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SHOCK SPECTRUM CALCULATION OF STRUCTURAL RESPONSE TO UNDEX

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ABSTRACT

The measured responses of a structure subjected to underwater explosion may deviate from the exact results due to high intensity impact on transducers and signal amplifiers, which will further cause fault SRS (shock response spectrum) analysis if this kind of disturbance is not filtered. In view of the disturbance characteristics, SVD (singular value decomposition) and ARMA filtering techniques are combined to recover the exact response signals from which SRS is computed. The results show that SVD in combination with ARMA filtering is able to separate step-like disturbances from the measured response signals and as a result improves the accuracy of SRS at low frequencies..

1 INTRODUCTION

Underwater explosion (UNDEX) is an energy conversion process of very short duration. Usually, the structural response to an explosive load is transient but with large deformation and nonlinear phenomena, which may cause damages to structures. Therefore, lots of efforts have been made to analyze structural response to the shock load of UNDEX and the severity of the accompanying damages [1-5]. Investigation of the characteristics of UNDEX responses is helpful to the anti-shock design of structures. Numerical simulation and field testing are two important measures for studying UNDEX responses. Although numerical tools are powerful and filed testing is complex and usually extremely expensive, UNDEX experiments cannot yet be replaced by numerical simulation. Due to the intensive shock load, transducers mounted on structures will subject to high strength impact, which causes electrical impact to signal amplifiers and sometimes bias between the measured and the exact response signals. Especially, the step signal may be included in a measured response signal, which may further affect the calculation of shock response spectrum and cause difficulties in establishing the shock environment. As such, it is meaningful to process measured response signals and recover them to the exact ones.

Among the numerous data filtering methods, the singular value decomposition (SVD) is widely used in noise filtering and signal detection . By performing SVD on a matrix that is specially constructed from measured signals, the matrix can be decomposed into signal and noise subspaces. Essentially, the SVD filtering is an orthogonal decomposition, which can strengthen useful signals and eliminate noises through intrinsic signal correlation. However, using SVD alone is difficult to separate signals with abrupt disturbance, such as the step disturbance, from the structural responses of UNDEX. At the same time, the step disturbance cannot be completely removed if only a phaseless ARMA filter is applied [6-9]. In this paper, SVD and the phaseless ARMA filtering are combined to remove the step-like disturbances. The advantages of the ARMA and SVD filtering are fully used to recover the exact shock responses with unperceivable phase inconsistency.

2 SVD and ARMA filtering

2.1 SVD filtering

The filtering method based on SVD should construct a Hankel matrix at first. Suppose the time sequence is $X=\{x_1, x_2, x_3, \cdots, x_{n-1}, x_n\}$.

The Hankel matrix can be constructed from this sequence as in Eq. (1) and its SVD is

$$H(X)=\begin{bmatrix} x_1 & x_2 & \cdots \\ x_2 & x_3 & \cdots \\ \vdots & \vdots & \ddots \end{bmatrix}=U\begin{bmatrix} \sigma_1 & \\ & \Sigma \end{bmatrix}V^T=u_1\sigma_1 v_1^T+u_2\Sigma v_2^T \tag{1}$$

For those signals containing a direct current component (by adding a sufficiently large direct current component to a signal), the subspace corresponding to the direct current signal is related by σ_1 . Let $\Sigma=O$ in Eq.(1), the filtered non-vibratory component can be obtained as in Eq. (2)

$$H(Y)=u_1\sigma_1 v_1^T, \qquad Y=\{y_1, y_2, y_3, \cdots, y_{n-1}, y_n\} \tag{2}$$

2.2 ARMA filtering

Suppose the ARMA model of a low pass filter is given as

$$a_1 z^p + a_2 z^{p-1} + \cdots a_p z + a_{p+1} = b_1 y^q + b_2 y^{q-1} + \cdots + b_q y + b_{q+1} \tag{3}$$

Filtering the sequence Y by this low pass filter, high frequency components can be removed. In view of the existence of time delay of a physically realizable filter, the phase delay cannot be avoided in the output sequence $Z=\{z_1, z_2, z_3 \cdots, z_{n-1}, z_n\}$. To give a phaseless filtering, backward filtering of Z with the same filter is necessary. Let $\bar{Z}=\{\bar{z}_1, \bar{z}_2, \bar{z}_3 \cdots, \bar{z}_{n-1}, \bar{z}_n\}$ be the result of the phaseless filtering, then, the recovered signal is

$$\{x_1-\bar{z}_1, x_2-\bar{z}_2, x_3-\bar{z}_3 \cdots, x_{n-1}-\bar{z}_{n-1}, x_n-\bar{z}_n\} \tag{4}$$

3 The spectrum of measured shock response signal

The measured shock response signal is usually transformed into certain spectrum in the frequency domain. The shock response spectrum (SRS) is often used to indicate the maximum shock response of the equipments mounted on a mass base and to assess the safety of the equipments subjected to the base shock. SRS is formed by the maximum responses of a series of SDOF systems of different natural frequencies that are subjected to the given shock loading.

The shock response spectrum can be calculated from the responses of SDOF systems with different methods, such as the Duhamel integral and numerical filtering. Here, the method based on numerical filtering is adopted.

The measured shock responses were obtained from the base of sufficiently large mass in an experiment of UNDEX conducted in a test pond, which is shown in Figure 1. During the explosion, an intense shock wave was generated, which impacted the experimental platform and caused the mounted equipments to oscillate. Fig. 2 shows the measured acceleration response of the mass base, where exists distinctly a step disturbance resulting from the transducers or the signal amplifier. The tendency part with step property results in the high speed of impact spectrum in the low frequency band, which is not up to the fact. It is necessary to remove the step-like disturbance from the measured response signal and recover the SRS in the low frequency band. With the proposed method, the step-like disturbance is extracted from the measured signal. The solid line in Fig.2 represents the separated disturbance. On account of the large number of data, the original data was divided into several segments, which is useful to construct a Hankel matrix of small dimension to reduce the computation load. The corresponding Fourier spectra are depicted in Fig.3, in which the spectrum magnitude of the measured signal attenuates by -20dB/dec at low frequencies and the vibration characteristics are almost buried at these frequencies. The Fourier spectrum of the disturbance coincides well to that of the measured signal. Therefore, the vibration characteristics of the measured response at about 10Hz are completely recovered. Fig.4 shows the SRS of the recovered signal, which indicates the property of constant displacement of SRS at low frequencies. Figure 5-8 are the measured response at another measurement point and the corresponding results of filtering. One can observe from the recovered velocity response that the maximum velocity occurs at about 0.5s, which is far behind the shock impact, and the oscillation frequency is about 10Hz. In fact, oscillating at about 10Hz is independent of the measurement points, which may cause damages to the equipments with mounting frequency near 10Hz.

Figure 1 Experiment of UNDEX

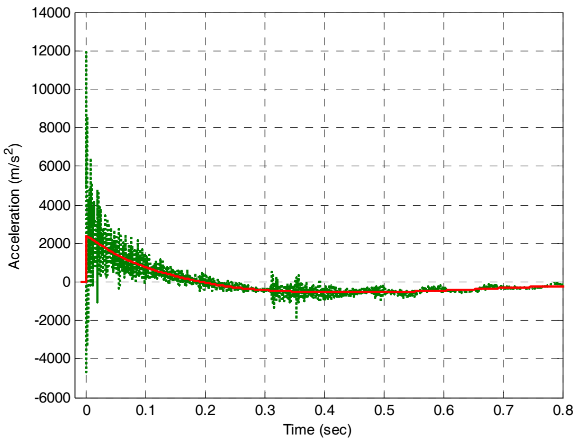
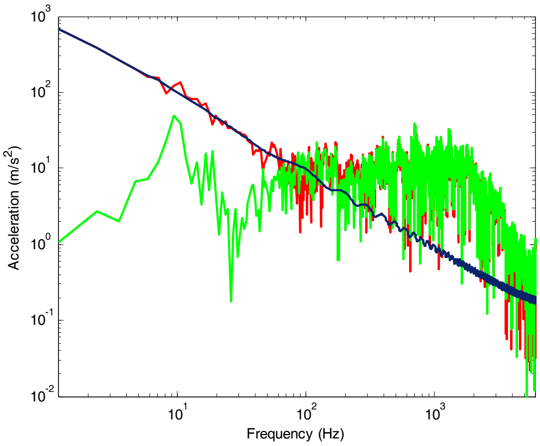


Figure 2 Measured shock response
(solid - filtered, broken – measured)



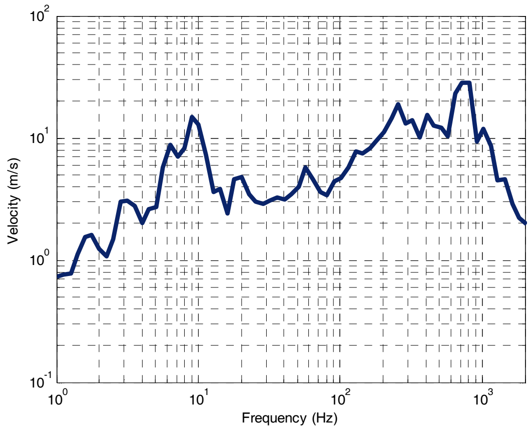
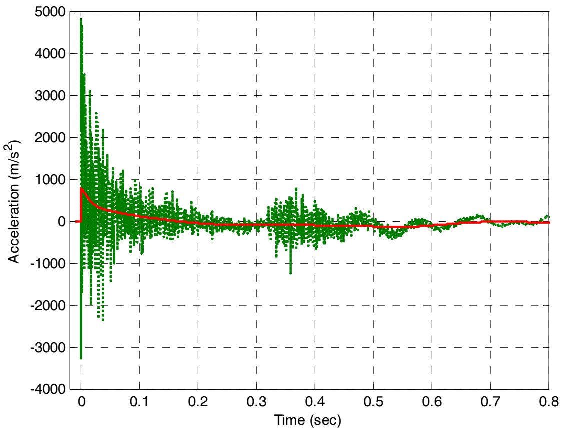


Figure 3 Fourier spectrum Figure 4 SRS of the recovered signal

(red - measured, green – recovered, blue – noise)



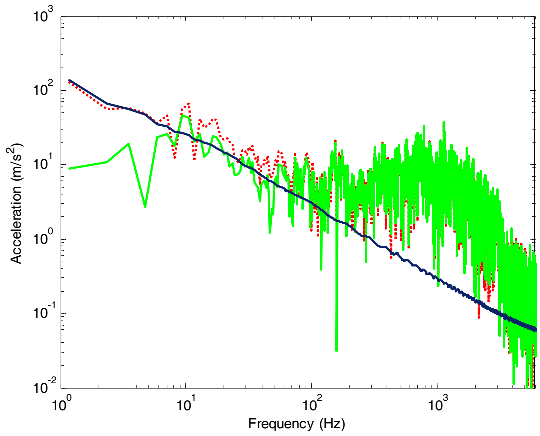
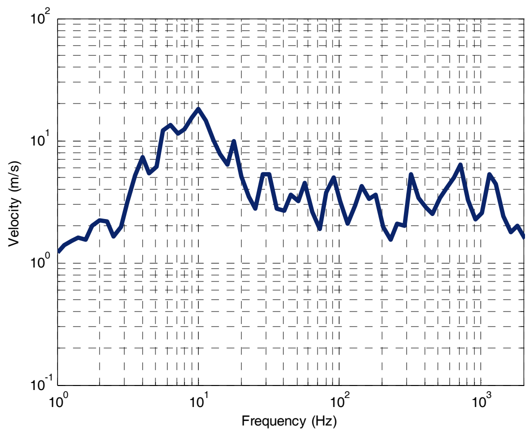


Figure 5 Measured shock response
(solid - filtered, broken – measured)

Figure 6 Fourier spectrum
(red - measured, green – recovered, blue – noise)



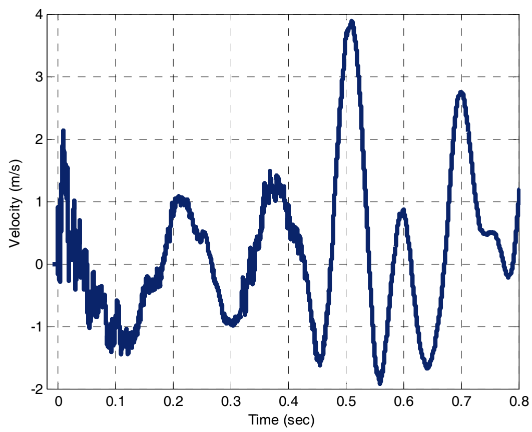


Figure 7 Shock response spectrum

Figure 8 Velocity response

4 Conclusion

The combination of SVD and ARMA filtering can remove the abrupt disturbance from the measured shock responses without any phase delay. Therefore, the distorted output caused by transducers and/or amplifiers can be remedied. According to the processing results, the characteristics of SRS at lower frequencies are recovered and the accuracy of velocity computed from the measured acceleration response can be guaranteed.

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