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COMPOSITE CORRUGATED PRECAST REINFORCED CONCRETE DECK SLABS

THESIS

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ABSTRACT

Composite reinforced concrete deck slabs have been widely used in buildings and bridges construction. A new configuration for composite reinforced concrete deck slabs has been proposed. It consists of a precast corrugated reinforced concrete layer and cast-in-situ lightly reinforced concrete topping slab. The bottom layer is made of high strength concrete panels of small thickness and reinforced by an orthogonal mesh of welded wire fabric. While the top layer is made of low strength concrete and reinforced with additional reinforcement (if required).

A nonlinear finite element program has been updated and prepared to study such composite slabs. Different parameters will be included into the theoretical study of the composite slabs, such as the effect of geometrical parameters, material parameters and reinforcement ratio. Experimental works were carried out to study the behavior of the composite slabs and to asses the validity of the theoretical analysis.

The comparison between theoretical and experimental results indicates that the finite element analysis was in a good agreement with experimental results. Therefore a simple design method of the composite slabs was presented in tables form in order to calculate the maximum deflection, ultimate moment and reinforcement area.

The main function of reinforced concrete slabs is to transmit loads acting normal to their plan in addition to loads acting in their plan or any thermal effect . Many types of slabs are used in different purposes, such that solid slabs, panelled beams slabs, hollow blocks slabs, precast slabs and composite slabs, the last one is our goal.

Since 1950, composite slabs have been developed. The composite section may be consist of two or many different materials, composite concrete construction is one of these

sections, this type consist of two layers; first called precast layer, and the other called cast-in-situ layer. The employment of composite concrete slabs leads to considerable economies, because there is no forms or shuttering are required and there is saving in time.

One of the important types of the composite slabs, is composite deck slabs which is widely used in buildings and bridges construction. . Conventional deck slab systems are composed of cold formed steel deck and in-situ reinforced concrete slab. The steel deck serves as tension reinforcement and also functions as form-work during the construction stage. In the present research the composite slab consists of a precast corrugated reinforced concrete layer, instead of the cold formed steel deck, and in-situ lightly reinforced concrete topping slab. The bottom layer is made of high strength corrugated precast concrete panels of small thickness and reinforced by an orthogonal mesh of welded wire fabric. The corrugated configuration is believed to provide extra strength due to the shell-like behaviour. The cast-in-situ slab atop of the precast R.C. corrugated deck is reinforced only by a temperature and shrinkage mesh or additional reinforced if required. When hardened, the whole slab acts as a composite section to resist the full design live load provided that sufficient shear connectors are used.

In this thesis, experimental and theoretical investigation were carried out on the proposed slab. Two main parameters were included in the experimental study of such slabs, the first is different types of interface connections between the two layers such as different roughness pattern and painting the surface with binding materials, the second is different reinforcement ratios. On the other hand the previous parameters and other parameters - geometrical and materials - are included in the theoretical study.

SCOPE AND OBJECTIVES

The scope of this study is determining the nonlinear behavior of composite reinforced concrete deck slab under the effect of static loads. The investigation aims to consider the flexural capacity, shear capacity, bond, cracking , deflection and reinforcement requirements (max. & min.).

The studied slab consist of high strength precast panels reinforced by an orthogonal mesh of welded wire fabric. The panels rest directly on the edge beams thus need no temporary supporting, cast-in-situ reinforced concrete slab with a minimum reinforcement percentage and shear connectors.

The behavior of such slabs under the effect of uniform static loads depends on the following parameters:

1. Geometrical shape of the corrugation.
2. Reinforcement requirement for precast unit.
3. Deflection at various loading stages.
4. Thickness of cast-in-situ concrete.
5. Deflection limitation.
6. Types of shear connectors.
7. Maximum and minimum reinforcement for strength and serviceability.

All above parameters will be included in this study

A finite element nonlinear program will be utilized in order to analytically predict the behavior of the composite slab. The program is able to handle the material nonlinearity of reinforced concrete up to ultimate loading conditions, orthotropy as a result of the corrugation , cracking and propagation of crack across the slab thickness and the interface between the precast unit and in situ concrete.

A limited number of experimental will be supplemented mainly to verify the mathematical model and computer program. Five experiments will be conducted on rectangular panels (100 cm x 200 cm) under the effect of uniform static load.

The objective of this study can be summarized as follows:

1. Study the magnitude of deflection of middle point of the studied slabs.
2. Study the flexural capacity of the studied slabs.
3. Study the cracking propagation of the studied slabs.
4. Develop design aids for deflection control.
5. Develop design aids for ultimate moment.

Proposing simple method and accurate analytical expressions to be used by designers of such slabs.

CONTENTS

The present study consists of eight chapters listed as follows:-

Chapter (1) **:-**

Deals with the general knowledge about the slabs, especially the composite slabs, and the proposed slab. It also contains the scope, the objectives and the contents of this study.

Chapter (2) **:-**

Presents a review of the previous work concerning precast slabs, composite sections and composite slabs .

Chapter (3) **:-**

Deals with the theoretical model used in the theoretical analysis. This model based on the finite element theory. And it also includes the utilized program used in the analysis of the proposed slab.

Chapter (4) :-

Presents the definition of the proposed slab, and the two stages of construction. It also includes the theoretical study of the slab using the utilized finite element program according the following parameters:

1. Geometrical parameters.
2. Material parameters.
3. Reinforcement ratios.
4. Interface connection.

Chapter (5) :-

Outlines the experimental work and the test program which were:-

1. Five specimens were experimented.
2. Each specimen casted in two different parts (precast part and cast-in-situ part).
3. The time between each part not less than 28 days.
4. Two main parameters were investigated in the study (Reinforcement ratio and interface connection)
5. All slabs are rectangular 100 cm x 200 cm and supported on the short side.
6. All slabs tested under a uniform static loads until the failure occurs.

Chapter (6) :-

Presents the comparison between the theoretical model and the experimental results according to the studied parameters.

Chapter (7) **:-**

Give a proposing simple method and accurate analytical expressions to be used by designers of such slabs. It also contains design aids for deflection control and ultimate moment capacity.

Chapter (8) **:-**

Presents conclusions and the recommendation for further study.

CONCLUSIONS AND RECOMMENDATIONS

In the present study, a composite reinforced concrete precast corrugated deck slab is presented. The slab consists of a precast corrugated reinforced concrete layer and an in-situ lightly reinforced concrete topping layer. The bottom layer is made of high strength corrugated precast concrete panels of small thickness and reinforced with an orthogonal mesh of welded wire fabric. The cast-in-situ layer on top of the precast reinforced concrete corrugated deck, is only reinforced with additional reinforcement; if required.

Experimental and theoretical investigations were carried out on the proposed slab. Two main parameters were included in the experimental study of such slab, the first was to study the influence of different types of interface connection between the two layers such as, different roughness pattern or painting the surface with binding materials, the second was to study the influence of different reinforcement ratios. Other parameters- geometrical and materials- are also included in the theoretical study.

A simplified method in table form, was carried out to design the composite corrugated deck slab under the effect of static loads. Empirical equations for both, maximum deflection and ultimate moment capacity were also presented.

The experimental and theoretical results have led to the following conclusions and recommendations which can be ranked as :

1. Conclusions obtained from the theoretical study.
2. Conclusions obtained from the experimental study.
3. Conclusions obtained from the comparison between theoretical and experimental study for the tested slabs.
4. Empirical equations and simplified method of design.
5. Recommendations for further study.

CONCLUSIONS OBTAINED FROM THE THEORETICAL STUDY

Existing Program

The comparison between the utilized finite element program and the previous works (experimental and theoretical) indicates that the existing program with the introduced modifications can efficiently be used to conduct extensive parametric study on the proposed composite corrugated deck slabs, accounting for concrete nonlinearity both at the working range and at the failure loads.

Corrugated Precast Layer of Slab (Construction Stage)

1. The main geometrical parameters affecting the performance of the corrugated precast layer are the semi-vertex angle $''\alpha''$ and the slab thickness $''t''$.
2. For a constant central radius $''R''$, as the number of waves increases, the overall slab performance shows signs of decline.

3. For a constant height ***"H";*** varying any other geometrical parameter produces mostly an insignificant change in the slab performance.
4. In the early stages of loading, the effect of changing the reinforcement ratio ***"μ"*** is almost insignificant due to the fact that the present study is limited to the stage of initial cracking in the bottom concrete fiber (layer in the finite element model). Since, no reinforcing steel is used in this particular bottom layer, it is logical that, the variation in steel reinforcement ratio in higher layers, almost, has no effect on the cracking characteristics of the lower layer(s).
5. As anticipated ; increasing the concrete grade enhances the overall slab performance.

Composite Slab (Service Stage)

1. The main geometrical parameter affecting the performance of the proposed slab is the height of the rib ***(H)***.
2. No significant changes occur in the maximum compressive stress due to changing any of the geometrical parameter.
3. Changing the number of ribs ***(N)*** for a constant rib height ***(H)***, results in insignificant change in the slab performance.
4. At full service load, increasing the reinforcement ratio ***(μ),*** affects significantly the bending moment capacity of the slab .
5. Ultimate moment, is mainly affected by the percentage of reinforcement ***(μ)*** and the rib height ***(H)***, other parameters nonsignificantly affected the ultimate moment.
6. Increasing the ratio between the concrete strength of precast layer and that of the cast-in-situ layer, enhances the overall slab performance.

CONCLUSIONS OBTAINED FROM EXPERIMENTAL STUDY

Two main parameters were investigated for the composite slab in its completed form.

Effect of Interface Surface

1. The results indicate that with the same percentage of additional reinforcement ratio (0.20 %) , slab S_1 with interface surface of pattern (I), had the largest failure load equaling to 15.7 t/m^2, while the other slabs gave a failure load less than slab S_1, by a percentage of 13.7 % and 16.8 % for slab S_2 and S_3 respectively.
2. The results also showed that the use of rough surface of pattern (I) or pattern (II) is more effective than the use of smooth surface with epoxy painting, this can be obtained from the comparison of the maximum crack width , maximum slip and maximum deflection.
3. For the maximum relative slip, using interface surface of pattern (II) was more effective than pattern (I) in the range of working loads, but beyond the working range and up to failure loads pattern (I) was the best.

Effect of Additional Reinforcement Ratio

1. The results indicated that with the same interface surface (smooth with epoxy painting) , slab S_5 which had the maximum additional reinforcement ratio of 0.45%, had the largest failure load equaling to 16.55 t/m^2, while the other slabs gave less failure load than slab S_5, by a percentage of 42.30 % and 21.10 % for slab S_4 and S_3 respectively.
2. The results also showed that the slabs with additional reinforcement larger than zero is more effective than the use of slab without additional reinforcement, this can be obtained from the comparison of the maximum crack width , maximum slip and maximum deflection.

3. Under loads, not exceeding 2.55 t/m^2 , the percentage of additional reinforcement did not affect the maximum relative slip, but for higher loads up to the failure load the effect of using additional reinforcement is clear on the maximum relative slip.

CONCLUSIONS OBTAINED FROM THE COMPARISON BETWEEN THEORETICAL AND EXPERIMENTAL STUDY FOR THE TESTED SLABS

1. It is clear that the theoretical and experimental results of the maximum deflection at the mid-point of the composite slab are in good agreement with each other specially in the range of working loads.
2. The maximum difference between theoretical and experimental results of the maximum deflection at mid-point, at working loads was about 20% for slabs S_2 and S_3, while it was 14% for slab S_5. The two values of deflection were the same for slabs S_1 and S_4 at their working loads.
3. At higher load levels, the measured deflection was larger than that of the calculated deflection for slabs S_1, S_2, S_3 and S_4.
4. For slab S_5 , the calculated deflections and the measured ones were identical for all ranges of loading, while for slab S_4, they were identical up to the working load, then they diverted.
5. The maximum theoretical compressive strain and the maximum measured compressive strain were nearly equal at lower load levels.

6. For Slab S_1 the calculated strain was larger than that of the measured strain for all ranges of loading, while for slab S_4 and S_5 the measured strain values is larger than that of the calculated ones for all stages of loading.
7. The two curves of theoretical and experimental compressive strain with the load were nearly conformed for slabs S_2 and S_3.
8. The percentage between the theoretical failure load and the experimental failure loads was nearly about (82-94) % for the tested slabs S_1, S_2, S_3 and S_5, while it was 106% for slab S_4.
9. Finally it can be concluded from the previous results that the used program is efficient enough to analyze composite precast deck slabs with a certain accuracy taken into account. Consequently, a simplified method for the design of such slabs is presented.

EMPIRICAL EQUATIONS AND SIMPLIFIED METHOD OF DESIGN

General Empirical Equation for the Ultimate Moment

According to the studied parameters and the previous assumptions, the ultimate moment of the composite corrugated precast deck slab can be calculated using the following equation:

$$\boxed{M_U = K_{M1} E_r^{K_{M2}}}$$

1. The values of constants K_{M1} and K_{M2} depend on the rib height and the percentage of reinforcement.
2. As the rib height increases the values of K_{M1} also increase.
3. As the reinforcement ratio increases the values of constant K_{M1} also increase.
4. The increase in rib height causes a decrease in the values of K_{M2}.

5. The same conclusions can be deducted for the relation between reinforcement ratio and the values of $\boldsymbol{K_{M2}}$.
6. High values of $\boldsymbol{E_r}$ cause an increase in the ultimate moment.

General Empirical Equation for the Maximum Deflection at the Mid Point

According to the studied parameters and the governing assumptions, the maximum deflection of the mid point of the slab can be calculated using the following empirical equation :

$$\delta_{max} = \frac{10 W L^4}{K_{\delta 1} E_r^{K_{\delta 2}}}$$

1. The values of the constants $\boldsymbol{K_{\delta 1}}$ and $\boldsymbol{K_{\delta 2}}$ depend on the rib height and the reinforcement ratio.
2. As the rib height increases the values of $\boldsymbol{K_{\delta 1}}$ also increase .
3. The same conclusion can be obtained for the relation between the reinforcement ratios and the constant $\boldsymbol{K_{\delta 1}}$.
4. The relation between the rib height and the values of $\boldsymbol{K_{\delta 2}}$ is nearly constant.
5. Increasing of the reinforcement ratios causes a decrease in the values of $\boldsymbol{K_{\delta 2}}$.
6. High values of $\boldsymbol{E_r}$ cause a decrease in the magnitude of the deflection.

A simple method for design was presented in table form by using the previous two equations. The steps for the design of the slab was stated in detail with an illustrative example.