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Effect of continuity on reduction factors of bending moments and shear forces in grid slabs

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ABSTRACT

Grid slab is a type of floor system consisting of beams running in both directions monolithic with the slab. It is usually employed for architectural reasons in large halls such as auditoriums, restaurants, theatres and other halls where column-free space is often the main requirement. The literature is silent on dealing with such type of slabs. Some international codes like the Syrian code focus on this type of slab and provide a table of reduction factors, but which is for simply supported slab only. These values are no longer valid for the case where continuity exists. Hence this paper attempts to study the effect of continuity on the reduction factors of bending moments and shear forces of grid beams in grid-slab and obtain the reduction factors for different cases of continuity. For validation of the results, SAP 2000 software is used to obtain those values for different cases of continuous slabs. For this, a number of models having different sizes of slabs are considered. A number of analyses are performed taking all probable cases into account for three different percentages of continuity: one-third, two-third and full-length. The investigation of the effect of continuity is carried out by considering a slab having five beams and the reduction factors of bending moments and shear forces are presented in tabular forms. The study shows that it is beneficial when continuity is taken into account ultimately resulting in an economical design.

1. Introduction

A grid slab is a type of slab spanning in two directions, consisting of a thin flat plate carried by grid beams in both the directions which lean in turn on the main beams on the boundary or the walls. It can be used for long spans which may extend up to 20 m, because providing a normal slab in such a case becomes uneconomical. Also the rectangular or square void formed in the ceiling can be advantageously utilized for concealing the architectural lighting etc. In practice, the beams running in both the directions are generally of the same size. The grid-beams form slabs of smaller dimensions which may be of solid ones or hollow blocks. When the span between beams is less than 1 m, it is a case of waffle slab and it is analyzed using the conventional methods. The spacings between the beams may vary from 2 m to 5 m and it is not mandatory to keep them uniform. The 3D view of a typical grid-slab is shown in Fig. 1 [1].

According to the theory of elasticity, a grid-slab (where the spacing between grid-beams is more than 1 m) can be designed as per the Syrian code [2] by taking strips of 1 m width in both the directions and considering the loads to be distributed in both the directions. The required reinforcement for the beam at the middle of the slab is calculated based on loads of the strip multiplied by the spacing between the grid beams. For the beams which are not in the middle, the required reinforcement is less than the calculated amounts, and it can be derived from Table 1 [2] according to the number of beams in each direction and the type of boundary conditions, where those values can be adopted for the simple support case.

These reduction factors are no longer valid for continuous grid-slabs. So the analysis of the effect of continuity on the reduction factors in grid-slab is necessary. Use of grid-beams parallel to the boundary beams as per Egyptian code [3] is found to be suitable when the elongation ratio of the total dimensions of the slab is ranging between 1 to 1.5 and in the case where it exceeds 1.5, it is better to use the skew grid. The internal forces in the grid-beams are calculated as per the elasticity theory.

Though some of the numerical and experimental works on waffle slabs can be found in the literature [4,5], the knowledge on this is still very limited. It is noteworthy to mention some of the works carried out by the researchers for analyzing the waffle slab system. The static analysis of waffle slabs by Schwetz et al. [6] aims to determine the amount and distribution of the shear forces, bending and torsional moments acting on the structure. It is intended to find out the required

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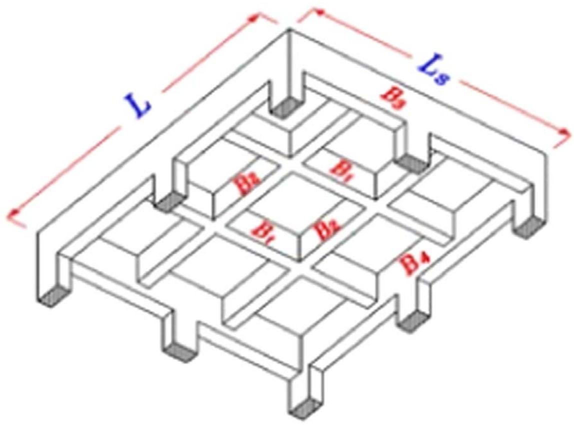

Fig. 1. 3 D view of a grid slab.

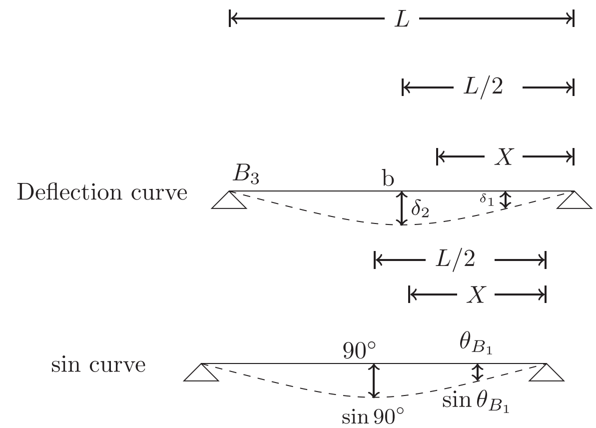

Fig. 2. Deflection curve and sine curve [1].

Table 1
Reduction factors of bending moments for simply supported case.

The location of the beam	The ratio of the moment of the non-middle beams to the middle beam moment The number of the grid beams					
	1	2	3	4	5	6
1	1.000	–	–	–	–	–
2	0.869	–	–	–	–	–
3	0.712	1.000	–	–	–	–
4	0.594	0.952	–	–	–	–
5	0.506	0.869	1.000	–	–	–
6	0.440	0.787	0.976	–	–	–
7	0.388	0.712	0.928	1.000	–	–
8	0.347	0.648	0.869	0.986	–	–
9	0.314	0.590	0.812	0.952	1.000	–
10	0.286	0.547	0.748	0.914	0.992	–
11	0.262	0.506	0.712	0.869	0.967	1.000
12	0.242	0.470	0.667	0.822	0.935	0.993

reinforcement necessary to satisfactorily resist to these effects. Moreover, it is essential to evaluate the displacements that occur in the structure submitted to the service load, considering a non-linear behavior.

Ibrahim et al. [7] considered nonlinear finite element models using ANSYS and evaluated the effect of various waffle slab parameters on the moment coefficients when the slab is subjected to a uniform load. They extended it to study the effect of openings and stiffening ribs on the design coefficients. The waffle slab was analyzed by Chowdhury and Singh [8] by a semi analytical method. Their proposition assumed the grid work as a simply supported system and employed the displacement compatibility method. Because of the absence of an analytical solution tool for other boundary conditions they proposed different shape functions to deal with different boundary conditions.

Ghanchi and Chitra [9] did a comparative study on the basis of flexural parameters such as bending moments and shear forces incorporating the Rankine-Grashoff method, plate theory, and stiffness method. The stiffness method showed a higher value of shear force Q_x as compared to the other methods. The stiffness method was found to be more accurate and more suitable to obtain the design moments and shear forces. Also, it takes less time for analysis.

A reinforced concrete waffle slab parking floor was studied by Schwetz et al. [10] considering it as a grillage model. They also performed the numerical study of the slab with SAP2000 using a three-dimensional finite element model. A real-scale ribbed slab was considered for experimentation and the deformations and deflections were measured with strain and deflection gauges under certain loading conditions.

Halkude and Mahamuni [11] noticed that the Rankine-Grashoff method is an approximate method and does not give the values of torsional moments. The plate theory and the Rankine-Grashoff methods are used for simple support conditions. The design moments and shear forces in peripheral beams cannot be obtained. On the contrary, the stiffness method can be used for rigid supports as well. By providing grid-beams of depth less than the depth of peripheral beam, the governing bending moment in peripheral beams as per Halkude and Mahamuni [12] can be optimized for a ratio of hall dimensions (L/B) @1.25. As one goes on increasing the (L/B) to more than 1.25, the optimization is not observed. The maximum shear force in peripheral beam increases with the increase in the depth of the grid beams. The difference between the depth of the peripheral beams and the depth of grid beams at an optimum value of maximum bending moment goes on reducing as the L/B ratio of the hall dimensions goes on increasing.

The present work aims at studying the effect of the continuity on the reduction factors of the bending moments and the shear forces of the grid slabs and to obtain the reduction factors for different cases of continuity by using SAP2000 software. These reduction factors can be used to analyze and design the continuous grid-slab Fig. 2.

2. Theory of grid slab

A typical grid-slab with deflection of the beams is shown in Fig. 3 [1]. In this case, the deflection of B_1 is less than that of B_2 i.e. $\delta_1 < \delta_2$. As per Rankine-Grashoff theory the reduction factor of B_1 can be calculated as following:

$$R = \frac{\text{Deflection of the beam B1}}{\text{Maximum deflection of the slab}} = \frac{\delta_1}{\delta_2} \quad (1)$$

For simply supported slab the deflection curve becomes a sine curve. Hence the reduction factors for the simply supported slabs can be obtained as

$$R = \frac{\delta_1}{\delta_2} = \frac{\sin\theta_{B1}}{\sin 90^\circ} \quad (2)$$

To calculate θ_{B1}

$$\frac{\theta_{B1}}{90} = \frac{X}{L/2} \rightarrow \theta_{B1} = \frac{X}{L/2} \times 90 \quad (3)$$

where θ is the angle between the tangent of the deflection curve at the location of the transverse beam with the horizontal axis.

So the reduction factor of any non-middle beam can be calculated easily in simply supported case from the equation:

$$R = \sin\theta_{B1} = \sin\left(\frac{X}{L/2} \times 90\right) \quad (4)$$

where X is the distance between the concerned non-middle beam and