Design and Analysis of Filler Slab

Mahananda R K¹, Vikas Mendi² and Raveesh R M³

¹PG student, Dept. of Civil Engineering, RV College of Engineering, India
²Assistant Professor, Dept. of Civil Engineering, RV College of Engineering, India
³Ph.D. Scholar, Dept. of Water Resources and Ocean Engineering, National Institute of Technology Karnataka, India
Email: vikasm@rvce.edu.in

Abstract. Filler slab technology is an innovative and cost effective technology where the dead load of slab is reduced by replacing the concrete with filler material. The concept behind the use of filler-slab technology is to reduce a substantial portion of concrete in the tension zone, since all the concrete in the tension zone does not contribute to the tensile properties. This concrete is replaced with lightweight, inert and inexpensive filler without compromising with the quality and structural stability of the structure. Two-way slab is designed; the filler blocks are placed between the reinforcement spacing by providing a cover of 20mm. The filler materials are granite dust and foundry sand. This filler slab is analyzed using STAAD.Pro and ANSYS software. Filler slab is compared with the conventional slab of same size. This study describes the Structural behavior and cost effectiveness of filler slab when compared to the standard slab.

1. Introduction

As per the annual reports of Census 2011, around two-thirds of the total Indian population cannot afford their shelter [1]. Affordability is one major reason for people to go shelter less. If houses can be constructed economically by using innovative techniques to reduce the consumption of materials, more people can afford to construct their own houses.

Concrete being the highest consumed material on earth after water (Cement Industry Federation, Australia), is produced and used at a large scale in the construction industry. Ideas to reduce the usage of concrete without compromising the quality of construction will not only lead to cost-effective buildings but also reduce carbon emissions when looked at a large scale.

Many innovative techniques and economical methods are being proposed and filler slab technology is one such innovative and cost-effective technology where a dead load of the slab is reduced by replacing the concrete. Concrete is good in withstanding compressive forces and steel is good in withstanding tensile forces. The main aim behind the use of filler-slab technology is to condense a substantial portion of concrete below the neutral axis since all concrete in the tension zone does not add to the tensile properties. This concrete is replaced with lightweight, inert and inexpensive filler without neglecting the quality and structural strength of the structure [2].

By reducing the quantity and weight of concrete, the slab becomes less expensive, but the strength has to remain the same as the conventional slab. In many of the areas, to reduce the heat impact in the building during hot weather at an economic cost, the filler-slab technology acts as an excellent thermal insulator and brings down the temperature inside the building.
2. Need for alternatives
Construction segment in India is accountable for major input of energy resulting in the major emission of CO$_2$ (22%) into the atmosphere [3]. To reduce the harmful effect, sustainable technology is required. This technology is used to remove a substantial portion of concrete in the tension zone and replace it with lightweight, inert and inexpensive filler. This particular technology can not only reduce the cost of the materials but will also reduce the amount of carbon emission by lowering the use of energy-consuming materials. Overall, it is concluded that 30% of the carbon emission is reduced [4].

3. Filler material selection
The filler materials are selected upon satisfying the following conditions:

- The material must be non-reactive (inert) in nature.
- The limitation must be applied in terms of water absorption as hydration of concrete is affected.
- It must be lightweight, which will result in the reduction of the overall weight of the structure.
- It must be cost-effective when compared to the cost of concrete replaced.
- The size and thickness of the material must satisfy the reinforcement spacing and the size of the slab.
- Aesthetic views must be considered to avoid ugly faces of the ceiling.

4. Materials used
Various materials such as Cement (53 Grade), M-sand, Coarse aggregate and reinforcement steel are used in this study. Cement is used as a binder which binds, sets and hardens the other materials in contact. M-sand is simply nothing but crushed granite rocks into finer particles. Its size is finer than coarse aggregate and coarser than silt. M-sand is generally used as a substitute for river sand due to its cost expense. Coarse aggregate are gravel stones of bigger size than M-sand. These are usually obtained by crushing granite rocks into smaller dimension. The size to be used in concrete should generally lie between 10 - 20mm. Reinforcement steel are hot round bars, provided with deformation patters to give a better bonding between the steel and concrete. These steel are used in concrete to provide tensile strength.

4.1 Filler materials procured
To maintain a sustainable environment, the materials to be chosen were to be of a waste or discarded material, which can help in reusing the waste. After researching many materials like the mine waste and many other waste, three filler materials were short listed which satisfied the criteria and were chosen as filler materials for design and analysis of a filler slab. These materials were chosen as they were easily available/accessible, locally available in abundant quantities and the process of manufacturing the filler blocks with these materials can be done at site with minimum cost. Granite dust, Foundry sand and discarded plastic are the materials chosen for this experimentation.
Cost estimation is one important parameter which is to be considered as it should cost less than that of the concrete being replaced. Upon visiting various Industries, looking out for the best price we found an Industry located near Magadi road where the price of each plastic portion was Rs19 of size 80mm x 80mm x 20mm. The combination of 36 of such plastic portions will make one single block as shown in Fig. 2.4. All these plastic portions can be attached by using epoxy resin to make it a block. The filler slab requires 25 of such blocks as per the design of the slab, which results in 900 plastic portions. Therefore, the total cost of the filler material is Rs 17,100/ which is not economic when compared to the amount of concrete being replaced.

STAAD Pro is inclusive structural designing software that reports all features of structural engineering including model development, verification, analysis, design and review of results which was being originally developed by Research Engineers International in 1997. It supports
over 90 international steel, concrete, timber & aluminium design codes. This software is basically designed for civil structures in designing and analyzing purpose. This software is constructed in such a way designing of 2D and 3D modelling can be done and the structure can be defined for analysis.

6. **ANSYS software**

It is a global software designed for engineering simulation to check the behaviour upon testing. It also acts as a mechanical software that can used to simulate the models of structures, fluid dynamics or to design any other machine components. This software is helpful in many fields in terms of simulation. The version used is ANSYS (2019) R1.

7. **Methodology**

The following steps are being followed in the project and a flow chart is being shown in Fig. 3:

1. Experimental procedure in finding the properties of the basic materials and the filler materials.
2. Casting and testing of granite dust cylinders by using various measures of stabilizer to find the optimum stabilizer content.
3. Designing two way slabs and introducing filler materials in the tension zone between the reinforcement spacing by proving optimum cover.
4. Using the basic properties obtained through experimentation and other literatures, modelling is done using STAAD.Pro and ANSYS software.
5. Results are extracted upon analyses. These results are compared with the conventional slab.
6. Cost comparison between the filler slab and conventional slab is done.

![Flow Chart](image)

**Fig. 3**: Steps being followed during the project
7.1 Construction of Filler slab

The shuttering of the slab is placed and held stiff. This is followed by the reinforcing bars are placed over the shuttering as per design of the slab. These bars are tied using binding wire at every cross section of the bars and cover is provided at the bottom of the bars by using cover clocks. Filler blocks are then placed over the shuttering proving a cover of 20mm between the reinforcement as shown in Fig. 2.6. Concrete of M20 grade is prepared and poured. Compaction is done using needle vibrator to get rid of air voids. On completing, deshuttering should be done after 7 days and curing must be done for 28 days to attain its strength.

Fig. 4 Typical Filler slab design
7.2 Experimental tests carried out to find basic properties

| Specific gravity test | Moisture content test | Cone penetration test |
|----------------------|-----------------------|----------------------|
| Bulking test         | Sieve analysis        | Proctor test         |
| Mixing of various composition | Casting of cylinders done using PVC moulds | Compression test of cylinder |

Fig. 5 Basic tests conducted

7.3 STAAD.Pro modelling
The modelling of slab was done using STAAD.Pro V8i (SELECT series 6). The following steps were followed in the analysis of the slab. Similar steps were followed for conventional slab and filler slabs using various filler materials:
1. Geometry of the slab
2. Meshing
3. Support conditions
4. Material properties
5. Design parameters

7.4 ANSYS modelling
The modelling of slab was done using a ANSYS (2019) R1. The following steps were followed in the analysis of the slab. Similar steps were followed for conventional slab and filler slabs using various filler materials:
1. Boundary conditions
2. Engineering properties (Concrete and Steel)

Fig. 6(a) Geometry conditions of conventional slab
Fig. 6(b) Geometry conditions of the filler slab

8. Results and discussion
The results of properties of filler materials and the compressive strength of filler material has been tabulated. The cost comparison between the conventional slab and filler slab is estimated. Also, the results from STAAD.Pro and ANSYS software are interpreted.

8.1 Properties of filler material
The basic properties of the filler material were found experimentally and the results are shown in Table 1.

| Property                                      | Granite dust | Foundry sand | Range as per Code | Acceptable or Not acceptable |
|-----------------------------------------------|--------------|--------------|-------------------|------------------------------|
| Specific Gravity [5]                         | 2.32         | 2.05         | 2 – 2.5           | Acceptable                   |
| Moisture content [5]                         | 1.45%        | Nil          | -                 | -                            |
| Cone penetration test (liquid limit) [6]     | 16%          | 5.04%        | -                 | -                            |
| Bulking [5]                                  | 66.67%       | 18.75%       | 30 - 40           | Not acceptable               |
| Fineness modulus (Sieve analysis) [5]        | 1.62 (very fine sand) | 2.3 (Medium sand) | 2 – 3.5          | Acceptable                   |
| Maximum Dry density (Proctor test) [7]       | 1.19 g/cc    | 1.75 g/cc    | Around 1.182      | Acceptable                   |
8.2 Properties of cement

Properties of Ordinary Portland cement (OPC) 53 grade was found experimentally satisfying the standards as per BIS specifications IS 12269 (2013) [7]. The properties of cement are presented in Table 2.

### Table 2 Properties of 53 grade Cement

| Property                  | Cement | Range as per Code | Acceptable or Not acceptable |
|---------------------------|--------|-------------------|------------------------------|
| Specific gravity [9]      | 3.14   | Around 3.15       | Acceptable                   |
| Normal consistency [9]    | 31% by weight of cement | 26 - 33 | Acceptable |

8.3 Compression tests of granite dust cylinders
The compression test of the filler material (Granite dust) with various dose of stabilizer was experimented in the laboratory to check its optimum stabilizer and the results are as shown in Table 3. A graph was being plotted for its compressive strength with various dosages of stabilizer as shown in Fig. 7

### Table 3 Compression test results

| Cement (%) | Water (%) | W/C ratio | Weight (kg) | Density (kg/m³) | Curing days | Load (kN) | Compressive strength (MPa) |
|------------|-----------|-----------|-------------|-----------------|-------------|-----------|--------------------------|
| 4          | 16        | 4         | 4.1         | 2204.30         | 7           | 5         | 0.58                     |
| 4          | 16        | 4         | 4.06        | 2136.84         | 14          | 8         | 0.92                     |
| 4          | 16        | 4         | 4.18        | 2200.00         | 28          | 9         | 1.04                     |
| 6          | 16        | 2.67      | 4.19        | 2327.78         | 7           | 9         | 1.04                     |
| 6          | 16        | 2.67      | 4.21        | 2263.44         | 14          | 11        | 1.27                     |
| 6          | 16        | 2.67      | 4.17        | 2241.94         | 28          | 14        | 1.62                     |
| 8          | 16        | 2         | 4.17        | 2194.74         | 7           | 14        | 1.62                     |
| 8          | 16        | 2         | 4.19        | 2252.69         | 14          | 17        | 1.96                     |
| 8          | 16        | 2         | 4.18        | 2200.00         | 28          | 20        | 2.31                     |
| 10         | 16        | 1.6       | 4.1         | 2204.30         | 7           | 23        | 2.66                     |
| 10         | 16        | 1.6       | 4.12        | 2168.42         | 14          | 26        | 3.00                     |
| 10         | 16        | 1.6       | 4.15        | 2231.18         | 28          | 29        | 3.35                     |
| 12         | 16        | 1.3       | 4.16        | 2236.56         | 7           | 28        | 3.23                     |
| 12         | 16        | 1.3       | 4.15        | 2184.21         | 14          | 37        | 4.27                     |
| 12         | 16        | 1.3       | 4.18        | 2309.39         | 28          | 41        | 4.74                     |
Fig. 7 Graph of compressive strength with various dose of stabilizer

The compressive strength of granite dust with various dosages of cement was found experimentally. As the percentage of cement increases, the strength also increases and the stabilizer content must also satisfy the economic parameters. Therefore, the optimum dosage percentage was found to be 10% using the increase in strength for every 2% increase in dosage as shown in table 4.

| % cement | 7 days Strength (Mpa) | 7 days % increase in strength | 14 days Strength (Mpa) | 14 days % increase in strength | 28 days Strength (Mpa) | 28 days % increase in strength |
|----------|-----------------------|-------------------------------|-----------------------|-------------------------------|-----------------------|-------------------------------|
| 4        | 0.46                  | 50.00                         | 0.81                  | 30.17                         | 0.92                  | 38.67                         |
| 6        | 0.92                  | 50.00                         | 1.16                  | 37.30                         | 1.5                   | 31.51                         |
| 8        | 1.5                   | 50.00                         | 1.85                  | 37.30                         | 2.19                  | 31.51                         |
| 10       | 2.54                  | 50.00                         | 2.89                  | 35.99                         | 3.23                  | 32.20                         |
| 12       | 3.12                  | 50.00                         | 4.16                  | 30.53                         | 4.62                  | 30.09                         |

8.4 Cost analysis of slab
On calculating the amount of concrete, the amount of steel, the cost for shuttering and the cement required for the making of filler material, cost analysis was done in comparison with the conventional slab as shown in table 5 and it was observed that the total cost required to construct conventional slab was Rs.6150 and the cost required to construct filler slab was Rs 5923.
Table 5 Cost comparison of slab

|                          | Conventional slab (2m x 2m) | Filler slab (2m x 2m) |
|--------------------------|-----------------------------|-----------------------|
| Volume of concrete (m³)  | 0.6                         | 0.4848                |
| Cement required (kg)     | 229.9                       | 185.7                 |
| Fine aggregate required (kg) | 405.8                   | 327.9                 |
| Coarse aggregate required (kg) | 667.2                  | 539                   |
| Cost of cement for concrete | Rs 2299                  | Rs 1857               |
| Cost of Fine aggregate for concrete | Rs 259.7 | Rs 209.9 |
| Cost of coarse aggregate for concrete | Rs 400.3 | Rs 323.4 |
| Cost of shuttering       | Rs 2000                     | Rs 2000               |
| Weight of steel (kg)     | 12.64                       | 12.64                 |
| Cost of steel            | Rs 632                      | Rs 632                |
| Cement required of filler material (kg) | -             | 36.3                  |
| Cost of cement for filler material | -                  | Rs 363                |
| Total cost               | Rs 5591                     | Rs 5385               |
| 10% over head            | Rs 559.1                    | Rs 538.5              |
| Final cost               | Rs 6150.1                   | Rs 5923.5             |

8.5 STAAD analysis

8.5.1 Conventional slab

Analysis of Conventional slab was done using STAAD.Pro software to study the behaviour of slab. Results obtained are mentioned in below.

The stress that is being experienced upon applying the maximum load is the Absolute stress. Stress contour is being obtained as shown in Fig.8(a) resulting the maximum stress of 0.2696 N/mm² acting along the diagonal and minimum stress of 0.093 N/mm² as shown in Fig.8(a) acting at the mid-corners of the slab.

![Fig. 8(a) Absolute stress contour](image-url)
These are the forces that resist flexural activity along both directions. The shear force contour along X-direction and Y-direction are obtained as shown in Fig. 8(b) resulting the maximum value to be 0.027 N/mm² and the minimum value to be -0.027 N/mm².

Fig. 8(b) Shear force contour along X-direction (left) and Y-direction (right)

Fig. 8(c) Bending moment contour along X-direction and Y-direction

The slab is allowed to deflect upon applying the required load and was observed to have maximum deflection at the centre of the slab as shown in Fig. 8(d). The slab experienced maximum deflection of 0.11mm.

Fig. 8(d) Deflection of slab

8.5.2 Analysis of Filler slab (Granite dust)
The stress that is being experienced upon applying the maximum load is the Absolute stress. Stress contour is being obtained as shown in Fig. 9(a) resulting the maximum stress of 0.262 N/mm² acting along the diagonal and minimum stress of 0.090 N/mm² as shown in Fig. 9(a) acting at the
mid-corners of the slab.

**Fig. 9(a)** Absolute stress contour

These are the forces the resists flexural activity along both direction. The shear force contour along X-direction and Y-direction are obtained as shown in Fig. 9(b) resulting the maximum value to be 0.026 N/mm² and the minimum value to be -0.026 N/mm² as shown in Fig. 9(b).

**Fig. 9(b)** Shear force contour along X-direction (left) and Y-direction (right)

Since, the designed two-way slab was simply supported, maximum bending moment occurs at the mid span. The bending moment contour along X-direction and Y-direction are was obtained as shown in Fig. 9(c) resulting the maximum value to be 0.940 kNm/m and the minimum value to be -0.052 kNm/m.

**Fig. 9(c)** Bending moment contour along X-direction and Y-direction

The slab is allowed to deflect upon applying the required load and was observed to have maximum deflection at the centre of the slab as shown in Fig. 9(d). The slab experienced maximum deflection
of 0.059mm.

**Fig. 9(d) Deflection of slab**

### 8.5.3 Analysis of Filler slab (Foundry sand)
The stress that is being experienced upon applying the maximum load is the Absolute stress. Stress contour is being obtained as shown in **Fig.10(a)** resulting the maximum stress of 0.249 N/mm² acting along the diagonal and minimum stress of 0.086 N/mm² as shown in **Fig.10(a)** acting at the mid-corners of the slab.

**Fig. 10(a) Absolute stress contour**

These are the forces resists flexural activity along both direction. The shear force contour along X-direction and Y-direction are obtained as shown in **Fig.10(b)** resulting the maximum value to be 0.025 N/mm² and the minimum value to be -0.025 N/mm².

**Fig. 10(b) Shear force contour along X-direction (left) and Y-direction (right)**

Since, the designed two-way slab was simply supported, maximum bending moment occurs at the mid span. The bending moment contour along Y-direction was obtained as shown in **Fig.10(c)**

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resulting the maximum value to be 0.895 kNm/m and the minimum value to be -0.050 kNm/m.

The slab is allowed to deflect upon applying the required load and was observed to have maximum deflection at the centre of the slab as shown in Fig. 10(d). The slab experienced maximum deflection of 0.056mm.

8.6 ANSYS software

8.6.1 Analysis of Conventional slab

The stress that is being experienced upon applying the maximum load is the Shear stress. Stress contour is being obtained as shown in Fig.11(a) resulting the maximum stress of 0.25 N/mm² acting along the diagonal and minimum stress of -0.35 N/mm² acting at the mid-corners of the slab. On calculating the readings obtained, it is observed that there was a maximum shear force of 32.5kN which is under the limit as per IS 456 [8] and minimum shear force acting ~45.5kN.
Fig. 11(a) Shear stress of slab

It is a one dimensional stress which is usually a stress for its plasticity. The equivalent stress contour is obtained as shown in Fig. 11(b) resulting the maximum value to be 2.44 N/mm$^2$ and the minimum value to be 0.008 N/mm$^2$ and it is observed that minimum stress is experienced on all four corners of the slab.

Fig. 11(b) Equivalent stress contour

Fig. 11(C) Deformation contour

8.6.2 Analysis of filler slab (granite dust)

The stress that is being experienced upon applying the maximum load is the Shear stress. Stress contour is being obtained as shown in Fig.12(a) resulting the maximum stress of 0.264N/mm$^2$ acting at the opposite corners of slab and minimum stress of -0.33 N/mm$^2$ acting along the diagonal.

On observing the readings obtained, it is observed that there was a maximum shear force of 34.32kN and minimum shear force acting -42.9kN.
It is a one dimensional stress which is usually a stress for its plasticity. The equivalent stress contour is obtained as shown in Fig. 12(b) resulting the maximum value to be 2.93 N/mm$^2$ and the minimum value to be 0.001 N/mm$^2$ and it is observed that minimum stress is experienced on all four corners of the slab as well as on the filler material.

The slab is allowed to deflect upon applying the service load and was observed to have maximum deflection at the centre of the slab as shown in Fig. 12(c). The slab experienced maximum deflection of 0.13mm.
8.6.3 Analysis of filler slab (foundry sand)

The stress that is being experienced upon applying the maximum load is the Shear stress. Stress contour is being obtained as shown in Fig. 13(a) resulting the maximum stress of 0.26 N/mm² acting at the opposite corners of slab and minimum stress of -0.325 N/mm² acting along the diagonal.

On observing the readings obtained, it is observed that there was a maximum shear force of 33.8kN and minimum shear force acting -42.25kN.

![Fig. 13(a) Shear stress of slab](image)

It is a one dimensional stress which is usually a stress for its plasticity. The equivalent stress contour is obtained as shown in Fig. 13(b) resulting the maximum value to be 2.91 N/mm² and the minimum value to be 0.001 N/mm² and it is observed that minimum stress is experienced on all four corners of the slab as well as on the filler material.

![Fig. 13(b) Equivalent stress contour](image)

The slab is allowed to deflect upon applying the service load and was observed to have maximum deflection at the centre of the slab as shown in Fig. 13(c). The slab experienced maximum deflection of 0.125mm.
Fig. 13(c) Deformation contour

9. Conclusions
Based on the results obtained from the analysis done using ANSYS software, a comparison is done between the filler slab and conventional slab. It has been explained by following terms:

- All the basic tests conducted experimentally satisfies the respective Indian standards.
- Construction of filler slab was found to be economical by saving 4% when compared to the RCC slab of the same size.
- On the application of load, the shear stress on the Filler slab using Granite dust as the filler material was increased by 5.3% and the shear stress on the Filler slab using Foundry sand as the filler material was increased by 3.9% when compared to the conventional slab.
- Upon applying load, the shear force on the Filler slab using Granite dust as the filler material was increased by 5.3% and the shear force on the Filler slab using Foundry sand as the filler material was increased by 3.9% when compared to the conventional slab.
- Upon analysis, the Equivalent stress on the Filler slab using Granite dust as the filler material was increased by 16.72% and the Equivalent stress on the Filler slab using Foundry sand as the filler material was increased by 16.15% when compared to the conventional slab.
- On testing for its deflection, the deflection of the Filler slab using Granite dust as the filler material was increased by 15.4% and the deflection of the Filler slab using Foundry sand as the filler material was increased by 12% when compared to the conventional slab while the deflection of the conventional slab was cross verified using STAAD.Pro software.
- In this study, it is observed that there is no much difference in terms of Deflection, Shear stress, Shear force and Equivalent stress. On the other hand, adopting this technique can reduce the cost by 4%.

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