Prediction of the behavior of a bridge using the deformation model

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Abstract

Deformation analysis, especially for constructions of particular importance, is an up to date theme. Improving the process of determining them and reducing the time needed to analyze the results are the main concerns of researchers in the field.
The present paper aims to highlight the steps necessary to achieve the prediction of the behavior of a bridge located on the A2 Highway over the Danube-Black Sea Canal, based on the measurements made for the deformations determination. It also aims to demonstrate the usefulness of implementing deformation analysis results in risk management.
Based on the measurements made in several phases, the deformation model is made using the finite element method. Information about the structure of the bridge and the forces acting on the structure, is later added to this deformation model. The model is tested and adjusted until it is stabilized, in other words the results provided by the model need to check out with measurements from the next phase.
After stabilizing the model, it can be used for various purposes, such as: determining the deformation values we expect in the next phase, which can be used for consolidating when required, verifying the maximum forces the bridge can sustain without incurring major physical depreciations, verifying some hypotheses that relate to limit situations to determine how the structure will react.
Therefore deformation analysis can be a starting point for risk management, especially when we consider large constructions or constructions of great importance. The data obtained for the deformation analysis can be used in simulation systems so that forecasts can be made regarding how the construction is going to behave in case of risk situations.
We can set the ”alarming” parameters that can be overcome without producing irreversible effects immediately, but which can draw the attention to potential problems of those responsible. Thus decision-makers have sufficient time to verify various assumptions, to take pre-decisions and apply them so that the negative effect is diminished or eliminated.
The destruction of great constructions can lead to environmental damage, but more than that, they can affect the health and integrity of the people exploiting it, and the safety of people and the reduction of pollution are priority issues at both national and international level, which is why it is necessary to implement a risk management system.
I believe that there is the necessary data to start such a process for many constructions of great importance and I also think it would bring many benefits to the big beneficiaries, giving them the chance to prevent unwanted events and to prepare properly the construction in order not to suffer major damage.

Keywords

Monitoring, deformations, finite element, prediction, deformation model, bridge, structure

1. Introduction

People have always been interested, for various reasons, to get from one place to another and their goods as well. So valleys, mountains or rivers have been considered an impediment or problem in achieving this goal. To meet this need, people have found various solutions, starting from swimming, then using a rope, to building a bridge from the simplest materials: stone, wood and other materials that were available at the time.
The history of bridge development is very closely related to human evolution and civilization. The first bridges were made up of a single beam, a tree trunk, bamboo sticks or ropes that used to be fitted with large baskets in which the traveler stood. Subsequently, bridges began to develop in a form closer to the one we know today, with much simpler structures, but allowing the transport of people and goods.
Bridges are art constructions of great importance from the past and were so far built to cross valleys, water courses or communication paths. They provide a link between two territorial elements that would otherwise not be possible.
As a testimony to their importance, there are bridges built a

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long time ago, some of which are still functional today, of course this is due to both good design and adequate maintenance work. These structures have had , from past to present, not only a everyday use importance, but even a strategic one.
The design of the bridges and their structure is determined by the function the bridge will perform.
The materials, design solutions and the technology for the realization of these type of works, as in the case of the other constructions in the field of civil engineering, have experienced a great development, so the final shape and the actual structure of the bridges has evolved from the traditional forms to the current, adapted to this technical and technological progress.
The evolution of the models used in the execution of the works came also in support of the execution of some special works in this domain, the current ones assume the use of machines that make it possible to carry out the work in a much shorter time than the previous ones.

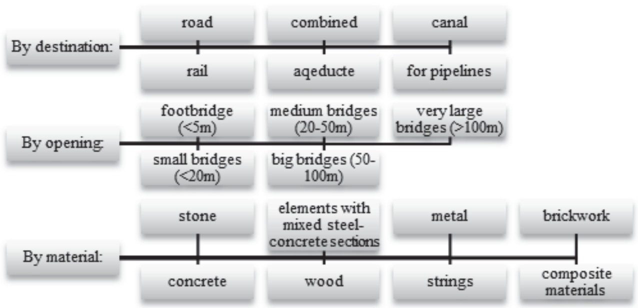

Fig. 1 Classification of bridges

Next in this paper we will refer to a road bridge, built over the Danube-Black Sea Canal, located on the A2 Highway, which connects Bucharest to Constanta.
Roads and bridges are constructions of special importance for ensuring daily human activities, being even vital, and even more a combination of them supports the communities where they are located, but also the people who transit them, significantly reducing the time and costs to get to the desired location.
In our country the road bridges have known a more pronounced development after 1953 when the Institute for Shipping, Naval and Air Transport Design (IPTANA) was established.
The permanent evolution of the bridges has been imposed due to the progressive and rapid growth of road traffic, due to the development and modernization of the road network, due to the development of urban areas and the need for fluidization of traffic in the intensely circulated areas and the entry and exit areas of the city.
The construction of such a structure is a complex mission involving several fields of activity, based on constructive solutions for technical and economic studies, which in turn are based on indices such as maximum flows, gauges and various local conditions.

The studied bridge is located at the highway mentioned above, Km 93 + 645 and it is composed of two independent structures, practically one bridge being made on each direction, both having the same structure and being symmetrical with respect to the highway axis.
Each bridge has a continuous beam structure made by console molding, having three openings. The total length of the bridge is 312 meters, being one of the longest road bridges in Romania.
The superstructure of the bridge is supported by seismic supports on the two-pile and two-pane infrastructure. Due to the dissipation provided by the dissipating supports, the bridge structure develops only elastic behavior under a rare seismic load. To prevent the slide from sliding as a precautionary measure, antiseismic locks have been provided for the supports on the piles.
The two piles of the bridge have identical shape, but different heights, respectively 17,40m and 16,15m, and at the base of the pile elevations were made identical abutments, drowned type, due to the relevant height of the back embankment of 8,80m, respectively 10.50m.

2. Deformation analysis

Deformation is the shape modification of an object and is manifested by changing the relative distance between the characteristic points of the examined objective.
A construction subject of a request regime during its operation and its exploitation, may suffer linear, angular or specific displacements and/or deformations.
For the studied bridge, linear displacements, arrows, are the object of the analysis. Their size is determined and verify that they fit within the allowed tolerance, as implied by the actual standards. The arrows appear on some linear construction elements, such as beams, pillars or plates submitted to horizontal and vertical displacements, which lead to their bending.
For the deformations analysis were recessed in the bridge tracing marks in:

- the central opening of the deck

B1-B2-B3 – to the Medgidia pile
A1-A2-A3 – bridge axis
B’1-B’2-B’3 – to the Constanta pile

- piles and abutments

C1-C2-C3 – in support on Medgidia pile
C’1-C’2-C’3 – in support on Constanta pile
G1-G2-G3 – in support on Medgidia abutment
G’1-G’2-G’3 – in support on Constanta abutment

- joints

F1-F2-F3
E1-E2-E3
D1-D2-D3
D’1-D’2-D’3
E’1-E’2-E’3
F’1-F’2-F’3.

This is suggestively represented in Fig. 2.

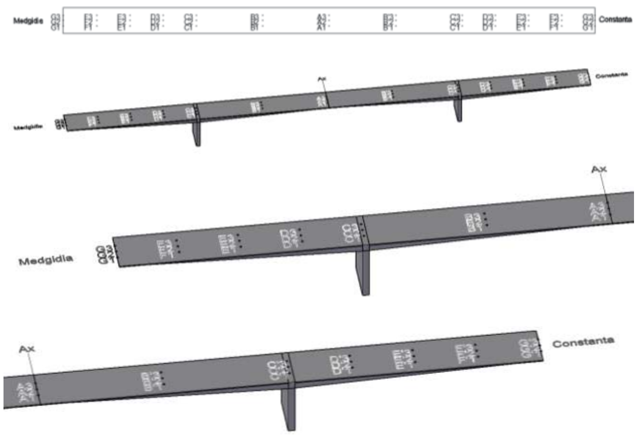

Fig. 2 Tracing marks – location on the bridge

The results of the deformation measurements were obtained as a result of bridge tests, with static and dynamic actions, to analyze the behavior of the bridge structure under their action. It is therefore analyzed whether or not the bridge behaves as foreseen in the design from the following points of view:

- the stability and strength of the structure;
- the dimension of the deformations occurring on the characteristic points of the bridge;
- operation under different static and dynamic loads;
- compliance with the calculation provisions;
- dynamic parameters of the structure.

The purpose of tracking deformations and making any necessary technical revisions is to locate in time possible bridges failures or degradations to take remedial action before these failures or degradations worsen and lead to irreparable damage that reduces capacity bearing or to road constraints on that bridge.

Track behavior of the bridge may be current or special. In current tracking, as in the case of constructions, observation and control operations are carried out over a period of time, in order to identify possible deficiencies or degradations, the dimension of their effect and informing decision-makers interested in timely remedial action.

Special tracking of the bridge behavior is made in certain exceptional situations, consisting in the observation and control operations, with the same purpose as the current tracking. The special situations for which this type of tracing is required according to STAS 2920-83 are:

- intense traffic or heavy traffic and / or gauge overtaken;
- after earthquakes higher than 6 degrees;
- after heavy floods or floods, or in the case of a change of bed in the bridge area;
- after visible defects of the bridge elements;
- visible change of the red (projected) line of the bridge.

Regarding technical revision, it may be: current, periodic or special.

According to the same STAS 2920-83, the current revision consists in following the verification of the state of operation and operation of the road bridge, as well as the control of the way in which the technical supervision and the maintenance of the bridge are performed. Periodic review consists of a thorough, systematic examination of bridge elements. The special revision is carried out in the case of exceptional situations, such as those mentioned above, in which the stages of the special pursuit are also carried out.

STAS 12504-86 Regulates the conditions under which superstructure tests are performed. The static efficiency of the static efficiency of the test load (E f_{stat}) is defined in this norm as follows: *"The static efficiency of the sample load, E f_{stat}, is the similarity criterion used to model the useful load by sample loading" and is determined with the relationship:*

$$E\, f_{stat} = S_{stat}/S_n \quad (1)$$

S_n is the amount of effort determined in the dimensioning of the section resulting from consideration of payloads with normalized values in the case of bridges that are checked by the limit state method or the payloads in the case of bridges that are verified by the tolerable resistance method, and

S_{stat} is the dimension of the corresponding effort obtained from the sample loads considered to be statically applied.

The magnitude of the static efficiency must be within the range of 0.8-1.0.

The testing of new bridges shall be carried out if provided for in the project at the request of the receiving committee, the beneficiary or the management body and the testing of old bridges already in operation shall be attempted at the request of the managing body or the beneficiary in certain cases, such as: to increase traffic, to increase the speed of traffic, before and after the performance of bridge consolidation works or bridge repair works, after the expiry of the normal operating period, if the necessary revisions are deemed necessary.

In the studied case, the static samples were made by conveyance of loaded trucks, 8,97m long, 2,50m wide and 14,80t (34,00t total weight after loading). The detailed dimensions of the trucks are shown in Fig. 3. Before each test begins, each truck will be weighed to check the actual weight of each and the accepted deviations are up to 7% of the theoretical value.

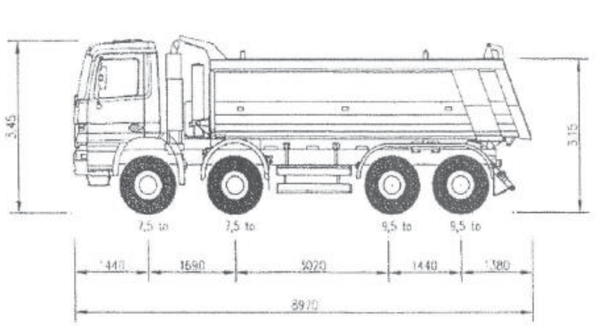

Fig. 3 The dimensions of the trucks used for the tests [12]

The static test measures the maximum arrow at each bridge opening and the specific deformations in the most demanded areas established by the project.

In order for the test to be considered static, the trucks convoys must travel on the bridge at a maximum speed of 5 km/h. They must stop in the position provided in the test scheme, and the exit on the bridge is also done at the maximum speed of 5km/h.
The trucks were positioned in the normal movement direction (from the first abutment on the second abutment) and the back (from the second abutment to the first abutment). Six trucks in the normal traffic direction and six rear-loaded trucks were positioned symmetrically in relation to the table axis as shown in Fig. 4.

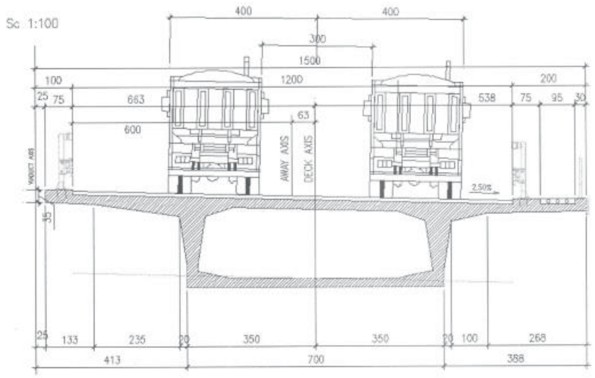

Fig. 4 The position of trucks in transversal section [12]

According to the project, the theoretical deformations expected from the static tests are those in Table 1, differentiated according to the location of the convoy.

Table 1 Control points and theoretical deformations associated with them

Control points	Theoretical deformations [cm]		
	Central opening	Constanta opening	Medgidia opening
G1 – G2 – G3	0.0	0.0	0.0
F1 – F2 – F3	2.3	-0.4	-2.2
E1 – E2 – E3	2.6	-0.5	-2.0
D1 – D2 – D3	1.5	-0.3	-1.1
C1 – C2 – C3	-0.3	0.0	0.0
B1 – B2 – B3	-4.2	0.8	2.0
A1 – A2 – A3	-8.2	2.2	2.2
B'1 – B'2 – B'3	4.2	2.0	0.8
C'1 – C'2 – C'3	-0.3	0.0	0.0
D'1 – D'2 – D'3	1.5	-1.1	-0.3
E'1 – E'2 – E'3	2.6	-2.0	-0.5
F'1 – F'2 – F'3	2.3	-2.2	-0.4
G'1 – G'2 – G'3	0.0	0.0	0.0

The dynamic test shall be carried out only if the bridge has behaved appropriately in the static test.
The dynamic test measures the evolution of the maximum arrow at each bridge opening, the evolution of the specific deformations in the most overworked sections, and the evolution fissures craking in reinforced concrete bridges.

Two trucks similar to those used in the static test were used. The trucks convoys travel on the bridge at constant speed. The trucks circulated with the following speed: 10km/h, 30km/h, 50km/h, 70km/h, 90km/h and 110km/h. As it is recommended, in order to increase the impact of the road bridges test, were created artificial bumps, made of wooden rods of 4cm and width of 30cm, length of 3.00m. These bumps are located in the axis of symmetry of the structure in the central opening.
For each test step, measurements were made at control points in which tracking tags were located, as described above.
Assessment results are based on data from measurements of the bridge behavior during the test and after their processing the results are interpreted. If the tests reveal that the bridge behavior criteria are not met, case identification is used and then appropriate action is taken, such as the imposition of traffic restrictions and the reinforcement or replacement of the bridge.
In our case, the deformations appear to differ partly from the theoretical ones in the six steps of the measurements, but nevertheless all the results fall within the maximum permissible tolerance, having an absolute lower value than expected under the project, and the bridge is considered to have a normal behavior, not being necessary to impose restrictions of any kind.
Additionally, the temperatures were determined at the time of each measurement step to determine the thermal variations to take account of their influence on the measured parameters.

3. Realization of the deformation model based on FEM

The Finite Element Method (FEM) is currently used in the vast majority of engineering calculations required to design or analyze a product.
For a certain geometry, well defined from a dimensional point of view, knowing the forces acting on it and the bearing conditions, its own vibrations frequencies etc., finite elements analysis (FEA) is used as a numerical verification calculation.
If it is used to determine optimum parameters in the design phase, so that certain imposed conditions are met, FEM. Is being implemented through highly developed programs currently, which have implemented special optimization procedures.
Such models allow the testing of a large number of hypotheses without the need for human, financial and human resources to build a test pattern after each test.
FEM is being used due to its many advantages, but particular attention should be paid to disadvantages when choosing this method for calculations and simulations.
Among the biggest disadvantages we mention: low precision it provides, the need to know the parameters and forces associated with the object studied, the need for advanced computer system and for the expensive programs, due to their complexity.

In the case of the studied bridge, we know exactly the dimensions and parameters of its elements, the materials from which it is built and the forces associated with the elements that make up the structure of the bridge, which is why the method for the deformation model was applied.
Of the six measurement steps, the first steps were used to stabilize the model, and the last practically confirms the viability of the created model.
On this deformation model, after its stabilization, numerous tests can be made that are associated with exceptional situations to highlight how the bridge will behave.
The steps taken to make and update the deformation model are those in Fig. 5 and are detailed below.

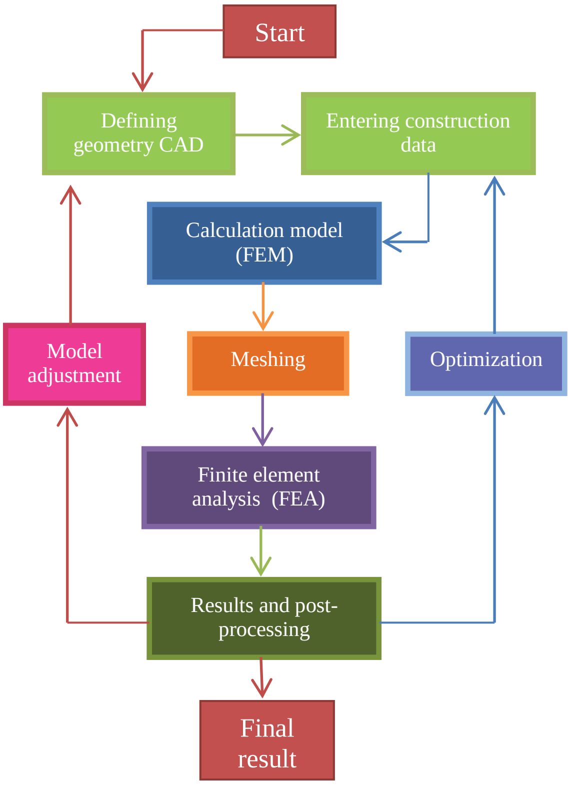

Fig. 5 The creating and updating process of the deformation model

3.1 Defining geometry
The geometry associated with the actual structure is defined and studied directly in ANSYS (Workbench 14.5), the program used to create the deformation model using FEM. We chose to build a three-dimensional model based on data from the tracking project of the bridge to get the most complete results.

Fig. 6 Geometry associated with the real bridge structure

3.2 Entering construction data
Within the ANSYS program (Workbench 14.5) you can select from a catalog of materials the materials specific to each bridge construction element.
3.3 Calculation model
In order to be able to perform a finite element analysis of a structure, the decisive step to be taken is to develop the calculation model. To achieve the transition from the real structure to its modeling model, there are no algorithms and general methods to ensure the development of a unique model. Generally, for a structure, many models are created, all correct but with different performance.
If the behavior of the raw material is linear and the displacements are "small", then the equations can be restricted to the linear case.
3.4 Meshing
Meshing is the fundamental approach in FEM and consists in turning a continuous surface (characterized by an infinite number of points) to a discrete model with a finite number of elements (called nodes).
FEM typically defines displacements or efforts at model points and calculates their values at these points. Under these conditions, the meshing must be made so as to define a sufficiently large number of points in the areas where, from the bridge design, we expect greater deformations so that the approximation of the geometry of the structure, the bearing conditions and the conditions Loading is satisfactory for the purpose pursued in the EAA.

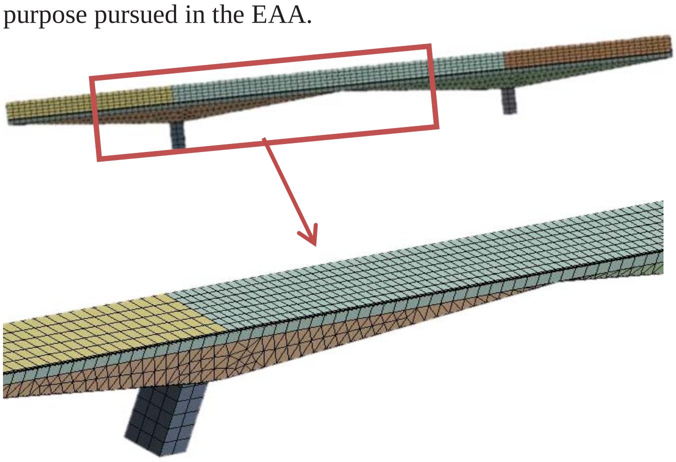

Fig. 7 Meshing the bridge model

3.5 Finite element analysis
The program used has implemented algorithms for automatic FEA, depending only on how the meshing was previously done and the forces defined on the construction studied.
3.6 Results and post-procesing
The results obtained are both numerical and graphical. After running the analysis, it will be noticed that the results do not coincide with the first stage of the measurements, even if they started from the same data from the reference stage and considered the force of the bridge's own weight. Therefore, other additional parameters such as temperature, water

force, vibrations, etc. will be considered. The model will be optimized with forces and values until the values in the first measurement step are obtained. Then, starting from this, the process resumes and the model will be adjusted again until the results of the next measurement step.

3.7 Final result

It is considered that we have obtained a stable model when running the model, it offers as results values that are similar to those in the various measurement steps.

In the case of this model, the first five measurement steps were used to stabilize the model, and for the model validation, measurements were compared to the sixth step.

Differences between the predictions obtained in the program and the results of the last measurement step are in the order of millimeters up to a maximum of 10mm, and for the simulation of exceptional situations such as: high magnitude earthquakes, floods, overloading, total or partial failure of an element, etc. this precision is considered sufficient and covering.

4. Conclusions

Based on such a stabilized model, various assumptions can be made to simulate their effect on the bridge and determine how it behaves. Such a model is difficult to stabilize, but if there is enough data to do so, the model thus obtained can prove to be very valuable to the beneficiary and those who use the construction.

Possible uses of the analyzed bridge deformation model, implemented in a risk management system:

- biger forces acting on the construction can be set, the size of which can be increased progressively until the deformations obtained exceed tolerance to determine the limit of resistance of the various elements of the bridge or bridge in its entirety;
- it is possible to amplify its own vibrations, or add some additional to help study the behavior of the bridge in the event of major seismic events. It is possible to analyze the bridge only with its own weight and forces or can analyze the bridge in a related situation under the conditions of normal traffic. Of course, the assumptions may vary, and the parameters considered in the analysis may also vary as far as we have sufficient data about them;
- it is possible to modify the water force on the piles and abutments or even on the bridge structure to study at what level of water the bridge would require repairs or would suffer major damage that would affect the traffic on it;
- it can also simulate the maximum admissible traffic on the bridge, the overloading it can undergo before consolidation interventions are needed;
- "alarm" parameters can be determined, values that fall within the tolerances allowed, but draw attention to the possibility of overtaking them in time, so that construction consolidation measures can be taken before its normal operating capacity be affected.

Applications of such a model to simulate undesirable events are numerous and very large.

Making measurements that include as many parameters as possible, provides exponentially greater opportunities for getting a good model, compared to measurements that are limited to a small number of parameters.

Simulation systems are multidisciplinary, specialists in various fields can work together to get a very complex model.

Such systems implemented in risk management can prevent massive environmental damage, warn about major issues of patrimony construction and, most importantly, eliminate the risk of endangering the live of those exploiting the construction.

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