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Load-Slip Curve of Shear Connectors Evaluated by FEM Analysis

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Summary

A new numerical method for the evaluation of the characteristics describing the mechanical behaviour of the shear connection in composite structures, is proposed. The method is based on F.E.M. and takes into account linear and non linear behaviour of the materials. The reliability of the method is proved by comparison with experimental results.

1. Introduction

From the very beginning of the application of composite structures many investigators have been concerned with the behaviour of the shear connection between concrete slab and steel beam. Many different types of shear connectors have been developed and investigated all over the world. Among them the most preferable are the headed studs and for the determination of their mechanical behaviour a numerous of papers has been published. In these works the experimental procedure of the push out test is mostly used in order to obtain the full load-slip curve, the failure load and the up-lift between slab and beam. Although this procedure has been established as the basic method for the design of composites elements, it has some disadvantages as time and money costs and need of specialized laboratories.

Due to the complexity of the three dimensional stress and strain state, no mathematical modeling of the push out test has been appeared. So, there are not closed analytical solutions of this problem and the only available formulas for the calculation of the parameters affected the behaviour of the shear connection, are based on the statistical evaluation of test results.

In our days Finite Elements Method (F.E.M.) can be used to solve such problems. This is the basic idea for the development of a new numerical method based on F.E.M. which is described in the current paper. The three parts consisted a composite section are simulated with different types of standard Finite Elements (F.E.) which can be found in the library of any F.E. package. The model is then analyzed taking into account linear and non linear behaviour of the materials and introducing the appropriate yield criteria. According to this procedure all the characteristics of the shear connection are determined.

The results of the proposed method were compared with experimental data in order to prove the reliability of the method. Experimental results obtained from series of push-out tests performed in the Steel Structures Laboratory of the Democritus University of Thrace (D.U.TH.), according to the push out test procedure of EC4 [1].

2. Numerical model and analysis

In the developing of the proposed method the basic idea is the modeling of the concrete slab, the steel beam and the shear connector of a push-out test specimen by different types of finite elements. In the beginning a simple model had been investigated taking into account the linear behaviour of the materials [7] and the reliability of that model had been proved by comparison with experimental results from Nakajiama and Abe[8]. The same model was used for a new series of push out tests which were performed in the Steel Structures laboratory of D.U.TH. according to the procedure and full instructions giving in EC4. The experimental results were more accurate with the F.E. model of the new specimen [6].

In the present paper, a modified F.E. model taking into account the inelastic behaviour of the materials, is studied. Each of the three parts of the composite section has been modeled by different elements. The concrete slab is modeled by non linear volume elements, the steel beam by a rigid bar element and the shear connectors by non linear beam elements. All these elements are offered as standard ones in all commonly used F.E. packages. In our case COSMOS/M program is used. The F.E.M. discretization of the push out test, as it is appeared in the F.E.M. program, is shown in Fig. 1.

The concrete slab is divided into 48 elements along X-direction, 40 elements along Y-direction and 5 elements along Z-direction. For the steel beam only one element is needed due to the high stiffness of the used element. Each of the shear connectors, is divided into 4 elements along the Z-direction. The resulted aspect ratio of the volume elements is 1:1:1.6, which satisfies the limits for these aspect ratios [3].

Only the half of the push out arrangement is modeled, due to the symmetry and the solution time. For the application of the support conditions all nodes at X1 and X2 surfaces (Fig. 1) are restricted to move in Y-direction as these surfaces resist in the compression load. All nodes along

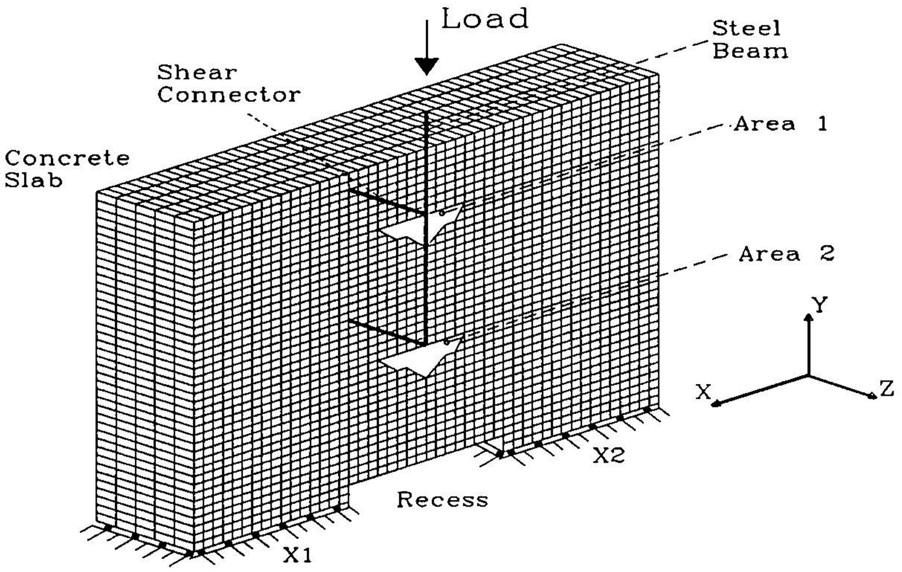

Fig. 1 Discretization of the push out test

the rigid bar element, which model the steel beam, are restricted to move in Z-direction due to the symmetry. A basic observation refers to the separation of the concrete behind the shear connector even when the loading is low [4,10]. According to this observation, a double grid of nodes towards the shear connectors (in Z-direction) is created producing volume concrete elements. The concrete nodes in front of the studs are merged with the nodes of the beam elements representing the studs (Fig. 1 - Area 1 & 2). The concrete nodes of the second grid behind the studs, are not merged with the nodes of the beam elements due to the detachment of the concrete. This assumption eliminates additional stiffness actually added in the area behind the studs.

For each material of the composite section, appropriate yield criterion is considered. The Huber-von Misses model is used to simulate the behaviour of the shear connector material. For this model the yield criterion can be written in the form :

$$F = \sqrt{3}\,\bar{\sigma} - \sigma_y = 0$$

where : $\bar{\sigma}$: the effective stress
σ_y : the yield stress

For the concrete two models are introduced, the Drucker-Pracker and the Huber-von Misses model. In Fig. 5 the load-slip curves obtained by both models, are compared with experimental data. As it seems, better results are obtained by the Drucker-Pracker model, for which the behaviour and the failure load are more close to the experimental data. For this reason the last model is preferred. In this case the yield criterion can be written in the form :

$$F = 3\alpha\sigma_M - \sigma_y + k = 0$$

where : σ_M : the mean stress
σ_y : the effective stress
α, k : material parameters

For the solution of the above F.E. problem the Newton-Raphson iterative method is used. A solution is reached when the difference between external and internal forces approaches zero. At each iteration, displacements are modified to minimize this difference. The COSMOS/M program is used in the non linear mode analysis.

In Fig. 2 the stress concentration is shown when the loading is applied to the model. Concentration of stresses is occurred at the surfaces X1, X2 (Fig. 1) and in the area in front of the stud connectors. Experiment verifies that concentration, by the crushed concrete area.

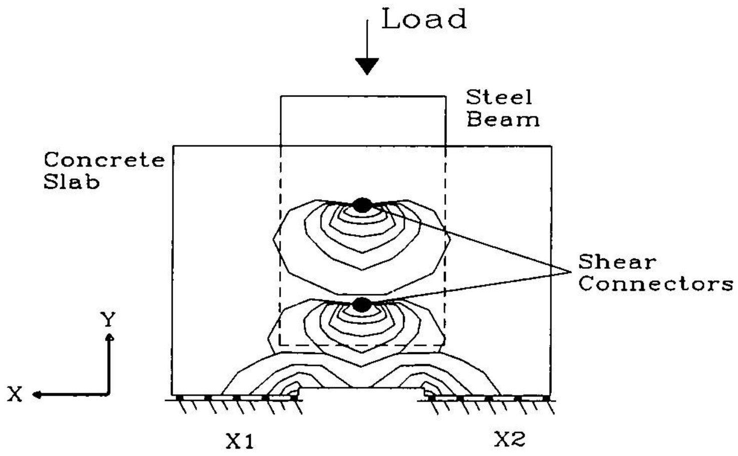

Fig. 2 Stress concentration when the loading is applied.

3. EXPERIMENTAL WORK

All the experimental work has been carried out in the Steel Structures Laboratory of the Democritus University of Thrace (D.U.TH.). Two categories of tests were performed. The first category is concerned with the determination of the mechanical behaviour of the materials used in the preparation of the push-out specimen. Such tests were performed according to EC2 [2] and EC3 specifications for the materials of the concrete slab and shear connector, respectively. In the second category a series of push-out tests were prepared and performed according to EC4 [1] specifications.

For the concrete, cube specimens, 15x15x15 mm, were tested according to EC2 [2]. The mean compressive strength at 28 days was found 21.4 N/mm^2. The elastic modules of the concrete is calculated according to the procedure proposed by EC2 and the strain-stress diagram is shown in Fig. 4. For the material of the stud connectors, tension test has been performed according to the procedure proposed by EC3. The idealized stress-strain diagram of the stud connectors is shown in Fig. 3. No tests for the material of the steel beam have been made, because the beam is deliberately very rigid in comparison with the other two elements, so a high stiffness element was introduced for which no additional information is needed.

Each push-out specimen consists of an HE 260 B steel beam of total length 600 mm, two concrete slabs attached to the flanges of the steel beam with dimensions 500x600x100 mm for each slab, and stud connectors with a shank of 13 mm in diameter and 75 mm in height. A short recess of 200 mm wide and 3-4 mm height is formed to the concrete slabs. The natural bond at the interface between the steel flange and the concrete is prevented by greasing the steel flanges before casting the slab. During the execution of the test, the slip between the steel beam and the concrete slabs is measured by four electronic deflectometers, which are placed at the top surface of the slab in different points to ensure the accuracy of the overall test. All the data from the gauges and the load cell are registered electronically into the computer for further elaboration. The mode of failure in all the cases was the shearing off, just above the weld collar of the connectors. A very small uplift separation was observed.

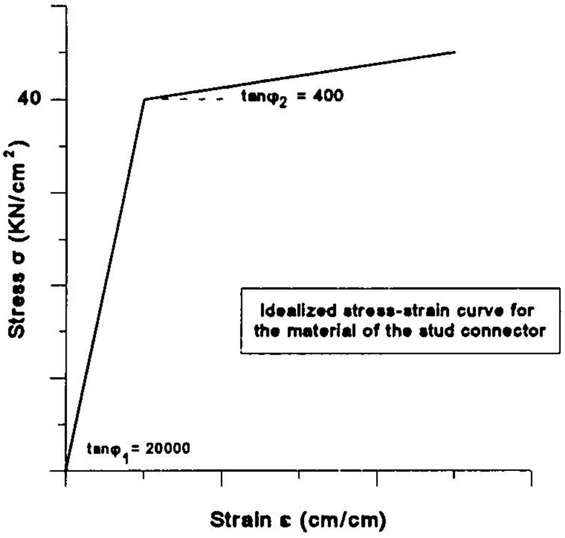

Fig. 3 Stress-Stain diagram for the of the shear stud connector.

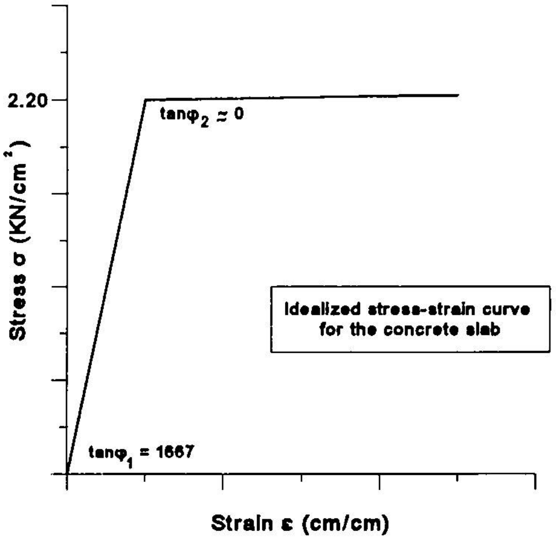

Fig. 4 Stress-Stain diagram for the concrete slab.

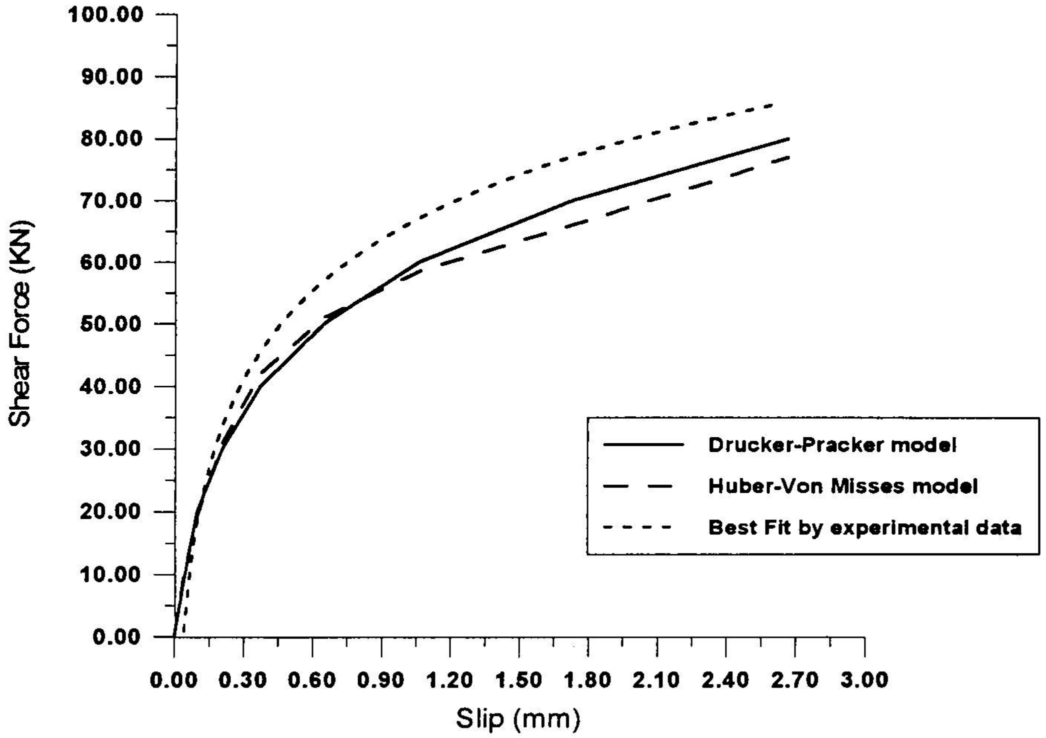

Fig. 5 Comparison of experimental data and F.E.M. analysis results

4. COMPARISON OF RESULTS

The comparison between experimental and numerical results, is shown in a slip-shear force plot (Fig. 5). Values of the shear force per stud are on the vertical axis and the corresponding average slip values are on the horizontal one. The upper dashed curve represents the best fitted line to the measurements of the push-out tests described in the previous paragraph. The other two curves have been obtained by the F.E.M. analysis of the present model. The continuous line represents the results of the analysis when the Drucker-Pracker yield criterion is used for the concrete, and the lower curve has been plotted for the results obtained by using the Huber-Von Misses model. As it is shown from the diagram the results of the F.E.M. analysis are in a good agreement with the experimental ones and always on the safety side. The Drucker-Pracker curve approaches the curve of the experimental data more closely. The deviation is very small when the load is low and becomes greater for higher values of the load. The maximum deviation between the experimental and the F.E.M. analysis (Drucker-Pracker model) results is about 14%, which is acceptable for the case.

The deviation appears to have greater values in the region corresponding to intermediate values of loading. There is only a slight deviation at the point of failure. The mean value of the failure load calculated from the test measurements, is 84 KN. The corresponding values taken by the present method are 80 KN and 77 KN for the Drucker-Pracker and the Huber-Von Misses model, respectively.

5. CONCLUSIONS

A simple method based on the finite element techniques has been developed to simulate and analyze the push out arrangement. Appropriate yield criteria are used for the materials. The numerical results are close to the experimental ones and on the safety side. The method is reliable for the elastic, which is restricted, and inelastic area.
The advantage of the present method is that the method permits a prediction of the behaviour of the shear connection and the stud. Since all the numerical results are conservative, but still close to the experimental ones, the proposed method can be used substituting or together with the experimental procedure cover cases such test procedures are a great percentage of the overall cost in money and time. Also, this method is useful in cases of lack of specialized laboratories needed for the performance of push out tests.

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