Relationship between acoustic emission distribution and stress variation through the depth of reinforced concrete beam cross sections

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Abstract. Stress/strain and Acoustic Emission (AE) are different forms of responses from loaded structures. The distribution of stress/strain through the depth of a beam cross section is well established theoretically and experimentally. However, little attention has paid to the variation of AE over the depth of the section and the relation between these two categories of structural quantities. Thus, the topics are addressed experimentally in this work. Six reinforced concrete (RC) beams were tested, employing the AE technique and the Digital Image Correlation (DIC) approach. The results showed that AE measurements can characterise behaviours of RC beams through the depth; that the distribution of AE matched very precisely with the variation of compressive stresses across sections especially in the post-reinforcement yielding stage. Therefore, a new option for estimating critical stress levels in concrete structures via AE parameters is highly possible.

Targets

The primary idea of this study is detailed as follow. Firstly, material mechanics shows that loads develop strains on the cross sections of beam structures as shown in Fig. 1(a), indicating that the strain varies across the sections linearly. Secondly, according to the stress-strain relation of concrete (Fig. 1(b)) [3], different strain values correspond to different stress magnitudes (Fig. 1(c)), meaning that the pattern of the stress distribution on the sections is deterministic and changes with load magnitudes. Meanwhile, cracking happens when concrete is stressed excessively. Thirdly, well-established research [1,2] has revealed that events, such as cracking, cause the release of energy in materials, forming elastic waves, i.e. AE. Therefore, the following two questions are considerably interesting:

1) How do the AE signals vary through the cross section? 2) Since AE and stress/strain are different forms of responses from structures loaded to failure, what possible relationships exist between them?

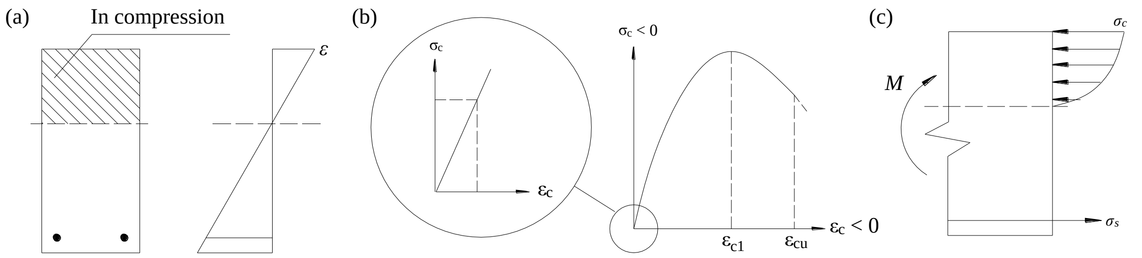
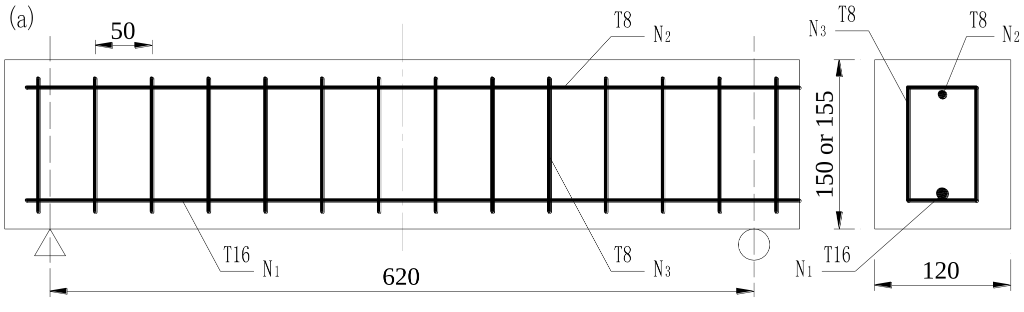


Fig. 1. (a) A typical theoretical distribution of strains on an RC beam cross section; (b) a stress-strain curve of the concrete material [3]; (c) the corresponding stress diagram across the section.

Experiment

Six RC specimens were tested. As shown in Fig. 2. N_1, 12 mm diameter steel, is provided as tensile reinforcement, while N_2, 6 mm diameter steel, as compressive reinforcement. Stirrups (N_3), 6 mm diameter, are placed at 50 mm c/c distance to avoid shear failure. The beam concrete was Grade C40 (British Standard) and the mix proportion was 1:2:3:0.5 (cement, fine aggregate, coarse aggregate and water). Steel fibres, 30mm or 60mm long, were mixed in the concrete, with a ratio of 0%, 1% or 2%.

AE signals were recorded with an eight-channel MISTRAS system and all sensors were mounted around the most probable site of damage – a pre-cut notch in the middle of the pure bending region (the lower panel of Fig. 2). A DIC device, two concrete strain gauges and a displacement transducer were employed. Specimens were subjected to the four-point bending and loads increase monotonically with a rate of 0.005mm/s.



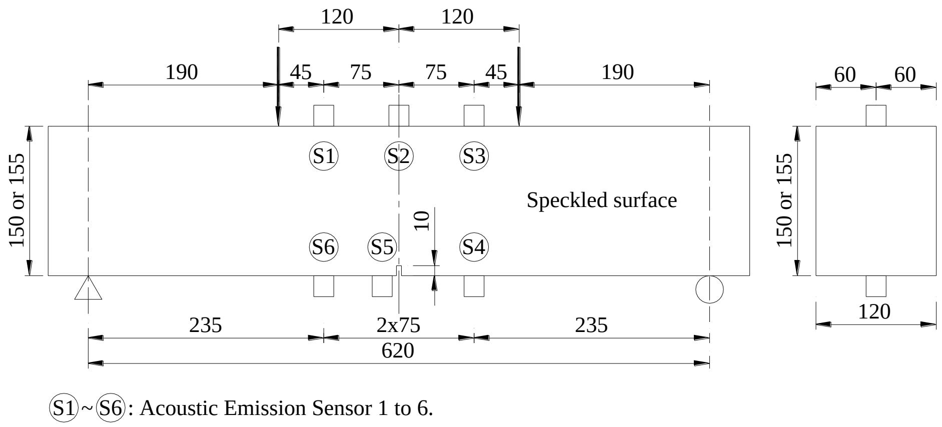


Fig. 2. Design details of the RC beams (Upper) and the layout of all six AE sensors (Units in mm).

Results

According to a load to deflection curve, three important stages, i.e. the elastic stage, the working stage and the failure stage, can characterise primary behaviours of RC beams[4].Hence, AE and structural responses in these stage were analysed carefully. The strain variation across a section was computed based on the DIC and the strain gauge measurements. Stresses were calculated by combining the strain data with the concrete stress-strain relation[3]. Major results are shown in Fig. 3. Note that the y-axis in Fig. 3(a) refer to the AE event amount (proportional to the AE event intensity), the AE absolute energy and the signal strength, respectively.

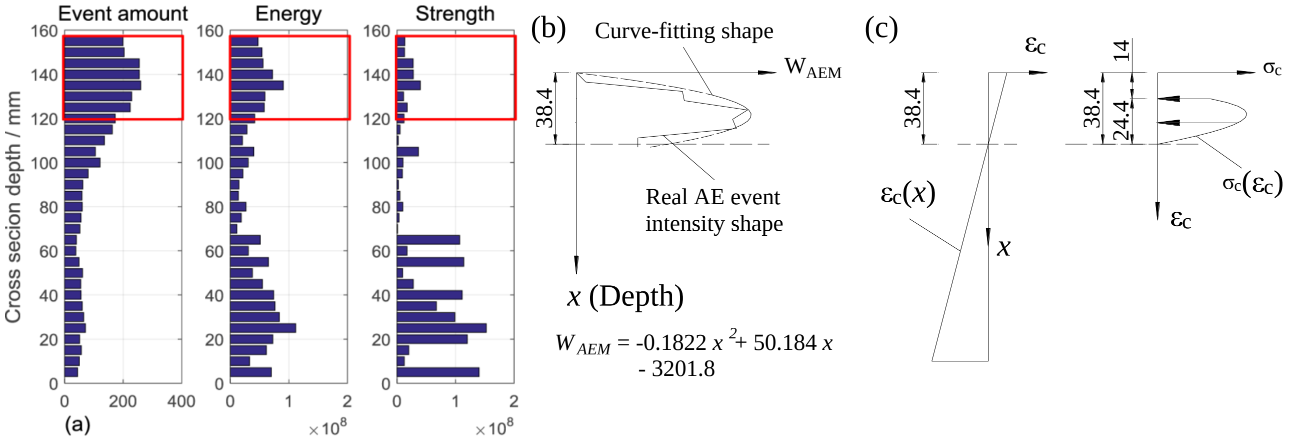


Fig. 3. (a)The distribution of the AE acquired in the failure stage, (b) the AE event intensity distribution along the compressive region (circled with red rectangles) and (c) the strain and corresponding stress diagram on the cross section of Beam 1 (Length in mm, stress and strength in MPa).

In the elastic stage and the working stages, the AE activity is considerably low. For example, less than 6% of total AE events are acquired during the two stages of Beam 1. Most AE come from the tensile region.

In the failure stage, as shown in Fig. 3, the distribution of the AE event intensity (Fig. 3 (a) and (b)) matches very well with that of the compressive stresses over the zone (Fig. 3(c)). Firstly, these two distributions are of very similar curve shapes. Secondly, the peak values of the AE event intensity and the stresses occur at almost the same location. More specifically, the former appears 20mm away from the top, while the latter 22mm. Meanwhile, data coming from, such as Beam 4, also strongly support the judgements.

Conclusions

The AE technology was highly capable of characterising the behaviours through the depth of RC beams.

In the elastic stage and the working stage, the AE activity was very low. In the failure stage, specimens were considerably active. For example, more than 90% of the total AE events were recorded during the failure of Beam 1. Specifically, beams behaved extremely actively in the AE aspect when loads dropped from peak.

Furthermore, the distribution of the AE event intensity matches accurately with that of the stresses over the compressive zone. The peaks of the AE event intensity and the stresses appeared at almost the same location.

References

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