IDENTIFICATION AND MODIFICATION OF FRAME STRUCTURE

P. Rosko[1]

[1] *Ass. Professor, Center of Mechanics and Structural Dynamics, Vienna University of Technology, Austria*
Email: pr@allmech.tuwien.ac.at

ABSTRACT :

The paper presents identification and upgrade of structure under earthquake loads on the base of optimization.

The measured frequency spectrum of the structure determines the numerical model design. The structure is excited by ground acceleration. Linear and nonlinear dynamic analysis in time domain is realized.

The identification of the model parameter is solved as an optimization problem. The objective is the error index minimization between measured response in real structure and calculated response of the numerical model. The hybrid optimization algorithm is applied.

In order to improve earthquake resistance of the structure the passive control with help of tuned mass damper is designed.

Three-storey frame is investigated. Experimental and parallel numerical analyses are realized. Accelerograms from the Friuly-earthquake are applied.

KEYWORDS: Identification, frame, optimization, passive control, tuned mass damper

1. INTRODUCTION

Dynamic behavior and resistance of civil structures under earthquake loads has a high importance. This is after thousands years experience not question.
To analyze concrete structure two different ways are available: experimental and numerical.
The civil engineering practice needs correct information about current state of building structures. The experimental analysis answers this question. The numerical models and analyses enable simulation of various loads and structural behavior. Advantage of this way is the nondestructive testing and possibility of easy model modification. Combination of experimental and numerical analysis profits from advantages of both. The result of this combination is numerical model with real parameters and feasibility for upgrade.
Over last years several methods have been evolved in this area.
The identification and upgrade of structure illustrated on three-storey frame example is presented in the paper. The methodology is chosen to be universal for linear and nonlinear cases.

2. EXPERIMENTAL ANALYSIS - MEASUREMENT

The three-storey frame is investigated [1].
Nowadays are available databases providing information and access to strong motion records (e.g. COSMOS Virtual Data Center, European Strong Motion Database [2] etc.).

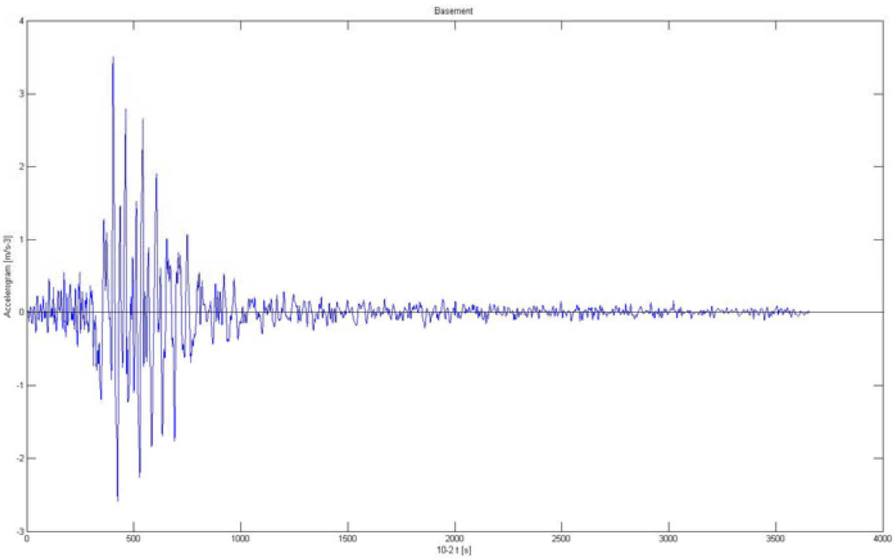

Figure 1 Accelerogram from Friuli earthquake

The record of Friuli earthquake is applied as excitation. The response of the structure is measured. The time history is output of the measurement. The output parameters of experimental analysis have to be compatible with output parameters from numerical analysis. From this reason we did not use instead frequency response functions displacement and its derivations.

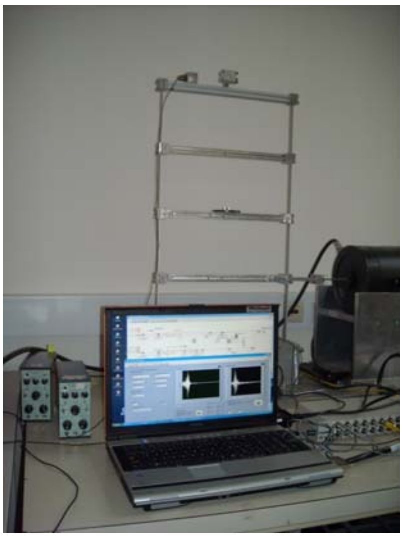

Figure 2 Three-storey frame

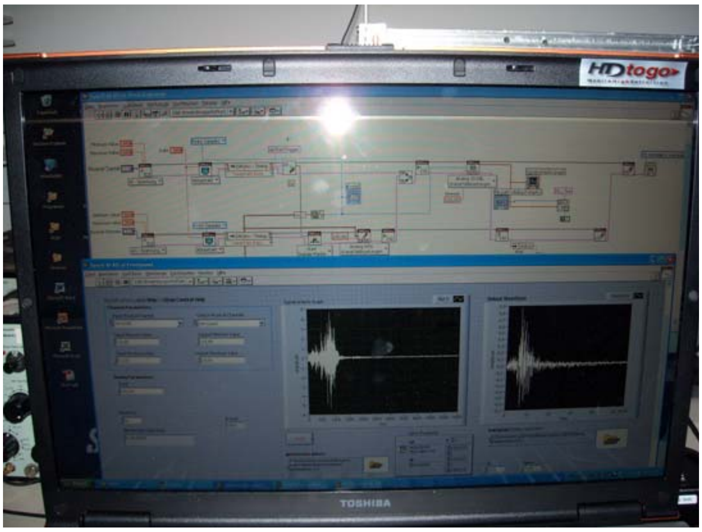

Figure 3 LabVIEW control program

Experimental setup consists of PC with LabVIEW control program, Shaker, National Instruments analogue digital converter, Brüel&Kjaer accelerometers and charge amplifiers.

3. NUMERICAL MODEL, ANALYSIS

In dynamics simple models with low number of degrees of freedom are preferable. They have to include complex information of the real structure and have to be able to simulate the same behavior as the real structures.
The geometry of the structure and analysis in frequency domain determines the model design.

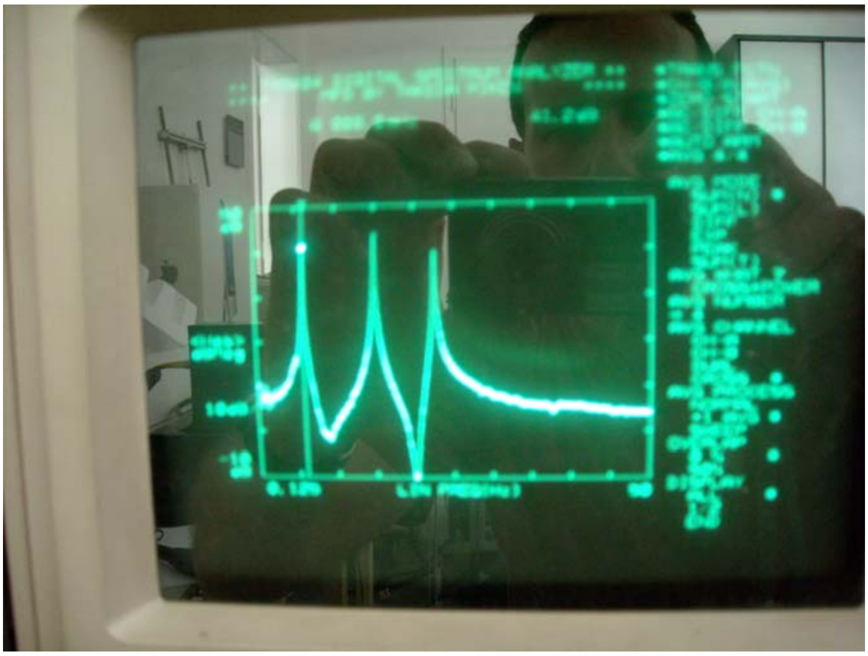

Figure 4 Response spectrum

3.1. Model

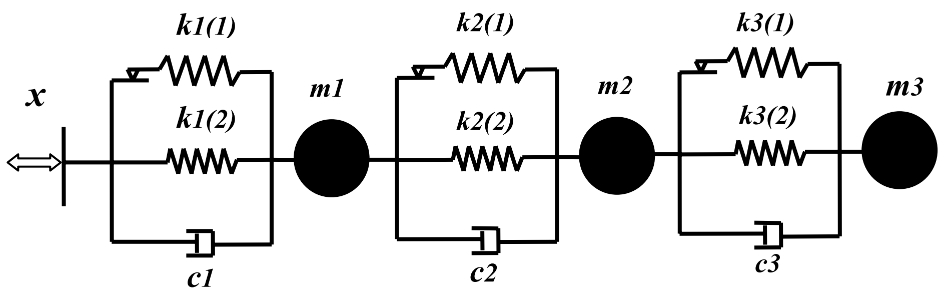

Figure 5 3-Degree of Freedom Model

3.2. Analysis

Dynamic equilibrium equations of elastic multi-degree-of-freedom (MDOF) system with ground excitation are

$$\boldsymbol{M}\,\ddot{\boldsymbol{x}} + \boldsymbol{C}\,\dot{\boldsymbol{x}} + \boldsymbol{K}\,\boldsymbol{x} = \boldsymbol{M}\,\boldsymbol{e}\,\ddot{u}_g \tag{3.1}$$

The equations governing the response of the inelastic MDOF system with ground excitation are

$$\boldsymbol{M}\,\ddot{\boldsymbol{x}} + \boldsymbol{C}\,\dot{\boldsymbol{x}} + \boldsymbol{f}_S\left(\boldsymbol{x},\dot{\boldsymbol{x}}\right) = \boldsymbol{M}\,\boldsymbol{e}\,\ddot{u}_g \tag{3.2}$$

with
$\boldsymbol{M}$ mass matrix
$\boldsymbol{C}$ damping matrix
$\boldsymbol{K}$ stiffness matrix
$\boldsymbol{f}_S\left(\boldsymbol{x},\dot{\boldsymbol{x}}\right)$ lateral force vector,
$\boldsymbol{e}$ is influence vector
$\boldsymbol{x}(t), \dot{\boldsymbol{x}}(t), \ddot{\boldsymbol{x}}(t)$ displacement-, velocity- and acceleration- vector
$\ddot{u}_g(t)$ is the ground acceleration

Chopra [3] proposed modal analysis concept for elastic and inelastic MDOF systems as well, although modal analysis in classical form is not valid for an inelastic system.
The dynamic response of an MDOF system is expressed in terms of modal contributions

$$\boldsymbol{x} = \sum_{k=1}^{N} \varphi_k q_k = \boldsymbol{\Phi}\,\boldsymbol{q} \qquad k = 1,2,\ldots,N \tag{3.3}$$

with
$\boldsymbol{x}(t)$ displacement vector, $\boldsymbol{\Phi}$ modal matrix, $\boldsymbol{q}(t)$ vector of modal coordinates.
Substituting (3) in equations (1), (2) and premultiplying by $\boldsymbol{\Phi}^T$ gives N independent equations

$$\ddot{q}_k + 2\zeta_k \omega_k\,\dot{q}_k + \omega_k^2\,q_k = -\frac{L_k^*}{m_k^*}\ddot{x}_g \tag{3.4}$$

$$\ddot{q}_k + 2\zeta_k \omega_k\,\dot{q}_k + \frac{F_{Sk}}{m_k^*} = -\frac{L_k^*}{m_k^*}\ddot{x}_g \tag{3.5}$$

with
ω_k natural frequency, ζ_k damping ratio,
L_k^* and m_k^* are elements of $\boldsymbol{L}^* = \boldsymbol{\Phi}^T \boldsymbol{M}\,\boldsymbol{e}$ (3.6)

$$\boldsymbol{M}^* = \boldsymbol{\Phi}^T \boldsymbol{M} \boldsymbol{\Phi} \tag{3.7}$$

$$F_{Sk} = F_{Sk}(q_k, \dot{q}_k) = \boldsymbol{\varphi}_k^T \boldsymbol{f}_S(q_k, \dot{q}_k) \tag{3.8}$$

F_{Sk} is nonlinear hysteric function of the *k*-th modal coordinate q_k.

Solution of equations (3.4) alternatively solution of equitations (3.5) result the output of numerical dynamic analysis.

4. PARAMETER IDENTIFICATION

The identification of the model parameter is defined as an inverse problem. The inverse problem is solved with help of optimization procedure. The objective is the error index minimization between measured response in real structure and calculated response of the numerical model.

Objective
$$min\left(\frac{\sum_{i=1}^{nt} \left(a_{mi} - a_{ci}(\boldsymbol{v}) \right)^2}{\sum_{i=1}^{nt} a_{mi}^2} \right) \tag{4.1}$$

with

a_{mi} measured response
$a_{ci}(\boldsymbol{v})$ calculated response function
$\boldsymbol{v}$ variables of optimization
nt number of time increments

To improve the efficiency the measured response is analyzed. Appearance of nonlinearities is checked and linear alternatively nonlinear numerical analysis procedure is chosen. Parameters of linear case are elements of stiffness-, mass- and damping- matrices. Parameters of nonlinear case are elements of mass- and damping-matrices and characteristics of bilinear hysteresis (details in [8]).

4.1. Optimization procedure

The hybrid optimization algorithm is applied. Before the genetic algorithm (GA) starts, the sensitivity analysis the measured response is executed. As result of sensitivity analysis only part of time history is needed. Using sensitivity in connection with GA improves the efficiency of optimization.

Flowchart of hybrid optimization procedure:

I. Sensitivity analysis

II. GA:
II.1 Initial population creation
II.2 Evaluation of initial population
Generational loop II.3 → II.8:
II.3 Fitness value calculation for each member of the population
II.4 Selection of individuals for breeding
II.5 Crossover of individuals
II.6 Mutation applying
II.7 Evaluation of the objective function
II.8 Replace the population with offspring

Details of GA are explained in basic books of Rechenberg [4] and Goldberg [5] and in contributions of Toropov et al. [6] or Wang et al [7]. The application is shown in [8]. Hysteresis of our frame example as result of experimental and numerical analysis is presented in fig.7. The minimum value of error is 0,1%.

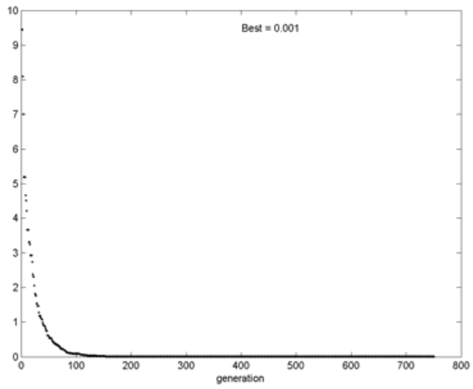

Figure 6 Objective - Optimization history

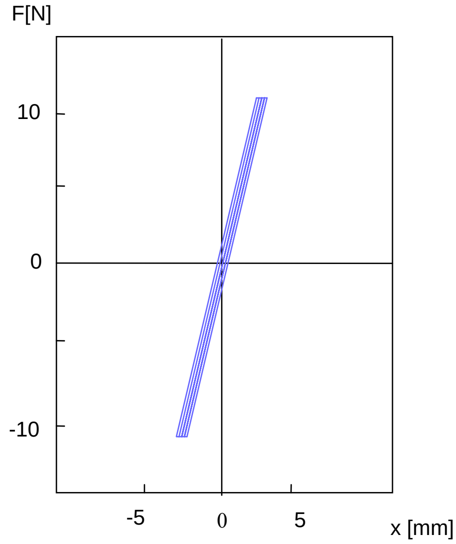

Figure 7 Force-deformation relation

5. MODIFICATION OF THE STRUCTURE - UPGRADE

In order to improve earthquake resistance of the structure the passive control with help of tuned mass damper is designed.
The optimization problem definition: minimization of dynamic response.

Objective: $$\min\left(\boldsymbol{x}(k_{TMD}, m_{TMD})\right) \tag{5.1}$$

Variables of optimization are added stiffness k_{TMD} and mass m_{TMD}. The hybrid algorithm introduced in part 4. is applied. Comparison of fig.4 and fig.9 shows changes by natural frequency.

Figure 8 Three-storey frame with TMD

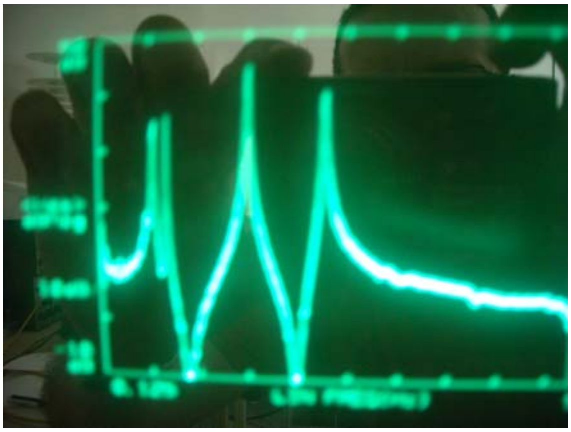

Figure 9 Response spectrum of frame with TMD

CONCLUDING REMARKS

The presented methodology allows creation of usable linear and nonlinear models of structures in dynamics. The features of these models are low number of degrees of freedom and physically good interpretable system parameters.

The identified model is usable for next analyses, for monitoring of the structure and for structural upgrade design.

The hybrid optimization is reliable procedure for structural parameter identification, upgrade of structure and improvement of structural behavior under earthquake loads.

REFERENCES

[1] Adam, C., Heuer, R. and Pirrotta, A. (2003). Experimental dynamic analysis of elastic-plastic shear frames with secondary structures. *Experimental Mechanics*, **43**, 124-130.

[2] Ambraseys, N., Smit, P., Berardi R., Rinalds, D., Cotton, F. and Berge, C. (2000). Dissemination of European Strong-Motion Data." European Commission, DGXII, Science, Research and Development, Bruxelles.

[3] Chopra, A.K. (2007). Dynamics of Structures, 3rd Edition. Prentice Hall, New Jersey.

[4] Rechenberg, I. (1973). Evolutionsstrategie – Optimierung technischer Systeme nach Prinzipen der biologischen Evolution, Frommann – Holzboog, Stuttgart.

[5] Goldberg, D. E. (1989). Genetic Algorithms in Search, Optimization and Machine Learning, Addison Wesley Publishing Company, New York.

[6] Toropov, V. and Yoshida, F. (2004). Application of advanced optimization techniques to parameter and damage identification problems. CISM course Udine, Springer.

[7] Wang, G.S., Huang, F.K. and Lin, H.H. (2004). Application of Genetic Algorithm to Structural Dynamic Parameter Identification, in Proceedings of 13th WCEE, Vancouver.

[8] Rosko, P. (2005). Dynamic System Identification of Civil Structure using Genetic Algorithm, in Proceedings of 6th World Congress of Structural and Multidisciplinary Optimization, Rio de Janeiro.

ACKNOWLEDGEMENTS

The author wishes to thank colleagues Prof. C. Adam and Prof. R. Heuer from Vienna University of Technology for experimental frame model creation.