Behaviour of profiled sheeting during composite floor construction

Behaviour of Profiled Sheeting during Composite Floor Construction

Comportement des tôles profilées lors du bétonnage des planchers mixtes

Verhalten von Stahlblechen während der Herstellung von Verbunddecken

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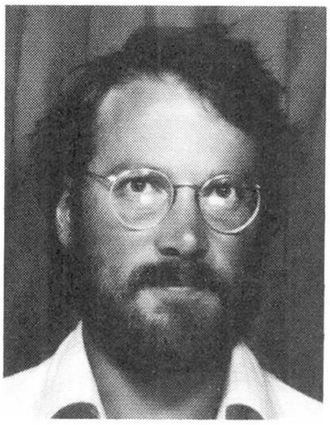

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SUMMARY

The behaviour of profiled steel sheeting under wet concrete loading is considered in this paper. Simple analysis techniques give acceptable prediction of centreline deflection but do not attempt to model the edge deformation. Such deformation is of consequence when imperfect lap or crimp joints are formed between sheets. A folded plate analysis method is developed and compared to experimental results. The analysis is then used to predict the edge deformation lap joint deformation and crimped joint deformation of profiled steel sheets subject to wet concrete loading.

RÉSUMÉ

Cette contribution concerne le comportement des plaques nervurées de planchers sous l'action du béton frais. Un simple calcul statique donne une bonne estimation de la flèche médiane de tels systèmes, mais ne permet pas de modéliser la déformation des bords des plaques. De telles déformations sont importantes lorsque les recouvrements ou les emboîtements latéraux sont imparfaits entre les plaques nervurées. Une méthode basée sur l'analyse des structures plissées a été développée, dont les résultats sont comparés aux essais. Cette analyse permet de calculer les déformations aux bords libres, aux recouvrements et aux emboîtements des plaques nervurées soumises au poids du béton frais.

ZUSAMMENFASSUNG

Das Verhalten von Profilblechen unter der Last von frischem Beton wird in diesem Aufsatz untersucht. Eine einfache statische Berechnung führt zu einer brauchbaren Bestimmung der Verformungen in der Mittellinie, eignet sich aber nicht als Modell für die Verformung der Kanten. Solche Verformungen müssen berücksichtigt werden, wenn unvollständige Überlappungs- oder Faltstösse zwischen den Blechen vorkommen. Eine Methode der Faltwerte wird angewandt und mit Versuchsergebnissen verglichen. Die Methode wird dann benutzt, um die Kantenverformungen bei Überlappungs- und Faltstössen von Profilblechen unter Frischbeton-Last zu ermitteln.

1. INTRODUCTION

In this paper the structural behaviour of profiled steel sheeting under load will be investigated with specific reference to the loading likely to occur during the construction of a composite floor slab. Installation of such a slab is carried out by laying lengths of profiled steel sheeting over supporting floor beams. The sheeting is normally fixed to the floor beams with self tapping screws or shot fired pins and connected along the longitudinal edges by screws or rivets. The resulting surface is then concreted.

The wet concrete exerts a pressure loading normal to each plate as the concrete may be assumed liquid at this stage. This pressure varies; between top and bottom flanges of the profile due to the increased depth of concrete, along the span due to the presence of ponding (see Fig. 1(a)) and occasionally across the sheet if there is reduced edge support (see Fig. 1(b)).

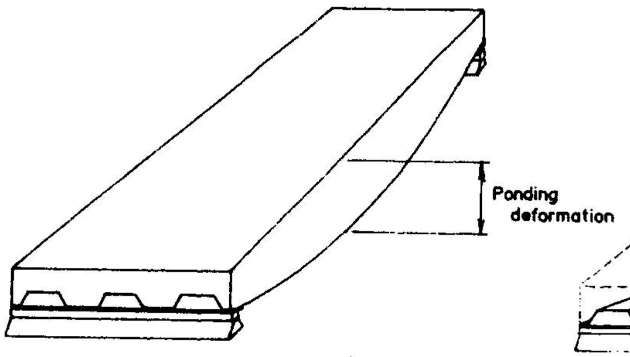


Fig. 1a

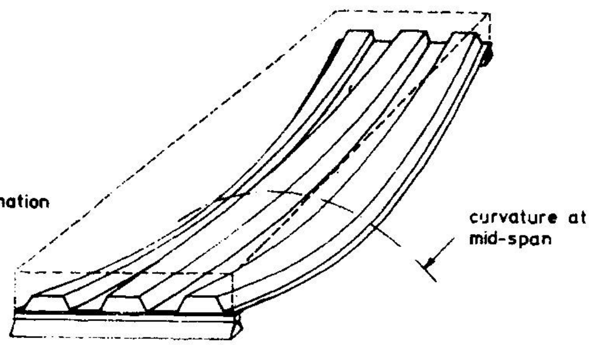


Fig. 1b

2. ANALYSIS FOR DESIGN

The application of simple beam theory gives good agreement with test results. The A.I.S.I. Specification for the Design of Cold Formed Steel Structural Members[1] uses this technique and adopts an effective width approach to plate buckling. This method provides a simple design solution for the complex behaviour of plate buckling. Its integration into the simple beam approach gives rise to the need for iteration and this makes the analysis tedious.

Despite the tedium of analysis and conservatism involved with stiffener design the A.I.S.I. code has become a model for both the British Code of Practice BS 5950 Pt[2] and the European recommendations on profile steel sheet design[3].

3. COMPARISON OF CODE PREDICTIONS AND TEST RESULTS

The A.I.S.I. code, British Code and European Recommendations have been used to evaluate the load deflection response of four typical profiles and the results have been compared to those of an experimental investigation.

The tests were carried out on samples of sheeting between 700mm and 800mm wide. The load was applied as a uniform pressure over the whole sheet by means of an air bag acting against a restraint frame. Deflections were measured by dial gauges at midspan and on the centreline only.

A typical load deflection plot for one of the profiles is given in Fig. 2 and superimposed are the plots evaluated by the A.I.S.I./ British Code and the European Recommendations. Reasonable agreement between experimental and predicted values is noted. However, since such sheets are to be mass produced, a more accurate analysis is required.

The results of a more accurate analysis capable of looking, not only at central pitch behaviour, but also at unsupported edge and longitudinal joint behaviour in the linear and post-buckling range is now presented.

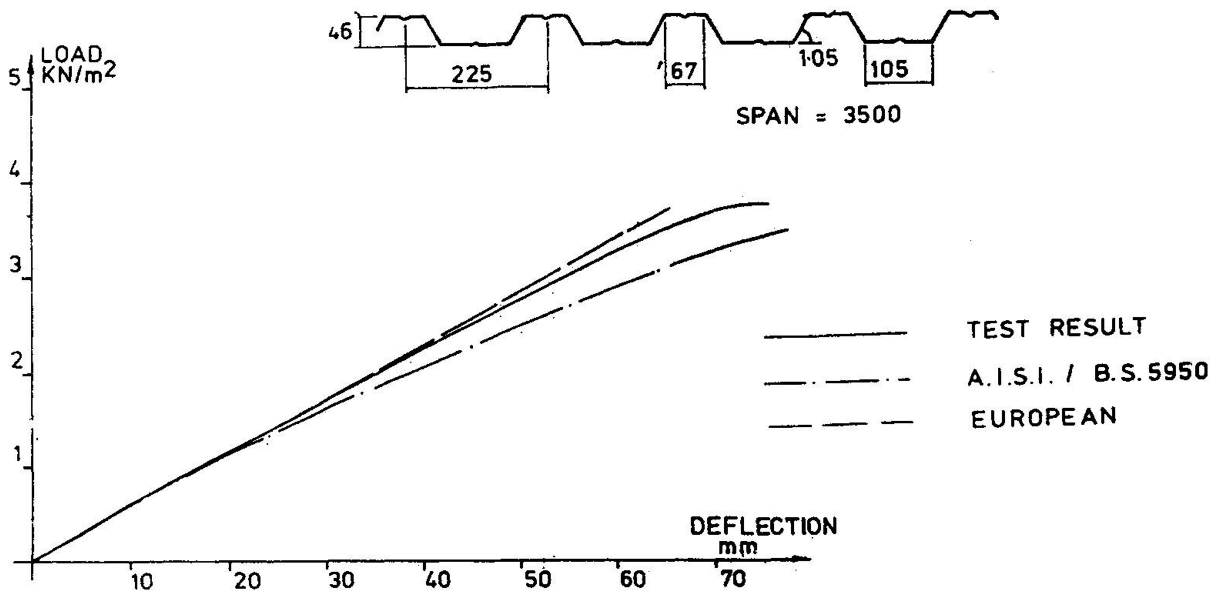


Fig. 2

4. ANALYSIS USING FOLDED PLATE METHODS

There are three possible analysis methods that could give a more accurate prediction of behaviour, viz. finite element, finite strip and folded plate methods. The last of these offers significant advantages for this situation and is adopted for the investigation in this paper.

The introduction (see Fig.1) cited loading and deformation characteristics of profiled steel sheeting that cannot be modelled by simple beam methods. The more complex folded plate methods can predict deformation under such loading. To demonstrate this, the application of the method to a typical representative profile[4] will be described and the results compared to analysis using the simple beam method.

a) Free Edge Effects

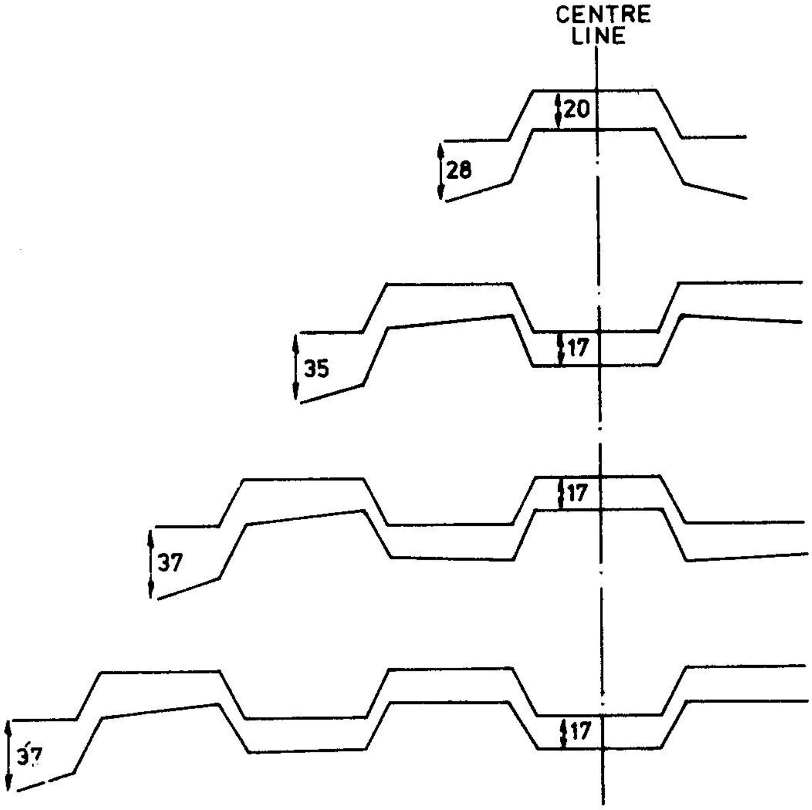
Even if the additional load due to lateral distortion and ponding is not taken into account profile edges will still distort more than the central pitches even under a uniform pressure distribution. To investigate this, folded plate analysis was used to predict the deflected shape of one, two, three and four pitch samples of a 3m span of the model profile subject to a uniform pressure of 2 kN/m^2 on each plate. The results of these analyses are shown in Fig. 3.

b) Edge Deformation of Lapped and Crimped Joints

Current codes of practice use the simple beam method to predict the deformation of entire floor areas. In the analysis it is assumed that the joints between adjacent profiled sheets are continuous and uniform vertical deflection results. In reality, the longitudinal joints between sheets may be lapped or have crimped upstands. These joints may not support the edge fully and the deflected shape of the floor may resemble that shown in Fig. 4.

The folded plate analysis developed for prediction of unsupported edge effects can be used to investigate the deformation pattern of joints. Figure 5 shows a typical lap joint with elemental plates numbered. It is assumed that the deformation of this joint will produce only one contact edge between the sheets and that this occurs along fold lines. The degree of connectivity between the nodes representing the folds may be adjusted to simulate real conditions.

This connectivity for a lap joint may be itemised as follows :



Mid-span deformation for 3m span samples carrying 2 kN/m^2.

Fig. 3

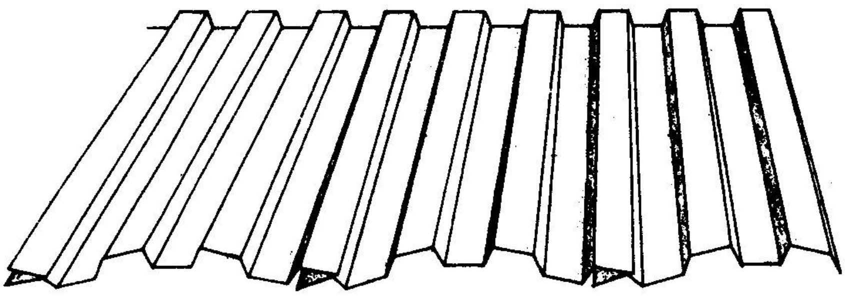


Fig. 4

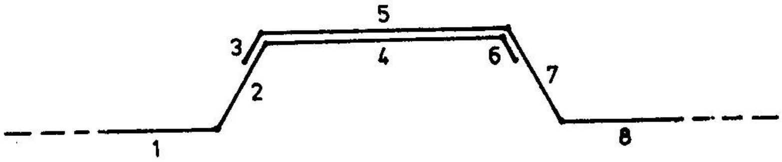


Fig. 5

a) Longitudinal connectivity:- There will be only slight frictional forces between the two sheets along the span and therefore complete freedom may be allowed.

b) Lateral connectivity:- This will depend on the keying effect of the two sheets. If they lap closely then no movement will occur and lateral movement will be restrained. If they lap loosely or relative vertical movement occurs before loading then there may be complete lateral freedom.

(c) Vertical connectivity:- The upper lap will normally carry load and deflect onto the lower lap. Consequently there is complete connection between nodes in the vertical direction.

(d) Rotational connectivity:- The two sheets are capable of free rotation and no rotational fixity is assumed.

Assuming this pattern of joint connection the folded plate analysis was used to determine the deformation of the lapped joint. It was found that considerable variation occurred when lateral connectivity was assumed fixed or free. If the lap between sheets is riveted then lateral movement is fully restricted and the joint becomes more stiff than the adjacent pitches. If the lap is left unconnected then considerable rotation and deformation occurs. These patterns of behaviour are shown in Fig. 6.

An alternative method of jointing is the crimped upstand joint shown in Fig. 7. This joint, when well formed, provides complete connectivity in all directions, but often the crimping may not be perfect and this will allow rotational freedom between sheets. It is also possible that uneven loading of a badly crimped joint may cause the two sheets to separate completely before loading. In this latter case the sheets act completely separately. The deformation predicted by folded plate methods for each of these conditions is shown in Fig. 7.

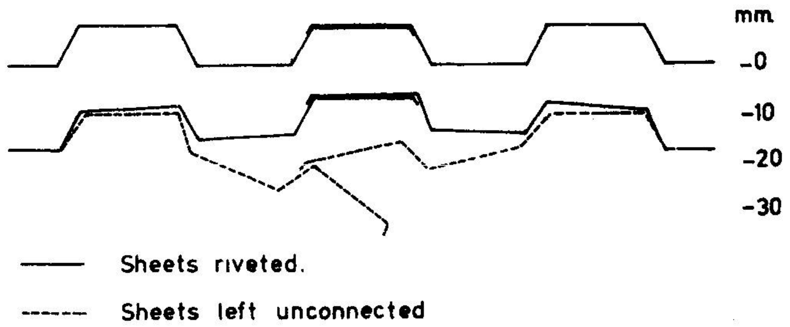


Fig. 6

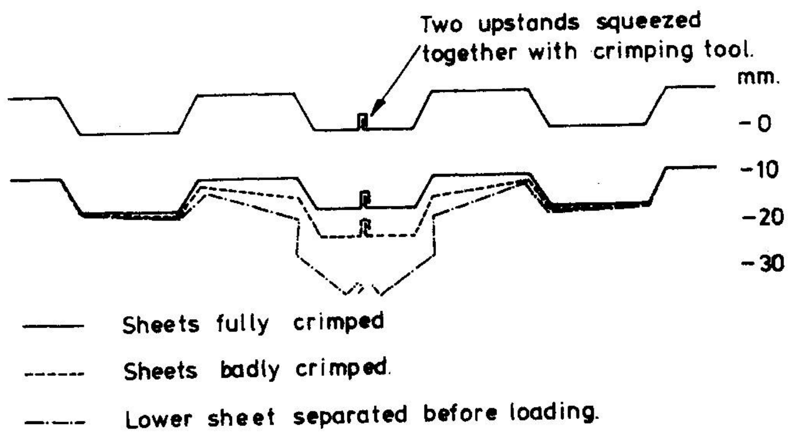


Fig. 7

The behaviour of both lapped and crimped joints has been shown to depend on the degree of connectivity between the sheets. It must also depend on the geometry of the sheet and upstand if used. Only one geometry has been investigated here and this has not been confirmed by test. However, test verification of the folded plate method has been undertaken for a free edge model and this is now described.

5. THE EFFECTS OF WET CONCRETE LOADING

As described in the introduction, wet concrete finished to a level surface gives rise to a non-uniform pressure distribution on the sheeting. The effects of this distribution can, conveniently, be split into three parts. Firstly, the effects due to the variation of pressure with depth, secondly, the effects of ponding and, thirdly, the effects of edge distortion of the sheeting.

a) The Effects of Variable Pressure Loading

During the casting operation the load of wet concrete acts as a liquid and the pressure on individual plates varies with depth of concrete. This fact is ignored when simple beam methods, where a uniform vertical pressure is assumed to act over the entire sheet, are used. The normal nature of pressure loading is also ignored by the simple beam method. The angled webs are subject to a vertical and a lateral load component of which only the vertical component, is used in the simple beam analysis.

Variable pressure is conveniently catered for by careful specification of the input data in the folded plate analysis.

b) Ponding Deformation

Ponding has been shown diagrammatically in Fig. 1. The European recommendations give guidance on the calculation of ponding deformation by adding an equivalent uniformly distributed load to simulate the ponding load. The equivalent load is determined from the mid span deflection under nominal concrete depth. An additional depth of concrete equal to 0.7 times this deflection is the resulting equivalent ponding load.

The use of equivalent uniformly distributed loads to simulate ponding is unnecessary with the folded plate method. Uniformly distributed loads are simulated, in this method, by the summation of harmonics of a sine wave. The first harmonic is identical in form to the assumed deflected shape. Consequently, when the deflection under a uniformly distributed load has been found the folded plate analysis can be repeated for the first harmonic only, thus giving a theoretically accurate distribution of ponding load. However, under this load further deflection ensues and subsequent first harmonic analyses are required to iterate to an acceptable convergence.

c) Lateral Distortion

As the folded plate computer program requires input data for each individual plate, the lateral distortion of an unsupported edge subject to ponding load is modelled automatically.

6. TEST VERIFICATION OF PONDING AND LATERAL DISTORTION ANALYSIS

A test was devised specifically to monitor the ponding and edge deformation of a profiled steel sheet loaded in a manner similar to that caused by wet concrete.

A 3.5 m long sample of "P.M.F. Ltd. CF 46 composite profile" was simply supported on roller bearings to give a clear span of 3.422 m . Timber formwork was then erected around the sample. Fine builders sand was then spread over the profile and finished to a level surface. Sand, rather than wet concrete, was used as it is a more manageable medium. Mid span deformation was measured at ten points across the sheeting with dial gauges.

Figure 8 shows the results of this test in comparison to the analysis developed in the previous Section. The accuracy of the analysis for the centreline profile deformation is shown and the edge deformation is also shown to be very close.

The centreline deflection of the profile was also calculated in accordance with the European recommendations to include the effects of ponding. This method also proved accurate, predicting the deformation within one millimetre of the folded plate and experimental value. It must be pointed out, however, that the European

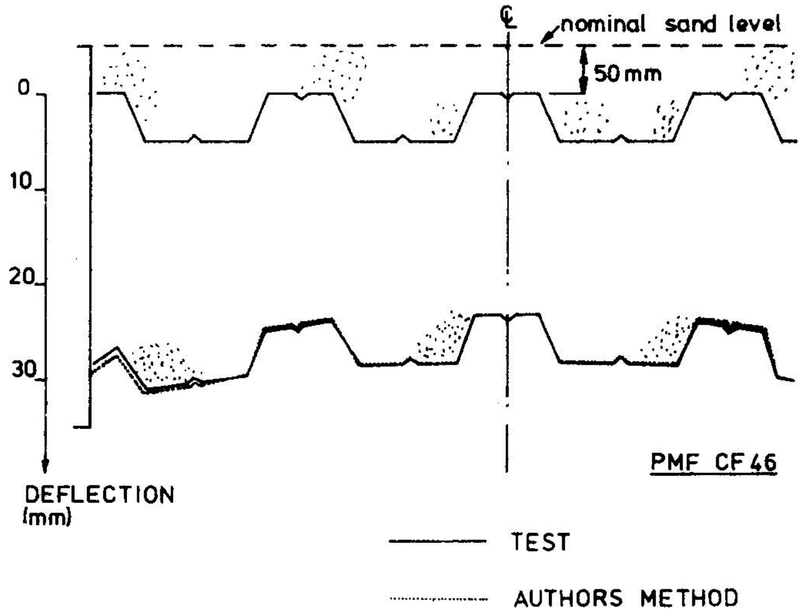


Fig. 8

recommendations cannot evaluate the very significant edge deformation.

The edge deformation in the test was sufficient to cause buckling in the outer plates. Considering the density of sand (14 kN/m^3) in comparison with wet concrete (24 kN/m^3) leads to the conclusion that the deformation under wet concrete would have been considerable. An analysis for the wet concrete case showed an edge deformation of 52 mm which was over 25% greater than that predicted by the European recommendations.

7. CONCLUSIONS

The development of a folded plate analysis method for the prediction of deflection of profiled steel sheeting has been described in this paper.

The deformations of profiled steel sheets have been predicted for free edges, lapped joints and crimped joints. The close comparison between the analysis and a test on a free edge specimen confirms the validity of these predictions. The observed and predicted deformation patterns indicate the large errors that can arise from using the simple beam method.

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