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THE EXPERIMENTAL TESTING AND NUMERICAL MODEL CALIBRATION OF A STEEL STRUCTURE

BY

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Abstract. The tests were carried out on the 3 DOFs shaking table from the Earthquake Research Laboratory of the Faculty of Civil Engineering and Building Services of Iaşi, Romania. The specimen is a 3 storey steel frame model with additional masses

The first testing phase consisted of the low level sweep sine tests (*OX* & *OY* directions) and the analytical model benchmarking was done after using several widely used computer software.

The next phase was of earthquake type excitation at several degrees of intensity (real and synthetic time-histories); the model calibration was achieved after applying system identification techniques.

The verification and validation of modeling assumptions of the finite element models for structural analysis was carried on by the means of dedicated software FEM tools.

The conclusions are focused on the accuracy of the models and the dynamic model matrices.

Key words: steel frame; shaking table tests; scaled model; finite element analysis, model validation.

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1. Introduction

Most of the engineering problems in vibrations are leading to the simple or generalized eigenvalue problem. It is commonly accepted and convenient to use the real eigenvalues; therefore the matrices of the dynamic system are symmetric and positive defined. Moreover, in the case of the time history analysis the eqs. of motion are decoupled, based on the assumption that the damping is proportional (Rayleigh type) to the mass or stiffness or both. The damping matrix, C, is then written as a linear combination of M and K ($C = \alpha M + \beta K$). Under these circumstances the time responses obtained separately can be superimposed using the modal participations.

In the structural analysis there are situations when non-proportional damped structures are considered. The hypothesis of proportional damping is advantageous from the numerical point of view and the experimental tests show that this approximation leads in most cases to acceptable results. However it is not demonstrated yet the proportional behavior of the damping.

In this paper it is presented a case-study consisting of a 3 storey steel frame tested on the master shaking table from the Laboratory of Earthquake Engineering from the Structural Mechanics Department of the Faculty of Civil Engineering and Building Services from Iaşi.

These tests were part of a larger program and some results and interpretations are presented here after.

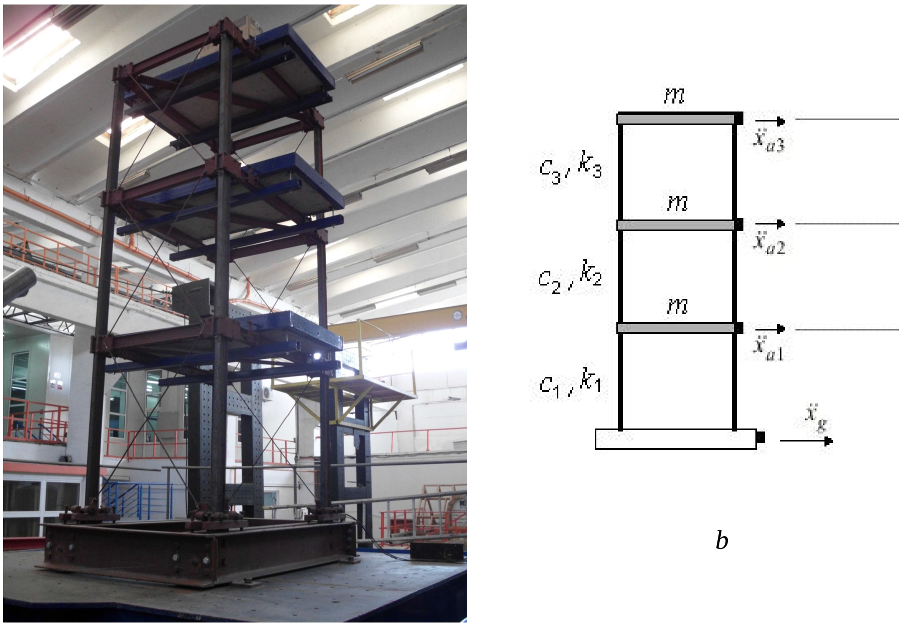
2. The Specimen

It is considered a 3 storey steel frame as depicted in the Fig. 1. For the dynamic model 3 translational DOFs are granted along the *OX* and *OY* orthogonal directions in plane, according to the governing directions of the shaking table. The DDOFs are numbered as shown.

The 3 storey steel frame model with additional weights respected a geometrical scale of 1/4.

The columns are made of I80 Romanian steel profiles. The beams and joint assemblages at each storey level assure a rigid plate behavior “in plane”. The physical model acts merely as a consequence of the column bending effect. The span on *OX* is of 1.40 m and the bay on *OY* is of 1.20 m. Each storey height is of 1.10 m. In the Fig. 2 there are depicted some details of the instrumentation that was applied on the test frame.

The supplementary masses consisted of RC plates with steel profile contours in order to pay respect to variable loads acting on a real building and the similitude criteria. The real mass at each storey is approximately of 300 kg.



b

a

Fig. 1 – *a* – The steel structure on the shaking table; *b* – the dymanic 2-D model on each direction.

a *b*

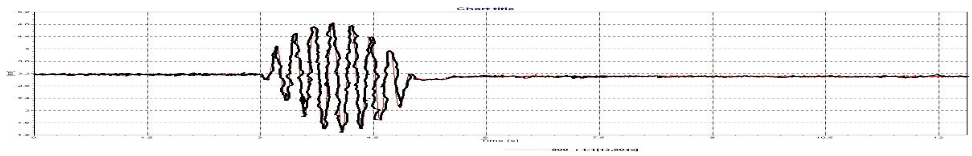
Fig. 2 – *a* – Instrumentation at the base plate level; *b* – LVDTs at each storey level.

3. The Testing Program

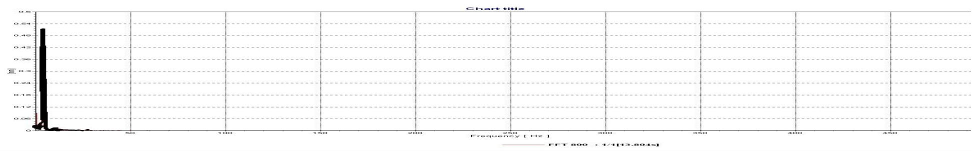
The first testing phase consisted of the low level sweep sine tests (*OX* & *OY* directions). As concerns the present paper we detail the results on the *OX* axis. After the sweep there were obtained the frequencies of the real model on the shaking given in Table 1.

Table 1
Modal Quantities (*Experimental*)

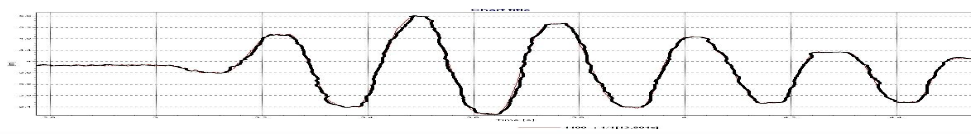
Natural mode of vibration	Frequency Hz	Modal shapes (normalized)		
1	3.8	0.0128	0.0319	0.0447
2	8.2	0.0361	0.0293	–0.0317
3	11.7	–0.0410	0.0357	–0.0319



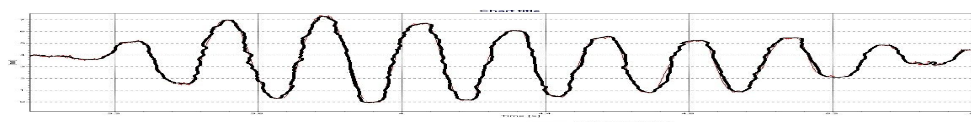
Absolute displacement at the base plate level (shaking table motion *OX* direction)



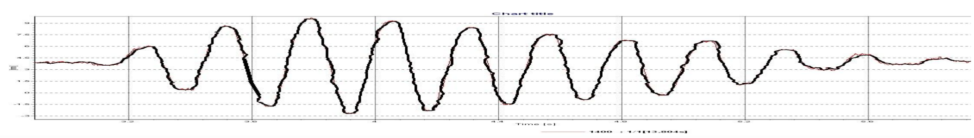
FFT of the displacement at the base plate level



Displacement at the first floor level (*OX*)



Displacement at the second floor level (*OX*)

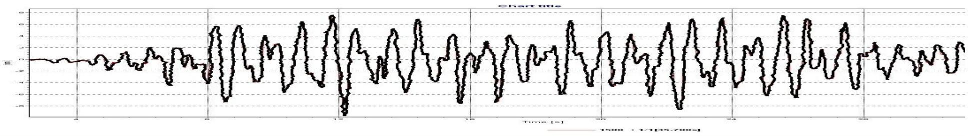


Displacement at the 3rd floor level (*OX*)

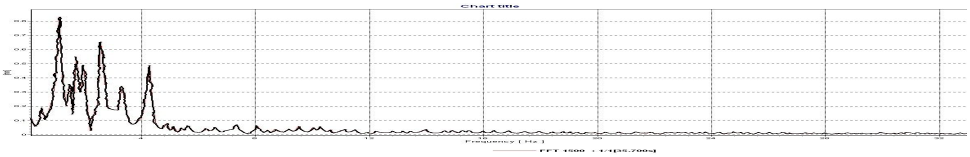
Fig. 3 – Sine motion along *OX* direction – displacement control.

After the scanning of the frequencies the model was subjected to sine motions in order to check out the modal behavior *i.e.* real mode shapes and the damping characteristics. Natural frequencies were applied at different amplitudes and input energies. In the Fig. 3 we depict an example of the measurements when the motion was applied with the frequency f_1 = 3.8 Hz.

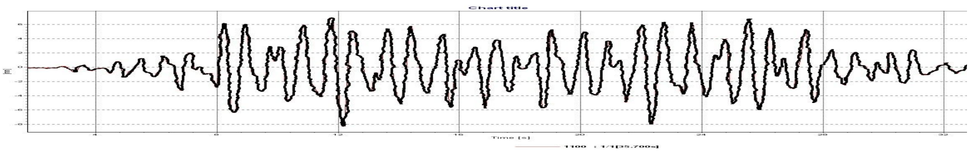
Even the logarithmic decrements were almost simple to evaluate, the selection of the appropriate method to calculate them leaded to a sensitive selection. Then several difficulties arise in the estimation of the damping matrix.



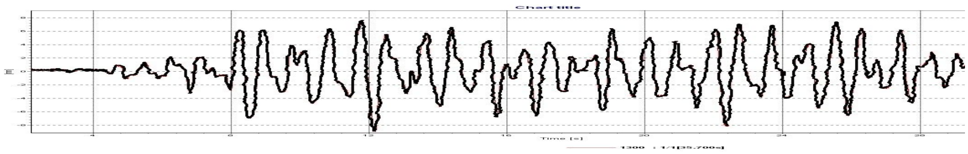
Absolute displacement at the base plate level (shaking table motion OX direction)



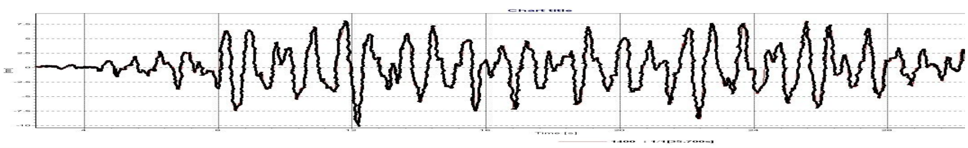
FFT of the displacement at the base plate level



Absolute displacement at the first floor level



Absolute displacement at the second floor level



Absolute displacement at the 3rd floor level

Fig. 4 – Time history response of the steel frame when Focşani 1986 Earthquake is applied.

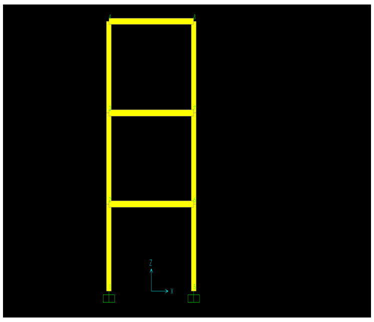
The next phase was of earthquake type excitation at several degrees of intensity. There were used the “Bucureşti 1986” and the “Vrancea 1986 – Focşani” accelerograms at several PGAs up to 0.6 g. The significant earthquake duration was about 30 s.

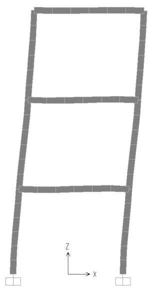
In the Fig. 4 are emphasized some time-histories for the Focşani 1986 input.

4. The Numerical Models

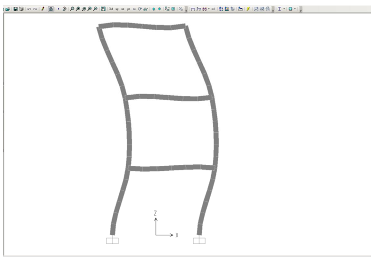
Several computer dedicated programs were used to advocate the analytical models. Taking into account this simple geometry no significant diffecences occured no matter what software was used.

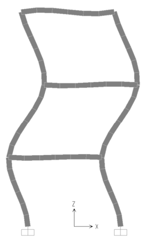
In the following we present a model realized with the SAP 2000 computer program which provided also the input for the analysis with the FEMtools software.





Mode 1 – f_1 = 3.46 Hz





Mode 2 – f_2 = 10.44 Hz

Mode 3 – f_3 = 16.11 Hz

Fig. 5 – The modal shapes obtained with a SAP 2000 model.

The model was of “shear type” and the geometrical and mechanical properties were input “as” the physical model looked like. In such a way there were obtained the results depicted in the Fig. 5. The computed natural frequencies, for instance, look a little bit far from the experimental frequencies.

The frame was designed and constructed to ensure the rigid behavior at each plate level and the details were carrefully checked. After the first inspection of the natural model of vibration the updating of the numerical model prooved necessary.

5. Numerical Calibration and FEM Updating

2.1. Model Validation

The model validation was carried on by the means of the FEM tools software. The software is a multi-functional, cross-platform and solver-independent CAE software suite used for the structural dynamics simulation, model validation, validation and updating. A brief view on the environment is presented in the Fig. 6.

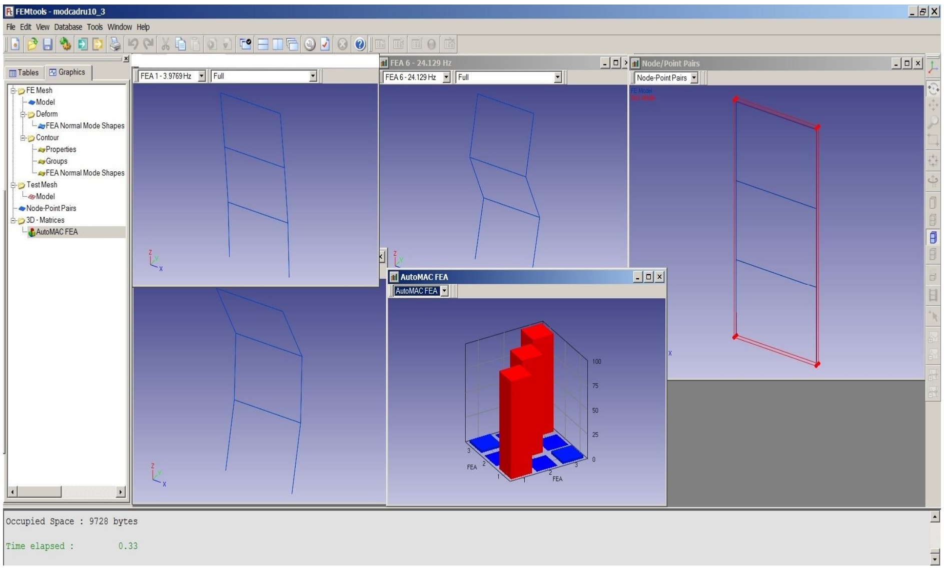


Fig. 6 – Model validation and updating using the FEMtools dedicated software.

The parameter validation included the spectral matrix and some material properties (*i.e.* Young modulus and Poisson’s ratio). The correlation was achieved mainly on the basis of the MAC (Modal Assurance Criterion) that is the correlation vector between the analytical and experimental mode shapes. The MAC matrix is depicted in the Fig. 7.

After the FEM updating the new modal quantities are those from the Table 2.

The stiff behavior of the physical model involved the consideration of some rigid areas in the columns, both sides of the joints.

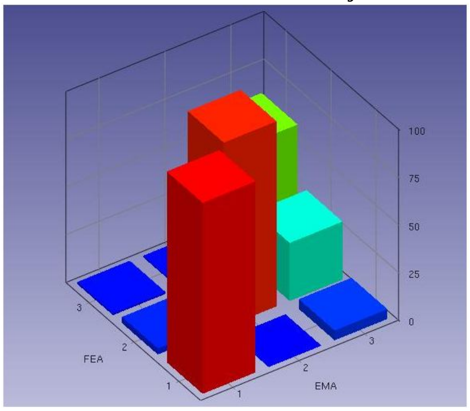


Fig. 7 – Model validation – MAC criterion.

Table 2

Modal Quantities (*Numerical, After the Model Updating*)

Natural mode of vibration	Frequency – tests Hz	Frequency – model Hz
1	3.8	3.439
2	8.2	8.433
3	11.7	11.558

2.1. The Damping Effect

Although tha damping was very small, it was a little bit difficult to check the proportionality of the damping matrix with respect to mass and stiff-

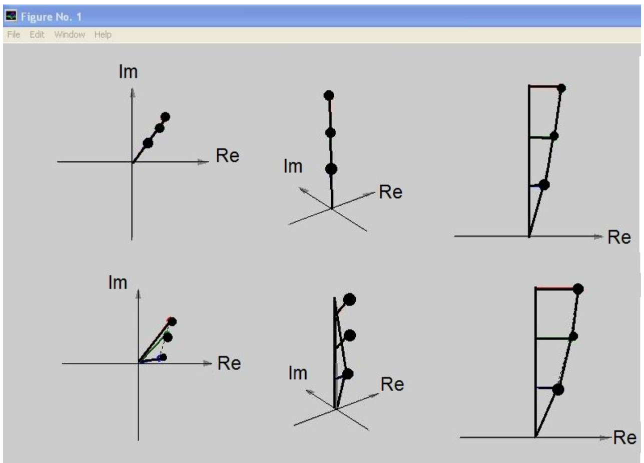


Fig. 8 – First mode of vibration in state-space representation.

ness. In the Fig. 8 we present the fundamntal mode of vibration (analytical) in the state-space.

5. Conclusions

In this paper it is presented a case- study consisting of a 3 storey steel frame tested on the master shaking table from the Laboratory of Earthquake Engineering from the Structural Mechanics Department of the Faculty of Civil Engineering and Building Services from Iaşi.

The first testing phase consisted of the low level sweep sine tests (*OX* & *OY* directions). In the present paper we detailed the results on the *OX* axis. After the scanning of the frequencies the model was subjected to sine motions in order to check out the modal behavior, *i.e*. real mode shapes and the damping characteristics.

Several computer programs were used build the analytical models. there are presented some model realized with the SAP 2000 computer program which provided also the input for the analysis with the FEMtools software. The model validation was carried on by the means of the FEM tools software, using parametric identification.

As from the start, the natural frequencies of the numerical model were far away enough from those obtained experimentally, some changes were demanded in the flexural stiffness of the SAP 2000 model. Then, using the MAC shape correlation, some model parameters were adjusted.

The next validation procedures shall be focused in the time domain, using the seismic time histories.

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STUDII EXPERIMENTALE ŞI CONSTRUIREA MODELULUI NUMERIC AL UNEI STRUCTURI METALICE

(Rezumat)

Testele au fost realizate pe platforma seismică cu 3 grade de libertate a laboratorului din cadrul Centrului de cercetare în Inginerie Seismică al Facultăţii de Construcţii şi Instalaţii din Iaşi. Modelul fizic este constituit dintr-un cadru metalic cu 3 niveluri, cu mase adiţionale.

In prima etapă din programul de testare a fost realizată scanarea la un nivel scăzut de amplitudine cu input de tip armonic (pe direcţiile *Ox* şi *Oy*). S-au realizat modele numerice cu ajutorul mai multor programe de calcul iar pe baza răspunsului modal şi în frecvenţă s-a realizat calibrarea unui model analitic.

In următoarea etapă modelul fizic a fost supus unor acţiuni de tip seismic pe platformă, la diverse grade de intensitate (s-au utilizat înregristrări seismice ale unor cutremure reale şi sintetice); calibrarea modelului s-a realizat prin identificare în domeniul timp.

Verificarea şi validarea ipotezelor pentru modelele cu elemente finite pentru analiza structurală s-a efectuat cu un program specializat, FEM Tools.

Concluziile se referă la acurateţa modelelor şi matricele caracteristice ale modelului dinamic.