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Study of Shear Bond in Steel Composite Slabs

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Summary

The aim of this paper (which consists a part of the doctoral thesis of the second author) is to study the collaboration (and especially the role of the embossments to the shear bonding) between the cold-formed profiled sheeting and the concrete in a composite slab. In order to attempt this aim, an experimental program has been undertaken on shear bond pull-out tests and a numerical model, with the help of a non-linear 3D finite element program, using large strains, has been developped to simulate the shear bond between the two materials.

1. Composite slabs

1.1 General

A composite slab consists of a cold-formed profiled steel sheet covered with a concrete (containing or not reinforcement). Such slabs, which incorporate profiled steel sheeting as both permanent formwork and tensile reinforcement of an in situ concrete slab and through deck welded shear studs to provide composite beam action, are becoming a very popular form of flooring system in a lot of countries. This success is due to the significant constuction benefits occuring as well as provision of an elegant structure.

There are many types of profiled sheets used for the construction of composite slabs, which vary, for exemple, in form, rib depth, by the methods of stiffenning the flat elements of the profil etc.

The bond between the concrete slab and the profiled sheet must be able to transmit longitudinal shear at the steel-concrete interface. This connection can be made, for exemple, by embossments, by the re-entrant shapes of the ribs creating a bond by friction or by other ways.

1.2 Types of shear bonding between cold-formed steel sheeting and concrete

Three types of shear bonding between cold-formed steel sheeting and concrete have been observed: (a) *chemical bond* (bond resulting from the adherence of the çement paste to the steel sheeting; such bonds are broken under impact or repeated loading); (b) *frictional resistance* (resistance to applied shear forces, proportional to the application of lateral force between the steel sheeting and the concrete); (c) *mechanical resistance* (the physical interlocking of concrete and steel sheeting; such physical interlock occurs at abrupt changes in geometry such as embossments)[1].

Frictional and mechanical resistances are in reality due to the same phenomenon. They differ only in scale: frictional resistance is related to microscopic variations in surface geometry i.e. roughness; mechanical resistance is related to macroscopic geomettic differences i.e. embossments[1].

1.3 Composite slab behaviour

Learning upon test observations, three failure modes were established as follows: (a) *vertical shear* (or punching failure near concentrated or line loads; this is associated with heavy wheel loads or short span lengths); (b) *shear debonding* (resulting in the loss of composite action; loss of full composite action is indicated by the initiation of end slip); (c)*bending* (due to plastification of sheeting or crushing of concrete; normally, partial or complete plastification is observed after the loss of full composite action for long spans)[1].

2. Shear bond pull-out test for cold-formed steel composite slabs

2.1 General

A shear bond test is used to determine the nature of composite action between two materials; so, the shear bond pull-out test is used to predict the full-scale behaviour of cold-formed steel composite slabs (Fig. 1).

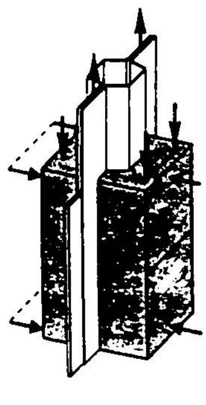

Fig.1 Pull-out test[1]

The experimental results help us to a better understanding of the failure procedure, of the shear-lateral force behaviour and of the shear-slip behaviour. For more informations about the pull-out test,like the test design (composite slab behaviour, modelling considerations), the experimental investigation (specimen geometry, materials, test frame, preparation of the specimens and test procedure) and so on, see [1].

An experimental program has been undertaken at the M.S.M. Laboratory on shear bond pull-out tests; different types of cold-formed steel sheeting have been used, but we chose to work only with one of them, the profiled sheeting of type Hibond 77 (Fig. 2).

The results of a pull-out test are resumed to a (P-u) curve (where P is the shear load and u is the average slip). The curves (P-u) for the Hibond 77 (M.S.M. Lagoratory) are presented in Fig. 3.

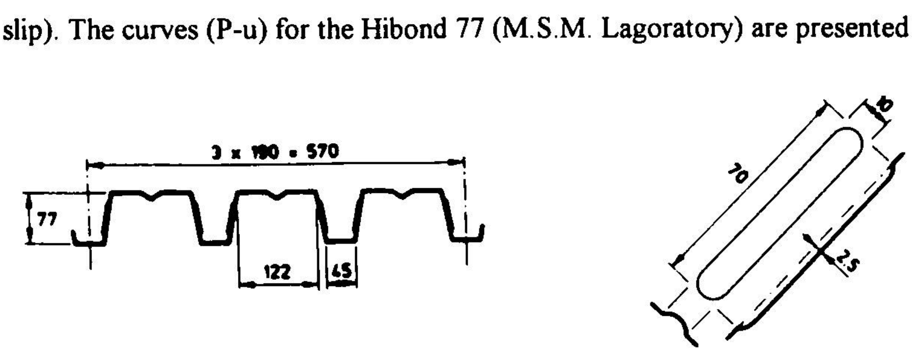

Fig. 2 Cross section and embossment pattern of Hibond 77 (all dimensions in mm)

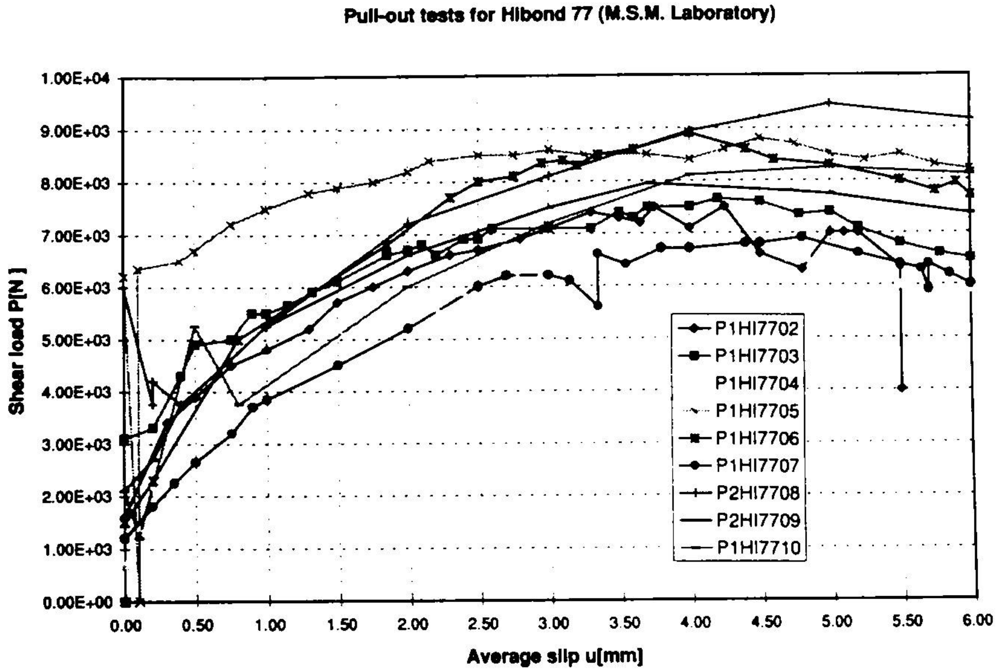

Fig 3 Shear-slip (P-u) curves for Hibond 77 from the pull-out tests (M.S.M. Laboratory)

3. Numerical simulation of a shear bond pull-out test

3.1 General

In this section, a finite element simulation of the pull-out test is presented in view to help us to understand better the shear bond mechanism between the steel sheeting and the concrete. The aim is to create a model, which -since we have proved its validation after a comparaison of its results with the experimental ones- can be used in the future, not only for examining the behaviour of the composite action (especially the shear bond mechanism) between the concrete and an existing at the market steel sheeting in a composite slab, but also for optimizing an existing sheeting (by changing its geometry, its thickness or a parameter of its embossments, such as their geometry, position, height)) or for creating a new one; so, since the model is reliable and accurate, it won't be necessary to fabricate a new steel sheeting (each time we change a parameter) and to submit it to a pull-out test for examining its behaviour (gain of money and time).

A non-linear 3D finite element program, using large strains, developped at the M.S.M. Departement, has been the appropriate tool with which this objective was achieved. In this 3D analysis, the contact between concrete and steel is assumed without friction ($\phi = 0$) (or with a very small Coulomb's friction coefficient ($\phi = 0.1$) for numerical reasons); so, there is only one type of shear debonding between the cold-formed steel sheeting and the concrete, i.e. the mechanical resistance due to the embossments. In this way, one can insist more on the important role of the embossments which consist one of the most important factors determining the behaviour of a composite slab. For our numerical simulation, we used a profiled sheeting of type Hibond 77 (with thickness 0.88mm).

3.2 Discretization

Of course, the symmetry of the two profiled sheetings used in the test has been taken into account for the finite element simulation. As we want to treat the case of an infinite number of embossments, only a small part of the profiled steel sheeeting (that is to say a part of the sheet with one embossment) has been discretized.

3.2.1 General assumptions
In first approximation, the following assumptions were made: *(i)* there is no friction ($\phi = 0$) at the contact between the concrete and the steel sheeting and *(ii)* only yhe initial normal pressure (p) (resulting from the real weight of the concrete over the embossment) is acting on the embossment (the shear stresses τ_R and τ_S are neglected). With tese assumptions, there is a big difference between the numerical and the experimental results. That's why, for the next approximations, we modified and improved (since they are closer to the real conditions of the test) the above assumptions, as following: *(i)* a very small value of the Coulomb's friction coefficient is accepted ($\phi = 0.1$); this value is small enough, so that it is always only the machanical resistance due to the embossments which is the predominant type of the shear debonding but also, big enough (no zero), so that it permits the second condition to exist: *(ii)* take into account not only the initial pressure (p) (this time, calculated from the lateral force used in the pull-out test, which is expressed in terms of equivalent concrete weight; expressing the normal pressure in this manner provides a physical representation of the lateral forces involved and is independent of specimen width or length), but also the initial shear stresses (τ_R and τ_S), which is quite important, because of the angle of the embossments.

3.2.2 Concrete discretization
The concrete represents the foundation of the problem. It is assumed rigid and is piloted only on displacements. The whole foundation is completely fixed, except of the directio in which the equivalent lateral force is imposed on the pilot node. For the discretization of the concrete, a type of 3D triangular segment is used.

3.2.3 Concrete-steel interface discretization

The contact surface (the interface between the concrete and the steel sheeting) is discretized by a type of 3D mechanical contact element (with 4 or 8 nodes), connected with the upper face of the sheeting. For the contact, we used a constitutive law for unilateral thermo-mechanical contact (a coupled Coulomb 3D law) (adequate for a thermo-mechanical analysis of problems involving unilateral contact between two bodies; Coulomb dry friction is used; the contact condition is enforced via a penalty method or augmented Lagrangian method).

3.2.4 Steel sheeting discretization
For the steel sheeting, the following three discretizations were tried :
(1) the first discretization consists of 88 volume elements working on large strains (bricks with 20 nodes); for this case, 88 contact elements (with 8 nodes) and 528 triangular segments were used;
(2) the second discretization consists of 88 solid 3D mixed elements working on large elastoplastic deformations (with 8 nodes); for this case, 88 contact elements (with 4 nodes) and 176 triangular segments were used.

For these two discretizations, the same mesh was used (only the type of finite element for the steel sheeting discratization and the number of nodes were different). In spite of the advantages of the mixed elements of the second case (for our problem, they can give almost the same results as the 3D shell elements [2],which consists a more logical approach for a sheeting of small thickness), they are much more rigid from the brick elements of the first case, when, of course, the same mesh is used). That's the reason, we tried to refine the mesh of the second case (by divising each element to 4!) and we set about the third case:

(3) so, the third discretization consists of 4x88=352 solid 3D mixed elements working on large elastoplastic deformations (with 8 nodes); for this case, 352 contact elements (with 4 nodes) and 704 triangular segments were used.

In order that the procedure of the loading of the simulation was closer to the one of the pull-out test, we imposed a uniform displacement in the z direction to all the nodes of the sheeting along the side z=const.

For the steel sheeting discretization, the following laws were tried:
(i) an elastic constitutive law for solid elements at constant temperature (adequate for a mechanical analysis of elastic isotropic solid undergoing large strains) and
(ii) an elastoplastic constitutive law for solid elements at constant temperature (adequate for a mechanical analysis of elastoplastic isotropic element undergone large deformations; mixed or isotropic hardening is assumed, when the volume elements (bricks with 20 nodes) or the solid 3D mixed elements (with 8 nodes) are used respectively.

3.2.5 Results
In Fig. 4, the curves (R-u) (with R the reaction to the movement caused by the imposed displacements) are presented; as this figure shows, we tried each of the cases of the steel sheeting discretization for both elastic and elastoplastic laws.

4. Conclusions

Since actually the last case of the numerical simulation (with the third try of the steel sheeting discretization and an elastoplastic law) is not yet completed, general conclusions on the advantages and disadvantages of the different discretizations can not be formulated.

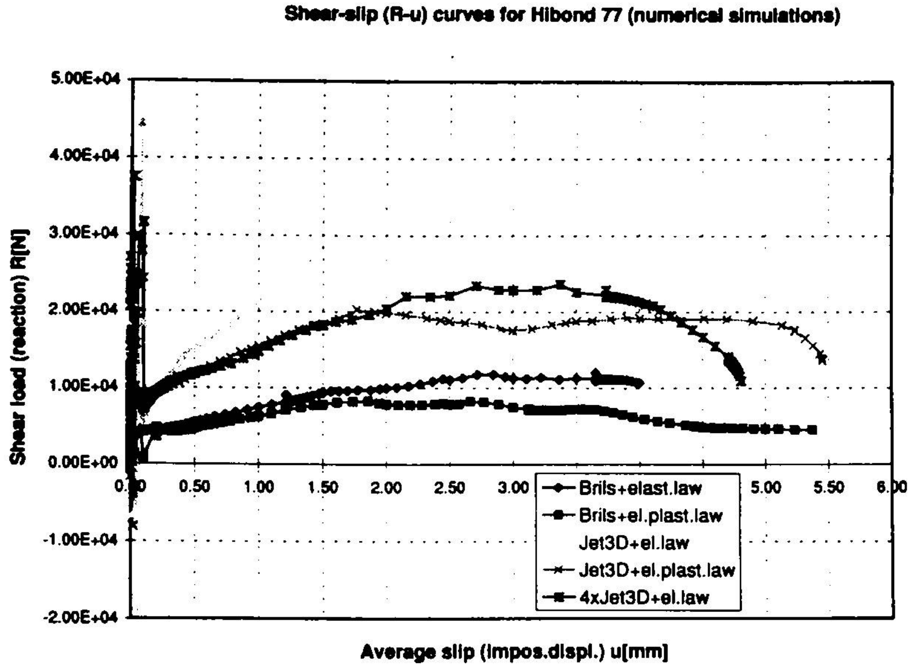

Fig. 4 Shear-slip (R-u) curves for Hibond 77 from the numerical simulation of the pull-out test.

References

[1] Daniels Byron J. , "Shear bond pull-out tests for cold-formed-steel composite slabs", Rapport d'essais, Ecole Polytechnique Fédérale de Lausanne, ICOM 194, Avril 1988.

[2] Kaiping Li , "Contribution to the finite element simulation of three-dimensional sheet metal forming", Thèse de doctorat, Université de Liège, Faculté des Sciences Appliquées, 1995.