COMPOSITE SLAB DESIGN

Zoltán V. Nagy[1] and István Szatmári[2]
Technical University of Budapest, Department of Steel Structures
H-1521 Budapest

SUMMARY

There is an enhanced intention imposed on building construction industry to improve time and structural efficiency of structures. Composite slabs, as a part of composite steel framed buildings satisfy these demands by integrating several recent developments of research, however they behavior is not yet fully understood. Questions including horizontal shear resistance, design requirements to achieve ductile behavior, independence from test data or they general interpretation are still to be answered. Here a short overview of composite slab behavior and design according to EC and its critics discussed. Further attention is paid to undergoing research approaches.

Keywords: composite slab, partial composite action, Eurocode 4, numerical analysis

1. INTRODUCTION

Corrugated iron, the ancestor of today's profiled sheet was patented as early as 1829. Forming iron into thin sheets with indulations to give stiffness was originally the idea of Henry Robinson Palmer who worked for the London Dock and Harbour Company. The composite slabs formed using profiled sheeting as a permanent formwork and tensile reinforcement to a concrete slab have now become a common form of construction of floor decks in steel framed steel-buildings. Nowadays approximately 40% of all new multi-storey buildings (Fig.1) in the UK use composite floor construction. This type of construction is structurally efficient because it exploits the tensile resistance of the steel and the compressive resistance of the concrete.

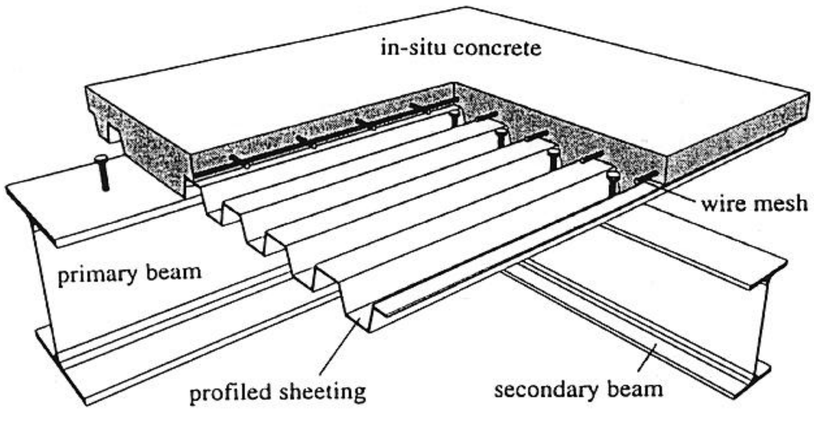

Fig.1 Composite slab in steel framed building

[1] PhD student
[2] Professor in Structural Engineering

Among others the benefits are:

- profiled sheeting acts as stay-in-place formwork
- offers an immediate working platform
- acts as slab reinforcement
- save up till 30% concrete material
- accommodate service ducks
- ease transportation and installation

Both strength and stiffness improved when the concrete slab acts compositely with its supporting profiled sheeting.

2. DUAL STRUCTURAL ROLE

A detailed composite slab design by nature is a two steps process. Under constructional loads the profiled steel sheeting behaves as a thin walled steel plate structure while under live load it is already a composite system with the concrete set on it. Similarly the research on the behavior of composite slab has been divided to deal separately with this two stages.

2.1. Formwork

Designing as a formwork, one of the main outcome to obtain optimal cross sectional geometries which are of the best in utilizing the needed profiled sheet material considering different shapes and spans. Investigating failure modes, we have checks for web crippling at support, also for web shear resistance, moment resistance of cross-section. More sever limitation lies in service limit state, namely the deflection control, which lead us to employ higher sections and use light weight concrete in many cases. The effective cross-sectional geometry (AISI,EC4,BS) which account for local buckling of sheeting, can be calculated as a function of the corresponding stress level, in an iterative process. Standards model differently the stiffeners, for example EC4 assumes as they act as beam on elastic foundation while preventing global instability. There are also secondary effects such as stretching between the stud anchorages, diaphragmatic action resisting wind loads during construction, increased deformations toward the sheet edges which should be considered.

2.2. Composite slab

Further step is to address a reliable load bearing characteristic prediction for composite slabs. To be more precise, our design intention is not just to satisfy strength limitations but also to choose a failure mode which is ductile enough. The composite-steel framed buildings, in which we place our composite slab, exhibits a superior ductility and it is also a major concern, for example, in earthquake design, to globally distribute energy dissipation, avoiding dangerous damage accumulation in critical structural members.

In ultimate limit state, we consider bending resistance, vertical and horizontal shear resistance of the section. The calculation of the bending resistance based on idealized fully plastic behavior. According to test results this bending capacity hardly ever reached in normal design conditions because the shear failure is preceding. Doing plastic design we might want to calculate moment redistribution due to the different stiffness of sagging and hogging regions. In this case we need to check if the available rotational capacity is sufficient. Here the reinforcement play a critical role. Also one needs to take into account that diffuse crack pattern only occur with a relatively high reinforcement ratio. Vertical shear or punching strength is rarely critical for composite slabs, only under high concentrated loads such as internal walls or heavy equipments. Lastly, the composite connection forces has to be checked and this is the point where we are hooked up on experimental data. The next paragraph will be devoted to this stressed topic.

3. HORIZONTAL SHEAR RESISTANCE

3.1. Design according to EC4

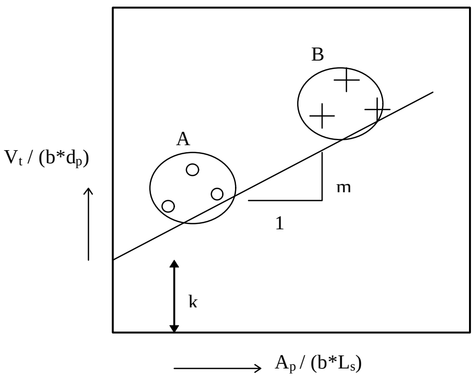

Fig.2 „m-k” Method for test result evaluation

The reassuring check of composite action between profiled steel sheeting and concrete has a crucial importance. Designing a composite slab, we encounter semi-empirical formulas at this step. The horizontal shear design according to EC4 offers two approaches which both necessitate serious laboratory work. One is called „m-k” method (Fig.2.), the other is the partial connection design (Fig.3). In both of them, the shear resistance has to be determined by means of slab tests, however the total number of test can be considerably reduced, because once the longitudinal strength τ_u is known, the partial design theory can be easily account for parameters such as, different spans, slab depths, steel grades, and concrete strengths. The effect of additional reinforcement and end anchorage can also be taken into account.

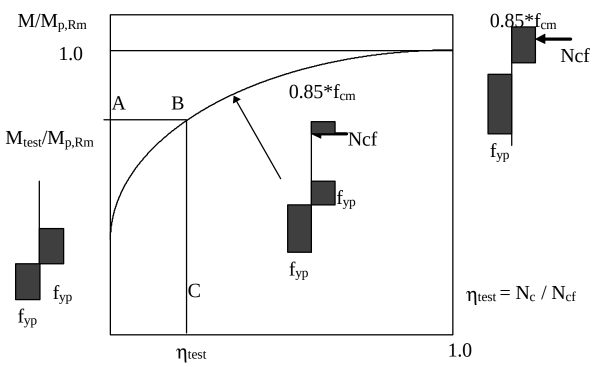

Fig.3 Determination of the degree of shear connection from M_{test}

The „m-k” method works for slabs with embossments and does not contains theoretical interaction diagram which can alter our results. The more versatile partial connection method only applicable for slabs with ductile behavior and gives save estimations of shear resistance.

3.2. Components of shear resistance

Generally, it is found that the concrete-steel structures with incomplete interaction represent a progressive trend in the development of structural members such that they can perform superior economy and safety. No significant influence due to the rigidity of the shear connectors was observed in the formation of the failure mechanism and the ultimate load. However, sheets with rigid connectors had smaller deflection elastic range. Also it has to be considered that we must avoid abrupt failures modes such as rigid horizontal shear rupture. Lets see, what effects shall we consider for horizontal shear resistance.

In the composite action the horizontal shear transfer mechanism is provided by a combination of the followings:

- chemical bond and friction at the interface of the deck and the concrete
- mechanical interlock between the embossments or intendations of the steel deck or frictional interlock for profiles shaped in a re-entrant form
- end anchorage in the form of stud bolts or deformation of the ribs

Though the chemical bond strength can be real high (≈0.45Mpa) we can not counted on it in design. It is largely dependent on the quality of the coating and clearness of surfaces, also its rupture is rather sudden. Eurocode tells us while conducting experimental work to apply 5000 cycle of dynamic loading proceeding the static test in order to destroy chemical bond.

We need to employ mechanical or frictional connectors. The embossments works as surface like mechanism however in the support region due to the high clamping forces of support reaction we have a line where the efficiency of these interlocks are much higher. It is addressed by the Australian Standard. A so-called slip block test has been developed where the influences of adhesion bond, friction due the transverse compression and mechanical interlocking can be separated. Profiles with re-entrant shapes are preferable from the structural behavior point of view. After the cracking of the concrete in the tensile zone, sheet with embossments needs to use this cracked concrete to transfer shear into compressed zone. With re-entrant shapes we have a fixed anchorage of sheet in the compression zone itself, which besides of shear transfer also prevents vertical separation up to the point of slab failure. Unfortunately, this shape is not efficient enough from production side.

4. EFFECTS OF SHEAR-STUD END ANCHORAGE

Ductility is major concern at the slabs structural behavior. According to Eurocode from the load-deflection curve recorded in the subsequent test, behavior is classified as brittle or ductile (Fig.4). The behavior is ductile if the failure load exceeds the load causing first recorded end slip by more than 10%. Otherwise the behavior is classified as brittle.

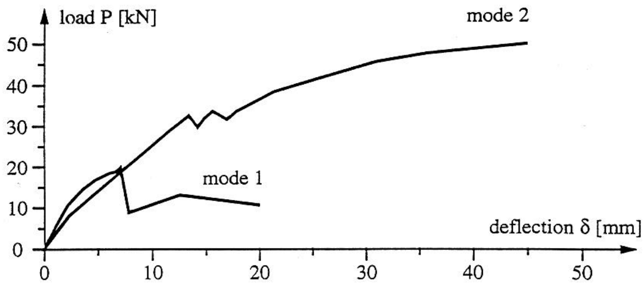

Fig.4 Ductile and brittle behavior

Recent studies seem to indicate more ductile performance (Fig.5) of the composite slabs built with stud bolts connectors. Slabs fabricated with plain sheeting and stud bolts reached in all cases a higher ultimate load compared to the same specimen built with ribbed decking only. No drop in the load during the entire monotonic loading procedure has been experienced with floors constructed with ribbed decking and stud bolts. In all cases the failure mode was by shear bond even in the slabs fabricated with end anchorage and ribbed sheeting.

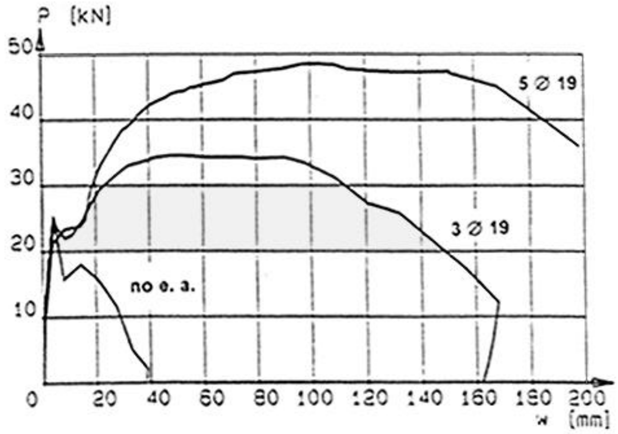

Fig.5 Effect of stud bolts connectors

5. CRITIC OF EUROCODE 4

5.1. Higher friction at support

As it was mentioned that Eurocode 4 does not distinguish explicitly between the resistance of the mechanical interlocking from the friction at the interface concrete decking over the supports. However depending on the position and shape of the embossments on the ribbed decking, and the length of the shear span, the contribution of each resistance mechanism can play a different role. Therefore a procedure which explicitly takes into consideration the effects of the mechanical interlocking and friction separately would be useful. Probably worth to mention here that it will not remove the scatter from experimental data interpretation, which is mainly caused by the slab thickness and the length of shear span of the slab.

5.2. Interpretation of tests for different slab depth

It has been pointed out by Tenhovuori that the present methods for considering the bond between the sheeting and the concrete in Eurocode 4 are applicable and give conservative results when the tests are carried out always for the minimum slab depth and one of the series of three tests employs slabs with a full degree of shear connection. This is because the bond strength is smaller for smaller slab depths and for longer shear spans. For the evaluation of τ, three slabs with a minimum depth and nearly full shear connection would be satisfactory, as they most certainly represent the minimum τ. Applying two depths of the slab in the 'm-k' method gives a wrong interpretation of the behavior and a wrong slope for the representative line. The variation in the results is the highest for smaller levels of the bond strength.

6. RESEARCH AREAS

6.1. Optimization of profile shape with neural network

In this paragraph from the aforementioned dual function of profile sheeting, the formwork function will be addressed. Here our objective is to obtain optimal cross sectional geometries which are of the best in utilizing the needed profiled sheet material considering different shapes and spans. One should keep it in mind that the consideration of composite state must also be a part of such an process. However, certain design parameters like horizontal shear resistance, are not yet soundly understood at the moment.

The important advantage of cold formed steel is the greater flexibility of cross sectional shapes and sizes. There are several shapes available on the market however the selection of the most economical shape is very difficult if not impossible. Here we propose to employ minimum weight design, where the problem is defined as to minimize W = F(X) subjected to constrains $g^k_j <= 0$, where ***W*** is the shape of the structure, *X* vector of design variables. Constrains are made to maintain the form of shape, limit certain structural sizes, limit stresses under loading, limit deflections. They can be rewritten as exterior penalty functions in order to obtain an unconstrained optimization problem. In an iterative solution for displacements, stresses, should derive from Standards (EC 3) or from more refined structural analysis such as folded plate method.

To solve this complex mathematical programming problem, neural dynamic optimization model can be used as it is proved to be robust and particularly effective for large and complex optimization problems. The model has been previously applied to design large steel structures including a 144-story super-high-rise building. Generally speaking the neural network is represented by a matrix of weighted connections between vectors of nodes. The input to a node is the weighted sum of outputs of the nodes connected to the layer. The output of the node is obtained by applying an appropriate activation function to the input. The operation of the networks governed by the learning rule that controls the evolution of the connection weights of the nodes outputs. This learning rule need to converge to a stable state representing the desired solution. Our system is still under development and not yet in a state such that worthy results could be presented here.

6.2. Modeling of horizontal shear rupture phenomenon

The question arises, is there a suitable analytical model to theoretically calculate composite interface forces as a function of geometry and applied load ? One which gives insight into the failure mode characteristic not just offers a limiting number for resistance.

There are fruitful results from studies done with numerical modeling of finite element of different complexity. All of them includes some previously estimated or test based interaction joint characteristic which prohibits their general application especially for shape optimization development purposes. It is hoped that the employment of a special fracture mechanic model could help toward deeper understanding. We can model the surface bonding as a microscopically not homogeneous material having distinguished properties for chemical, mechanical, frictional shear bond surfaces, connectors, also for counting on the clamping effect of support reaction. Then macroscopical general material properties can be calculated and after assuming initial crack sizes a fracture mechanical analysis can be done.

7. CONCLUSIONS

Composite slab construction is structurally efficient because it exploits the tensile resistance of the steel sheet and the compressive resistance of the concrete. Generally, it is found that the concrete-steel structures with incomplete interaction represent a progressive trend in the development of structural members such that they can perform superior economy and safety. However the question of ductility still has to be addressed. Recent studies seem to indicate more ductile performance of the composite slabs built with stud bolts connectors. Eurocode 4 does not distinguish explicitly between the resistance of the mechanical interlocking from the friction at the interface concrete decking over the supports.

Further studies will be projected to obtain optimal cross sectional geometries which are of the best in utilizing the needed profiled sheet material considering different shapes and spans. Robust neural network model to solve this weight minimization problem will be employed. However, certain design parameters like horizontal shear resistance, are not yet soundly understood at the moment. It is hoped that the employment of a special fracture mechanic model could help to move toward deeper understanding.

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