Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte
Band: 60 (1990)

Artikel: Prediction of the behaviour and strength of composite slabs
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DOI: https://doi.org/10.5169/seals-46455

Prediction of the Behaviour and Strength of Composite Slabs

Prévision du comportement et de la résistance des dalles mixtes

Voraussage des Verhaltens und des Widerstandes von Verbunddecken

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SUMMARY
Many factors which are important in the design of typical composite slabs are not incorporated into present design methods, for example: the behaviour of interior spans, supplementary negative or positive moment reinforcement and combined loading cases. To rectify this situation testing and theoretical research has been carried out on simple and multi-span one-way slabs. This paper presents typical results of this research.

RÉSUMÉ
Dans les méthodes de dimensionnement existantes des dalles mixtes avec tôle profilée, plusieurs paramètres importants ne sont pas considérés; il s'agit par exemple du comportement des travées intermédiaires, de l'armature supplémentaire dans les zones de moment négatif ou positif, des combinaisons de cas de charges. De manière à faire progresser les connaissances dans ces domaines, un programme de recherche théorique et expérimental pour des dalles en travées simples et continues a été réalisé. Cette contribution présente les résultats les plus caractéristiques de ces recherches.

ZUSAMMENFASSUNG
In den bestehenden Bemessungsmethoden für Verbunddecken mit Profilblechen sind mehrere, wichtige Parameter nicht berücksichtigt, zum Beispiel das Verhalten der Mittelfelder und der Zusatzarmierung im Bereich negativer oder positiver Momente, sowie die Kombinierung verschiedener Lastfälle. Um die Kenntnisse in diesem Gebiet zu vertiefen, wurde ein Versuchs- und Forschungsprogramm über Decken als einfache Balken oder Durchlaufträger ausgearbeitet. Der vorliegende Artikel beschreibt die wichtigsten Ergebnisse dieser Untersuchung.

1. INTRODUCTION

Published and private references on composite slabs with profiled steel sheeting are related almost exclusively to the testing of simple-span line-loaded one-way slabs and the interpretation of results. The predominant failure mode for such slabs is often due to horizontal debonding. In practice however, few simple-span composite slabs are constructed. Slabs are normally multi-span, two directional and may have anchorages at supports. Failure due to horizontal debonding may be expected only on exterior spans without anchorage.

A lack of understanding of the underlying mechanisms by which such members resist applied loads is apparent for researchers and code writing authorities alike. This has lead to confusion when establishing testing procedures and analysing results. Improved understanding will allow for significant increases in load carrying capacity due to continuity, anchorage and two-way action and for more flexibility in their use; combining of loading cases for example.

To address this situation research is being conducted with the following objectives :
- To determine the behaviour of the connection between profile and slab and investigate parameters which affect its strength.
- To numerically model the behaviour of simple or multi-span slabs. A data base containing 70 tests on several different profiles has been established for this comparison.
- To separate parameters according to their importance.
- To explore alternative design methods.

The above mentioned research is described in this paper. Comparisons between numerical analyses and tests are shown for simple and three-span composite slabs.

2. EXPERIMENTAL INVESTIGATIONS

Series one. Six simple-span slabs containing three different rib geometries were tested. The objective was to investigate differences between brittle and ductile slab behaviour [1].

Series two. Eighteen simple-span tests investigated, the influence of load placement, slab and profile thickness for one rib geometry [2].

Series three. Explored the vertical shear resistance of composite slabs using 21 tests [2].

Series four. Based upon the results of the earlier series a pull-out test was devised to determine the characteristics of the profile-slab connection [3]. The specimen consists of two single rib widths of profile placed back to back with an intermediate backing plate. The profiles are bolted to each other through the backing plate which eliminates lateral movement and simulates the presence of adjacent ribs. Concrete is poured on both sides of the specimen. An initial normal force is applied between the concrete and profile. Longitudinal shear force is gradually increased which separates the profile from the concrete blocks. To date more than 250 specimens have been tested, including 20 different profile geometries.

Series five. Seventeen one and three-span composite slabs were tested [4]. Slabs were constructed following typical construction practices. This included concrete mix design, concreting procedures and the design of the underlying supports. Based upon previous test results, spans and slab thicknesses were chosen such that the failure mode of an unanchored simple-span specimen would be due to horizontal shear. Varying degrees of complexity were investigated for the same profile; span lengths, heights, widths, support and load placements were not varied. The simplest slab tested was a single span without embossments or anchorage. The most complex was a three-span slab with embossments, anchorage and negative moment reinforcement over interior supports (FIGURE 1).

Series six. A push-off test was designed to investigate the behaviour of profiled sheeting attached with shear connectors [4]. Two types of connectors were tested, welded studs and shot fired shear connectors. Typical push-out tests are used to determine shear behaviour between the slab and the underlying steel section for composite beams. For these tests, load is applied between the profile and the slab. Due to the difficulty of applying large compressive loads to the profile, force is applied in tension.

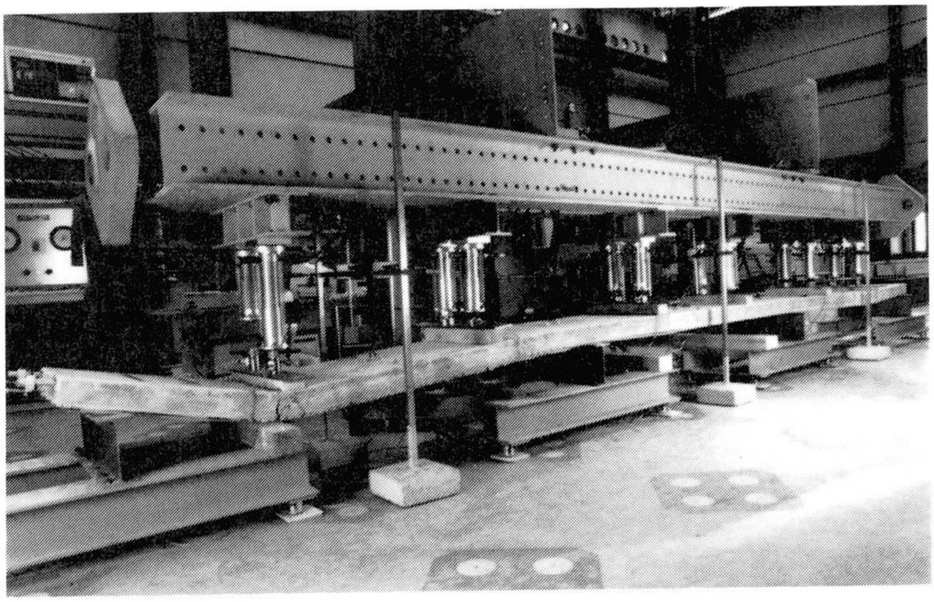

FIGURE 1 Three span composite slab with embossments, anchorage and negative moment reinforcement after failure.

3. THEORETICAL INVESTIGATION

A software tool [5] was written to analyse both the behaviour and the maximum load carrying capacity of simple or multi-span one-way composite slabs consisting of two components :

- Concrete with or without reinforcement.
- Thin-walled profiled steel sheeting.

The following two-step procedure has been adopted as follows :

a) Step one : Cross-sectional analysis.

Cross-sectional component behaviour was studied for the entire range of possible solutions using two parameters, normal force and curvature. Two components are defined: reinforced concrete and profiled sheeting. Three materials are defined according to the models given in FIGURE 2 : steel sheet, reinforcement and concrete.

A limited number of solutions are stored for future use for each component. These solutions contain necessary cross-sectional properties for the evaluation of member behaviour, strength and cross-sectional strains. It is important to note that both pre and post-maximum moment behaviour are modelled.

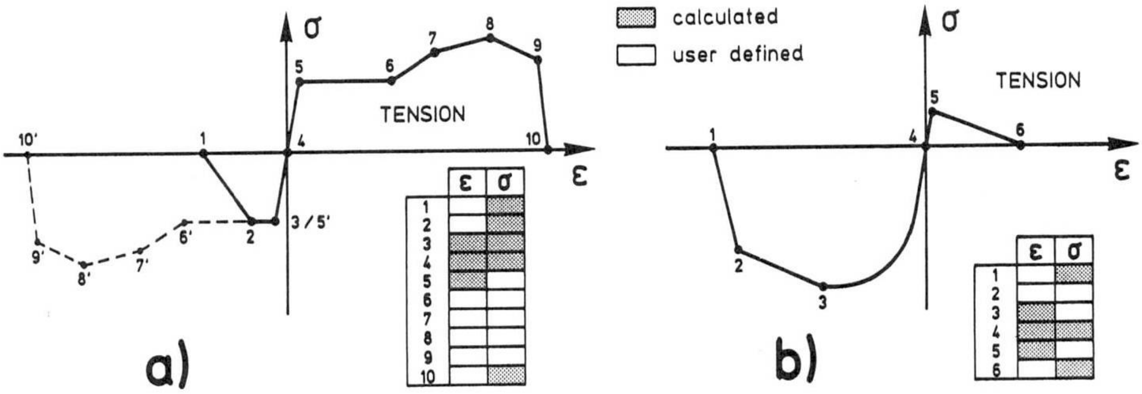

FIGURE 2 Modelling of material stress-strain behaviours.
a) Profile and reinforcement.
b) Concrete.

b) Step two : Composite slab analysis.

Member behaviour and strength were estimated using a partial interaction finite element. Several loading cases were analysed, each case consists of permanent and variable loads. Solutions were determined iteratively due to the non-linear behaviour of the connection and of the cross-sectional components.

Two types of connection behaviour are defined, continuous and concentrated. Continuous connection is present over the entire length of the specimen and is the combination of chemical bonding, friction and mechanical interlock. This is normally obtained from pull-out test results (series four). Concentrated connection is placed at individual elements simulating the presence of anchorage, single or grouped. This is normally obtained from push-off test results (series six).

This two-step procedure was chosen for the following reasons :
- Cross-sectional behaviour may be calculated and modified independently of the member analysis. Separation of variables facilitates the parametric analysis of individual variables.
- The resolution time for the non-linear finite element analysis is minimised. This is important as solutions at many different load levels are needed to determine member behaviour.

In addition to the previously mentioned analysis, behaviour is modelled assuming full interaction between the slab and profile. This program has been written so that all other parameters, geometric and material, are identical. Differences between program results are due to the presence of a partial connection only.

Modelling of slab behaviour requires the estimation of several values that are difficult to obtain by direct measurement. These are the following :
- Initial tangent concrete modulus of elasticity. For short term loading, when more accurate information is not available, a modular ratio E_a/E_c of 5 is assumed.
- Tension behaviour of concrete. A crack smearing model is used to approximate real behaviour. Maximum concrete tension strength is assumed equal to 10 % of the compressive strength. Maximum concrete strains are assumed equal to the strain at first yielding for the profile.
- Compression behaviour of the profile. Flexural tests on the profile alone are used to approximate the stress strain behaviour of the compression flange.
- Chemical bond between the slab and profile. One-way simple-span slab tests without embossments are used to estimate the effective strength of chemical bond.

4. ANALYSIS OF RESULTS AND COMPARISONS

4.1 Composite slab test results

Test results emphasizing the influence of anchorage and negative moment reinforcement (N.M.R.) are presented, test series five. Anchorage refers to shear connectors placed at supports which provide additional connection between the slab and profile. These parameters are presented as they are the least studied for composite slabs. For all of the following specimens, cross-sectional geometry, materials, span length and loading conditions are similar. Cross-sectional geometry and span length are typical of many as-built structures for the chosen profile. Load-midspan deflection are presented here (FIGURE 3), end slips, concrete and profile strains were also recorded.

For the simple-span specimens (FIGURE 3a), the load carrying capacity at a midspan deflection of L/50 for a slab with embossments and anchorage (test 3) is four times larger than for a similar slab without embossments or anchorage (test 15). The mode of failure is due principally to the loss of interaction and may be classified as ductile. Without embossments or anchorage failure is observed at the initiation of end slip and may be classified as brittle. For slabs with embossments only (test 16), or anchorage only (test 5), comparable behaviours are noted. For both specimens, the load carrying capacity at a midspan deflection of L/50 is about three times that of specimen without embossments or anchorage. These behaviours may also be classified as ductile.

For three-span specimens, the effects of N.M.R. and anchorage are observed for the end-spans (FIGURE 3b). All such specimens were provided with embossments on the profile. For the specimens without N.M.R., behaviour both with and without anchorage is similar to comparable simple span test behaviour (test 7, 13). Anchorage increases both load carrying capacity and ductility (test 7). For the specimens with N.M.R., maximum load is significantly increased due to the improved continuity with the adjacent span (test 6, 8). This increase is near 40 % for similar specimens regardless of the presence of anchorage. Again, anchorage increases both load carrying capacity and ductility (test 6). Failure due to vertical shearing was imminent in a number of slabs with N.M.R. at the maximum applied load.

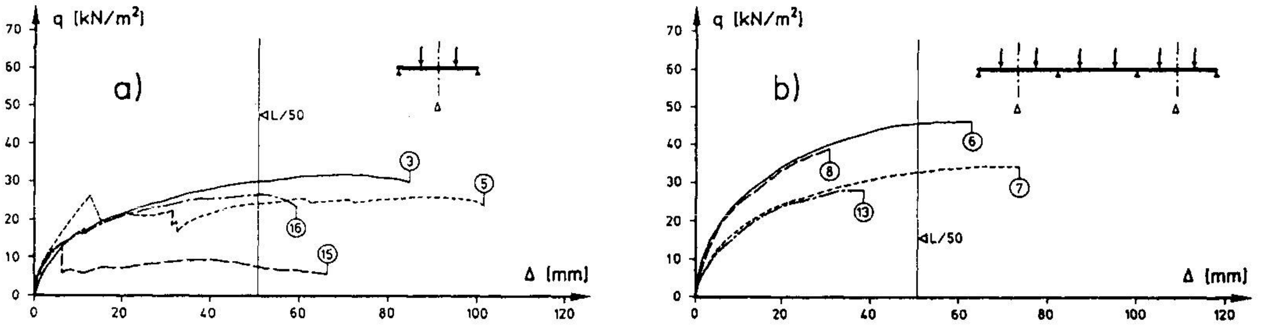

FIGURE 3 Composite slab load-midspan deflection test results.
a) Simple span specimens.
b) three span specimens.

4.2 Model predictions

Model predictions are shown for two of the previously examined specimens (FIGURE 4). Observed load-midspan deflections and two model predictions are given. The model predictions correspond to the analysis with full and partial interaction. The tests chosen for this comparison are the following :

- A simple-span composite slab with embossments but no anchorage (test 16). This is typical of tests that are presently performed to determine design load values.
- A three-span composite slab with embossments, anchorage and N.M.R. (test 6). This specimen is more representative of as-built composite slabs.

In both cases the full interaction model predicts upper bounds to observed behaviour. Maximum load corresponds to material failure, concrete crushing, profile and/or reinforcement yielding. Upper bound predictions do not correspond to test behaviour as slip was observed well before maximum loading was reached.

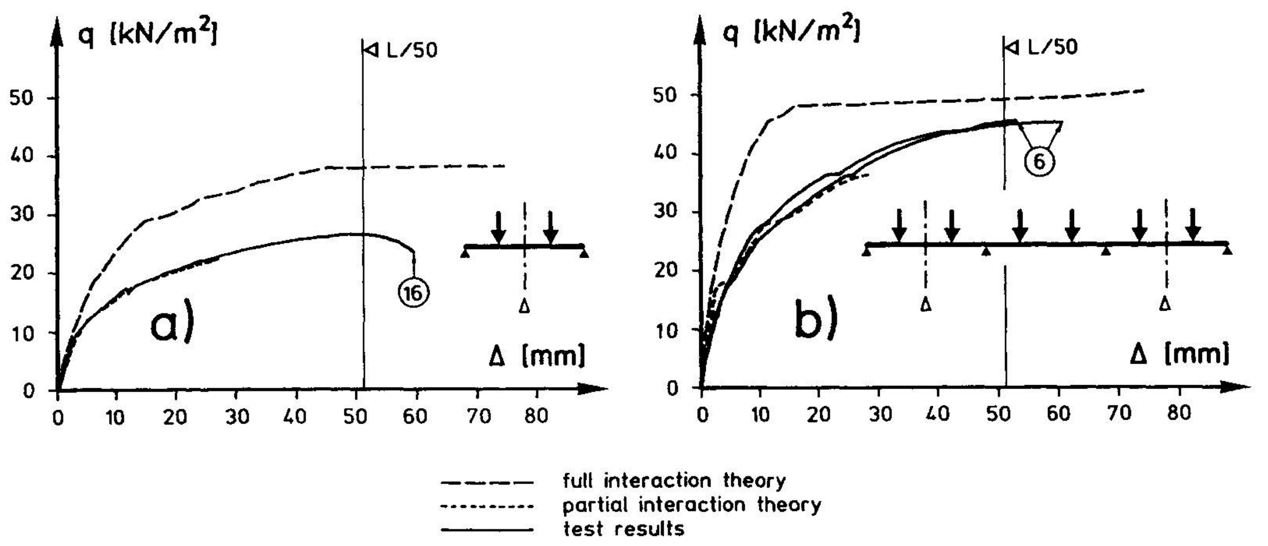

FIGURE 4 Comparison of test and model predictions of load-midspan deflection behaviour.
a) simple-span specimen.
b) three-span specimen.

For the simple-span specimen, the partial interaction model follows observed behaviour to 90 % of the failure load (FIGURE 4a). The model predicts failure due to inadequate horizontal shear bonding. This is the same mode of failure as observed during testing.

For the three-span specimen, the partial interaction model follows observed behaviour to 80 % of the failure load (FIGURE 4b). Maximum load was indicated due to inadequate horizontal shear bonding. Observations during testing suggest that total yielding in negative moment regions had occurred and some tension field action was developed between the applied load and support reaction.

The intent of such comparisons is not to obtain a perfect correspondence with test results. Given the complexity of the analysis and the observed variability of test results themselves, the purpose of such comparisons must concentrate upon the following :
- Defining the range of geometries for which these analyses give reasonable predictions.
- Estimate the relative importance of individual parameters using a parametric analysis of model predictions.

5. CONCLUSIONS

Two models have been presented for predicting composite slab behaviour. These models have been shown to give reasonable correspondences with test results. Thus, a tool allowing individual parameters affecting composite slab behaviour to be studied has been developed. Use of this tool should allow for the more rational development of future design methods.

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