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Comparative Study of Composite Slab Tests

Etude comparative d'essais de dalles mixtes

Vergleichsstudie von Versuchen an Verbundplatten

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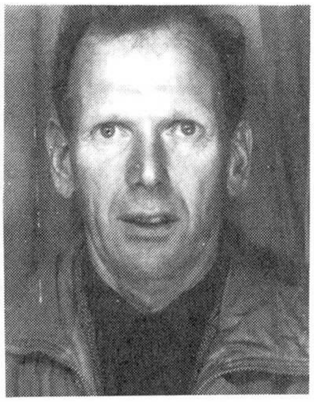

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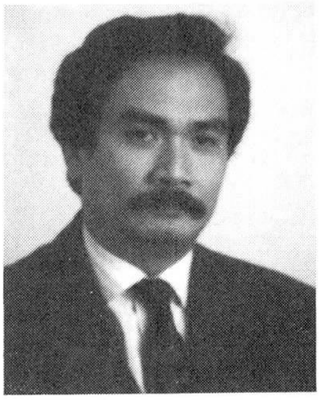

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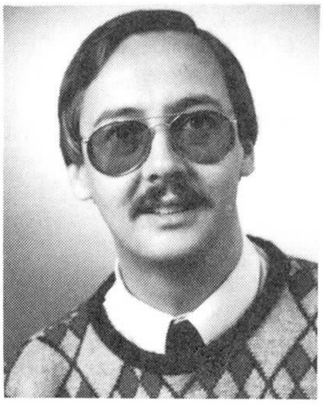

J. W. P. M. Brekelmans, born in 1951, was educated at the school for Building Engineering in Heerlen (HTS) and Structural Engineering in Amsterdam (HTI) After he worked for six years in industry he became a research engineer at the institute TNO-IBBC.

SUMMARY

The results are presented of a joint research programme between France, the Netherlands and the United Kingdom on the testing procedure for composite slabs. The results are statistically evaluated using the techniques derived from Eurocode 3. This comparative study has lead to in proposals to Eurocode 4 for the evaluation of test results for composite slabs.

RÉSUMÉ

Cette étude présente les résultats d'un programme de recherche commun à la France, aux Pays-Bas et au Royaume-Uni relatif à la procédure des essais à appliquer à des dalles mixtes. Ces résultats ont été évalués du point de vue statistique en utilisant les techniques tirées de l'Eurocode 3. Cette étude comparative tend à définir des suggestions pour l'Eurocode 4, en vue d'exploiter les résultats d'essais relatifs à des dalles mixtes.

ZUSAMMENFASSUNG

Die Resultate eines gemeinsamen Forschungsprogrammes der Länder Frankreich, Niederlande und England betreffend der experimentellen Prüfung von Verbunddecken werden vorgestellt. Die Resultate wurden gemäss Eurocode 3 ausgewertet. Diese Vergleichsstudie hat zu Vorschlägen für Eurocode 4 geführt betreffend der Auswertung von Versuchen an Verbunddecken.

1. FOREWORD

This paper presents the results of a joint research programme between France, the Netherlands and the United Kingdom which comprised a cross-testing of composite slabs using profiled steel sheeting from each country carried out according to National procedures.

The study has been performed by:
- CTICM (F);
- TNO Institute for Building Materials and Structures (in ass. with CS/CUR, NL);
- Department of Civil Engineering, Salford University (in ass. with BCSA, UK).

The object of the collaboration (carried out with the financial support of EEC commission DG XIII-SPRINT) was to examine the differences between National testing techniques and interpretations of results and to use the study as a basis for proposals to Eurocode 4 for the testing of composite slabs.
Therefore the work concentrated on:
- the exchange of information on current practice within F, UK and NL;
- testing existing products in different laboratories according to National standards;
- a statistical evaluation of the test results of each product and to make a comparison between the derived semi-experimental design values and live load values from loading codes used in the various countries.

The statistical evaluation of the test results will be discussed in this paper. For the detailed information reference is made to the final report of the SPRINT-project RA31 [1].

2. INTRODUCTION

Three types of profiled steel sheeting were used in the comparison study. Each participant selected a profiled steel sheet that was manufactered and already tested in that particular country. The selected steel profiles are:
- COFRADAL 60/0,75 mm (Laminoirs de Strasborg, F);
- PRINS PSV 73/0,75 mm (Prins n.v. Dokkum, NL);
- SUPER HOLORIB 51/0,90 mm (Richard Lees, UK).

In each country a full set of six tests on one type of profile and two check tests on another profile was carried out. Furthermore the test results of the manufacturer and some additional tests carried out in the Netherlands (TNO) were available. The tests for which the results were available are shown in table 1.

country where the tests are performed	SPRINT tests of product			Already available and additional tests of product		
	SUPER HOLORIB	PRINS	COFRADAL	SUPER HOLORIB	PRINS	COFRADAL
NL	6	-	2	6	6	-
F	2	6	-	-	-	6
UK	-	2	6	10	-	-

Table 1 Test details.

The tests were carried out according to the National standards or the current practice in the country where the tests are performed. These regulations are the BS 5950: part 4 1982 (UK), the draft RSBV 1984 (NL) and the Procedure d'Avis Technique (F). The differences in testing procedures are described in detail in the Sprint programme report [1].

For each product the longitudinal shear resistance and allowable live loads are determined according to these regulations. Serviceability requirements and modes of failure other than longitudinal shear are not considered.

As an objective way of comparing the results of ultimate strength tests and to clarify the differences between the allowable design loads in the various countries, a statistical evaluation technique derived from EC3 [4] was used. This process enables a standard method to be used which provides the characteristic values, the design values and the values for the strength from tests which are in compliance with the basic safety assumptions of Eurocode 3 (chapter 2).

3. TESTS RESULTS USED FOR THE DETERMINATION OF THE LONGITUDINAL SHEAR RESISTANCE

Certain tests listed in table 1 could not be used for the determination of the longitudinal shear resistance, because either a flexural or shear failure occured or the test procedure was incomplete.
Flexural failure was assumed to occur when the positive bending moment in the test reached 95% or more of the theoretical maximum bending moment (M_{max}) capacity.
Vertical shear could influence the failure when the shear span length (ℓ_{s2}) of the test specimen subjected to two line loads was less than three times the slab depth.

4. DESIGN MODELS

Two design models are frequently used. One model is based on the partial connection theory and the other is the 'm and k' design model.

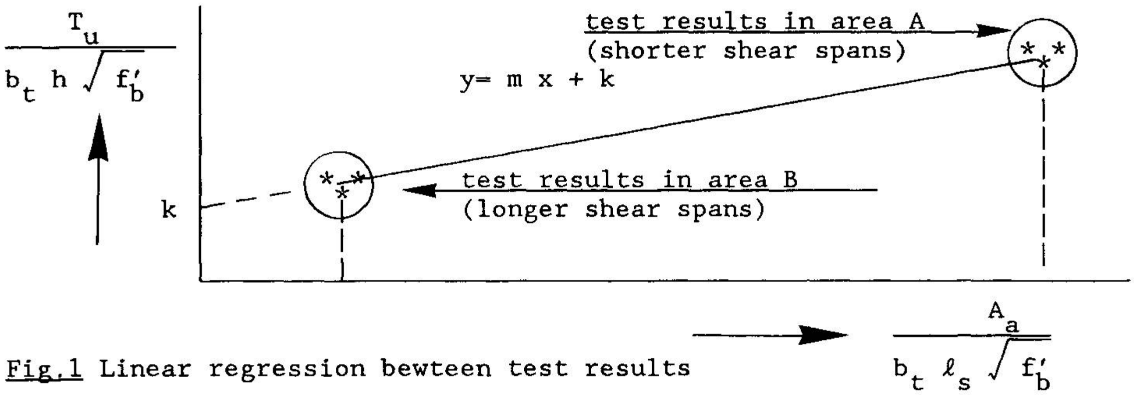

Fig.1 Linear regression bewteen test results

The national regulations of the three countries involved in the research program are based on the 'm and k' method which is related to a linear regression line between test results: y = m x + k (Fig. 1)

This method, introduced by Porter and Ekberg [2], yields the following design expression which is used in BS 5950 Part 4 1982 and draft RSBV 1984.

$$\frac{T_u}{b_t\, h} = m \frac{A_a}{b_t\, \ell_s} + k \sqrt{f'_b} \tag{1}$$

where:
m , k = factors that are derived from the regression analysis.
f'_b = compressive strength of the concrete.

Similarly the Avis Technique expression is: $$\frac{T_u}{b_t\, h} = m^* \frac{A_a}{b_t\, \ell_s} + k^* \tag{2}$$

The partial connection theory was used by Stark [3] for the design of the PRINS PSV 73 composite slab. The design model is similar to the one for composite beams.

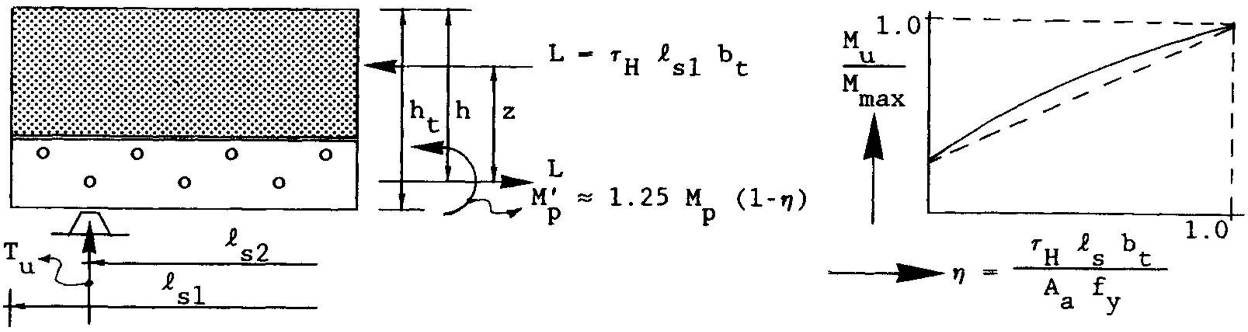

Fig.2 Partial connection theory

Consideration of the equilibrium of the composite section and the assumptions:

$$\frac{z}{h} \approx 0.8 \quad \text{and} \quad \frac{\ell_{s1}}{\ell_{s2}} \approx 1.0, \text{ leads to:}$$

$$\frac{T_u}{b_t\, h} = f_y \frac{M_p}{M_{max}} \frac{z}{h} \frac{A_a}{b_t\, \ell_{s2}} + \tau_H \left(0.8 - \frac{M_p}{M_{max}}\right) \approx m^{**} \frac{A_a}{b_t\, \ell_s} + k^{**} \tag{3}$$

where:

A_a = cross sectional area of profiled sheet;
b_t = width of the composite slab;
ℓ_s = shear span length (ℓ_{s2} = $\ell/4$ for simulated uniformly distributed load).

Equation (3) is similar in form to the 'm and k' form used in both the BS 5950 Part 4 and French Avis Technique. Depending in part of the evaluation carried out in these studies, a design model based on partial connection theory similar to the above may be included as an annex to EC4.

5. STATISTICAL EVALUATION OF TEST RESULT

For the 'm and k' method a statistical evaluation of test results has been performed. Procedure for the statistical evaluation will be briefly discussed.

The assumed 'theoretical' (semi-experimental) strength function r_t is: $\bar{m}\, f_x + \bar{k}\, g_x$

In the 'theoretical' strength function the measured values for each test should be used, for the variables in the statistical evaluation.

The values for $\bar{m}$ and $\bar{k}$ are 'the best fit mean value' from a linear regression of the test results: $y = \bar{m}\, x + \bar{k}$

or: $\left(\frac{r_e}{g_x}\right) = \bar{m} \left(\frac{f_x}{g_x}\right) + \bar{k}$ or: $\frac{T_u}{b_t\, h \sqrt{f'_b}} = \bar{m} \frac{A_a}{b_t\, \ell_s \sqrt{f'_b}} + \bar{k}$

where:

r_e = the experimental resistance (support reaction in the test)

In a background report to EC3 [4] there is a description of how to determine:
mean strength function : $r_m = r_t\, \bar{b}$
characteristic strength function: $r_k = R_k\, r_t\, \bar{b}$
design strength function : $r_d = R_d\, r_t\, \bar{b}$

and furthermore: $\gamma_M = \frac{r_k}{r_d}$ and $\gamma_M^* = \frac{r_n}{r_d}$

The characteristic values for m and k are: $m = \bar{m}\, \bar{b}\, R_k^d$ and $k = \bar{k}\, \bar{b}\, R_k^d$

where:

r_n = the nominal resistance (support reaction determined with the form in the regulations where f'_b is a characteristic strength.

In table 2, results are given of a statistical evaluation of the manufacturers test results, the Sprint-project test results and all usable test results together. For the design strength functions and values of r_d in area A and B determined with all usable test results see also fig.3.

country	profile	number of tests	ρ	γ_M	γ^*_M	r_d (for $\ell = \ell_{s2}$) area A	r_d (for $\ell_s = \ell_{s2}$) area B
NL(RA31)	SH	6	0.90	1.18	1.21-1.26	35.5 kN	50.4 kN²)
UK	SH	9	0.95	1.23	1.52-1.56	53.6 kN	54.3 kN²)
NL+UK+F	SH	14	0.99	1.14	1.29-1.33	**40.2 kN**	**38.5 kN**
UK(RA31)	COF	5	0.92	1.24	1.72-1.86	14.4 kN	10.6 kN
F	COF	6	0.91	1.16	1.40	12.1 kN	10.5 kN
NL+UK+F	COF	14	0.82	1.34	2.03-2.28	**13.3 kN¹)**	**7.9 kN¹)**
F(RA31)	PSV	6	0.82	1.11	1.12-1.17	38.1 kN¹)	42.6 kN¹)²)
NL	PSV	6	0.99	1.10	1.17-1.19	34.8 kN	33.0 kN
NL+UK+F	PSV	11	0.99	1.12	1.20-1.24	**33.7 kN**	**32.7 kN**

¹) Correlation factor $\rho < 0.9$ does not comply with [4].
²) Depending on the yield strength of the profiled steel sheet there is a flexural failure in area B (longer span length).

Table 2 Results of the statistical evaluation.

6. CONCLUSIONS

From the statistical analysis it may be concluded that in the 'theoretical' (semi-experimental) strength function for the 'm and k' method the shear span length ℓ_s should be ℓ_{s2}. This leads to the best correlation and γ^*_M values which indicates improvement of the 'theoretical' strength function.

Taking all the usable test results of COFRADAL together, results in a correlation factor less than 0.9 which does not comply with requirements of [4]. When the Uk and F test results are evaluated separately the correlation is acceptable and the design values are within a small region. The different test procedures may influence this although it cannot be proved for the SUPER HOLORIB and PRINS profiled steel sheet. The 'm and k' design model does not recognize fully the more brittle failure mode of certain profiles.

The result of an investigation with a smaller number of tests does not differ significantly from the results with all usable test results together (see table 2). Often results in area B are influenced by yielding of the steel sheet and this variable is not included in the 'theoretical' strength function.

With respect to the SUPER HOLORIB test results it should be mentioned that the UK investigations were carried out with a sheet thickness of 1,0 mm and the NL investigations with 0.87 mm. This could explain the difference in the design values for area A.

country	profile	number of tests	BS 5950 Part 4 area A	BS 5950 Part 4 area B	draft RSBV 1984 area A	draft RSBV 1984 area B
NL+UK+F	SH	14	36.8 kN	35.3 kN	39.5 kN	37.5 kN
NL+UK+F	COF	14	13.7 kN	10.4 kN	13.1 kN	11.3 kN
NL+UK+F	PSV	11	29.2 kN	26.4 kN	28.3 kN	24.7 kN

Table 3 Design value r_d according to the approximate evaluation method in the regulations.

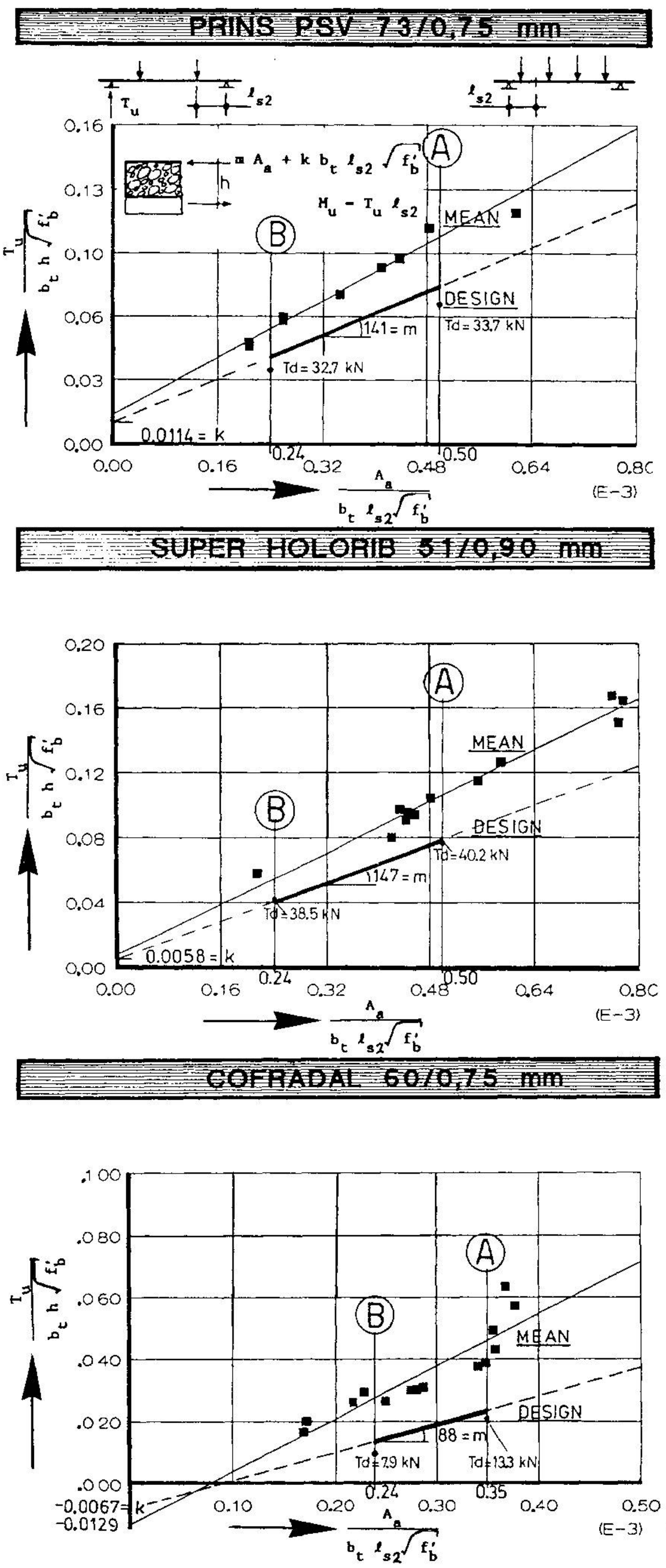

Fig. 3 'Theoretical' and statistical determined (semi-experimental) design function of the profiles examined in the SPRINT-project RA31

If the correlation of test results is sufficiently good, γ_M can be taken approximately 1.25 according to EC4 (see table 2).

In table 3, results are given for the design value r_d for all usable test results according to the approximate evaluation method given in BS 5950 Part 4 and the draft RSBV 1984.

The approximate evaluation method in the BS 5950 Part 4 and the draft RSBV 1984 are useful (compare table 2 and 3). In general it is a safe approximation, which is more conservative for a large number of test results especially using the draft RSBV 1984 because the characteristic value is related to the lowest test result.

The statistical evaluation method described in this paper has been shown to be a very useful method for the evaluation of test results and provides an important 'instrument' for the development of a design model.

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