ANALYSIS OF NON-STATIONARY RESPONSE OF STRUCTURES DUE TO SEISMIC RANDOM PROCESSES OF EVOLUTIONARY TYPE

Jiří NÁPRSTEK[1] And Cyril FISCHER[2]

SUMMARY

Seismic random processes are characterized by high non-stationarity and, in most cases, by a marked variability of frequency content. The hypothesis modelling seismic signal as a simple product of a stationary signal and a deterministic modulation function, consequently, is hardly ever applicable. Several mathematical models aimed at expressing the recorded process by means of a system of stationary random processes, and deterministic amplitude and frequency modulations are proposed. Models oriented into the frequency domain with subsequent response analysis based on integral spectral resolution and models oriented into the time domain based on the multicomponent resolution are investigated. The resolution into individual components (nonstationary signals) is carried out by three methods. The resolution into Intrinsic Mode Functions (IMF) seems to possess the best characteristics and yields results almost not differing from the results obtained by stochastic simulation. An example of the seismic response of an existing bridge obtained by two conventional models and three variants of multicomponent resolution is given.

INTRODUCTION

An analysis of a number of seismic records has shown that the widely used hypothesis of the resolution of the nonstationary random signal in the form of a product of a deterministic modulation function and a stationary signal $\mathbf{v}(t) = \mathbf{m}(t)\cdot\mathbf{v}_s(t)$ can be applied to simple cases only, as it conserves frequency content throughout the seismic event [Náprstek and Fischer, 1998b; etc.]. In case of more complex seismic signals this resolution is non-satisfactory, as the spectral density of processes $\mathbf{v}_s(t)$ depends on time. It is necessary to construct a model converting the recorded process into a stationary process with non-variable frequency content. Mathematical models of random seismic processes devised in recent years have always aimed either into the frequency domain to link up with the integral spectral resolution method of structure analysis [Náprstek and Fischer, 1993; 1994; Zembaty and Krenk, 1994; etc.], or have been oriented on the generalized correlation method in the time domain [Náprstek and Fischer, 1995; Zerva and Zhang, 1996]. The same approach can be accepted also in the case of evolutionary processes with the purpose of linking up with the existing FEM systems. It seems that an adequate mathematical model of an evolutionary process can attain very good agreement with the results obtained by far more time consuming simulations considered as decisive criteria [Boore, 1983].

SPECTRAL RESOLUTION OF SEISMIC EVOLUTIONARY PROCESSES

The models of evolutionary seismic processes can be founded on the following spectral expression:

$$\mathbf{v}(t) = \int_{-\infty}^{\infty} \mathbf{m}(t,\omega)\exp(\mathrm{i}\omega t)\, d\mathbf{Z}(\omega) \tag{1}$$

[1] *Institute of Theoretical and Applied Mechanics, Academy of Sciences of the Czech Republic, Email:naprstek@itam.cas.cz*
[2] *Institute of Theoretical and Applied Mechanics, Academy of Sciences of the Czech Republic, Email:naprstek@itam.cas.cz*

where $d\mathbf{Z}(\omega)$ is the spectral differential of the stationary part of excitation and $\mathbf{m}(t,\omega)$ the modulation function. The function $\mathbf{m}(t,\omega)$ is dependent on both variables t,ω and it is able to describe both amplitude and frequency modulations simultaneously. If the spectral density of the process $d\mathbf{Z}(\omega)$ is differentiable, the spectral density of the evolutionary process $\mathbf{v}(t)$ can be written in the form as follows [Lin and Cai, 1995]:

$$\Psi_{\mathbf{v}}(t,\omega)=\mathbf{m}(t,\omega)\cdot\overline{\mathbf{m}(t,\omega)}\cdot\Psi_{\mathbf{Z}}(\omega) \tag{2}$$

In a general case the determination of the function $\mathbf{m}(t,\omega)$ is difficult, as both modulation types intermingle in their mathematical expression. However, it is possible to consider special cases, as the change of frequency content often shows distinct tendencies which can be expressed by parameters dependent on „slow time“, while using the same basic formula describing the spectrum.

A frequent case is that in which the excitation process is of narrow band character, while the position of the apex shifts into higher frequencies with time. Such „change of scale“ on the frequency axis can be expressed in the form of:

$$\mathbf{v}(t)=\int_{-\infty}^{\infty}\mathbf{m}_a(t,\omega)\cdot\exp(\mathrm{i}\varphi(t,\omega))\cdot\exp(\mathrm{i}\omega t)\,d\mathbf{Z}(\omega)\ ; \qquad \mathbf{m}(t,\omega)=\mathbf{m}_a(t,\omega)\cdot\exp(\mathrm{i}\varphi(t,\omega)) \tag{3}$$

where $\varphi(t,\omega)$ means the change of scale. If the function $\varphi(t,\omega)=\varepsilon\,(t\cdot\omega)$, the whole spectrum is merely affinely extended in direction ω. This approximation is often satisfactory, only the constant ε should be determined. The remaining function $\mathbf{m}_a(t,\omega)$ merely describes the amplitude modulation which also has a time-variable form due to the side-effect of frequency modulation and due to variable multiplicative amplitude modulation. In a number of cases the apex of the spectrum drops with time so that the influence of frequency modulation on amplitude is negligible. In such a case it is possible to separate the frequency and the amplitude modulations entirely and write:

$$\mathbf{v}(t)=\int_{-\infty}^{\infty}\mathbf{m}_a(t)\cdot\exp(\mathrm{i}\varphi(t,\omega))\cdot\exp(\mathrm{i}\omega t)\,d\mathbf{Z}(\omega)=\mathbf{m}_a(t)\int_{-\infty}^{\infty}\exp(\mathrm{i}\varphi(t,\omega))\cdot\exp(\mathrm{i}\omega t)\,d\mathbf{Z}(\omega) \tag{4}$$

where the integral expresses the nonstationary process with reference to frequency content. For $\varphi(t,\omega)=0$ Eq. (4) degenerates into a conventional amplitude modulation which, however, is unable to respect the frequency content evolution. However, it is possible to find the way out by making the function $\mathbf{m}_a(t)$ dependent explicitly on „slow time“ τ, i.e. $\mathbf{m}_a(t,\tau)$. The frequency modulation can be also understood in the meaning of „slow time“.

The second special case consists in a direct modification of the spectrum by a modulation function of a variable $(\tau\omega)$ such as a rational fraction, exponential with a real exponent, etc. In this way preferences of some frequency ranges can be achieved the scope of which can be changed more or less arbitrarily in dependence on „slow time“. This approach influences backwards the amplitude modulation which must be adapted accordingly with this phenomenon.

With reference to the analysis of a response of the structure, Eq. (1) is oriented on the method of integral spectral resolution, see e.g. [Náprstek and Fischer, 1994; 1998b; etc.]. This method enables a relatively accurate analysis of the structure response. However, it is rather time-consuming in particular applications. It is suited to deal with stationary periodical processes, as it corresponds with the character of Fourier analysis. This means that it is not sufficiently adaptable particularly to strong non-stationarities which often lead to results difficult to be interpreted. On the other hand, if the frequency content varies significantly and continuously, the model (1) is probably the most suitable in spite of the above shortcomings.

MULTICOMPONENT RESOLUTION

Physically more transparent than the previous one seems to be a resolution of an initial process into components which can be described by conventional methods. Its application means that each component is written in the form of a product of a random stationary process of approximately time-independent frequency content and a deterministic amplitude modulation. The time-dependence of the frequency content of the initial signal is expressed by an adequate selection of individual modulation functions. The number of these components is not limited in principle; however, the practical criteria of determination of partial stationary processes and modulation functions do not permit a large number of these components. Therefore, we write:

$$\mathbf{v}(t)=\sum_{i=1}^{n}\mathbf{m}_i(t)\cdot\mathbf{v}_{si}(t) \tag{5}$$

Eq. (5) can be interpreted in various manners - hence also the respective forms of further analysis. The summation of individual components and an adequate selection of modulation functions can be understood as a certain form of dependance on „slow time“. However, the structure of Eq. (5) is more transparent than of the Eq.

(1). It works with one type of modulation only. The initial process is modelled in the time domain and, consequently, is far more flexible than the expression in the frequency domain. It admits without any problem various beat types and does not generate any side-effects, typical for resolutions (1) or (4) in such cases.

A frequent reason for variable frequency content of a seismic process consists in the participation of seismic waves of several types arriving at the investigated site with different time delay. Assuming that each of them has an approximately time-independent frequency content, each of addends in Eq. (5) can be considered as the influence of one type of the seismic waves. However, the separation of the individual waves from the initial signal is difficult. For practical application it is far easier to divide the initial signal into narrow-band components. In the framework of the individual bands the changes of frequency content are negligibly small. The variable frequency content of the initial signal is effected by means of modulation functions. These narrow-band signal components can be determined by various methods. There are outlined three of them.

The simplest way is to determine the Fourier spectrum of a seismic record and divide it into parts according to certain criteria and separate the individual components by filtering. The component bands do not overlap and it is meaningful to assume that each of these component can be written in a form of the product of a deterministic function and a stationary random process $\mathbf{m}_i(t)\cdot \mathbf{v}_{si}(t)$. The filtering of the initial signal, however, results in considerable phase distortion particularly in the margins of individual frequency intervals. This is due to heavy frequency discontinuity of the so-introduced filters which principally have the characteristics of curvilinear trapezes. Also the division of the frequency axis into disjuncted intervals may be debatable as it is not determined by any objective criterion. The fundamental shortcoming, however, is the very Fourier analysis which operates too globally within the whole interval and cannot cope sufficiently with nonstationary signals and particularly with local excesses.

A better basis for the resolution (5) is provided by wavelet analysis introduced by [Malat, 1989]. It gives much better results thanks to the fact that its effect - as compared with Fourier analysis - is rather of local character and, consequently, it does not impose any requirements on a priori stationarity and periodicity of the process. The analysis of the response of several structures subjected to the Sierra Madre seismic excitation by means of the above method and by means of simulation resulted in minimum differences of results [Fischer, 1999]. However, the whole procedure still contains subjective elements in connection with the particular application of wavelet analysis and could fail in case of seismic processes with heavy beats. The effectivity of the structure response computation drops with the square of the number of components in (5), as it is necessary to respect the cross-correlation of components $\mathbf{v}_{si}(t)$.

If the processes $\mathbf{v}_{si}(t)$ make an orthogonal series, the computational effort would rise only linearly with the rising n. This can be achieved by the resolution of the process $\mathbf{v}(t)$ into Intrinsic Mode Functions (IMF) the properties and algorithms of which are described in detail e.g. in [Huang et al., 1998; Náprstek and Pospíšil, 1999]. These functions were introduced originally in connection with an assessment of the frequency content of a signal by means of Hilbert spectrum. Their principal characteristics are:

- the process as a whole should comprise the same number of zero and extreme values;
- the process should be symmetrical with reference to the zero mathematical mean value or, in other words, the mean value of the envelope of local maxima and minima should equal zero in every point.

The processes obtained by measurements do not by far satisfy these requirements in the majority of cases. Therefore, it is necessary first to resolve them into components the characteristics of which correspond with IMF. There are several algorithms of this resolution. The relatively most stable and numerically most effective is the EMD (Empirical Decomposition Method) described, with several examples, in [Huang et al., 1998]. The result of this computation is a finite number of IMF and a residual trend which, however, usually equals zero in the case of seismic processes. The number of important characteristics of IMF includes their orthogonality and balanced frequency content only little dependent on time. Consequently, they can be written without problems in the form of $\mathbf{m}_i(t)\cdot \mathbf{v}_{si}(t)$. The partial processes $\mathbf{v}_{si}(t)$ are narrow-band processes. However, their frequency contents are not burdened by any distortion like in the case of a simple division of the frequency interval.

As regards the matrix of amplitude modulation it can be obtained by means of existing knowledge. As a rule it is formulated in the form of:

$$\mathbf{m}_i(t) = \mathbf{m}_{0i}(t)\cdot h(t)\cdot m_i(t) \tag{6}$$

where $\mathbf{m}_{0i}$ is a constant diagonal matrix, $h(t)$ Heaviside function, and $m(t)$ a scalar modulation function. The construction of the function $m(t)$, or $m_i(t)$ was afforded great attention in the past. Most frequently it has the form of various combinations of exponential functions, possibly multiplied by various polynomials [Bolotin, 1961; Shinozuka and Sato, 1967; Náprstek, Fischer, 1995; etc.], such as $Pol(t)\cdot(\exp(-\alpha t)-\exp(-\beta t))$, where $\alpha<ß$. It has come to light, however, that this form does not satisfy a whole number of seismic events particularly when the process is of significant beat character. The dropping exponential functions are incapable of influencing with sufficient sensitivity the modulation at major distances from the origin and are suitable only for such events as El Centro, characterized by a fast increase at the beginning followed by a slow continuous drop without further beats. The study of numerous records and their subsequent analysis has made the authors come to the conclusion that a general case is best satisfied by a modulation function of the B-spline type, see e.g. [Boor de, 1987; Náprstek and Fischer, 1998a] which means:

$$m(t) = \sum_{j=0}^{k-N} \alpha_j \, B^N (t - t_j) \qquad (7)$$

where $0 = t_0 < ... < t_k = T$ is the interval division and B^N is a B-spline of the N-th degree. The advantage consists in a continuous differentiable function enabling a sufficiently accurate approximation of the modulation while its expression is relatively simple. A sufficient spline degree is N = 2 or 3. The number of segments into which the interval is dependent on signal history.

The stationary part of the excitation $\mathbf{v}_s(t)$ or one component of this vector can be described by spectral density in the form, see e.g. [Tajimi, 1960; Bolotin, 1961; etc.] (Kanai-Tajimi model):

$$\psi(\omega) = \frac{\sigma_0^2}{\pi} \cdot \frac{c^2 b}{(c^2 - \omega^2)^2 + 4b^2\omega^2} \qquad (8)$$

Such spectral density is achieved by the filtering of white noise of the variance σ_0^2 by a second order filter representing a system of one degree of freedom, of stiffness c and relative damping b. Hence the idea that the structure is excited by a system of white noises introduced into its supports through simple second order filters. Supplementing the original structure in every support), with the appropriate number of above mentioned filters, an extended system arises which is excited by white noises only. The number of these filters should correspond with the number of degrees of freedom and number of components in Eq. (5). In seems that in practical cases the formula (8) or the second order filter can be satisfactory. Having obtained the individual stationary processes v_{si} (t), corresponding spectral densities of the (8) type can be numerically determined using the minimization procedure of the functional min|| $\psi^*(\omega)$ - $\psi(\omega)$||.

[Kozin, 1977] proposed the description of a variable frequency structure of excitation corresponding with the basic formula (8) using a second order filter with variable coefficients dependent on „slow time" τ :

$$\ddot{v}(t) + 2b(\tau) \cdot \dot{v}(t) + c^2(\tau) \cdot v(t) = w(t) \qquad (9)$$

The application of (9) could eliminate the resolution into components in the meaning of Eq. (5). The problem is, however, the determination of time dependences $b(\tau)$, $c(\tau)$ and the link with amplitude modulation which must be dependent on time of both scales, i.e. both t and τ. In particular, this approach represents a return to one variant of the special case (4) of the frequency resolution.

The authors afforded great attention to the problems of the practical performance of the resolution of (5) into the modulation functions and the stationary components or its parameters in the meaning of Eqs. (6), (7), (8). Partial results were tested by means of numerous records of actual seismic events (El Centro 1940, Joshua Tree 1992, San Fernando 1971, Northridge 1994, etc.) and carefully verified by simulations.

RESPONSE OF A STRUCTURE

The movement of a discrete or discretized (FEM) structure excited kinematically in supports can be described by the system:

$$\mathbf{M}\,\ddot{\mathbf{u}}(t) + \mathbf{B}\,\dot{\mathbf{u}}(t) + \mathbf{C}\,\mathbf{u}(t) = -\mathbf{F}\,\dot{\mathbf{v}}(t) - \mathbf{G}\,\mathbf{v}(t) \qquad (10)$$

where **M, B, C** are constant $(n\times n)$ square matrices of parameters of the system and the **F**, **G** $(n\times m)$ matrices of parameters of the system connection to support nodes; $\mathbf{u}(t)$ vector of the system response in free nodes - n elements; $\mathbf{v}(t)$ vector of kinematic excitation by seismic processes in the supports - m nonstationary random processes according to (1). If the vector of acceleration processes $\ddot{\mathbf{v}}(t)$ and velocities $\dot{\mathbf{v}}(t)$ are available, it is possible to work with an alternative system:

$$\mathbf{M}\,\ddot{\mathbf{u}}_p(t) + \mathbf{B}\,\dot{\mathbf{u}}_p(t) + \mathbf{C}\,\mathbf{u}_p(t) = -\mathbf{F}_a\,\ddot{\mathbf{v}}(t) - \mathbf{G}_a\,\dot{\mathbf{v}}(t) \qquad (11)$$

where:

$$\mathbf{u}(t) = \mathbf{u}_p(t) + \mathbf{u}_q(t)\,; \quad \mathbf{F}_a = \mathbf{M}\mathbf{C}^{-1}\mathbf{G}\,; \quad \mathbf{G}_a = \mathbf{B}\mathbf{C}^{-1}\mathbf{G} - \mathbf{F} \qquad (12)$$

while $\mathbf{u}_p(t)$ is a dynamic part of free nodes displacements in the state of fixed unmovable supports and $\mathbf{u}_q(t)$ is the quasi-static part of free nodes displacements, governed by the simple equation:

$$\mathbf{C}\mathbf{u}_q(t) = -\mathbf{G}\,\mathbf{v}(t) \qquad (13)$$

The authors have elaborated in detail and tested the solution of nonstationary stochastic response of the system (10) or (11) by the integral spectral analysis method [Náprstek and Fischer, 1993; 1994], by the application of Markov processes and FPK equation and by the original version of the correlation method [Náprstek and Fischer, 1995]. Although each of the above methods has its advantages and is suitable for a certain range of the problems, it is coming to light that it is the correlation method combined with Lyapunov bilinear equations that is most suitable for practical application. It lends itself best to algorithmization, links up best with the existing FEM systems and yields relatively most transparent and most easily analyzable results in a very broad range of problems. The solution of Eq. (10) or (11) is formulated in the form of the mathematical mean value of the response, which represents its deterministic part, and the covariance matrix which describes fully its stochastic part. The deterministic part is determined by the solution of Eq. (10) or (11) for the mathematical mean value of excitation on the right-hand sides of these equations. As we consider the seismic excitation processes as centered processes, the deterministic part of the response is identically equal zero. It can be shown that the covariance matrix of the response $\mathbf{D}_u$(t) is represented by the solution of Lyapunov matrix differential equation:

$$\dot{\mathbf{D}}_u(t) = \mathbf{Q}\mathbf{D}_u(t) + \mathbf{D}_u(t)\overline{\mathbf{Q}}^t + 2|m_0(t)|^2\,\mathbf{H}\mathbf{D}_w\overline{\mathbf{H}}^t \qquad (15)$$

where $\mathbf{Q}$ is the square matrix comprizing the parameters of the structure **M**, **B**, **C**, **F**, **G**, or $\mathbf{F}_a$, $\mathbf{G}_a$ as well as the parameters of auxiliary filters c_j , b_j ; $\mathbf{D}_w$ is the matrix of white noise intensities of the stationary component of excitation, and **H** is the ancillary matrix of coincidence.. Eq. (15) can be solved in a closed form in most practically important cases of the modulation function $m_0(t)$ incl. the splines (7) by the method of unknown constant matrices and algebraic bilinear Lyapunov equations. The tools for their solution can be found in various packages, such as IMSL, MATLAB, etc.

SAMPLE PROBLEM

Let us demonstrate now the procedure of resolution of a seismic signal and its subsequent application to an analysis of the seismic response of an existing bridge, see Figure 1., using the following record: Sierra Madre earthquake recorded at Altadena, Eaton Canyon Park station, June 28, 1991, magnitudo 5.8, epicentral distance 49.3 km, E-W component. The record was corrected to exclude the influence of the data acquisition system.This process was modelled by five different methods:

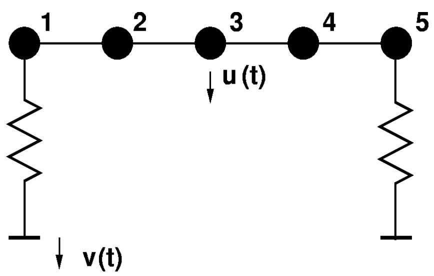

Figure 1: Lumped mass modelled bridge

a) simple amplitude modulation using function: (exp($-\alpha t$)-exp($-\beta t$));
a) simple amplitude modulation using spline: B^N (N=2, n=31);
b) resolution in the meaning of Eq. (5); narrow-band components correspond with frequency intervals in Fourier spectrum;
c) resolution in the meaning of Eq. (5); narrow-band components were obtained by wavelet analysis;
d) resolution in the meaning of Eq. (5); narrow-band components are the IMF (EMD method).

By way of a sample, Figure 2 shows a narrow-band component of the above signal obtained by wavelet analysis. Column (a) shows the nonstationary components alone (functions $m_i(t)\cdot\ v_{si}(t)$; i=1-5) demonstrating their narrow-band character. Column (b) gives the respective amplitude modulations $m_i(t)$. Their history shows that the application of a flexible function of spline type is necessary. The above mentioned exponential curves cannot model them. Column (c) shows the processes $v_{si}(t)$ stationary in amplitude and in frequency content. Their regular frequency content, visually observable in the column (a), was verified by the independence of spectral densities on partial time intervals. Spectral densities $\Psi_i(\omega)$, valid for the whole time interval, and their approximations corresponding with the general formula (8), are given in column (d). Their actual approximative history shows that they are of narrow-band character, indeed, with a very small overlap and correspond with the case (4) in the 2nd paragraph, viz. $\varphi(t,\omega)=\varepsilon\,(t\cdot\omega)$. The apex of the spectrum is moving regularly towards higher frequencies being accompanied by the drop of spectral density values.

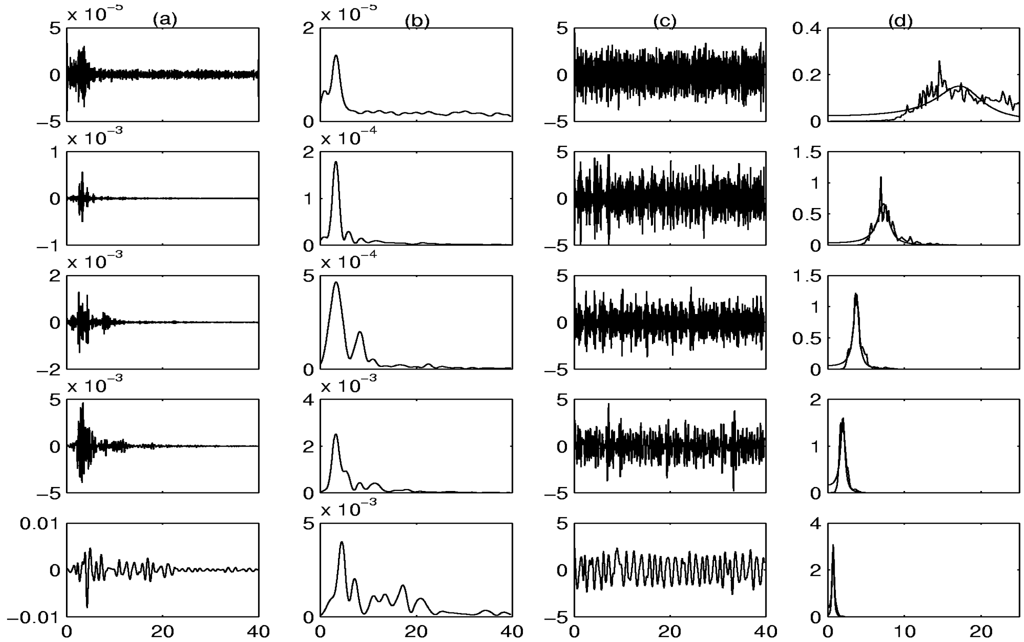

Figure 2: Resolution of Sierra Madre signal; (a) narrow band components $m_i(t)\cdot\ v_{si}(t)$**;**
(b) amplitude modulation $m_i(t)$**; (c) stationary process** $v_{si}(t)$**; (d) spectral density** $\Psi_i(\omega)$

The stochastic response of the structure according to Figure 1 is fully described by the covariance matrix $\mathbf{D}_u(t)$ of components of the vector [$\mathbf{u}$, $d\mathbf{u}/dt$]. It is obtained solving Eq. (15) or substituing into its general solution. With regard to a marked nonstationarity of the response elements of the matrix are functons of time. The most important elements of the matrix are variances of displacements in nodes 1-5 of the model in Figure 1. Selected results are given in Figure 3 and in Table 1. Analysis by the correlation method was made for all five above mentioned models of excitation and by the stochastic simulation method. Figure 3 shows the results of above alternatives (a)-(d). The highest curves in Fiures 3(a)-3(d) correspond with the middle node (#3) of the model in Figure 1. The lowest curves correspond with the boundary nodes (#1 and #5). The maximum values of variance in the middle node corresponding with all six variants are given in Column 3 of Table 1.

Figure 3(a) shows the history of the centre displacement variance, if the excitation is modelled by a simple model with amplitude exponential modulation while neglecting the variability of the frequency content in time. Results are substantially different form those obtained by means of simulations. Visibly better results were obtained using more flexible amplitude modulation by a spline, Figure 3(b). The difference of the maximum variance from simulation results, however, is still considerably great. The application of multicomponent resolution according to Eq. (5) has revealed that its introduction alone need not represent any quality jump, if not accompanied by a careful analysis of the frequency content of the initial process. Figure 3(c) reveals that the simple division of the Fourier spectrum into disjunct intervals is not very adequate. Only Figure 3(d), and lines 5 and 6 in Table 1 show that a smooth division of the frequency content, whether affected by wavelet analysis or by IMF, yields the results comparable with stochastic simulation.

A comparison with the results obtained on the basis of standards [Eurocode 8, 1996; and others] has confirmed the well known fact that in case of stiff structures the analysis using response spectra yields excessively pessimistic results while in case of soft structures (pipelines, roofs, cooling towers) yields results considerably underrating reality.

Table 1: Peak value of the displacement variance [m^2] in the middle node of the bridge

	Resolution	Ampl. modulation	Peak value [m^2]	Fig. 3
1.	simple ampl.modulation, no freq. modulation	(exp(-αt)-exp(-βt)); $\alpha < \beta$	~ $0.1 \cdot 10^{-5}$	(a)
2.	simple ampl.modulation, no freq. modulation	B^N spline (N=2, n=31)	~ $0.5 \cdot 10^{-5}$	(b)
3.	splitted Fourier spectra	B^N spline (N=2, n=31)	~ $0.7 \cdot 10^{-5}$	(c)
4.	wavelet resolution	B^N spline (N=2, n=31)	~ $2.2 \cdot 10^{-5}$	(d)
5.	Intrinsic mode functions	B^N spline (N=2, n=31)	~ $2.3 \cdot 10^{-5}$	
6.	Monte Carlo simulation		~ $2.5 \cdot 10^{-5}$	

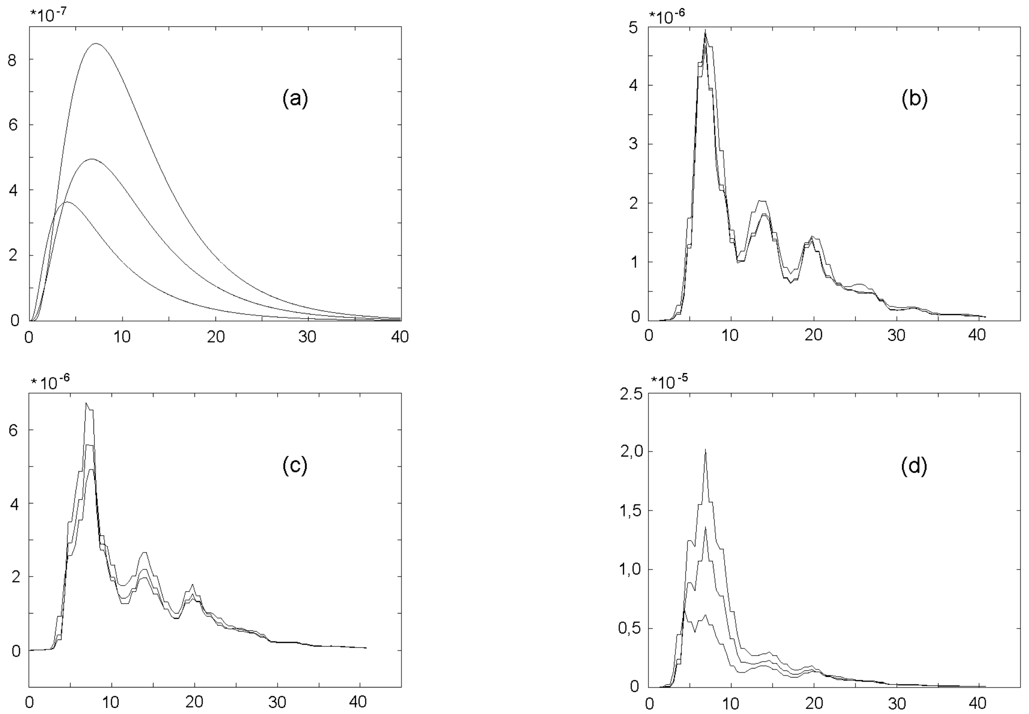

Figure 3: Displacement variance [m^2] as a function of time [*s*] in the middle node (#3) of the bridge

CONCLUSION

Comparing results of theoretical investigations and results of numerical analysis of actual structures it is possible to conclude that the problem of influence of the variable frequency content of the nonstationary seismic signal can be solved in practical cases by means of multicomponent resolution combined with the generalized correlation method. The results obtained by this method and those obtained by stochastic simulation are almost identical both in maximum values and in the histories of corresponding quantities. As the seismic process selected for the sample case belongs to the category with considerable variability of frequency content, the presented method of analysis can be considered acceptable for practical purposes. However, it is also possible to repeat the conclusion of a previous paper [Náprstek and Fischer, 1998b] according to which the seismic processes of El Centro type, which do not change much their frequency content during the seismic event, can be analyzed with sufficient accuracy and without great influence on result quality by a simple amplitude modulation by means of B^N splines. In a standard case, however, it is necessary to consider the seismic process as an evolutionary process and, consequently, respect the variable frequency structure of the signal. It is necessary to construct a model of either spectral type or of multicomponent resolution type. If the variation of the frequency content is not too great, it is preferable to stick to the multicomponent resolution model. This model is rather oriented to the generalized correlation method of structure response analysis, which gives more transparent results, lending itself better to algorithmization and easier link with existing FEM system. The structure of the multicomponent resolution itself is much more transparent and enables a more natural physical interpretation. The resolution into components, however, must be performed with circumspection and all procedures which could result in discontinuities, such as the simple cutting of Fourier spectrum, must be avoided. The processes based on wavelet transformation and the IMF resolution have proved well. The latter has slightly better properties and lower requirements with regard to the orthogonality of components into which the initial process is resolved. The problems with numerical stability of resolution itself, however, perserve and need an intensive investigation.

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