REINFORCED CONCRETE INTERFACES: CONTRIBUTION OF THE TWO SHEAR MECHANISMS BASED ON MEASURED STEEL STRAINS

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Abstract

Interfaces between concretes cast at different times typically occur within repaired and strengthened RC elements, where the connection between the old and the added concrete is ensured by means of connectors that are post-installed in the existing concrete and anchored by bond to the added concrete. Most frequently, reinforcing steel bars are used to connect the two concretes. Due to geometrical limitations, the embedment depth of the post-installed bars is frequently smaller than that required for their full anchorage. Thus, the development of the yield strength of the bars due to clamping effect is not possible. On the other hand, tensile and compressive stresses are developed in the bars due to dowel action. The contribution of each mechanism to the transfer of shear, as well as their interaction, depends on several parameters, such as embedment length of the post-installed connectors, roughness of the interface, etc. A physical model, allowing for the calculation of the shear resistance of interfaces subjected to cyclic shear slip, was developed at NTUA. In order to calibrate the model and to identify the contribution of the clamping effect and of the dowel action to the overall shear resistance of interfaces, the measurements of strains in the bars crossing the interface were evaluated. The contribution of each mechanism to the tensile strains developed in the bars was calculated and plotted against influencing parameters, such as embedment length of bars and roughness of the interface. The results show that the contribution of clamping effect is increasing with increasing embedment length of the bars, as well as for increasing roughness of the interface. The contribution of dowel action seems to be not strongly dependent on either the embedment length or the interface roughness. The strain measurements during the third loading cycle are reduced compared to those of the first cycle. Taking into account the scatter of the test results, safe values for the contribution factors are introduced in the equation for the design of interfaces under cyclic actions.

Keywords: reinforced concrete interfaces; post-installed bars; steel strain; friction and dowel action; cyclic behavior

1. Introduction

In many intervention techniques applied to existing RC structures for their pre- or post-earthquake strengthening, new layers of concrete or new RC elements are added. To ensure the joint action of the existing and the added portions of the strengthened elements, adequate behaviour of the interfaces between them has also to be ensured. To this purpose, the interfaces are typically crossed by connectors of various types. The connectors are post-installed to the existing element and they are anchored either by bond or mechanically to the added concrete. Reinforcing steel bars constitute the most common type of connectors used to reinforce interfaces between concretes cast at different times. Due to geometrical limitations ensuing from the dimensions of the existing elements, quite frequently the depth at which the post-installed connectors are embedded is smaller than that required for their full anchorage in tension. Parallel to the shear resistance mobilized due to the clamping effect of the reinforcement (usually termed as shear friction or aggregate interlock), the dowel action of the connectors does also contribute to the shear resistance of the interface. The tensile stresses developed in the connectors are, therefore, due to both shear transfer mechanisms and their sum cannot exceed the yield strength of the steel. As proven by several investigators ([1], [2], [3], [4]), the contribution of each mechanism under cyclic loading does depend on several parameters, such as the embedment length of the reinforcement, the roughness of the interface, the imposed shear slip amplitude, etc.

A physical model was developed at NTUA ([5] and [6]) for the calculation of the shear resistance of interfaces subjected to cyclic shear slips. In the equation proposed by the authors, the contribution of the two shear transfer mechanisms is taken into account, using adequate contribution factors. Those factors are evaluated also on the basis of the steel strains measured in the bars crossing the interface, during the experimental campaigns at NTUA. In the current paper, selected strain measurements are presented and evaluated.

2. Literature Review

Although measurements of strains developed in connectors crossing an interface provide significant information allowing for a thorough understanding of the behaviour, in most of the tests reported in the international literature, either the strains of the reinforcement are not measured or the measurements that are taken, as reported by the investigators, are not analyzed in detail ([7], [8]).

Relevant results are reported by Randl ([9], [10]). The interfaces tested by Randl were reinforced with bars of 6mm, 12mm, or 20mm (limited number of specimens) diameter. The embedment of the bars varies from 5d up to 20d. The position of the strain gauges in Randl's tests was such that only the strains developed to the connectors due to clamping effect were measured. Thus, the respective (tensile or compressive) strains due to dowel action and, hence, the contribution of the dowel mechanism could not be quantified. Those strain measurements on reinforcement crossing artificially roughened interfaces (applying either high pressure water or sand blasting) were quite scattered. It is noted that the roughness of the interface in case of interfaces subjected to high pressure water varied from 2.11mm up to 3.25mm, while in case of sandblasted interfaces varied from 0.35mm up to 0.65mm. Indeed, the axial strains range between less than 20% (in case of bars with limited embedment) up to more than 80% (in case of bars sufficiently anchored) of the yield strain of the reinforcement, with the most frequent (and average) value being close to 50% of the yield strain [10].

Detailed measurements of the strains of the reinforcement are reported in [11]. The interface was reinforced with 2, 4 or 8 bars, 16mm diameter. The interface of the old concrete was either smooth, or artificially roughened; chipping treatment was provided until the aggregates protruded from the joint surface by several millimeters; no measurements of the interface roughness are reported. The reinforcement was anchored to both parts of the specimens by bond, and the embedment length was equal to 30d. In this work, the location of the strain gauges allowed to distinguish the portion of the total strain due to clamping effect and the portion due to dowel action of the reinforcement. The Authors report that, in case of smooth interfaces, the stresses developed due to clamping effect correspond to one third of the yield strength of the steel. This percentage slightly exceeds 50%, in case of rough interfaces. As for strains due to dowel action, they do not seem to differ significantly for rough and smooth interfaces. However, the Authors concentrate more on the axial stresses developed in the bars due to clamping effect and, thus, no detailed evaluation of the strains due to dowel action is provided.

The published information on the strains (and stresses) developed in the reinforcement crossing interfaces being rather limited, within the testing campaign performed at NTUA, detailed measurements were taken during tests performed under cyclic conditions. A synopsis of the obtained results is presented herein.

3. Experimental investigation of interfaces crossed by post-installed bars

3.1 Experimental Program

The cyclic behaviour of interfaces reinforced with conventional rebars, cast-in [5] or post-installed ([6] and [12]) has been the subject of several experimental campaigns at LRC/NTUA. The selected results presented herein derive from an experimental campaign focusing on investigating the behaviour of concrete-to-concrete interfaces, reinforced with post-installed reinforcing bars. The incentive of this study is the evaluation of the strain measurements of the connectors crossing the interfaces and the investigation of their dependence on several parameters, such as diameter of the reinforcement, embedment length and interface roughness.

3.1.1 Description of the specimens

As the specimens are designed to simulate interfaces between concretes cast at different times, they are constructed in two distinct phases. The first constructed part corresponds to the existing portion of the concrete element. After its construction, the surface either remains as cast, against steel formwork, or is manually roughened with a chiseling tool and the resulting roughness is measured with the sand patch method [13]. After roughening the interface, the post-installed bars are embedded into the existing concrete and approximately 28 days after casting the first part of the specimen, the second concrete block, corresponding to the portion added to the concrete element, is cast. The resulting interface area is equal to 200x500 [mm] and the geometry of the specimen allows for displacements to be cyclically imposed (Fig. 1a). The secondary reinforcement of the specimens is designed in order to prevent any parasitic or premature cracking in locations other than along the interface or its vicinity and has a sufficient distance (100mm) from the interface in both blocks of concrete, in order to prevent any beneficial effect of this reinforcement on the behaviour of the interface.

Each interface is reinforced with three post-installed bars, aligned at mid-width of the interface, with the distances between the consecutive bars and between the bars and the edges (Fig. 1b) being adequate in order to avoid concrete splitting [14]. There is no significant difference (up to 7MPa approximately) in the compressive strength of the concrete of the two parts of the specimens. Two diameters, namely 12mm and 16mm, typical to repair/strengthening common applications are investigated. The yield stress of the diameter 12mm bars is equal to 524MPa (ε_{YIELD}=2.62‰) and the corresponding ultimate stress is equal to 622MPa. The yield stress of the diameter 16mm bars is equal to 550MPa (ε_{YIELD} =2.75‰) and the corresponding ultimate stress is equal to 627-693MPa. The bars are inserted into the old part at a depth equal to 6d, 8d or 10d, by using the same adhesive (injectable epoxy mortar) for all specimens. The length of the protruding part (with a bent at its end) into the new concrete is sufficient to ensure full anchorage, achieved by means of bond. The behaviour of the interface is, thus, governed by the old concrete block, where the post-installed dowels are chemically anchored.

3.1.2 Test setup and measuring devices

The setup used for testing is illustrated in Fig. 1c [12]. The tests were conducted without the presence of external compressive normal stress acting on the interface. Tests were performed under cyclically imposed shear slip (displacement-controlled) at low speed; three cycles were executed at each displacement amplitude value.

Two electrical strain gauges glued on each connector are used to measure the strains developed in the bars during the test. Each of the two strain gauges was positioned in a different part of concrete (one in the old part and one in the new part- Fig. 1a, b). The strain gauges are positioned close to the interface, at a distance of approximately 1.5d, oriented along the direction of loading. Shear slip along the interface is measured by means of four displacement transducers (two per face of the specimen), placed in close proximity to the interface, whereas in total six displacement transducers placed perpendicular to the interface measure the width of the crack at the interface.

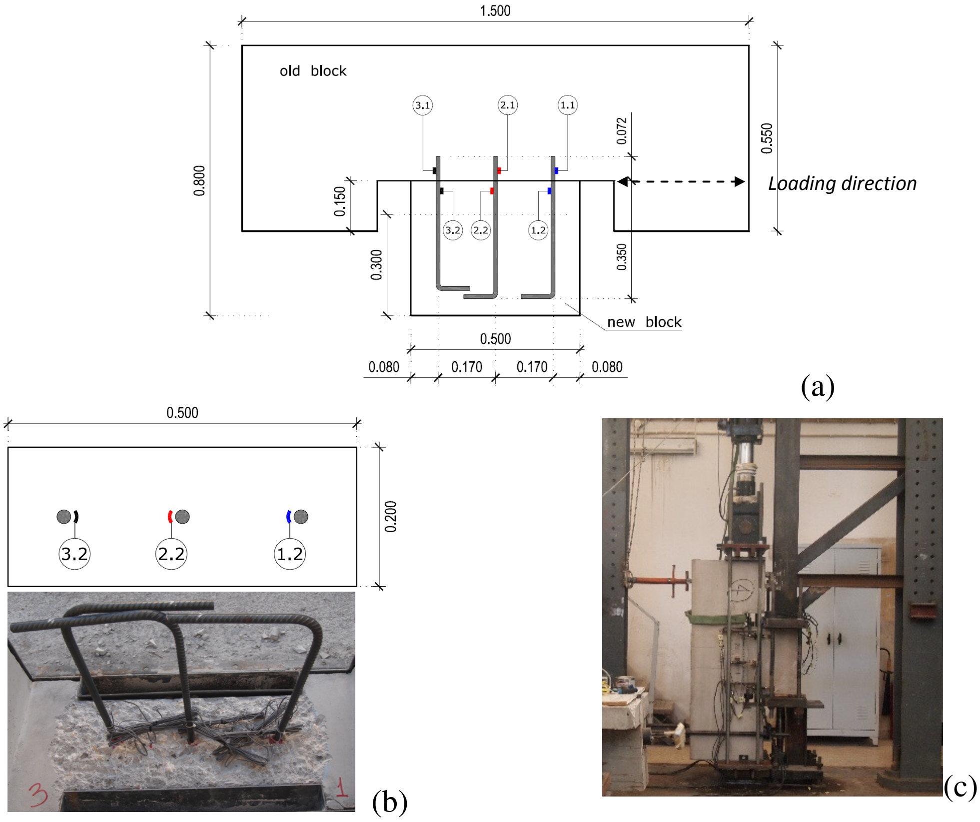


Fig. 1- (a) Geometry of specimens and indication of the loading direction. The positions of the strain gauges in the old and the new block are illustrated, (b) Interface reinforcement with strain gauges and photo of roughened reinforced surface before concreting the new block, (c) Specimen in the setup, in testing position

3.2 Experimental Results

3.2.1 Failure modes and shear resistance of interfaces

It is noted than an unfavourable failure mode has been recorded for specimens with bars embedded at 6d. In these cases, a crack first develops and opens along the interface followed, at small imposed slips, by a second crack parallel to it and running along (or close to) the end of the embedded bar length. The development of the second crack generally leads to failure (Fig. 2a). In contrast to post-installed bars with shallow embedment, where a concrete cone failure seems to be imminent, when a 10d embedment length is provided, the failure mode is due to the failure of the interface (Fig. 2b). It is clear that when the embedment length is increased, also the maximum shear capacity of the interface is enhanced, as illustrated in Fig. 2c. The key information of each specimen regarding the failure mode, the maximum shear resistance in terms of stresses, the corresponding shear slip and the interface roughness are given in Table 1.

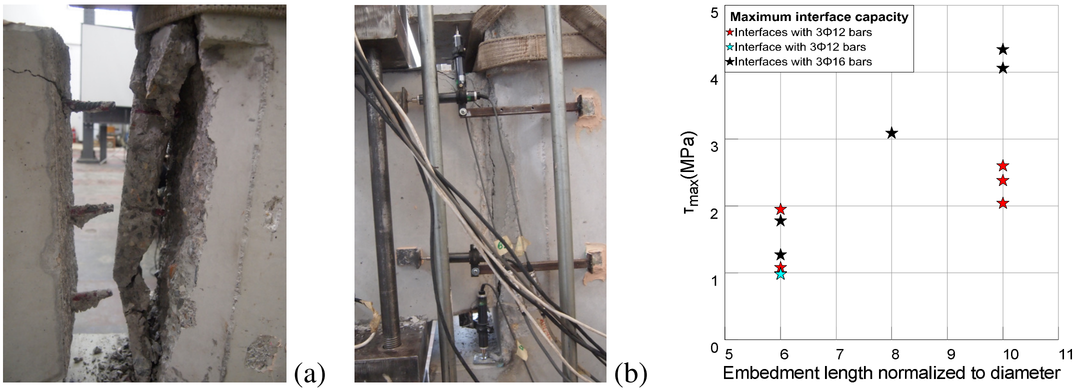


Fig. 2- (a), (b) Failure of rough interfaces reinforced with diameter 12mm bars, after testing: embedment length of 6d and 10d respectively, (c) Maximum resistance of the interfaces (average of the two loading directions) plotted against the measured roughness

3.2.2 Evaluation of steel strain measurements

The measurements taken from the strain gauges installed close to the interface are assessed for determining the degree of mobilization of the reinforcing bars crossing the interface. Selected typical results of the steel strains measured inside the old or the new part of concrete are given herein.

Fig. 3a shows the in-time development (for a part of the entire test) of steel strains for a specimen reinforced with three diameter 16mm bars embedded 10d into the old concrete block. The recordings of all six strain gauges are presented, with the solid lines denoting the measurements into the old concrete part and the dotted lines of the same colour corresponding to the measurements into the new part. As the distances between the strain gauges and the interface are almost equal in both concrete blocks (≈1.5d) and the strain gauges in every bar are positioned along the loading direction, but in opposite locations on the bar perimeter for every concrete block (Fig. 1a), it is anticipated that the respective measurements are to be similar. Indeed, the straight and the dotted lines for each connector practically coincide, thus confirming that the measurements are reliable.

Furthermore, the specimens are subjected to cyclic loading and the interface reinforcement is symmetrical. Therefore, the bars near the edges ("upper" and "lower" bars, as perceived in testing position) are expected to exhibit approximately the same deformations. The fact that the strain gauges placed on two adjacent bars are located at the same side, whereas the strain gauges of the third bar are oppositely located (Fig. 1b), is reflected in the obtained strain measurements plotted against time (Fig. 3a). This means that the strain maxima of the two bars near the edges will not appear simultaneously, but at consecutive semi-cycles. Additionally, due to the interface dimensions and the limited number of the connectors, also the middle bar has similar deformation to the other two bars.

Also, as the test progresses, increasing deformations (and stresses, subsequently) are induced to the bars, as revealed by following the in-time evolution of the peak strains. By taking all the above mentioned information into account, the recorded steel strains are considered to be reliable and, therefore, allow for an in-detail process towards reaching conclusive results associated with the mobilization of the connectors.

3.2.3 Effect of parameters on the steel strains

It is generally observed that, when the rough interfaces reinforced with diameter 16mm are examined, the bars crossing rough interfaces are constantly in tension, with insignificant exceptions (Fig. 3a). In addition, there is a clear difference between specimens provided with shallow bars (embedment length equal to 6d) and those provided with longer bars (embedment length equal to 8d or 10d). In the case of short bars, the maximum measured tensile strains typically do not reach the rebar yield strain (Fig. 3b). This is due to the premature brittle concrete failure of those specimens which occurred at small shear slip (as described in detail in [12]) and, in turn, at a small interface crack opening, limiting the maximum steel strains to values as low as 1‰. On the contrary, in specimens with larger embedment length (Fig. 3d), the reinforcement is more efficiently exploited as steel strains much higher than the strain corresponding to yielding (actually, as high as 4‰) are recorded (for two or three of the rebars), so the interfaces could take profit from the yield strength of the reinforcement. Although there is only one specimen with bars embedded at a depth of 8d (steel strains exceeding 2‰-Fig. 3c), the respective result confirms the noted trend.

The observations described above are valid also for rough interfaces crossed by three diameter 12mm bars, insufficiently embedded (at 6d), as shown in Fig. 4b or with longer anchorage (10d) into the old part (Fig. 4c). In this case, a very smooth interface with short connectors, embedded at 6d (Fig. 4a) is also tested. Although the available results are very limited, they clearly justify the continuation of the research in this field, as they reveal crucial differences in the behaviour between smooth and rough interfaces. In particular, for all three bars of this specimen (smooth interface), the sign of the strains changes from positive to negative values in every semi-cycle. This fact could be attributed to the enhanced contribution of the dowel action (see also Section 3.2.4) in smooth interfaces. The absolute values of the strains are of comparable amplitudes and are higher than 3‰, even for small values of crack opening (0.30mm).

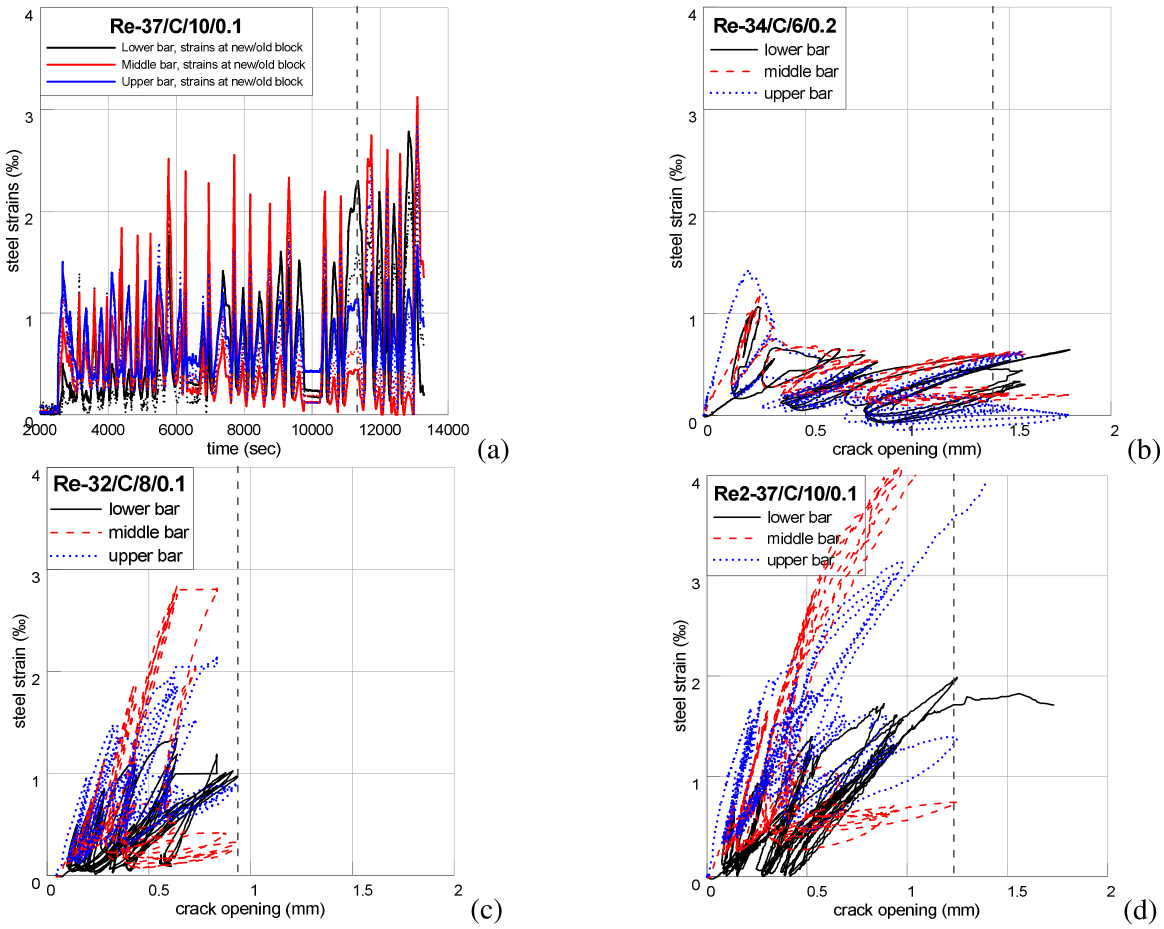
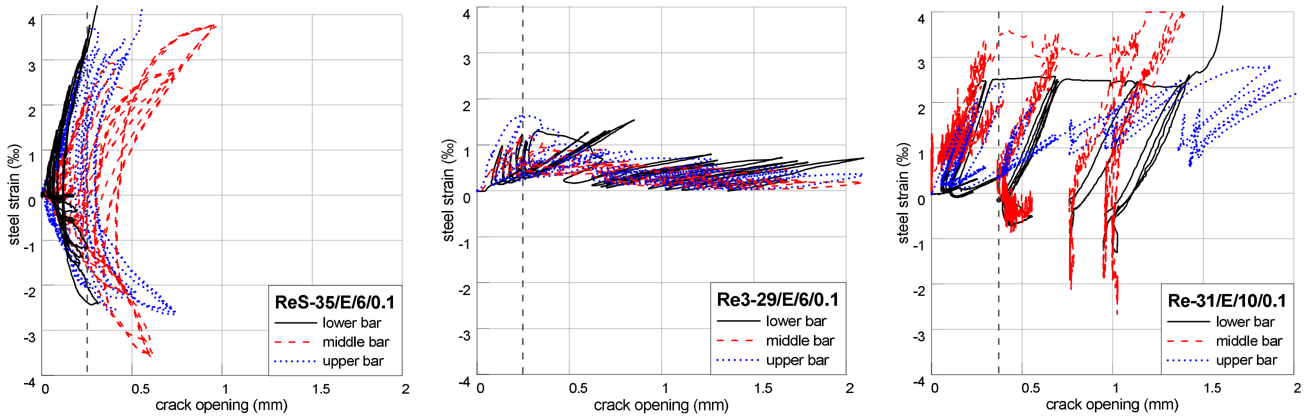


Fig. 3 - Steel strains for interfaces reinforced with diameter 16mm bars (a) strains measured in the existing and the added concrete blocks, plotted against time, (b)-(d) strains measured in the existing concrete block, plotted against crack opening for embedment equal to 6d, 8d and 10d respectively.

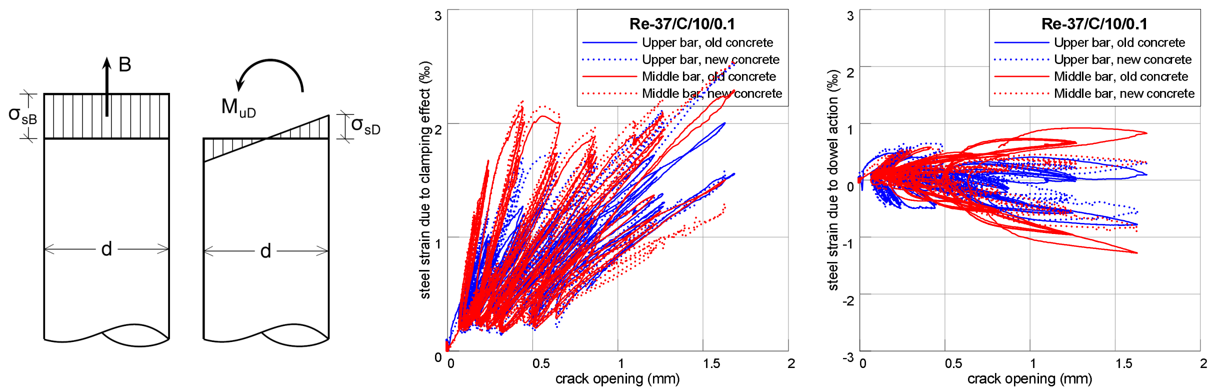


(a) (b) (c)

Fig. 4 - Steel strains plotted against crack opening, measured in the existing part of concrete for interfaces reinforced with diameter 12mm bars (a) very smooth interface with bars embedded at 6d, (b) rough interface with bars embedded at 6d, (c) rough interface with bars embedded at 10d.

3.2.4 Steel strain components

The strain gauges are glued on the interface reinforcement in positions (Fig. 1a) that allow for detecting the development of the total strain of the bars (Fig. 5a). Actually, the recorded strains are caused both by axial tension (clamping effect) and by dowel action (with a positive or negative sign, depending on the position of the strain gauge and the loading direction). As illustrated in Fig. 1a, b, the SGs of the connectors in the old as well as the new part are not arranged at the same side for all dowels. This feature gives the opportunity of combining the records from two adjacent rebars with opposite orientation of SGs and, subsequently, of calculating the two components of the steel strains. For each block of concrete (old or new), to isolate the part of strains due to axial stress, the average value of steel strains is computed. Afterwards, to calculate the strains due to dowel action, the computed strain due to axial stress is subtracted from the recorded total value of the strain. Finally, the strains due to the clamping effect (pullout of anchor) have always positive values, whereas the strains due to dowel action acquire positive or negative values, as the interfaces are subjected to cyclic loading. When a sufficient embedment length is provided, the tension due to clamping effect is dominant, whereas, contrarily, when the embedment length is limited, the dowel action prevails, resulting to recording of negative strains as well.



(a) (b) (c)

Fig. 5- (a) Stresses of a reinforcing bar section due to its axial loading (clamping effect) and its simultaneous flexural loading (dowel action). For a specimen reinforced with three diameter 16mm bars embedded at 10d, (b) the component of steel strain corresponding to the clamping effect and (c) the component of steel strain corresponding to the dowel action are illustrated. The strains are plotted against the crack opening.

The so calculated strain values corresponding to the clamping effect and the dowel action are presented in Table 1, for all tested specimens. The strains due to each distinct shear transfer mechanism have been plotted for a specimen reinforced with three diameter 16mm bars embedded 10d into the old concrete block (Fig. 5b, c). It is evident that the component of the axial deformation due to clamping effect (Fig. 5b) is dominant in this case, as expected.

Table 1- Summary of experimental results

Specimen name[1]	Roughness (mm)	τ_{max} [2] (MPa)	s_{max} [3] (mm)	ε^4 (‰) at s_{max}, due to:		Concrete cone failure
				Clamping effect	Dowel action	
Re-29/E/6/0.1	0.89	1.08	0.10	0.95	0.46	Yes
Re2-29/E/6/0.1	0.62	1.95	0.07	0.26	0.23	Yes
Re3-29/E/6/0.1	0.89	0.99	0.10	0.67	0.31	Yes
ReS-35/E/6/0.1	0	0.98	0.40	1.45♦	1.10♦	Yes
Re-24/E/10/0.1	2.48	2.38	0.40	0.95	0.38	No
Re-31/E/10/0.1	1.79	2.6	0.40	2.18	0.23	No
Re2-31/E/10/0.1	1.65	2.04	1.20	1.35*	0.91*	No
Re-34/C/6/0.1	0.96	1.27	0.20	0.73	0.34	Yes
Re-34/C/6/0.2	0.89	1.78	0.60	0.40	0.19	Yes
Re-32/C/8/0.1	1.58	3.09	0.80	0.93	0.07	No
Re-37/C/10/0.1	2.13	4.06	1.20	1.69	0.56	No
Re2-37/C/10/0.1	1.37	4.34	1.20	1.68	0.30	No

[1]Re: anchorage by means of epoxy resins at rough interface, ReS: anchorage by means of epoxy resins at smooth interface
The first number indicates the compressive strength of the weaker concrete block in MPa
E: specimens with three diameter 12 mm bars, C: specimens with three diameter 16 mm bars.
The second number indicates the embedment depth into the old part normalized to the bar diameter.
The third number indicates the magnitude of the shear slip imposed in the first set of cycles in mm.
[2]Maximum shear resistance of the interface, given as the average value between the two loading directions for the first cycle.
[3]Shear slip value corresponding to the mobilization of the maximum capacity of the interface τ_{max}
[4]Steel strain components, owing to axial pullout of the connector and dowel action, for the shear slip value corresponding to the mobilization of the maximum capacity of the interface. The average strain values of the first loading direction are given herein.
♦ The dowels of this specimen had already yielded for a shear slip equal to s_{max}. The values corresponding to 0.2mm shear slip (amplitude of “s” at the previous cycle before s_{max}) are given instead.
*The strains of this specimen acquired unrealistically high values for small shear slips. The values corresponding to 0.1mm shear slip are given, as for higher shear slips the strain measurements are considered to be unreliable and are omitted.

3.2.5 Contribution of the two mechanisms to the steel strains

In Fig. 6, the steel strains due to clamping effect, as well as those due to dowel action, normalized to the yield strength, are plotted against (a) the embedment length of the bars to the old part of the specimen and (b) the roughness of the tested interfaces. The following observations can be made.

Firstly, a fact that agrees with the previously mentioned observations (Section 3.2.3) is that, despite the scatter of the experimental results, there is a tendency of the strain values due to clamping effect to increase with increasing embedment length (Fig. 6a). For a significant number of specimens, quite small $\varepsilon_S/\varepsilon_{YIELD}$ values (smaller than 0.6) are mobilized. The observations are valid for both tested diameters. In addition, a sensible comment would be that the maximum mobilized steel strain is expected to depend on the roughness of the interface, and there is a tendency indeed. Fig. 6c, however, shows that the experimental results remain very scattered and the evaluation of this parameter is obscured by the fact that the specimens with higher embedment length coincidentally have higher roughness as well.

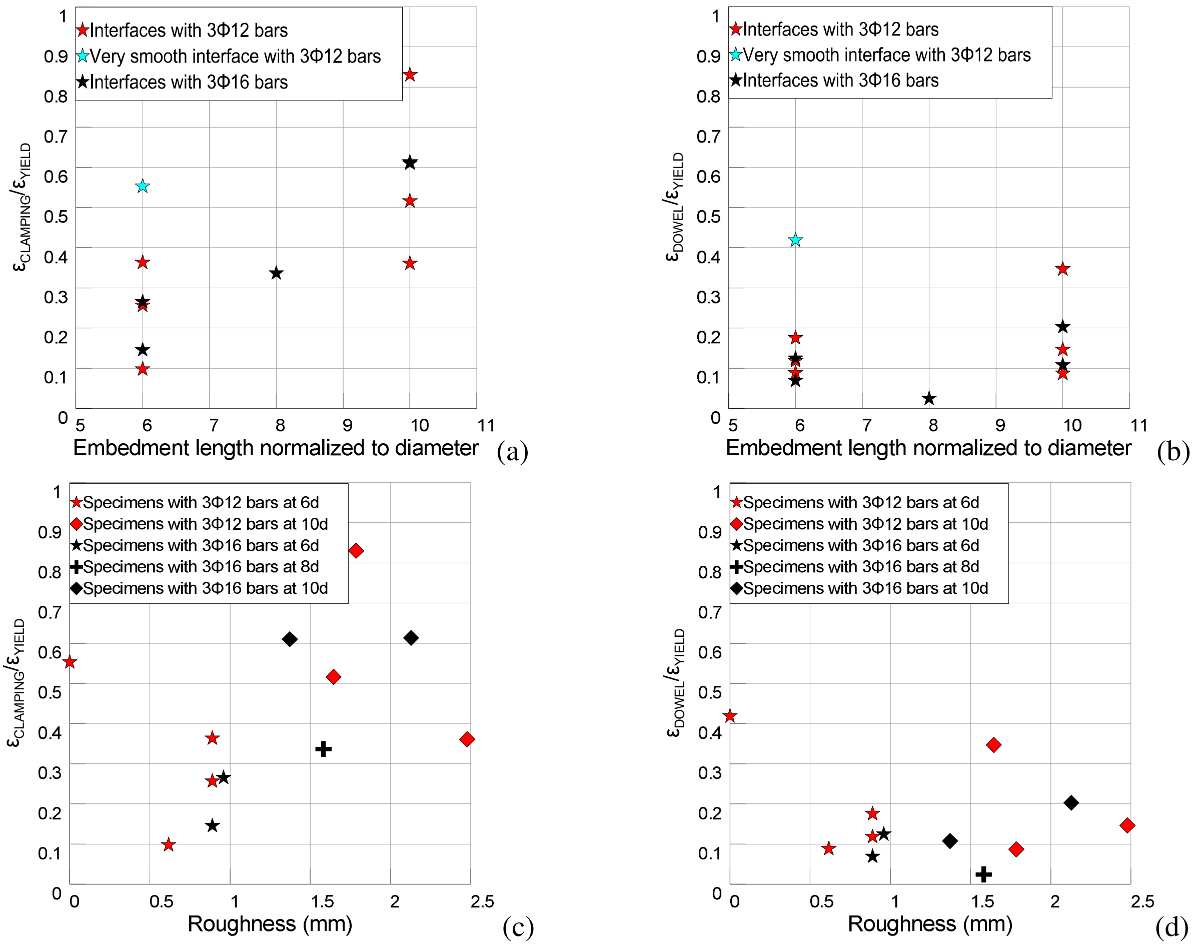


Fig. 6- The steel strains due to clamping effect, as well as due to dowel action, normalized to the yield strength are plotted against the embedment length of the bars [(a) and (b) respectively] and the measured roughness [(c) and (d) respectively]. The strains measured at the old part of the specimen are given.

As for steel strains due to dowel action, it seems that they do not depend significantly on the embedment length of the post-installed bars (Fig. 6b). This is a sensible result, as the dowel action mobilizes the bar at a limited length [15]. Therefore, the respective strains are not expected to depend on the embedment length of the bars (at least equal to 6d in the tests reported in this paper). Although the results remain quite scattered, one could assume that the tensile strains due to dowel action are in average between 15% and 20% of the yield strain of steel. It should be noted though that, as the strain gauges are installed (for their protection purposes during casting of concrete) at a distance of 1.5d from the interface, the contribution of dowel action is somehow underestimated. The data plotted in Fig. 6d, do not show a clear dependence of the dowel mechanism on the interface roughness.

In Fig. 7, the total steel strain measurements (Fig. 7a, d) in function of the embedment length of the post-installed bars and the roughness of the interface are shown for the first loading direction of the first cycle. In the same figure, also the contribution of each shear transfer mechanism, normalized to the total axial strain developing in the bars is given (Fig. 7b, c, e, f), against the aforementioned parameters. It should be noted that the total strain of the bars is not necessarily equal to the yield strain of the steel, in fact it is smaller in most of the cases. It can be noticed that there is a clear tendency of the total strains to be increased with increasing embedment length and roughness. Regarding the separated components corresponding to each mechanism, the following comments can be offered: (a) Independently of the value of the two examined parameters, the contribution of clamping effect to the total steel strain clearly exceeds 50% (Fig. 7b and e), (b) it is interesting to observe that when the embedment length of the bars is limited to 6d, cases where a concrete breakout failure is expected to occur, the contribution of the dowel action to the total steel strain reaches 30% to 50% (Fig. 7c). This contribution is reduced for larger embedment lengths allowing for higher mobilization of the clamping effect. Finally, (c) it seems that, the effect of the roughness on the mobilization of the dowel mechanism remains unclear (Fig. 7f).

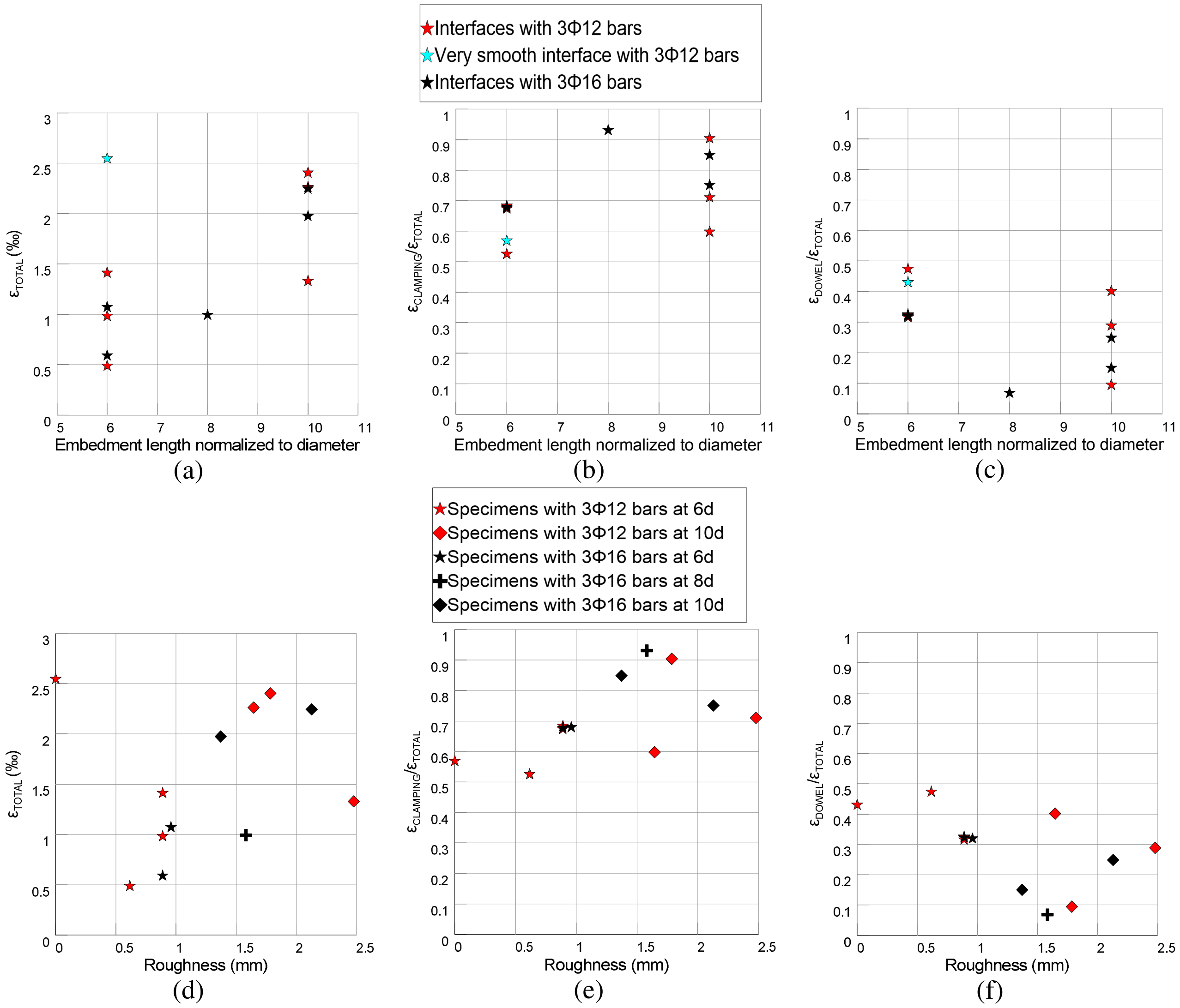


Fig. 7- The effect of embedment length on (a) the total strain measurements, (b) the strains due to the clamping effect normalized to the total measured strains, (c) the strains due to the dowel action normalized to the total measured strains. The effect of roughness on (d) the total strain measurements, (e) the strains due to the clamping effect normalized to the total measured strains, (f) the strains due to the dowel action normalized to the total measured strains. The strains measured at the old part of the specimen are given.

Finally, in Fig. 8, the same information as in Fig. 7 is given, but for the third loading cycle of the same shear slip amplitude. Compared to the results deriving for the first cycle, the total values of the strains are reduced when a larger embedment length is provided, an observation that is not valid for the case of insufficient anchorage (Fig. 8a, d) and the contribution of the dowel action is in general smaller for the third cycle (Fig. 8c, f). The significant difference between the first and the third cycle is identified in the severely pronounced scatter of the results in the third cycle, especially for the case of the small embedment (6d).

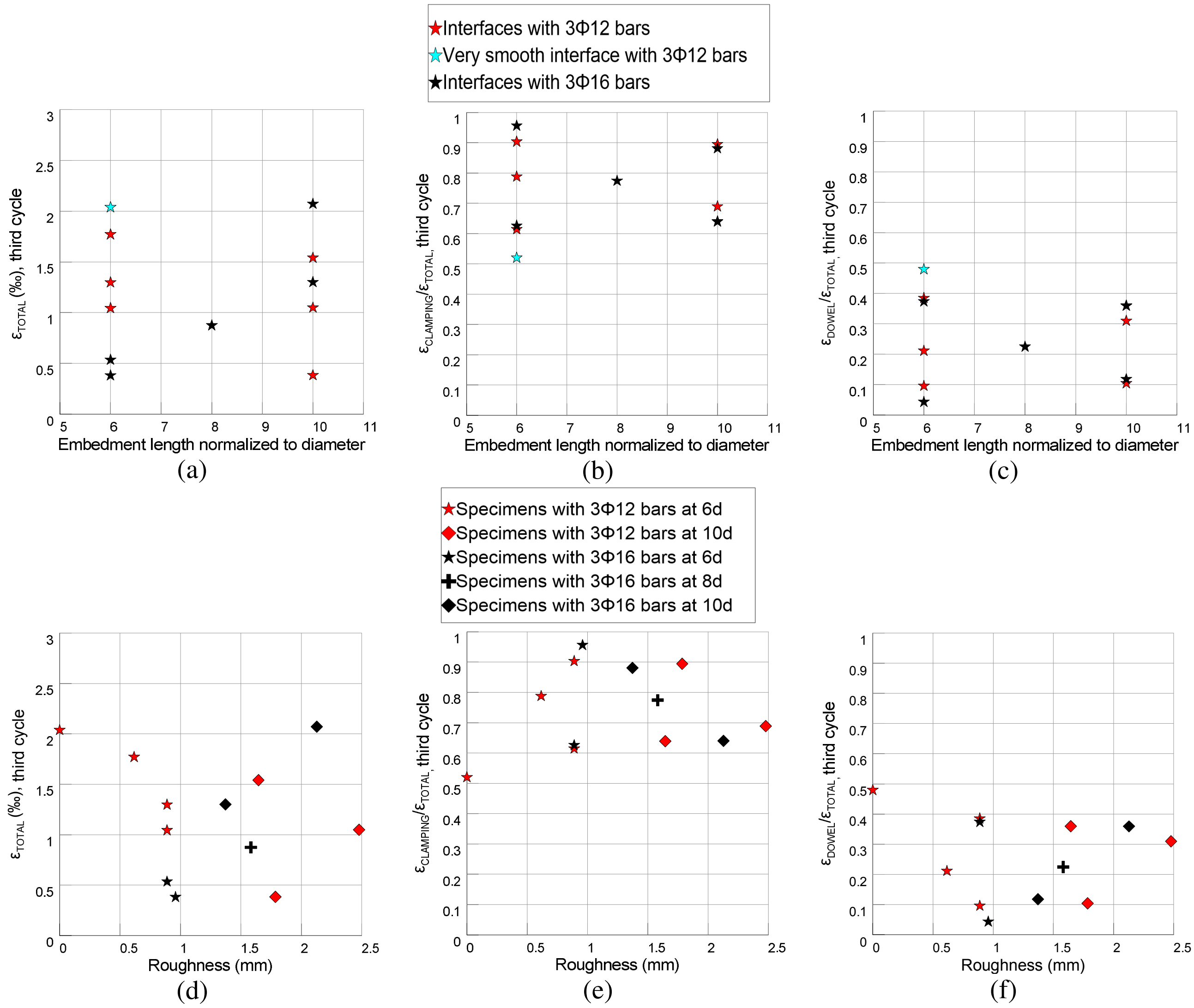


Fig. 8- Same as Fig. 7 for the third cycle

4. Conclusions

The measurements of strains on the reinforcing bars crossing interfaces between concretes cast at different times were presented and evaluated. The following conclusions can be made:

(a) Based on the locations of the strain gauges, the reliability of strain measurements was proven. Thus, the strains due to each distinct mechanism, namely, clamping effect and dowel action were calculated for each specimen.

(b) On the basis of the calculated values, the effect of the embedment length of the post-installed bars on the strains due to clamping effect was identified: The strains developed in the bars increase for increasing embedment length.

(c) A similar trend is identified for the strains due to clamping effect in function of the interface roughness.

(d) On the contrary, it seems that the strains due to dowel action are not strongly dependent on either the embedment length or the interface roughness.

(e) Those results were used to calibrate an equation proposed by the authors for the calculation of the shear resistance of interfaces subjected to cyclic shear displacements. In that equation, contribution factors are included for the two mechanisms, depending on the embedment length and the interface roughness for clamping effect and independent of those two parameters for dowel action.

(f) The strain measurements during the third loading cycle are somehow reduced, as compared to those of the first cycle, whereas the contribution of the dowel action is reduced. Taking into account the large scatter of the test results, especially in the case of limited embedment length, safe values for the contribution factors are introduced in the equation for the design of interfaces under cyclic actions.

References

[1] Bass RA, Carraquillo RL, Jirsa JO (1989): Shear Transfer across New and Existing Concrete Interfaces. *ACI Structural Journal,* **86**(4): 383-393.

[2] Valluvan R, Kreger ME, Jirsa JO (1999): Evaluation of ACI 318-95 Shear-Friction Provisions. *ACI Structural Journal*, **96**(4): 473-481.

[3] Kono S, Tanaka H, Watanabe F (2001): Interface Shear Transfer for High Strength Concrete and High Strength Shear Friction Reinforcement. *Proceeding of the Conference on High Performance Materials in Bridges, ASCE*, 319-328, 29 July- 3 August, Kona, Hawaii.

[4] Palieraki V, Zeris Ch, Vintzileou E, Sfikas I (2012): Experimental Investigation of the Behaviour of Interfaces in RC Elements Subjected to Cyclic Actions. Effect of Compressive Stress Normal to the Interface. *Proceedings of the 15th World Conference on Earthquake Engineering*, p. 24-28, Lisbon, Portugal

[5] Palieraki V (2014): *Seismic behaviour of reinforced interfaces in repaired/ strengthened reinforced concrete elements*. Ph.D. Thesis, National Technical University of Athens, Greece, 578 pp (in Greek).

[6] Vintzileou E, Palieraki V, Genesio G, Piccinin R (2018): Shear behaviour of interfaces within repaired/strengthened RC elements subjected to cyclic actions. *In International Workshop on Advanced Materials and Innovative Systems in Structural Engineering: Seismic Practices*, p. 89.

[7] Kono S and Tanaka H (2000): Interface shear transfer for high strength concrete and high strength reinforcement. *12th World Conference on Earthquake Engineering (No. 641).*

[8] Shaw D and Sneed L (2014): Interface shear transfer of lightweight-aggregate concretes cast at different times. *PCI Journal,* **59**(3).

[9] Randl N (1997): *Untersuchungen zur Kraftübertragung zwischen Alt- und Neubeton bei unterschiedlichen Fugenrauhigkeiten*. Ph.D. Thesis, Universität Innsbruck 1997, Austria, 379pp (in German).

[10] Randl N (2013): Design recommendations for interface shear transfer in fib Model Code 2010. *Structural Concrete*, **14**(3), 230-241.

[11] Mishima T, Suzuki A, Shinoda Y, Maekawa K (1995): Nonelastic behavior of axial reinforcement subjected to axial and slip deformation at the crack surface. *Structural Journal*, **92**(3), 380-385.

[12] Palieraki V, Vintzileou E, Piccinin R, Genesio G (2019): Behaviour of Concrete Interfaces Crossed by Post-Installed Rebars. *4th Greek Conference of Earthquake Engineering and Technical Seismology, Hellenic Association for Earthquake Engineering-Technical Chamber of Greece*, September 5-7, 2019, Athens, Greece.

[13] Kaufmann N (1971): *Das Sandflachenverfahren*. Strassenbautechnik, **24**(3): 131-135.

[14] Earthquake Planning and Protection Organization (EPPO) (2013): *Code for Interventions to Existing RC Buildings*. 2nd Review, Greece.

[15] Rasmussen BH (1962): Strength of transversely loaded bolts and dowels cast into concrete. *Laboratoriet for Bygningastatik, Denmark Technical University, Meddelelse*, Vol. **34**(2), 1962.

