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Autor: Wright, Howard D. / Evans, H. Roy / Harding, Philip W.

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Composite Floors: Comparisons of Performance Testing and Methods of Analysis

Dalles mixtes: comparaison des méthodes d'essais et d'analyses

Verbunddecken: Vergleich der Versuche mit den Berechnungsmethoden

Howard D. WRIGHT
Lecturer
University College
Cardiff, United Kingdom

Howard Wright, born 1952, obtained his degree at Sheffield University, Britain. He has worked for the Electricity Board and the Boots Co P.L.C. as a structural engineer before joining the lecturing staff at University College, Cardiff in 1982.

H. Roy EVANS
Prof. of Struct. Engineering
University College
Cardiff, United Kingdom

Roy Evans, born 1942, obtained his degree at University College, Swansea. Following a period with Freeman Fox and Partners he joined the staff of University College, Cardiff in 1969, where he is now Professor of Structural Engineering and Head of the Department of Civil and Structural Engineering.

Philip W. HARDING
Director
Alpha Eng. Services Ltd
Cheddar, United Kingdom

Philip Harding, born 1956, obtained his degree at University College, Cardiff and has spent 3 years working towards a Ph.D. He is now a director of Alpha Stud Welding and is currently managing composite floor system construction.

SUMMARY

Profiled steel sheeting may be used as both permanent formwork and tension reinforcement to concrete slabs, the composite action being provided by embossments to the surface of the steel sheet. Current design is based on performance testing of representative slabs to obtain empirical factors which may then be used in analysis for differing span and load conditions of the same profiled steel sheet and embossment. This paper presents the results of a series of performance tests on a British manufactured composite steel deck and compare the results of the various methods of analysis.

RÉSUMÉ

Les tôles profilées sont utilisées à la fois comme coffrage permanent et comme armature de la dalle, l'effet mixte étant assuré par les bosses à la surface de la tôle. Les méthodes de calcul courantes, basées sur des essais de dalles types, utilisent des coefficients de correction empiriques, pour tenir compte des conditions particulières de charge, de portée, etc., pour chaque modèle de tôle. Cet article présente les résultats d'essais conduits sur une tôle, produite en Grande-Bretagne, et compare les résultats obtenus avec différentes méthodes d'analyses.

ZUSAMMENFASSUNG

Profilierte Stahlbleche werden als bleibende Schalung und Zugbewehrung für Betondecken verwendet, wobei die Verbundwirkung durch die Oberflächengestaltung des Stahlblechs erzielt wird. Die gegenwärtigen Bemessungsmethoden basieren auf Versuchen an repräsentativen Plattenelementen, bei denen Erfahrungswerte ermittelt wurden, welche dann in den Berechnungen für unterschiedliche Spannweiten und Belastungsbedingungen desselben profilierten Stahlblechs und Oberflächengestaltung angewendet werden können. Dieser Vortrag beschreibt eine Reihe von Versuchen einer in England hergestellten Verbundstahldecke und vergleicht die Resultate mit den verschiedenen Berechnungsmethoden.

I. OUTLINE OF THE SYSTEM AND DEVELOPMENT

Profiled steel sheeting has, for many years, been used as permanent formwork to reinforced concrete slabs. As such its use depends on its strength and stiffness when supporting wet concrete and other construction loads, additional conventional reinforcing bars being required to provide strength and stiffness of the flooring decks under working loads.

The presence of the steel sheeting in the tensile area of the resulting slab was first utilised by the Granco Steel Products Co of St. Louis. They patented a product, known as 'Cofar', in 1950 which, by means of hard drawn wires welded to the top of the profiled steel sheeting, enabled shear forces to be transmitted from the concrete into the steel, thereby allowing the sheeting to act as tensile reinforcement. No additional reinforcement of the concrete slab was then required.

The advantages of this system were soon recognised and many more manufacturers commenced production in the sixties. The cost of welding wires to the top of the sheeting was, however, high and alternative shear transfer devices were developed. The most popular method, and the one now used almost universally, is by forming embossments in the surface of the profiled sheet. These regular embossments, which are normally made in the web, act in a similar way to the protrusions on cold deformed reinforcing bars, and provide the necessary shear key between the steel and concrete. The first system that became generally available in Britain was the 'Holorib' system marketed by Richard Lees. This sheeting has a re-entrant profile with embossments to the compression flange (Fig.1). Other

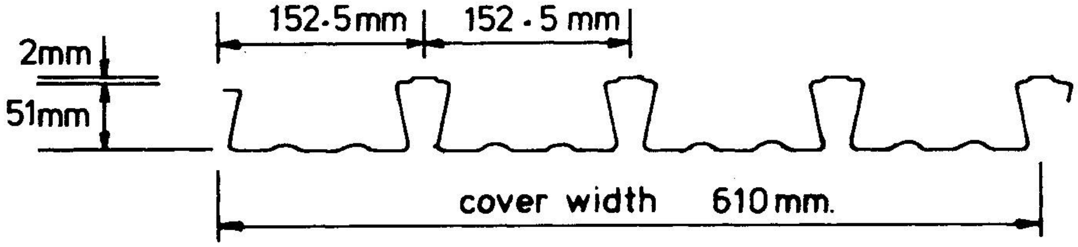

Fig.1 Richard Lees Super Holorib

profiles were introduced to Britain in the seventies from America and Europe and in the early eighties another British manufacturer, Precision Metal Forming, commenced production (Fig.2). The use of the system in Britain has been very limited in comparison to American practice, possibly because of the relatively small size of construction and the more onerous fire regulations. However,

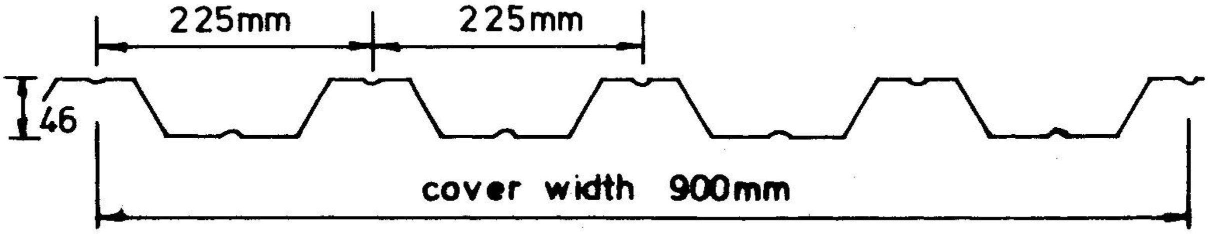

Fig.2 Precision Metal Forming CF 46.

recent large projects in Britain using this system include the National Westminster Tower, Victoria Station redevelopment and the proposed London Bridge City development. There is, currently, widespread interest in its use and development.

2. SHEAR BOND

The structural action of the system under working load relies almost entirely on the shear transfer device: without adequate bond the slab will have no additional strength over its unreinforced capacity. The bond achieved, known as "shear bond", is very dependent on the geometry and frequency of the embossments. Ultimate failure of the slab will occur with a breakdown of shear bond often preceded by tensile cracking at a position defined as the "shear span" (Fig.3).

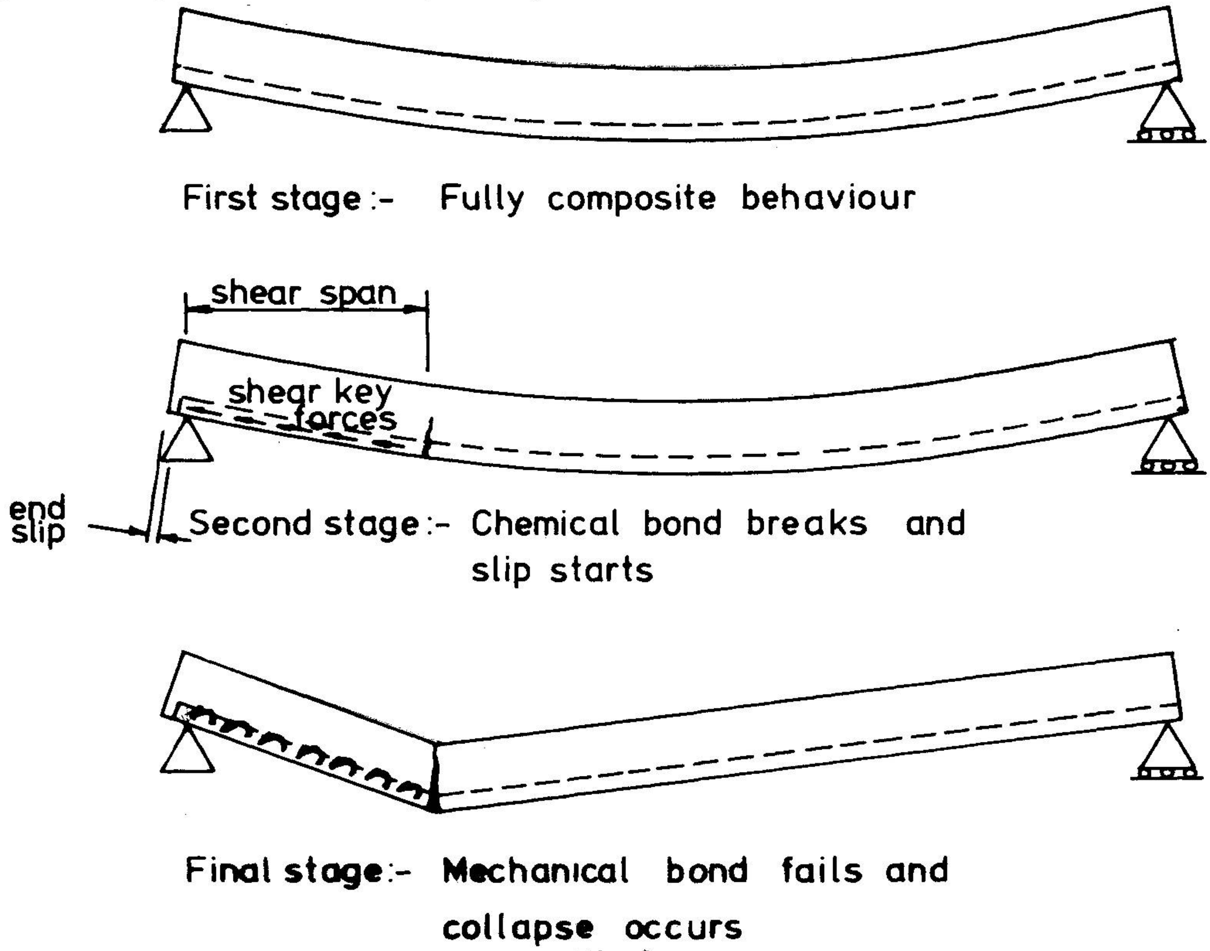

Fig.3

The shear span is normally defined by the distance from the support to the nearest point load or approximately $\frac{1}{4}$ span for a uniformly loaded slab. After initial slip has occurred at the breakdown of shear bond, the concrete slab separates, lifts and rides over the embossments and collapse occurs.

The geometry of embossment can be extremely complex involving many parameters such as embossment height, shape, overall size and orientation. Its effect on the shear bond may also be influenced by the flexibility and geometry of the sheeting itself. Consequently, the prediction the bond capacity of each system is difficult and performance testing has become the recognised alternative.

3. PERFORMANCE TESTING

The system's adoption in America was slightly delayed by the lack of standard test procedures or methods of analysis. Each manufacturer was required to carry out independent tests, often for individual jobs, and it was not until 1967 that the American Iron and Steel Institute initiated a research project at Iowa State University under the direction of Schuster and Ekberg [1]. Further research carried out by both Schuster [2] and Porter and Ekberg [3] led to the linear regression method that forms the basis for the testing requirements included in the new British code of practice; B.S.5950 Pt.4 [4].

The Code requires a minimum of 6 tests to be carried out on representative composite slabs from which a straight line may be drawn (the regression line) relating :

$$\frac{V_E}{B_s.d_s.\sqrt{f_{cu}}} \quad \text{on the vertical axis to} \quad \frac{A_p}{B_s.L_v.\sqrt{f_{cu}}} \quad \text{on the}$$

the horizontal axis, as in Fig.4. This line is then adjusted by a reduction of between 10% and 15%, depending on the number of tests carried out. Two values may be taken from this reduced line; the first value (m_r) represents the slope and the second value (k_r) represents the intercept (Fig.4). These values of the

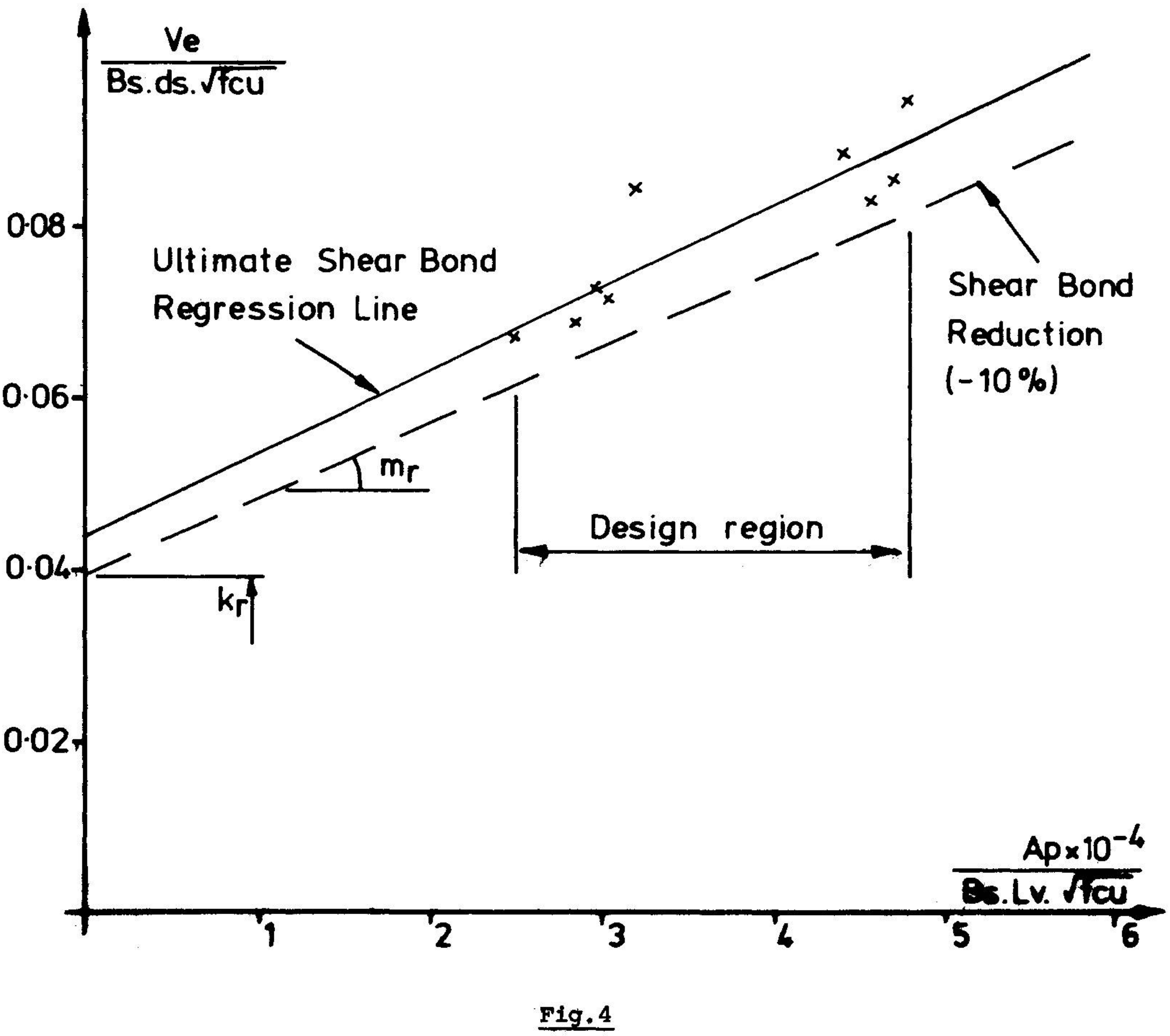

Fig.4

m and k factors may then be used subsequently to determine the strength and stiffness when the same sheet is used for different spans and with different concrete thicknesses.

The Code requires a complex preliminary procedure, involving the application of some 10,000 load cycles around the design load attained in each test. This preliminary cyling ensures that any chemical bond between concrete and steel has been destroyed before the slab is loaded to collapse so that a true value of embossment capacity is measured.

4. CARDIFF TESTS

The introduction of the CF 46 composite flooring system in 1982 preceded the final introduction of the new British Code by nearly a year. The manufacturers, Precision Metal Forming, required confirmation, not only of the new system's potential, but also of its compliance with the proposed Code. At that time, the draft version of the Code was available as the European Convention for Structural Steelwork Committee 11 report [5]. A series of tests based on this Code were carried out on the CF 46 system in the summer of 1982.

In all, twelve tests were carried out on production specimens. In addition to the measurements taken to satisfy the requirements of the Code, steel strains at mid-span and end slip between concrete and steel were measured.

The following conclusions were reached on the basis of the detailed test observations :

a) The shear transfer device in the form of a 3mm high chevron embossment provided considerable shear bond. In many tests, the strain gauges recorded yield strains in the steel sheet before ultimate failure. Extremely high load-carrying capacities were measured; generally the failure loads exceeded the required design loads by a factor of 5.

b) The use of cyclic loading to break the chemical bond may not be strictly necessary. One of the tests was carried out without preliminary cycling and a value of failure load similar to that obtained for specimens that had been cycled was obtained.

c) The height of the embossment is of vital importance. Two tests were carried out on sheets where the embossment height had been reduced from 3mm to 2mm. Both showed a reduction of approximately 50% in load capacity.

d) Variation in concrete strength, beyond a certain required minimum, does not affect the ultimate load capacity. Concrete grades ranged from 25 N/mm^2 to 55 N/mm^2 and similar load capacities were recorded in each case.

5. METHODS OF ANALYSIS

The regression line and reduction line allows the determination of slab capacity for varying spans and concrete thicknesses without recourse to further testing. The regression formula :

$$\frac{V_u . s}{bd} = \frac{m_r \rho d}{L'} + k_r \sqrt{f_{cu}} \qquad \text{(Porter and Ekberg [3])}$$

utilises two unknown quantities m_r and k_r which are often thought to represent the mechanical bond and chemical bond, respectively, between steel and concrete. This is, however, not accurate and the two factors in fact have no physical meaning.

Seleim and Schuster [6] presented a further formula in 1982 in which the thickness of the sheeting was included, thus further reducing the number of tests required.

$$\frac{V_u}{bd} = \frac{k_1 t}{L'} + \frac{k_2}{L'} + k_3 t + k_4 \qquad \text{(Seleim and Schuster [6])}$$

This formula increases the number of unknowns and proves very complex to use as computer statistical packages are required. Again the unknown factors have no physical meaning.

The reliance on testing to provide certain factors for use in further analysis appears to be inevitable. However, Parasannam and Luttrell have recently proposed a design method which completely removes the requirement for testing [7]. The formula is based on an elastic analysis with four modification factors, one of these factors being determined empirically from a large number of test results obtained from Luttrell's comprehensive studies over many years.

$$M_t = \frac{k_3}{k_1+k_2} m_f - k_4 . s \qquad \text{(Parasannam and Luttrell [7])}$$

The factors used in the Parasannam and Luttrell formula do have some physical meaning, although their accuracy is dependent on whether the previous test results are entirely representative.

6. COMPARISON OF RESULTS

The results of these methods can be compared to those obtained from the series of tests carried out by the Authors. For this, the 12 tests may be divided into a group of 10, all of which have an embossment depth of 3mm, and a group of two, which have an embossment depth of 2mm. Clearly, the m_r and k_r factors obtained for the 10 test group cannot be applied to the 2 test group and only the Parasannam Luttrell formula can be used for the latter tests.

Table 1 summarizes the results of this comparison, several conclusions may be reached :

a) Both methods of analysis requiring test information give accurate prediction of shear bond capacity.

b) The additional complexity of the Seleim Schuster formula does not appear to achieve additional accuracy.

c) The Parasannam Luttrell formula appears unacceptable for deep embossments but reasonably accurate for shallow embossments. (This is most probably due to the formula being based on previous American testing. Most American decks have very shallow embossments).

TABLE 1

MEAN ERRORS OF METHODS FOR PREDICTING SHEAR BOND CAPACITY			
	PORTER ET AL	SELEIM & SCHUSTER	PARASANNAM & LUTTRELL
10 TEST RESULTS OF PMF CF 46 TRAPEZOIDAL DECK WITH 3mm EMBOSSMENTS	3.6%	4.3%	> 50%
2 TEST RESULTS OF PMF CF 46 TRAPEZOIDAL DECK WITH 2mm EMBOSSMENTS	N/A	N/A	12%

7. CONCLUSIONS

The test series and the comparison of methods of analysis shows 3 important facets of this form of construction :

1) The strength of the concrete does not affect the shear bond strength of the system, providing a minimum concrete strength is achieved.

2) The depth of the embossment has a significant effect on the shear bond capacity.

3) The requirement for representative testing appears unavoidable but decks of similar geometry and indentation may be compared by the Parasannam and Luttrell formula.

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