Localization of Acoustic Emission Sources in Geometrically Sparse Structures

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Abstract

Increasing safety demands are in recent years supported by integration of Structural Health Monitoring (SHM) systems into e.g. aircrafts, bridges or other civil structures including modern buildings. Collapse of civil structures or failure of their parts would cause significant material or human losses. One of the highly effective early-warning methods is AE detection. The AE method is frequently exploited on geometrically very complicated structures, which needs sophisticated AE source location procedures. In this paper we discuss AE localization on typical latticed construction composed of interconnected girders. The utilization of artificial neural networks is compared with segmented localization based on the chronology of signal arrivals to selected groups of AE sensors in such "geometrically sparse" structures. Results obtained with both AE source localization methods are illustrated on real building experiment, where the primary roof truss was gradually loaded up to the final breakdown. AE signalized the limit state approaching as soon as at 60% of maximal loading.

LOCALIZATION OF ACOUSTIC EMISSION SOURCES IN GEOMETRICALLY SPARSE STRUCTURES

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LOCALIZATION OF ACOUSTIC EMISSION SOURCES IN GEOMETRICALLY SPARSE STRUCTURES

- INTRODUCTION
- EXPERIMENT DESCRIPTION
- DATA ANALYSIS
  - *APPLICATION OF NEURAL NETWORKS*
  - *ZONAL LOCALIZATION*
- SUMMARY

SHM
(Structural Health Monitoring)

Reliable estimation of the structure integrity, early warning systems...

Overloaded roof collapse issue

Obligatory monitoring of structures: *fire alarms, safety services, etc..*

SHM: *mostly not done*
- depending on statics computations durin designing
- depending on good-quality building construction
- marginalizing aspects as degradation of materials, corrosion, hidden defects...
- current state of the structure can be unlike the expectations

GOALS:
- *to forecast or reveal malfunctions*
- *to avoid fatal failures and material or human losses*

...

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EXPERIMENT

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LOADED STRUCTURE

- Steel roof structure *(3 segments part)*

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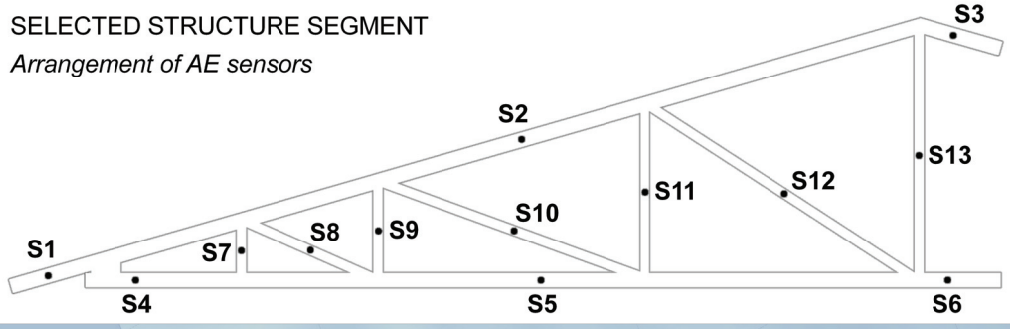
SHM SYSTEM

Experiment: gradual loading of a roof structure part

- **AE** monitoring *(13 emission channels)*
- **8 NEWS** channels *(NLTRM - with time reversal mirrors)*
- Monitoring of **geometrical changes** *(by telemeters - 1x LASER, 3x US)*
- **Imaging evaluation** of truss deformation *(image processing)*

SELECTED STRUCTURE SEGMENT

Arrangement of AE sensors



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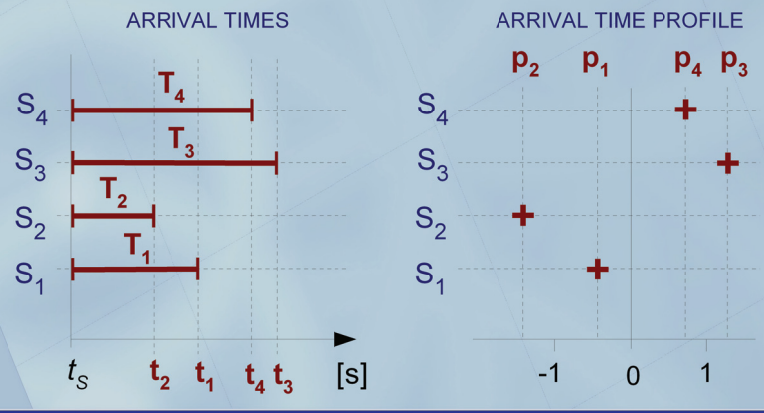
LOCALIZATION OF AE SOURCES BY ARRIVAL TIME PROFILES

- *Arrival time profile* is a vector with following elements p_i :

$$p_i = \frac{N T_i - \sum_{j=1}^{N} T_j}{\sum_{k=1}^{N} \left| T_k - \frac{1}{N} \sum_{j=1}^{N} T_j \right|} = \frac{N t_i - \sum_{j=1}^{N} t_j}{\sum_{k=1}^{N} \left| t_k - \frac{1}{N} \sum_{j=1}^{N} t_j \right|} = \frac{N d_i - \sum_{j=1}^{N} d_j}{\sum_{k=1}^{N} \left| d_k - \frac{1}{N} \sum_{j=1}^{N} d_j \right|}$$



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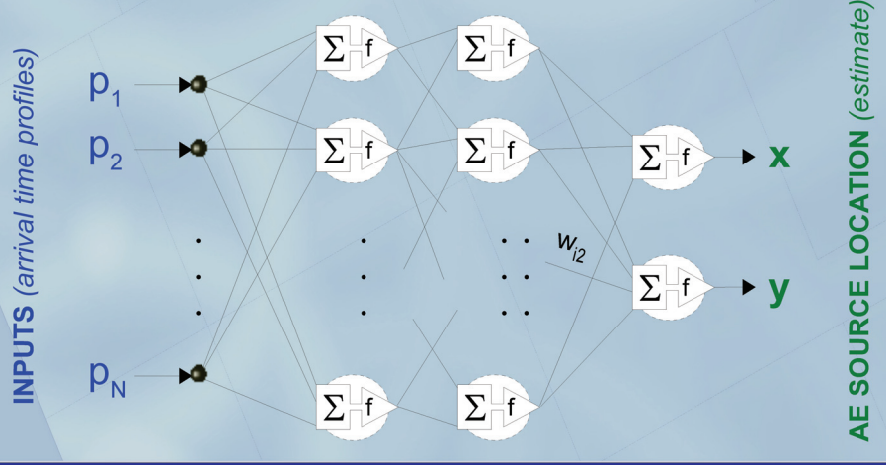
LOCALIZATION OF AE SOURCES BY ARRIVAL TIME PROFILES

- **Training of neural network**
  - *network architecture (approximate numbers of neurons in each layer)*: ***N-50-25-2***
  - initial weights were adjusted by *statistical optimization* of starting neuron potentials
  - weights and biases were adjusted by fast *resilient back-propagation* algorithm with *momentum and regularization* (training data -> set of virtual AE sources)



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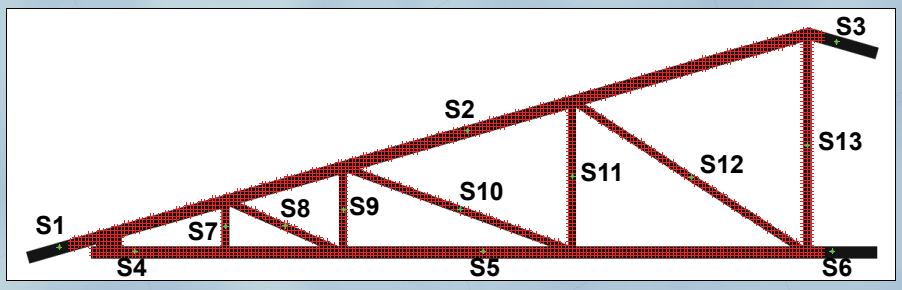
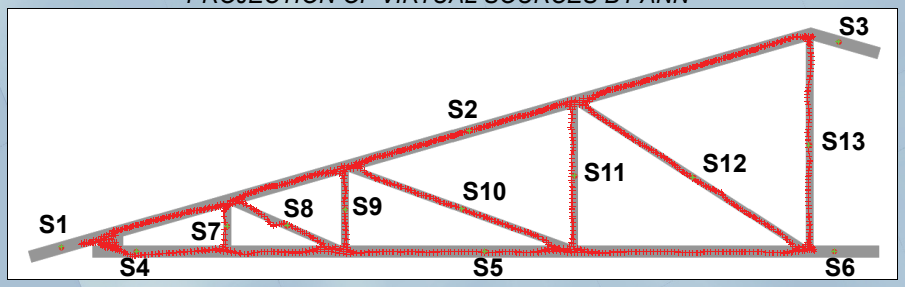
LOCALIZATION BY ANN

ARRANGEMENT OF TRAINING VIRTUAL SOURCES



PROJECTION OF VIRTUAL SOURCES BY ANN



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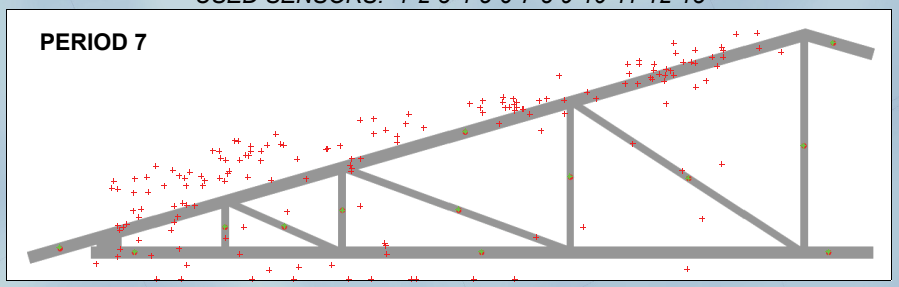
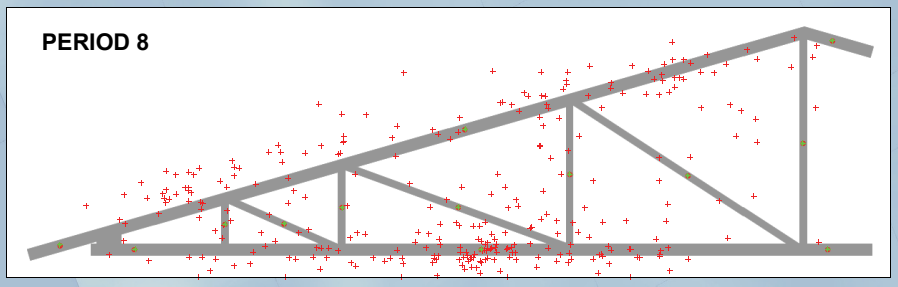
LOCALIZATION BY ANN *(final results)*

USED SENSORS: 1-2-3-4-5-6-7-8-9-10-11-12-13



USED SENSORS: 1-2-3-4-5-6-7-8-9-10-11-12-13



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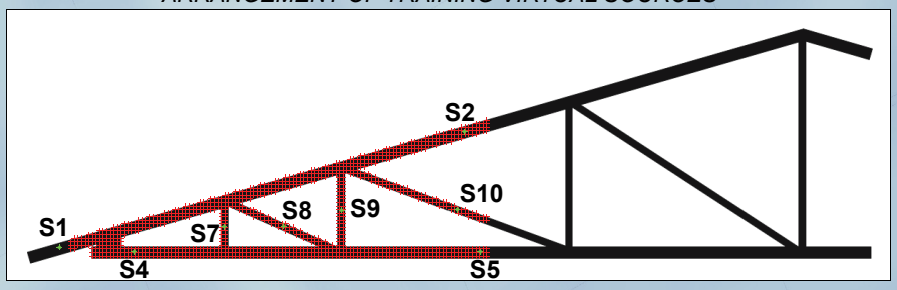
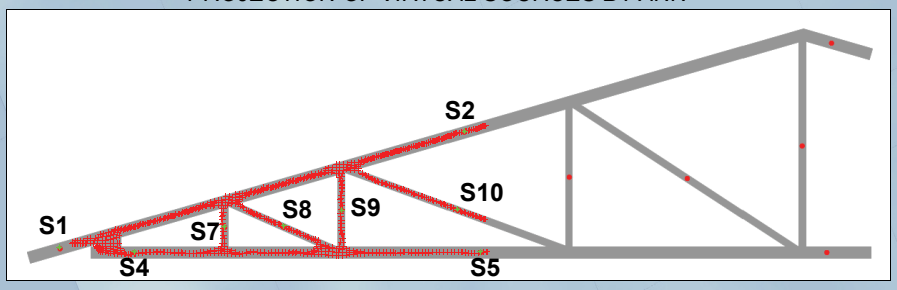
LOCALIZATION BY ANN *(left structure part)*

ARRANGEMENT OF TRAINING VIRTUAL SOURCES



PROJECTION OF VIRTUAL SOURCES BY ANN



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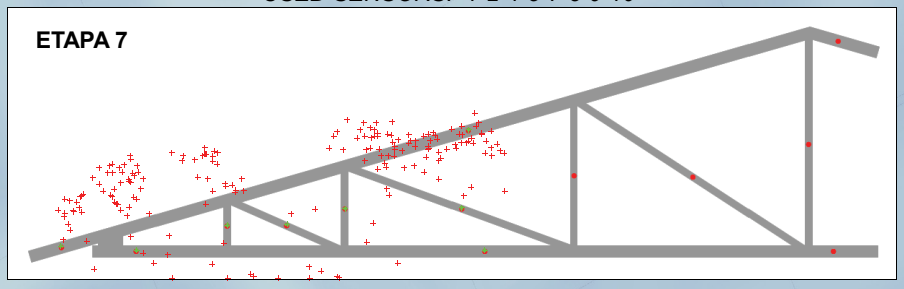
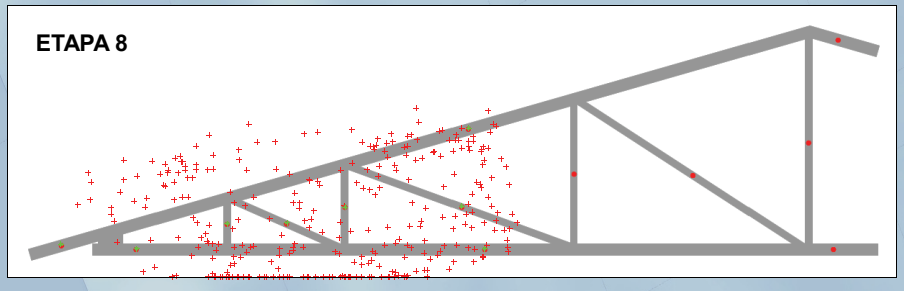
LOCALIZATION BY ANN *(final results)*

USED SENSORS: 1-2-4-5-7-8-9-10



USED SENSORS: 1-2-4-5-7-8-9-10



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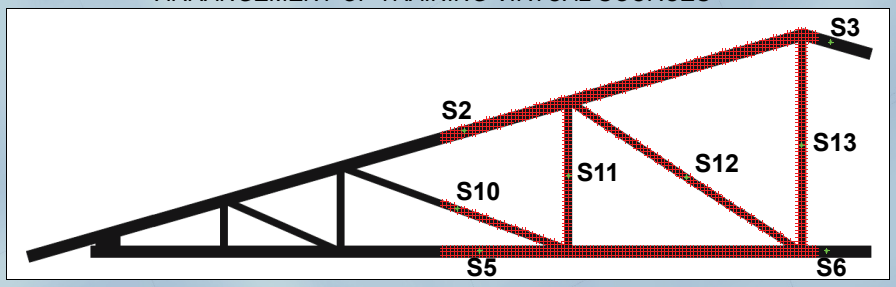
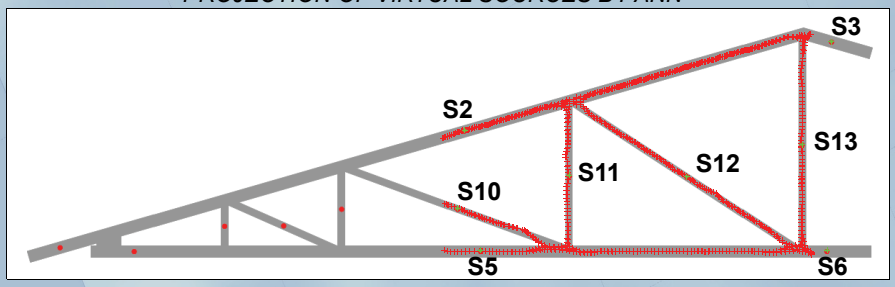
LOCALIZATION BY ANN *(right structure part)*

ARRANGEMENT OF TRAINING VIRTUAL SOURCES



PROJECTION OF VIRTUAL SOURCES BY ANN



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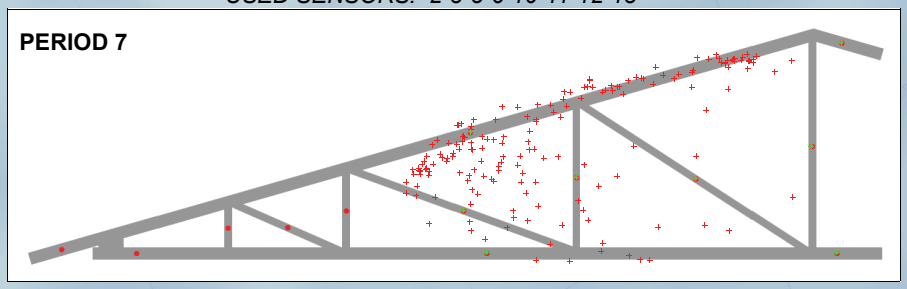
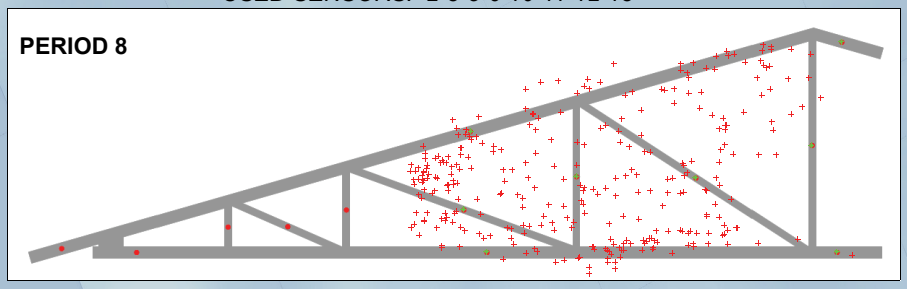
LOCALIZATION BY ANN *(final results)*

USED SENSORS: 2-3-5-6-10-11-12-13



USED SENSORS: 2-3-5-6-10-11-12-13



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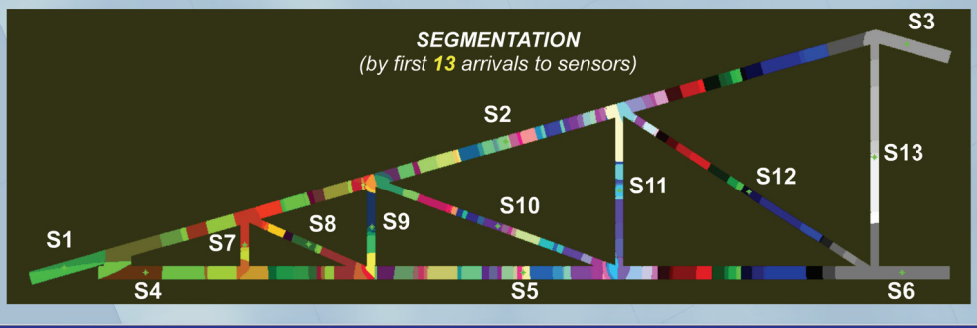
ZONAL LOCALIZATION

- Badly interpretable results of ANN location *(points out of body)*.
- An alternative: algorithm of segment (zonal) location
  (structure is divided up by the chronology of signal arrivals to sensors)
- For *geometrically sparse structures* it is rather difficult to specify particular segments with *unique chronology of arrivals* of elastic waves to sensors
  (It is needed to use an algorithm for finding the shortest ways in the structure).
- Analysis of all possible elastic wave arrival chronologies in the structure:
  *(number of sensor permutations: **13!=6 227 020 800**, there out **235** possible).*



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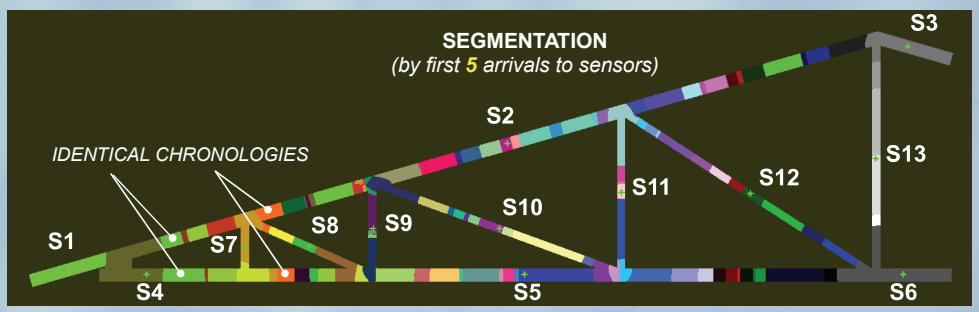
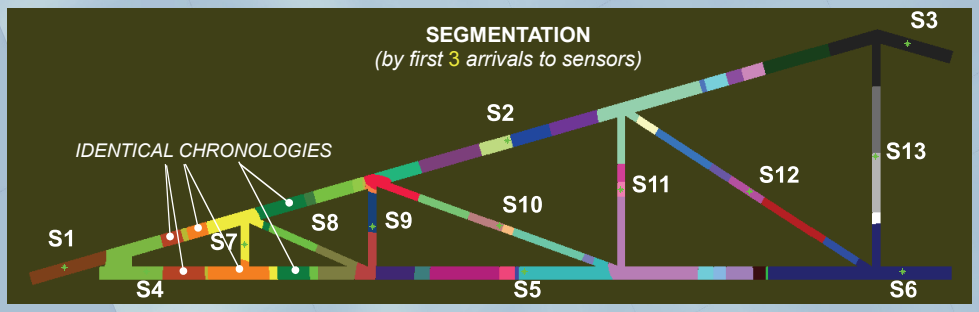
ZONAL LOCALIZATION





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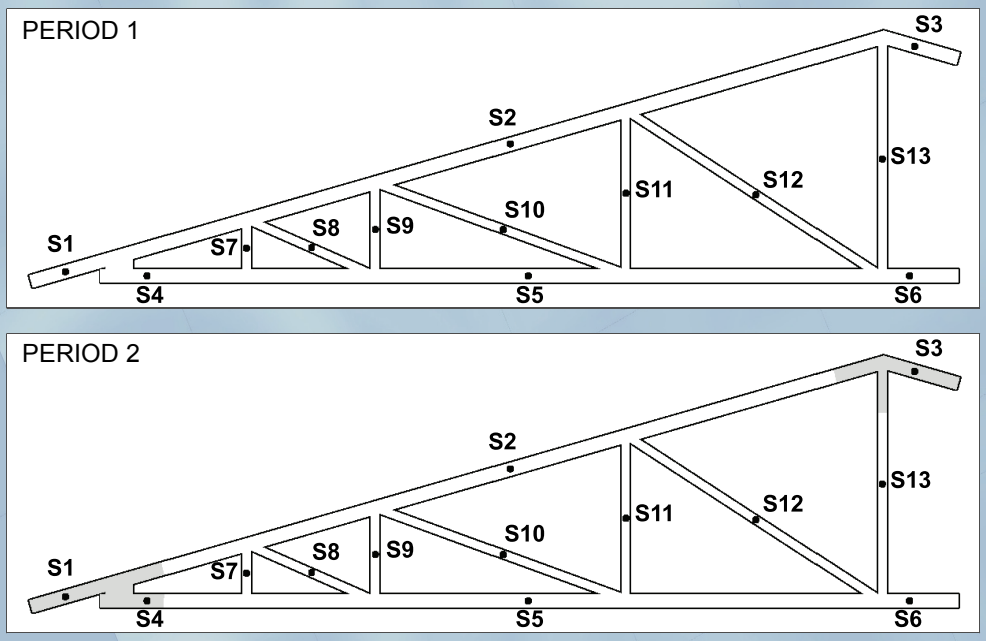
LOCALIZATION RESULTS



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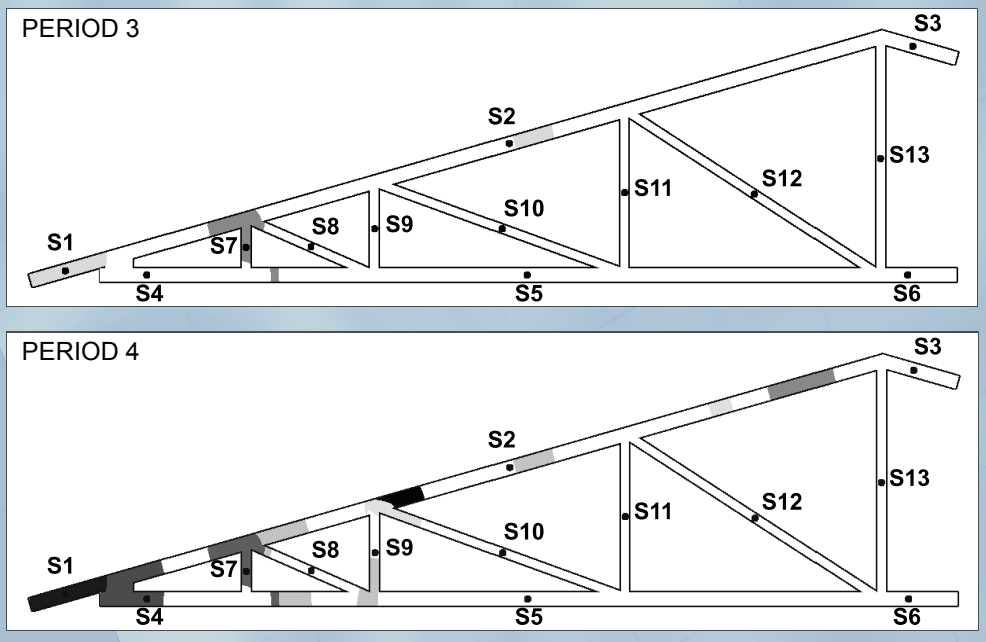
LOCALIZATION RESULTS



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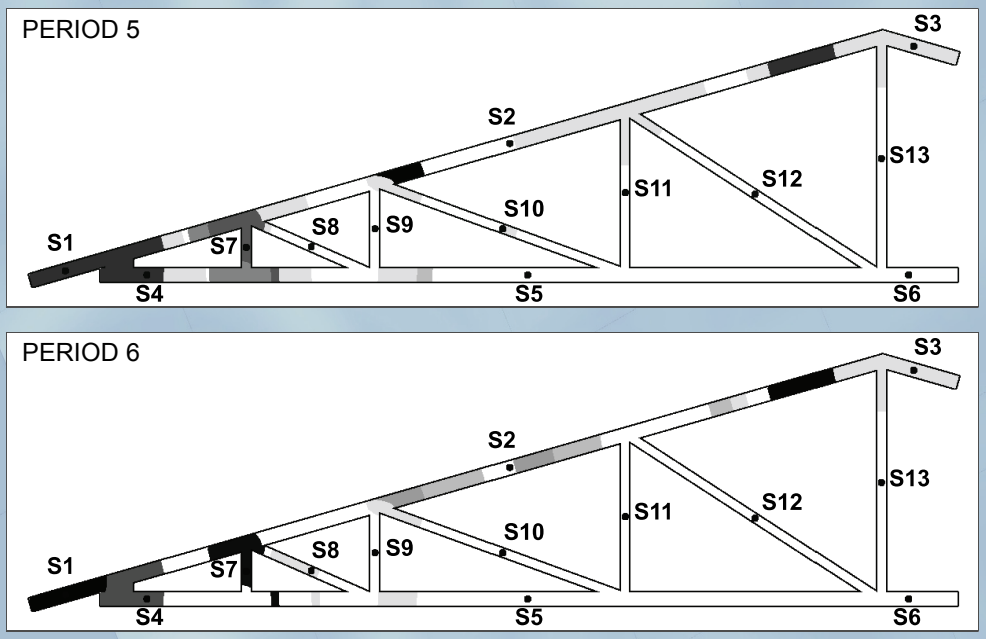
LOCALIZATION RESULTS



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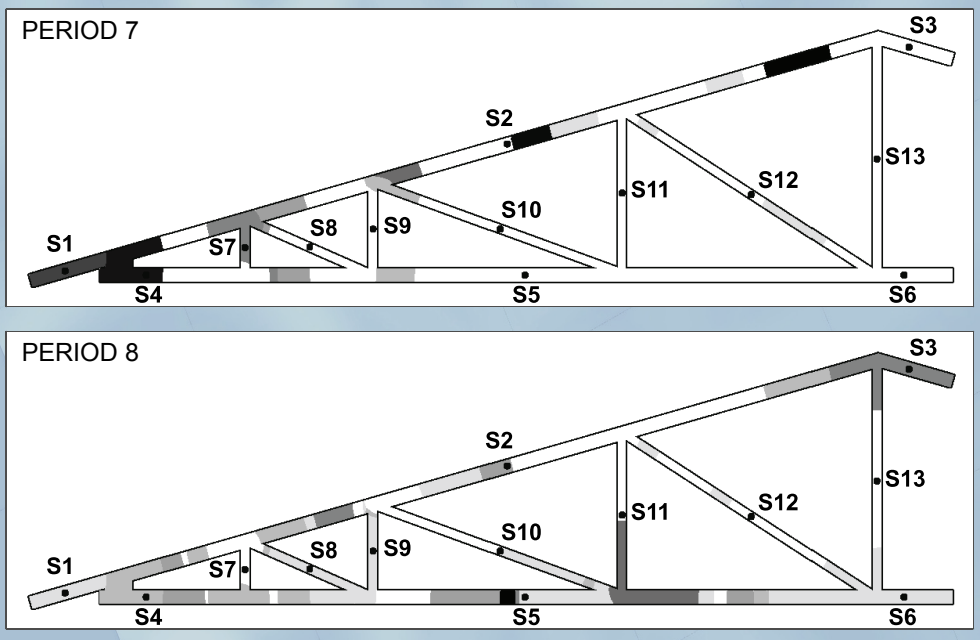
LOCALIZATION RESULTS



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SUMMARY

- All AE data measured during *gradual loading of roof structure* was processed by **ANN** and also by the algorithm of **segment localization** based on first three arrivals of signals to sensors.
- Zones with the *strongest AE activity* correspond to a gradual (incremental) increasing of roof loading, while the emission activity is noticeable especially on *the upper roof segment (period 1-7)*, and final breakdown (period 8) with a strong deformation of *bottom tube*.
- Emission activity was largely influenced by the *deformation of Z-girder*, transmitting the load onto a truss.

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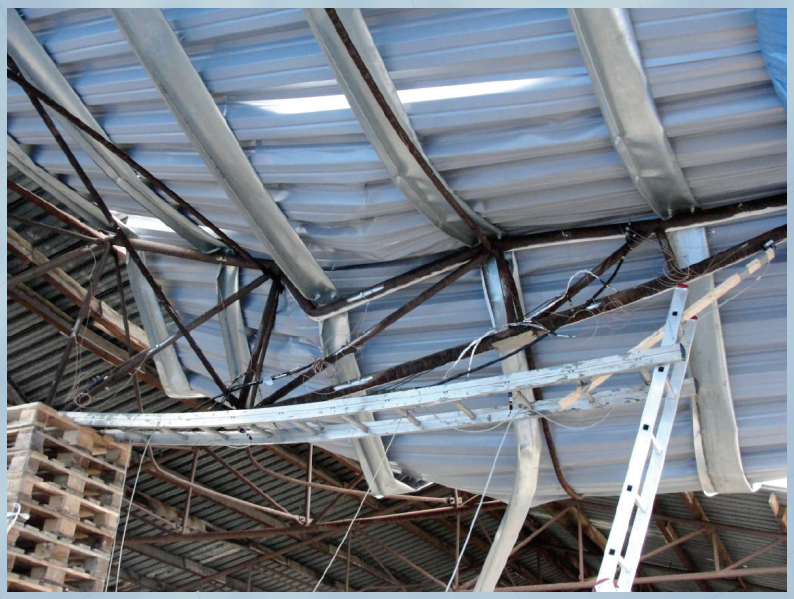

… thank you for attention ...

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