

## Evaluation of the Closed-Form Formulation Aimed at Fitting Strong Ground Motions in Near Fault Zones

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### Abstract

Strong ground motions in the near field to the fault rupture mechanism, due to the presence of large and energetic pulses in the relevant time history, can produce and induce the seismic wave-type behavior in the continuum contour of the site and strongly affect the variation domain of the structures response parameters. This trend is such that there is a significant increase in the possibility of extensive structural damage and the occurrence of dynamic instability modes. Therefore, evaluating the seismic performance of structures under such strong ground motions is very complex and many factors are involved in it. Based on recognizing and evaluating the special features of near-field records, determining the time intervals of pulses and the related spikes, as well as assessment of the corresponding high-energy frequency bands, it is possible to determine the corresponding artificial time series and waveforms by the implementation of closed form-fitting procedure. The application of fitting artificial time series and mappings is in the subject of behavioral analysis and evaluation of the seismic performance of structures under a specific frequency band of strong near-field records.

In this study by using several mathematical parametric expressions with the ability to fit the shape of the velocity and acceleration pulses, the waveform structures in the time history of near-field records have been modeled and adjusted. The process of simulation and closed-form fits was performed in a way that in addition to matching the existing pulses in the velocity and acceleration time histories, the diagram of cumulative changes of kinetic energy also has a good agreement with the corresponding one related to the real record. In addition to modeling velocity pulses, diagram of cumulative changes of energy release under artificial time series and the real record has also been calculated and compared. The results of this study describe the features and functionalities for the closed form-fitting model in performing simulations and computational validation on strong earthquake records. Analytical considerations and computational outcomes indicate a range of results in numerical domains very close to the earthquake record parameters which can be increased to the area of large variations. The nonlinear interaction between the effective parameters in the analytical fitting process and then the computational processing of both sets of time history and spectral responses considered for the evaluations made on the closed-form model, is the cause of the emergence of different convergence ranges.

**Keywords:** *Earthquake Record, Near-Field Zone, Fault Mechanism, Velocity Pulse, Closed-Form Fitting, Response Spectrum*

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## Extended Abstract:

### 1. Introduction

The experience of various earthquakes in the past has shown extensive damage and, as a result, great financial and human losses at different times. These effects are due to extensive damage to structural elements and the lack of adequate resistance of the structure to the forces caused by strong earthquakes. Considering target site conditions and the general characteristics of past seismic events in that area and designing the structure accordingly, would prevent damage to some extent. In order to estimate the seismic demands and sustainability requirements of structures and to predict their post-earthquake stability, it is of particular importance to recognize and pay attention to pulse-type ground motions, especially in near-field zones to active faults. The characteristics of the aforementioned motions clearly depend on the conditions of the seismic source, the direction of fault rupture relative to the site, and the general direction of fault slip. Also, due to the directivity effects in both the parallel and normal components of the rupture direction in the fault mechanism, the spectral structure and physical characteristics of near-field earthquake records are distinguished from those of far-field ones (Rodriguez-Marek et al., 2006, Bradley et al., 2017, Cao 2025). In the meantime, there is also the possibility of a directivity process with fling-step effects, especially in the time history component parallel to the fault rupture direction. Strong directivity effects emerge when the shear wave velocity and direction of propagation are equal to or close to the fracture velocity of the ground structure, which manifests as long-amplitude pulses in the ground velocity time history and short-duration high-energy spikes in the ground acceleration time history, too. Forward directivity conditions can exist for both strike-slip and dip-slip faulting events. In strike-slip events, forward directivity conditions are typically greatest for locations near the end of the fault plane, as the rupture front moves toward the site. In dip-slip events, progressive directivity conditions would occur for the locations in ruptured zone of the fault mechanism (Khansefid et al., 2020, Kohrangi et al., 2019, Li et al., 2024).

### 2. Methodology

There are various analytical frameworks and procedures have been proposed for fitting and modeling the distinct pulses in the time history of near-field earthquake records (Makris et al., 2003, Mavroeidis et al., 2004, Nadim, et al., 2025). In this study, a method has been proposed that apply simple polynomial functions (Equation 1) with analytical degree one to three through using MATLAB software (MATLAB 2009). The analytical formulation of this method is the application of trial and error steps and the corresponding computational cycles.

$$V = a t^3 + b t^2 + c t + d \quad (1)$$

The analytical model and fitting procedure proposed in this study, in addition to being simple, is highly efficient, and its accuracy is reflected in the related computational framework. Furthermore, the attention to low-amplitude, small-period spikes before and after the main distinct velocity pulse, and the possibility of simulating them in the closed-form mappings are of the essential characteristics of the proposed method in this study.

In this method, considering the wave-like features in the main coherent velocity pulse and a number of high-amplitude spikes before and after it, the time interval and the degree of analytical fitting are

selected in accordance with what is given in the manuscript of this study, and their formulation is a function of changes in corresponding spectral parameters, (Figure 1).

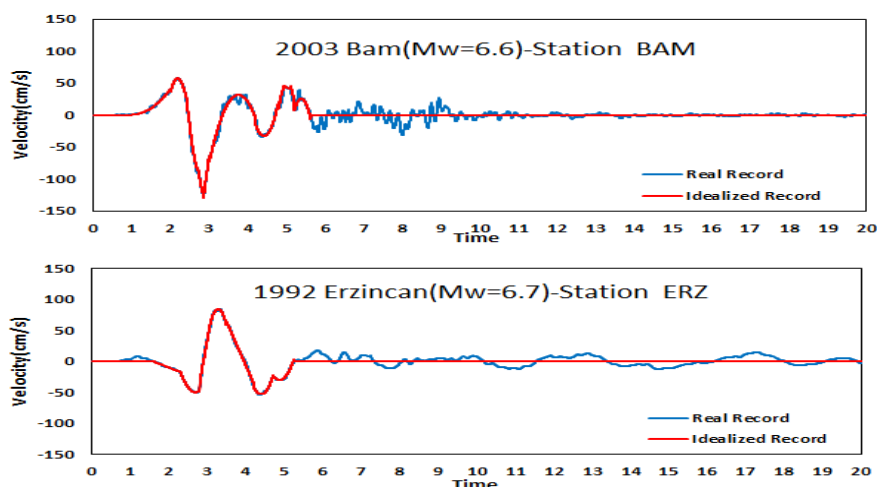


Figure 1. Matching display of fitted velocity pulses (red) on the velocity time history of the real earthquake record (blue), corresponding to the recorded accelerograms Bam 2003 (BAM) and Erzincan 1992 (ERZ).

It should be noted that in these mapping processes, a general and efficient closed-form of the velocity pulse as well as an effective fitting structure is developed. Moreover, the resulted analytical representations are taking into account the high-amplitude spikes before and after the main distinct velocity pulse, in which the maximum possible correspondence for the selected strong earthquake records is obtained.

### 3. Conclusion

Coherent and high-amplitude velocity pulses contain a very large fraction of the energy of the earthquake record. Therefore, in the process of fitting synthetic earthquake tremors, the analytical focus is on simulating these pulses. An important point in constructing and approximating artificial earthquakes is to pay attention to the distinct velocity pulse and the temporal arrangement of high-energy spikes located on both sides of the main wavelet of the aforementioned pulse in the time history of a strong near-field record. Computational coverage over a number of high-amplitude and large-scale spikes will increase the accuracy of the closed-form mapping. The calculations and approximations made in the analytical method of this research are based on the selection of time intervals and the estimation of the characteristics of the velocity pulses along with the use of a trial and error process. Also, by modeling multiple high-amplitude spikes on both sides of a distinct velocity pulse, a more accurate mapping of the earthquake record can be achieved.

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