. NUMERICAL MODELLING

Two way reinforced concrete slab of size 1500 x 1450 x 200 mm is modelled in Ansys software. 8 mm diameter bars are given at 100mm spacing. Materials such as CFRP, mild steel and carbon fibre rods are used for strengthening the RC slab. CFRP strips and mild steel laminates are provided with a thickness of 10 mm and 5mm respectively. Properties of the materials used for modelling is shown in table 4.1.

Table 5.1 Material properties

| **Materials** | **PROPERTIES** | | | |
|---|---|---|---|---|
| | Young's Modulus (GPa) | Poisson's ratio | Compressive strength (MPa) | Yield strength (MPa) |
| Concrete | 30 | 0.18 | 40 | - |
| Steel | 200 | 0.3 | - | 415 |
| CFRP | 220 | 0.2 | - | 1230 |
| Mild steel | 200 | 0.28 | - | 250 |
| Carbon fibre rod | 500 | 0.3 | - | 2500 |

There are 6 models in total including conventional reinforced concrete slab. Each reinforced concrete slab had a different strengthening scheme as described below:

Table 4.2 Model name and description

| **Model name** | **Model description** |
|---|---|
| RCS | Conventional reinforced concrete slab |
| CFRP-1 | Reinforced concrete slab externally strenghtened with CFRP strips horizontally |
| CFRP-2 | Reinforced concrete slab externally strenghtened with CFRP strips vertically in both direction |
| CFRP-3 | Reinforced concrete slab externally strenghtened with CFRP strip horizontally in both direction |
| MS | Reinforced concrete slab externally strenghtened with mild steel laminate |
| CF ROD | Reinforced concrete slab internally strenghtened with carbon fibre rod |

Fig. 4.1 shows conventional reinforced concrete slab with no strengthening.

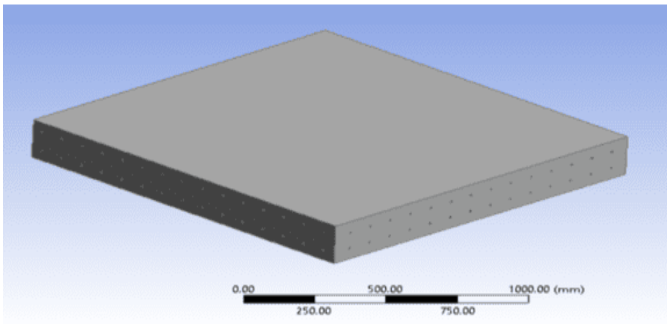


Fig. 4.1 Conventional reinforced concrete slab

Fig. 4.2 shows reinforced concrete slab externally strengthened with CFRP strips oriented along the length of the slab. Here CFRP strips are provided with 10 mm thickness.

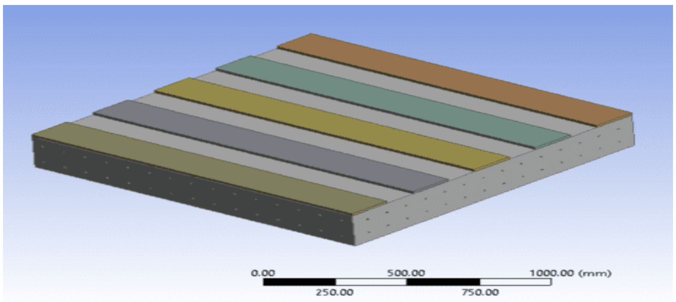


Fig. 4.2 Reinforced concrete slab externally strengthened with CFRP-1

Fig. 4.3 shows reinforced concrete slab externally strengthened with CFRP strips vertically oriented along the length and width of the slab and with CFRP laminates wrapped around the sides. Here the CFRP strips are provided with a thickness of 10 mm and with 20 mm depth.

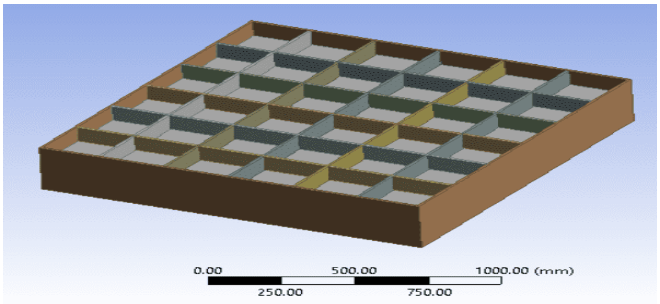


Fig. 5.3 Reinforced concrete slab externally strengthened with CFRP -2

Fig. 4.4 shows reinforced concrete slab externally strengthened with CFRP strips of 10 mm thickness horizontally oriented along the length and width of the slab and with CFRP laminates wrapped around the sides.

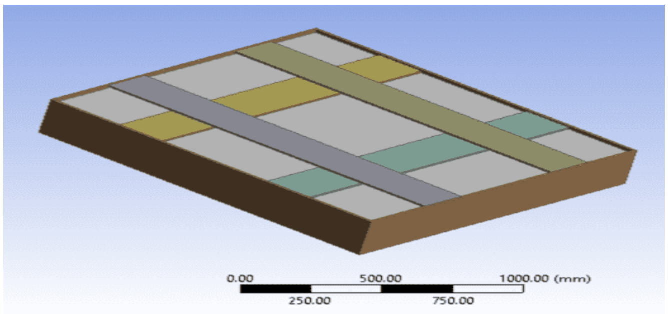


Fig: 4.4 Reinforced concrete slab externally strengthened with CFRP -3

Fig. 4.5 shows reinforced concrete slab externally strengthened with mild steel laminates of thickness 5 mm attached to the bottom of the slab.

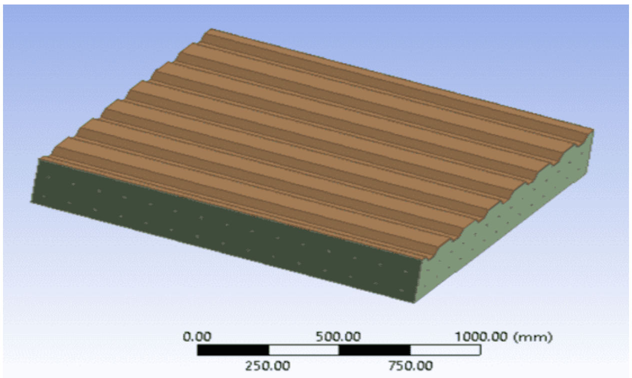


Fig. 4.5 Reinforced concrete slab externally strengthened with MS

Fig. 4.6 shows reinforced concrete slab internally strengthened with carbon fibre rod.

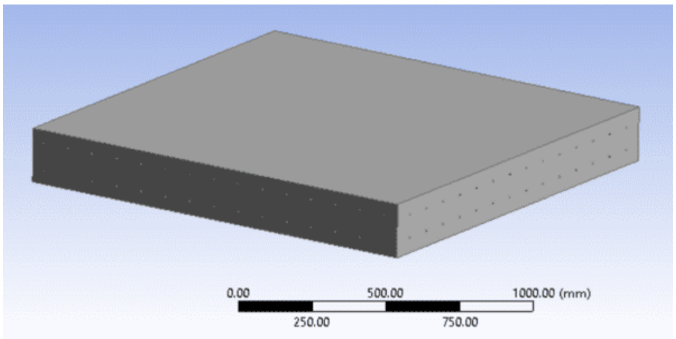


Fig. 5.6 Reinforced concrete slab internally strengthened with CF rod

## 5.MESH CONVERGENCE STUDY

Mesh convergence determines how many elements are required in a model to ensure that the results of an analysis are not affected by changing the size of the mesh. System response (stress, deformation) will converge to a repeatable solution with decreasing element size.

Table of Design Points

| | A | B | C |
|---|---|---|---|
| 1 | Name | P1 - Body Sizing Element Size | P2 - Total Deformation Maximum |
| 2 | Units | mm | mm |
| 3 | DP 0 (Current) | 100 | 0.071627 |
| 4 | DP 1 | 110 | 0.071618 |
| 5 | DP 2 | 120 | 0.071056 |
| 6 | DP 3 | 90 | 0.071816 |
| 7 | DP 4 | 80 | 0.071819 |
| 8 | DP 5 | 70 | 0.071915 |
| 9 | DP 6 | 60 | 0.071961 |
| 10 | DP 7 | 50 | 0.071976 |
| * | | | |

Fig. 5.1 Table showing element size and corresponding deformation

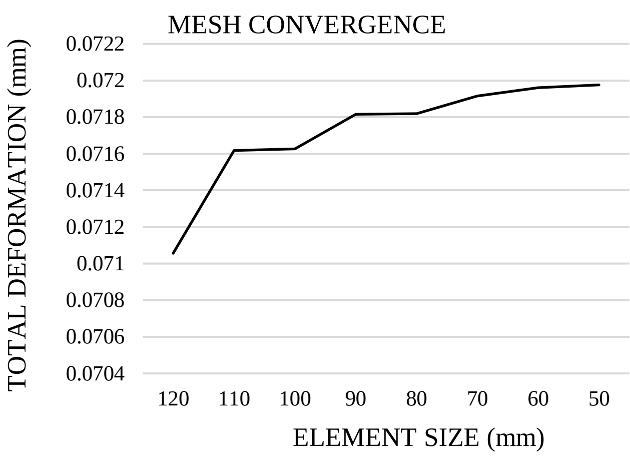


Fig. 5.2 Graphical representation of mesh convergence

From the above graph the total deformation corresponding to element size 100 mm and 110 mm converges to a same value. From this mesh size of 100 mm can be adopted.

Table 5.1 Mesh sizing adopted

| Feature | Element size (mm) |
|---|---|
| Body sizing | 100 |
| Face sizing | 5 |

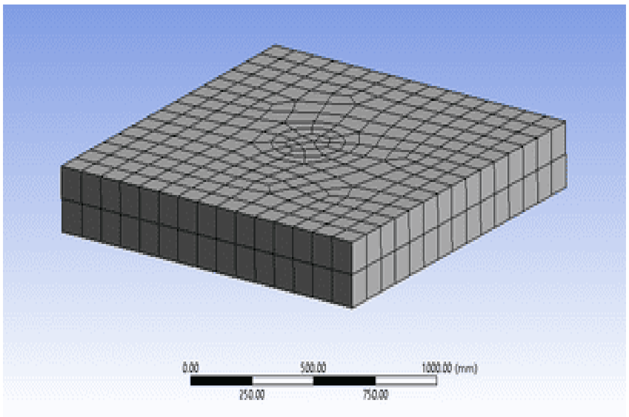


Fig. 5.3 Meshing of RC slab

## 6. NUMERICAL ANALYSIS

Analysis of reinforced concrete slab is done in this thesis using ANSYS 18.1. ANSYS is the most advanced, comprehensive finite element analysis and design software available for structural engineering. It is a unique and powerful tool having a wide range of civil engineering applications.

### 6.1 GRADUAL LOAD ANALYSIS

Gradual load is the type of load that starts from zero and increases gradually till the body is fully loaded. The reinforced concrete slab under different strengthening schemes i.e. conventional RC slab without strengthening, RC slab externally strengthened with CFRP and mild steel laminates and RC slab internally strengthened with carbon fibre rod are analyzed under gradual load of 100 kN using ANSYS 18.1.

Table 6.1 Gradual load parameters

| | | |
|---|---|---|
| Load type | | Gradually applied load |
| Force | | 100 kN |
| Analysis settings | Define by | Substeps |
| | Number of substeps | 20 |
| | Auto time stepping | on |
| | Step end time | 1s |
| Support condition | | Fixed |
| Loading region | | Centre of slab |

#### 6.1.1 Analysis of conventional RC slab without strengthening

Reinforced concrete slab of size 1500 x 1450 x 200 mm provided with 8 mm diameter bars at 100 mm spacing is analysed using ANSYS. Fig. 6.1 depicts the geometry of conventional RC slab.

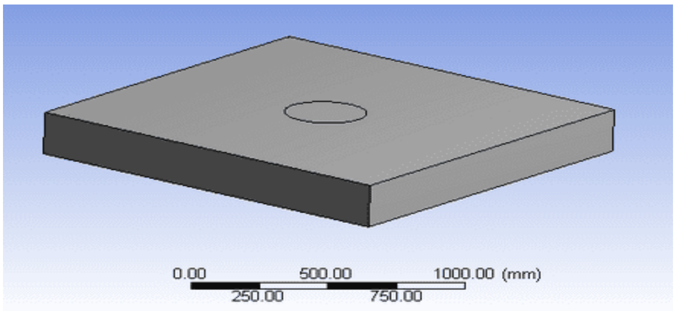


Fig. 6.1 Geometry of RCS

Fig. 6.2 shows meshing of conventional RC slab. The RC slab is provided with mesh size of 100 mm which is obtained after mesh convergence study.

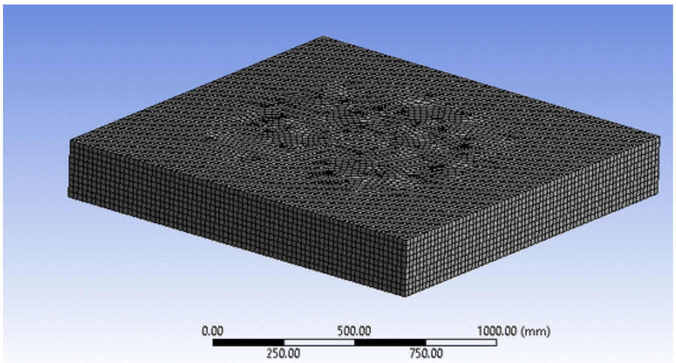


Fig. 6.2 Meshing of RCS

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Fig. 6.3 shows the boundary conditions provided. The RC slab is provided with fixed support condition and a gradual load of 100 kN at the centre of slab.

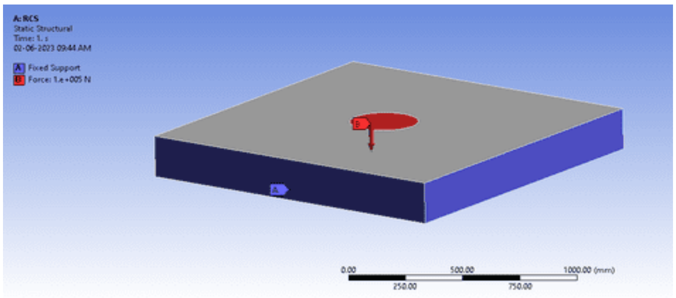

Fig. 6.3 Boundary conditions of RCS

Fig. 6.4 shows the deformation of conventional RC slab without strengthening when subjected to gradually applied load. The maximum deformation obtained is 0.071627 mm.

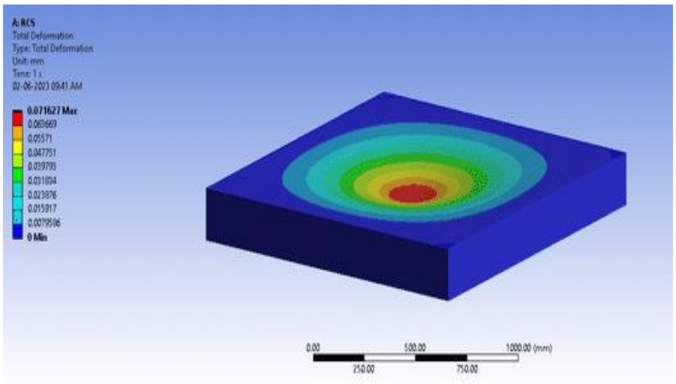

Fig. 6.4 Total deformation of RCS under gradually applied load

Fig. 6.5 depicts the load deformation diagram and table 6.2 shows the results obtained for conventional RC slab under gradual load.

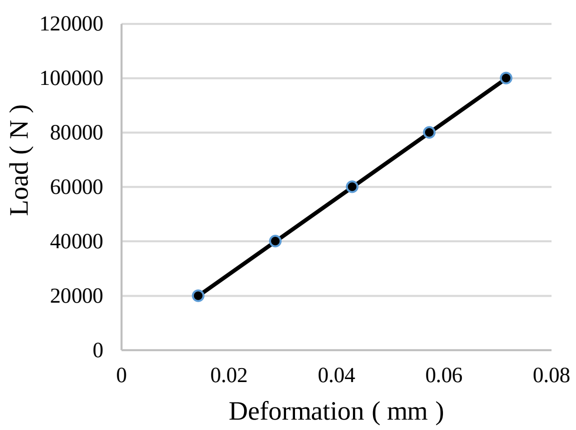


Fig. 6.5 Load deformation graph of RCS

Table 6.2 Results obtained for RCS under gradual load

| Model name | Maximum total deformation ( mm ) | Stiffness ( kN/mm ) |
|---|---|---|
| RCS | 0.071627 | 1396.12 |

From the above results conventional RC slab shows a maximum deformation of 0.071627 mm and shows a stiffness of 1396.12 kN/mm when subjected of gradually applied load.

### 6.1.2 Analysis of externally strengthened RC slab

Reinforced concrete slab of size 1500 x 1450 x 200 mm provided with 8 mm diameter bars at 100 mm spacing which is externally strengthened using CFRP strips of 10 mm thickness and mild steel laminates of 5 mm thickness is analysed using ANSYS.

1. **Analysis of RC slab externally strengthened with CFRP-1 arrangement**

Fig. 6.6 shows the geometry of reinforced concrete slab externally strengthened with CFRP strips oriented along the length of the slab and Fig. 6.7 shows the arrangement of CFRP strips in CFRP-1 slab.

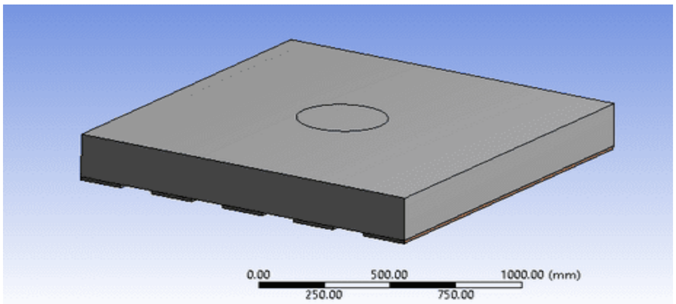

Fig. 6.6 Geometry of CFRP-1

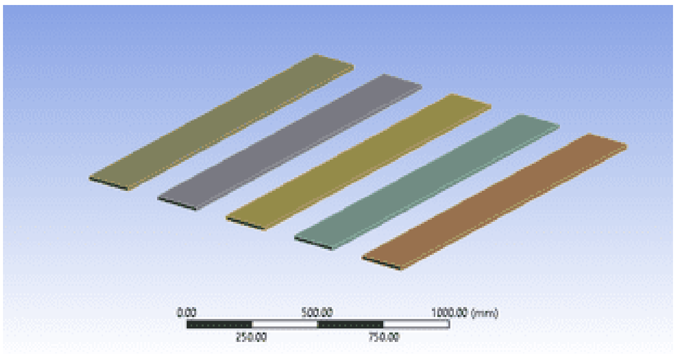

Fig. 6.7 Arrangement of CFRP strips in CFRP-1 slab

Fig. 6.8 shows boundary conditions of RC slab strengthened with CFRP-1. The slab is provided with fixed support condition and gradual load of 100 kN.

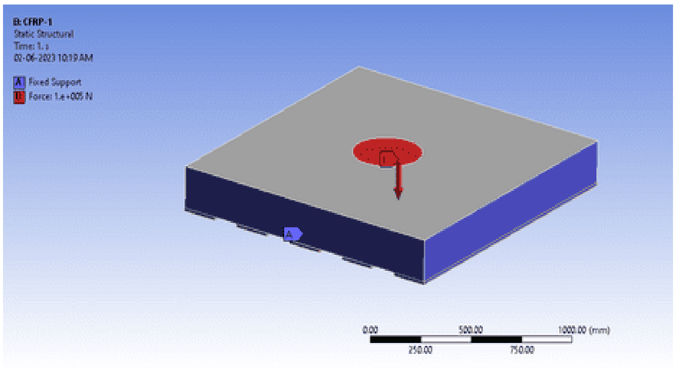


Fig. 6.8 Boundary conditions of CFRP-1

Fig. 6.9 shows the deformation of RC slab strengthened with CFRP-1 when subjected to gradually applied load. The maximum deformation obtained is 0.059252 mm.

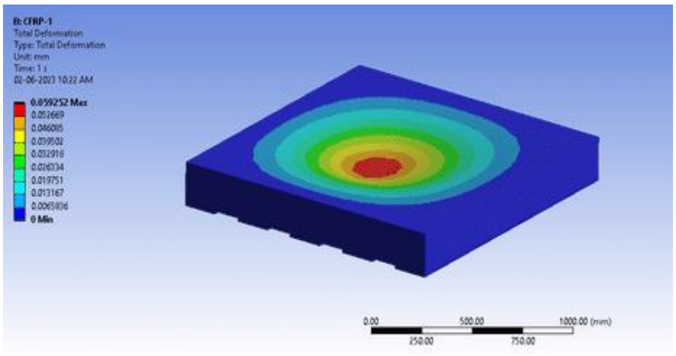


Fig 6.9 Total deformation of CFRP-1 under gradually applied load

Fig. 6.10 depicts the load deformation diagram obtained for RC slab strengthened with CFRP-1 under gradual load.

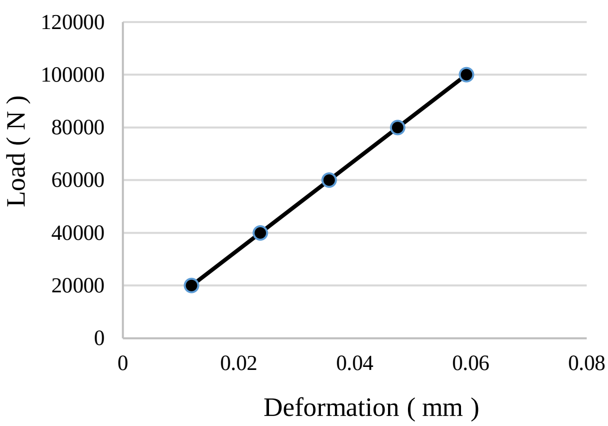


Fig. 6.10 Load deformation graph of CFRP-1

## 2. Analysis of RC slab externally strengthened with CFRP-2 arrangement

Fig. 6.11 depicts geometry of reinforced concrete slab externally strengthened with CFRP strips vertically oriented along the length and width of the slab and with CFRP laminates wrapped around the sides and Fig. 6.12 depicts the arrangement of CFRP strips in CFRP-2 slab.

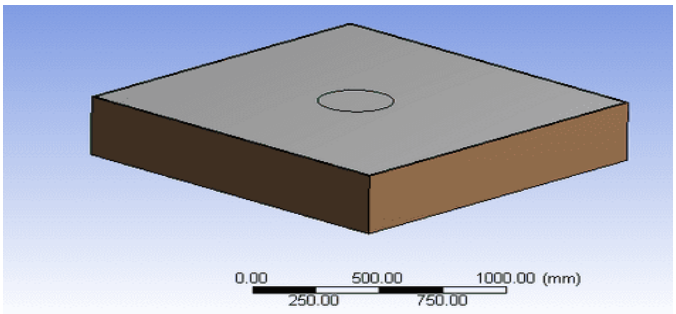


Fig. 6.11 Geometry of CFRP-2

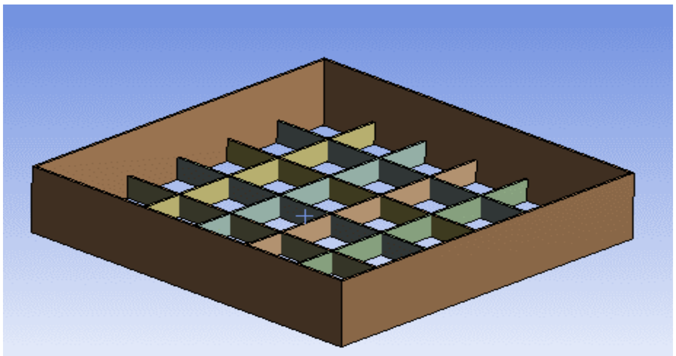

Fig. 6.12 Arrangement of CFRP strips in CFRP-2 slab

Fig. 6.13 shows boundary conditions of RC slab strengthened with CFRP-2. The slab is provided with fixed support condition and gradual load of 100 kN.

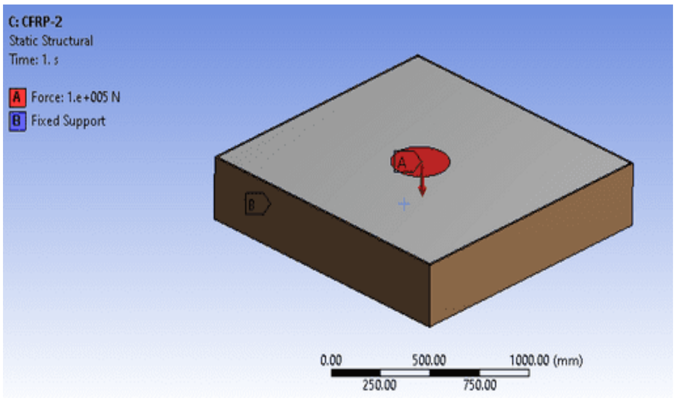


Fig. 6.13 Boundary conditions of CFRP-2

Fig. 6.14 shows the deformation of RC slab strengthened with CFRP-2 when subjected to gradually applied load. The maximum deformation obtained is 0.071322 mm.

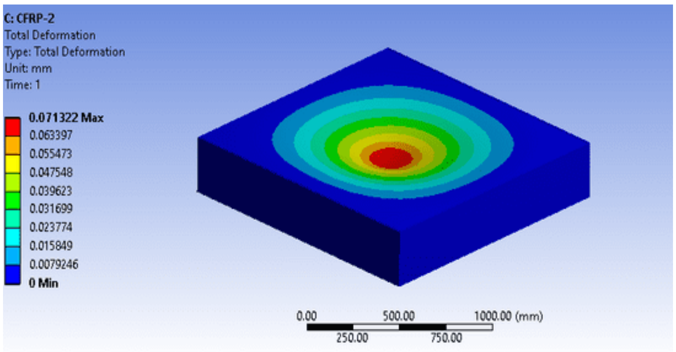


Fig. 6.14 Total deformation of CFRP-2 under gradually applied load

Fig. 6.15 depicts the load deformation diagram obtained for RC slab strengthened with CFRP-2 under gradual load.

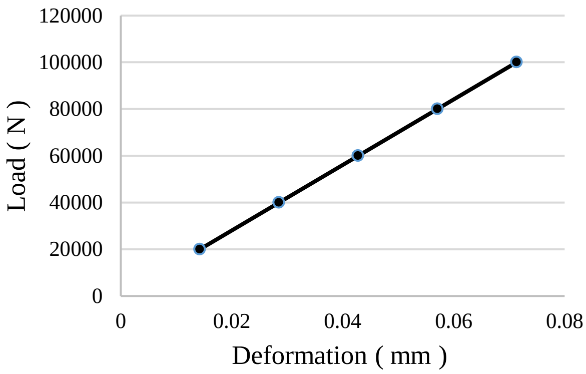


Fig. 6.15 Load deformation graph of CFRP-2

**3.Analysis of RC slab externally strengthened with CFRP-3 arrangement**

Fig. 6.16 shows reinforced concrete slab externally strengthened with CFRP strips horizontally oriented along the length and width of the slab and with CFRP laminates wrapped around the sides and Fig. 6.17 shows the CFRP-3 arrangement.

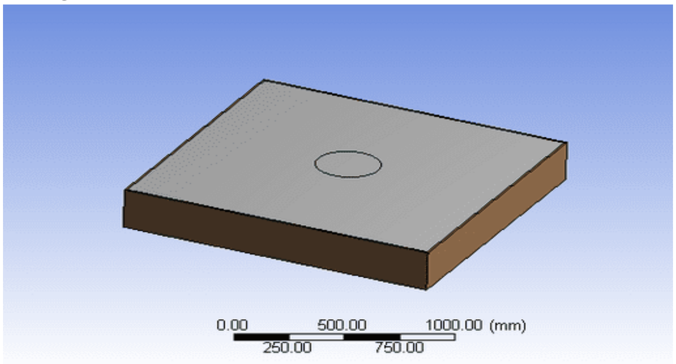


Fig. 6.16 Geometry of CFRP-3 slab

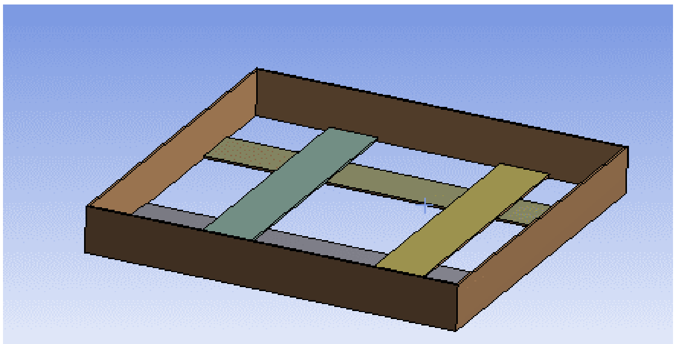

Fig 6.17 Arrangement of CFRP strips in CFRP-3 slab

Fig. 6.18 shows boundary conditions of RC slab strengthened with CFRP-3. The slab is provided with fixed support condition and gradual load of 100 kN.

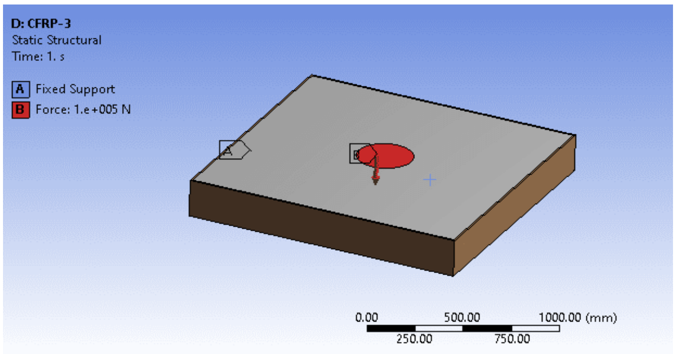


Fig. 6.18 Boundary conditions of CFRP-3

Fig. 6.19 shows the deformation of RC slab strengthened with CFRP-3 when subjected to gradually applied load. The maximum deformation obtained is 0.07148 mm.

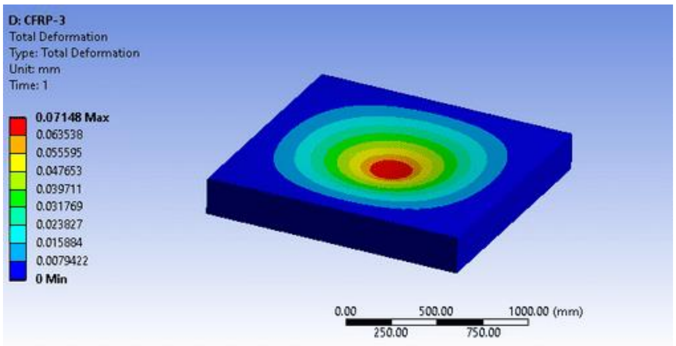


Fig. 6.19 Total deformation of CFRP-3 under gradually applied load

Fig. 6.20 depicts the load deformation diagram obtained for RC slab strengthened with CFRP-3 under gradual load.

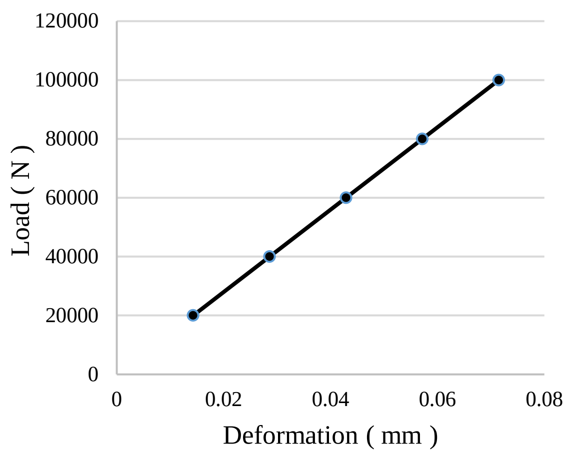


Fig. 6.20 Load deformation graph of CFRP-3

## 4. Analysis of RC slab externally strengthened with mild steel

Fig. 6.21 shows reinforced concrete slab externally strengthened with mild steel laminates attached to the bottom of the slab and Fig. 6.22 shows mild steel laminate.

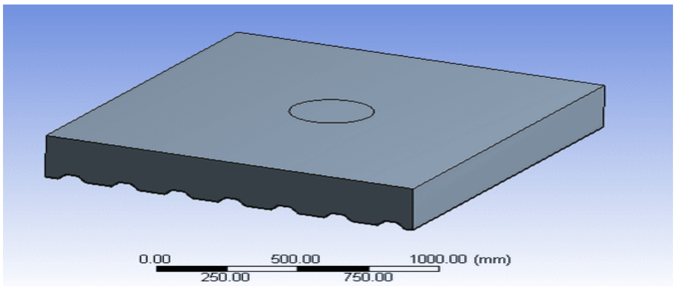


Fig. 6.21 Geometry of MS

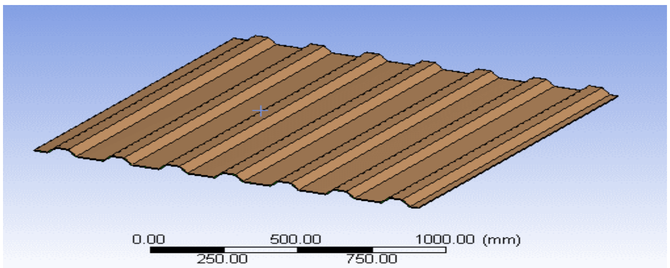


Fig. 6.22 Mild steel laminate

Fig. 6.23 shows boundary conditions of RC slab strengthened with mild steel laminate. The slab is provided with fixed support condition and gradual load of 100 kN.

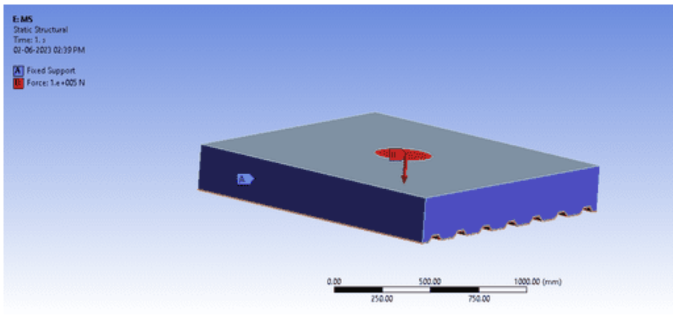

Fig. 6.23 Boundary conditions of MS

Fig. 6.24 shows the deformation of RC slab strengthened with mild steel laminate when subjected to gradually applied load. The maximum deformation obtained is 0.050655 mm.

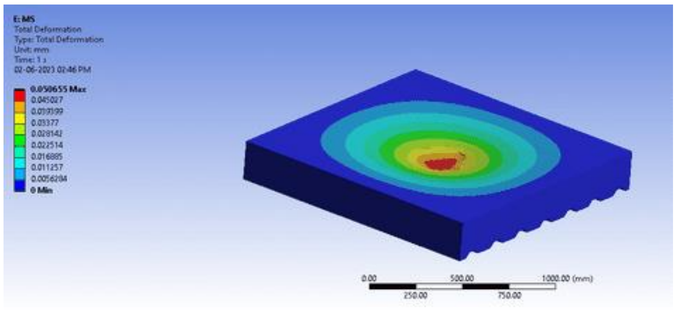

Fig. 6.24 Total deformation of MS under gradually applied load

Fig. 6.25 depicts the load deformation diagram obtained for RC slab strengthened with mild steel laminate under gradual load.

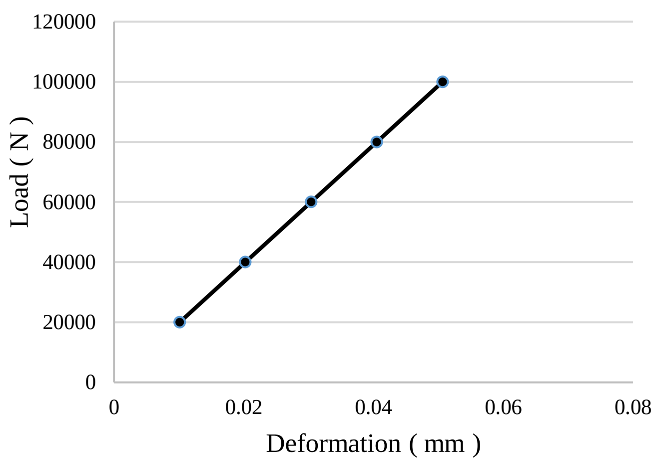


Fig 6.25 Load deformation graph of MS

Table 6.3 Results of externally strengthened RC slab under gradual load

| Model name | Maximum total deformation ( mm ) | Stiffness ( kN/mm ) |
|---|---|---|
| CFRP-1 | 0.059252 | 1687.71 |
| CFRP-2 | 0.071322 | 1402.09 |
| CFRP-3 | 0.07148 | 1398.99 |
| MS | 0.050655 | 1974.13 |

Table 6.3 shows the summary of results obtained for externally strengthened RC slab under gradual load. From this we can conclude that for different arrangement of CFRP laminates CFRP-1 shows the best results for deformation and stiffness i.e. 0.059252 mm and 1687.71 kN/mm respectively under gradually applied load. RC slab strengthened with mild steel laminate shows a total deformation of 0.050655 mm and stiffness 1974.13 mm. So among different external strengthening schemes, CFRP-1 and MS strengthened RC slabs are selected for impact analysis.

### 6.1.3 Analysis of internally strengthened RC slab

Here the RC slab is internally strengthened using carbon fibre rod of varying diameter. Table 6.4 presents the carbon fibre rod type and rod diameter.

Table 6.4 Carbon fibre rod type and diameter

| Rod type | Rod diameter (mm) |
|---|---|
| 1 | 5.27 |
| 2 | 5.50 |
| 3 | 5.75 |
| 4 | 5.78 |
| 5 | 5.98 |
| 6 | 6.00 |
| 7 | 6.40 |

Fig. 6.26 shows geometry of reinforced concrete slab internally strengthened with carbon fibre rod. For gradual load analysis a quarter symmetric model is developed with symmetric regions. Fig. 6.27 shows the boundary conditions. The slab is provided with fixed support condition. As the model is a quarter symmetric model the force applied is also a quarter of total load i.e., 25000N. Fig. 6.28 represents the symmetric regions and Fig. 6.29 shows the contact regions provided.

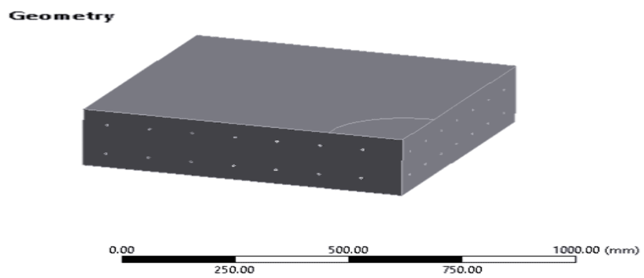


Fig. 6.26 Geometry of RC slab strengthened with CF rod

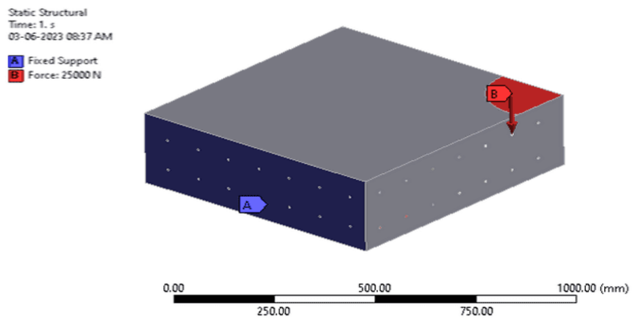


Fig. 6.27 Boundary conditions of RC slab strengthened with CF rod

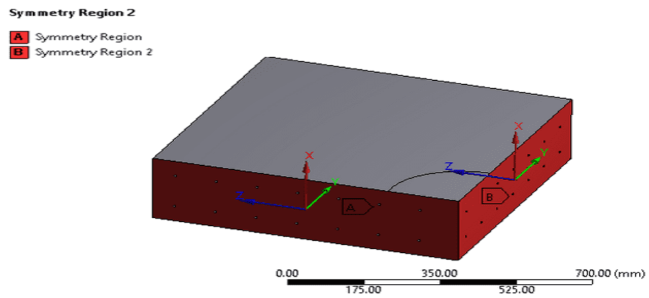


Fig. 6.28 Symmetric region provided for RC slab strengthened with CF rod

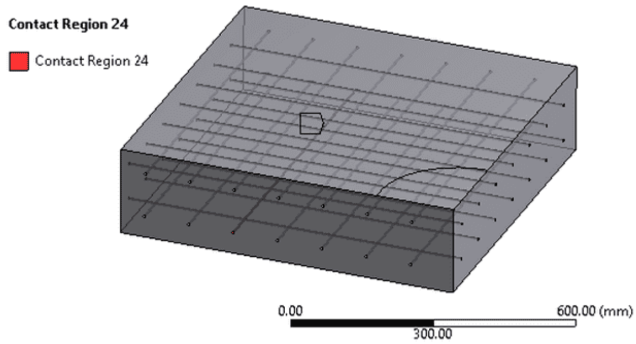


Fig. 6.29 Contact region provided for RC slab strengthened with CF rod

From Fig. 6.30 to Fig. 6.64 shows the total deformation, equivalent stress and load deformation graph for RC slab internally strengthened with different type of CF rod under gradually applied load.

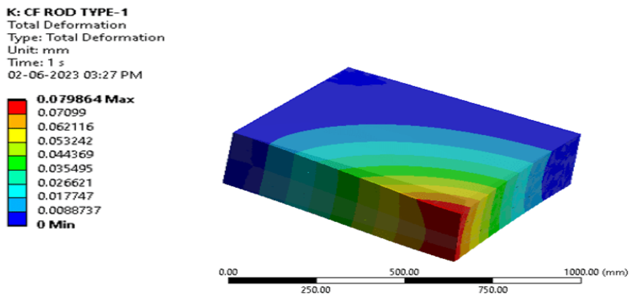


Fig. 6.30 Total deformation of RC slab strengthened with CF rod -1 under gradually applied load

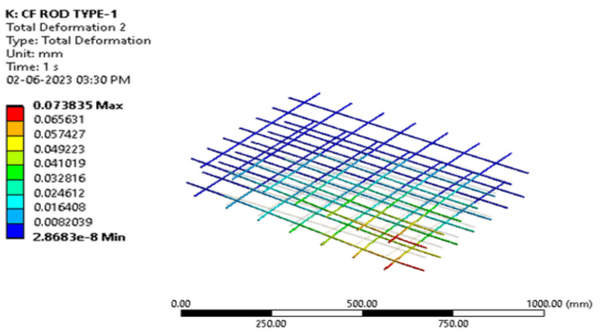


Fig. 6.31 Total deformation of CF rod -1 under gradually applied load

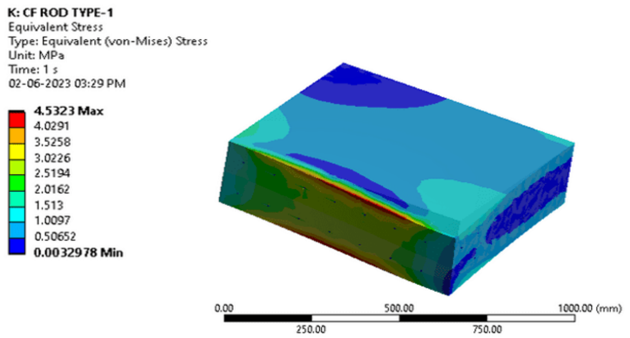


Fig. 6.32 Equivalent stress of RC slab strengthened with CF rod -1 under gradually applied load

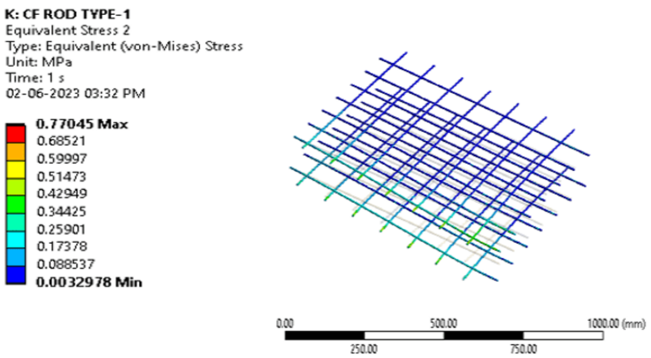


Fig. 6.33 Equivalent stress of CF rod -1 under gradually applied load

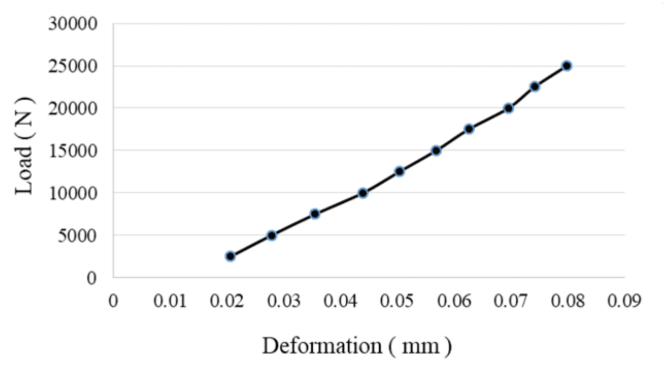


Fig. 6.34 Load deformation graph of RC slab strengthened with CF rod-1

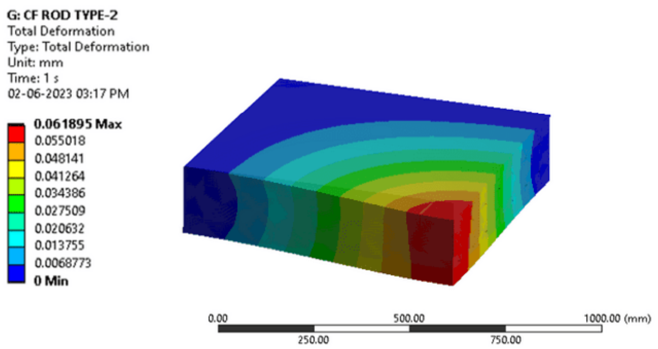


Fig. 6.35 Total deformation of RC slab strengthened with CF rod -2 under gradually applied load

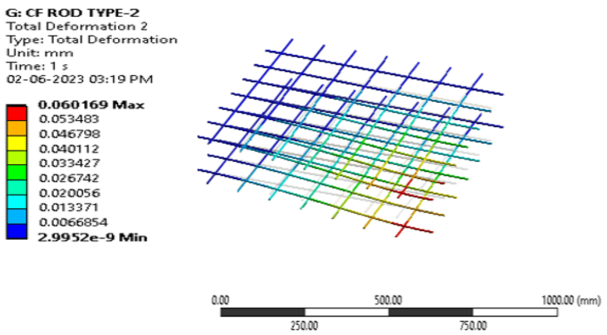


Fig. 6.36 Total deformation of CF rod -2 under gradually applied load

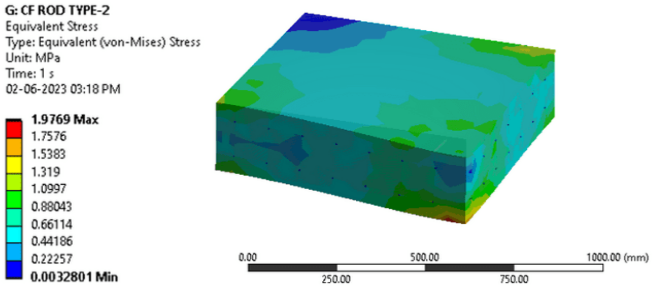


Fig. 6.37 Equivalent stress of RC slab strengthened with CF rod -2 under gradually applied load

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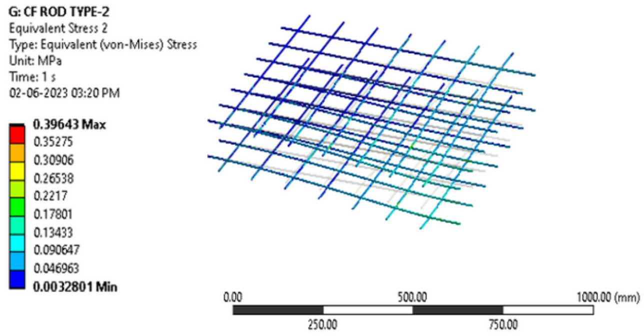


Fig. 6.38 Equivalent stress of CF rod -2 under gradually applied load

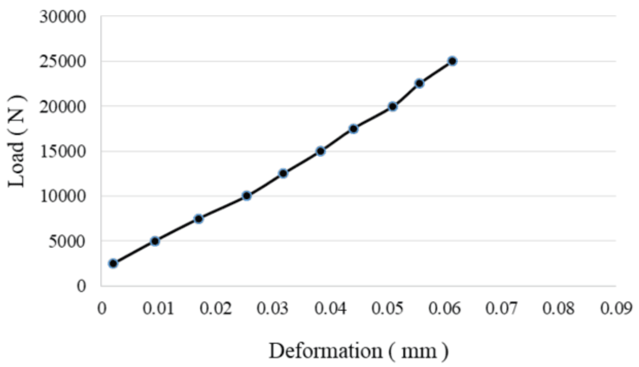


Fig. 6.39 Load deformation graph of RC slab strengthened with CF rod-2

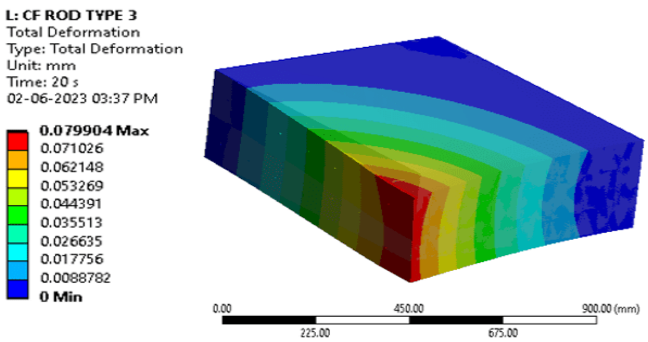


Fig. 6.40 Total deformation of RC slab strengthened with CF rod -3 under gradually applied load

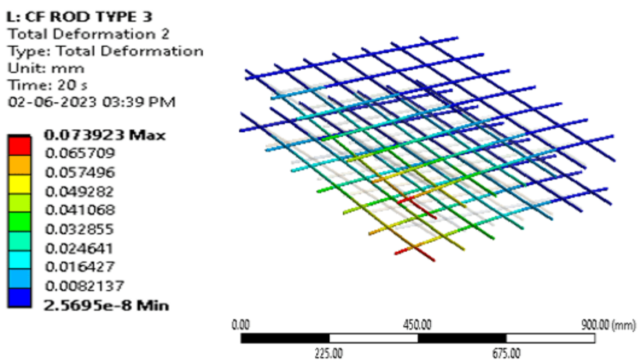


Fig. 6.41 Total deformation of CF rod -3 under gradually applied load

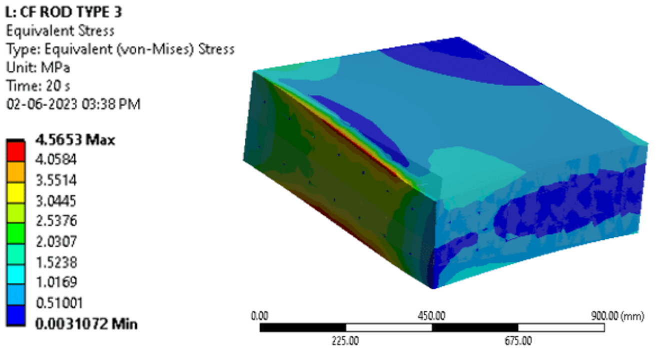


Fig. 6.42 Equivalent stress of RC slab strengthened with CF rod -3 under gradually applied load

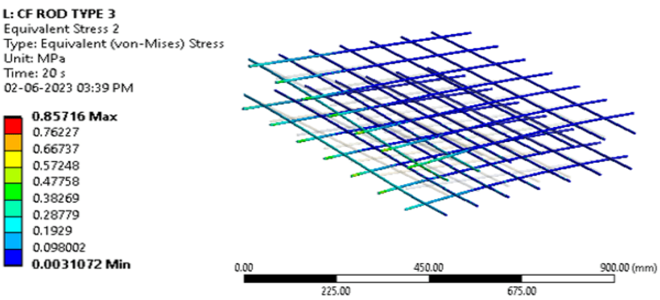


Fig. 6.43 Equivalent stress of CF rod -3 under gradually applied load

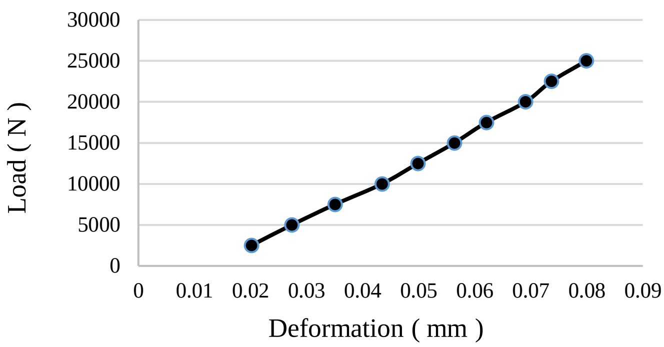


Fig. 6.44 Load deformation graph of RC slab strengthened with CF rod-3

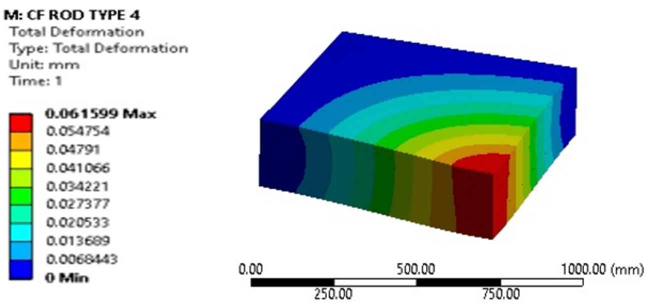


Fig. 6.45 Total deformation of RC slab strengthened with CF rod - 4 under gradually applied load

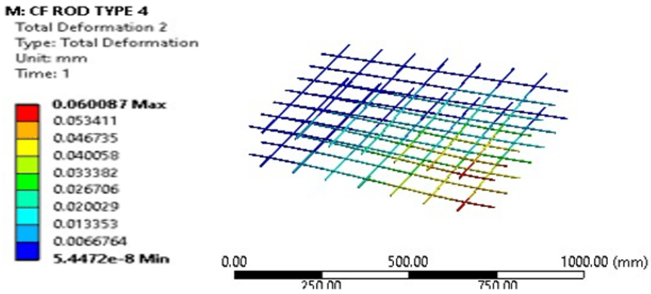


Fig. 6.46 Total deformation of CF rod -4 under gradually applied load

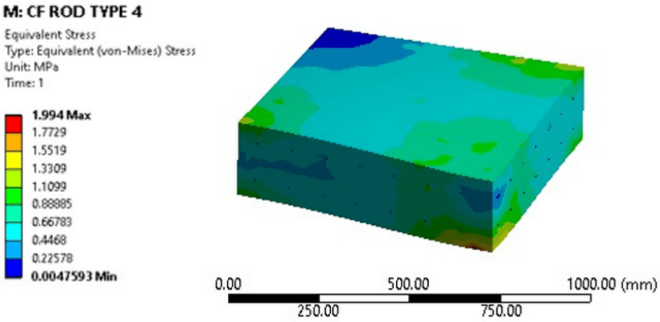


Fig. 6.47 Equivalent stress of RC slab strengthened with CF rod -4 under gradually applied load

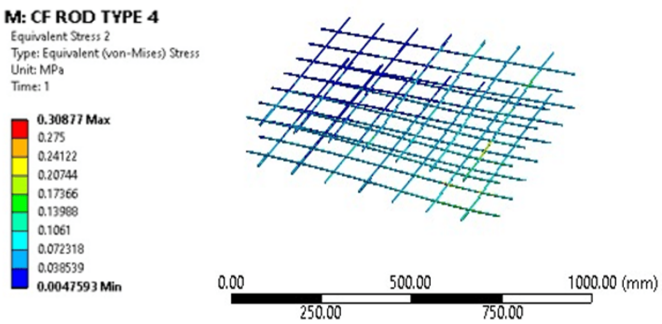


Fig. 6.48 Equivalent stress of CF rod -4 under gradually applied load

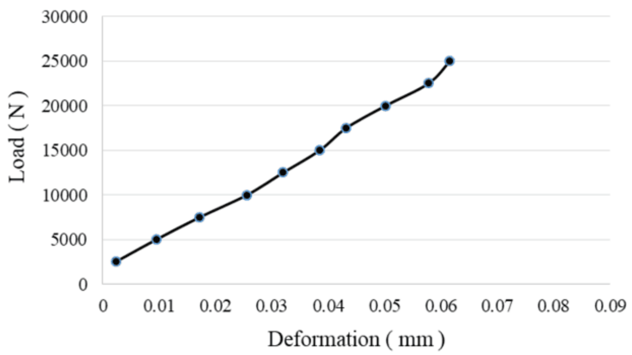


Fig. 6.49 Load deformation graph of RC slab strengthened with CF rod-4

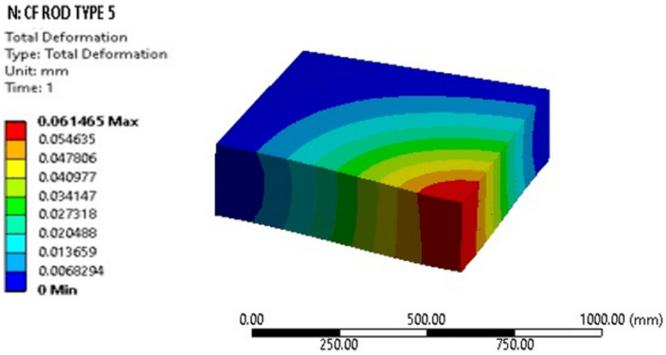


Fig. 6.50 Total deformation of RC slab strengthened with CF rod -5 under gradually applied load

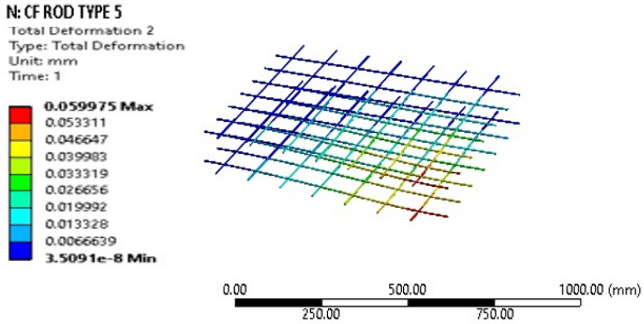


Fig. 6.51 Total deformation of CF rod -5 under gradually applied load

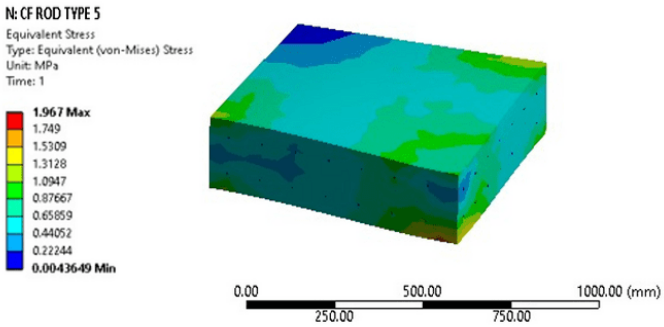


Fig. 6.52 Equivalent stress of RC slab strengthened with CF rod -5 under gradually applied load

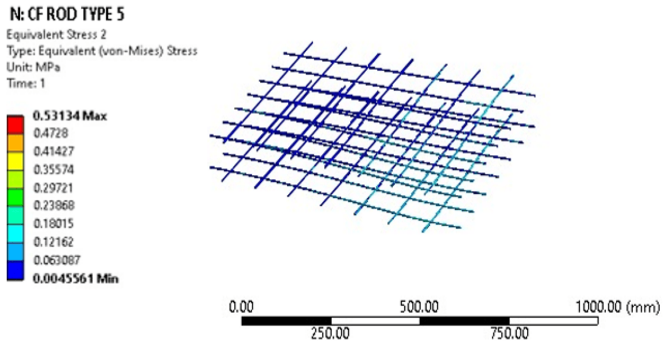


Fig. 6.53 Equivalent stress of CF rod -5 under gradually applied load

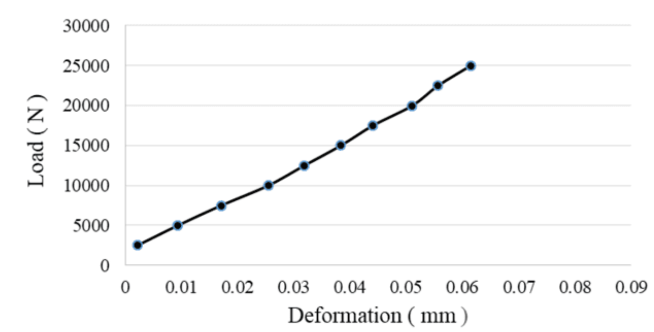


Fig. 6.54 Load deformation graph of RC slab strengthened with CF rod-5

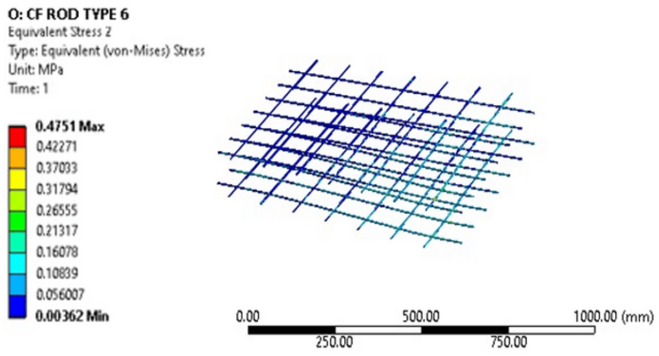


Fig. 6.58 Equivalent stress of CF rod -6 under gradually applied load

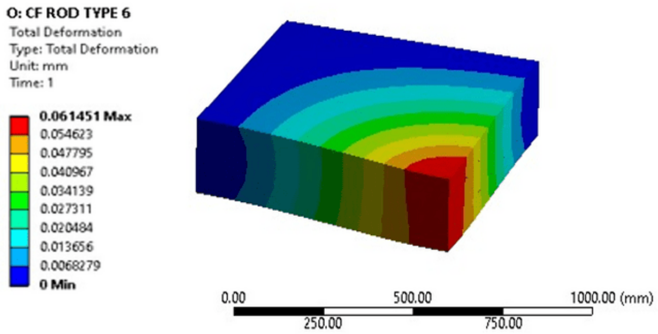


Fig. 6.55 Total deformation of RC slab strengthened with CF rod -6 under gradually applied load

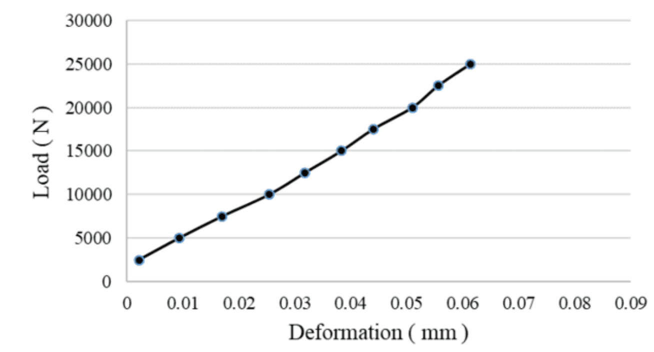


Fig. 6.59 Load deformation graph of RC slab strengthened with CF rod-6

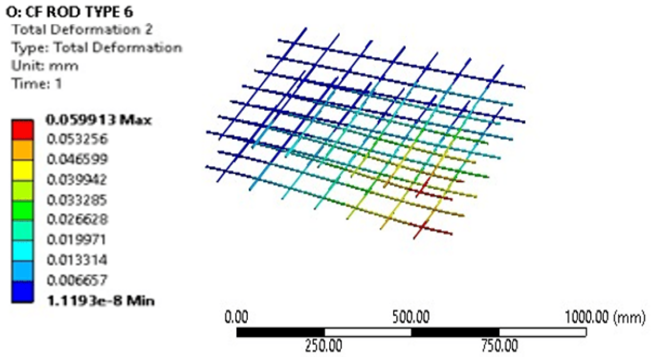


Fig. 6.56 Total deformation of CF rod -6 under gradually applied load

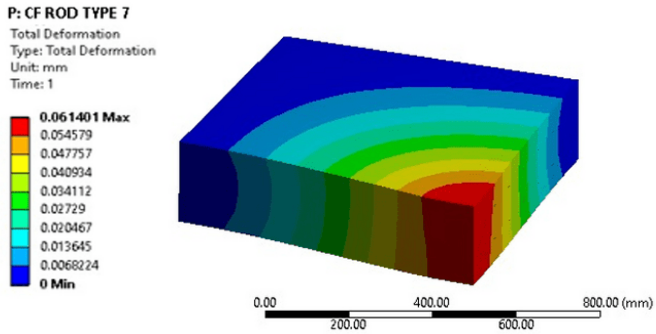


Fig. 6.60 Total deformation of RC slab strengthened with CF rod -7 under gradually applied load

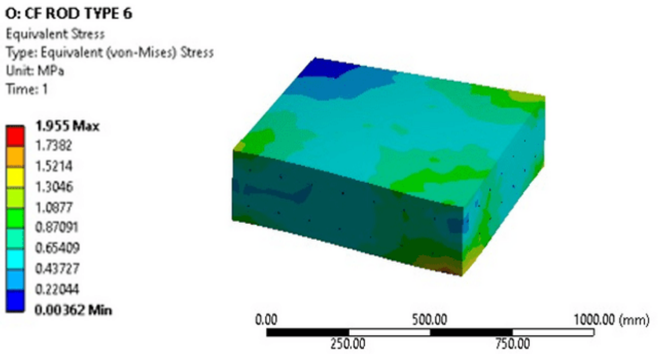


Fig. 6.57 Equivalent stress of RC slab strengthened with CF rod -6 under gradually applied load

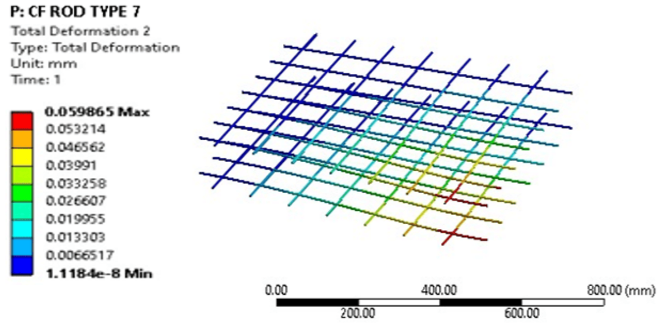


Fig. 6.61 Total deformation of CF rod -7 under gradually applied load

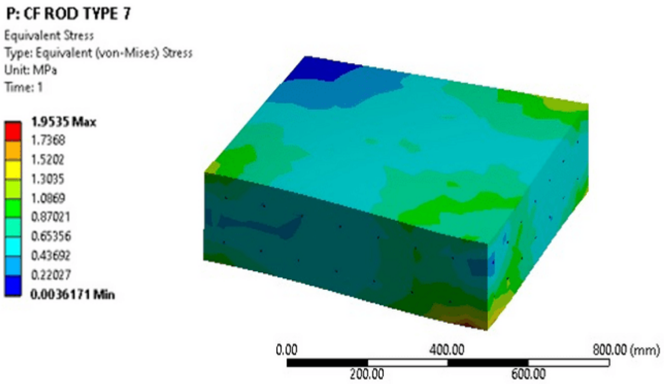


Fig. 6.62 Equivalent stress of RC slab strengthened with CF rod -7 under gradually applied load

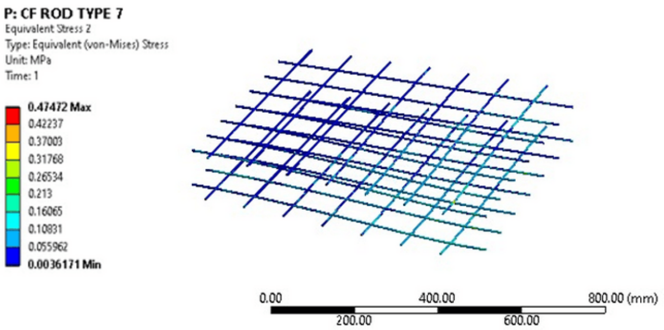


Fig. 6.63 Equivalent stress of CF rod -7 under gradually applied load

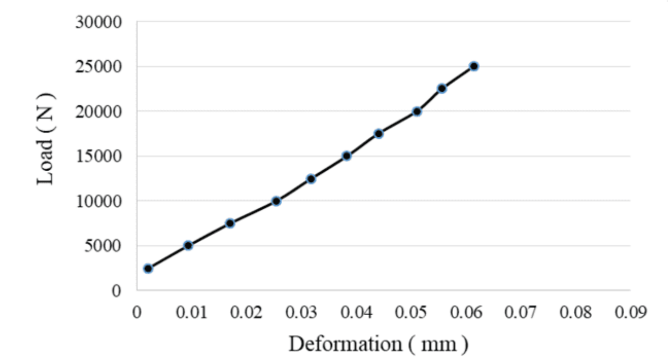


Fig. 6.64 Load deformation graph of RC slab strengthened with CF rod-7

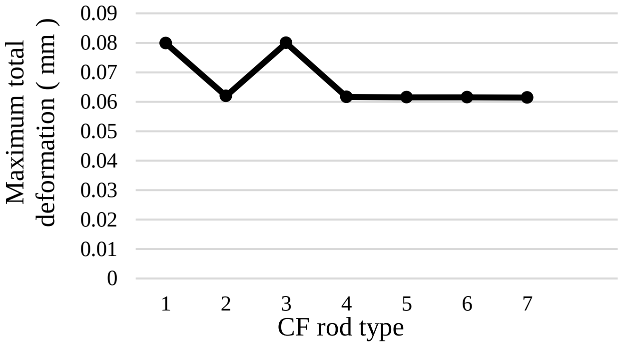


Fig. 6.65 Maximum total deformation corresponding to each CF rod type

From Fig. 6.65 it is clear that CF rod type 4, 5, 6 and 7 shows almost same results for deformation when subjected to gradually applied load. So, we can select any one among these four types of CF rod for impact analysis. Here in the point of view of standard diameter, CF rod type 6 is selected for impact analysis.

### 6.1.4 Summary of gradual load analysis

After gradual load analysis four models including the conventional RC slab are selected for impact analysis as they showed the better results for deformation and stiffness. The selected RC slab models are shown in the table 6.6.

Table 6.5 Models selected for impact analysis

| **Model name** | **Total deformation (mm)** | **Stiffness ( kN/mm)** |
|---|---|---|
| RCS | 0.071627 | 1396.12 |
| CFRP-1 | 0.059252 | 1687.71 |
| MS | 0.050655 | 1974.13 |
| CF ROD-6 | 0.061451 | 1627.31 |

## 6.2 IMPACT LOAD ANALYSIS

An impact load is a type of dynamic load that results from a sudden and short-lived force or impulse being applied to a structure or object. The reinforced concrete slabs selected after analysis under gradual load is subjected to impact load using ANSYS 18.1. The impact load analysis is done using explicit dynamics finite element analysis. Explicit dynamic analysis is capable to reveal the dynamic response of structures subjected to short time impact loads.

For impact load analysis a drop-weight simulation is used. Here the drop weight is a steel ball of 350 mm diameter having density 7850 $kg/m^3$ which is considered to fall from 2000 mm height.

For the simulation an initial velocity has been applied to the drop weight which is calculated based on the travelling time of the steel ball dropped from the height with respect to the top surface of slab i.e., using the equation $v = \sqrt{(2gh)}$. Here g is the acceleration due to gravity which is taken as 9806.6 $mm/s^2$. From calculation velocity obtained is 6264.2 mm/s. Interaction between the drop-weight and the concrete slab has been modelled with a standard surface to surface contact i.e., without friction between contact bodies. Table 6.7 shows the

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impact load analysis details. Fig. 6.66, Fig. 6.73 and Fig. 6.78 shows the geometry of the models under impact load. Fig. 6.67, Fig. 6.74 and Fig. 6.79 shows the boundary conditions when subjected to impact load.

Table 6.6 Impact load parameters

| | |
|---|---|
| Load type | Impact load |
| Impact type | Steel ball drop |
| Diameter of steel ball | 350 mm |
| Density of steel ball | 7850 kg/m$^3$ |
| Falling height | 2000 mm |
| Standard earth gravity | 9806.6 mm/s$^2$ |
| Velocity | 6264.2 mm/s |
| Support condition | Fixed |

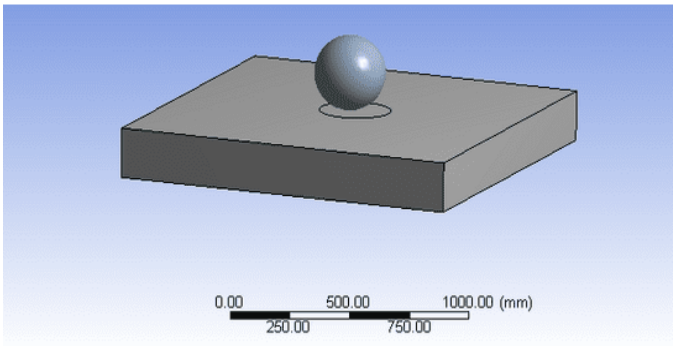


Fig. 6.66 Geometry of RCS subjected to impact load

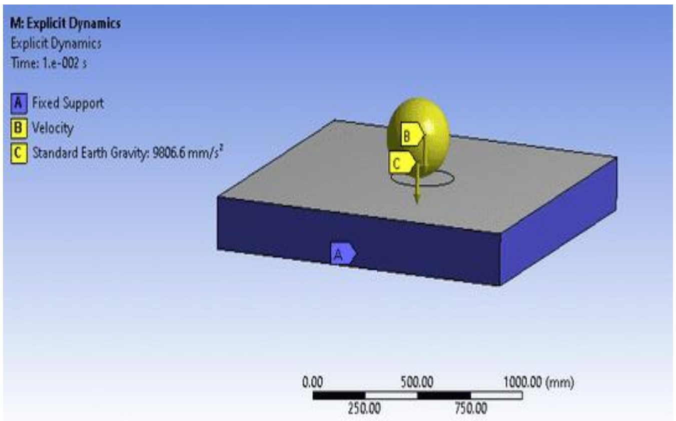


Fig. 6.67 Boundary conditions of RCS subjected to impact load

Fig. 6.68 and Fig. 6.69 shows the total deformation of RC slab subjected to impact load. The maximum deformation obtained is 125.59 mm.

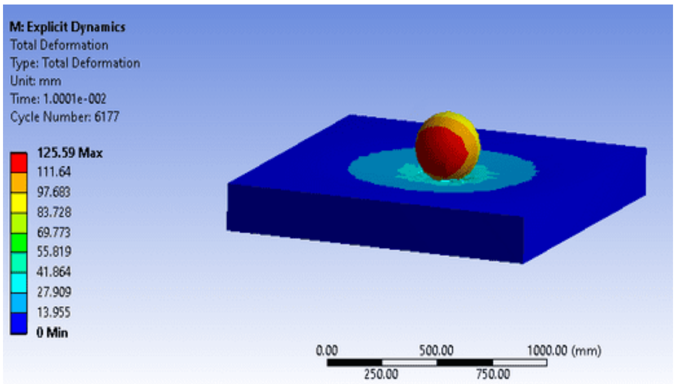


Fig. 6.68 Total deformation of RCS subjected to impact load

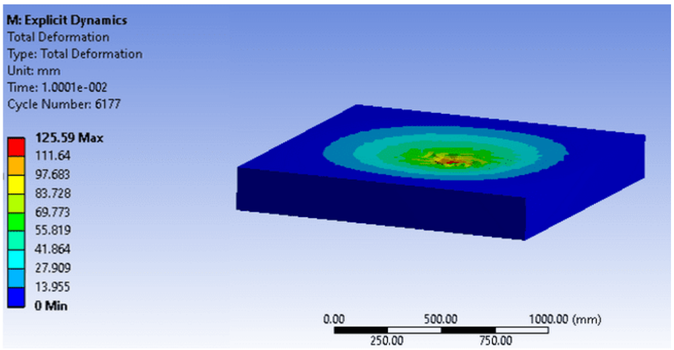


Fig. 6.69 Total deformation of RCS

Fig. 6.70 and Fig.6.71 shows the total deformation of CFRP-1 subjected to impact load. The maximum deformation obtained is 75.157 mm.

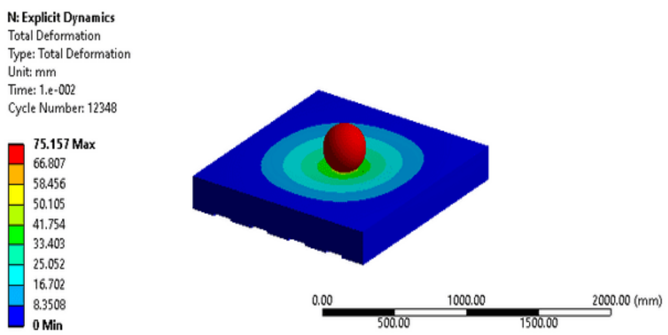


Fig. 6.70 Total deformation of CFRP-1 subjected to impact load

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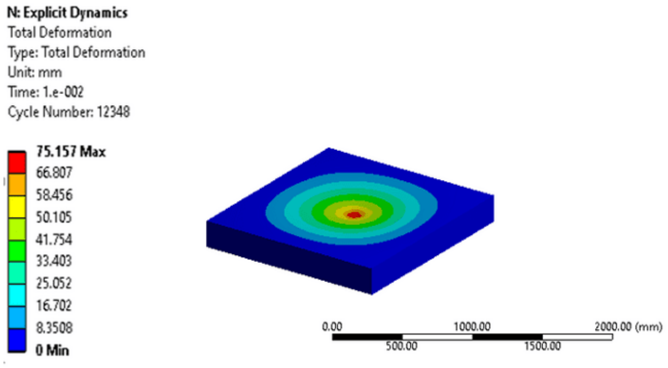


Fig. 6.71 Total deformation of CFRP-1

Fig 6.72 shows total deformation of CFRP-1 laminate subjected to impact load. The maximum deformation obtained is 42.105 mm.

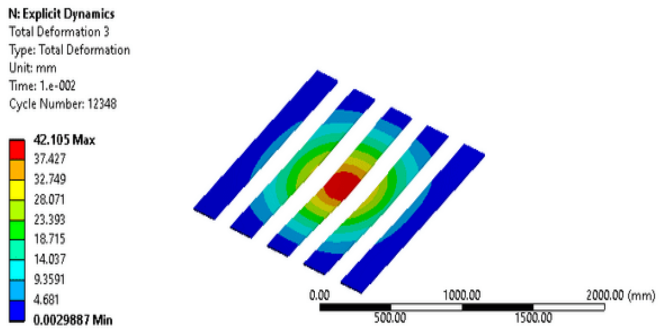


Fig. 6.72 Total deformation in CFRP-1 laminate subjected to impact load

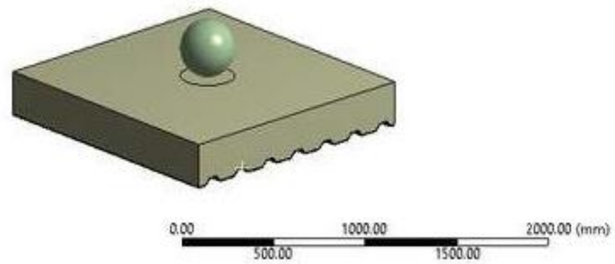


Fig. 6.73 Geometry of MS subjected to impact load

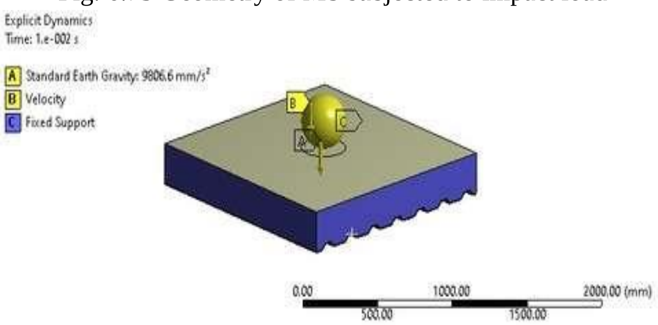


Fig. 6.74 Boundary conditions MS subjected to impact load

Fig 6.75 and Fig. 6.76 shows total deformation of MS subjected to impact load. The maximum deformation obtained is 65.066 mm.

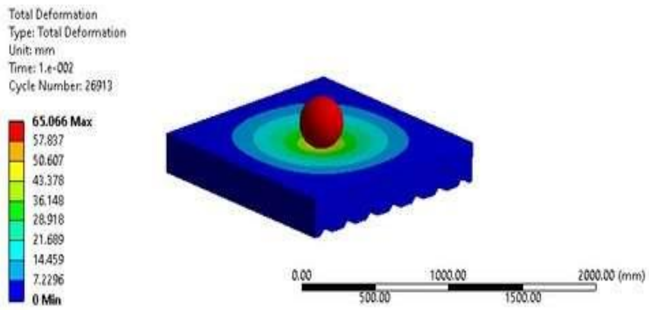


Fig. 6.75 Total deformation of MS subjected to impact load

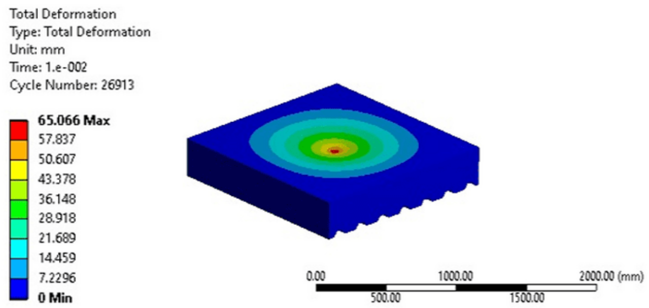


Fig. 6.76 Total deformation of MS

Fig. 6.77 shows total deformation of MS laminate subjected to impact load. The maximum deformation obtained is 49.08 mm.

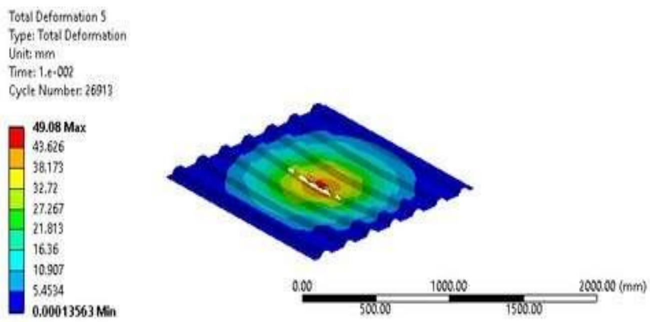


Fig. 6.77 Total deformation of MS laminate subjected to impact load

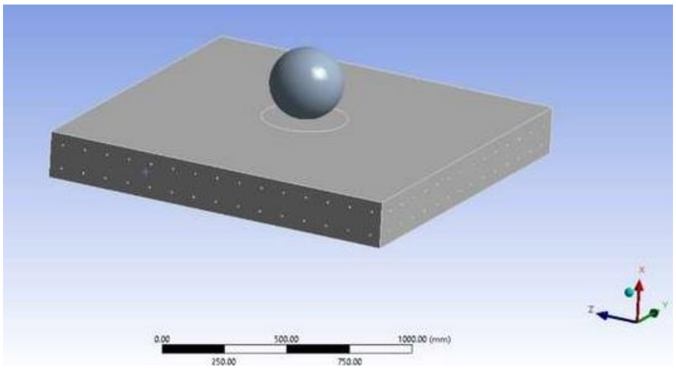

Fig. 6.78 Geometry of CF rod-6 subjected to impact load

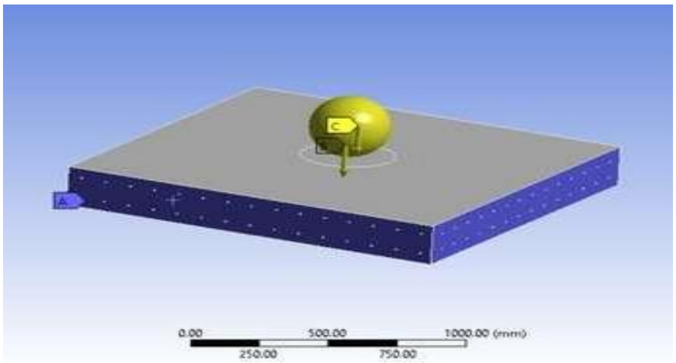

Fig. 6.79 Boundary conditions of CF rod-6 subjected to impact load

Fig. 6.80 and Fig. 6.81 shows total deformation of CF rod-6 subjected to impact load. The maximum deformation obtained is 73.536 mm.

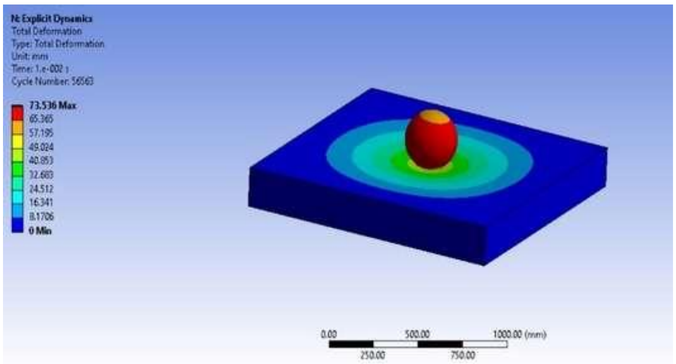

Fig. 6.80 Total deformation of CF rod-6 subjected to impact load

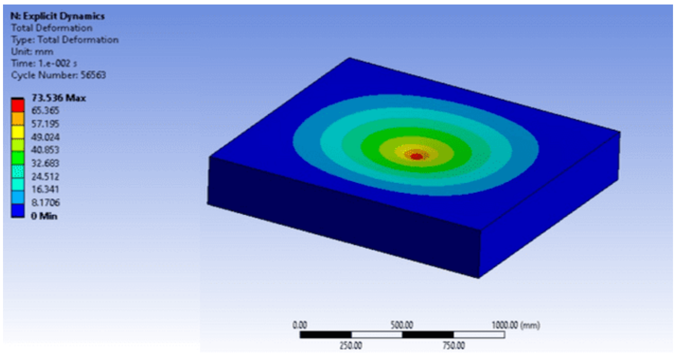

Fig. 6.81 Total deformation of RC slab strengthened with CF rod-6

Table 6.7 Results obtained from impact analysis

| Model name | Total deformation ( mm ) | Stiffness ( N/mm ) |
|---|---|---|
| RCS | 125.59 | 13.7 |
| CFRP-1 | 75.157 | 23.05 |
| MS | 65.066 | 26.62 |
| CF ROD - 6 | 73.536 | 23.55 |

## 7. RESULTS AND DISCUSSION

A total of 12 RC slab specimens were analyzed to examine the behavior of RC slab under different strengthening schemes under different loading conditions such as gradually applied load and impact load. In the first stage RC slab specimens were analyzed under gradually applied load and selected specimens after gradual load analysis is analyzed under impact load.

Under gradually applied load RC slab specimen without strengthening (RCS) shows a deformation and stiffness of 0.071627 mm and 1396.12 kN/m respectively. RC slab specimen externally strengthened with CFRP-1, CFRP-2 and CFRP-3 shows a total deformation of 0.059252 mm, 0.071322 mm and 0.07148 mm respectively under gradual load. Among these three arrangements of CFRP strips, CFRP-1 shows the best results i.e., it shows 17.28 % decrease in deformation and 20.89 % increase in stiffness compared with conventional RC slab. RC slab specimen externally strengthened with mild steel shows deformation of 0.050655 mm under gradual load i.e., it shows 29.28 % decrease in deformation and 41.40 % increase in stiffness compared with conventional RC slab. Among RC slab internally strengthened with CF rod of different diameters, RC slab strengthened with CF rod-6 shows the best result i.e., it shows 14.21 % decrease in deformation and 16.56 % increase in stiffness compared with conventional RC slab. Table 7.1 shows the results of RC slab specimens under gradually applied load in detail and Fig. 7.1 shows graphical representation of stiffness under gradually applied load.

Table 7.1 Percentage decrease in deformation and increase in stiffness under gradually applied load

| Model name | Total deformation ( mm ) | Decrease in deformation ( % ) | Stiffness ( kN/mm ) | Increase in stiffness ( % ) |
|---|---|---|---|---|
| RCS | 0.071627 | - | 1396.12 | - |
| CFRP-1 | 0.059252 | 17.28 | 1687.71 | 20.89 |
| MS | 0.050655 | 29.28 | 1974.13 | 41.40 |
| CF ROD-6 | 0.061451 | 14.21 | 1627.31 | 16.56 |

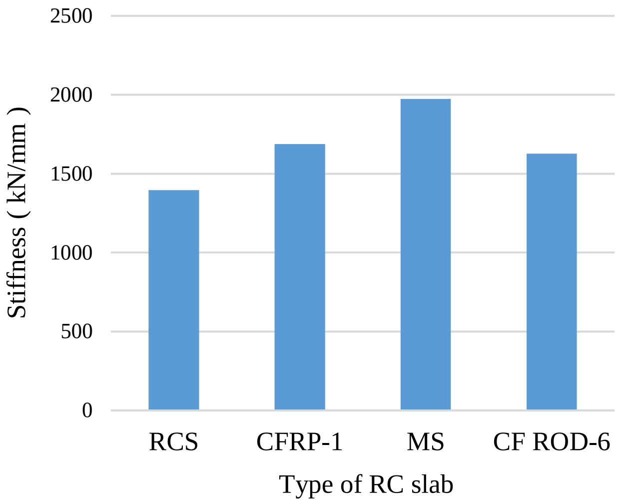


Fig. 7.1 Graphical representation of stiffness under gradually applied load

Under impact load RC slab specimen without strengthening (RCS) shows a deformation and stiffness of 125.59 mm and 13.7 N/m respectively. RC slab specimen externally strengthened with CFRP-1 shows a total deformation of 0.059252 mm under impact load i.e., it shows 40.16 % decrease in deformation and 68.25 % increase in stiffness compared with conventional RC slab. RC slab specimen externally strengthened with mild steel shows deformation of 65.066 mm under impact load i.e., it shows 48.19 % decrease in deformation and 94.31 % increase in stiffness compared with conventional RC slab. RC slab internally strengthened with CF rod-6 shows deformation of 73.536 mm i.e., it shows 41.45 % decrease in deformation and 71.89 % increase in stiffness compared with conventional RC slab. Table 7.2 shows the results of RC slab specimens under impact load in detail and Fig. 7.2 shows graphical representation of stiffness under impact load.

Table 7.2 Percentage decease in deformation and increase in stiffness under impact load

| Model name | Total deformation ( mm ) | Decrease in deformation ( % ) | Stiffness N/mm | Increase in stiffness ( % ) |
|---|---|---|---|---|
| RCS | 125.59 | - | 13.7 | - |
| CFRP-1 | 75.157 | 40.16 | 23.05 | 68.25 |
| MS | 65.066 | 48.19 | 26.62 | 94.31 |
| CF ROD - 6 | 73.536 | 41.45 | 23.55 | 71.89 |

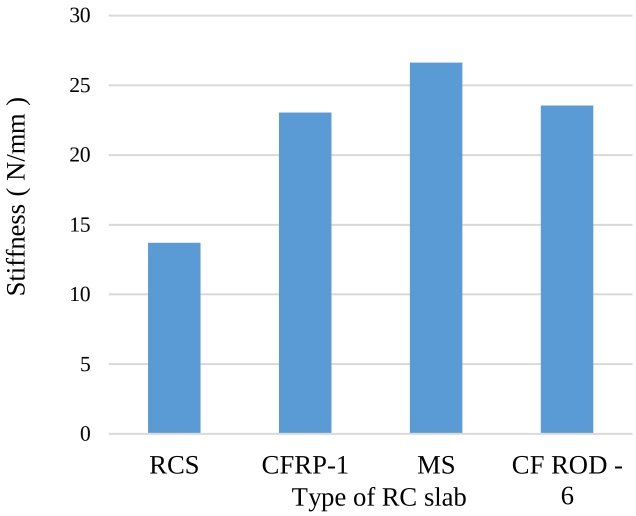


Fig. 7.2 Graphical representation of stiffness under gradually applied load

## 8. CONCLUSION

Based on the numerical results the following conclusions are drawn:

- Strengthened RC slab shows a decrease in deformation and increase in stiffness compared to conventional RC under both gradual and impact load.
- Externally strengthened RC slabs shows better results for deformation and stiffness when compared with RC slab internally strengthened with carbon fibre rod under both loads.
- Among different external strengthening schemes RC slab strengthened with mild steel shows better results.
- RC slab strengthened with mild steel shows 29.28 % and 48.19 % decrease in deformation and 41.4 % and 94.31 % increase in stiffness under both loads.
- Also, mild steel laminates are affordable, durable and corrosion resistant so it can be a better option.
- It can be concluded that strengthening of RC slab is effective in reducing damage severity and deformation and increase load carrying capacity.

## 9. FUTURE SCOPE

- Alternate materials can be used such as GFRP, BFRP sheet or rebar etc. to strengthen the slab.
- The percentage of CFRP, mild steel can be decreased or increased in order to check the impact resistance.
- The RC slab can be analysed under different loading condition.

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