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Original Article

Cost Effective Design Technique for Hollow-Core Concrete Slab for Typical Forms & Shapes of Cut Outs

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Abstract *- In the modern era, construction industries play a vital role in the construction of civil structures. In India, house construction is generally carried out with concrete as a major constituent. The use of concrete is mostly used for slabs, beams, columns, and footings. It was observed that the total consumption of concrete and cement takes about 40% of the total concrete work for the slab. Searching for an economy in concrete components for the slab was felt necessary. Various alternatives were thought to save the concrete in a slab. It is well-known that the concrete bears maximum compression and is very weak to resist tension. Due to dead load, live load, and floor finish load, the slab deflects and takes a concave shape. With this concept, the concrete was pulled up from the tension zone, and recycled waste plastic with different forms and shapes in core holes was placed in the concrete. Five forms were selected for the core holes. These forms included the square, circular, elliptical, hemi spherical dome, and the frustum of a cone form. The depth of the core hole was based on the depth of the actual neutral axis. The program in excel was prepared for the analysis and design of the concrete slab with core holes of various spacings in the x direction and the y direction. For the analysis and design of the concrete slab, a 3.5 m X 3.5 m panel was considered. Three different thicknesses, 250 mm, 200 mm, and 150 mm, were considered to check the stability of the concrete slab. Mix-20 and Fe-415 were used to design the slab per the I.S. code 456 - 2000. The spacing, size, and depth of core holes for five forms were selected to determine the maximum saving of concrete in terms of percentage. All the cases for 250 mm, 2000 mm, and 150 mm slab thickness were considered using 12 mm, 16 mm, or 20 mm bar diameter as per the requirement of stability of all checks as per IS-Code. The results thus obtained were shown in a tabular form for the maximum percentage of saving of concrete for the selected two-way slab.*

Keywords *- Deflection, Flexure Moment, Hollow Core, Reinforcement, Shear Strength.*

1. Introduction

Construction industries play a key role in the present scenario. Requirements of common habitat are adequate food to eat, normal clothes to wear, and the third and most important factor is to have a shelter to stay in. Construction of homes is now becoming the priority of every habitat. But the basic concept of construction is a structure's economy, safety, and stability. Nowadays, homes are constructed using concrete, as concrete is strong and has a long life span. In R.C.C., structures generally for major components are considered footing, column, beam, and slab compared with the other three components. Various experiments were carried out to minimize the quantity of concrete in the design of the slab.

To achieve this goal of the economy, it was essential to study the behavior of concrete. It was observed that the concrete is strong in compression and weak in tension. Maximum compression and tension in concrete take place at the extreme fibers. It is required to know the depth from the top of the compression zone to search the plane where there is no compression and no tension. This depth of the axis is known as the neutral axis. Below the neutral axis, tension develops and reaches a maximum at the bottom-most fibers. Keeping this concept in mind, it was decided to replace the concrete from the tension zone. For this reason, recycled plastic waste material is used to create voids in a block of concrete with zero tension up to or less than the depth of tension zero from the bottom-most fiber to reduce the quantity of concrete. These core holes are made up of different forms and shapes.

The paper deals with five forms and shapes of core holes, such as square, cylindrical, elliptical, dome, and the frustum of a cone. These forms and shapes are shown in Fig. 1.

To check the saving of concrete, the two-way concrete slab with a span of 3.5m X 3.5m was considered. For the design, M-20 and Fe-415 steel were selected. The saving of concrete is calculated in terms of percentage basis. The general forms and shapes of holes were square, circular, elliptical, dome, and frustum of cone type. The plan and sections of the cut-out forms are shown in Fig. 2.

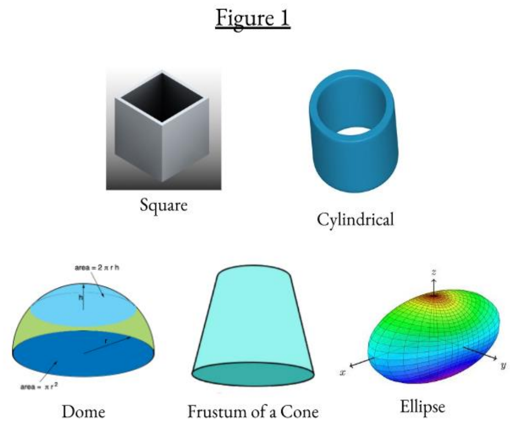

Fig. 1 Showing forms and shapes of cut-outs

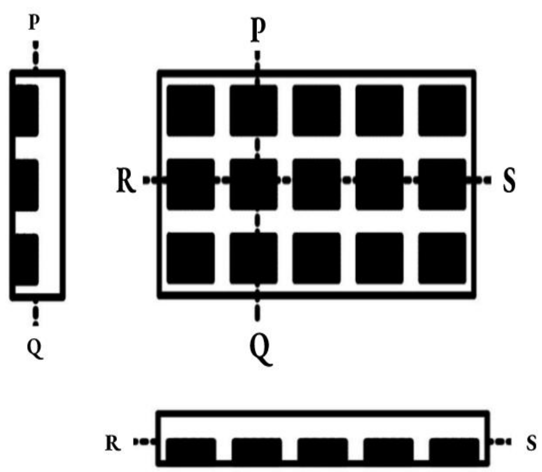

Fig. 2 Showing plan and sections of core slab

To achieve the maximum saving of concrete, permutations, and combinations of size and depth of cut-out holes were selected. The results for the maximum concrete saving for the five types of cut-out holes were shown in a tabular form. Three conditions for the overall slab thickness were considered 250 mm, 200 mm, and 150 mm. The outcome was shown in a tabular form separately for the overall three depths of concrete slabs.

2. Methodology

To achieve the maximum saving of concrete due to providing the core holes in the longitudinal direction as well as in a transverse direction, a two-way concrete slab was selected. When L/B is less than or equal to two, the slab is known as a two-way slab. The aspect ratio is considered equal to one. The length and width of the two-way slab were selected as 3.5 m and 3.5 m, respectively. Five different forms and shapes of core holes were selected to achieve the goal of saving concrete in a selected two-way slab. Core holes were considered with five types of forms and shapes. The shapes of the core holes were square, circular, elliptical, hemispherical, dome, and the frustum of a cone. The size, cross-section, depth of the core holes, and spacing of the core holes were finalized till the maximum saving was not achieved.

The overall thickness of this two-way concrete slab of 3.5 m X 3.5 m was considered for three cases. In case one, In the second case, the overall thickness of the concrete slab was reduced by 50 mm, and the thickness was 200 mm. In the third case, the overall depth of the same concrete slab was still reduced by 50 mm. Finally, the thickness of the slab was taken as 150 mm (overall thickness),

M-20 concrete mix and steel Fe-415 were adopted for the analysis and design of concrete slab for all three cases. A computer program was prepared in excel to analyze and design this selected two-way concrete slab. All the required checks were incorporated as per I.S. - code 456-2000. With all the trial-and-error methods, the spacing of core holes. The size of the core holes and depth of the core holes was selected in such a manner that the maximum saving of concrete was achieved in this percentage only.

As per steel requirements, a bar diameter of 12 mm, 16 mm, or 20 mm was provided. The depth of the actual neutral axis was calculated from the selected data. The height/depth of openings was provided less than the depth of the actual neutral axis, minus the actual depth of the neutral axis, measured from the top of the compression fiber. This precaution was taken to observe that the depth of openings should always remain in the tension zone. The results obtained were shown in a tabular form, showing the saving of concrete in terms of the percentage of a concrete quantity.

3. Observations

3.1. Case No. 1

During the analysis and design of the two-way concrete slab, as a first case, the overall thickness of the concrete slab was considered 250 mm, with design parameters taken as M-20 and Fe-415/ Core holes for five different forms of cut-outs, which were considered to calculate the maximum saving of concrete in terms of percentage. The results thus obtained are shown in a tabular form in table 1 for the concrete slab panel as 3.5 m X 3.5 m and overall slab thickness as 250 mm.

3.2. Case No. 2

Another case was considered for the same panel size of the two-way slab as 3.5 m X 3.5 m. In this case, the design and analysis of the concrete slab were considered for M-20 and Fe-415. However, in this case, the overall thickness of the slab was reduced from 250 mm to 200 mm. The results obtained for the maximum saving of concrete in terms of percentage are shown in table 2.

3.3. Case No. 3

Finally, in case No. 3, the concrete slab panel was considered as 3.5 m X 3 .5 m, but the overall thickness of the concrete slab was still reduced from 200 mm to 150 mm. The results thus obtained for the overall thickness of slab of 150 mm for the design of concrete slab for mix M-20 and steel as Fe-415 were categorically shown in a tabular form in table 3.

Table 1. Showing the results in Percentage for slab span: 3.5 x 3.5 m D = 250 mm

Description	Square	Cylindrical	Ellipse	Dome	Frustum of cone
Size (mm)	325 x 325	Dia = 250 mm	A = 400 mm B = 360 mm	D = 450 mm	D_1 = 400 mm D_2 = 300 mm
Area (mm^2)	105625	49087.5 mm^2	113076 mm^2	38026.25 mm^2	226636.8 mm^2
Height (mm)	200	200	200	225	200
Clear Spacing	100	100	100	100	100
Total # of Voids	64	100	36	36	49
% of Saving	44.14%	32.05%	26.58%	28.03%	30.68%

Table 2. Showing the results in Percentage forslabSpan: 3.5 x 3.5 m D = 200 mm

Description	Square	Cylindrical	Ellipse	Dome	Frustum of cone
Size (mm)	L = 325 B = 325	D = 250	A = 400 B = 360	D = 300 mm	D_1 = 400 mm D_2 = 300 mm
Area (mm^2)	105625	7363125	113076 mm^2	141345	173822.5 mm^2
Height (mm)	150	150	150 mm	150 mm	150 mm
Clear spacing (mm)	100	100	100 mm	100	100
Total number of Voids	64	100	36	64	49
% of Saving	41.38%	30.05%	24.92%	18.46%	28.76%

Table 3. Showing the results in Percentage forslabSpan: 3.5 x 3.5 m D = 150 mm

Description	Square	Cylindrical	Ellipse	Dome	Frustum of cone
Size (mm)	L_1 = 325 L_2 = 325	D = 400	D_1 = 400 D_2 = 360	D = 200	D_1 = 400 mm D_2 = 300 mm
Area (mm^2)	105625	125664	113076	62820	122911.06 mm^2
Height (mm)	100	100 mm	100	100 mm	D = 100 mm
Clear spacing (mm)	100	100 mm	100	100 mm	100 mm
Total # of Voids	64	49	36	64	49
% of Saving	36.79%	33.51%	22.15%	7.29%	25.56%

4. Conclusion

The hollow core slab is economical as compared with the solid concrete slab. The percentage of saving on concrete slabs is based on the openings' form, size, and shape. A hollow core slab is designed as a T beam slab with normal checks. The maximum concrete saving can be achieved by providing a square hollow core. The minimum saving of concrete was observed for the dome shapes of openings in concrete. In the square shape of the opening, the saving of concrete decreases by about three percent for every50 mm reduction of concrete slab thickness.

Similarly, in the frustum of cone openings, at every 50mm decrease of slab thickness as well as reduction of 50 mm of cut-out height, the saving of concrete is decreasing by a regular percentage of saving concrete by about 2%. In the dome shape of the opening for a decrease of concrete slab thickness at a regular interval of 50mm, it was observed that the percentage of saving of concrete decreases at a regular interval by 10%. For the Elliptical form of opening in a concrete slab, a regular decrease of saving of concrete was found to be 2% at an equal decreasing interval of slab thickness by 50 mm.

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