Systemic Analysis

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Structural Identification – Decision Factor in Bridge Rehabilitation

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Summary

The bridges from a motorway network are extremely vulnerable points. Interrupting their function may lead to severe economic, social and political consequences. In case to produce some catastrophic events (floods, earthquake, terrorist attack, etc.), the most serious consequences affect resistance of the bridge structure, affect serious the traffic and pedestrians comfort and. To re-establishment the traffic on the hi-way ,it is necessary to make an rapid intervention where the bridges are effected, to take in real time the decision to continue or to stop the circulation, to stabilize and identify the best reparation solution.

All this objectives can be touch thought construction a mobile laboratory with modal attestation and diagnostic in real time and who can ensure the possibility an quick intervention at distressed bridges, he is equipped with an electronic device capable to adopt and prioritize in real time the optimum reparation solution, who can give as the possibility to reestablish the vehicle traffic in the short time possible.

1. STRUCTURAL IDENTIFICATION OF BRIDGE STRUCTURES

National Roads Administration of countries throughout the world has the responsibility of maintaining the safe and efficient road networks that are important for a nation's economic development. A key element of any road network is the bridge infrastructure. Also, bridge maintenance is becoming an increasingly important issue in most developed countries. Limitations in the budgets available to Road Transport Authorities for bridge maintenance, rehabilitation, and reconstruction programs necessitate implementing comprehensive Bridge Management System that can accurately priorities this expenditure.

Damage or fault detection, as determined by changes in the dynamic properties or response of structures, is a subject that has received considerable attention in the literature. The basic idea is that modal parameters (notably frequencies, mode shapes, and modal damping) are functions of the physical properties of the structure (mass, damping, and stiffness). Therefore, changes in the physical properties will cause changes in the modal properties.

A system of classification for damage-identification methods, as presented by Rytter (1993), defines four levels of damage identification, as follows:

Level 1. Determination that damage is present in the structure

Level 2. Determination of the geometric location of the damage

Level 3. Quantification of the severity of the damage

Level 4. Prediction of the remaining service life of the structure

For bridges damage may be material or structural defect formed during the construction stage or during its service life span resulting from natural disasters or man-made actions. Concrete bridges, for example, may experience tensile cracking, compression crushing and other forms of damage due to various types of loading such as earthquake, wind, thermal effect and accidental impact. If not detect and rectified early, such damage would increase maintenance cost, render the structures of bridges unserviceable and, in the extreme event, cause them to collapse catastrophically involving fatalities and injuries. It is therefore essential and necessary to carry out regular monitoring for early detection of structural damage.

While periodic visual inspections provide a generally economical means of condition assessment, they tend to be subjective so that reported results can vary from operator to operator.

Current damage-detection methods are either visual or localized experimental methods such as acoustic or ultrasonic methods, magnet field methods, radiographs, eddy-current methods or thermal field methods. All of these experimental techniques requests that vicinity of the damage is known a priori and that the portion of the structure being inspected is readily accessible. Subjected it these limitations, these experimental methods can detect damage on or near the surface of the structure.

Structural health monitoring systems, based upon some form of bridge response measurements, can be used to alleviate some of the shortcomings of traditional visual inspection techniques. Ideally, the SHM system should be inexpensive, non-invasive and automated, so that subjective operator differences are avoided. In particular, neither the implementation nor operation of the system should involve closure of the bridge.

Vibration data are ideally suited as the basis for a structural health monitoring system; they are cheap to collect, give a picture of the global response from relatively few sensors, and they can be used to identify changes in stiffness associated with damage from changes in the modal parameters. A reduction in

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stiffness will lead to a reduction in natural frequency and a change in distribution of stiffness will lead to changes in mode shape.

2. STRUCTURAL IDENTIFICATION

Traditionally, vibration data for structural health monitoring or damage detection have been processed according to a system identification paradigm, the aim being to obtain the modal characteristics and track changes.

The use of system identification (SI) for structural health monitoring (SHM) has received considerable attention in recent years. System identification can be described as the process of deducing or updating structural parameters based on dynamic input and output (I/O) measurements, or in some cases solely based on output measurements. The structural parameters of concern could be stiffness, damping or modal parameters. Based on the change of structural parameters, the condition of structure of bridge can be monitored.

Many different methods of system identification have been developed. They can be broadly classified in various ways, such as frequency and time domain, parametric and nonparametric models, deterministic and stochastic approaches, on-line and off-line identifications, and classical and nonclassical methods (Koh and See, 1999). Thus far, the main categorization is by means of frequency and time domain methods.

Besides the disturbing action on the traffic, the methodology applied at this time in Romania and other countries of European Community has another series of major disadvantages, such as:

1. The low precision in indicating the moment of appearance, the evolution and the moment in which a critical point is reached during the process of deterioration that can be observed on the structure.

2. The observations are made exclusively visual without any possibility of receiving information about the gravity of the structural degradation process.

3. The great time interval between the moment in which the technical state is established and the decision of intervention, in case of major structural degradation which can seriously affect the safety and traffic, comfort on the highway.

4. In Romania there is no protocol meant to assure the results continuity and correlation between the stages of establishing the technical state.

5. There is no possibility to determine the exact time interval in which the bridge can still be exploited until the next stage of intervention.

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6. There is no possibility for optimized administration of the financial resources by rational planning of repair and maintenance works.

Appling the of system identification (SI) for structural health monitoring (SHM) of composite bridges by creating a mobile laboratory, leads to elimination of any deficiency of the current methodology used at this time in Romania and allows it to become compatible with the technical requirements specified by the technical standards applied in the European Community.

The interest for applying system identification (SI) is an up-to-date matter and the numerous studies, research programs and scientifically manifestations of the last few years underline the increased attention given to this matter on the international level. Important research groups from the European Union (Switzerland, Germany, Great Britain, Italy, Denmark, France) but also from the USA, Canada and Japan, have begun since 1996 the implementation of important research programs whose results have already been communicated in conferences organized in this field of activity.

3. OBJECTIFS OF RESEACH PROGRAM

The research program has as goal the creation of a mobile laboratory with a complete set of equipment and calculation technique in order to accomplish the following objectives:

1. Dynamic testing of bridges with electrodynamics vibrators. The modal testing will be made every 5 years for the functional bridges or after special events – terrorist attack, earthquakes, and accidents by striking the structural elements of the bridge, exceptional transportation.

2. The determination of the dynamic characteristics (mode shapes, natural frequencies and damping ratios) with the help of electronic equipment and a calculation program dedicate to modal analysis.

3. The 3D modulation of the tested bridge structure with the help of a specially designed calculation program based on the method of finite elements.

4. The calibration process of the 3D calculation model is made in the auto laboratory in due time and consist in comparing the model's theoretical dynamic characteristics with those of the real structure obtained at the site. In successive stages the theoretical dynamic values of the 3D model are changed until these will be equal to the experimental ones, case in which the model is considered calibrated.

5. The permanent comparison process in due time of the characteristics calculated at the moment of the bridge testing with those calculated in the previous testing stage.

6. The diagnosis of the structure in due time. When receiving the warning signal, the direct consequence is the immediate redirecting of the attention on the 3-D calculation calibrated model.

7. The application of the bridge protection protocol.

4. EXPERIMENTAL MODAL ANALYSIS

Experimental modal analysis (EMA) testing techniques use in this research program, require identification of the frequency response functions (FRFs) for each response measurement location of the composite bridge, obtained from a controlled form of excitation (such as an impact device or some form of shaker).

Estimation of the FRFs, $\tilde{h}_{jk}(\omega)$, are obtained via:

$$\tilde{h}_{jk}(\omega) = \frac{X_j(\omega)}{F_k[\omega]} \tag{4.1}$$

where $X_j(\omega)$ and $F_k(\omega)$ are the Fourier Transforms of $x_j(t)$, the displacement response at point "j", and $f_k(t)$, the excitation force at position "k", respectively. The EMA algorithms seek to fit modal properties (mode shapes, natural frequencies and damping ratios) contained in the theoretical form of the FRF, $h_{jk}(\omega)$, given by:

$$h_{jk}(\omega) = \sum_{n=1}^{N} \left(\frac{\varphi_{jn} \cdot \varphi_{kn}}{(i\omega - \lambda_n)} + \frac{\varphi_{jn}^* \cdot \varphi_{kn}^*}{(i\omega - \lambda_n^*)} \right) \tag{4.2}$$

in which φ_{jn} and φ_{kn} represent the jth and kth elements of the complex eigenvector for the nth mode shape of vibration and λ_n is the complex eigenvalues for this mode, and the symbol "*" represents complex conjugation.

Commercially available EMA packages normally exercise a two-stage fitting procedure to obtain estimates of the modal properties from the experimentally obtained FRFs. The complex eigenvalues, λ_n, are first estimated followed by a linear least squares fitting procedure to establish the eigenvectors. The Direct

Simultaneous Modal Analysis (DSMA) algorithm is an alternative approach which has been found to exhibit superior performance over conventional methods. This uses a non-linear least squares fitting procedure described by:

$$\left\{\lambda_s,\varphi_{jn}\right\}_{\omega}^{\min} = \sum\left[\sum_k\left(\sum_{j=1}^{N}\left|\tilde{h}_{jk}(\omega)-\sum_{n=1}^{M}\left[\frac{\varphi_{jn}\cdot\varphi_{kn}}{(i\omega-\lambda)}+\frac{\varphi_{jn}^{*}\cdot\varphi_{kn}^{*}}{(i\omega-\lambda)}\right]\right|^2\right)\right] \tag{4.3}$$

where $\omega_{\min}$ and $\omega_{\max}$ represent the minimum and maximum values of circular frequency pertinent to the test results. A "Simplified" form of Experimental Modal Analysis (SEMA) can still be performed on a structure in the event that measurement data for response alone is available. This situation normally arises in practice when it is not possible to measure the excitation force, such as when ambient excitation is used on bridges. Here, the assumption is made that response measurements are dominated by "resonant" modes at their corresponding natural frequencies. The method is based on the relative response function, (FRF), defined by:

$$\tilde{R}_{qo}(\omega)=\frac{X_q[\omega]}{X_o(\omega)} \tag{4.4}$$

in which $X_q(\omega)$ and $X_o(\omega)$ are the Fourier Transforms of the measured response records at locations "*q*" and "o" respectively, in which "*o*" is treated as the "reference" point.

Now,

$$X_q(\omega)=\sum_{k=1}^{N}h_{qk}(\omega)\cdot F_k(\omega) \tag{4.5}$$

where $F_k(\omega)$ would correspond to the Fourier transform of the force trace at point "k". Substituting Equation (4.5) into Equation (4.4), the RRF, $R_{qo}(\omega_i)$ can be approximated to:

$$R_{qo}(\varpi_i)=\frac{X_q[\varpi_i]}{X_o(\varpi_i)}\approx\frac{\varphi_{qi}}{\varphi_{oi}} \tag{4.6}$$

provided that the "separated modal frequency" assumption holds good for mode "I". Under these circumstances, the RRF reduces to the ratio of the modal amplitudes of mode "I". Modal frequencies can be ascertained from inspection of

$S_o(\omega)$, the autospectrum of response at the reference location. Locations in frequency of well-defined peaks in this spectrum correspond closely to natural frequencies of participating modes in the response.

5. CONCLUSIONS

The use of system identification (SI) for structural health monitoring (SHM) of bridges involves:

1. The optimized administration of the financial resources dedicated to the bridges maintenance and repair. The significant drop of the resources used for this sector, allows them to be redirected to other sectors such as the investment one.

2. The optimization of the maintenance and repairing works leads to an increased duration of exploitation of the bridge in question, which allows the achievement of benefits that can be redirected towards the investment sector.

3. The maintenance for a long time in a good technical state of the bridges on a highway section, for which are necessary only current maintenance works, leads to the traffic fluidization on that highway sector.

References

1. *Aktan A.E., Chuntavan C., Toksoy, T., Lee, K.L.* - Modal Testing for Structural Identification and Condition Assessment of Constructed Facilities, Proc., 12th IMAC, 1994
2. *Comisu Cristian Claudiu* - Sistem integrat de monitorizare pentru îmbunătăţirea durabilităţii structurilor de poduri inteligente. Program de cercetare Facultatea de Construcţii si Instalaţii Iaşi, cod CNCSIS 438, 2006
3. *Comisu Cristian Claudiu* - Mobile Laboratory for dynamic Testing and Diagnosis of Highway Bridges, Propunere program de cercetare COST, 2006
4. *Hunt D.L, Weiss S.P., West W.M., Dunlap T.A., Freesmeyer, S.R.,* - Development and Implementation of a Shuttle Modal Inspection System, Sound and Vibration Magazine, August, 1999
5. *Tomoyuki I.* - Development of Takenaka Mobile Laboratory, Intelligent Structures - 2, Monitoring and Control, ed., Wen, Y.K., Elsevier Publ., 218-227, 2004