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# IDENTIFICATION OF HYSTERETIC STRUCTURES USING NONPARAMETRIC MODELS

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## SUMMARY

The analysis of the recorded seismic response of buildings by means of system identification is very useful to throw light on the structural behaviour and to improve modelling. Since only a few points are frequently instrumented, the use of nonparametric models, which are very flexible, appear attractive. The response of an elastoplastic oscillator and that of a stiffness/strength degrading oscillator have been employed as experimental data. Identification techniques are used to determine two nonparametric models (ordinary and Chebyshev polynomials) and the results are compared with those obtained by means of two different parametric models. Numerical investigation reveals the capacity of the models to fit the data and predict future response for different accelerograms and intensities.

## INTRODUCTION

In the design of structures which have to resist severe earthquakes, it is generally accepted that the structures will undergo inelastic deformations. Many analytical models have been developed to simulate the response of different structures; notwithstanding the great efforts expended in elaborating sophisticated models and accurate algorithms, many uncertainties remain of course. The inadequacy of the analytical prediction is particularly felt when existing structures are considered. However alternative procedure can then be followed or at least additional information can be obtained by using 'synthetic' models derived from available records of nonlinear seismic response of real structures through an identification process. Moreover, experimental results can also be utilized appropriately to analyse the response of monitored structures and evaluate the damage state. The aim of experimental data processing is thus two fold: firstly interpretation and fitting of data in such a way as to facilitate successive damage evaluation, secondly construction of a mathematical tool to correctly predict future effects of stronger loads. Various models can be employed depending on which of the two aims is predominant [1-4].

In this paper the use of nonparametric models (NPMs) has been investigated, an analysis being made of the effectiveness of such models in the description of the experimental response and its predictive capability. Pseudo-experimental data are referred to in the identification process. A comparison has been developed with results obtained from two different parametric models (PMs): one is a quite general hysteretic relationship and the other is closer to the analytical sophisticated model used as a source of experimental data.

## IDENTIFICATION PROCEDURE

A structural problem described by only one variable y(t) is considered here; y(t) can really represent the configuration component of a sdof system or in a wider sense the generalized modal displacement of a mdof system. The equation of motion reads:

$$m\,\ddot{y}(t) + f(y, \dot{y}) = -\,\alpha\; m\, a(t) \tag{1}$$

where $f(y, \dot{y})$ is the generalized modal restoring force and $\alpha$ is the partecipation factor. Since in this paper attention is focused mainly on models suitable for representing the restoring force, it is assumed that $\alpha$ is known and that the contribution of higher modes is negligible or even it has been filtered. In substance the response of an equivalent sdof system is considered.

Assuming m to be known and $\ddot{y}$ and a to be measured, f is consequently obtained. If y is the response of the analytical model characterized by the restoring force f, the best approximation f of $\overline{f}$ is identified by the minimization of the two functionals:

$$l(f) = \int_0^T [\overline{y}(t) - y(t)]^2\, dt \quad , \qquad l(f) = \int_0^T [\overline{f}(t) - f(t)]^2\, dt \tag{2}$$

The first functional is related to the response errors, and the second to the resistant force. The use of $(2_1)$ is in general more onerous since the solution of differential equation (1) is required at each step of minimization procedure, but it furnishes a less distorted estimate of f. On the contrary, the use of eq. $2_2$ is straightforward, but the equation errors are not directly experimental errors, since they are filtered through the eq. 1. In the following elaboration both eqs. 2 are used.

## MODELLING OF THE RESTORING FORCE

The description of the force-deflection relationship given by eq. 1, when experimental values are introduced, is not suitable to be used, since it is in a tabular form and is irregular due to the presence of errors: it is therefore convenient to adopt a model.

NPMs are the first class of models referred to; these have no well-established physical structure and they are very flexible for representing different structural behaviours but with a well-defined analytical form [5-6].

It is assumed that f is a regular function of displacement and velocity, being represented as a series expansion:

$$f(y,\dot{y}) = \sum_{0}^{\infty}{}_j \sum_{0}^{\infty}{}_i \; a_{ij}\, g_i(y)\; h_j(\dot{y}) \tag{3}$$

Two families of nonparametric models are considered: one (NPM1) makes use of classical polynomials in which $g_i$ and $h_j$ are replaced by the monomial $y^i\,\dot{y}^j$, while the other (NPM2) adopts Chebyshev polynomials. Besides two models are considered in the first family, NMP1A is based on a complete poliynomial, NMP1B retains only odd terms.

Taking eq. 3 into account, and considering a finite number N of time points $t_k$, the functional ($2_2$) can be expressed as follows:

$$l(a_{ij}) = \sum_{1}^{N}{}_k \left\{ \bar{f}(z_k, \dot{z}_k) - \sum_{0}^{n}{}_i \sum_{0}^{n}{}_j a_{ij}\, g_i(z_k)\, h_j(\dot{z}_k) \right\} \tag{4}$$

The minimization of $l(a_{ij})$, which permits the best estimation of the coefficients $a_{ij}$, leads to the solution of a linear system of equations $(n + 1) \times (n + 1)$. When Chebyshev polynomials are adopted, each $a_{ij}$ can be directly evaluated due to the orthogonality property of these polynomials; this approach has been followed in [6].

PMs are the second class of models adopted, still considering two families. The first (PM1) is a general hysteretic force-displacement relationship obtained from the model proposed by Ramberg-Osgood according to the formulation reported in [7]; the model is mainly governed by four parameters. The second model (PM2) is a simplified form of the stiffness/strength degrading model (DHM) used to generate the "experimental" data. This model has been elaborated by the authors [7] to represent the cyclic behaviour of reinforced concrete columns and depends on many parameters. Model PM2 has the same structure and rules as the DHM but only four quantities are considered as parameters, while the other are assumed to be fixed and four of them have values which differ from the true values.

In the case of PMs here, the minimization of $l(x)$ leads to a nonlinear problem which is solved by a modified Powell algorithm.

## RESULTS AND DISCUSSION

A wide numerical investigation has been performed to analyse the effectiveness of nonparametric models in fitting the recorded data and in working as predictive models; parametric models are also considered for comparison. The description capabilities are investigated first. Pseudo-experimental data produced by the response of the elastoplastic oscillator (EPL) under the Taft accelerogram (Taft 21.07.52 N69W) have been fitted by means of NPM1 (A and B) and NPM2 for two levels of maximum ductility, $\mu = 2$ and $\mu = 5$; only this latter has been illustrated in fig. 1.

Though the EPL force-displacement relationship is a difficult case to match, since it exhibits discontinuity in its derivative, the approximation is not very satisfactory for the force history and unsatisfactory for the loops for both ductilities, however the accuracy of the period and the maximum force is better.

The greater effectiveness of NPMs emerges when they are used in identification of the DHM response (figs. 2 and 3). The description of the loops and of the time-history of the force is better, the latter being very satisfactory when a smaller response amplitude is considered. Moreover, in this case the differences among the NPMs used are not very evident.

The response of DHM is also identified by means of PM1 (fig. 4); though the intrinsic characteristics of the two models are different, the law of the force is well described, while a lack of accuracy is encountered in representation of the loops.

In the following figures the prediction effectiveness of the identified models is verified by comparison with the exact responses for stories that differ (in amplitudes or in accelerograms) from those used in the identification procedure.

In fig. 5 the exact response furnished by DHM under the Taft accelerogram for two values of amplitude ($\mu = 2$ and 5) is compared with that obtained by NPM1A and PM1 previously identified by referring to the response with $\mu = 2$. For this latter amplitude the comparison is not very satisfactory but acceptable; for $\mu = 5$ NPM1A furnishes divergent results, while PM1 behaves quite well, exhibiting a similar time-history with comparable maximum values.

An analogous comparison is shown in fig. 6, where the response refers to an artificial accelerogram, which matches a design spectrum of the C.E.B. Code, and the model adopted has been identified by referring to the response with a comparable amplitude but obtained with the Taft accelerogram. In this case the results are satisfactory, although some discrepancies occur just in the range of the maximum value; in particular the behaviour of NPM1A and PM1 is similar, while that of PM2 is quite a lot better. PM1 has also been identified by means of eq. $(2_1)$; the results (fig. 6d) appear to indicate that identification according to this equation is more effective.

Some conclusions can be drawn from the analysis performed.

- As far as the fitting capabilities are concerned, both parametric and nonparametric models are satisfactory with respect to the time-history of the force, but less satisfactory in the case of the f-y loops. This latter circumstance should be investigated in greater depth if damage indexes are to be determined.
- In this context parametric models can be very effective if they possess the characteristics of the real hysteretic laws; while nonparametric ones are probably less effective but more flexible with respect to different nonlinearities.
- As far as predicting capabilities are concerned, they seem to be satisfactory only when the identified models parametric or not, are used to predict response of amplitude similar to that referred to in the identification process.
- No important differences have emerged among the three different nonparametric models used, so attention as regards response prediction has been focused on the simplest symmetric classical polynomial NPM1A.

Effords should be made to establish the above points satisfactorily, to analyse the influence of experimental erros and to extend the investigation to more general time-histories obtained from a measured point in a multidegree-of-freedom structure.

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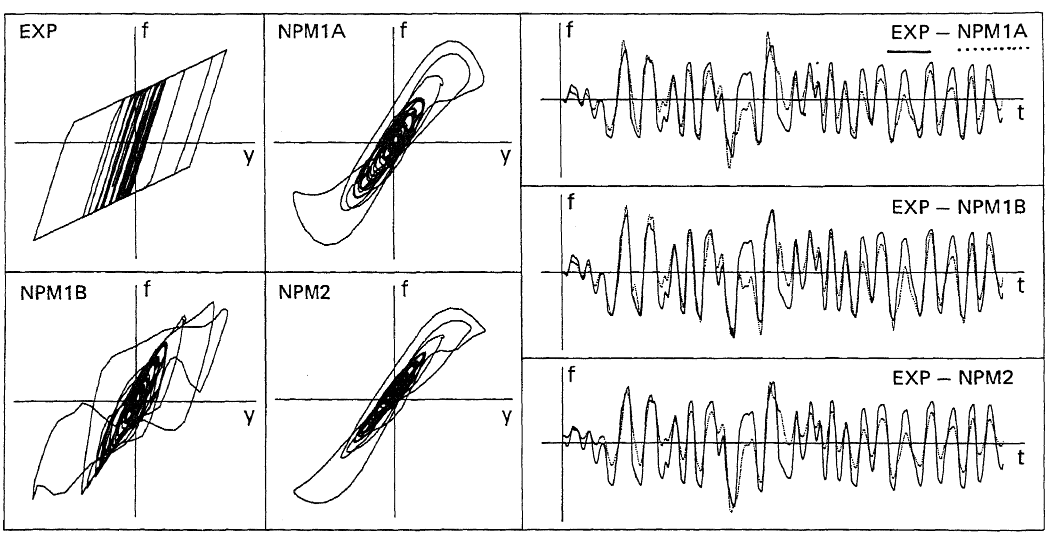


Fig. 1 - Experimental (EPL) and identified (NPM1, 2) restoring force. Taft accelerogram - $\mu = 5$

REFERENCES

1. Natke, H.G., Juang, J.N., and Gawronski, W., "A Brief Review on the Identification of Nonlinear Mechanical Systems", 6th IMAC Conf., Orlando, Florida, (1988).
2. Toussi, S., and Yao, J. T. P., 'Hysteresis identification of existing structures", J. of the Engineering Mechanics Division, ASCE Vol. 109 No. 5, 1189-1202, (1983).
3. Anderson, J. C., Masri, S. F., and Mohasseb, P., "Dynamic Response Correlation Using Simplified Models", Proc. of Cong. Dynamic Response of Structures, ASCE, Univ. of California, Los Angeles, 828-835, (1986).
4. Peng, C.Y., and Iwan, W.D., "Identification of Hysteretic Structural Behaviour from Strong Motion Accelerograms", in Structural Safety Evaluation Based on System Identification, Natke and Yao Eds., Vieweg Werlag, (1988).

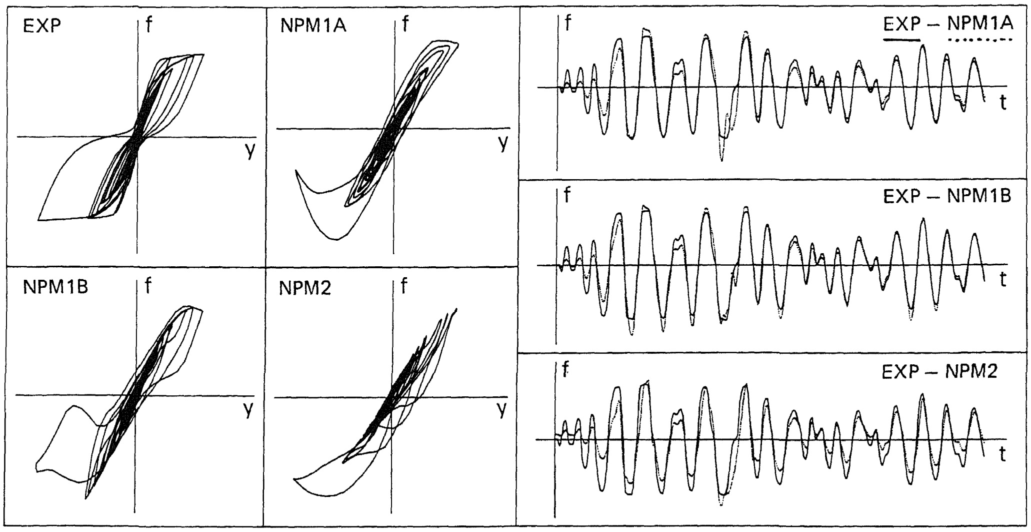


Fig. 2 - Experimental (DHM) and identified (NPM1, 2) restoring force. Taft accelerogram - $\mu = 5$

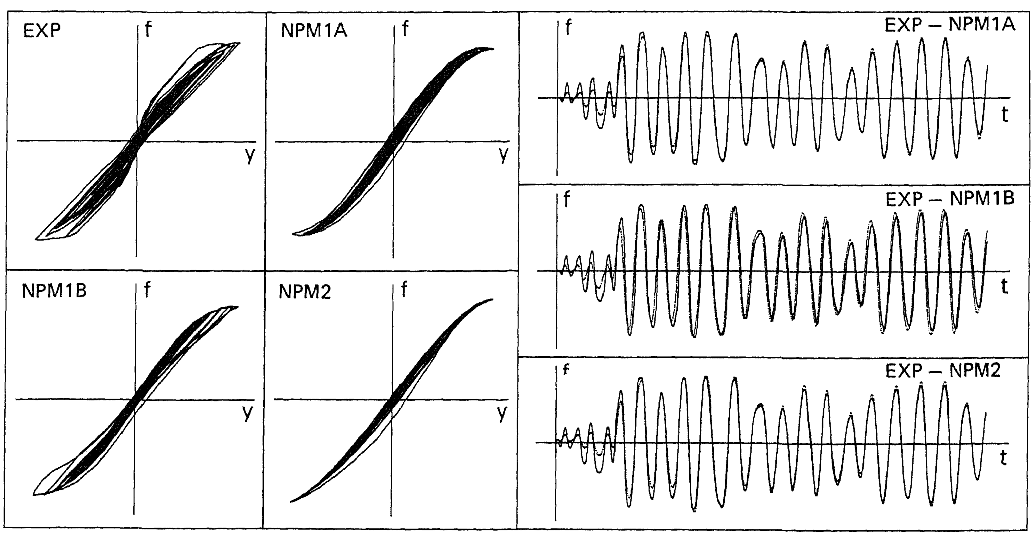


Fig. 3 - Experimental (DHM) and identified (NPM1, 2) restoring force. Taft accelerogram - $\mu = 2$

5. Crawley, E. F., and O'Donnel, K. J., "Force-state mapping identification of nonlinear joint", AIAA Journal, Vol. 25 No. 7, 1003-1010, (1987).
6. Masri, S. F., and Caughey T. K., "A nonparametric identification technique for nonlinear dynamic problems", Journal of Applied Mechanics, 6, 433-447, (1979).
7. Capecchi, D., and Vestroni, F., "Cyclic Behaviour and Seismic Response of a Model with Decay for Reinforced Concrete Members", 2nd ICEE, Rapallo, (1984).

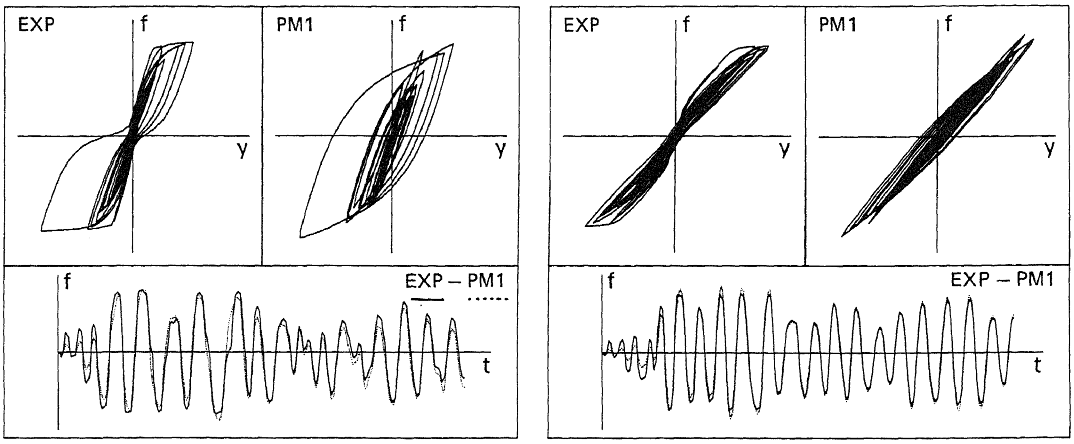


Fig. 4 - Experimental (DHM) and identified (PM1) restoring force. Taft accelerogram - $\mu = 5$ (a), $\mu = 2$ (b)

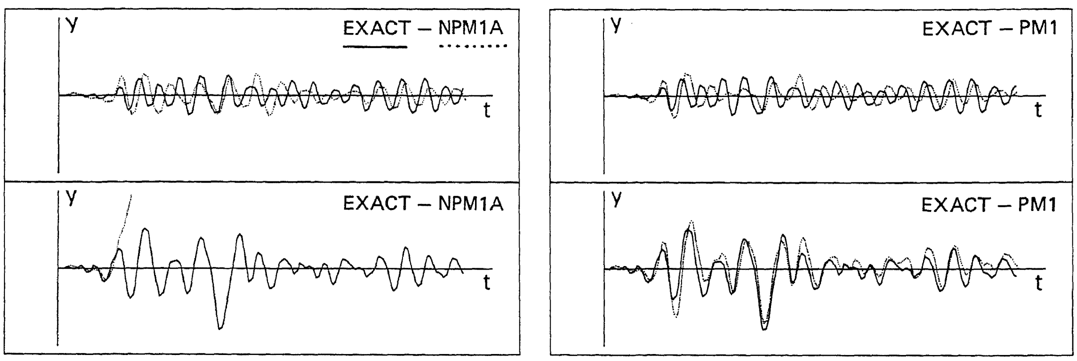


Fig. 5 - Exact and predicted response - parametric and nonparametric models. Taft accelerogram

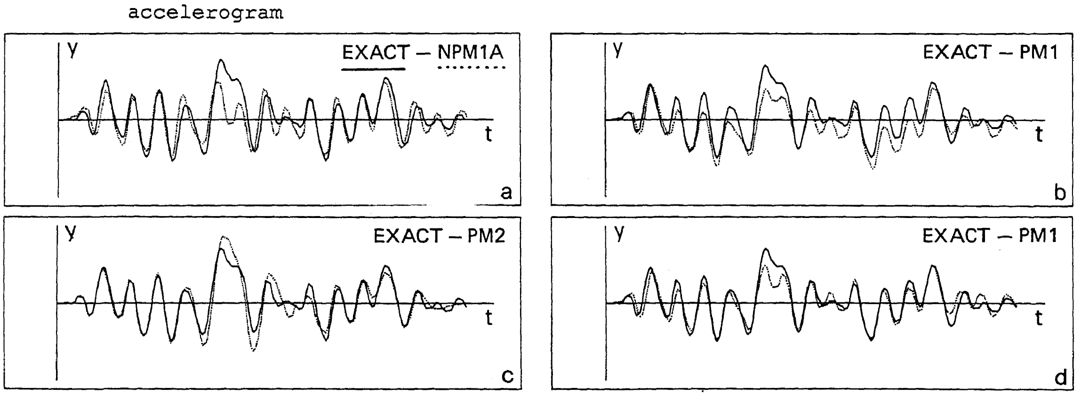


Fig. 6 - Exact and predicted response - parametric and nonparametric models. CEB accelerogram