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Parameters Affecting the Design and Behaviour of Composite Slabs

Paramètres influençant le calcul et le comportement des dalles mixtes

Parameter welche die Gestaltung und das Verhalten von Verbundplatten beeinflussen

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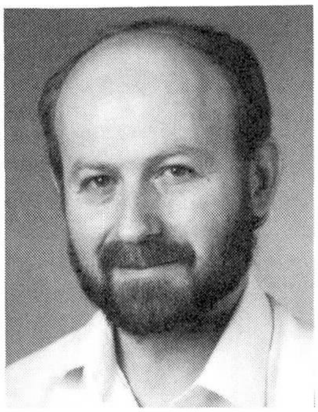

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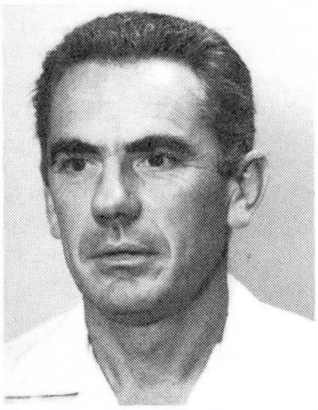

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SUMMARY

The shear-bond design model for simply-supported composite slabs is used to predict the strength of a series of slabs which have been tested. The scatter of the results shows that this empirical model does not account for the variability of the parameters. A partial shear connection model has been developed which considers equilibrium of a slab segment under any loading condition and incorporates shear connection performance derived from tests on small slab elements. Good agreement has been obtained with the test rtesults. As it is a reliable physical model, it is being developed for an Australian Standard.

RÉSUMÉ

Le modèle de contrainte de cisaillement-adhérence pour dalles mixtes sur appuis simples est utilisé pour déterminer la résistance d'une série de dalles. La dispersion des résultats montre que ce modèle empirique n'explique pas la variabilité des paramètres. Un modèle partiel pour évaluer l'effort de cisaillement a été développé. Dans ce modèle, on considère l'équilibre d'un segment de dalle sous n'importe quelle condition de chargement et on incorpore l'efficience du joint de cisaillement dérivée d'essais effectués sur des petits éléments de dalle. Une bonne concordance a été obtenue avec les résultats des essais. Etant considéré comme un modèle fiable, à présent il va être mis au point pour servir de norme australienne.

ZUSAMMENFASSUNG

Das Schub-Verbundbemessungsmodell für einfachgelagerte Verbundplatten wird dazu benutzt die Festigkeit einer Reihe von getesteten Platten vorauszuberechnen. Die Streuung der Ergebnisse zeigt, dass dieses empirische Modell die Variabilität der Parameter nicht berücksichtigt. Ein Teil-Schubverbundmodell ist entwickelt worden. Das Letztere berücksichtigt das Äquilibrium eines Plattenausschnittes unter jeglichen Belastungsbedingungen, einschliesslich des Schubverhaltens im Verbund, hergeleitet von den Tests kleiner Plattenausschnitte. Die Testergebnisse zeigten eine gute Übereinstimmung. Da dieses physikalische Modell zuverlässig ist, wird es für einen australischen Standard weiter entwikkelt.

1. INTRODUCTION

An Australian Standard for composite slab construction is being considered and a study was made of available design methods. Current design codes and specifications almost universally use the shear-bond model for predicting the strength of simply-supported composite slabs [1,2,3]. It is an empirical method and relies on testing to determine a regression line which is used in the design method. The codes require testing of slabs with a particular profile to cover the full range of the design parameters, e.g. span, shear span, gauge thickness, depth and concrete strength. It is normal to use either two- or four-point loading arrangements in the tests although the results are used to design slabs which, in practice, may have different loading patterns to these.

A series of well-controlled tests has been conducted on simply-supported composite slabs. The particular profile exhibits strong slip-flexure behaviour with end slip occurring prior to ultimate load; otherwise flexural failure occurs [4]. The effects of the following parameters were investigated: span, "shear span", loading pattern, depth, gauge thickness, concrete strength and loading history. All specimens were constructed with full propping and for some slabs, companion slip blocks were cast at the same time to determine shear connection performance [5].

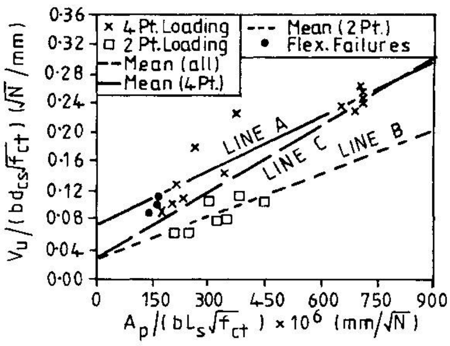


Fig. 1 Shear-Bond Plot of Test Results

The results of the tests were examined using the shear-bond model. The plot (see Fig. 1) showed considerable scatter with large variations over the range of parameters tested. Any regression line would have poor correlation. Therefore, an alternative design method was sought. The parameters were examined to see if their effects could be explained in a rational rather than an empirical manner. To do this, equilibrium of a segment of the slab was studied. This required a knowledge of the development of the longitudinal slip resistance and the strength in bending of slab cross-sections with partial shear connection.

2. SHEAR-BOND STRENGTH MODEL

The parameters adopted in the shear-bond strength model are shown on the axes in Fig.1. It should be noted, however, that the cross-sectional area of the profile, A_p, is not necessarily a variable [1], although it was taken as such here. The shear span, L_s, can be defined as the distance from the closest end support to the critical cross-section. In general it was not possible to measure L_s during the tests since a number of significant cracks could appear. For consistency, therefore, L_s was calculated as M_{max}/V_u (see Notation).

The results of the tests have been plotted in Fig. 1. A total of twenty-six slabs were tested, and the parameter ranges were as follows: spans of 1350 to 5775 mm; shear spans of 338 to 1444 mm; four-point loading patterns of (5@L/5), or (L/8,3@L/4,L/8) which simulates bending in a uniformly loaded slab, and two-point loading patterns; slab depths of 90 to 250 mm; sheeting gauges of 0.76 or 1.0 mm; concrete strengths of 24 to 63 MPa; and some slabs were dynamically cycled prior to being failed statically. The age of the slabs when tested varied between one to sixteen months. Three shear-bond lines have been fitted to the test data for those slabs which exhibited end slip, i.e. line A fits the four-point loading test data, line B the two-point loading test data, and line C fits both groups of test data. Slabs which did not exhibit end slip were considered to fail in flexure.

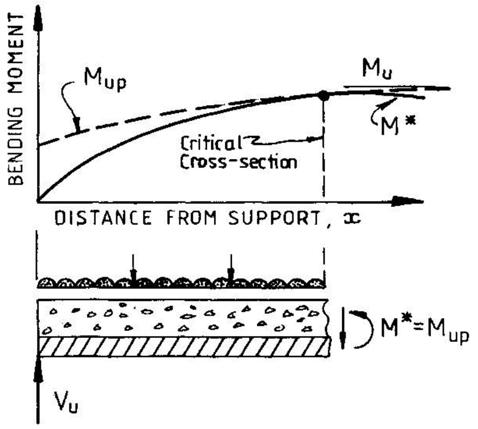
3. PARTIAL SHEAR CONNECTION STRENGTH MODEL

A free-body diagram of an end segment of a simply-supported composite slab is shown in Fig. 2(a). The equilibrium of horizontal forces per unit width for the steel profile, acting at the critical cross-section, is shown in Fig. 2(b), where:

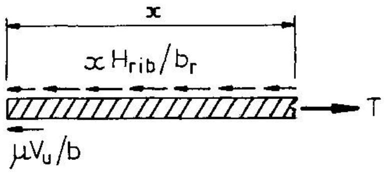
$$T = x\, H_{rib}/b_r + \mu V_u/b \qquad (1)$$

The rib resistance per unit length, H_{rib}, and the coefficient of friction, μ, are derived from slip block tests [5]. The resultant tensile force T acts within the depth of the steel profile, which is also subject to bending. As there may be slip between the profile and the concrete, its influence on the development of the tensile force T must be determined from moment-curvature relationships as indicated in Fig. 3. For a particular profile, slab depth and set of material properties, curves for different slip strains, ε_s, can be derived using standard procedures [6]. The tensile strength of the concrete may be accounted for in the analysis. The maximum bending moment, M_{up}, for a limiting value of tensile force T as calculated from Eq. 1 can be determined directly from the set of curves generated.

Fig. 2 Partial Shear Connection Strength Model



(a) Free-Body Diagram of Slab End Segment Bounded by Critical Cross-section



(b) Horizontal Force Equilibrium for Steel Profile Over Critical End Region

For each loading arrangement, the variation of moment capacity, M_{up}, with distance x along the slab can be established as indicated in Fig. 2(a). The calculation must be performed iteratively for each cross-section in turn. For large enough values of x, M_{up} is limited by the flexural capacity M_u. The maximum load capacity of a slab is reached when the bending moment M^* at a critical cross-section reaches the moment capacity M_{up} (or M_u) of that cross-section as indicated in Fig. 2. It should be noted that the method does not predict the load at which first end-slip occurs, which corresponds to when adhesion bond is broken over the region between the critical cross-section and the end support, as H_{rib} and μ are determined after slip has been induced.

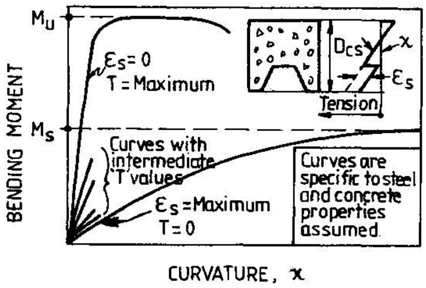


Fig. 3 Derivation of Composite Slab Moment-Curvature Relationships

4. COMPARISON OF MODELS

In the shear-bond plot in Fig. 1, any regression line would show poor correlation despite the fact that the tests were carefully controlled and all the parameters were accurately determined. There is a significant difference between the three lines A, B and C fitted. There is still considerable scatter even when the results are considered separately.

As the method is not derived from any physical model, the importance of the various parameters has to be assumed and the selection and relationships of the parameters will influence the accuracy of the method. It is obvious from Fig.1 that loading pattern has had a significant effect on the strength of the slabs. If the four-point loading tests had been used to establish the regression line (i.e. line A), this would have resulted in considerable overestimates of strengths for slabs with two-point loading. There is also a consistent trend for the thinner slabs to lie above and the thicker slabs to lie below the regression line for each loading configuration. These observations highlight that there is a fundamental problem with the method, particularly as current design codes and specifications permit the use of a single loading arrangement to establish slab strength.

The proposed partial shear connection model has been applied to the same test data. The resulting curves have been plotted in Fig. 4 using for comparison purposes the same variables as the shear-bond plot and including the effect of uniformly-distributed dead load. To indicate certain trends, the curves have been generated using representative values of concrete strength, f_{ct}, rib resistance, H_{rib}, and coefficient of friction, μ, viz. 30 MPa, 100 kN/m per rib spacing of 300 mm and 0.6 respectively. The curves clearly show the influence of loading pattern and slab depth on the strength of the slabs and correctly follow the trends of the test data.

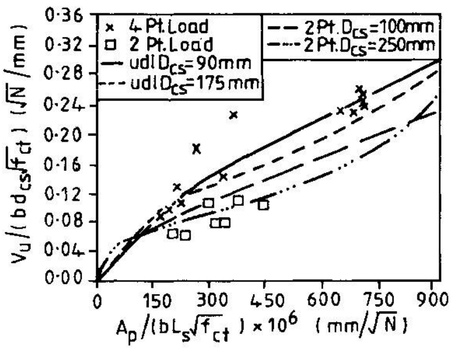


Fig. 4 Representative Strength Curves Derived Using Partial Shear Connection Theory

A typical curve exhibits three distinct regions: flexural failures without end slip as indicated by the initial linear portion of the curve (long spans); strong slip-flexure failures as indicated by the second linear portion of the curve (moderate to short spans); and a rising tail where the influence of friction is dominant (very short spans). As well as being affected by loading pattern and slab depth, it can be shown that the slope of the second linear portion is influenced by the bending strength of the profile, M_s, while the ordinate intercept varies directly with H_{rib}; this broadly explains for the profile concerned the physical significance of the m and k values, respectively, of the shear-bond method.

The shear-bond model has been compared with the test results in Fig. 5 using a regression line fitted to all the relevant test data (i.e. line C in Fig. 1). Again, the poor correlation is obvious. The partial shear connection model has been compared with the test results in the same figure using actual values of the parameters and shear connection performance data obtained from slip block tests. (In Fig. 1 it can be noticed that two of the four-point loading test results are unexpectedly high, lying well above line A; slip blocks were cut directly from the slabs after testing and high values of H_{rib} were confirmed and used to calculate the corresponding points in Fig. 5.) It can be seen that the model accurately predicts the strengths of the slabs.

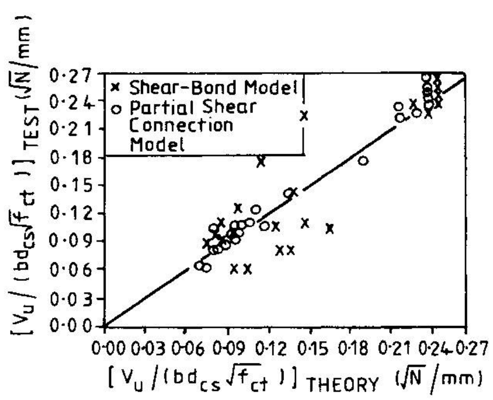


Fig. 5 Comparison of Test Results with Theoretical Predictions

5. DERIVATION OF A DESIGN METHOD AND CONCLUSIONS

The accuracy of the partial shear connection model has beeen established and therefore the model can be used as the basis for a design method. Simplified procedures using rectangular stress block theory to calculate M_{up} are being considered. In design, account has to be taken of the variability of the design parameters. In concrete and steel construction, the variabilities of parameters such as geometry, loading and material strengths have already been included to establish load factors and strength reduction (material) factors. In the partial shear connection method, the variability of the rib resistance and the coefficient of friction need to be determined from slip block tests before the reliability of the composite slab can be established. The possible effects of construction sequence will also need to be considered.

Alternative methods are also being developed for the design of composite slabs which depend on adhesion bond for ultimate strength. However, in practice such members exhibit non-ductile behaviour and more variable strengths than do slabs incorporating profiles with strong longitudinal slip resistance [4]; their use in Australia should be discouraged by any future Australian Standard. This should not cause any difficulties in Australia since all of the current manufacturers produce profiles with strong longitudinal slip resistance.

NOTATION

A_p/b = nominal cross-sectional area of profiled steel sheeting per unit width.
b = width of slab.
b_l = length of slip block.
b_r = effective width of slip block, usually equal to the profile rib spacing.
d_{cs} = effective depth at a slab cross-section.
D_{cs} = composite slab depth inclusive of profiled steel sheeting.
f_{ct} = average site compressive cylinder strength of concrete in test slab at the time of testing.
H = horizontal resistance to slip measured in slip block test.
H_{rib} = rib resistance per unit length in absence of clamping force determined from slip block test.
k = ordinate intercept of shear-bond regression line.
L_s = theoretical shear span taken as M_{max}/V_u.
m = slope of shear-bond regression line.
M_{max} = maximum bending moment in a test slab, taking into account slab self-weight and the magnitude and distribution of applied loads.
M_s = bending strength of steel profile.
M_u = flexural capacity of a slab cross-section.
M_{up} = moment capacity at a slab cross-section derived using partial shear connection theory.
M^* = applied bending moment at a slab cross-section.
T = resultant tensile force in sheeting at a slab cross-section per unit width.
V = clamping force in slip block test.
V_u = total vertical reaction at an end support when the slab ultimate strength is reached.
x = distance to a slab cross-section measured from the closest end support inclusive of the length of any overhanging portion.
μ = coefficient of friction between sheeting and concrete determined from slip block test.
ε_s = interface slip strain.
χ = cross-section curvature.

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