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, introduced to simplify and standardise designs. Visual inspection of hinge joints 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 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 this investigation was to determine the effectiveness of the acoustic emission (AE) technique in detecting and locating the cracking of concrete at the throat. AE sensors were attached to the steel reinforcement bars using waveguides and to the concrete face of the model. The model was statically loaded 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.

Keywords: Acoustic emission, bridges, concrete hinge joints

1. 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.

2. Experimental Procedure

The hinge joint specimen was restrained as shown in Fig. 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 10 kN intervals to 125 kN followed by 15 kN interval to 290 kN and then 0.5 mm 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.

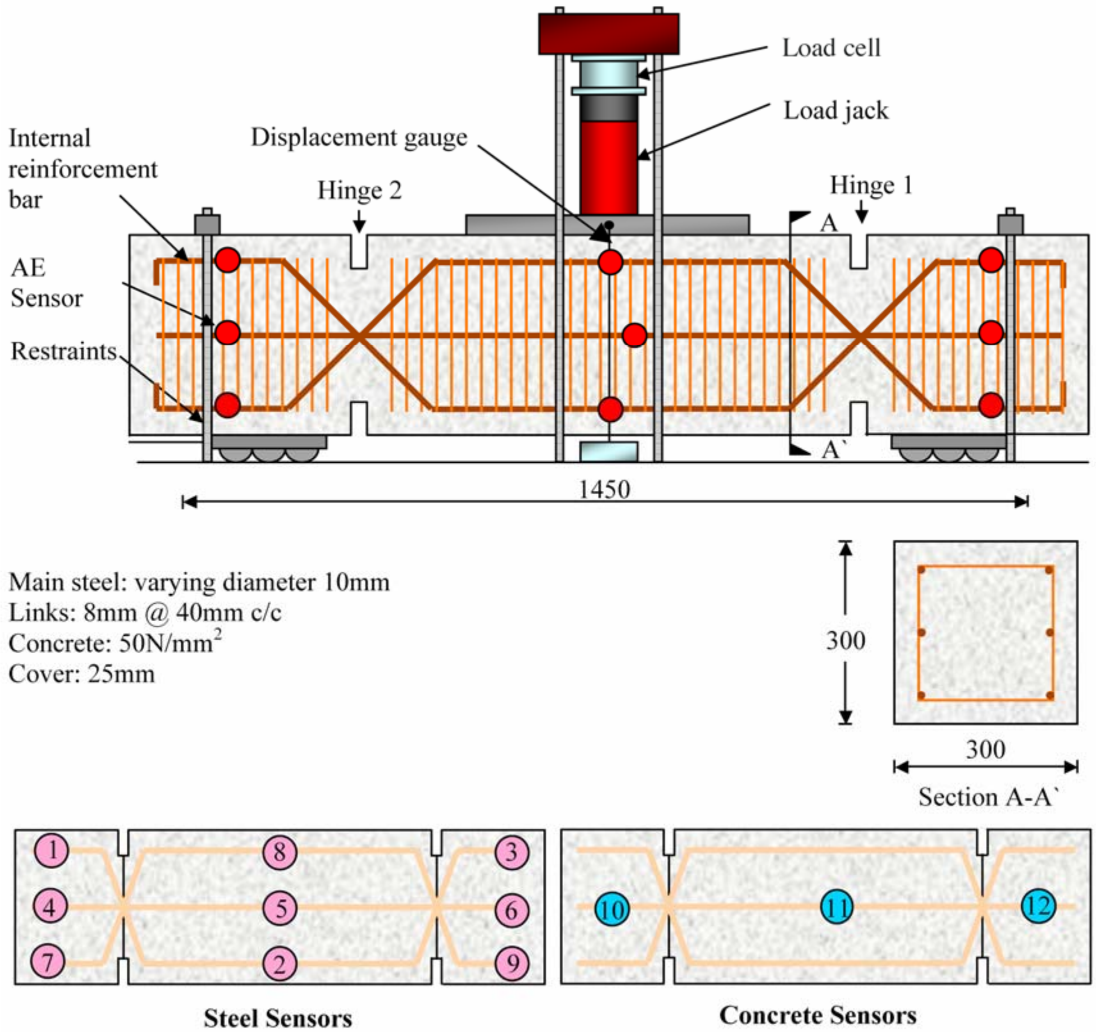

Fig. 1 Test specimen and instrumentation.

Nine AE 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 5 mm 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 above 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 35 dB on the sensors attached to the steel and 45 dB on the sensors attached to the concrete. (0 dB = 1 μV) Waveforms over 65 dB were recorded. Time marks were logged within the data to signify the start and finish of each load step increment.

3. Results and Discussion

The response of all sensors to PLFs adjacent to the sensor was above 97 dB. 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 97 dB, 78 dB and 43 dB, 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 200 mm.

Details of the load and direction of concrete cracking based on post-test photographs are presented in Fig. 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.

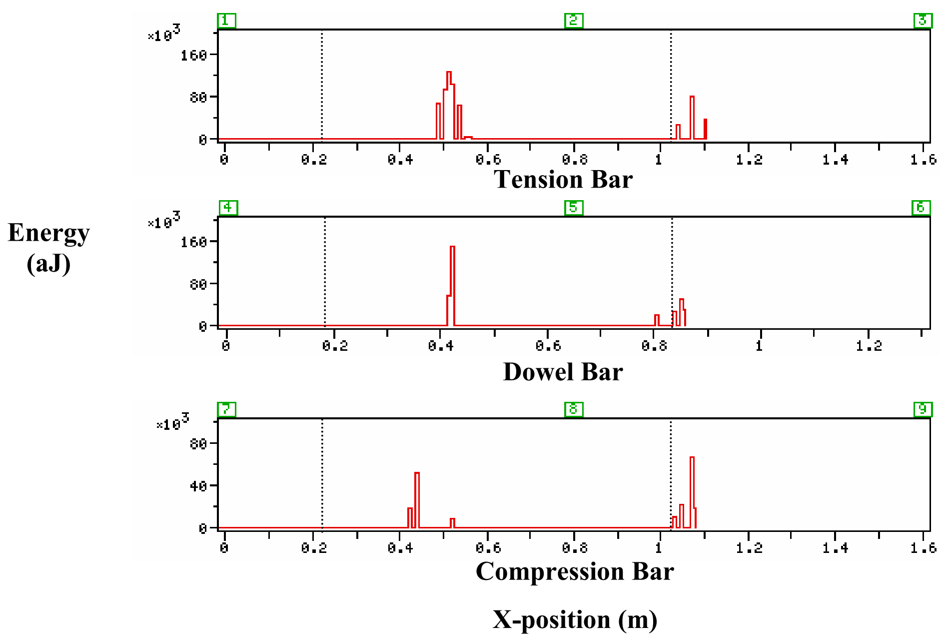

Fig. 2 Location of pencil lead fractures from centre of each hinge joint.

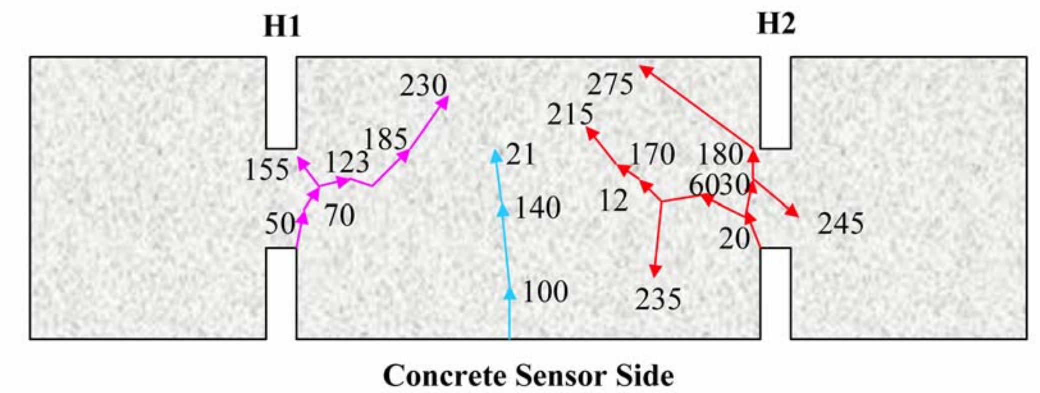

Fig. 3 Location and direction of cracks with respective loads.

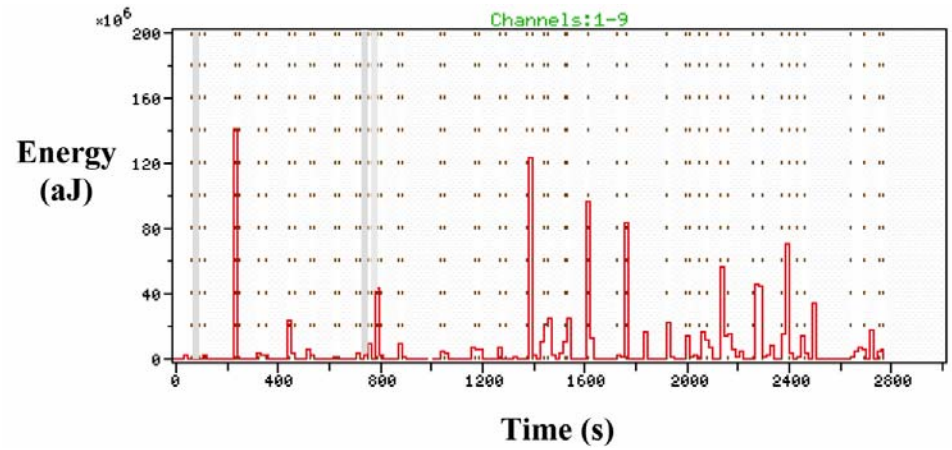

Fig. 4 Energy detected and located from reinforcement mounted sensors.

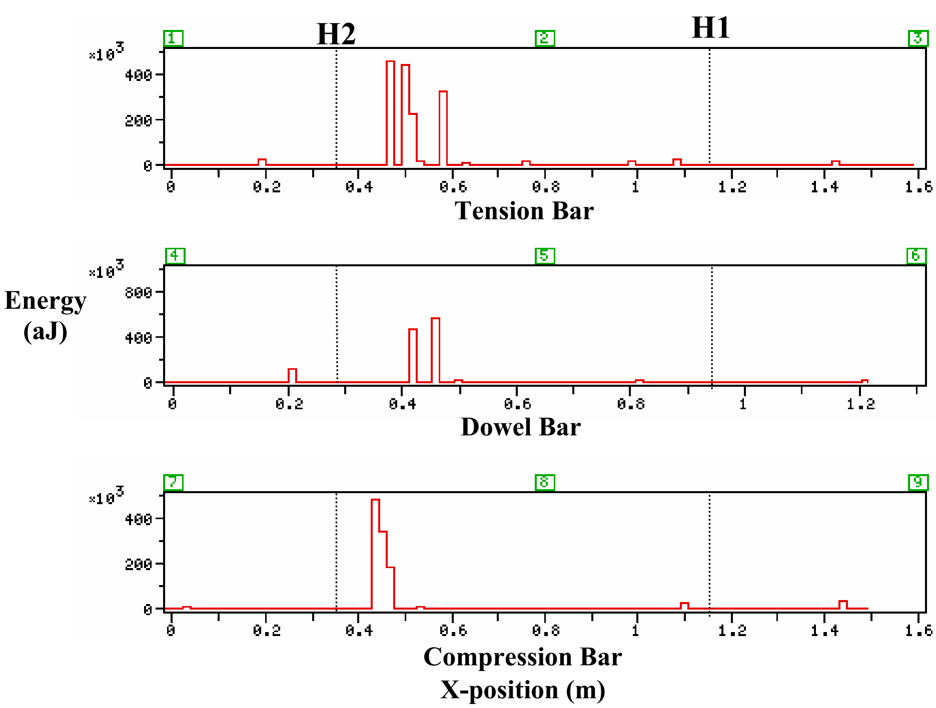

Fig. 5 Location of signals detected from sensors attached to steel reinforcement during 10-20 kN load stage.

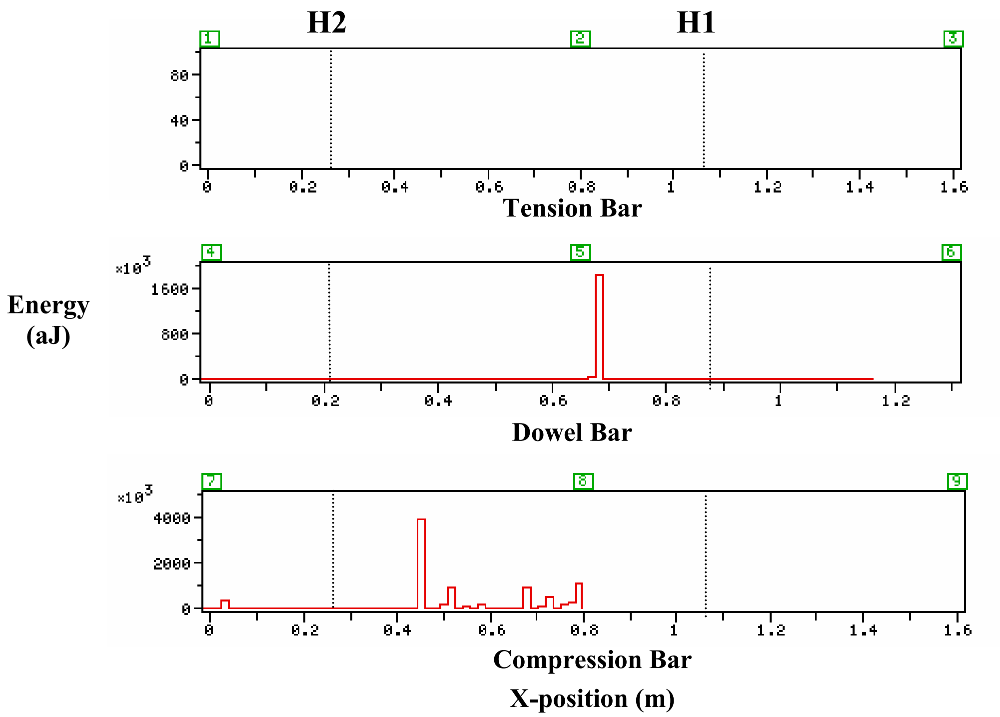

Fig. 6 Location of signals detected from sensors attached to steel reinforcement during 250-353 kN load stage.

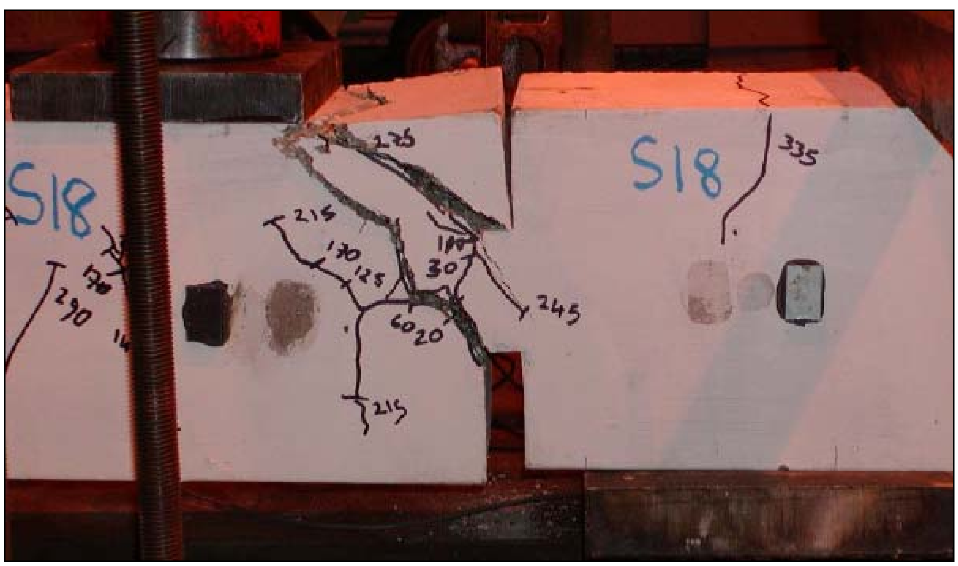

Fig. 7 Final failure of notched reinforcement model at Hinge 2 (photograph taken from surface sensor mounted side).

The location and magnitude of energy recorded during the 10-20 kN load stage is shown in Fig. 5. Comparing the location graphs with details of concrete cracking (Fig. 3), 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 Fig. 6 (350-353 kN), and 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 cannot be validated currently as it would require the removal of concrete from the bars.

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.

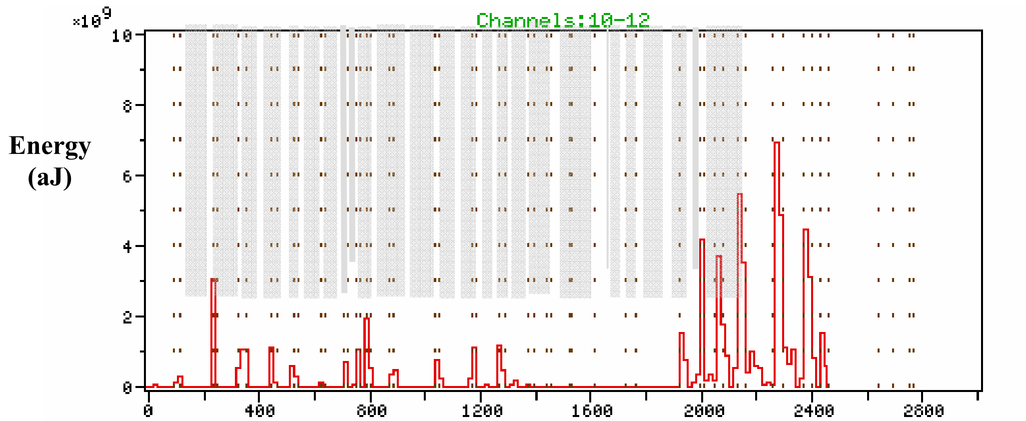

Fig. 8 Energy detected and located by the concrete mounted sensors.

From Fig. 9, showing location of signals recorded by concrete mounted sensors in the 0-50 kN loading stages, the initial cracking at Hinge “1” is detected at the load at which it was first seen (50 kN). However the cracking at Hinge “2” is detected prior to visual observation. Note that emissions are detected at locations not included in Fig. 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 closing of motorway. It is then possible to monitor a structure under normal loading conditions avoiding further bridge closures during heavy traffic periods.

4. 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

The authors wish to express their gratitude to the Highways Agency for their financial support of this research and to the technician staff of the Transport Research Laboratory for their assistance.

References

Daly, A. F., 2004. “Durability and Performance of Deck Hinges: Report on Preliminary Load Tests”, Transport Research Laboratory, TRL Project Report

Wilson, C.B., 1995. “Assessment of the Reinforced Concrete Hinges on Five M6 Overbridges in Staffordshire”, Proceedings Institution Civil Engineers, **110** (1995) 4-10.

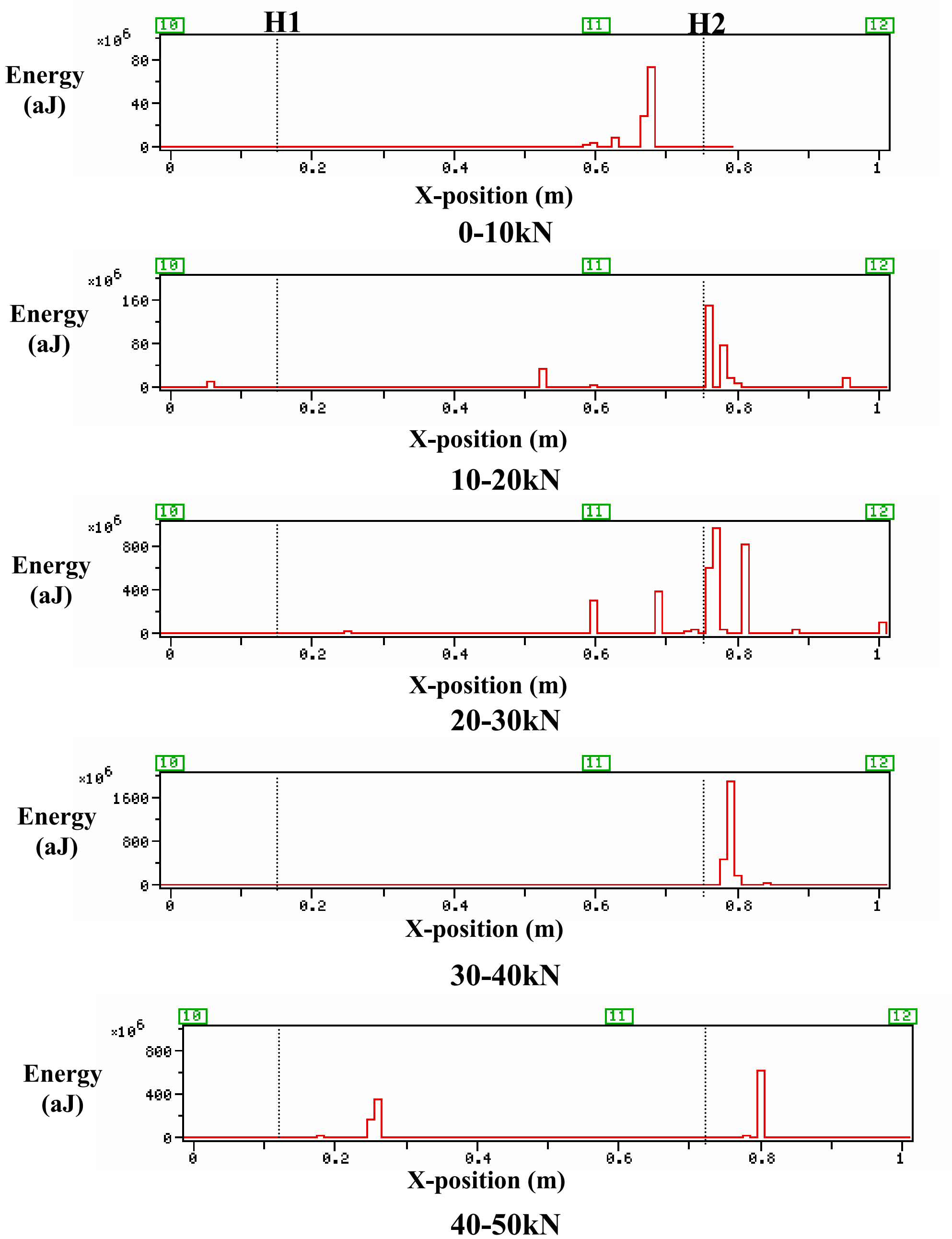

Fig. 9 Location of signals detected from sensors attached to concrete surface during 0-50 kN loading stages.