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A simple and intuitive procedure to identify pulse-like ground motions

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A B S T R A C T

Near-fault seismic ground motions are frequently characterized by intense velocity and displacement pulses of relatively long periods that clearly distinguish them from typical far-field ground motions. Intense velocity pulse motions can affect adversely the seismic performance of structures. In response to the realization of the importance of near-fault motions on structural performance, a number of studies have been directed to developing procedures for the identification of ground motions containing velocity pulses. The present paper reviews these studies briefly and presents a simple and efficient procedure to identify pulse-like ground motions based on a new parameter called “development length of velocity time history”. The procedure is applied to a representative series of records, and the results show positive efficiency to identify pulse-like ground motions at low computational cost.

1. Introduction

When a fault ruptures toward a site, a rupture velocity slightly slower than the shear wave velocity produces an accumulation of seismic energy released during rupture [1–3]; this generally results in a large pulse in the velocity-time series. Thus, near-fault seismic ground motions are frequently characterized by intense velocity and displacement pulses of relatively long periods that clearly distinguish them from typical far-field ground motions. Intense velocity pulse motions can affect adversely the seismic performance of structures [4–10].

In response to the realization of the importance of near-fault motions on structural performance, a number of studies have been directed to developing predictive relationships for parameters that characterize this special type of ground motions in the near-fault zone [11–13]. Bray and Rodriguez-Marek [14] identified key parameters in the characterization of forward-directivity pulse motions including amplitude (PGV), velocity pulse period, and number of significant cycles. However, Rupakhety and Sigbjörnsson [15] found that equivalent pulses often used to characterize the structural response of tall buildings to near-fault ground motions underestimate the peak interstory drift.

Following the same objective, other researchers assembled sets of pulse-like or near-fault ground motion, but these sets were selected using different criteria. Somerville, Mavroeidis and Papageorgiou, Bray and Rodriguez-Marek, Cox and Scott, and Fu and Menon [2,13,14,16,17] prepared lists of near-fault records regarded as having strong ground motion pulses. Since pulse orientation is often assumed to have a fault-normal direction, the focus of these researchers was on identifying pulses on fault-normal components; in this way, only a few fault-parallel pulse records were identified [10–26].

Baker [18] and Shahi and Baker [31] developed a method for quantitatively identifying ground motions containing strong velocity pulses, such as those caused by near-fault directivity. The approach uses wavelet analysis to extract the largest velocity pulse from a given ground motion. The size of the extracted pulse relative to the original ground motion is used to develop a quantitative criterion for classifying a ground motion as "pulse-like". The criterion was calibrated by using a training data set of manually classified ground motions.

Khanse and Lui [19] present a methodology for identifying earthquake pulses. Because directivity effects are most significant for frequencies less than 1.67 Hz (i.e., a period longer than 0.6 s), this criterion is used in his study to identify pulse characteristics. The methodology classifies a record as pulse-type (pulse-like) if in the ground velocity Fourier Amplitude Spectrum, it shows a high peak with a frequency lower than 1.6 Hz. In this case, shear frequency (fc) has to be identified and ground velocity time history has to be filtered in order to prove the existence of the pulse. These two aspects need human intervention with some degree of subjectivity. Therefore, the procedure cannot be easily replicated with identical results. Zamora and Riddell [20] take Baker's index as a base and, additionally, consider the parameters of acceleration pulse intensity and movement velocity taking into account the range of orientation over movement. The classification is empirical with no intention to explain its origin based on the seismological properties of the rupture process.

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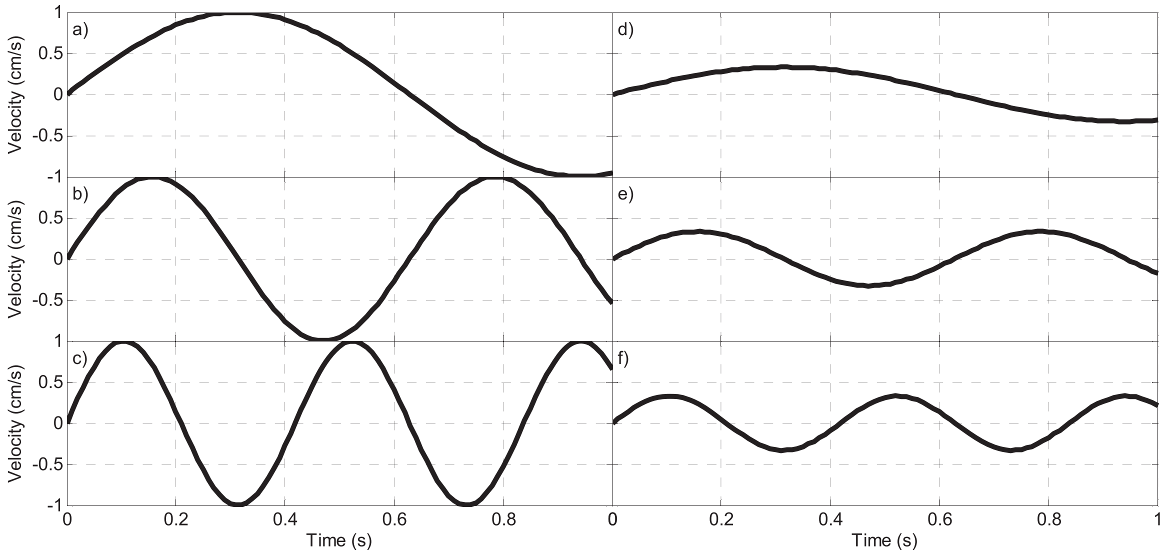

Fig. 1. Sine waves: (a) A=1.0 y ω=5; (b) A=1.0 y ω=10; (c) A=1.0 y ω=15; (d) A=1/3 y ω=5; (e) A=1/3 y ω=10 y (f) A=1/3 y ω=15.

Table 1
Lengths developed and Impulsivity Index for sine waves with different wave amplitudes *A* and frequencies ω for a time interval of 1.0 s.

Case N°	Amplitude *A*	Frequency ω	Period *T*	Length Ld_v	Impulsivity Index *IP*
a	1,0	5	1,26	2,36	2,4
b	1,0	10	0,63	3,07	3,1
c	1,0	15	0,42	3,41	3,4
d	0,33	5	1,26	1,79	5,4
e	0,33	10	0,63	2,19	6,6
f	0,33	15	0,42	2,39	7,2

Hayden et al. [21] developed a quantitative scheme to classify near-fault motions as pulse or non-pulse. This scheme involves filtering the record, calculating several parameters at all orientations, followed by scoring motions based on two key ground motion parameters. The developers manually reviewed the results and adjusted the classification of a limited number of records, realizing that no numerically based classification procedure would be able to capture all the nuances of a record. It identifies pulse-like movements for those records with one or two intense cycles in the recording of velocity. It uses two parameters related to ground velocity: the difference between two successive peaks for different orientations and the square of the normalized cumulative velocity. In this way, it defines a logistic regression with the purpose of classifying a certain record as pulse-like.

Mukhopadhyay and Gupta [22] state that the pulse-like movement may be visually identified due to the presence of a large-amplitude pulse, long period, and significant energy content in the history of ground velocities. It defines fractional energy as the ratio between the energy of the signal of each half-cycle and the total energy of the signal. The maximum value of fractional energy contributes to pulse-like movement. Zhai et al. [23] propose a quantitative method based on energy to assess pulse-like movements. It considers that in a coherent medium the pulse makes a great contribution to the total energy of ground motion. The energy of movement is represented by the integral of the square of ground velocity in the time history. The relative energy of the pulse is used as a prediction variable to identify a pulse. The seismic motions whose dominant velocity pulses have relative energy values over 0.3 can be classified as pulse-type; otherwise, they are classified as non-pulse or ambiguous. Maniatakis et al. [24] performed a comparison between Greek records and well-known international near-source records from small, moderate and strong earthquakes. They found that the maximum ratio of spectral velocity to peak ground velocity (PGV) is a good indicator of velocity pulse-type. However, the study does not present a formal criterion to classify pulse-type records.

In general, the different criteria for pulse-like record classification resort to a visual control of results through direct observation of record traces [18–20]. Thus, the observation of the velocity record trace is an effective tool for classification, and so the shape adopted by the velocity history trace is a sign of its impulsive character, despite being qualitative and keeping a certain degree of subjectivity.

On the other hand, in the procedures developed so far to identify pulse-type records, a certain kind of operational complexity makes it difficult to be used by non-specialists. Therefore, for the identification of future records, it may be necessary to resort to the proposers of such procedures, so that they perform the classification correctly.

The present study describes a new procedure to classify pulse-like records from velocity time series. This procedure is simple, easily reproducible and captures the visual classification criterion in a quantitative fashion. The parameters involved in this new classification criterion also allow to assess the influence of the time series orientation and to determine the direction of greater impulsivity.

2. Impulsivity index

2.1. Development length of a velocity time series

Given a curve on the plane *x-y*, expressed in parametric fashion x=x(t) and y=y(t) with a < =t < =b, the length of such curve is given by

$$L = \int_a^b dl = \int_a^b \sqrt{\left(\frac{dx}{dt}\right)^2 + \left(\frac{dy}{dt}\right)^2}\, dt \tag{1}$$

If the curve is defined through n discrete values y_i for equally spaced abscissas Δx, then the length of the curve shall be

$$L = \sum_{i=1}^{n} \left(\sqrt{(\Delta x)^2 + (\Delta y_i)^2}\right) \tag{2}$$

Departing from a velocity time history of ground motion, the "developed length of velocity" parameter Ld_v is defined as the length reached by the trace of velocity records as if it were "extended" like a string (Eq. (3)) [27].

$$Ld_v = \sum_{i=1}^{n} \left(\sqrt{(\Delta t)^2 + (\Delta v_i)^2}\right) \tag{3}$$

where Δt is the time lapse of the record between two successive points $t_{(i+1)}$-$t_{(i)}$, Δv_i are velocity increments between $t_{(i)}$ and $t_{(i+1)}$ in *cm/s*,