SIA 269/4 – THE NEW SWISS STANDARD FOR EXISTING COMPOSITE STRUCTURES

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Abstract: *More and more of today's construction works are done on existing buildings. The design issues when working on existing structures differ strongly from those with new structures. Still, present standards give only very poor information on how to treat existing structures. In Switzerland a novel set of standards, the SIA 269 family, is about to be published in the near future. For existing steel-to-concrete composite structures standard SIA 269/4 is applicable.*
The new Swiss standard SIA 269/4 provides a useful set of rules to the engineers working with existing composite structures.

1. INTRODUCTION

1.1. General

The novel Swiss Standard SIA 269/4 for existing composite structures is part of the SIA 269 family and therefore strictly limited to issues not covered by other standards.
Along with this, issues on how to obtain information on the structural elements embedded in the concrete are given in SIA 269/2, whereas steel-based issues are covered by SIA 269/3. The basis of design and the load-related issues for existing structures are treated in SIA 269/0 and SIA 269/1, respectively.
According to Swiss Standards philosophy, Swiss Standards must not be teaching books nor cookbooks allowing scarcely educated people to do structural analysis, but are made as an open framework of rules supporting the practical engineers in designing safe and economical constructions, while leaving plenty of room for innovation.
Based on this Swiss Standard philosophy, SIA 269/4 provides an open-formulated set of useful rules.

1.2. Maintenance-related design practice

In general, when working with existing composite structures the same safety principles as with new structures are to be respected. Apart from serviceability and resistance-related questions, in composite structures the slip compatibility in shear interfaces is of crucial importance. In existing structures these compatibility issues even gain importance.
Further, in existing structures often a much deeper structural analysis and design process is justified in order to ensure structural safety while limiting structural measures as far as just possible.
On the other hand, for many issues very similar structural treatment for existing and new structures is justified e.g. by the lack of maintenance-specific knowledge or due to the fact that design rules are dictated by the authorities.

1.3. Useful references to past

Whereas standards for new structures can be prescriptive and limited to construction types considered favourable at present time, standards for existing buildings must be open to deal with any type of structure found in application.
For this reason, SIA 269/4 gives valuable information on shear connectors often used in the past, but not covered by today's standards for new structures.
SIA 269/4 contains important information on the design rules of many types of shear connectors used in the past. The information included in SIA 269/4 are mostly based on the German „Verbundträgerrichtlinie“.

1.4. Maintenance of existing composite members

Many composite columns found in existing buildings were originally designed using proprietary design methods and parameters. Determination of their characteristics is often

very complex. Therefore the primary aim is then to obtain manufacturer's information, experimental investigations being one of the few alternatives.
Again, on composite slabs, the composite action between steel sheet and concrete slab is typically determined experimentally using the m-k-method, whereas obtaining reliable manufacturer data is a pleasing alternative. Still, in some cases, experimental investigations can be performed in parts of existing structures which are subject to deconstruction later [4].
On the other hand, existing composite beams can be investigated, analysed and retrofitted at relatively low effort.

2. STRENGTHENING OF COMPOSITE BEAMS

2.1. General

When strengthening composite beams, several alternatives are given. At first sight, strengthening the concrete slab or steel beam seems to be the preferred solution. However, this is restricted by the limited deformation capacity of the shear connectors. Therefore, in special cases, strengthening of the shear interface is necessary.

2.2. Strengthening the shear interface

In the absence of more detailed, converse information, shear connectors in existing composite beams must be assumed to already have almost or fully reached their deformation capacity. This assumption is justified irrespective of whether the elastic or plastic design or full./.partial shear connection was used in the original design.
Thus, when strengthening the shear connection in existing composite beams, special attention must be paid to the available deformation capacity. In general, failure of the existing shear connection prior to the additional connectors reaching their ultimate resistance must be avoided.
Therefore, the first simplified approach would then be to strengthen the shear interface by means of rigid shear connectors in the most-strained regions of the shear interface, such as near to the support in simply-supported beams.
Alternatively, a detailed analysis considering the load-deformation behaviour of all shear connectors must be performed. For elastic design simple design methods are given such as the γ-method by Möhler [5] as an alternative to the analytical solution. For plastic design of existing composite beams the most common way is to establish an appropriate numerical model and perform a nonlinear FEM analysis, this being a major effort. As a simple alternative, the θ-method [3] is recommended.
The θ-method determines the slip in the shear interface for a composite beam without any shear connection. With increasing shear connection, the maximum slip in a shear interface is gradually reduced. Slip without shear connection is determined based on a simple, kinematic model. The reduction of slip occurring in the shear interface is estimated based on vast parametric studies and experimental data [3].

2.3. Reinforcing steel or concrete chords – improving for the worse?

The often very much preferred solution for strengthening existing composite beams is to cast an additional layer of concrete on top of the existing concrete slab. While this often increases the bending resistance of both concrete slab in perpendicular direction and composite beam in longitudinal direction, it also increases the self-weight of the structure. Besides this premature failure of the shear interface can occur, reducing instead of increasing the composite beam's bending resistance.
Another common solution for strengthening existing composite beams found in practice is to weld additional steel lamellas to the existing steel beam. Such a measure generally increases the resistance in bending and that in axial tensile force of the steel beam. On the other hand, this reduces the degree of partial shear connection. If the degree of partial shear connection was already close to the minimum degree of partial shear connection or the steel beam is strongly reinforced by the additional lamellas, the degree of partial shear connection of the final beam could become lower than the minimum degree of partial shear connection for the respective composite beam.

3. EXAMPLES

3.1. Description of Original State

The existing composite deck shown in Figure 1 with the beam's cross-section as shown in Figure 2 was originally designed for a live load of 2 kN/m² and an imposed load of 1.2 kN/m² (Pavement layer of 50 mm thickness). This deck is now to be strengthened for a live load of 5 kN/m² or 10 kN/m². Still, a pavement layer of 50 mm must remain.

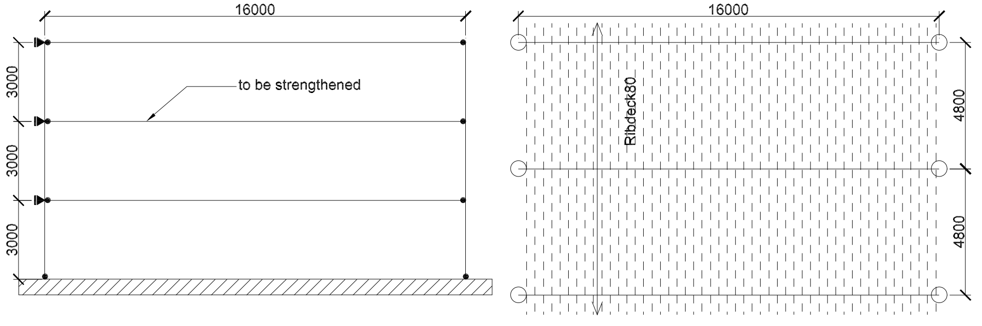

Figure 1: Existing composite deck. Longitudinal section (left), plan view (right)

The composite deck is originally built of steel beams HEB 400 in S355 spaced 4.80 m. The composite slab consists of a trapezoidal steel sheeting (Ribdeck 80, 1.20 mm) and 14 cm of concrete C40/50.
In the shear interface two rows of diameter 22 mm headed studs are spaced 300 mm over the whole span. This results in 52 studs per half-span.
The shear capacity of these studs is then

$$P_{Rd,tot} = 52 \cdot P_{Rd} \cdot \alpha_t = 52 \cdot 109.5kN \cdot 0.563 = 3206kN \tag{1}$$

while the axial resistance of the steel beam is

$$N_{a,Rd} = 6687kN \tag{2}$$

and that of the concrete

$$N_{c,Rd} = 0.85 \cdot h_{eff} \cdot b_{eff} \cdot f_{cd} = 0.85 \cdot 50mm \cdot 4000mm \cdot 26N/mm^2 = 4420kN\ . \tag{3}$$

Thus, the beam is in partial shear connection with a degree of partial shear connection of

$$\eta = \frac{3206kN}{4420kN} = 0.73\ . \tag{4}$$

The minimum degree of partial shear connection is

$$\eta = \frac{355N/mm^2}{f_y} \cdot \left(0.75 - 0.03 \cdot L_e\right) = \frac{355N/mm^2}{355N/mm^2} \cdot \left(0.75 - 0.03 \cdot 16m\right) = 0.73\ . \tag{5}$$

Thus, the composite beam is at minimim degree of partial shear connection.

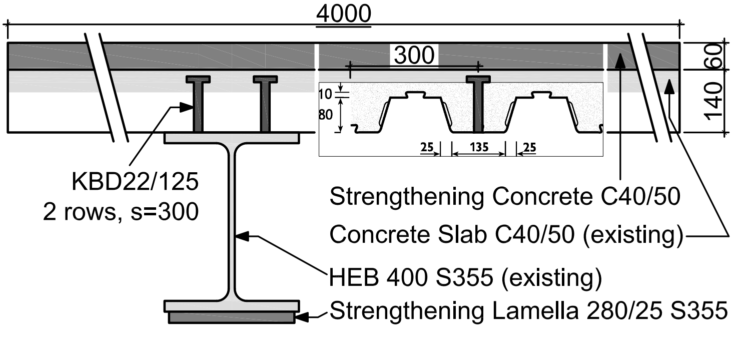

Figure 2: Cross-section of composite beam with strengthening measures

The bending resistance of the original composite beam amounts to 1897 kNm in full shear connection and to 1761 kNm with a degree of partial shear connection of $\eta = 0.73$.
The original design load amounts to $q_{E,d} = 43.2$ kN/m', resulting in a design bending moment of $M_{E,d} = 1390$ kNm. Thus, most of the headed studs were originally placed not for structural reasons, but only to respect the minimum degree of shear connection.
On the other hand, the beam's bending resistance is higher than required for the actual loads.

As a strengthening measure, three options are investigated:

1. Strengthen the shear interface by installing additional block dowels at the supports.
2. Strengthen the steel beam by welding a steel lamella to the underside of the lower flange.
3. Strenghten the concrete chord: Remove pavement, roughen concrete surface, add another 6 cm of concrete, re-place pavement.

3.2. Strengthening to 5 kN/m² live load

The composite slab in its original state is already able to carry 1.2 kN/m² imposed load and 5 kN/m² live load. With 5kN/m² live load the design load to the composite beam amounts to $q_{E,d}$ = 47.7 kN/m', resulting in a design bending moment of $M_{E,d}$ = 1526 kNm.
As the resistance of the original construction is greater than the design forces, the live load on the composite deck can be raised to 5 kN/m² without any structural measures.

3.3. Strengthening to 10 kN/m² live load

For a live load of 10 kN/m² the existing composite deck is too weak. Thus, the existing pavement is removed and the surface of the structural concrete is roughened. Then an additional layer of 6 cm concrete C40/50 is cast without propping either slab or beams. After all, the pavement is cast again on the new composite slab.
With the additional concrete and the new live load of 10 kN/m² the new loads are shown in Table 1.

Load	**Dimensions**	**kN/m²**	**kN/m'**
Dead loads (self-weight and imposed loads)			
Steel beam	HEB 400		1.55
Concrete slab, original	$h_{c,eff}$ = 140 mm - 42 mm + 4800 mm/250=117 mm. 117 mm x 24 kN/m³	2.800	13.50
Concrete slab, new	$h_{c,new}$ = 60 mm. 60 mm x 25 kN/m³	1.500	7.20
Profiled steel sheeting	t = 1.2 mm	0.145	0.70
Pavement	Layer thickness: 50 mm, 24 kN/m³	1.200	5.76
Total dead load		**g_k =**	**28.71**
Live load		10.000	48.00
Total dead load		**q_k =**	**48.00**

Table 1: Self-weight, imposed loads and live loads of strengthened composite beam

The design load to the composite beam is thus $q_{E,d}$ = 110.8 kN/m', resulting in a design bending moment of $M_{E,d}$ = 3544 kNm.
The bending resistance of the strengthened composite beam with additional concrete in full shear connection is $M_{R,d}$ = 2442 kNm and thus too low. Therefore, a steel lamella 280/25 mm in S355 is welded to the underside of the steel beam's lower flange. Thus, a bending resistance of $M_{R,d}$ = 3689 kNm is reached for full shear connection, whereas the bending resistance of the pure steel section (consisting of HEB 400 and lamella) amounts to 1223kNm.
Still, the shear interface of the strengthened beam is insufficient.
The axial resistance of the steel beam is now

$$N_{a,Rd} = 6687kN + \frac{280mm \cdot 25mm \cdot 355N/mm^2}{1.05} = 9054kN \quad (6)$$

and that of the concrete

$$N_{c,Rd} = 0.85 \cdot h_{eff} \cdot b_{eff} \cdot f_{cd} = 0.85 \cdot (50mm + 60mm) \cdot 4000mm \cdot 26N/mm^2 = 9724kN \ . \qquad (7)$$

Without any measure to the shear interface, the beam shows a degree of partial shear connection of

$$\eta = \frac{3206kN}{9054kN} = 0.35 \ . \qquad (8)$$

Using the linear interpolation theory, the degree of partial shear connection to reach the required bending resistance must be at least

$$\eta = \frac{3544kNm - 1223kNm}{3689kNm - 1223kNm} = 0.94 \ . \qquad (9)$$

Using the equilibrium theory, the degree of partial shear connection to reach the required bending resistance must be at least

$$\eta = \frac{8050kN}{9054kN} = 0.89 \ . \qquad (10)$$

Therefore, the shear resistance of the composite beam's shear interface must be increased by at least

$$\Delta P_{Rd} = 8050kN - 3206kN = 4844kN \ . \qquad (11)$$

As it must be assumed that the original shear connectors have already reached their deformation capacity, the additional shear resistance must be realised by means of a rigid shear connection, such as block studs near to the supports.
Therefore, a solution with four U-shaped shear connectors is chosen (cf. Figure 3). Each shear connector is made of a UPE 220 steel section of 150 mm length, welded to the steel beam in 300 mm of longitudinal spacing. In order to allow a proper load introduction the steel sheet is removed locally such that a solid concrete slab occurs in the vicinity of the new studs.

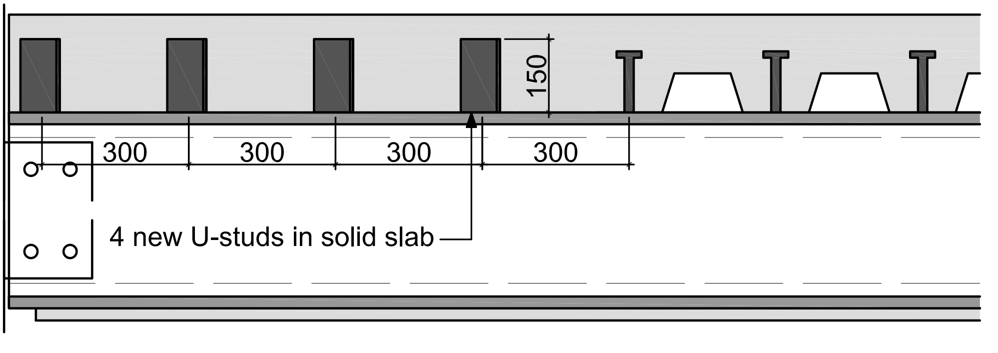

Figure 3: Additional rigid shear connectors to strengthen the shear interface

After SIA 269/4, formula (A1), the shear resistance of these four dowels amounts to

$$\Delta P_{Rd,B,act,tot} = 4 \cdot \sqrt{\frac{340mm \cdot 200mm}{220mm \cdot 150mm}} \cdot 220mm \cdot 150mm \cdot 26N/mm^2 = 4927kN \quad (12)$$

The weld between the U-connectors and the steel beam is made with a 20% overstrength in order to prevent brittle failure of the welds. Additionally, the shear forces are introduced into the concrete by means of an appropriate reinforcement.

3.4. Possible critical faults

Under the given circumstances one might assume that the steel beam was made of S235. This would lead to a critical situation, as the degree of partial shear connection would be over-estimated. This can only be avoided either by doing material tests on the steel beam, or by finding out that the composite deck was originally cast without propping, which clearly requires the steel beam to be of S355.

Further, after a rather superficial investigation of the existing structure one might choose to simply weld an additional lamella to the steel beam when strengthening to a live load of 5 kN/m². This would lead to an insufficient degree of partial shear connection and thus cause brittle failure of the shear interface prior to reaching the estimated bending resistance.

4. CONCLUSIONS

In Switzerland a novel set of standards, the SIA 269 family, is about to be published. For existing steel-to-concrete composite structures standard SIA 269/4 is applicable. The new Swiss standard SIA 269/4 provides a useful set of rules to the engineers working with existing composite structures.

With its open formulation SIA 269/4 favours innovation on the still relatively new field of retrofitting existing composite structures.

As SIA 269/4 – following SIA's Swiss standard philosophy – does not form a cookbook, many rules available for application in special issues are not included in the standard text, but will be described and taught in special introductory courses and the respective consultative documentations.

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