Concrete Capacity as Part of Total Shear Capacity of Reinforced Concrete Beams Support Zone in Current Standards

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Abstract. The use of new materials such as high strength concretes and high strength steels is pressurising researchers to modify computational models on continuous basis, in particular the models for the calculation of shear capacity of reinforced concrete beams. Some of these changes can be observed in current European standards, for example in fib Model Code 2010 (PreNorm), were in contrast to Eurocodes, in the case of shear capacity of reinforced concrete beams support zone, concrete capacity was included. This paper presents a comparative analysis of theoretical and experimental shear load capacities of reinforced concrete beams support zone. The theoretical capacities used in this paper were calculated based on currently used standards which were divided into two groups. The first group included standards which identified the support zone capacity as the capacity of only shear reinforcement without concrete capacity taken into account (PN-EN-1992-1-1). The second group were standards in which the support zone shear capacity was a sum of concrete and reinforcement capacities (fib Model Code 2010, ACI-318). Shear capacities calculated based on designated standards were verified by the experimental tests carried out on single-span, statically determinable, reinforced concrete beams, loaded monotonically to failure. It should be noted that in the case of ModelCode2010, the calculations took into account the higher values of concrete capacities than those specified in the standard regulations. The comparative analysis showed smaller differences between the experimental and theoretical shear capacities in the case of results calculated according to MC 2010, with higher level of concrete capacities, and ACI-318 then in case of PN-EN-1992-1-1. These results of shear capacity were obtained as the sum of the concrete and shear reinforcement capacities. The smallest differences were obtained by using the method given in ACI-318, which takes into account the bigger values of concrete load capacity than other standards. In this regard further analysis of the shear capacity of reinforced concrete beams support zone needs to be performed to enable the introduction of corrections to the standards in which the shear capacity of the concrete is neglected in total shear capacity of the support zone.

1. Introduction
The problem of shear capacity in reinforced concrete structures, although has been the subject of research and analysis for many years, is not yet fully understood. This is mainly due to the complexity of this problem related to many aspects of reinforced concrete beam performance. The main ones are above all: the presence of a complex state of stress in the support zone and non-parallel, to the axis of the element, trajectory of the main stresses, for which also the actual angle of inclination is difficult to determine. Also the nature of reinforced concrete itself, as a conglomerate of concrete and steel, causes lack of isotropy and homogeneity. Moreover, commonly used high strength concrete and steel cause
additional problems related to the description of the behaviour of a reinforced concrete beams support zone under load. In addition, this issue is also impeded by such parameters as: the degree of transverse and longitudinal reinforcement, the dimensions and shape of the cross-section, as well as the method of load application. As a result, the theoretical solution to the shearing problem is very difficult and still valid. This makes it necessary to look for computational models based on experimental results that can describe, as accurately as possible, the behaviour of the reinforced concrete beams support zone under load. However, until now, no model has been created that would fully reflect the behaviour of this zone.

The models adopted in the standard regulations were selected from these that are as simple as possible in use, gave the most reliable results possible and above all providing the safety of the structure. However, due to the implementation of base models to standards and the associated with that normalization, obtained theoretical values are not always sufficiently consistent with the real ones. Additionally to the universality of the standard provisions applied to the design and assess of load-bearing capacity during exploitation it was particularly important in terms of ensuring an adequate level of structural reliability. Therefore, there is a significant necessity obtain fully reliable results on a specific and fully recognized security level based on models that are guidelines for designers.

The current European regulations, Eurocode 2 (PN-EN-1992-1-1) [1], intended for the design of the reinforced concrete beams support zone, were based on the modified Mörsch truss analogue according to the Kupfer-Rüsch modification [2]. In this model when shear reinforcement is computationally necessary, the load-bearing capacity of the concrete cross-section is neglected, as a result of which only the transversal reinforcement capacity is considered to be the total bearing capacity of the support zone. This approach has been modified in the fib Code Model 2010 standard (PreNorm) [3]. In fib Code Model 2010 [3], unlike to the truss analogy, one possible approach allows to include some part of the concrete capacity, as the friction in the diagonal crack, to the total shear capacity of the support zone. A similar approach in terms to the concrete load capacity can be found in the American ACI-318 regulations [4]. In which, in addition to the shear reinforcement, the capacity of the concrete, much greater extent than in other regulations [1, 3], is taken into account in the overall shear capacity of the support zone. Accordingly, carrying out works related to the comparative analysis of the experimental and theoretical results obtained on the basis of calculation models adopted to the standards seems to be fully justified. Also modern equipment used today during tests, which allows to track the cracks, measuring their width and angle of inclination at any load level, as well as the implementation of various load programs allows for a new significant extension of conducted analysis.

2. Current standard calculations models

2.1. Eurocode 2 (PN-EN-1992-1-1) [1]

The European standard EC2 [1] is based on the Mörsch truss analogy, modified by Kupfer-Rüsch [2]. It uses the concept of a changed inclination angle of concrete struts $\theta$ (figure 1), which should be taken in the range from $45^\circ$ to $21.6^\circ$ or to $26.6^\circ$ according to the national annex [5, 6].

![Figure 1. The Mörsch truss analogy scheme according to Eurocode 2 [1]](image)

The basic load capacities, according to the EC2 [1], should be calculated according to the following formulas:
• $V_{Rd,c}$ - design shear capacity of an element without shear reinforcement:

$$V_{Rd,c} = \max \left\{ \left[ \frac{C_{Rd,c} \cdot k \cdot (100 \cdot \rho_L \cdot f_{ck}^{1/3}) + k_1 \cdot \sigma_{cp} \cdot b_w \cdot d}{\nu_{min} + k_1 \cdot \sigma_{cp} \cdot b_w \cdot d} \right], \right\}, \tag{1}$$

where: $C_{Rd,c} = 0.18/\gamma_{cs}$, $k$ – scale factor, $\rho_L$ – longitudinal reinforcement degree, $f_{ck}$ – characteristic compressive strength of concrete, $k_1 = 0.15$, $\sigma_{cp}$ – the average compressive stress in the concrete caused by the longitudinal force or the sum of the longitudinal force and the prestressing force in prestressed elements, $b_w$ – width of the cross-section in the tensile area, $d$ – usable height of the cross-section, $\nu_{min} = 0.035k^{1/2}f_{ck}^{1/2}$

• $V_{Rd,s}$ – design shear capacity of a transversal reinforcement:

$$V_{Rd,s} = \frac{A_{sw} \cdot z \cdot f_{ywd} \cdot (\text{ctg} \theta + \text{ctg} \alpha) \cdot \sin \alpha}{s}, \tag{2}$$

where: $A_{sw}$ – the cross-sectional area of the shear reinforcement, $z$ – arm of internal forces, $f_{ywd}$ – design yield strength of the shear reinforcement, $s$ – the spacing of the stirrups, $\alpha$ – the angle of inclination of the stirrups, $\theta$ – the angle of inclination of the compressed concrete struts

• $V_{Rd,max}$ – design load capacity of compressed concrete struts due to their crushing:

$$V_{Rd,max} = \alpha_{cw} \cdot V_{t} \cdot f_{cd} \cdot b_w \cdot z \cdot \frac{\text{ctg} \theta + \text{ctg} \alpha}{1 + \text{ctg}^2 \theta}, \tag{3}$$

where: $\alpha_{cw}$ – coefficient taking account of the state of the stress in the compression chord, $V_{t}$ – strength reduction factor for concrete cracked in shear, $f_{cd}$ – design compressive strength of concrete,

According to EC2 [1] during designing of the reinforcement concrete beams support zone two cases are possible. A first one is characterized by the load-bearing capacity of the concrete cross-section $V_{Rd,c}$ (1) and $V_{Rd,max}$ (3) greater than the design shear force $V_{Ed}$. As result of which the shear reinforcement must fulfill only the construction conditions regarding to the maximum longitudinal ($s_{l,max}$) and transverse ($s_{w,max}$) spacing, and minimum shear reinforcement degree ($\rho_{w,min}$). In the second case, the load-bearing capacity of the concrete cross-section $V_{Rd,c}$ (1) is exceeded. Therefore, concrete capacity is skipped and the shear reinforcement need to be calculated, according to equation (2), assuming that it carries all the shear force and provided total load bearing capacity of the support zone.

2.2. Fib Model Code 2010 (Preliminary Standard) [3]

In the latest regulations for designing of the reinforced concrete structures described in fib Model Code 2010 (PreNorm [3]), a changed approach for design of the reinforced concrete beams support zones can be found. Because these provisions are to be used in the next version of the European standard, they have become a topic of several scientific works [7, 8, 9]. The basic differences, in relation to the currently used standard [3] it is a possibility of use four levels of calculations approximation. Those approximations were based on the truss analogy, an analysis of generalized stress fields approach [10] and a simplified modification of the compression field theory. Considering the possible approaches, the general rule can be formulated, that in the case of cracked concrete the shear load capacity $V_{Rd}$ of the reinforced concrete beam is defined as the capacity of only the shear reinforcement $V_{Rd,s}$ (4):

$$V_{Rd,s} = \frac{A_{sw} \cdot z \cdot f_{ywd} \cdot (\text{ctg} \theta + \text{ctg} \alpha) \cdot \sin \alpha}{s_w}, \tag{4}$$
Only in the case of the third level approximation total shear capacity of the support zone can be increased by the concrete capacity $V_{Rd,c}$ (5) calculated as:

$$V_{Rd,c} = k_v \cdot \sqrt{\frac{f_{ck}}{\gamma_c}} \cdot z \cdot b_w$$  \hspace{1cm} (5)

where: $k_v$ – the coefficient depending on the considered level of calculations accuracy, $\gamma_c$ – partial safety factor.

Also as the calculated shear force $V_{Ed}$ cannot be greater than the maximum shear capacity $V_{Rd,max}$ (6).

$$V_{Rd,max} = k_c \cdot \frac{f_{ck}}{\gamma_c} \cdot b_w \cdot z \cdot \sin \theta \cdot \cos \theta \, ,$$  \hspace{1cm} (6)

These capacities are specified based on the distribution of forces scheme in the analysed cross-section which shows figure 2.

![Figure 2. The force scheme according to fib Model Code 2010 (PreNorm) [3]](image)

In the case of elements without computationally required transversal reinforcement, the shear capacity of the support zone corresponds to the concrete load bearing capacity $V_{Rd,c}$ (5), which also depends on the approximation level. At higher levels of accuracy, it also depends on a longitudinal strains $\varepsilon_x$ measured in the middle of the useful section height, as well as on a size of aggregate grains which is relevant for concretes with a strength greater than 70 MPa. In elements which the shear reinforcement was needed and fulfilled the condition of a minimum shear reinforcement, in addition to capacity of the concrete, capacity caused by the friction in a crack should be also taken into account. However, the sum of these values cannot be greater than the maximum capacity $V_{Rd,max}$ (6). The value of the inclination angle of the compressed concrete struts occurring in the formulas (4), (6) should be taken from the range of $\theta_{min}$ to $45^\circ$ and depended on the adopted level of approximation, like calculated shear capacity $V_{Rd}$.

The first level is based on a truss model with a variable inclination angle of the compressed concrete struts. In this case the total load capacity $V_{Rd}$ depends only on the capacity of shear reinforcement $V_{Rd,s}$ (4) and the acceptable angle of the compression struts inclination is strictly defined as:

- $\theta_{min} = 25^\circ$ - for elements with large axial compressive or prestressed forces,
- $\theta_{min} = 30^\circ$ - for reinforced concrete elements,
- $\theta_{min} = 40^\circ$ - for elements with large axial tensile forces.

The second approximation level was based on the method of stress fields, according to which the minimum inclination angle of compression strut, $\theta_{min}$ (7), depended on a longitudinal deformation $\varepsilon_x$.

$$\theta_{min} = 20^\circ + 10000 \cdot \varepsilon_x$$  \hspace{1cm} (7)

Also the total capacity of support zone $V_{Rd}$, as it was previously depended only on the capacity of shear reinforcement $V_{Rd,s}$ (4).

The approximation of the third level was based on the simplified modification of the compressed fields. In this case total load capacity $V_{Rd}$ should be determined by taking into account not only the shear
reinforcement capacity $V_{Rd,s}$ (4), but also the concrete capacity as a result the friction in the crack $V_{Rd,c}$ calculated according to formula (5), with the corrected value a $k_c$ factor and adopted $\theta_{min}$ (2) as it was in the second approximation level.

The last possible approach allows to use an appropriate calculation models of stress strain relationships for both steel and concrete. However, the usage of advanced methods of analysis should be supported by experience and obtained results must ensure the required safety level of the designed structure.

2.3. ACI-318 (14) [4]

Based on the standard full text and the paper [8], it can be concluded that the concept of the shear reinforcement design, contained in it, referred to the method of Kani [11], as well as to the modified truss analogy. Shear capacity in the case of a one-way shear $V_n$, which is considered in this work, was defined as the sum of the load capacity of concrete $V_c$ and transverse reinforcement $V_s$. However, for designing purposes, in order to obtain an adequate level of structural safety this value is decreased by the specified safety factor $\phi$, which for the shear was 0.75. It was also assumed that the concrete capacity, $V_c$, was the same for both reinforced and non-reinforced elements, because even after cracked the properties of concrete in the shear zone, such as: interlock of the aggregate in the crack, pin effect and transfer of shear force through the concrete compressed zone were considered. In order to ensure additional safety of the structure, the size of the cross-section is assessed in the first step by met the appropriate dependencies. The $V_c$ value can be determined using the basic method (8) or one of the more precise methods (9), (10), (11).

\[
V_c = 2 \cdot \sqrt{f_c'} \cdot b_w \cdot d,
\]  
\[
V_c = \left( 1,9 \cdot \sqrt{f_c'} + 2500 \cdot \rho_w \cdot \frac{V_u}{M_u} \right) \cdot b_w \cdot d,
\]  
\[
V_c = 3,5 \cdot \lambda \cdot \sqrt{f_c'} \cdot b_w \cdot d
\]  

where: $f_c'$ – compressive strength of concrete, $\rho_w$ – longitudinal reinforcement degree, $M_u$ – bending moment from external load, $V_u$ – shear force from external load, $\lambda$ – modifying factor regarding the mechanical properties of light concrete for normal concrete with the same strength, $b_w$ – cross-section width, $d$ – usable height of the cross-section.

The capacity of shear reinforcement $V_s$ (12) is determined on the basis of a modified truss analogy with the assumption of a constant inclination angle of concrete struts of $45^\circ$.

\[
V_s = \frac{A_v \cdot f_y \cdot (\sin \alpha + \cos \alpha) \cdot d}{s}.
\]  

where: $A_v$ – the cross-sectional area of the shear reinforcement, $f_y$ – the characteristic yield strength of the shear reinforcement, $\alpha$ – the angle of inclination of stirrups, $s$ – the spacing of the stirrups.

In the case when the cross-section carrying capacity is too small, the required amount of transverse reinforcement has to be calculated, to carry only a part of the shear force above the concrete cross-section capacity, as it assumed that the concrete always worked and carried out a specified value of shear force. The standard provisions indicate that in addition to the basic approach to the design of shear reinforcement also other methods which were documented in scientific works, such as the ST method [12] can be used.
3. The research elements and test stand
The tests were carried out on four reinforced concrete beams with a rectangular cross-section of
0.12x0.30 m (S2) and two T-beams (S2T, S2T1) with the dimensions of shelves 0.10x0.40m and web
0.12x0.30m. The effective span length of those beams was 3.00m, with a total length of 3.30m
Additionally, the accompanying tests to obtain the actual material characteristic were carried out.
These were the axial compression test carried out on 0.15x0.15x0.15m specimens made of the concrete
batch used for the beams, and the axial tensile test for rebar specimens. Obtained strength characteristics
of the materials are summarized in Table 1.

Table 1. The material characteristic of the tested elements

| BEAMS  | $f_{cm}$ [MPa] | $f_{ck}$ [MPa] | $f_{ck}^{CUBE}$ [MPa] | $f_{yk}$ [MPa] | $f_{ywk}$ [MPa] |
|--------|----------------|----------------|----------------------|----------------|-----------------|
| S2M-1  | 57.5           | 49.5           | 63.9                | 562.0          | 561.8           |
| S2M-2  |                |                |                     |                |                 |
| S2M-3  | 59.3           | 51.3           | 66.1                |                |                 |
| S2M-4  |                |                |                     |                |                 |
| S2T-1  | 45.9           | 37.9           | 49.4                | 565.4          | 703.3           |
| S2T1-1 | 45.2           | 37.2           | 48.5                |                |                 |

where: $f_{ck}^{CUBE}$ – characteristic concrete compressive strength measured on cubic samples, $f_{ck}$ –
characteristic concrete compressive strength, $f_{yk}$- characteristic steel rebar yield point, $f_{ywk}$- characteristic
steel stirrups yield point

Main tensile longitudinal reinforcement of tested beams was made up of 3ϕ12 and 2ϕ14 ($\rho_{As} 2\%$)
arranged in two rows, and 2ϕ8 (beams S2, S2T1) or 4ϕ8 (S2T) in the compression zone. Transverse
reinforcement was made in the form of orthogonal stirrups $\phi 4.5$ spaced, every 20 cm in the support
zones and 0.225 cm in the mid-section of the beam. The adopted shear reinforcement provides a
minimum degree of shear reinforcement according to the instructions given in EC2 [1]. The structure of
the reinforcement bars along with the adopted symbols is shown in figure 3. Additionally, in the case of
the S2T beam, the stirrups were additionally carried from the web to the shelf, figure 3c, which was not
made in the S2T1 beam, leaving the stirrups only in the web, figure 3d.

![Figure 3. The reinforcement of the tested beams and cross sections b) S2 c) S2T, d) S2T1](image)

The tests were carried out on the test stand shown in figure 4.
The tested elements had static scheme of single-span, statically determinate, freely supported beams. They were loaded by two forces (S2 and S3), placed 0.60m from the axis of the supports, Figure 4. Beams were loaded monotonically (M) until failure at a rate of 0.4 kN/min. During the study two types of the support were used: beams S2M-1, S2M-2 and S2T were supported by the pot-bearings 0.30 and 0.34m wide, while beams designated S2M-3, S2M-4 and S2T1-1 were supported on the steel rolls, simulating a point support, figure 5. The loading was carried out by an automatically controlled hydraulic actuators.

During the tests, among the other equipment an optical measuring system Aramis was used to record a field deformation of prepared measurement areas. The results of measurements from the Aramis system were used to determine the angle of inclination and width of the diagonal cracks, figure 6.

4. The results of the tests and calculations
The destructive forces obtained on the basis of experimental tests were compared to the theoretical values calculated according to standards provisions adopted for the analysis [1, 3, 4]. In the case of
standards based on a truss analogy [1, 3], the concrete cross-section capacities, \( V_{Rd,c} \) were calculated by formulas (1), (5) while the shear reinforcement capacities, \( V_{Rd,s} \) were designated according to formulas (2), (4). They were used to estimate the total bearing capacity of the support zone \( V_{Rd} \). According to the EC2 [1] guidelines the total support zone capacity should be equal to the shear reinforcement capacity. Additionally, it was also calculated as the sum of the bearing capacity of concrete and steel. While in the case of fib Model Code 2010 [3] three of four possible approximations were adopted for the analysis. In the third level approximation in the total shear capacity also a partial share of the concrete capacity, as a result form friction and interlocking in the diagonal crack, was taken into account. Regarding US regulations [4] the total bearing capacity of the support zone was assumed as the sum of the capacity of shear reinforcement, \( V_s \) (12) and concrete \( V_c \) (8), (9), (10), (11). Theoretical values of both concrete and steel shows in Tables 2 and 3. Also Table 2 presents experimental values of the inclination angle of concrete compression struts \( \theta \). They were adopted as corresponding to the inclination angle of the diagonal cracks in the support zone. The angles values were estimated on the basis of the field deformation maps obtained from the optical measuring system Aramis, which were in the range of the standards regulations.

### Table 2. The shear capacity of a concrete \( (V_{Rd,c}) \) and a reinforcement capacity \( (V_{Rd,s}) \)

| BEAMS  | Angle \( \theta \) [º] | Eurocode 2 [1] \( [kN] \) | Fib Model Code 2010 [2] |
|--------|------------------------|-----------------------------|--------------------------|
|        | \( V_{Rd,c} \) | \( V_{Rd,s} \) | \( V_{Rd,c} \) | \( V_{Rd,s} \) | \( V_{Rd,c} \) | \( V_{Rd,s} \) | \( V_{Rd,c} \) | \( V_{Rd,s} \) |
| S2M-1  | 31.0                   | 51.4                        | 35.2 | 29.7 | 35.2 | 21.9 | 35.2 | 21.9 | 38.6 |
| S2M-2  | 30.0                   | 51.4                        | 35.7 | 29.3 | 35.7 | 21.3 | 35.7 | 21.3 | 39.0 |
| S2M-3  | 27.0                   | 50.0                        | 38.9 | 28.7 | 38.9 | 22.1 | 38.9 | 22.1 | 42.1 |
| S2M-4  | 27.0                   | 50.5                        | 38.6 | 28.7 | 38.6 | 22.2 | 38.6 | 22.2 | 45.1 |
| S2T-1  | 38.0                   | 47.5                        | 33.0 | 26.2 | 33.0 | 18.1 | 33.0 | 18.1 | 36.1 |
| S2T1-1 | 29.0                   | 48.3                        | 46.0 | 25.8 | 46.0 | 19.2 | 46.0 | 19.2 | 48.9 |

### Table 3. The total shear capacity as a sum of the concrete \( (V_{Rd,c}) \) and the reinforcement capacity \( (V_{Rd,s}) \)

| BEAMS  | Eurocode 2 [1] \( [kN] \) | Fib MC 2010 [2] \( [kN] \) | ACI-318-14 [3] \( [kN] \) |
|--------|---------------------------|-----------------------------|-----------------------------|
|        | \( V_{Rd} = V_{Rd,c} + V_{Rd,s} \) | \( V_{Rd} = V_{Rd,c} + V_{Rd,s} \) | \( V_{R} = V_{c} + V_{s} \) |
|        | Ap. Lv I | Ap. Lv II | Ap. Lv III | Ap. Lv I | Ap. Lv II | Ap. Lv III | V_R1 | V_R2 | V_R3 | V_R4 |
| S2M-1  | 86.6     | 64.9     | 70.3 | 73.7 | 64.3 | 67.3 | 73.7 | 94.5 |
| S2M-2  | 87.1     | 65.1     | 69.9 | 73.1 | 64.2 | 67.1 | 67.3 | 94.5 |
| S2M-3  | 88.9     | 67.6     | 74.0 | 77.2 | 61.8 | 64.6 | 71.2 | 91.0 |
| S2M-4  | 89.1     | 67.4     | 73.9 | 80.3 | 62.2 | 65.0 | 71.6 | 91.7 |
| S2T-1  | 80.5     | 59.2     | 62.3 | 65.4 | 65.3 | 68.4 | 74.9 | 92.1 |
| S2T1-1 | 89.1     | 71.7     | 68.8 | 79.6 | 64.7 | 67.6 | 74.3 | 91.8 |
Figure 7. The values of the destructive force and the theoretical capacities of reinforced concrete beams support zone a) total capacity equal to shear reinforcement capacity, b) total capacity equal to shear reinforcement and concrete capacity.

The total theoretical load capacities of the shear zone from Table 3 were additionally illustrated in figures 7a and b as a dot plots. Figure 7a presents the load capacities determined according to [1, 3], as the only capacity of shear reinforcement and the sum of reinforcement and concrete capacities according to the standard [4]. While, in Figure 7b, in the case of standards [1, 3], as in [4], the presented theoretical capacities were estimated as the sum of the load capacity of shear reinforcement and concrete. In addition, in both figures theoretical capacities were compared with experimental destructive forces, drawn in the form of a bar graph. Based on a comparison of figure 7a and b, it can be concluded that the total shear capacity calculated as the sum of the shear reinforcement and concrete capacities gives smaller differences to destructive forces than capacities calculated as an only the shear reinforcement. Also they were still smaller than forces received from the experimental tests but consequently on the safe side. Therefore, on the basis of the tests and carried out analyses it can be concluded that concrete cooperates with shear reinforcement in transferring shear stresses also after concrete cracked, and it was unjustified, as it was in the case of standards [1, 3], to ignore that cooperation when load exceeded value $V_{Rd,c}$. This was also confirmed by the analysis of the support zone degradation level. It consisted of determined the width of the leading diagonal crack on the lateral surface of the support zone at the load equal to concrete capacity ($V_{Rd,c}$) determined according to analysed standards [1, 3].

Figure 8. Diagram of the diagonal cracks width for the tested beams with the load level equal to $V_{Rd,c}$.
Figure 8 shows, in the form of a bars chart, exemplary analysed crack widths. Those widths were determined on the basis of deformation maps obtained from the optical system Aramis, at the level corresponding to the concrete capacity \( (V_{Rd,c}) \) calculated according to standard EC2 [1]. They were compared with the border cracks levels from the analysed standards [1, 3, 4]. It is clear from that the level of degradation of the support zone is negligible. The largest recorded crack width at the tested load level does not exceed 0.1 mm. As a result, it can be considered legitimate to recognize, as it is in the case of the American standard [4], also in the regulations based on the truss analogy [1, 3] that concrete load capacity, in addition to the shear reinforcement capacity \( (V_{Rd,s}) \), as an important component of the total load capacity of the support zone \( (V_{Rd}) \).

5. Conclusions

The following conclusions can be constructed on the basis of the experimental studies and carried out analyses:

- the width of the diagonal cracks in reinforced concrete beams with the load corresponding to the load-bearing capacity of the concrete cross-section calculated on the basis of the analysed standards [1, 3, 4], is smaller than the minimum limiting crack width (0.1 mm),
- the obtained level of the tested reinforced concrete beams support zone cracking does not exclude taking into account the concrete capacity during transferring the shear force after achieving capacity \( V_{Rd,c} \),
- the design shear capacities of the support zone for all tested reinforced concrete beams calculated as the sum of the concrete and shear reinforcement capacities, based on standards [1, 3, 4], gives smaller differences relative to forces obtained from tests than these determined based only on the shear reinforced,
- the smallest differences between the values of destructive forces and theoretical load capacities were observed in case of the American standard [4],
- results obtained from reinforced concrete beams test confirm the validity of the statement given in the American standard [4], that it is reasonable to take into account the shear capacity of concrete, throughout the design, despite the appearance of cracks, as this is a positive result of aggregates interlock in the crack or for example results from the blocking effect.

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