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PROPOSED SHM SYSTEM WITH ACOUSTIC EMISSION (AE) TECHNOLOGY FOR TRAN HOANG NA STEEL ARCH BRIDGE

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ABSTRACT: Tran Hoang Na arch bridge connects the Tran Hoang Na Street and Can Tho Bridge's approach road. The arch bridge is a kind of arch structure with super-static, high deformation. For large steel, the arched bridge is essential to control stress, deformation, and temperature values in the bridge's main structure. It allows managing quality during bridge construction and operation stage. This kind of structure is also affected by environmental factors, especially temperature influence, temperature difference during the day and in the annual cycle, and the impact of wind on hanging cables. The main girder, arches, and arch support construction can be deformed due to the effect of creeping (CR), shrinkage (SH), temperature changes (TU), and temperature gradients (TG). This paper presented the proposed complete SHM system for this arch bridge integrated with acoustic emission (AE) technology to control destructive activities in the bridge and monitor cracks in steel and concrete structures.

Keywords: SHM system, Arch bridge, Acoustic emission, Steel bridge

1. INTRODUCTION

On September 18, 2020, the Tran Hoang Na arch bridge started construction over the Can Tho river, connecting Cai Rang and Ninh Kieu districts. A bridge has a length of nearly 600m, the width of 23m. The main structure is a steel arch with prestressed reinforced concrete. The bridge has been designed for a speed of 60km/h with four lanes. The bridge helps solve the problem of connecting urban traffic between National Highway No 1 and central routes of the Can Tho City, reducing the vehicles passing through the city center, reducing traffic jams at the rush hours. Besides, the bridge has excellent architecture, which is the showcase of the Can Tho City, which is supposed to impact tourism and trade in the region positively.

Fig. 1 The 3D design of the Tran Hoang Na arch bridge crossing the Can Tho river.

Since the arch bridges have been around for a long time, they have become associated with romantic poems and heroic stories. They have become the meeting place of fictional lovers and the dying places of mythical heroes and villains. However, even real-life arch bridges have gained popularity for being charming and enchanting (Fig. 1).

The arch bridge is a complex, hyperstatic structure with multiple indeterminate. With time, the bridge's main facility, such as bridge girders, bridge arches, and arch mounds, may be deformed due to the influence of actual load, environmental conditions, and temperature changes. Besides, the The bridge is a composite steel and prestressed concrete structure, so the determination of the overall deformation and displacement is one of the main goals to determine the effects of the facilities (Fig. 2) [1].

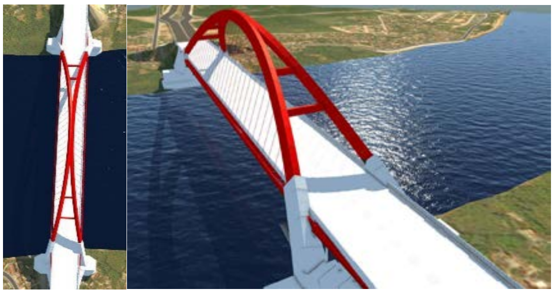

Fig. 2 3D model of the bridge.

Designing arch steel bridges can be challenging since many factors have to be considered. Building them can also be time-consuming, and many workers are required to put them up. Arch bridges need stronger supports than ordinary bridges would since, as explain above, their structural integrity greatly depends on how sturdy their abutments are and how they're well-set into the ground. This is one reason why arch bridges take a lot of time and effort to be built. Arch bridges become stronger over time, but this doesn't mean that they should just be left independently. They need more frequent repair and maintenance than other kinds of bridges since their flexible design makes them more prone to cracking and tearing when exposed to harsh elements. The costs that come from keeping them in good shape can make them more expensive over time [2].

It is very important to control stress, deformation, and temperature values in structural parts with large steel arch structures to control quality during construction and exploitation. Even during construction and operation (Fig. 3).

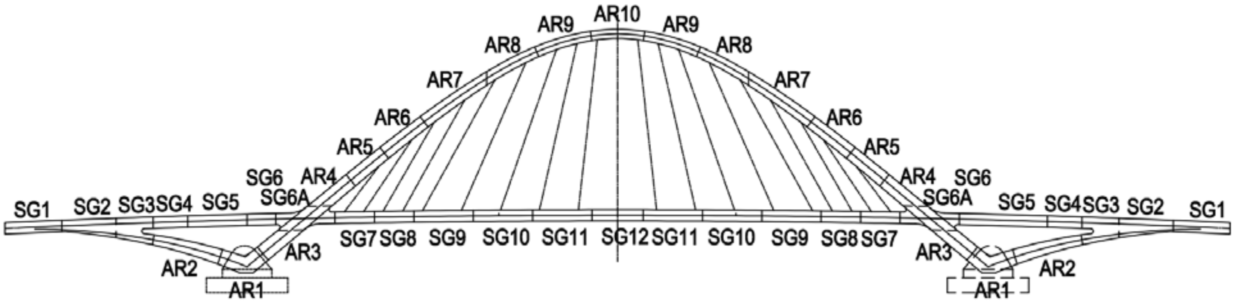

Fig. 3 Construction segment of main bridge steel arch

The arch bridge is also a type of structure greatly affected by environmental factors, especially the impact of temperature, the difference in temperature during the day and night cycle, and the influence of wind on the bridge cable hangers.

To supervise the construction works and manage the works during the exploitation process, experts' regular and periodic inspections have a significant role, especially in assessing structure status and constructing the maintenance frequency reasonably and effectively. However, it takes time and effort to collect and record all the necessary data to understand and evaluate the structural state of the bridge accurately. Thus, the SHM system to overall monitoring system for this bridge is needed. At the same time, combining monitoring with a regular inspection will give us a general and comprehensive view of the bridge [3].

2. RESEARCH SIGNIFICANCE

In this article, the author sets out the requirements and objectives for the monitoring system of the steel arch bridge. And on this basis, propose a general monitoring system for the Tran Hoang Na arch bridge, apply acoustic emission (AE) technology coupled with periodic bridge inspection to allow the bridge management unit to monitor the entire bridge.

3. PROPOSALS FOR THE STRUCTURAL HEALTH MONITORING (SHM) SYSTEM OF THE ARCH BRIDGE

3.1. Objectives of the Bridge SHM Monitoring System

The impact of environmental factors, weather, or other load factors on the bridge is significant. The arch bridge is a complex structure built in areas with modern elements. The amplitude of temperature changes during the day is also very high, so the weather and climatic factors on the project are huge [1].

Because of the above factors, the SHM system's application and the inspection and operation later in the management, operation, and maintenance of the project will bring more efficiency and advantages from the provided data by monitoring equipment. However, stating too many devices can lead to data overload, and the cost of the system will increase. Therefore, the design of a monitoring system to operate appropriately or optimally for the bridge is necessary.

From the above bases, the SHM system for the bridge must be designed based on the design characteristics and technical features of the bridge and clearly defining the number of objects, the main reasons need to measure and observe. Furthermore, the selection of the system's monitoring equipment should consider the following factors [4]:

- Design features, the structure of the bridge, surrounding natural environment
- Components to be observed, quantities to be observed
- Economic efficiency
- Precision and durability of sensors.

The main objectives applied to the SHM system of the bridge, including:

- *Verification of design hypotheses:*

- Provide actual construction data to verify design hypotheses.

- Provide databases to develop appropriate analytical and evaluation methods for the project and develop analytical methods for similar projects.
  - *Maintenance and rehabilitation work [5]:*
- Provide data to detect and evaluate the deformation and deterioration of the building.
- Provide data to develop appropriate and timely maintenance and maintenance plans.
  - *Traffic safety management:*
- Using monitoring data to manage vehicle flow, vehicle load in traffic on the bridge ensures traffic safety on the bridge, like WIM - weight in motion (Fig. 4) [6].

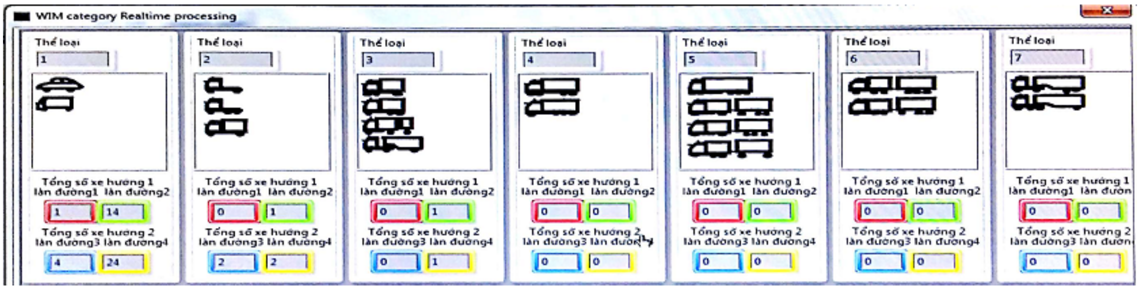

Fig. 4 Example of the WIM screen for traffic and vehicle load management on Bai Chay Bridge.

With the above goals, the SHM system analyzes the data collected from the sensors and identifies the damage pattern. Therefore, it is necessary to build real observation criteria, allowing the collection of all necessary data to accurately assess the health status of the bridge (Fig. 5).

In addition, one of the other important objectives is to establish a model observation system suitable for Vietnamese conditions for large steel arch bridges, ensuring the following conditions:

- Lower the cost of the bridge monitoring system during the construction and installation process and operation and operation by standardizing and selecting appropriate monitoring technologies.
- Improve the effectiveness of the monitoring system by developing sound monitoring procedures and building a structural status assessment system of the building and a decision support system in the operation process, application of construction monitoring system.
- Establish a common database for arch bridges of the same type to manage and process monitoring data and make reasonable operation, operation, and maintenance requirements according to working conditions of each bridge structure from observed data.

3.2. The Scale of The SHM System for the Bridge

Based on the above objectives and requirements, the SHM system for the bridge is proposed; the diagram block of the monitoring system for the bridge is shown in the figure below (Fig. 5) [2].

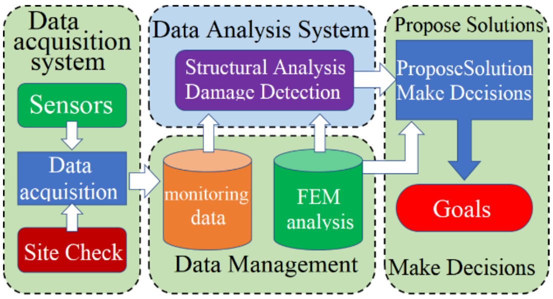

Fig. 5 Block diagram of the monitoring system for the bridge.

Diagram of the monitoring system for the bridge includes four main components:

- Data Collection System - is responsible for collecting data from sensors installed on the bridge, combined with regular and periodic bridge checks.
- Data Management System - Data collected from the Data Collection system will be screened and excluded from noise or inaccurate data using mathematical algorithms; these results combined with calculation results from finite element model FEM for the structural analysis. The application of the finite element model helped to reduce the number of sensors of the monitoring system and, at the same time, perform the inverse calculation from the observed data to determine the factors that could be harmful to the bridge [7, 8].
- Data Analysis System - The next system aims to synthesize data from the Data Management

system to analyze the structural state of the bridge and detect damages that may cause damage to the bridge [8].

- Finally, it is to give solutions and decisions to the management and operation of the bridge to ensure the continuous and efficient operation of the bridge.

3.3. FEM Calculation Model Analysis

To accurately determine the installation locations of the measuring devices and sensors and the growth of physical quantities required monitoring of the the bridge. At the same time, to determine the warning thresholds during the exploitation and evaluation of the changes occurring inside the structure, it is necessary to implement the structural calculation model by FEM finite element method [7]. Therefore, all the parameters of loads a load's combinations (Table 1) are applied to the calculation by a structure analysis program RM2004 (Engineering Software – TDV/Austria/Graz), and a FEM calculation model is obtained as follows (Fig. 6) [9].

Table 1. Load combinations used to calculate the bridge at the design process

NO.	Comb	LOAD COMBINATION LIMIT STATE		DC	DW	LL IM BR CE	WA	WS	WL	CR SH	TU	TG	SE	EQ-T	EQ-L	CV-T	CV-L	Cable Exchange forces (CEX)	Cable Loss Dynamic forces (CLO)	Remark
1	Comb1	STRENGTH I-1	STR1-1	1.25	1.50	1.75	1.00	-	-	0.50	0.50	-	1.00	-	-	-	-			
2	Comb2	STRENGTH I-2	STR1-2	0.90	0.65	1.75	1.00	-	-	0.50	0.50	-	1.00	-	-	-	-			
3	Comb3	STRENGTH II-1	STR2-1	1.25	1.50	-	1.00	1.40	-	0.50	0.50	-	1.00	-	-	-	-			
4	Comb4	STRENGTH II-2	STR2-2	0.90	0.65	-	1.00	1.40	-	0.50	0.50	-	1.00	-	-	-	-			
5	Comb5	STRENGTH III-1	STR3-1	1.25	1.50	1.35	1.00	0.40	1.00	0.50	0.50	-	1.00	-	-	-	-			
6	Comb6	STRENGTH III-2	STR3-2	0.90	0.65	1.35	1.00	0.40	1.00	0.50	0.50	-	1.00	-	-	-	-			
7	Comb7	SERVICE I	SER1-1	1.00	1.00	1.00	1.00	0.30	1.00	-	1.00	0.50	0.50	-	-	-	-			Before CR&SH 30year
8	Comb8	SERVICE I	SER1-2	1.00	1.00	1.00	1.00	0.30	1.00	1.00	1.00	0.50	0.50	-	-	-	-			After CR&SH 30year
9	Comb9	SERVICE II	SER2-1	1.00	1.00	1.30	1.00			-	1.00	0.50	0.50	-	-	-	-			Before CR&SH 30year
10	Comb10	SERVICE II	SER2-2	1.00	1.00	1.30	1.00			1.00	1.00	0.50	0.50	-	-	-	-			After CR&SH 30year
11	Comb11	EXTREME I-1	EXT1-1	1.25	1.50	0.50	1.00	-	-	-	-	-	-	0.30	1.00	-	-			Longitudinal
12	Comb12	EXTREME I-2	EXT1-2	0.90	0.65	0.50	1.00	-	-	-	-	-	-	0.30	1.00	-	-			
13	Comb13	EXTREME I-3	EXT1-3	1.25	1.50	0.50	1.00	-	-	-	-	-	-	1.00	0.30	-	-			Transverse
14	Comb14	EXTREME I-4	EXT1-4	0.90	0.65	0.50	1.00	-	-	-	-	-	-	1.00	0.30	-	-			
15	Comb15	EXTREME I-1	EXT1-C1	1.25	1.50	0.50	1.00	-	-	-	-	-	-	0.15	0.50	-	-			Longitudinal
16	Comb16	EXTREME I-2	EXT1-C2	0.90	0.65	0.50	1.00	-	-	-	-	-	-	0.15	0.50	-	-			
17	Comb17	EXTREME I-3	EXT1-C3	1.25	1.50	0.50	1.00	-	-	-	-	-	-	0.50	0.15	-	-			Transverse
18	Comb18	EXTREME I-4	EXT1-C4	0.90	0.65	0.50	1.00	-	-	-	-	-	-	0.50	0.15	-	-			
19	Comb19	EXTREME II-1	EXT2-1	1.25	1.50	0.50	1.00	-	-	-	-	-	-	-	-	-	1.00			Longitudinal
20	Comb20	EXTREME II-2	EXT2-2	0.90	0.65	0.50	1.00	-	-	-	-	-	-	-	-	-	1.00			
21	Comb21	EXTREME II-3	EXT2-3	1.25	1.50	0.50	1.00	-	-	-	-	-	-	-	-	1.00	-			Transverse
22	Comb22	EXTREME II-4	EXT2-4	0.90	0.65	0.50	1.00	-	-	-	-	-	-	-	-	1.00	-			
23	Comb23	SERCIVE Disp	SER-Disp	1.00	1.00	1.00	1.00	0.30	1.00	1.20	1.20	0.50	0.50	-	-	-	-			
24	Comb24	FATIGUE	FAG	-	-	0.75	-	-	-	-	-	-	-	-	-		-			
25	Comb25	CABLE REPLACEMENT	CAB-RE	1.20	1.40	1.50												1.00		PTI 2012, A5.4
26	Comb26	LOSS OF CABLE	CAB-LO	1.10	1.35	0.75													1.10	PTI 2012, A5.5

Note: Note

SERVICE II Load combination intended to control yielding of steel structures and slip of critical-slip connections due to live load

Where DC Dead load of structural components; DW Dead load of wearing surfaces and utilities; BR Vehicular braking force; CR, SH Creep and Shrinkage; CT Vehicular collision force; CV Vessel collision force; EQ Earthquake; IM Vehicular dynamic load allowance; LL Vehicular live load; PL Pedestrian live load; SE Settlement; TG Temperature Gradient; TU Uniform temperature; WS Wind on structure; WL Wind on Live load

0.166666667
0.833333333
1.25

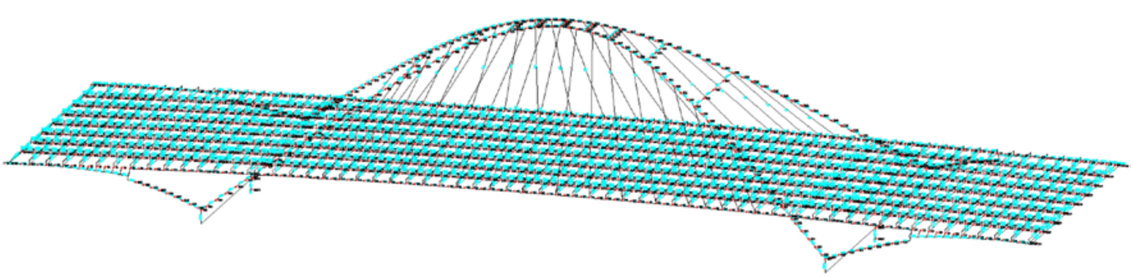

Fig. 6 Finite element analysis (FEM) model of bridge using RM2004 software [9]

The accuracy of the FEM model determines the equipment installation locations and selects the technical criteria applied to the model. It is necessary to perform audit calculations based on technical design documents of the bridge as well as measured values of the required physical quantities from the sensor devices. The analytical calculation model must satisfy the following requirements [8]:

- Correct representation of the bridge, in reality, allows it to the analysis of all the appropriate environmental conditions (wind, temperature) and load combinations impacting the bridge.
- The structure of the calculated model and the accuracy must allow considering the historical factors of the building, the changes of the work from construction to operation and operation.

- The FEM model has to be built by specialized software of the design consulting units in non-linear computational analysis of structures using the finite element method.
- Analytical calculations performed on this model allow us to determine the fundamental physical quantities (displacement, internal force, stress, deformation, etc.) at locations where direct measurement is not possible (not installing sensor). Therefore, the calculation results must be presented in graphic form (load charts and diagrams applicable to the model) and text form (data tables).
- Verify the applied solutions in the calculation model - it is necessary to compare with similar values collected in the past or from direct measurement results (e.g., measuring current tension in a cable car).

Calculation of the bridge during the construction process was divided into 35 stages; the main stages are presented below [9]:

- Construction main pier and temporary pillars
- Assemble the bottom of the arch.
- Assemble the bottom part of the arch with X-shaped beams.
- Assemble the main beam with the rear arch of the main arch, horizontal beam
- Assemble the main beam of section 1 with a horizontal beam
- Assemble the main beam of section 2 with a horizontal beam
- Installing arch supports, assemble arch segments 1 and 2
- Install 52m steel arch section, horizontal frame, temporary cable after that assemble main 52m main girder section with horizontal beams.
- Deinstallation temporary support system, arch support frame, and temporary cable
- Assemble hanger cables (10, 9+11, 8+12…1+19), deinstallation scaffolding system, and temporary pillar
- Constructing concrete slab of the bridge
- Unite bridge deck slab and construction of asphalt concrete layer.

The final calculation model impacted various load combinations such as temperature difference, shrinkage and concrete creeping, wind loads, and a load sequence at the service stage (Fig. 7). In this way, deformations shapes, displacements of arches, and main girders are obtained from these load combinations as Fig. 8 below [9].

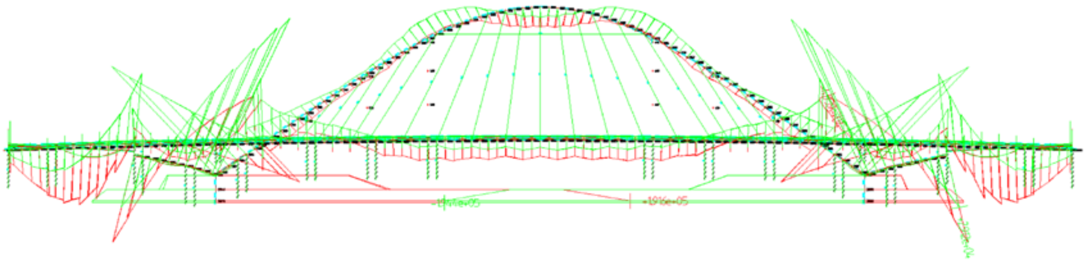

Fig. 7 Example of internal force results of demand extracted from RM2004 software.

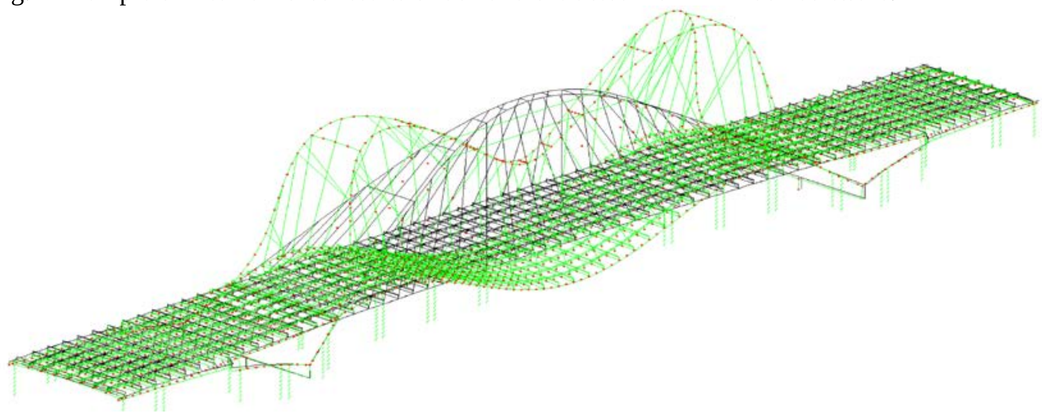

Fig. 8 Bridge buckling shape under extreme combination load at service stage.

3.4. Requirements for Sensors Installed on the Monitoring System for the Bridge

To determine the location and type of monitoring equipment for the bridge, we need to consider technical and economic factors based on the main objectives and the main quantities to be measured and refer to the development of technology for monitoring similar bridges in the world.

The quality of the measurement results (physical quantities) should be close to the reality and the goal set for the system. Therefore, it is essential to choose the types and devices of sensors to ensure all necessary data for the most effective monitoring and maintenance of the bridge [2]. Hence the vibrating wire sensor and the acoustic emission (AE) technology were proposed (Fig. 9, 10) [10].

Fig. 9 Some types of vibrating wire sensors of Geokon.

Sensors must be durable enough to withstand the harsh influences of the weather and climate in Vietnam [2, 11].

- The arrangement of monitoring sensors must ensure a complete collection of monitoring data to reflect the most accurate reality of the work. Therefore, the wind gauge is necessary to obtain data on the deformation of the building under the impact of high winds.
- To effectively monitor and manage traffic, sensors for wind measurement and rain measurement are needed.
- Next is the accelerometer, electromagnetic sensors, altimeter, erosion gauge; the need is lower because these measurements can be measured directly by measuring, periodically by experts.
- The installation of the concrete stress monitoring device in the arch base and the mound from the structural stage is required because the thrust force along the bridge center directly at the bottom of the large arch is large (similar to Dragon Bridge in Da Nang).
- The sensors to monitor the cracking phenomenon in concrete before appearing on the structure surface is also an essential factor to warn of adverse events happening to the structure.
- The number of sensors must be sufficient to ensure reliable data so that the maintenance is carried out effectively and appropriately.

3.5. Acoustic Emission Evaluation of Steel Structures

Basic acoustic emission monitoring is carried out during the routine operation of the facility under load (in exceptional cases under the test load).

The tests performed during the routine operation of the facility aim to [10]:

- look for active damage processes (progressing under service conditions) in the structure;
- identify and locate the damage;
- estimate the risk potential of the damage;
- determine the extent of the risk posed to the safety of the facility under routine operation.

The µSamos system (PAC MISTRAS Corp., 195 Clarksville Rd, Princeton Jct, NJ 085, USA) with three PCI-8 cards was used to develop the reference signal databases (24 measurement channels) used in subsequent stages to assess the condition of steel and concrete structures. Flat type sensors operating in the frequency range of 30–80 kHz were used for all structures. A 55 kHz sensor was also used in the concrete structures. Signal amplification was 40 dB. AEWin software was used for the measurements (Fig. 10).

To analyze the measurement data, Noesis 5.8 - ADVANCED DATA ANALYSIS PATTERN RECOGNITION SOFTWARE (PAC MISTRAS Corp., Princeton, NJ, USA) was applied. The reference signal database was created using 13 parameters of acoustic emission: rise time (µs), counts to peak amplitude, counts, energy (EC), amplitude (dB), average frequency (kHz), root-mean-square (RMS) (V), reverberation frequency (kHz), initiation frequency (kHz), absolute energy (aJ), signal strength (pVs), duration (µs), and average signal level (ASL) (dB) (Fig. 11) [12, 13].

Fig. 10 AE Sensors and Multichannel processor of acoustic emission technology (Vallen).

Acoustic Emission Evaluation of Steel Structures involves analyzing changes in the intensity of acoustic emission signals generated in particular zones of structural elements under routine use. Recorded AE signals are grouped into classes to which various destructive mechanisms are assigned. The number of parameters used to build the database of reference signals must be consistent with the number of previously registered parameters of AE signals [11,12].

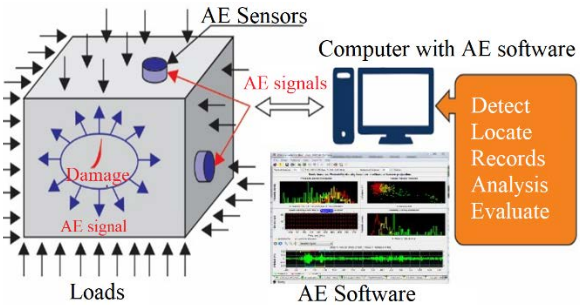

Fig. 11 Acoustic Emission equipment set-up [14]

The risk posed by generating processes within one class is determined by the so-called intensity code of destructive processes. These processes are best illustrated by graphs where each AE signal is assigned to one point. The color and shape of the point indicate the class to which the given AE signal belongs. The classes, symbols, and codes are summarized in Table 2. Training patterns are used for the grouping and classification of AE signals.

Table 2. Classes, symbols, and risk codes for steel bridges [12].

Color	Class Risk	Code	Risk	Mean
(light blue square)	No. 1	0	Very high	-
(green square)	No. 2	1	High	crack propagation
(blue square)	No. 3	2	Medium	crack initiation
(red square)	No. 4	3	Low	yielding of steel at the crack tip
(purple square)	No. 5	4	No risk	-

Class No.5 - the constant AE noise generates signals. Classes No. 4, No. 3, and No. 2 of signals are generated by single destructive mechanisms. Class No.1 includes the signals resulting from the superposition of waves generated by more than one destructive process and crack surface friction.

The occurrence of signals of all classes during the monitoring period is regarded as another item among the codes defining the influence of defects on the structural condition. It indicates the presence of destructive processes in the structure.

The extent of damage is assessed using the zone location results and AE signal classification in the zones [15]. The individual signal of class means is shown in Table 3.

Table 3. Classes, symbols, and risk codes for steel engineering constructions [12].

Color	Class Risk	Code	Risk	Mean
(red square)	No. 1	0	Very high	rupture
(pink square)	No. 2	1	High	friction
(blue circle)	No. 3	1	High	crack propagation
(light blue square)	No. 4	2	Mid-to-high	crack initiation
(blue diamond)	No. 5	3	Medium	Perforation deformation
(lilac triangle)	No. 6	3	Medium	material losses
(black triangle)	No. 7	4	Low	surface corrosion
(green square)	No. 8	5	No risk	work in the elastic range

3.6. Monitoring Data Acquisition Software

The specialized Monitoring Data Acquisition Software of the bridge monitoring system needs to be integrated with the following components [2, 16]:

- Collection of monitoring data (collect and store static/dynamic monitoring data of the structure under the impact of the load combination operators)
- Analysis (perform calculations and analyze monitoring databases collected from the monitoring system)
- Supporting decisions (allowing checking, comparing with safety criteria, pre-established monitoring thresholds)
- Report - alerting (passing the internet warning information to the owner/building management agency when the technical specifications are not guaranteed, making the report forms with the support of SHMS expert on safety and construction status).

The software of the monitoring system for the bridge should perform the following functions:

- Establish and control monitoring processes, monitoring cycles,
- Collect monitoring data from sensor devices,
- Store the database of monitoring for inspection, periodic inspection,
- Display processed monitoring data and historical data in different graph formats as required by the investor,
- Perform the necessary calculations according to the request of the investor
- Display information, warnings (in the case observed values exceed the allowable threshold, set up reports),
- Assigning access rights, detecting system errors, detecting unauthorized accesses, securing the system.

The monitoring software should include two main components - the user-only component, the manager-only component, with deep access to the system. The feature to communicate with normal users (system monitoring specialists) needs to transfer and display the most basic information of the scenario through communication channels such as the internet, mobile networks by email or text message. The component is only for regular users, can only be accessed anywhere, anytime through the web browser when the user/group of users has been licensed and authorized with the Security Code. The monitoring system management software requires a user-friendly interface, easy to understand, easy to use, highly informative, and graphic with 3D models of the bridge. At the same time, the model (3D) must clearly show the technical elements of the project and the locations where the actual outdoor monitoring equipment is set up [7, 8, 16]. The software must also allow the display of graphs showing the observed quantities after mouse manipulation on the installation positions of the monitoring equipment on the model [7, 8].

4. PROPOSED DESIGN OF MONITORING SYSTEM FOR THE BRIDGE

Based on the results of calculations of the FEM model bridge in the RM2004 program, regarding the bending moment (Mz) of load check at the service stage (Fig. 12, Fig. 13) [9], the shape of displacements and deformations of arches and main girders under various loads, such as temperature difference, shrinkage and concrete creeping, wind loads as well as a load combination at the service stage, the number of the sensors were selected and presented in the table below, while the location of the sensors is shown at Table 4 and in Fig. 14 below.

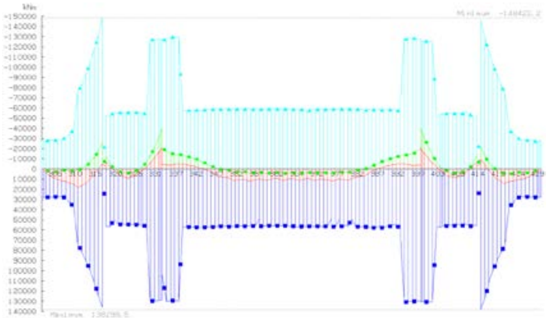

Fig. 12 Ultimate extreme bending moment (Mz) of load check at service stage.

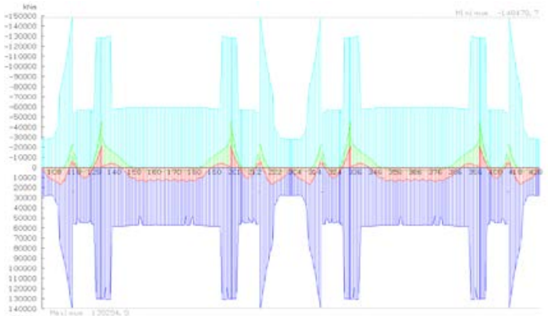

Fig. 13 Ultimate strength bending moment (Mz) of load check at service stage.

A monitoring system for the bridge is proposed, and the block diagram of monitoring equipment for the bridge is shown in the figure below (Fig. 14). A diagram of the monitoring equipment and sensors arrangement of the bridge is shown in Fig. 15. Finally, the list of devices and their functions proposed for the SHM system of the bridge is shown in Table 4.

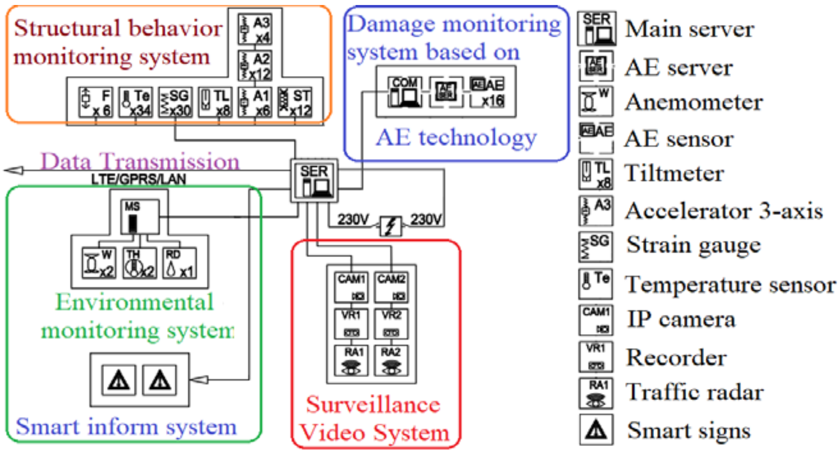

Fig. 14 Block diagram of the bridge monitoring system

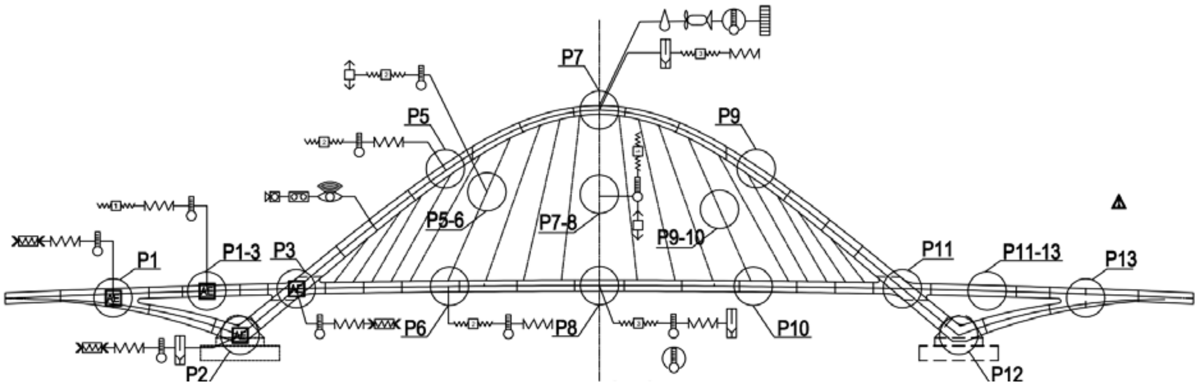

Fig. 15 Diagram of arrangement of monitoring equipment for the bridge.

Table 4. List of devices and their functions proposed for the SHM system of the bridge

No.	Sensor and device	Description	Symbol	Quantity
1	Traffic radar	Radar monitors vehicle flow and controls vehicle speed	RA	2
2	Acoustic Emission Sensor	to monitor the phenomenon of cracking in concrete before appearing on the surface	AE	16
3	Acoustic Emission Multichannel Server	digital multi-channel AE measurement system	AE-SER	1
4	Force sensor in cable	Force measurement sensor in the cable hanger	F	6
5	Anemometer	Measure wind speed and direction, also a typical weather station instrument	W	3
6	Air thermometer	The sensor measures air temperature and humidity	TH	2
7	Thermometer	Temperature sensor - thermometer, measuring the temperature inside the structure	TE	34
8	Strain Gauge	for the measurement of strains in structures	SG	30
9	Rain Gauge	measure the amount of rain precipitation over an area in a predefined period	RD	1
10	Accelerometers (1-axis)	Measure the vibration frequency of an element's structure in one direction (main girder, steel arch)	A1	6
11	Accelerometers (2-axis)	Measure the vibration frequency of an element's structure in two directions (hanger cable)	A2	12
12	Accelerometers (3-axis)	Measure the vibration frequency of an element's structure in two directions (top of the steel arch)	A3	4
13	Embed Strain Gauge	Embedment Strain Gauge measure dynamic strains in concrete structures	ST	12
14	IP Camera	High-definition surveillance IP cameras and video recording and storage equipment	CAM+VR	4
15	Tiltmeter	Tilt sensors allow detecting orientation or inclination of the steel arch base	TL	8
16	Monitoring server	Monitoring server and software	SER	1

5. CONCLUSION

The proposed SHM system for the Tran Hoang Na arch bridge with acoustic emission evaluation for steel structures and the proposed global monitoring system based on the measurement of acoustic emission signals accompanying destructive processes covers the entire volume of the element under test its selected part. Therefore, it allows locating and identifying active, destructive processes and their dynamics in real-time.

The data collected can be the basis for determining the structural condition of the structure [2, 16]. The SHM system is a useful tool for:

- the assessment of the health of a structure and identification of potential risks;
- the monitoring of the dynamics of destructive processes;
- the support in the decision-making process concerning the risk management;
- the assessment of the repair work quality and outcome;
- the assessment of non-standard vehicle traffic.

The findings presented in this article indicate that the use of the acoustic emission method with the systems of the global structural health monitoring ensure insight into the condition of structures.

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