Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte
Band: 62 (1991)

Artikel: Influence of contact surface problems on design practice
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DOI: https://doi.org/10.5169/seals-47719

Influence of Contact Surface Problems on Design Practice

Influence de problème des joints de contact sur le dimensionnement

Einfluss von Kontaktflächenproblemen auf die Bemessungspraxis

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SUMMARY
Large buildings contain construction joints which may have a great influence on the loadbearing capacity of the structure. The design concepts of various standards for concrete structures will be presented and discussed briefly. Unfortunately, these design concepts treat the same problem in different ways. Based on a failure criteria of Mohr-Coulomb it will be shown how joints can be treated consistently in the design concept of strut-and-tie-models.

RÉSUMÉ
Les grands bâtiments comportent des joints qui influencent beaucoup la capacité portante de la structure; des concepts divers de dimensionnement sont brièvement présentés puis discutés. Le critère de rupture de Mohr-Coulomb constitue la base d'une démonstration décrivant comment les joints sont considérés dans le cadre d'un dimensionnement utilisant le modèle des bielles (analogie du treillis).

ZUSAMMENFASSUNG
Grössere Bauwerke beinhalten Fugen, die einen grossen Einfluss auf die Tragfähigkeit der Konstruktion ausüben können. Für Betonbauwerke werden Bemessungskonzepte verschiedener Normen vorgestellt und kurz diskutiert. Leider wird das gleiche Problem in diesen Bemessungskonzepten unterschiedlich behandelt. Auf der Grundlage eines Mohr'schen Versagenskriteriums wird aufgezeigt, wie Fugen in dem Bemessungskonzept der Stabwerkmodelle einheitlich behandelt werden.

1. DESCRIPTION OF THE PROBLEM

There are many structures where forces have to cross contact surfaces. In concrete structures this occurs for example at cracks or at construction joints between cast in situ or precast elements. The behaviour of the contact surfaces cannot solely be described by well-known material characteristics like the tensile and compressive strength, but also the surface condition (like smooth or rough) must be considered. Therefore an additional failure criterion for the contact surface must be defined.

In the following an attempt is made how the contact surface problems in connection with construction joints are treated in the consistent and translucent dimensioning concept of strut-and-tie-models according to Breen /B2/ and Schlaich /S1,S2/. This is desirable because contact surface problems may have an important effect on the structural behaviour. Up to now they are dealt with not systematically and partly unsufficiantly in the design practice.

2. PRESENT DESIGN PRACTICE AND EXISTING CODES FOR CONCRETE STRUCTURES

In codes for concrete structures these problems are so far treated either as dimensioning problems for shear and normal stress in the contact surface or/and in terms of construction requirements.

2.1 German Standards

The German Standards /D2/ require a sufficient roughness for longitudinal joints between prefabricated parts and concrete cast in situ. The description of the appropriate surface condition is only given in a comment upon the Standards /E1/. An increased transverse reinforcement is needed, apart from a few exceptions, and the permissible shear stress is limited to 60 % of the regular value. The specialities of construction joints transverse to the loadbearing direction are specified only for prestressed structural members. Thereby a rough (or keyed) surface is a precondition, too. Additionally a value for the compression strength for the joint section is given.

2.2 ACI Standard 318-77

In the ACI Standard 318-77, section 11.7 /A1/ the dimensioning of construction joints is described on the basis of the shear-friction-theory which was originally developed by Birkeland /B2/ and Mast /M1/. An ultimate shear force V_u is defined for rough surfaces.

$V_u = 1.0\ A_s f_y < 0.2 f'_c A_c$ [N] or $5.5\ A_c$ [N]

A_s : total crossectional area of reinforcement across interface

f_y : yield strength of reinforcement < 420 N/mm^2

Thereby rough means a clean interface which is free of laitance and roughened to a full amplitude of approximately 5 mm.

2.3 SIA-Standard 162

The SIA-Standard 162 /S3/ section 4 45 limits the concrete strength and steel strength of the prefabricated and connected parts.

Concrete: $f_{c,red} = 0.35\ f_{cw,min}$ Steel: $f_{y,red} = 0.80\ f_y$

According to section 6 06 2 only rough or keyed joints are permissible preferably perpendicular to the direction of the compression field. The rough joint should be realized by removing the cement-sand grout from the concrete surface.

3. A CONSISTENT DIMENSIONING-CONCEPT USING STRUT-AND-TIE-MODELS

3.1 Mathematical Description of the Loadbearing Capacity of Joints

The mathematical description of the loadbearing capacity of joints is based on the extended shear-friction-theory of Mattock /M1,M2/. It is drawn from a proposal by a FIP-Commission /F1/ supplemented by Walraven /W1/. The results are shown graphically in fig. 1.

$$\tau_u = K1\,(\mu f_y + \sigma_N) + K2\, f_{ctk} \leq 0.25\, f_{ck}$$

μ : A_s/A_c

f_y : yield strength of reinforcement <400 N/mm^2

σ_N : normal stress

$f_{ctk} = 0.25\ \sqrt{f_{ck}}$

surf.cond.	K1	K2
very smooth	0.6	0.1
smooth	0.6	0.2
rough	0.9	0.4

Table I

The coefficient K1 is equivalent to a frictional coefficient and the term K2 f_{ctk} corresponds to the so-called cohesion, which here is proportional to the tensile strength of the concrete. Both coefficients depend on exactly described surface conditions which are subdivided in three categories (Tab. I). By comparison with an extensive series of experiments carried out by Daschner /D1/ Walraven found out that the concept is on the safe side, if the steel strength is limited to $f_y < 400\ N/mm^2$. For comparison, the parabolic description of the joint behaviour according to Tassios /T1/ is shown in fig. 2.

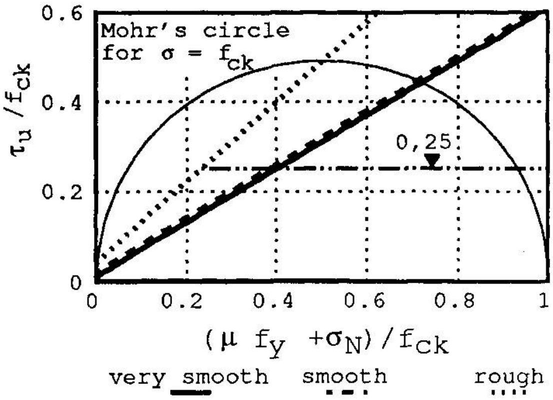

Fig. 1: acc. to FIP

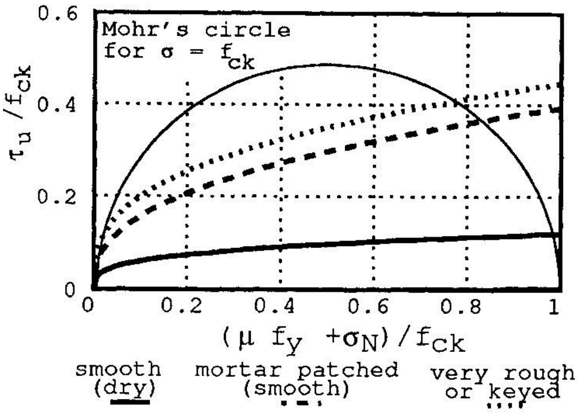

Fig. 2: acc. to Tassios

3.2 The Influence of a Joint on the effective Strength of a Prism

With the above given proposals the loadbearing capacity of a prism with a joint (fig. 3) is given according to Zelger and Rüsch /Z1/ and can be seen in fig. 4 and fig. 5. The diagrams clearly show that the capacity of the prism is only reduced by the joint, if the inclination of the joint exceeds a critical angle α_{crit}. If the inclination is smaller than α_{crit} the prism fails in concrete-compression. These dependencies can also be shown in a different way using Mohr's circle (see: Guckenberger /G1/ and Basler /B1/).

according to FIP /F1/:

$$\frac{\sigma_u}{f_c} = \frac{K2\ f_{ctk}}{f_c} \cdot \frac{1 + \tan^2 \alpha}{\tan \alpha - K1} \leq 1$$

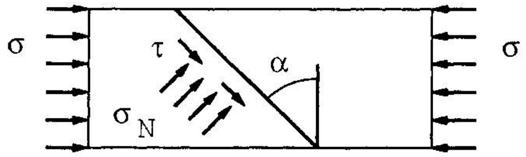

Fig. 3: prism with a joint

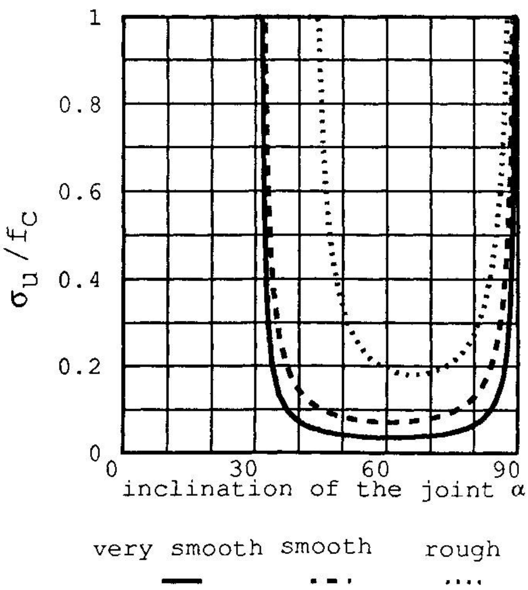

Fig. 4: acc, to FIP

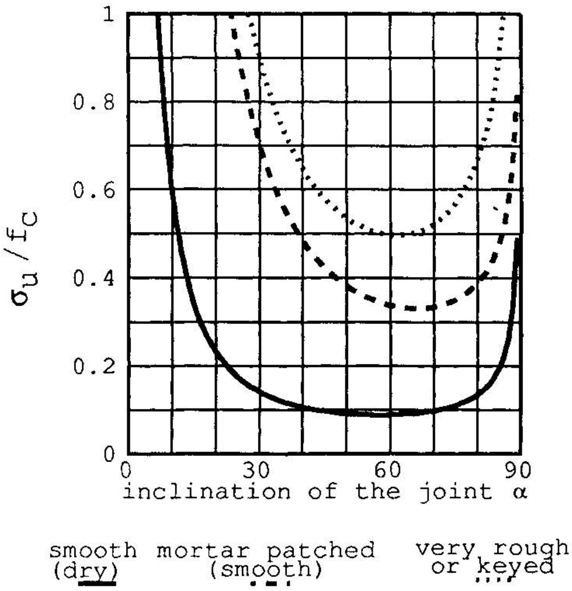

Fig. 5: acc. to Tassios

The following diagrams show in a different way some characteristics of the loadbearing behaviour of the prism. They are based on the FIP proposal, because it satisfies the demands of the structural engineer better than other proposals. Fig. 6 shows the dependence of the critical inclination on K1 and K2 f_{ckt}. It is remarkable that the critical inclination of the joint is almost totaly independent of the term K2 f_{ckt} (cohesion). Fig. 7 shows the dependence of the minimal effective strength on K1 and K2 f_{ckt}.

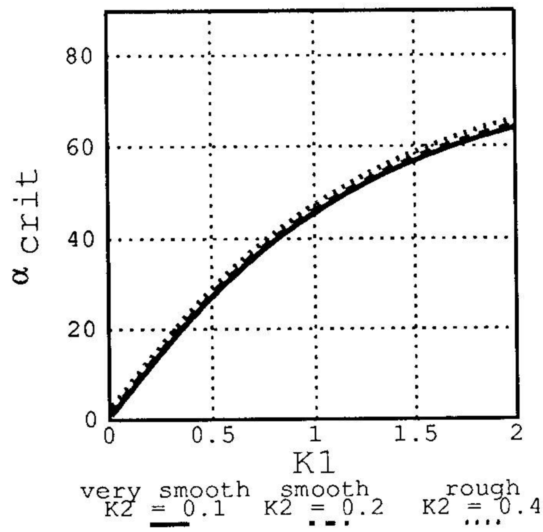

Fig. 6: crit. inclination

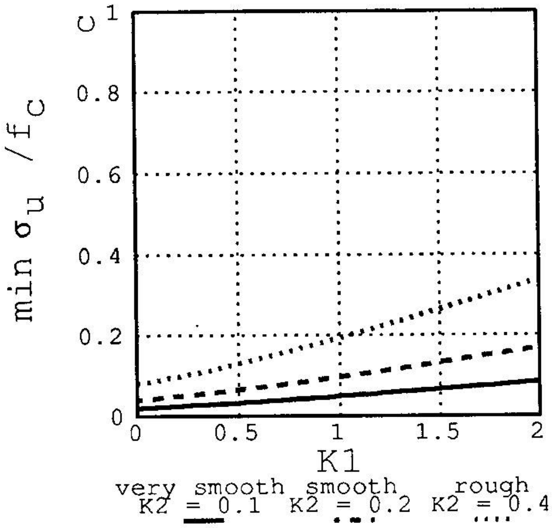

Fig. 7: minimal effective prism strength

With the above diagrams some problems of dimensioning structural members with joints can be solved directly, as e.g. for a joint in an arch bridge between the bottom edge of a column and the supporting arch.

3.3 Joints in the web of a Beam

In the following the influence of the joint on the ultimate shear force of a beam is explained. Two cases are considered either a longitudinal joint between a precast part and a layer of cast in situ concrete or a transverse construction joints between two stages of construction or precast elements (fig. 8). The loadbearing behaviour of the beam is described with a strut-and-tie-model. Thereby the joint influences essentially the effective strength of the compression strut. It is assumed that the effective strengths of the chords are not reduced. This leads to the conclusion that the reduction of the ultimate shear force depends mainly on the inclination of the strut - and accordingly on the transverse reinforcement - and the roughness of the joint.

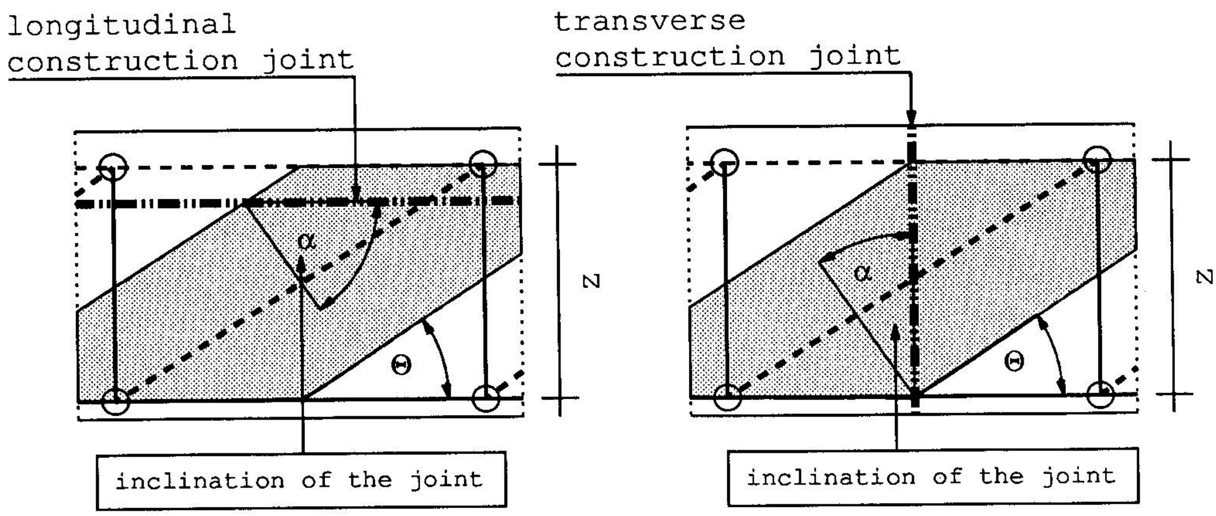

Fig. 8: strut-and-tie-model of a beam

The reduced ultimate shear force due to joint failure can be calculated as follows:

$$\frac{V_u}{b\,z\,\sigma_{cw,u}} = \frac{K2 \sin\Theta \cos\Theta (1+\tan^2\alpha)}{\tan\alpha - K1} \frac{f_{ctk}}{\sigma_{cw,u}} \leq 1 \qquad \text{for } \alpha > \alpha_{crit}$$

Considering $\alpha = 90° - \Theta$ in case of a longitudinal joint and $\alpha = \Theta$ in case of a transverse joint yields the curves shown in fig. 9 and fig. 10. In both cases the ultimate shear force of a beam without joints can be reached nearly if the surface is rough. However for a longitudinal joint an inclination 45° for the compression field and an accordingly increased tie reinforcement is required. For a transverse joint the inclination of the compression field varies between 30° and 45° as usually.

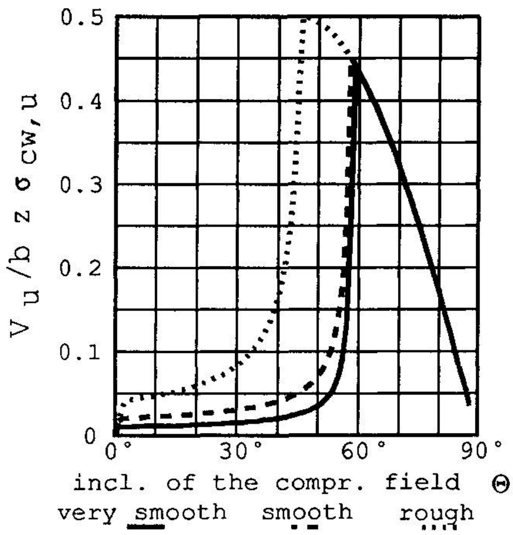

Fig. 9: Longitudinal joint

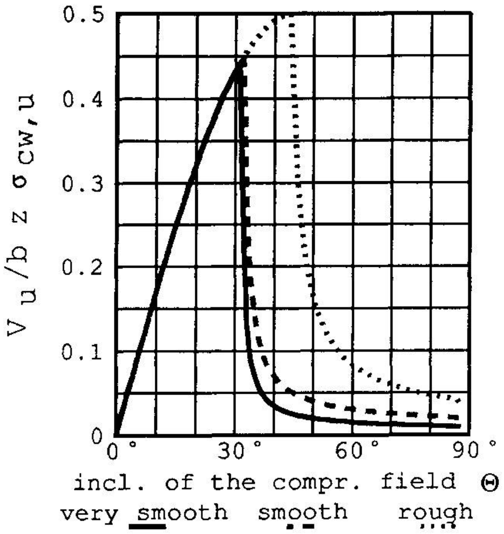

Fig. 10: Transverse joint

Fig. 12 and fig. 13 show diagrams for the necessary vertical shear reinforcement. For longitudinal joints highly increased reinforcement is required even if the joint is rough. For rough transverse joints only the maximum value for the ultimate shear force is reduced by the joint.

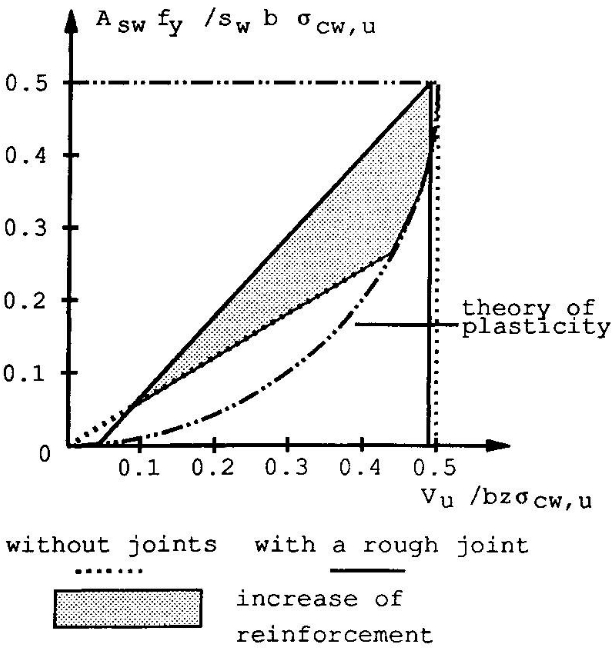

Fig. 11: Longitudinal joint

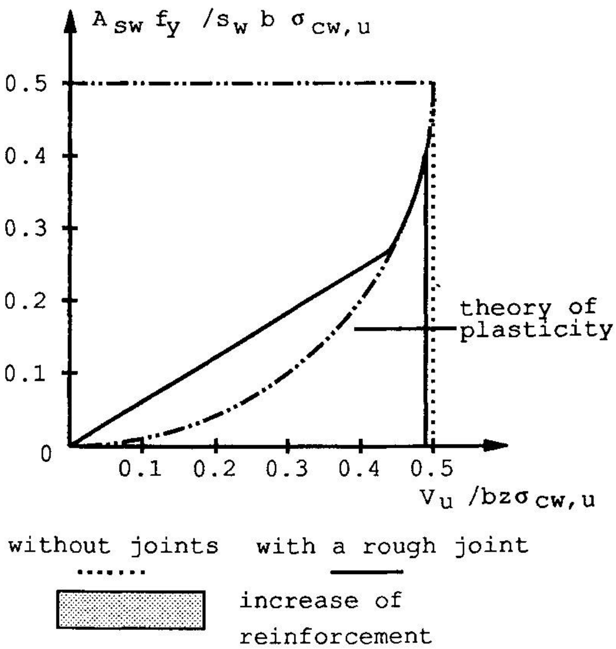

Fig. 12: Transverse joint

4. SUMMARY AND PROSPECTS

It was shown that the influence of a joint on a structural concrete member can be expressed by an reduced effective strength of the struts in a strut-and-tie-model. Therefore the normally given relation between the normal stress and the ultimate shear stress of a joint must be transformed into a relation between the inclination of the joint in a strut and of its effective compressive strength. This relation depends on the roughness of the contact surface, which has to be described exactly. Reineck shows a similar approach in /R1/ concerning the influence of friction mechanisms in cracks on the ultimate strength of the web compression field. The advantage of these methods is that it becomes more obvious how a structural member with a joint or cracks works and which element will fail under ultimate load.

Prospective efforts should aim in the direction of integrating composite structures with contact surface problems between their different materials in a consistent dimensioning concept. At the moment this is unfortunately complicated by the splitting of codes according to materials which leads to different approaches for the same problem. Further types of contact surface problems will arise in future, when the advantages of combining new or unusual materials will be used to realize new kinds of structures with different and novel qualities.

REFERENCES:

/A1/ ACI Standard 318-77: Building Code Requirements for Reinforced Concrete.

/B1/ Basler, E., Witta, E.: Grundlagen für kraftschlüssige Verbindungen in der Vorfabrikation. Beton-Verlag GmbH, 2. Auflage, Düsseldorf 1967

/B2/ Birkeland, P.W., Birkeland, H.W.: Connections in precast concrete constructions. ACI-Journal V.63, March 1966, pp.345-368

/B3/ Breen, J.E.: Why Structural Concrete. Introductory Report, IABSE Colloquium "Structural Concrete", Stuttgart, April 1991

/D1/ Daschner, F.,: Versuche zur notwendigen Schubbewehrung zwischen Betonfertigteilen und Ortbeton. DafStb Heft 372, Berlin 1986

/D2/ DIN-Normen 1045 und 4227 Teil1 und Teil3

/E1/ Erläuterungen zu DIN 1045 Beton- und Stahlbeton Ausgabe Juli 1988, DafStb, Heft 400, Berlin 1989

/F1/ FIP-Commission on Prefabrication: Shear at the interface of precast and in situ concrete. FIP-Report, Jan. 1982

/G1/ Guckenberger, K., Daschner, F., Kupfer, H.: Segmentäre Spannbetonträger im Brückenbau. DAfStb, Heft 311, Berlin 1980

/M1/ Mast,R.F.: Auxiliary reinforcement in concrete connections. Journal of the Structural Division, ASCE, V. 94, ST6, June 1968, p. 55-75

/M2/ Mattock, A.H., Hawkins, N.M.: Research on shear transfer in reinforced concrete. PCI-Journal, V. 17,No.2, March-April 1972, pp. 55-75

/M3/ Mattock, A.H.: Shear transfer in concrete having reinforcement at an angle to the shear plane. ACI-Special Publication 42, Detroit, Michigan, 1974, pp. 17-42

/R1/ Reineck, K.H.: Consistent Modelling of Structural Concrete Members with Transverse Reinforcement Considering Strains and Cracks. IABSE Colloquium "Structural Concrete", Stuttgart, April 1991

/S1/ Schlaich, J.: The need of consistent and translucent models. Introductory Report, IABSE Colloquium "Structural Concrete", Stuttgart, April 1991

/S2/ Schlaich, J., Schäfer, K., Jennewein, M.: Toward a Consistent Design of Structural Concrete. PCI-Journal Vol.32, No.3, May/June 1987

/S3/ SIA-Norm 162: Betonbauten. Ausgabe 1989

/T1/ Tassios, T.P.: Physical and mathematical Models for RE-Design of repaired Structures

/W1/ Walraven, J.,: Über den kraftschlüssigen Verbund von Betonen unterschiedlichen Alters und unterschiedlicher Oberflächenbeschaffenheit der Verbundfuge. VDI Berichte Nr. 840, Oktober 1990

/Z1/ Zelger, C.,Rüsch, H.: Der Einfluß von Fugen auf die Festigkeit von Fertigteilschalen. Beton- und Stahlbetonbau (1961), Heft 10, S.234-237