ACOUSTIC EMISSION MONITORING OF CONCRETE HINGE JOINT MODELS

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Abstract

Currently in the United Kingdom there are over 100 bridges containing hinge joint components. Hinge joints were first introduced into bridge construction as a method of simplifying and standardising designs. Investigations of hinge joints by visual inspection have noted bridge deck waterproofing failure, which can cause steel reinforcement bar corrosion. This reinforcement is crucial to the integrity of the joint, and the loss of reinforcement section can induce higher stresses leading to eventual failure by yielding.

The Transport Research Laboratory (TRL) created a model of two hinge joint assemblies typical of those found in reinforced concrete slab bridges. The model had notched reinforcement bars at the hinges. The aim of the investigations was to determine the effectiveness of the Acoustic Emission (AE) technique in detecting and locating the cracking of concrete at the throat.

Sensors were attached to the steel reinforcement bars using waveguides and sensors were mounted to the concrete face of the model. The model was statically loaded using a hand operated hydraulic actuator until failure. To allow the visual inspection and logging of concrete cracking around the throat, the load was applied in stages with a brief hold period between each stage.

AE results showed that it was possible to identify and locate cracking of the concrete around the throat and that this technique needs to be further evaluated on bridge structures under live loading.

Introduction

Concrete hinge joints were introduced into bridge decks as a means of simplifying the design, and standardising details on bridges having a range of span and functional requirements. It is thought that the hinge joints transfer shear and accommodate small angular movements but restrict longitudinal movement (Wilson 1995). The hinges also enabled the bridges to cope with possible differential settlement. The disadvantages with hinge joints are that they are not easily accessible for inspection or maintenance due to their form and their location over or under live traffic lanes.

Previous attempts to investigate the deterioration of hinge joints by visual inspection, which involves the removal of structural concrete around the joint to expose the reinforcement bars, have noted particular defects; the majority have cracks running through the throat and a loss of waterproofing. Waterproofing failure can lead to chloride rich seepage through the joint that can cause reinforcement bar corrosion leading to eventual failure.

The Transport Research Laboratory (TRL) created a model, of two hinge joint assemblies. The model created was part of a larger testing programme commissioned by the Highways Agency to investigate the behaviour of the hinges under load (Daly 2004). The hinge joint model is typical of those found in reinforced concrete slab bridges. The model reinforcement was notched at the hinge to ensure failure of the steel reinforcement. The investigation presented here reports the results the effectiveness of the acoustic emission (AE) technique in detecting both damage in the steel reinforcement and cracking of concrete at the throat in the notched hinge joint model.

Experimental Procedure

The hinge joint specimen was restrained as shown in Figure 1 and loaded using a hand operated hydraulic actuator. Load was measured using a load cell and the vertical displacement of the centre span was measured using a displacement gauge. The model was loaded in 10kN intervals to 125kN followed by 15kN interval to 290kN and then 0.5mm increases in deflection until failure. Following each load step there was a brief hold period to log cracking of the concrete. The position of the crack tip and the respective load was marked on the beam.

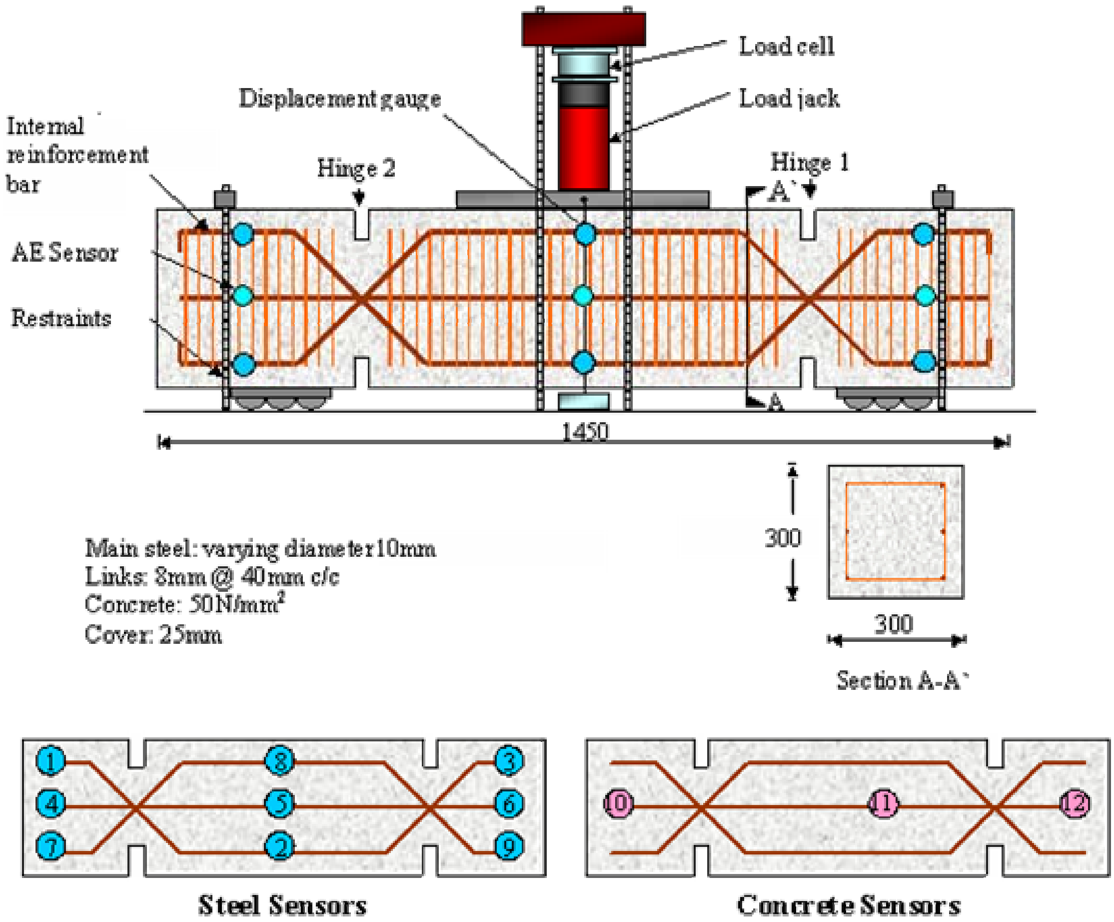

Figure 1: Test specimen and instrumentation

Nine sensors operating in the 70-300 kHz frequency range were attached to the internal reinforcement bars of the model (sensors 1-9). The sensors were attached via waveguides with grease as a couplant. Prior to casting of the concrete a hole suitable for 5mm studding was drilled and tapped into the reinforcement bar at the required positions. The studding was screwed into the hole and cut so the studding finished proud of the surface allowing a waveguide to be attached. This type of connection allows signals emitted from the steel to travel directly to the sensors. Three low-frequency sensors operating in the 20-50 kHz range (sensors 10-12) were used to evaluate the cracking of the concrete. Steel pieces were bonded to the concrete using a two part hardening system, enabling magnetic clamps to hold the sensor in place. Grease was used as an acoustic couplant. The concrete sensors were attached on the opposite side of the beam to the waveguides.
Sensor response, attenuation and signal location were evaluated using the pencil lead fracture (PLF) technique. Signals resulting from the PLF adjacent to each sensor were recorded to evaluate response. To assess attenuation a PLF adjacent to sensor 1 was recorded on all other sensors. Location of signals from the concrete using sensors attached to steel reinforcement was evaluated using PLFs at the centre of each joint. The specimen was monitored for the entire loading at a threshold of 35dB on the sensors attached to the steel and 45dB on the sensors attached to the concrete. Waveforms over 65db were recorded. Time marks were logged within the data to signify the start and finish of each load step increment.

Results and Discussion

The response of all sensors to PLFs adjacent to the sensor was above 97dB. This demonstrates that all sensors were attached correctly. The responses to a PLF at sensor 1 as recorded by sensors 1, 2 and 3 were 97dB, 78dB and 43dB respectively. This suggests that the location of signals from the steel reinforcement at the hinge will be possible as the loss of signal between sensor pairs is relatively low. Figure 2 shows the results of the PLF test to establish the accuracy of the time of arrival location method using sensors attached to the steel reinforcement to locate concrete damage. These results indicate that the location of damage in the concrete using the steel mounted sensors will be possible but has an error of 200mm.

Details of the load and direction of concrete cracking based on post-test photographs is presented in Figure 3.

Figure 4 shows the AE activity of the joints as recorded by the steel mounted sensors in terms of the amount of energy detected on all sensors. The plots show that higher levels of energy were recorded during the loading periods compared with the hold periods (hold periods are shaded), showing that AE is detecting the damage occurring during each load stage.

The location and magnitude of energy recorded during the 10-20kN load stage is shown in Figure 5, Comparing the location graphs with Figure 3, details of concrete cracking, it can be seen that the sensors attached to the steel reinforcement bar via waveguides can detect and locate the concrete cracking. The last loading stage of the model is shown in Figure 6 (350-353kN), a number of emissions were located. The highest energy level emission is at hinge “2” suggesting the final failure as detected by AE must be at Hinge “2”. Figure 7 shows the ultimate failure at hinge “2”. The remaining energy also located at failure may be due to the de-bonding of the bars as a result of the failure. This can’t be validated currently as it would require the removal of concrete from the bars.

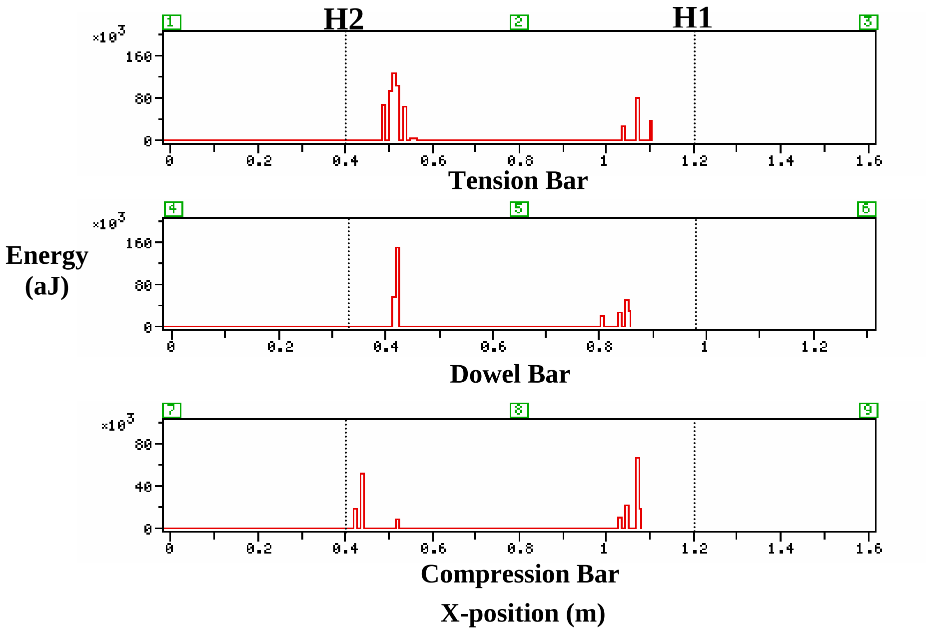

Figure 2: Location of pencil lead fractures from centre of each hinge joint

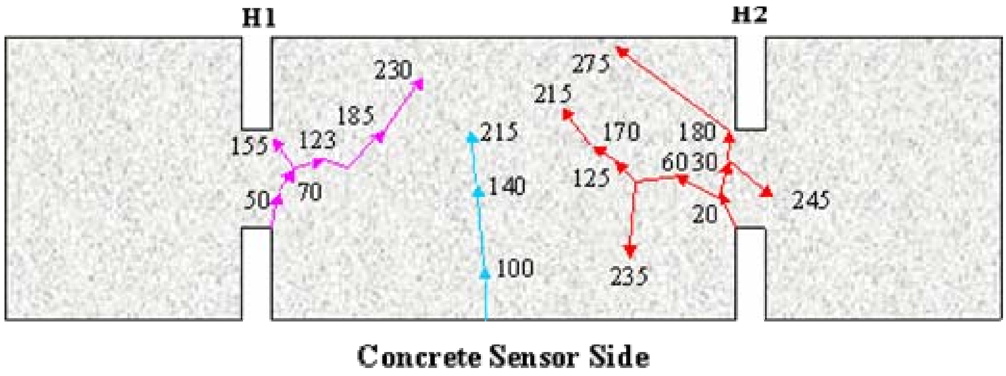

Figure 3: Location and direction of cracks with respective loads

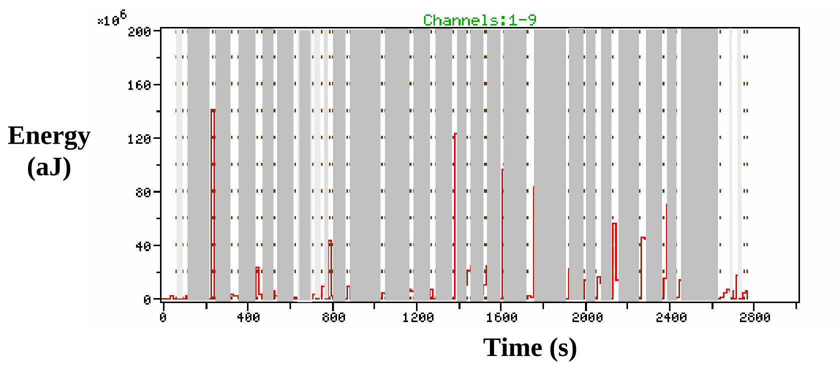

Figure 4: Energy detected and located from reinforcement mounted sensors

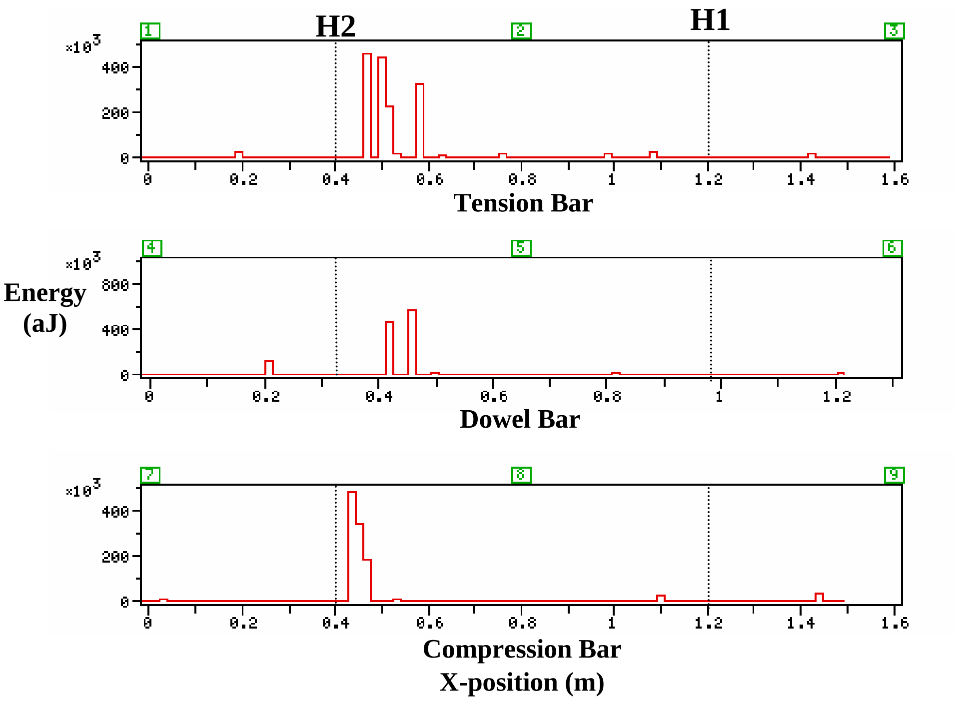

Figure 5: Location of signals detected from sensors attached to steel reinforcement during 10-20kN load stage

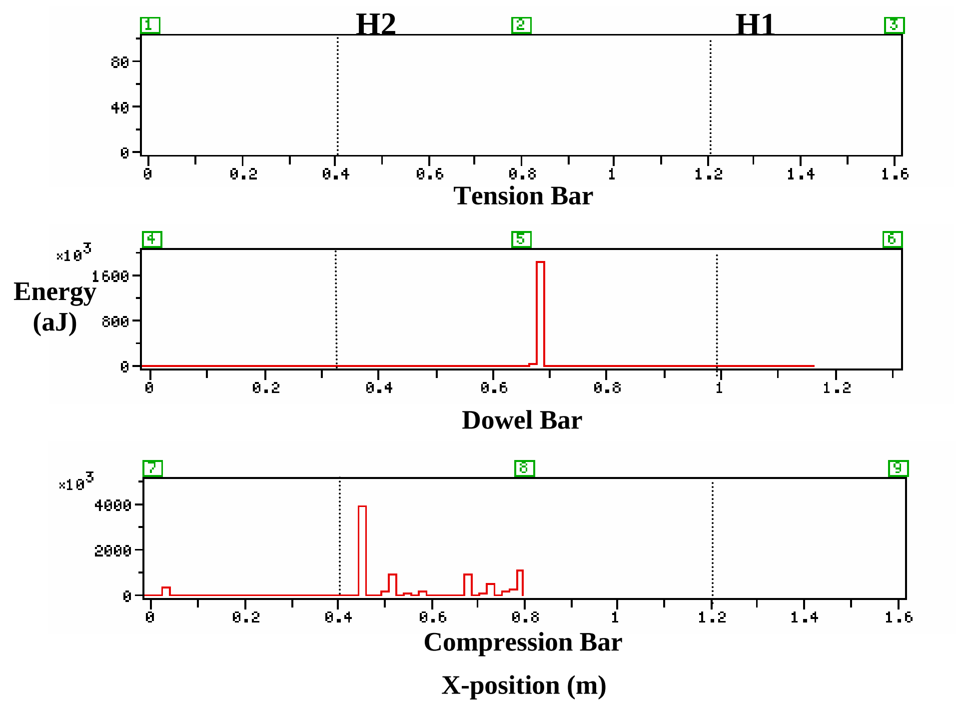

Figure 6: Location of signals detected from sensors attached to steel reinforcement during 250-353kN load stage

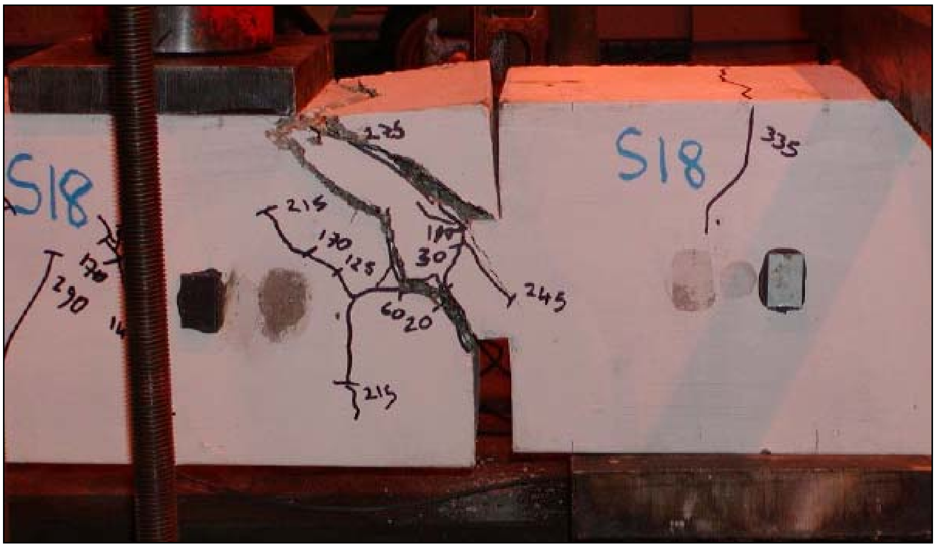

Figure 7: Final failure of notched reinforcement model at hinge 2 (photograph taken from surface sensor mounted side)

Figure 8 shows the energy recorded during the monitoring of the model by the concrete sensors. The plots again show that higher levels of energy were recorded during the loading periods compared with the hold periods (hold periods are shaded), showing that AE detects the damage occurring during each load stage. The concrete sensors did not record the total duration of the test as surface cracking of the specimen caused the failure of the hardening compound under the clamps, dislodging the central sensor.

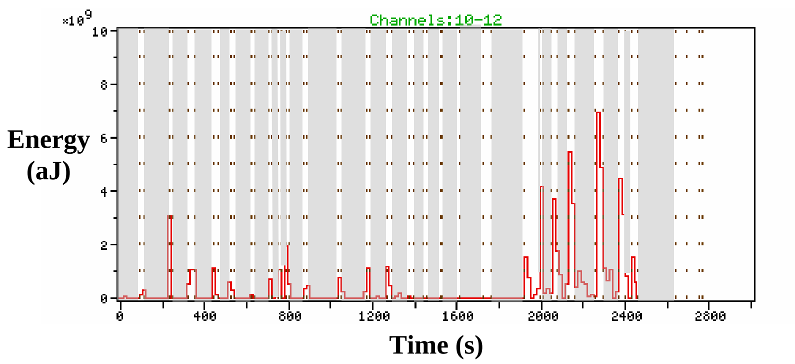

Figure 8: Energy detected and located by the concrete mounted sensors

From Figure 9, location of signals recorded by concrete mounted sensors in the 0-50kN loading stages, it can be seen that the initial cracking at hinge “1” is detected at the load at which it was first seen (50kN). However the cracking at hinge “2” is detected prior to visual observation. Note that emissions are detected at locations not included in Figure 3 as the sensors detect damage in the concrete throughout the model and not just surface cracks logged.

The disadvantage with hinge joints is that they are not easily accessible for inspection or maintenance due to their form and their location over or under live traffic lanes. Results reported in this paper shows that the damage of concrete as it occurs in model hinge joints can be identified using sensors attached to the structure using waveguides or surface mounted sensors. The use of surface mounted sensors does not further damage the structure and can be implemented during night possessions. It is then possible to monitor a structure under normal loading conditions avoiding further bridge closures during heavy traffic periods.

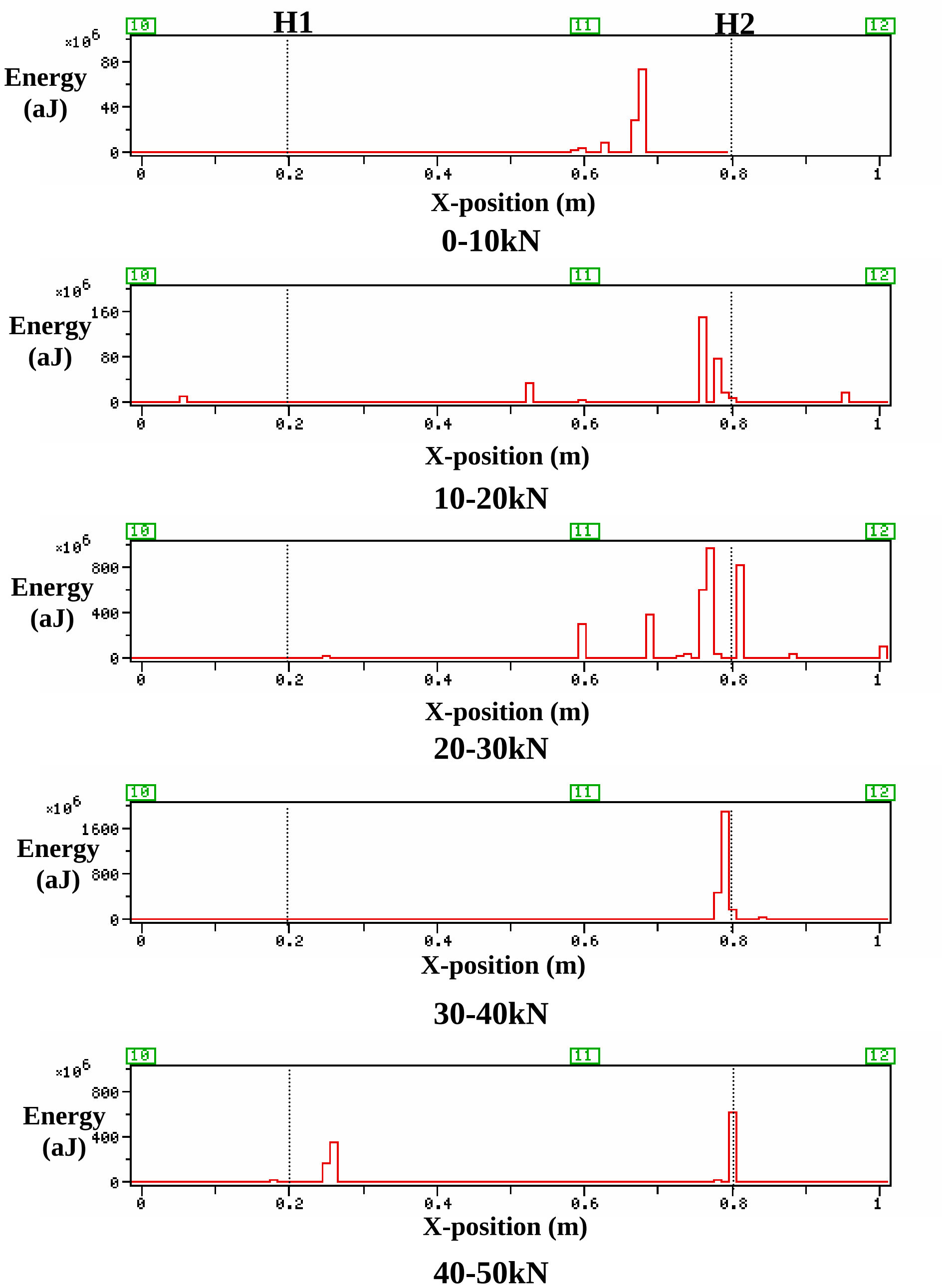

Figure 9: Location of signals detected from sensors attached to concrete surface during 0-50kN loading stages

Conclusions

This trial shows that it is possible to detect and locate concrete cracking in concrete model hinge joints using sensors attached to the steel reinforcement bars and sensors attached to the concrete surface

Acknowledgements

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