AUTOMATED INCLUSION OF PERMANENT DISPLACEMENT INTOR NEAR-FAULT GROUND MOTIONS WITH FLING-STEP EFFECTS

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Extended Abstract

Near-fault pulse-like ground motions have long been recognized as a major threat to the safety of buildings and infrastructure due to their characteristics of long periods, short durations, and high amplitudes. The velocity pulses contained in these motions represent the cumulative effect of fault rupture processes and are governed collectively by factors such as rupture mechanisms, fault geometry, asperity distribution, slip direction, and surface permanent deformation. Research indicates that Forward Directivity (FD) and Fling Step (FS) are the two primary physical mechanisms generating velocity pulses: FD typically manifests as a bidirectional velocity pulse, whereas FS is characterized by a distinct unidirectional pulse. The difference becomes particularly significant after integration into displacement time histories—FS pulses result in non-zero permanent displacement (PD) at the end of shaking, a feature absent in FD pulses. Generally, FD effects appear mainly in directions perpendicular to the fault plane, while FS effects develop along the direction of fault slip.

Historical destructive near-fault earthquakes, such as the 1999 Chi-Chi earthquake, have demonstrated that permanent displacements induced by fling-step effects can lead to catastrophic consequences for structures crossing or adjacent to faults. Consequently, extensive research has been conducted over recent decades focusing on pulse identification, parametric modeling, numerical simulation, and the impact of near-fault ground motions on structural response. However, existing studies have predominantly concentrated on FD pulses, with relatively limited attention paid to FS pulses. A key reason for this lies in the fact that most ground motion records used in engineering analysis are sourced from mainstream international databases like NGA-West2, where records have undergone high-pass filtering or baseline correction, leading to the systematic removal of low-frequency permanent displacement information closely associated with FS.

Taking the Chi-Chi earthquake as an example, as shown in Fig. 1, the velocity time histories clearly exhibit significant unidirectional pulses, yet the displacement time histories fail to show the expected permanent displacement. This is a direct consequence of standard processing workflows. Although some studies have attempted to recover PD through specialized baseline correction techniques, these methods are highly sensitive to baseline selection and suffer from notable uncertainty in the absence of prior PD information. Meanwhile, a growing body of evidence suggests that ignoring PD may severely underestimate the inelastic demands of near-fault structures. For instance, for bridges and isolated structures spanning rupture zones, asymmetric permanent displacements across the fault significantly alter internal force distributions and deformation modes; for steel frame structures, excessive filtering can overestimate collapse capacity by more than 50%. Thus, accurately recovering or predicting permanent displacement in FS-type ground motions has become a critical aspect of seismic analysis and design for near-fault structures.

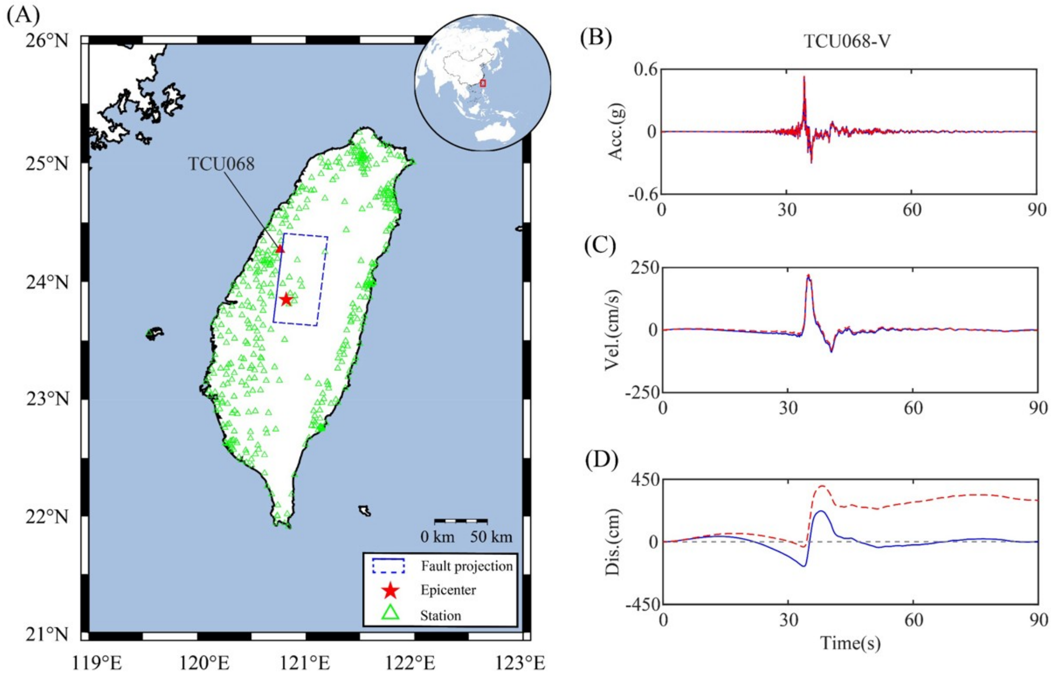

Figure 1- (A) Map view of the 1999 Chi-Chi earthquake in China. (B), (C), and (D) show the acceleration, velocity, and displacement time histories from the PEER NGA database (blue solid lines) and the corrected ground motion (red dashed lines)

To address these issues, three main technical approaches currently exist: (1) segmental baseline correction of raw records based on geodetic data; (2) artificial generation of ground motions with PD using source simulation techniques; and (3) superimposing predicted FS pulses onto processed ground motions based on pulse models. Given that global engineering practice relies heavily on processed database records, the third approach offers the highest engineering applicability. Accordingly, this paper proposes an automated correction method to restore fling-step effects and permanent displacement in processed ground motions while preserving their original frequency domain characteristics.

The core concept treats the FS pulse as a physical signal dominated by low-frequency components, realized through recursive fitting of Gabor wavelets for pulse extraction. Specifically, a progressive iterative algorithm is first employed to extract the low-frequency pulse component containing PD from processed records in the NGA-West2 database. Subsequently, a Butterworth non-causal low-pass filter is applied to this pulse component to retain the permanent displacement while avoiding significant "overestimation" of the original acceleration and velocity time histories. Finally, the filtered low-frequency pulse is superimposed onto the original record to obtain corrected ground motions that retain both the original spectral characteristics and the true permanent displacement. Comparisons with GPS coseismic displacement observations confirm the reliability of the proposed method in terms of PD recovery accuracy. To facilitate automated application, this study proposes a strategy for determining the optimal low-pass filter cutoff frequency based on the slope of the fitted straight line in a designated section of the time history. This method adaptively selects filtering parameters across different ground motion records, significantly improving correction efficiency and stability.

This presentation will systematically introduce the theoretical basis of the method, the pulse extraction and filtering mechanisms, and the automated implementation workflow. The findings provide not only a more reliable technical means for selecting ground motion inputs in near-fault regions but also offer important support for refining strong-motion data processing protocols and enhancing the accuracy of fault displacement hazard analysis.

Keywords: *Near-fault; fling-step; permanent displacement; velocity pulse; baseline error*