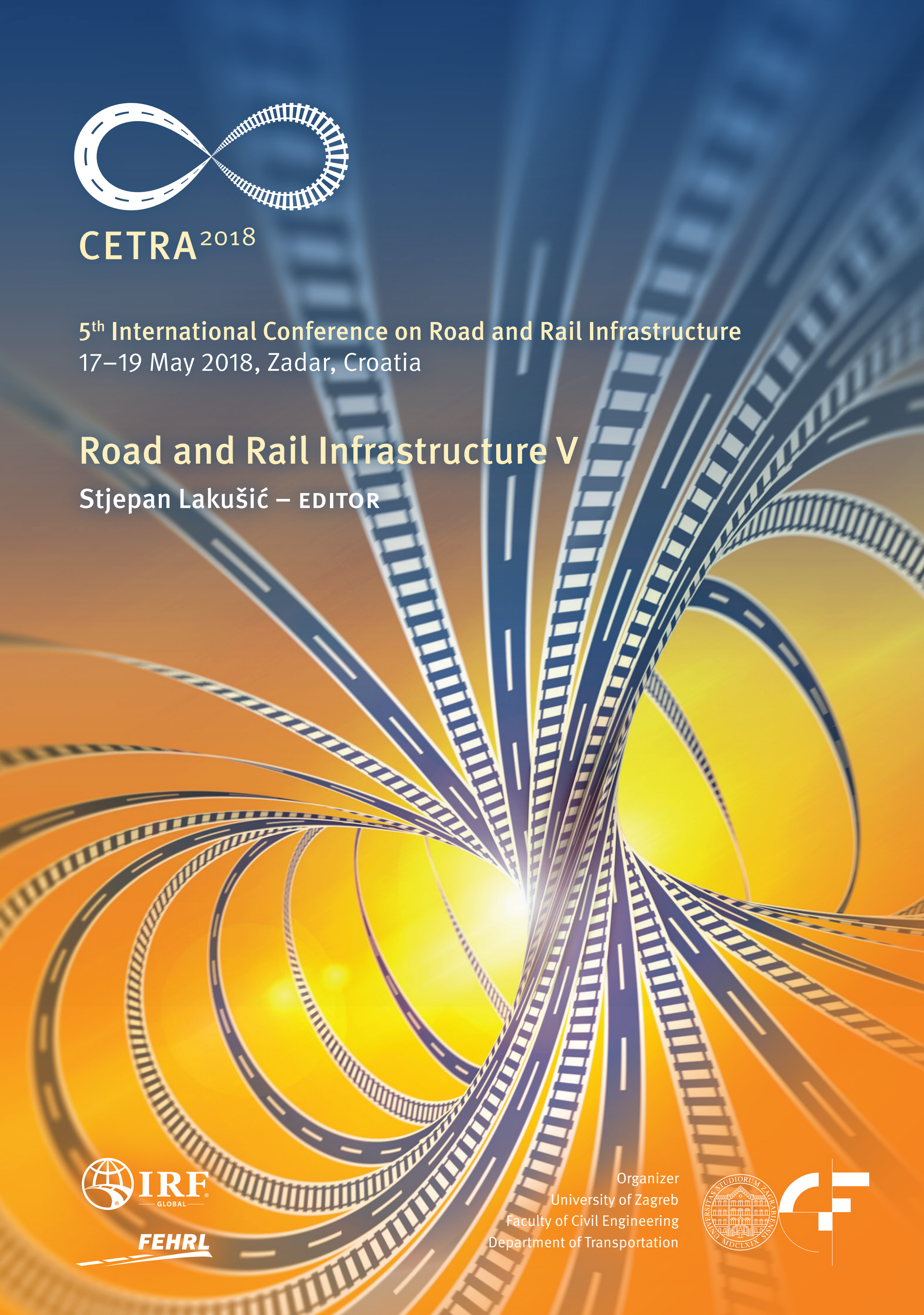

CETRA2018

5th International Conference on Road and Rail Infrastructure
17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – **EDITOR**

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ACOUSTIC EMISSION FOR MONITORING OF STRENGTHENED RC BEAM-COLUMN JOINTS

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Abstract

Beam-column joints are the crucial zones in reinforced concrete (RC) structures as they are subjected to large forces during earthquakes and their behaviour has a significant effect on the response of the whole structure. When the shear capacity of a joint is insufficient, the structure may fail in a brittle behaviour due to large amount of shear stress concentrations in this region. Thus, strengthening of deficient RC beam-column joints is important. In most cases, the strengthening material covers the structure and it is not possible to see any damage on the surface when the joint is subjected to a force. Acoustic Emission (AE) is a useful method to detect crack development and progress in concrete non-destructively. Location of the fracture source in a material, the size and energy of the crack and the time it starts cracking can be identified by AE method. In this study, identification of fracture mechanisms of strengthened RC beam-column joints was aimed. For this purpose, the specimens were tested under cyclic loading and monitored by AE. Afterwards, obtained AE data of the specimens were analyzed and they were compared with the mechanical results.

Keywords: beam-column joint, acoustic emission, parameter analysis, crack localization analysis, fracture mechanism

1 Introduction

Beam-column joint is the crucial zone in a reinforced concrete (RC) moment resisting frame because it is subjected to large forces during severe earthquake loading and its behaviour has a significant influence on the response of the structure. Under a severe earthquake, there may be a large amount of shear stress concentrated on the beam–column joint area. The brittle shear failure in the joint area may lead to serious consequences of severe damages and total collapse of the structure. Consequently, enhancing the shear capacity of the joint becomes more of a concern in the area of seismic design of RC structures. Some strengthening techniques have been developed such as anchoraging, applying external reinforcement or wrapping with different strengthening materials. According to the results of the studies conducted, ultimate load capacities and ductilities of the joints were enhanced after strengthening by Carbon Fiber Reinforced Polymer (CFRP) [1, 2]. [3] enhanced the shear capacities of the beam-column joint specimens with using CFRP laminates. [4] investigated the effect of CFRP and anchoraging on RC beam-column joints. [5] obtained high rigidity, ultimate load capacity and ductility by using CFRP strips with different schemes.

Monitoring of invisible damages has also been an important task for quality control of the structures. By means of current test methods it is not possible to identify invisible cracks. Acoustic emission (AE) is one of non-destructive testing methods and used for detecting micro cracks in concrete even at low load levels [6]. It has been used in different applications

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for a long time and the studies show that AE is an effective monitoring technique for damage detection in concrete [6-8].
This paper is focused on detection of damage progression in RC beam-column joints exposed to cyclic loading and identification of mechanical and AE behaviours of a reference and a CFRP-strengthened joint. For these purposes, experimental tests were carried out, specimens were loaded and were simultaneously monitored with AE and the results were compared.

2 Structural Inspection by Acoustic Emission (AE)

Acoustic Emission (AE) can be defined as micro-scale earthquake due to propagation of elastic waves in a stressed material and detection of them by appropriate receivers. As presented in Figure 1.a, when damage occurs due to the release of stored strain energy, elastic waves are generated and propagate through the material. Afterwards, these waves are detected by an AE sensor placed on the surface, transformed into the electrical signal and pre-amplified.

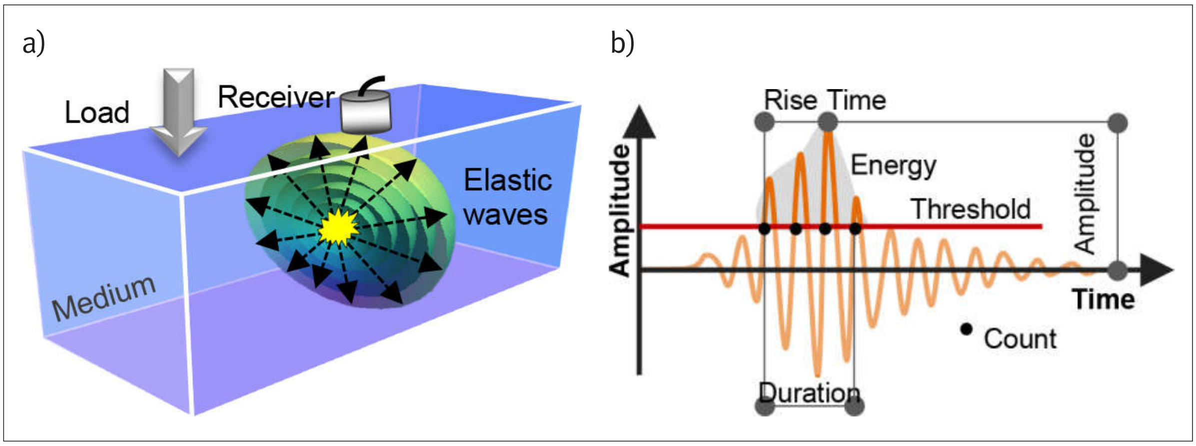

Figure 1 a) AE phenomenon, b) AE parameters

In addition, in order to consider only meaningful signals apart from the noises, a “threshold” is set. Obtained AE signals can be processed by different analysis methods to have information about crack locations, their origination times and types. However, to carry out all of these analyses, AE parameters -characteristic features of the AE signals- are needed (Figure 1.b).

3 Laboratory Experiments

3.1 Layout of test specimens

In the experimental study, cyclic lateral loading were applied on test specimens simulating exterior beam-column joints of RC frames. Two specimens from C25/30 concrete were designed with same S240 longitudinal reinforcements and stirrups in their joints. While Reference beam-column joint (BCJ) is the reference specimen, Strengthened BCJ was produced by wrapping the joint with 45° diagonal CFRP (MasterBrace FIB 300/50 CFS) strips having 4900 MPa tensile strength. Geometrical and reinforcement details of both specimens are presented in Figure 2.

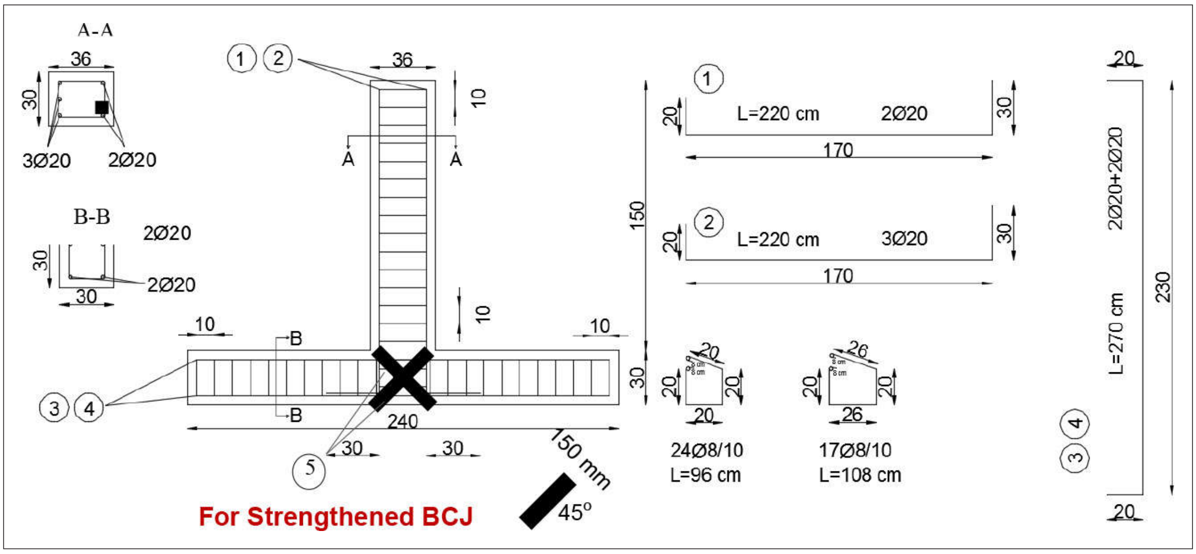

Figure 2 Geometrical and reinforcement details of the test specimens

3.2 Test setup & equipment

The specimens were tested under cyclic lateral loadings using the test setup as shown in Figure 3. Acoustic emission measurements were taken by an 8-channel Micro II SAMOS AE system by Mistras Group Inc. including sensors, preamplifiers, cables and a computer as shown in Figure 3. The AE sensors were in 150 kHz resonance frequency range, the preamplifiers were used with 40 dB gain and threshold was set as 40 dB.

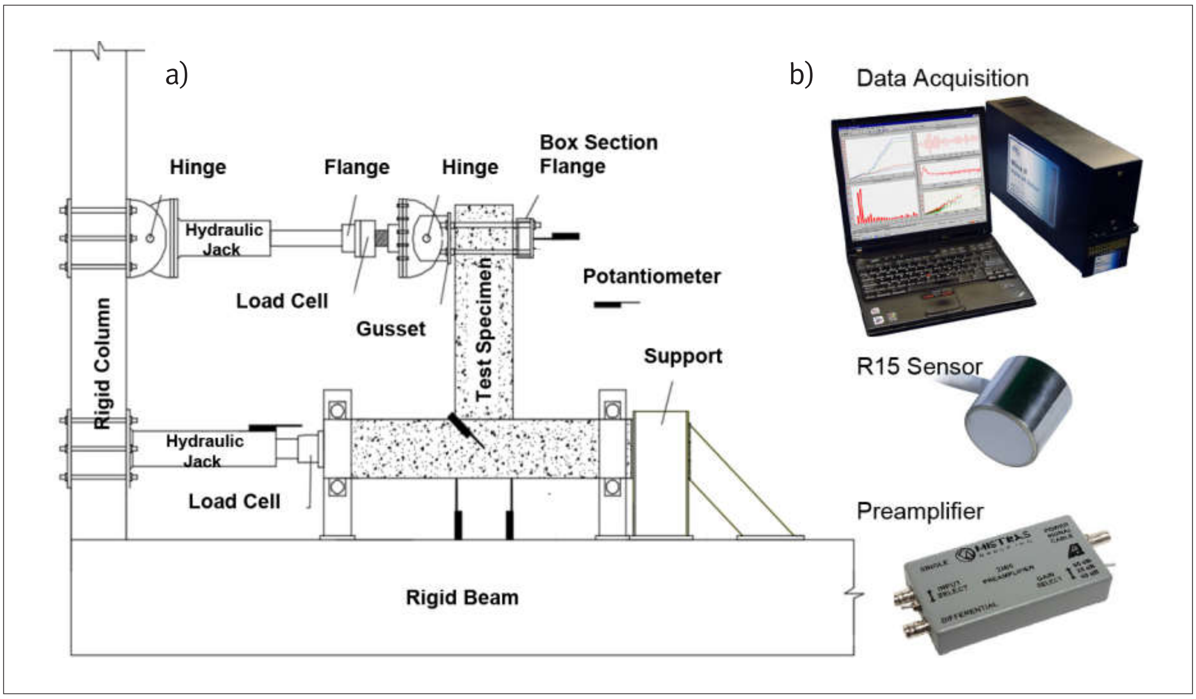

Figure 3 a) Test setup, b) AE system

4 Results & Discussions

4.1 Mechanical observations

First tensile crack on Reference BCJ was observed at forward loading of 5th cycle. At backward loading of this cycle, first diagonal cracks were observed and existing flexural cracks propagated. As the load increased, all existing cracks widened and propagated. First diagonal crack was observed at forward loading of 7th cycle at 36 kN on the joint and at this moment existing flexural cracks also widened. Existing diagonal cracks propagated and joined to each other at backward loading of 7th cycle and their width increased to 1 mm at forward loading of 8th cycle. Present flexural cracks propagated through neutral axis of the beam. Longitudinal reinforcement of the specimen yielded at 52 kN load level of forward loading of 11th cycle. Ultimate load capacity and maximum displacement of Reference BCJ were 58.22 kN and 91.18 mm. Beam-column joint of Strengthened BCJ was strengthened with diagonal CFRP strips. First diagonal crack on the beam was observed at backward loading of 4th cycle. At forward loading of 5th cycle, this crack propagated and stayed on hold up to the backward of 6th cycle. The first noises from activities of CFRP strips were heard at forward loading of 7th cycle and rigidity of the specimen decreased at backward loading of this cycle. First concrete-CFRP debonding was observed at forward loading of 9th cycle and longitudinal reinforcement of the specimen yielded at 59 kN load level of backward loading of 11th cycle. Ultimate load capacity and maximum displacement of Strengthened BCJ were 70.14 kN and 96.13 mm. Figure 4 shows load vs displacement curves of both test specimens.

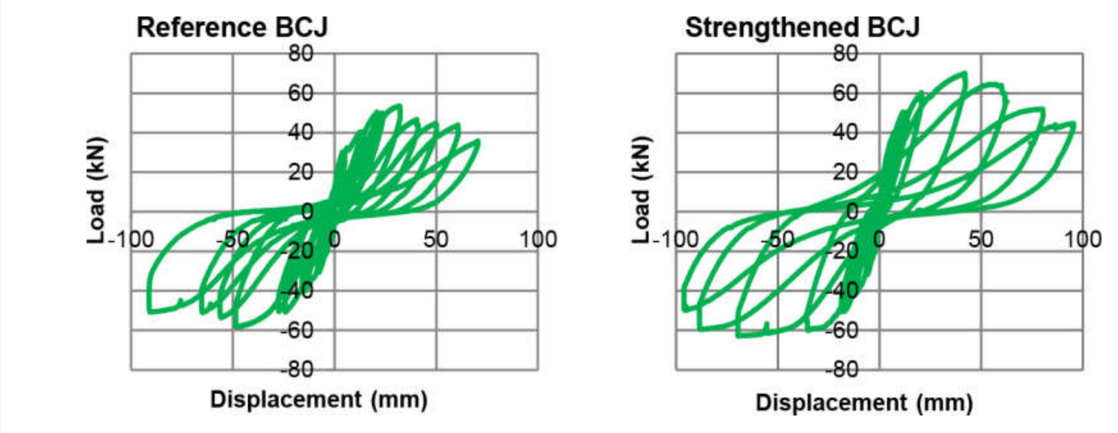

Figure 4 Load vs displacement curves of the test specimens

4.2 Parametric AE analysis results

As shown in Figure 5, generally maximum 80 dB amplitude values were obtained during the test of Reference BCJ. Punctuated increases of cumulative AE energy exist at 342. sec and 1048. sec. While the first punctuation occurred at forward loading of 5th cycle, the other was at forward cycle of 7th cycle. These moments are attributed to originations of the first flexural and shear cracks. As clearly seen, the first activity is in 99 dB, which is the maximum amplitude of the test. In contrast to Reference BCJ, bigger punctuations in cumulative AE energy and higher amplitude values are observed during Strengthened BCJ test. At backward loading of 3rd cycle (1665. sec), the first flexural crack propagated and energy increased. Afterwards, a new punctuation in cumulative AE energy was observed at 2104 sec where the noises from CFRP strips were firstly heard. In addition, all AE parameters of Strengthened BCJ are higher than those of Reference BCJ. In order to compare crack types of the specimens, RA values, which are calculated by dividing rise time to amplitude, were plotted versus average frequency values (Figure 6).

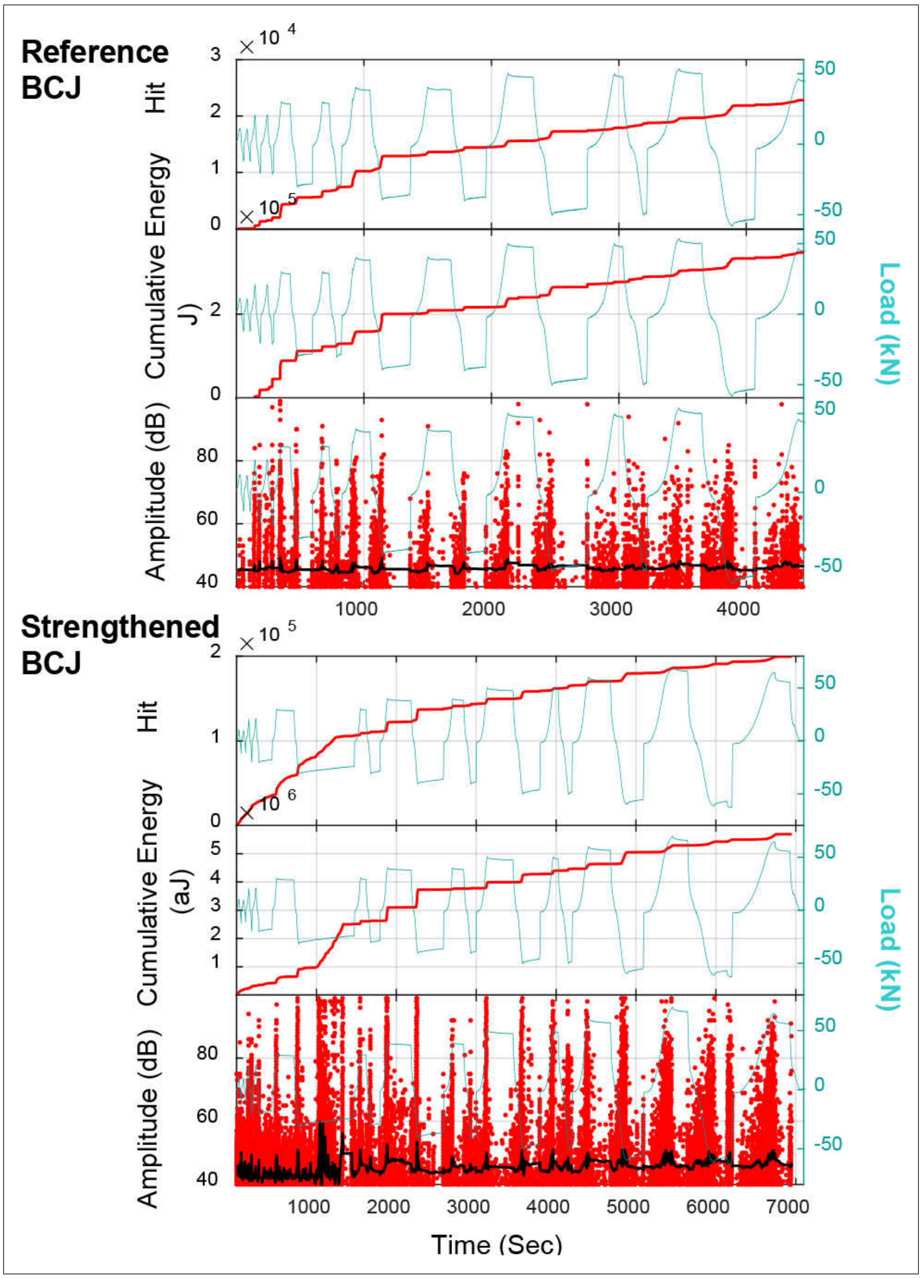

Figure 5 Parametric AE analysis results of the test specimens

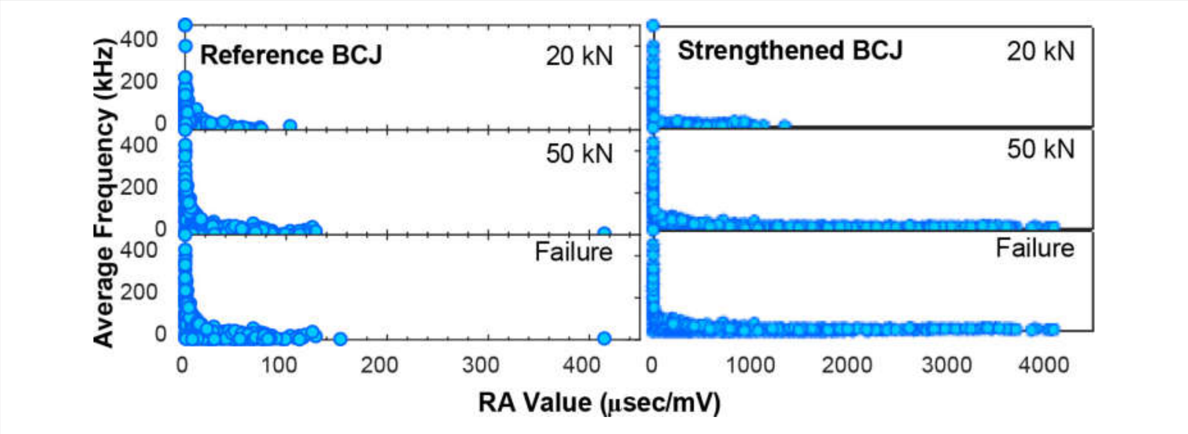

Figure 6 RA value vs average frequency distributions of both specimens

[9] standardizes higher RA values and lower average frequencies as more shear effective cracks and vice versa. Accordingly, as clearly seen in Figure 6, tensile characteristics are more effective in low load levels for both specimens. As the load increased, shear characteristics dominated. However, RA values of Strengthened BCJ's cracking activities are higher than those of Reference BCJ at all load stages. Thus, this indicates that activities of CFRP de-bonding from concrete surface are characterized as shear. In addition, although Strengthened BCJ has higher load capacity and rigidity, invisible shear activities in this specimen increased and the joint resisted even to these more shear-effective cracks in higher loads.

4.3 AE source localization results

Apart from the mechanical observations, crack source locations of the specimens were also obtained by conducting crack localization algorithm using AE data. By this means, arrival times of the hits were captured via AIC Picker [10] and all AE events were localized by solving multiple hyperbolic equations including distance between the source and the sensor, wave velocity and arrival time. As a result of this procedure, Figure 7 was formed.

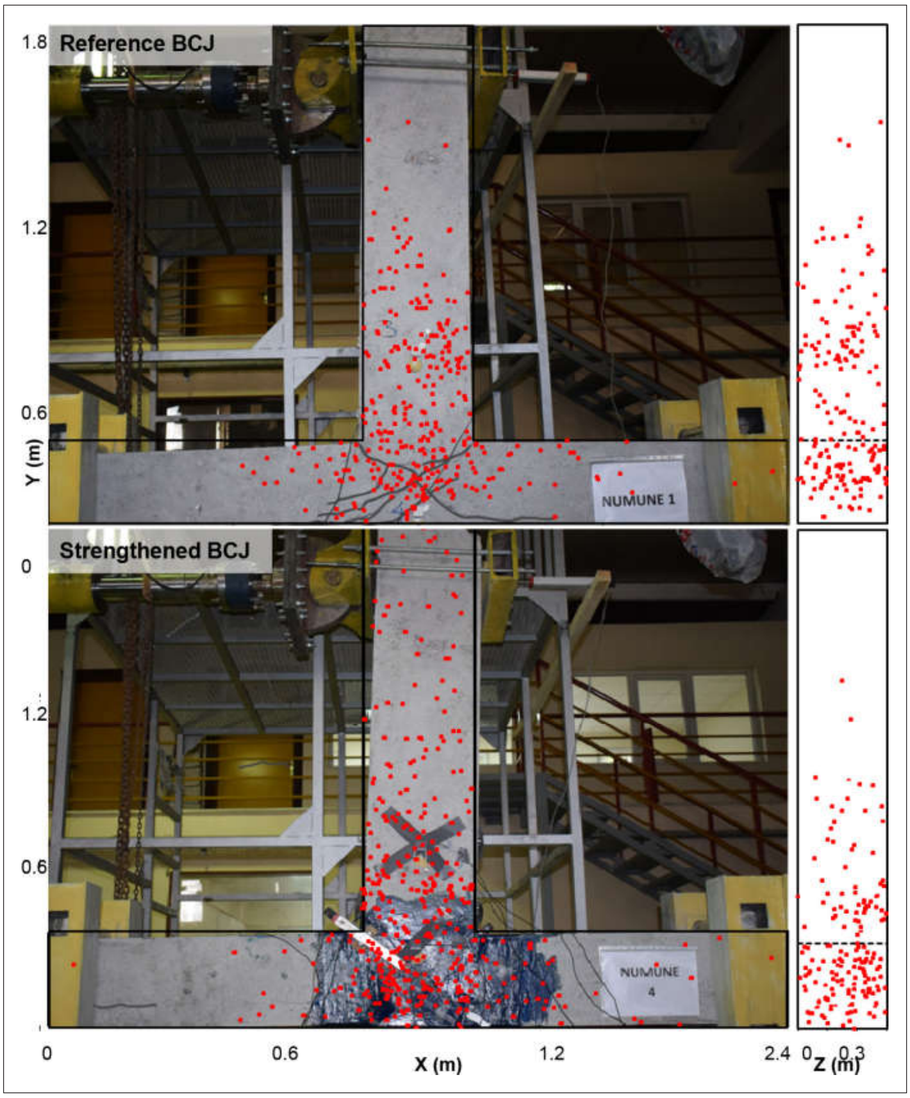

Figure 7 Crack patterns of the specimens analysed by AE source localization

As clearly seen, cracks mostly concentrated on the joints of the specimens. Although the capacity of the joint increased due to CFRP strengthening, a large number of cracks were also observed in the joint of Strengthened BCJ.

5 Conclusion

The main purpose of this study was to clarify damage progressions of a reference and a CFRP-strengthened RC beam-column joint exposed to cyclic loading by acoustic emission (AE) technique. For these targets, experimental tests were carried out on two RC beam-column joints which one of them was strengthened with diagonal CFRP strips, they were simultaneously monitored by AE and the results were compared. Following conclusions about RC beam-column joints were obtained: Strengthening the joint with diagonal CFRP strips increases the ultimate load capacity. AE is an effective non-destructive testing tool to identify the fracture mechanisms. Strengthening with diagonal CFRP strips changes AE behaviour by increasing hits, cumulative energies and amplitude values and creates more explicit punctuations in cumulative energy. Tensile cracks are more effective in low load levels and shear cracks dominate as the load increases. However, strengthening the joint with diagonal CFRP strips increases RA values, ie. shear effect. Thus this indicates that, although CFRP-strengthened RC beam-column joint has higher load capacity and rigidity, it faces more shear activities in higher load levels. AE source localization is considerably an effective algorithm to obtain damage mechanisms of the beam-column joints. Localized AE events draw similar cracking pattern to visual observations and provide information about nonvisible crack locations.

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