A benchmark for identification of structural modifications and inelastic impacts: the structure, test data and an example solution

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ABSTRACT: This paper proposes a simple lab-size benchmark for testing algorithms in two identification problems related to global structural health monitoring (SHM): identification of structural modifications and identification of inelastic impacts. A 3D truss-like structure, constructed of a commercial tube/node system, is used. Structural modifications are implemented by attaching additional nodal masses or by cutting a selected element to reduce its stiffness. Inelastic impact is simulated by an impulsive excitation of an additional nodal mass. Technical specification and experimental characteristics of the unmodified structure are provided for model updating. Several modification and impact cases are experimentally tested. All the data and measurements are freely accessible in Internet. An evaluation system is proposed for assessing the solutions, based on identification accuracy, instrumentation and source lines of code. The authors encourage the readers to test their approaches on the provided data. With each solution received, the evaluations will be calculated and published online.

1 INTRODUCTION

Although a lot of innovative techniques have been proposed for global structural health monitoring (SHM), see for example the reviews in Doebling et al. (1998), Fritzen & Kraemer (2009) or Kołakowski (2007), their actual effectiveness is hardly comparable due to different involved assumptions, tested structures, identification examples and goals. This paper aims at filling this gap by proposing a small and simple lab-size experimental benchmark for standardized testing of algorithms in two typical problems: identification of structural modifications and identification of inelastic impacts.

At least three existing SHM-related benchmarks seem to be widely known:

1. The oldest one is the well-known ISAC-ASCE Benchmark Problem (Lam 2002, 2011). It is based on a finite element (FE) model of a 4-story, 2-bay by 2-bay steel frame structure with 120 degrees of freedom (DOFs). A range of different damage and modification patterns, has been simulated (Bernal et al. 2002). The simulated measurement data and the FE model are freely available for download. However, although experimental data have been collected in 2002 using a scaled (2,5 m x 2.5 m x 3.6 m) model of the structure (Dyke et al. 2003), it seems they are no longer available for download and the main homepage of the benchmark is offline.
2. The IABMAS Benchmark Problem (Catbas et al. 2007) is an analytical benchmark problem directed toward health monitoring of medium-span bridges. Experimental measurements of a healthy and damaged 18 ft x 6 ft (approx. 5.5 m x 1.8 m) grid model along with the “official” numerical model are available online for download and testing.
3. The newest of the three is the benchmark based on the measurements taken during the construction of the Guangzhou New TV Tower (Ni & Xia 2008). Thus, unlike

the other two, this valuable benchmark features real-world output-only measurements, which have not been recorded in well-controlled lab conditions. For obvious reasons, no FE model of the structure is provided; interested participants can update a reduced model using the provided measurement data.

The benchmark featured in this paper is a small lab-size structure, which, unlike the large real-world benchmark structures, allows the modifications and impacts to be actually implemented in an easy way and in a wide variety. Moreover, in a laboratory experiment, the fluctuations of the environmental factors can be neglected. The simplicity of the structure allows a relatively comprehensive instrumentation to be used and to shift the focus from structural modeling problems to identification. In comparison to the first two lab-size benchmarks, the structure used here is much smaller (4 m x 0.5 m x 0.35 m) and truss-like. Although detailed technical specifications are available for download on the companion webpage (Suwała & Jankowski 2011), no official FE model is provided. If required, interested participants are encouraged to update their own models using the provided set of impulse response measurements (which includes, besides responses, also excitations applied with a modal hammer). Alternatively, the provided responses, which essentially constitute a reduced non-parametric structural model, can be directly used in identification as in the example solution presented below.

The following section describes the structure. The third section discusses the test cases. An evaluation system for assessing solutions is proposed in the fourth section. The fifth section describes and illustrates an example approach using a frequency-domain model-free approach, which is based on the time-domain approach from Suwała & Jankowski (in press). All the technical details and data files are freely available for download on a dedicated webpage, see Suwała & Jankowski (2011).

2 STRUCTURE AND INSTRUMENTATION

A 3D truss-like structure is used, which has been built using one of the commercially available systems of nodes and connecting tubes, see Meroform M12 (2011). The structure is made of steel, four-meter-long, and it includes 26 nodes and 70 elements of 0.5 m and 0.707 m. See Figure 1 for a general overview of the structure. All the technical specifications that are necessary to build a parametric numerical model of the structure are available online for download (Suwała & Jankowski 2011). The webpage includes also a comprehensive set of impulse-response measurements that can be used for updating and validation of the model, that is the responses (accelerations and computed displacements) in z-direction in nodes S1 to S3 to impulsive excitations in nodes M1 to M6 (x, y and z directions) and in E1 to E4 nodes (z direction only). Impulsive excitations are applied with a modal hammer, the excitation profiles are measured and also available for download. All the measurements are repeated three times.

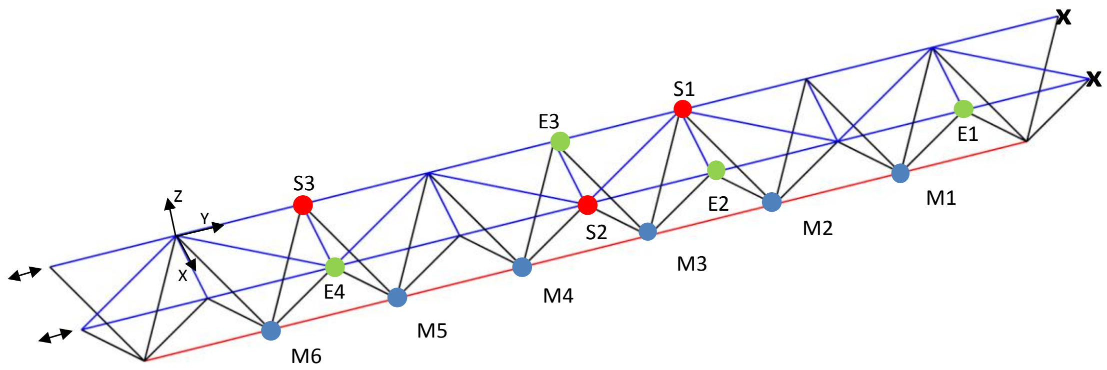

Figure 1. The test structure. M1 – M6 denote modes with added masses; S1 – S3 denote nodes with accelerometers (z direction); E1 – E4 denote locations of testing excitations (z direction)

For identification purposes, four acceleration sensors are used (nodes S1 to S4, z direction). The responses are recorded using a PULSE system and stored in the form of accelerations and the corresponding displacements, which are automatically computed by the measurement system.

3 IDENTIFICATION PROBLEMS

Three specific identification problems are considered:

1. Identification of added masses.
2. Identification of modifications of stiffness of an element.
3. Identification of inelastic impacts (mass and velocity).

3.1 *Identification of structural modifications*

Structural modifications (the first and the second problem) are implemented in the form of adding additional nodal masses or replacing a selected structural element:

- (*problem 1*) Additional nodal masses are attached in selected nodes of the structure. Up to three masses are attached to one, two or three nodes out of the six nodes denoted M1 to M6, see Figure 1. Several identification cases are considered by using different masses and attaching them to different nodes. In a part of the cases, placement of the masses is known; in other cases, it is unknown and needs to be identified along with the masses. The number of additional masses (one, two or three) is always known.
- (*problem 2*) Cuts are made to the structural element between nodes M3 and M4 in order to reduce its effective stiffness. Identification cases differ by the number of cuts.

The added masses, as well as the modifications of the effective stiffness of the cut element, are unknown and need to be identified by comparing the structural responses of the modified and unmodified structures to the same excitations. The responses are measured in nodes S1 to S3 (z direction), while the excitations are impulsive and applied using a modal hammer in nodes E1 to E4 (z direction). The excitations and the corresponding responses are available online for download.

3.2 *Identification of inelastic impacts*

The third considered problem is concerned with identification of *inelastic impacts*:

- (*problem 3*) Inelastic impacts are simulated by attaching a single additional mass in a single node (selected from the nodes denoted M1 to M6) and an impulsive excitation of the attached mass in the z direction. The excitations are measured, so that the equivalent impact velocity can be calculated given the impulse and the mass. The identification has to be performed based on the structural responses (measured in nodes S1 to S3, z direction) of the impacted structure. The impact is simulated in all the six nodes M1 to M6, so that there are six identification cases.

4 EVALUATION

A range of evaluation systems based on different criteria is potentially possible. Three criteria seem to be the most reasonable and practical:

1. Identification accuracy c_1.
2. Number c_2 of sensors and testing excitation used for identification.
3. Number c_3 of the source code lines.

A fourth common sense criterion is based on the identification time. However, such a criterion is not practical, as it requires executing all the algorithms on the same computer, which is not always possible. Moreover, the identification time may significantly depend on the compilers and libraries.

Identification accuracy c_1.can be assessed by comparing the actual modifications with the identification results. In the first problem (see Section 3) of identification of added masses, the following formula can be used:

$$c_1 = \sum_i \frac{\left\| \mathbf{m}_i^{(\text{actual})} - \mathbf{m}_i^{(\text{identified})} \right\|^2}{\left\| \mathbf{m}_i^{(\text{actual})} \right\|^2}, \tag{1}$$

where i indexes the identification cases, while $\mathbf{m}_i^{(\text{identified})}$ and $\mathbf{m}_i^{(\text{actual})}$ denote the six-element vectors of, respectively, identified and actual masses added to nodes M1 to M6. In the second considered identification problem (identification of modifications of effective stiffness of a selected element),

$$c_1 = \sum_i \left(\frac{\Delta AE_i^{(\text{actual})} - \Delta AE_i^{(\text{identified})}}{\Delta AE_i^{(\text{actual})}} \right)^2, \tag{2}$$

where $\Delta AE_i^{(\text{actual})}$ and $\Delta AE_i^{(\text{identified})}$ denote the actual and identified effective stiffnesses of the selected element and i indexes the identification cases. In the third identification problem (identification of inelastic impacts),

$$c_1 = \sum_i \left(\frac{m_i^{(\text{actual})} - m_i^{(\text{identified})}}{m_i^{(\text{actual})}} \right)^2 + \sum_i \left(\frac{v_i^{(\text{actual})} - v_i^{(\text{identified})}}{v_i^{(\text{actual})}} \right)^2, \tag{3}$$

where $m_i^{(\text{actual})}$ and $m_i^{(\text{identified})}$ denote the actual and identified impacting mass, $v_i^{(\text{actual})}$ and $v_i^{(\text{identified})}$ denote the actual and identified equivalent impact velocities and i indexes the identification cases.

The second criterion c_2 takes into account the number of sensors and testing excitation,

$$c_2 = N_{\text{E}} N_{\text{S}}, \tag{4}$$

where N_{E} and N_{S} denote respectively the number of excitations (up to four in problems 1 and 2, E1 to E4, and always one in inelastic impact identification) and sensors (up to three, S1 to S3) whose measurements are used in the identification process.

The simplest criterion is the third criterion that scores the length of the source code in terms of the number of lines.

All the received solutions will be first evaluated according to these three criteria. Then, a simple weighted total score c will be computed,

$$c = \frac{c_1 - c_1}{\sigma_{c_1}} + \frac{c_2 - c_2}{\sigma_{c_2}} + 0.25 \frac{c_3 - c_3}{\sigma_{c_3}}, \tag{4}$$

which involves the mean scores and the standard deviations of all the received solutions. A smaller weight is assigned to the criterion c_3 (source lines of code), as it may significantly depend on the in-built functions of the programming environment.

Using the rules stated above, the scoring will be assigned independently in each of the three considered identification problems (identification of added masses, stiffness modifications and inelastic impacts).

5 EXAMPLE SOLUTION

This section describes and further develops a model-free identification approach and illustrates it with example solutions that use a part of the available benchmark data. The full example set of solutions is presented on the benchmark webpage (Suwała & Jankowski 2011). The approach is based on the general methodology of the virtual distortion method (VDM), see Kołakowski et al. (2008) or Holnicki-Szulc & Gierliński (1995). Structural modifications are modeled with the equivalent pseudo-loads that act in the related degrees of freedom (DOFs) of the original unmodified structure. The influence of the pseudo-loads on the response is computed using a convolution with the experimentally obtained local impulse-responses. As a result, measurement results are directly used to model the response of the modified structure in an essentially non-parametric way. The approach thus obviates the need for a parametric numerical model of the structure and for laborious initial updating of its parameters, which is characteristic enough to name it a *model-free* approach.

The approach is first proposed in Suwała & Jankowski (in press), where a problem of model-free identification of added masses is studied in time domain. Numerous convolutions of the pseudo-loads with experimentally measured structural impulse responses yield a system of linear integral equations of the Volterra type, whose solution is considerably time-consuming, even with the proposed effective numerical techniques. Here, the approach is extended to include stiffness modifications as well as inelastic impacts. Moreover, the problem is transferred here into frequency domain, which converts the original Volterra integral equation into a series of simple decoupled linear equations that can be solved in a time smaller by an order of magnitude. As a result, the original sensitivity analysis based on the adjoint variable method is still possible and even faster.

The problem is formulated using the terminology of the finite element method. The structure is assumed to be linear and to obey the time domain equilibrium equation

$$\mathbf{M}\ddot{\mathbf{u}}^{\mathrm{L}}(t)+\mathbf{C}\dot{\mathbf{u}}^{\mathrm{L}}(t)+\mathbf{K}\mathbf{u}^{\mathrm{L}}(t)=\mathbf{f}(t), \tag{5}$$

where $\mathbf{M}$, $\mathbf{C}$ and $\mathbf{K}$ denote respectively the mass, damping and stiffness structural matrices, $\mathbf{u}^{\mathrm{L}}(t)$ denotes the response of the unmodified structure and $\mathbf{f}(t)$ is the external excitation. In frequency domain, (5) takes the following quasi-static form:

$$\mathbf{D}(\omega)\mathbf{u}^{\mathrm{L}}(\omega)=\mathbf{f}(\omega), \tag{6}$$

where ω is the angular frequency and

$$\mathbf{D}(\omega)=-\omega^2\mathbf{M}+\mathrm{i}\omega\mathbf{C}+\mathbf{K} \tag{7}$$

is the complex-valued dynamic stiffness matrix, the vectors $\mathbf{u}^{\mathrm{L}}(\omega)$ and $\mathbf{f}(\omega)$ contain the complex amplitudes of the response and the excitation. The inverse of the dynamic stiffness matrix,

$$\mathbf{H}(\omega)=\mathbf{D}^{-1}(\omega)=\left(-\omega^2\mathbf{M}+\mathrm{i}\omega\mathbf{C}+\mathbf{K}\right)^{-1}, \tag{8}$$

is called the dynamic compliance matrix.

For each angular frequency ω, submatrices of $\mathbf{H}(\omega)$ can be easily measured, as they are composed of the response vectors to harmonic excitations. However, if a large frequency range needs to be considered such an approach is time-consuming, as it requires the excitations and measurements to be repeated for each frequency of interest. An effective and much quicker approach is possible via the FFT (Hou et al. 2010): the results can be obtained for all the frequecies of interest at once by using an impulsive excitation and performing the FFT of the excitation and the measured responses.

5.1 *Problem 1: Identification of added masses*

The mass matrix of the modified structure,

$$\hat{\mathbf{M}}=\mathbf{M}+\Delta\mathbf{M}(\mathbf{m}), \tag{9}$$

includes the effect of the added masses $\mathbf{m}=(m_1, m_2, \ldots, m_6)$. If assumed that the stiffness and damping matrices do not depend on the added masses, the modified structure obeys the following counterpart of (6):

$$\mathbf{D}(\omega)\mathbf{u}(\omega,\mathbf{m})=\mathbf{f}(\omega)+\mathbf{p}(\omega,\mathbf{m}), \tag{10}$$

where $\mathbf{u}(\omega,\mathbf{m})$ is the amplitude of the response of the modified structure to the considered external excitation $\mathbf{f}(\omega)$ and $\mathbf{p}(\omega,\mathbf{m})$ denotes the pseudo-loads that model the effects of the added masses,

$$\mathbf{p}(\omega,\mathbf{m}) = \omega^2 \Delta\mathbf{M}(\mathbf{m})\mathbf{u}(\omega,\mathbf{m}). \tag{11}$$

Equations (6), (7) and (10) yield together

$$\mathbf{u}(\omega,\mathbf{m}) = \mathbf{u}^{\mathrm{L}}(\omega) + \mathbf{H}(\omega)\mathbf{p}(\omega,\mathbf{m}), \tag{12}$$

which, if substituted into (11), yields the following linear equation

$$\left[\mathbf{I} - \omega^2 \Delta\mathbf{M}(\mathbf{m})\mathbf{H}(\omega)\right] \mathbf{p}(\omega,\mathbf{m}) = \omega^2 \Delta\mathbf{M}(\mathbf{m})\mathbf{u}^{\mathrm{L}}(\omega), \tag{13}$$

where $\mathbf{I}$ is the identity matrix. Notice that $\Delta\mathbf{M}(\mathbf{m})$ is a diagonal matrix with non-vanishing diagonal entries only in the DOFs corresponding to the affected nodes. As a result, the pseudo-loads vanish in all other DOFs and (13) is in practice reduced to a small system with dimensions $3n$ x $3n$ (for a truss structure) or $6n$ x $6n$ (in the general case), where n is the number of the added masses. Moreover, only the corresponding small submatrix of the full dynamic compliance matrix $\mathbf{H}(\omega)$ needs to be measured.

Given (12) and (13), the direct problem can be solved straightforwardly: for each angular frequency ω and vector $\mathbf{m}$ of the added masses, (13) is solved and the resulting pseudo-loads are substituted into (12) to compute the corresponding amplitudes of the response of the modified structure. The time domain response can be then quickly recovered via the inverse FFT.

The inverse problem of identification is formulated here in the standard way as an optimization problem of minimization of the following discrepancy between the measured and modeled time-domain responses of the modified structure:

$$F(\mathbf{m}) = \sum_{i=1}^{N_{\mathrm{E}}} \sum_{j=1}^{N_{\mathrm{S}}} \frac{\int_0^T \left\| u_{j,i}(t,\mathbf{m}) - u_{j,i}^{\mathrm{M}}(t) \right\|^2 \mathrm{d}t}{\int_0^T \left\| u_{j,i}^{\mathrm{M}}(t) \right\|^2 \mathrm{d}t}, \tag{14}$$

where $u_{j,i}(t,\mathbf{m})$ is the modeled response of the jth sensor to the ith testing excitation and $u_{j,i}^{\mathrm{M}}(t)$ is the corresponding measured response.

5.2 *Problem 2: Identification of stiffness modification*

The direct problem is formulated in a similar way as in Section 5.1 with the stiffness matrix being modified instead of the mass matrix,

$$\hat{\mathbf{K}} = \mathbf{K} + \Delta\mathbf{K}(\Delta AE), \tag{15}$$

where the modification is due to the stiffness modification ΔAE. It is assumed that the structural damping is not considerably affected by the stiffness modifications. Equations (10) to (13) take the following forms:

$$\mathbf{D}(\omega)\mathbf{u}(\omega,\Delta AE) = \mathbf{f}(\omega) + \mathbf{p}(\omega,\Delta AE), \tag{16}$$

$$\mathbf{p}(\omega,\Delta AE) = -\mathrm{i}\omega\Delta\mathbf{K}(\Delta AE)\mathbf{u}(\omega,\Delta AE), \tag{17}$$

$$\mathbf{u}(\omega,\Delta AE) = \mathbf{u}^{\mathrm{L}}(\omega) + \mathbf{H}(\omega)\mathbf{p}(\omega,\Delta AE), \tag{18}$$

$$\left[\mathbf{I} + \mathrm{i}\omega\Delta\mathbf{K}(\Delta AE)\mathbf{H}(\omega)\right]\mathbf{p}(\omega,\Delta AE) = -\mathrm{i}\omega\Delta\mathbf{K}(\Delta AE)\mathbf{u}^{\mathrm{L}}(\omega). \tag{19}$$

Similarly as $\Delta\mathbf{M}(\mathbf{m})$ in Section 5.1, the matrix $\Delta\mathbf{K}(\Delta AE)$ has non-vanishing entries only in the DOFs that are related to the affected element. As a result, the pseudo-loads vanish in all other DOFs and (19) is in practice reduced to a small 6 x 6 system (for a single modified truss element). As in Section 5.1, only the corresponding small submatrix of the full dynamic compliance matrix $\mathbf{H}(\omega)$ needs to be measured.

The direct problem is solved straightforwardly by solving (19) and substituting the resulting pseudo-loads into (18). The time domain response can be recovered via the inverse FFT. The inverse problem is formulated as an optimization problem of minimization of the following discrepancy between the measured and modeled time-domain responses of the modified structure:

$$F(\Delta AE) = \sum_{i=1}^{N_\mathrm{E}} \sum_{j=1}^{N_\mathrm{S}} \frac{\int_0^T \left\| u_{j,i}(t, \Delta AE) - u_{j,i}^{\mathrm{M}}(t) \right\|^2 \mathrm{d}t}{\int_0^T \left\| u_{j,i}^{\mathrm{M}}(t) \right\|^2 \mathrm{d}t}, \tag{20}$$

where $u_{j,i}(t, \Delta AE)$ is the modeled response of the *j*th sensor to the *i*th testing excitation and $u_{j,i}^{\mathrm{M}}(t)$ is the corresponding measured response.

5.3 *Problem 3: Identification of inelastic impacts*

Structural response to an inelastic impact can be modeled in a similar way as the response of a structure with added masses (Section 5.1), because the inelastically impacting mass attaches to the impacted node, and consequently, can be treated as an added mass. However, the external excitation is not arbitrary, as it has to model an impulsive excitation:

$$\mathbf{f}(t,m,v) = mv\mathbf{e}_k \delta(t),$$

where *m* is the impacting mass, *v* the impact velocity, $\delta(t)$ is the Dirac delta function, *k* is the number of the DOF along which the impact happens and $\mathbf{e}_k$ is the versor that indicates the direction of the *k*th DOF (if the impact direction is unknown, an unknown velocity component can be considered for each involved DOF). Consequently, the excitation depends on the unknown impact parameters, *m* and *v*. As a result, equations (10) to (13) take the following forms:

$$\mathbf{D}(\omega)\mathbf{u}(\omega,m,v) = \mathbf{f}(\omega,m,v) + \mathbf{p}(\omega,m,v), \tag{21}$$

$$\mathbf{p}(\omega,m,v) = \omega^2 \Delta\mathbf{M}(m)\mathbf{u}(\omega,m,v). \tag{22}$$

$$\mathbf{u}(\omega,m,v) = mv\mathbf{u}^{\mathrm{L}}(\omega) + \mathbf{H}(\omega)\mathbf{p}(\omega,m,v), \tag{23}$$

$$\left[\mathbf{I} - \omega^2 \Delta\mathbf{M}(m)\mathbf{H}(\omega)\right]\mathbf{p}(\omega,m,v) = \omega^2 mv \Delta\mathbf{M}(m)\mathbf{u}^{\mathrm{L}}(\omega), \tag{24}$$

where $\mathbf{u}^{\mathrm{L}}(\omega)$ is the response of the unmodified structure to $\mathbf{e}_k\delta(t)$, that is to a unit impulsive excitation along the *k*th DOF. Such a response can be easily obtained by scaling the measured response of the unmodified structure to a (measured) modal hammer excitation (if such an excitation is not enough impulsive, a deconvolution might be necessary). In (22) and (24), $\Delta\mathbf{M}(m)$ is a diagonal matrix with non-vanishing entries only in the DOFs corresponding to the impacted node. As a result, the pseudo-loads vanish in all other DOFs and (24) is reduced to a small system with dimensions 3 x 3 (for a truss structure) or 6 x 6 (in the general case). Moreover, only the corresponding small submatrix of the full dynamic compliance matrix $\mathbf{H}(\omega)$ needs to be measured.

The direct problem is solved straightforwardly by solving (24) and substituting the resulting pseudo-loads into (23). The time domain response can be recovered via the inverse FFT. The inverse problem is formulated as an optimization problem of minimization of the following discrepancy between the measured and modeled time-domain responses of the modified structure:

$$F(m,v) = \sum_{i=1}^{N_\mathrm{S}} \frac{\int_0^T \left\| u_i(t,m,v) - u_i^{\mathrm{M}}(t) \right\|^2 \mathrm{d}t}{\int_0^T \left\| u_i^{\mathrm{M}}(t) \right\|^2 \mathrm{d}t}, \tag{25}$$

where $u_i(t,m,v)$ is the modeled response of the *i*th sensor to the inelastic impact with parameters *m* and *v*, and $u_i^{\mathrm{M}}(t)$ is the corresponding measured response.

5.4 *Selected results*

In this section, some of the results are illustrated, which have been obtained using the introduced model-free method. Figure 2 show the objective functions corresponding to the case of the added mass of 3.61 kg in node M3 and a single testing excitation in E2. Three of the objective functions correspond to the three sensors S1 to S3 used separately, while the fourth objective function has been computed using the weighted average of the three responses, see (14). Figure 3 shows the masses identified using the same setup and the actual added masses of 1.11 kg, 2.61 kg and 3.61 kg. Figure 4 illustrates the computed and measured responses of the modified structure in the worst-case fit.

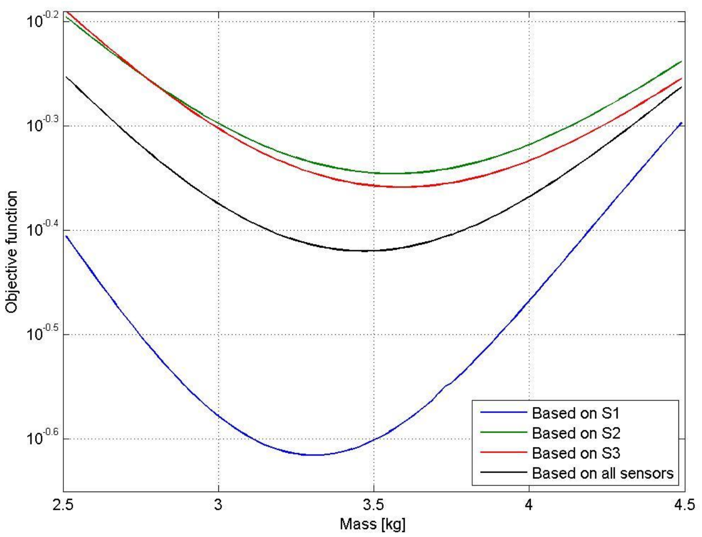

Figure 2. Objective functions computed for the added mass of 3.61 kg in M3 and a single testing excitation in E3

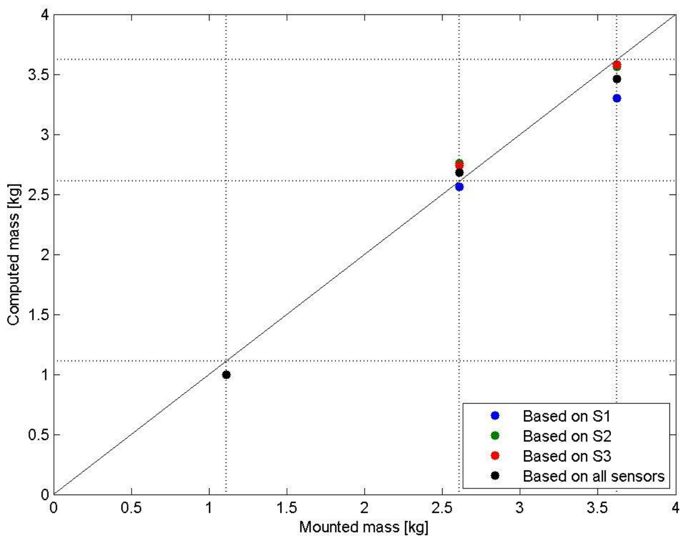

Figure 3. Identification results for the masses of 1.11 kg, 2.61 kg and 3.61 kg added in M3 and a single testing excitation in E3

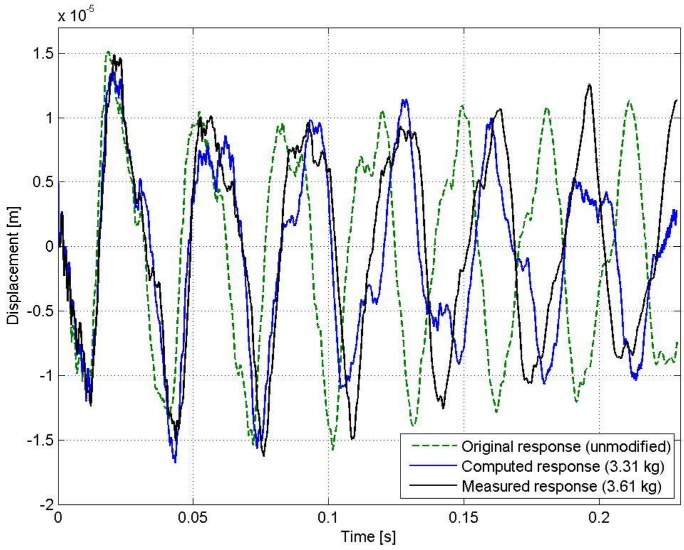

Figure 4. Identification of a single added mass, worst case fit. Structural responses in S3 to the testing excitation in E3: original unmodified structure, computed response and measured response

Figure 5 shows the objective function, which illustrates the process of identification of two added masses of 2.61 kg in M1 and 1.11 kg in M3 with a single testing excitation in E2. The minimum corresponds to the identified masses of 2.6 kg and 1.4 kg (mass increments at 0.1 kg).

Finally, Figures 6 and 7 illustrate the process of identification of element stiffness modifications. Actual reduction of the axial stiffness of the element between nodes M3 and M4 was $\Delta AE = 4580$ kN , the impact testing load was applied at S2, and the sensor was placed in M3. Figure 6 shows the objective function with the minimum (identified reduction) at 4290 kN. Figure 7 show the structural responses: the original unmodified structure, as well as the computed and the measured responses of the modified structures.

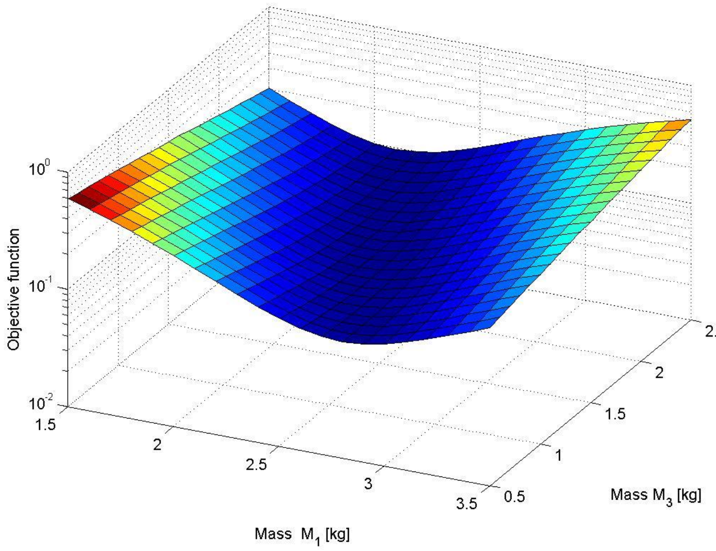

Figure 5. Objective function computed for the actual added masses of 2.61 kg in M1 and 1.11 kg in M3. The minimum is found at 2.6 kg and 1.4 kg (mass increments at 0.1 kg)

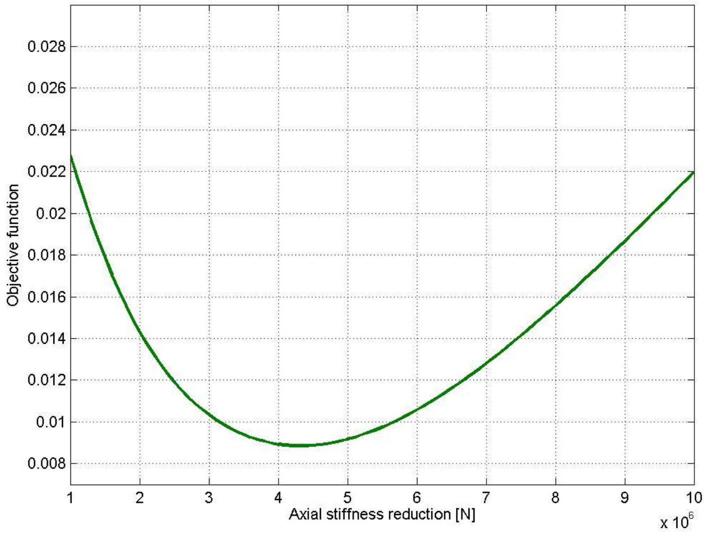

Figure 6. Model-free identification of reduction of axial stiffness of an element. Actual reduction 4580 kN; the minimum shows the identified reduction of 4290 kN

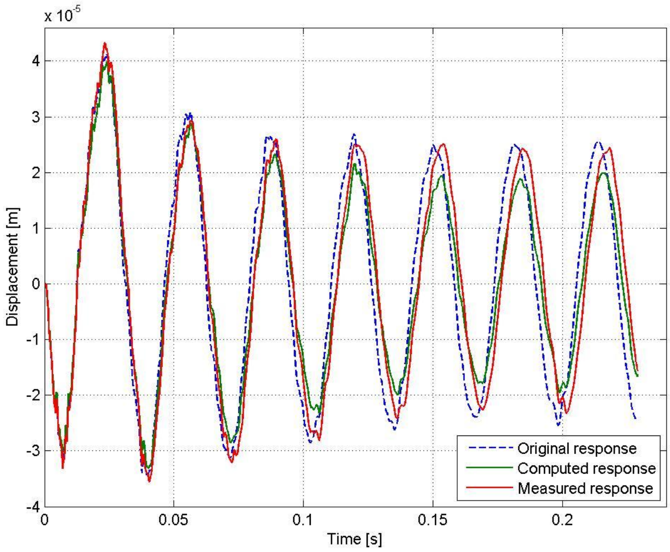

Figure 7. Identification of reduction of axial stiffness of an element. Structural responses in M3 to the testing excitation in S2: original unmodified structure, computed response and measured response

6 CONCLUSIONS

In this paper, a simple lab-size benchmark is proposed for assessing approaches and algorithms in two typical problems in structural health monitoring (SHM): identification of structural modifications and identification of inelastic impacts. The structure, test cases and an evaluation system is proposed along with an example solution. All the technical specifications of the structure, test cases and measurements are available online for download (Suwała & Jankowski 2011). The authors encourage the readers to download the data, test their approaches in any or all of the considered identification problems and send the solutions for evaluation. The scores will be calculated, updated and published online for each solution received.

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