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EXPERIMENTAL AND ANALITICAL STUDY OF LOAD AND SLIP CAPACITY OF HEADED STUD CONNECTORS IN COMPOSITE SLABS FOR BUILDINGS

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ABSTRACT
The behavior of shear connections in composite beam construction has been determined by a comprehensive experimental examination conducted in compliance with EC4-1-1Annex B.2. In order to illustrate the steel-concrete composite construction's ultimate strength behavior from the component level to the structural level, six push-out experiments were published. Push- out tests were used to examine the specimens while varying constructive parameters. Longitudinal and transverse steel sheeting types and positions were varied for headed stud connectors with d=19mm and hsc=100mm. Additionally, there were variations in the number of shear connections in the cross section (1 or 2) and the welding process, both via deck welding and with holes. We re-adopted concrete with grade C25/30, which is the commonly used grade, and reinforcing with a low percentage. When the results of load capacity were compared to the intended load capacity as per EC4-1-1 (6.6.3 and 6.6.4), there were sometimes notable variances.
The design and execution of an experimental examination for two models with three push test components and one shear connection in the cross section are presented in this paper. Additionally shown are the obtained load and slip capacities. The analytical model for the shear connection is established by investigating the failure mechanism and ductility.
The correctness of the analytical solution with the experimental one has also been assessed using the analytical solution with 3D/FM

1. Overview

Composite structures composed of steel and concrete have a very broad range of applications in construction; they are utilized worldwide to create administrative buildings, high-rise buildings, and bridges. These buildings provide quick, affordable, and eco-friendly construction. These structures are particularly popular among architects and civil engineers since they can be used in huge expanses with relatively modest beams and decks, are 20–40% lighter, and can be built more quickly. Sadly, apart from generally pleasant experiences, concrete and composite steel are sometimes employed in building projects in our nation. Lack of expertise and conventional concrete- oriented construction are potential causes. Building floor slabs are one area where composite steel and concrete structural advancements are seen. Composite action is made possible by the typical concrete slab placed on a steel beam, which is typically made of welded or rolled I or H steel sections. Either profiled steel sheeting or conventional formwork might be utilized to cast the concrete slab. The most popular second scenario provides quick construction and the ability to create composite activity in a flor slab. However, the composite action of the concrete slab and steel beam yields the most advantage. Installing different kinds of mechanical devices known as shear connectors allows

the longitudinal shear between the steel beam and the concrete slab to be transferred. Shear connections at composites labs for buildings are typically headed studs (Fig.1). In the case of profiled steel sheeting, headedstuds might be welded through the deck or through a hole in the steel sheeting (Fig. 2).



Figure1.Headedstudshearconnectors



Figure2.Weldedheaded studs

The resistance and deformation capacity of shear connectors must be enough to convey the shear force and to support any inelastic redistribution of presumed shear in the design. Therefore, before using the headed stud connectors in construction, it is vital to ascertain their slip capacity and shear resistance.
The design guidelines and concepts for composite steel and concrete structures are prescribed by Eurocode 4 [1]. When using headed studs with profiled steel sheeting, the design resistance of the connections is specified in clauses 6.6.3 and 6.6.4 for solid slabs and concrete encasements. The guidelines for testing shear connections are also included in Annex B.2. In composite slabs, a variety of profiled steel sheeting types with open and re-entrant profiles are used. Numerous factors influence the design resistance and ductility of headed stud connectors, including the type of steel sheeting, the position of the connectors over the steel beam (longitudinal or transversal), the height and number of connectors in the cross section (1/2), the welding technique, the depth of the slab, the quality of the concrete, the reinforcement, and the relative positions of the elements in the cross section. Our experience has shown that the EC4 design resistance and ductility guidelines do not always match the actual resistance and ductility. In some instances, the values of the reduction factors Kland Kt are questioned. To more effectively demonstrate compliance between the design resistance and the actual resistance of headed stud connections, experimental research is required. Profiled steel sheeting FR38/158 and headed stud connections NELSON, with a diameter of 19 mm and a total height of 100 mm, are often utilized. Additionally, research has been done on the matching solid slabs. For floor slabs, concrete grade C25/30 has been selected as the most often utilized concrete quality. Six specimens have undergone the specific push test as per EC4-part1.1 appendix B.2. This page presents the test specimen preparation, testing process, measurements, and results.
1. A particular push test Standard push tests may be applied when the shear connections are utilized in T-beams with haunches or a uniformly thick concrete slab. Other situations involving longitudinal or transversal sheeting call for the application of a particular push test. In accordance with the guidelines and suggestions provided in EN 1994-1-1, Annex B.2, a specific push test should be performed to ensure that the slab and the reinforcement are appropriately dimensioned in relation to the beams. Getting the specimens ready The longitudinal spacing of the connections in the composite

steel-concrete construction has been correlated with the length of each slab. Each slab's width was selected so as not to surpass the beam's effective slab width. For FR38/158 steel sheeting, a 100mm slab thickness was used. Since the slabs represent a component of a composite construction, they were cast horizontally (Fig. 3).





Figure3. Castingofconcrete

On one side of the test sample, the concrete was cast first, and then it turned on the other side. As is customary with composite beams, the concrete was allowed to air-cure. Four concrete specimens (cubes) were collected from each concrete mix in order to determine the concrete's strength for each side of the sample. Together with the push test specimen, the concrete specimens were cured. Using the relevant standard tests, the yield strength, tensile strength, and maximum elongation of a representative sample of the shear connection material—steel beam and profiled steel sheeting—were ascertained. Test methods and assessment The load was applied incrementally up to 40% of the estimated failure load, as advised in EC4-1-1 annex B.2. After that, it was time-cycled 25 times between 5% and 40% of the expected failure load. Following the 25th cycle, further load increases were applied until the specimen failed, but not until at least 15 minutes had passed. The longitudinal slip between the steel beam and the concrete slab is continuously monitored during testing. Additionally, the transverse distance between the steel section and the slab was measured as near to each connection group as feasible. According to paragraph 6.6.3.1 of EC4-1.1 (1), the expected failure load is calculated by multiplying the designed shear resistance of a headed stud by the number of applied connections.

d2 · π · f · d2fE /4 0.8 · α · 0.29 PRd u or V PRd ? ck→cm V (1) The smaller of the two, with =1forhsc/d=100/19>4.
Given a partial factor of 1.0, the concrete's stipulated ultimate tensile strength (fu) is 500 MPa, its typical cylinder compressive strength (fck) is 30 MPa, and its secant modulus of elasticity (Ecm) is 33000 MPa. 192/4.·πWith the given values in equation (1), the shear resistance of the headedstud is PRd 0.8_500_ (2.1) or 1.0 10□3 113.35kN 33000_10□3?104.16kN (2.2) PRd 0.29_1.0_192◡1.0 30

The assumed head resistance is 104.16kN. Shear resistance should be increased by the reduction factor kl(3) when profiled steel sheeting is used with ribs parallel to the supporting beam (Fig. 4). 1.0

(3) ≤ | 1 (b‖ hsc k ? 0.6 ⁾p⁽ p |h| ℓ h

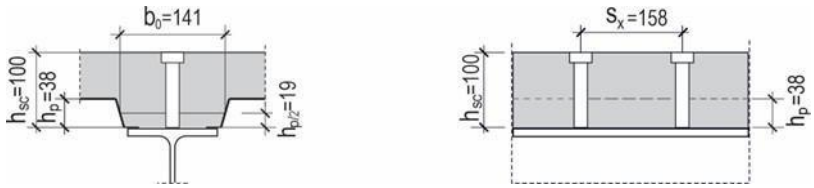


Figure4.Beamwithprofiledsteelsheetingparalleltothebeam(cross-sectionaland longitudinal sections)

In Part 3, the reduction factor values for various steel sheeting types are computed and shown. Shear resistance should be increased by the reduction factor kt(4) when profiled steel sheeting with ribs transverse to the supporting beam is used (Fig. 5). □1 (4) = ‟ kt ⁾ 0,7b‖ hsc nrhp hp

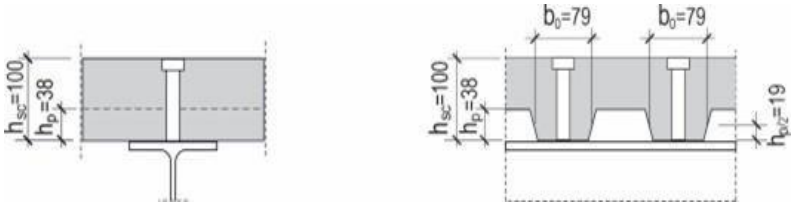


Figure5.Beamwithprofiled steelsheetingtransversetothebeam

In one ribata beam cross section, the number of stud connections is one. Maximum value for kt is: kt,max=0.85 for nr=1 and throughdeck welding kt,max=0.75 for nr=1 and throughhole welding In Part 3, the reduction factor values for various steel sheeting types are computed and shown. Measuring apparatus measurement devices (Fig. 6) and data collecting tools (Fig. 7) make up measurement equipment.

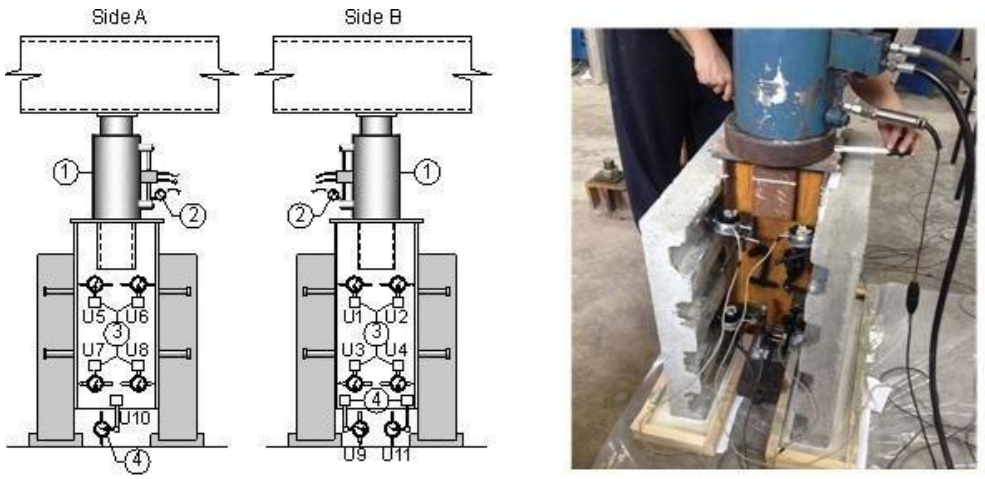


Figure6.Test equipment –measuring devices

1) 100-ton hydraulic jack; 2) load cell; 3) displacement transducers to measure the longitudinal

(vertical) slip (U10 on one side and U9, U11 on the other); 4) displacement transducers to measure the transverse separation between the steel beam and the slabs (U1, U2, U3, U4 on one side and U5, U6, U7, U8 on the other side).





Figure7. Testequipment–data acquisition

A 1000kN hydraulic jack with a straing gauge pressure transducer in a complete bridge applied the force. On U5, U6, U7, U8, and U10, five strain gauge displacement transducers in full bridge (Kyowa) with a 20mm measuring range were installed. On U1, U2, U3, and U4, four inductive displacement transducers (HBM) with a measuring range of 10 mm were installed. On U9 and U11, two inductive displacement transducers (HBM) with a 50 mm measuring range were installed. Data processing tools HBM Quantum and HBM Spider 8 were linked to measuring equipment. Data was stored on two personal computers using the Catman Easy (HBM) application. A frequency of 5 Hz was used for data gathering. 1. Specimen descriptions

Push tests on six specimens were used in the experimental investigation. FR38/158 steel sheets was used to create two kinds, each including three specimens. Information pertaining to the specimen's description may be found in Table 1.

Profiled steel sheeting FR38/158 In our nation, FR38/158 steel sheeting is commonly used. It is not advised to use this steel sheeting for composite slabs since it lacks embossments or indentations. Nevertheless, there are no restrictions on the use of this kind in formwork and in steel beam and concrete lab composites. In our lab, composite beams with concrete slabs made of FR38/158 were experimentally investigated.

Six examples of each of the two kinds were made using FR38/158 steel sheets (d=1.0mm). One kind (1.1, 1.2, and 1.3) has ribs positioned longitudinally, a single shear connection in the cross section, and holes that are welded through (Fig. 12).

Forbo=79, hp=38, and hsc=100, the reducing factor kl(3) is 2.035>1, meaning that kl=1. For type 11, the expected failure load (2) is 104.16 x 1x 6 = 625.0kN.

The reinforcement is Q188 (Ø6/15cm), and the steel beam is IPE240 (S275JR).

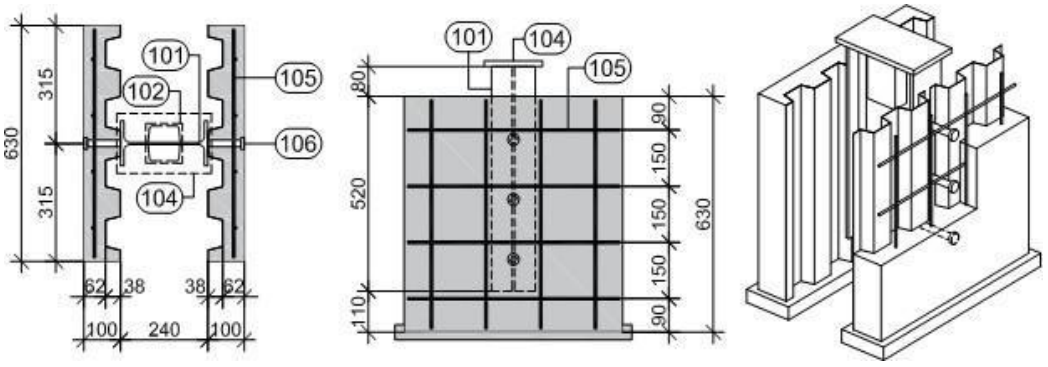


Figure12.FR38/158–longitudinal position

One kind (2.1, 2.2, and 2.3) has a welded through deck, one shear connection in the cross section, and ribs positioned transversally (Fig. 13). Forbo=79, hp=38, hsc=100, and nr=1 is 2.374>kt,max=0.85, the reducing factor kt(4). For type 10, the expected failure load (2) is 104.16 x 0.85 x 6 = 531.2 kN. The reinforcement is Q188 (Ø6/15cm), and the steel beam is IPE240 (S275JR).

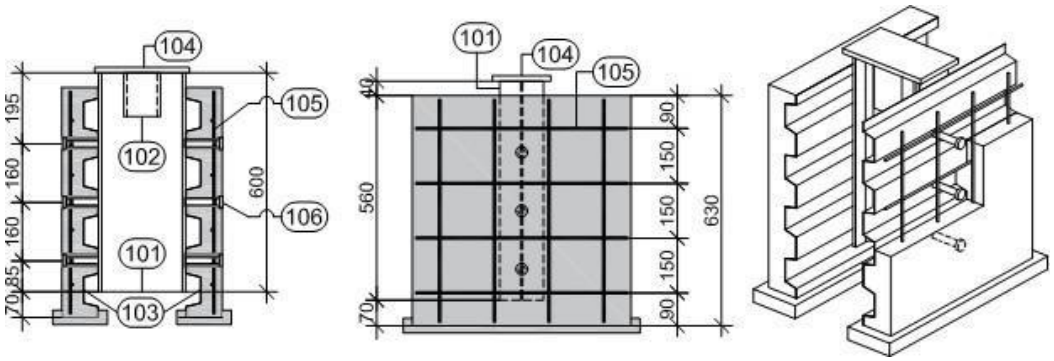


Figure13.FR38/158–transversalposition

1. Resultsof testing

General description of specimens and data for measured and expected load capacity are presented in Table 1.

Table1.Specimenscharacteristics,measuredand expectedforces

Spec. No.	Typeofprof. steel sheeting	Position L long. T trans.	Number of shear connect.	Welding TDthro.deck H with holes	Pmaxexp. [kN]	PmaxEC4 [kN]
1.1	FR38/158	L	1	H	570.3	625.0
1.2	FR38/158	L	1	H	486.5	625.0
1.3	FR38/158	L	1	H	520.3	625.0
2.1	FR38/158	T	1	TD	462.9	531.2
2.2	FR38/158	T	1	TD	431.8	531.2
2.3	FR38/158	T	1	TD	399.9	531.2

The measured maximum force for each specimen and P-behavior are shown in the accompanying figures. The estimated maximum force is shown by the horizontal line. According to EC4, the ductile behavior of the shear connection necessitates a minimum slip capacity of 6mm in push tests at representative load levels (0.9Pmax). The headed stud shear resistance suggested by EC4 is clearly underestimated for steel sheeting with more ribs (hp). The value of ribheight (hp) largely determines the values of the reduction

factors (kl, kt). The whole height of the concrete or the height of the concrete above the ribs is not taken into account. Compared to the EC4 analytical forecast, the measured maximum forces for type 1 (Fig. 14) are about 16% lower. The ductility request is not fulfilled. Concrete failed. Compared to the EC4 analytical forecast, the measured maximum forces for type 2 (Fig. 15) are about 19% lower. The concrete failed, and specimens 2.1 and 2.3 met the ductility requirement. Specimen 2.2 had connection failure due to shear.

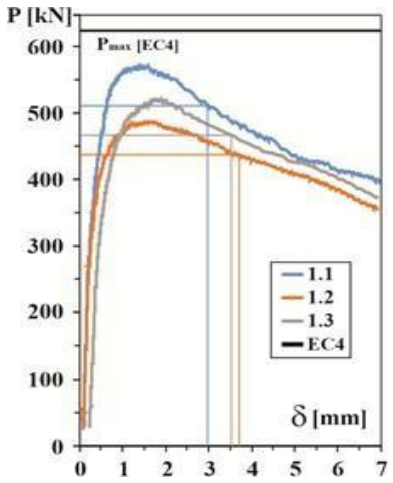


Fig14.Load-slipcurvesSpecim.1.1,1.2and1.3

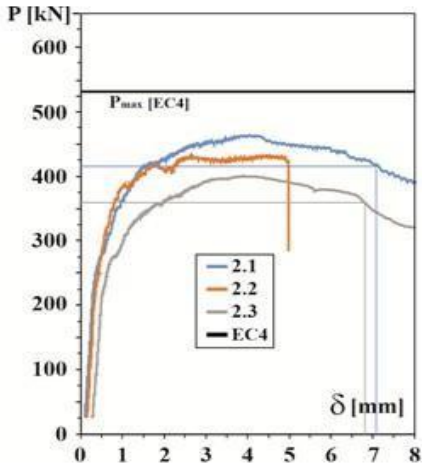


Fig15. Specim. 2.1,2.2 and 2.3

Followingpicturesillustrate thefailurestateoftwo specimens.



Figure16.Specimen1.2



Figure17.Specimen2.1

4. MODELS OF ASSESSMENT

The push-out test specimens with elastic

concrete were FE modeled using the general FE code ABAQUS [9]. The ABAQUS/Explicit 2024 type of solver was

employed in the FE analysis to resolve the convergence issue, taking into account the material and geometric nonlinearities in the FE simulation. Both in shape and loading technique, the models closely match the test models previously reported. A material nonlinearity elastic-plastic study was performed.

Steel, concrete, reinforcement, connections, and profiled sheets are the five components that make up the FE model. To simulate the steel beams, connections, and concrete lab, 3D solid components with eight nodes (C3D8R) are used. Surface (shell) elements with four nodes (S4R) are used to represent the profiled sheet, and two node lattice elements are used to simulate the reinforcement (T3D2). Tao et al. [10] created an elastic-plastic stress (σ)–strain (ε) model with strain hardening for structural steel, which is applied in the current investigation for steel beams. It should be mentioned that mild steel is very ductile, allowing for significant bending of the steel beam. Additionally, no steel beam fracture has ever been documented in the literature. Therefore, the material model of steel beams does not account for steel fracture. In general, the steel used to make shear studs is ductile. It is fairly usual for connections subjected to shear and bending to fail. Based on this, the connections were subjected to a full range σ-ε relation, where the failure phase is also determined (εu=25εy, εu2=90εy) [11]. It is rather typical for a portion of the concrete slab to be undertension while the remainder is undercompression throughout the loading process. This explains the usage of a concrete damaged plasticity (CDP) module [12]. Concrete tension fractures and potential compressive crushing may be addressed using this module.

Followingpicturesillustratethefailurestateoftwospecimens(analyticalmode).

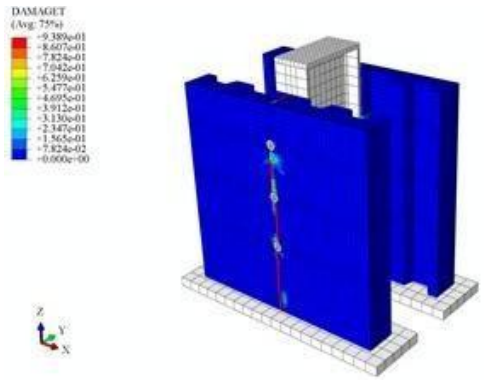


Figure18.SpecimensA1Parallelribs

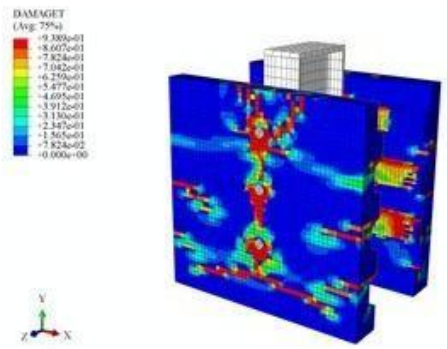


Figure19.SpecimensA2Transversalribs

4. RESULTS ANALYSIS

Figure 20-21 displays the findings of the load-slip relationship for the test specimens and analytical mode. "Numerical1.1..." denotes the experimental mode, whereas "A.i" denotes an analytical model. The findings obtained for the two presented models show an acceptable level of compliance. The analytical calculation curve A.1 is roughly between the experimental curves 1.3 and 1.2, according to Fig. 20. However, we can see from Fig. 21 that the analytical calculation's curve A.2 roughly falls between the experimental curves 2.2 and 2.3. Figure 16-18 and Figure 17-19 clearly show that the failyre state is in line with the analytical and experimental modes.

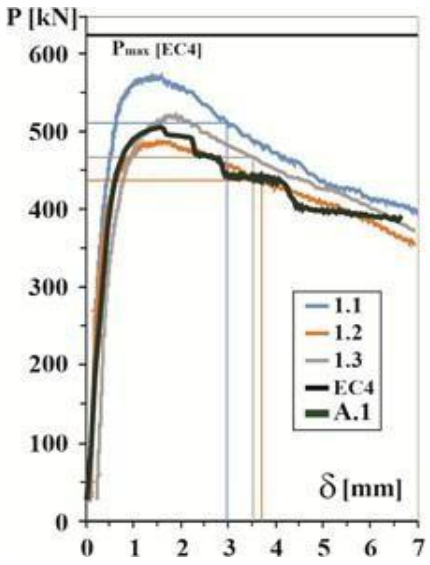


Fig. 20. Load-slip curves, eks. modes modes (1.1,1.2,and1.3) andanalytical mode A.1

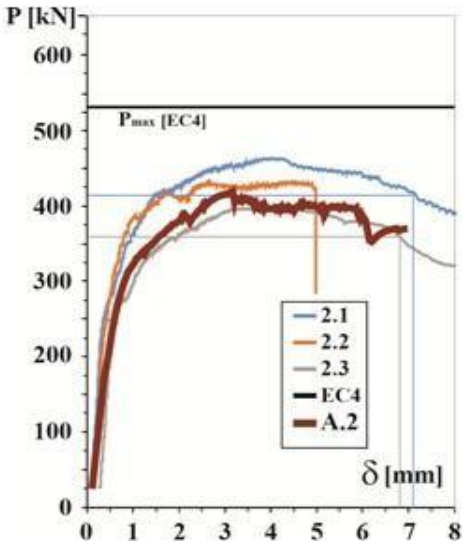


Fig. 21. Load-slip curves, eks. (2.1,2.2,and2.3)andanalyticalmodeA.2

4. Findings

One may draw the following conclusions from the experimental study of the load and slip capacity of headed stud shear connections in composite slabs for structures that is described in this article:

• The resistance of the headed stud connections is lower than the acceptable value in EC4, according to the experimental measurement of their resistance using the standard test. In the case of the profiled sheet's longitudinal ribs, the difference is around sixteen percent for the studs that are welded directly to the steel flange. • In the case of transverse ribs from the profiled sheet, the difference is around 19% for studs welded through the sheet. • When steel sheeting is positioned longitudinally, through deck welded headed studs have a greater shear resistance than those welded through holes. Regarding the welding technique, there are no more corrections or limitations for reduction factor klin EC4. • More experimental research is advised for steel sheets with a low hc/hp ratio.
• There are no special regulations governing the resistance of headed stud connections in the absence of a concrete covering above the stud head. There is no discernible drop in resistance, according to the test data. Additionally, other variables may be responsible for the decline in resistance. The constructed FE model simulates the behavior of push-out specimen components, corresponding to composite beams, with extremely excellent accuracy. Due to the area and time needed for the testing, as well as the equipment necessary, it offers important insights into the mechanical behavior of components that are difficult to evaluate via experimental experiments.
• By permitting parametric analysis of the elements, the FE technique provides complete data that might be used to suggest an analytical design process in line with Eurocode's component method design approach.

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