Case study regarding the dynamic compensation of steel-concrete bridge hybrid structures

M C Scutaru¹, N Țăranu¹, C C Comisu², G Boacă³, D N Isopescu¹ and D Ungureanu¹
¹Department of Civil and Industrial Engineering, Gheorghe Asachi Technical University of Iasi, Blvd. Mangeron, no. 1, 700050, Iasi, Romania
²Department of Transport Infrastructure and Foundations, Gheorghe Asachi Technical University of Iasi, Blvd. Mangeron, no. 1, 700050, Iasi, Romania

E-mail: scutaru.my@gmail.com

Abstract. Transport infrastructure is one of the most important elements needed for the reliable development and economic growth in an evolving country. Because most of the infrastructure is already built, road managers consider necessary to study, develop and implement bridge degradation monitoring systems. If the technical state of the structures is known in every moment, decisions to intervene on degradations at the right moment from the very first stages of their development can be made more easily. In order to implement an efficient monitoring system, it is necessary to know the dynamic characteristics of the non-degraded structure, and that is difficult to achieve when bridges are already in operation. To minimize those disadvantages, researchers have developed various methods of modelling structures to address the lack of initial data. In this paper, the authors present a case study about the determination of the modal shapes, the frequencies and the displacements of the bridge located on the national road DN 28 at km 6 + 957, in Șcheia, Romania. The superstructure will be modelled through the Ansys program, determining the theoretical dynamic characteristics. These will be needed in the next stage of the experimental process to compare the numerical data to those from the in-situ monitoring system.

1. Introduction
For any society, facilities to move people and transport goods are essential. Annually, EU governments allocate up to € 1.000 billion or more than 10% of the Gross Domestic Product (GDP) to transport industry, which employs more than 10 million people. Most of the industry is occupied by the road network. Due to its high percentage of use, its role is essential for the social and economic life not just of Europe, but of the whole world [1-3].

Bridges are designed to ensure the continuity of the communication path against obstacles leaving space for the continuity of the obstacle [4] to establish new economic relations and to contribute to the faster transport of goods and people. However, due to budget constraints, the engineers responsible for bridge design and construction strive to develop new methods of cost reduction of both construction and maintenance, improving the sustainability of the structure. In all developed countries, most of the transport infrastructure is already built; the challenge is, therefore, the maintenance of the road network. Most of the time, this challenge is more expensive than the total replacement of the structure.

Nowadays, the process of tracking the behaviour of bridges over time is mostly done through visual inspections. As this approach does not provide a high degree of safety with regard to how the
resistance and safety ratings are provided by the structure, researchers in the field together with administrators have developed complex systems to estimate and identify the occurrence and evolution of degradation as quickly as possible. These permanent monitoring systems are denoted by Structural Health Monitoring (SHM) [5, 11].

SHM represents the process of implementing a defect identification strategy. At the beginning of the development of these technologies, they were used in aerospace and mechanical engineering [6-8]. This type of system can integrate the actual practice of visual inspections and combine it with the data provided by different sensors installed on the structure [9].

SHM systems involve observing structural behaviour over a relatively long period of time using direct measurements of various parameters considered to be defining for the quantification of structural degradation status, extraction of variance of these parameter values, and statistical analysis thereof. All these steps are performed in order to determine the degradation state of the structure. In the long term, the monitoring process aims at periodically updating information on the evolution of the structure resistance and its capacity to take up traffic and environmental loads. The defects and degradations suffered by any bridge are mainly caused by the inevitable aging of the structure and materials used to build it, as well as the accumulation of damages due to external environment. In exceptional cases (e.g. the occurrence of a bridge explosion or earthquake), SHM systems are used to perform a rapid assessment of the condition and performance of the structure [8, 10].

To ensure the efficient use of the SHM systems, the first step is the numerical modelling of the structure through the finite element method to determine its dynamic characteristics. Following this modelling, the characteristic sections where the data capture units will be mounted are established.

At the same time, the modelling of the instrumented structure is also used during the actual monitoring phase, especially in cases where no dynamic data are available for the structure since it was put into operation. The lack of this information is a real problem for researchers in the field, due to the impossibility of comparing the data captured in-situ on degraded structures with the data from the ungraded structures. In order to perform this comparison, degradation needs to be determined.

The purpose of this paper is to describe the first steps taken in an experimental program aimed at modelling and instrumentation of the bridge located on the national road DN 28 at km 6 + 957 near Șcheia, Romania. Thus, the paper presents the first steps in modelling the mixed bridge structure using the finite element method in ANSYS program, along with the characteristics of the non-degradation metallic structure that result from this modelling.

2. Presentation of the Șcheia Bridge structure
Șcheia Bridge is located at km 6 + 957, near Șcheia, Iasi County, ensuring the continuity of the national road DN 28 over the River Siret.

The structure was built in 1958; rehabilitation works were carried out most recently in 2002 and regular maintenance works in 2015. Due to the specific national road that ensures their continuity, the bridge has two lanes, one for each sense and two sidewalks (figure 1). The width of the structure road section is 7.44 m with two sidewalks of 0.85 m each and the width measured between the inner sides of the parapet is 9.52 m.
In longitudinal section, the structure has 4 spans of different lengths (two spans are 50.35 m long and two spans – 60.00 m), resulting in a length of the superstructure of 220.70 m and a total length of 236.90 m (figure 2). The bridge is made up of a mixed steel-concrete structure and has a static beam pattern, with two expansion joints at the ends of the structure and 21 intermediate joints of the concrete slab in the mixed structure.

The bridge superstructure is made up of two full-length continuous steel girders with a reinforced concrete plate on top. The main girders have a constant height of 2.40 m, the distance between them being 7.00 m. They are stiffened with short strips disposed at the interax distance of 5.00 m, and, at the bottom, with horizontal bracings (figure 3).
3. Presentation of the superstructure modelling through the Finite Element Method (FEM) using the ANSYS program

In order to determine the dynamic characteristics of the metal structure of the bridge under consideration, the ANSYS R15.0 software was used because of its convenient performance. Due to the complex geometry of the structure, the authors have decided to make their modelling in 3D form through AutoCAD 2015, which provides a more user-friendly environment for developing such a structure (figure 4).

At the end of the modelling, the structure was imported into the ANSYS environment for analysis. The elements thus modelled were considered to be of beam and of shell type (figure 5).
Figure 5. Modelling the Şcheia Bridge superstructure in ANSYS R15.0.

The limit conditions of the experimental model used were those of a double embedded beam. In this way, any movement of both ends of the type I beams was blocked.

Through the indicated program, the first 6 vibration modes of the steel structure of the bridge were determined along with the characteristic frequency of each mode and the total displacements of the structure. For this purpose, weight loading was used, this being a first step in the proposed experimental program.

After loading the model of the Şcheia Bridge in the ANSYS program, the structure coordinate system was defined and discretised (figure 6). This discretization resulted in 384,825 nodes and 52,855 elements, values considered to provide increased confidence in the analysis results.

Figure 6. Discretization of the Şcheia Bridge in ANSYS R15.0.

4. The dynamic response of the resistance metal structure of the Şcheia Bridge
As mentioned before, following a modal analysis implemented by the ANSYS program, the characteristic frequencies, the vibration modes of the resistance structure and the total displacements corresponding to each vibration mode were determined. The frequency values of the first 6 modes are given in table 1.

It can be seen that the range of frequency variation is between 1 and 8 Hz for the analysed vibration modes. The main advantage of knowing these values, and implicitly, the variation range, is the ease of purchase of the most suitable types of accelerometers. They will be responsible, in the next stages of the experimental study, for monitoring the structure of the analysed bridge and for automatically
capturing and transmitting data to a central server where they will be processed to determine the occurrence and development of degradations that affect the safety of the structure and users.

Table 1. The structure frequency values according to the vibration mode.

| Mode | Frequency [Hz] |
|------|----------------|
| 1    | 1.4835         |
| 2    | 3.1442         |
| 3    | 3.2007         |
| 4    | 4.0631         |
| 5    | 5.0618         |
| 6    | 7.1264         |

The studied vibration modes of the metallic structure are illustrated in figures 7 – 11. As it can be observed, the most required elements correspond to the characteristic cross section located at the midspan. This is due to the fact that, in 4 of the 6 cases (figures 7, 8, 10, 11 and table 2) maximum values of the movements are recorded in the respective sections.

At the same time, other characteristic sections that we will focus on are also the sections arranged at 1/3 of the span of the analysed beams on both sides of the central area. These sections recorded maximum values in vibration modes 3, 5 and 6 as shown in figures 9, 11, 12 and in table 2.

Figure 7. The first vibration mode.

Figure 8. The second vibration mode.
However, it can be observed that in case of vibration mode 3, the maximum displacement value is recorded only for the 1/3 section of the span, with lower values recorded in the central section (figure 9 and table 2).

![Figure 9. The third vibration mode.](image)

In the vibration mode no 5 (figure 11), for the characteristic frequency of 5.0618 Hz, the structure presents, at the same time, 3 characteristic sections in which the maximum displacement of 4.5341 mm (table 2) is recorded. These sections are located in the centre of the beam and 1/3 of the span, on both sides of the central area. From this point of view, the 5th vibration mode can be considered one of the most complex of the six analysed.

![Figure 11. The 5th vibration mode.](image)
The 6th vibration mode shows a special deformation (figure 12). The maximum displacement is recorded in the section corresponding to the 4th central cross bar point within the main girders and the longitudinal struts in the left-hand section of the analysed span. Low values close to 0 mm are recorded in the centre of the structure.

![Image of vibration mode](image_url)

**Figure 12.** The 6th mode of vibration.

Table 2. Displacement values according to vibration mode.

| Mode | Displacement [mm] |
|------|-------------------|
| 1    | 4.5622            |
| 2    | 4.2232            |
| 3    | 4.8733            |
| 4    | 5.566             |
| 5    | 4.5341            |
| 6    | 5.0511            |

5. Conclusions

This paper presents the modal analysis of the mixed concrete – steel structure of the Scheia Bridge, located near Scheia, on the national road DN 28 at km 6 + 957. The first stage consisted in modelling the steel framing system of the bridge in order to determine its modal characteristics. In a following stage, the concrete bedding should be shaped, establishing the cooperation between the two materials.

Knowing the vibration modes of the structure in the experimental stage the accelerometers will be mounted at the points where the maximum values of the movements were recorded in all the vibration modes analysed. These characteristic sections are pushed to the centre of the structure and 1/3 of the length, in both directions.

A next step in using modal data through the Finite Element Method is to validate and verify the resulting data. This is done by comparing the frequencies of the structure obtained from the software with those recorded by the sensors. Depending on the differences found, the geometry of the structure used in the modal analysis is validated or improved (if there are different inconsistencies between the results). These steps occur at the beginning of the monitoring and after comparing the in-situ data with the structure `modelling`. In this way it is easy to determine the occurrence and the development of degradations that could affect the structural safety.

The paper is part of a complex research program developed within the “Gheorghe Asachi” Technical University, Faculty of Civil Engineering and Building Services in Iasi, Romania. This
research is about studying the way bridges are maintained throughout the world and our country and developing SHM system for bridges.

6. References

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