# STOCHASTIC MODELING AND SIMULATION OF NEAR FAULT GROUND MOTIONS

## *PEER Transportation Systems Research Program*


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## Introduction

Near-fault ground motions (GMs) often contain large pulses in the velocity and displacement time histories.

These pulses are due to rupture directivity – in the fault normal (FN) direction – or to the fling step – in the fault parallel (FP) direction.

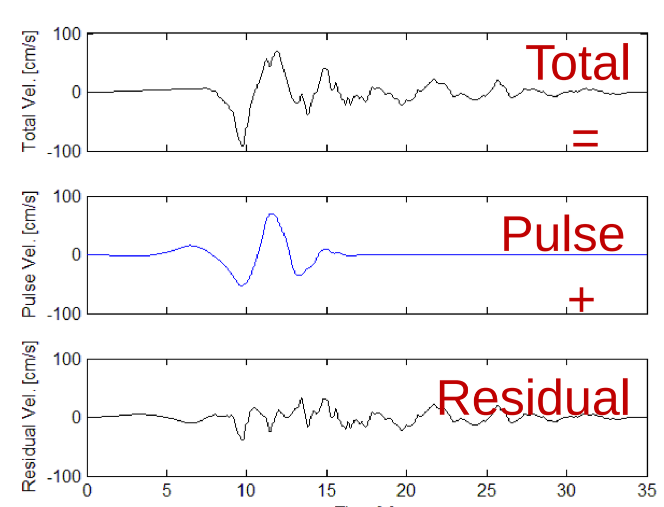
Long-period structures can be particularly vulnerable to these pulses.

Recorded near-fault ground motions are scarce

A need for realistic synthetic ground motions exists

## Stochastic Model of Near-Fault Ground Motion

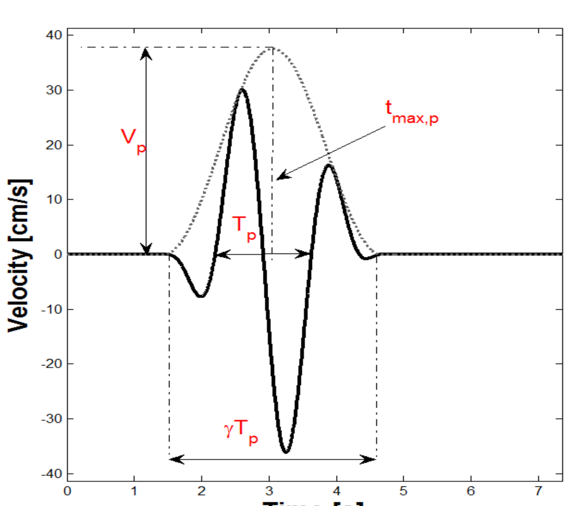
Parameterized model of pulselike near-fault GM in the FN direction.




1. Model of the Velocity Directivity Pulse – 5 parameters:

**Modified** Mavroeidis and Papageorgiou (mMP) pulse (2003)

Corrects for the non-zero residual displacement $D_r$ at the end




$$v(t) = \left\{\frac{1}{2}V_p \cos\left[2\pi\left(\frac{t-t_{max,p}}{T_p}\right)+\nu\right] - \frac{\boldsymbol{D_r}}{\boldsymbol{\gamma T_p}}\right\} \times \left\{1+\cos\left[\frac{2\pi}{\gamma}\left(\frac{t-t_{max,p}}{T_p}\right)\right]\right\},$$

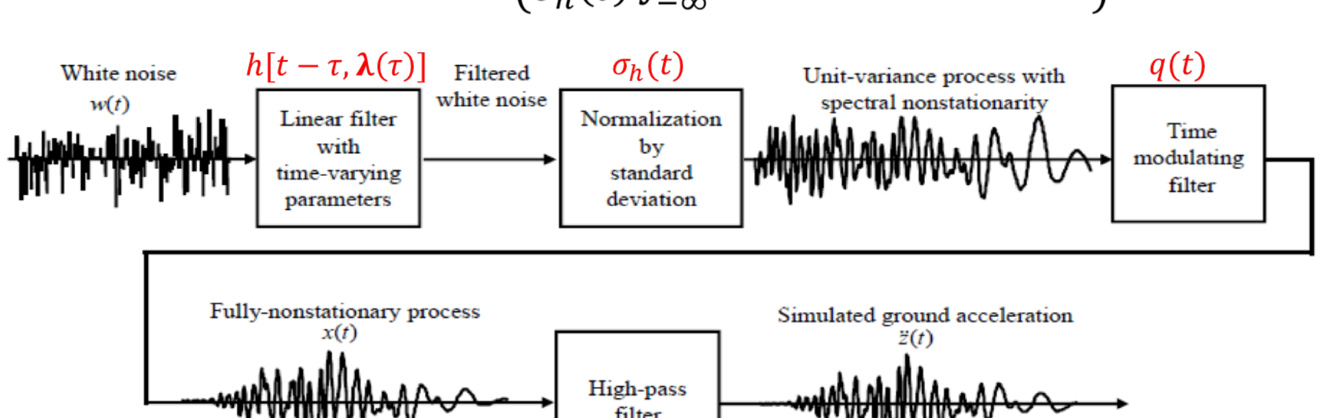
$$t_{max,p} - \frac{\gamma}{2}T_p < t \le t_{max,p} + \frac{\gamma}{2}T_p$$

$$D_r = V_p T_p \frac{\sin(\nu+\gamma\pi) - \sin(\nu-\gamma\pi)}{4\pi(1-\gamma^2)}$$

2. Model of the Residual (and Non-Pulselike) GM – 7 parameters:

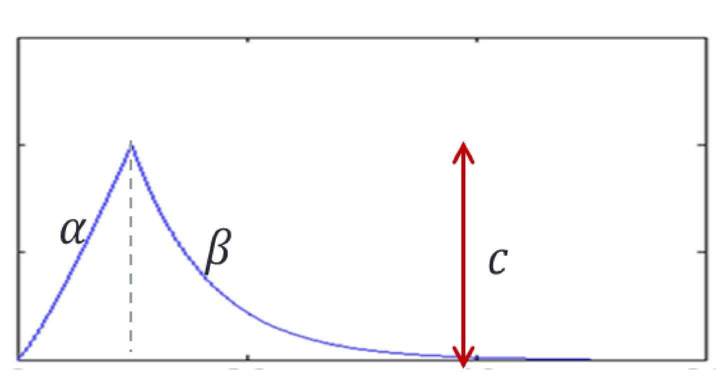
Non-stationary modulated and filtered white noise model with time-varying filter parameters (Rezaeian and Der Kiureghian, 2010)

$$a(t) = q(t)\left\{\frac{1}{\sigma_h(t)}\int_{-\infty}^{t} h[t-\tau, \boldsymbol{\lambda}(\tau)]w(\tau)d\tau\right\}$$




Similar to far-field GM model but with different modulating function $q(t)$ because near-fault GMs have:

- No long strong-motion phase
- Sharper build-up and decay segments




## Estimation of Model Parameters

Database of FN component of recorded GMs (100 records):

- Subset of PEER's NGA database
- $R \le 30$km
- Records containing a directivity pulse in the FN direction
- Pulse identification and extraction: wavelet-based method (Baker, 2007)

Pulse Fitting: parameters $(V_p, T_p, \gamma, \nu, t_{max,p})$ of the mMP pulse model are fitted to the extracted pulses

Residual Motion Fitting: $(\alpha, \beta, c)$ are related to $(I_a, D_{595}, t_{30})$ and then $(I_a, D_{595}, t_{30}, t_{max,r}, \omega_{mid}, \omega', \zeta_f)$ are fitted to the recorded residual motions

Predictive Equations: Model parameters are regressed against explanatory variables (earthquake source and site characteristics and directivity parameters).

$$z_i = g_i(F, M_w, R, V_{s30}, \theta, s) + \epsilon_i \qquad i = 1, \dots, 12$$

where $z_i$ are the model parameters $\alpha_i$ transformed to the standard normal space.

Some Regression Trends

| $i$ | $\alpha_i$ | $F$ | $M_w$ | $R$ | $V_{s30}$ | $\theta$ | $s$ | $R^2$ | $\sigma^2$ |
|---|---|---|---|---|---|---|---|---|---|
| 1 | $V_p$ | | + | – | | + | | 0.36 | 0.68 |
| 2 | $T_p$ | + | + | | – | | + | 0.71 | 0.29 |

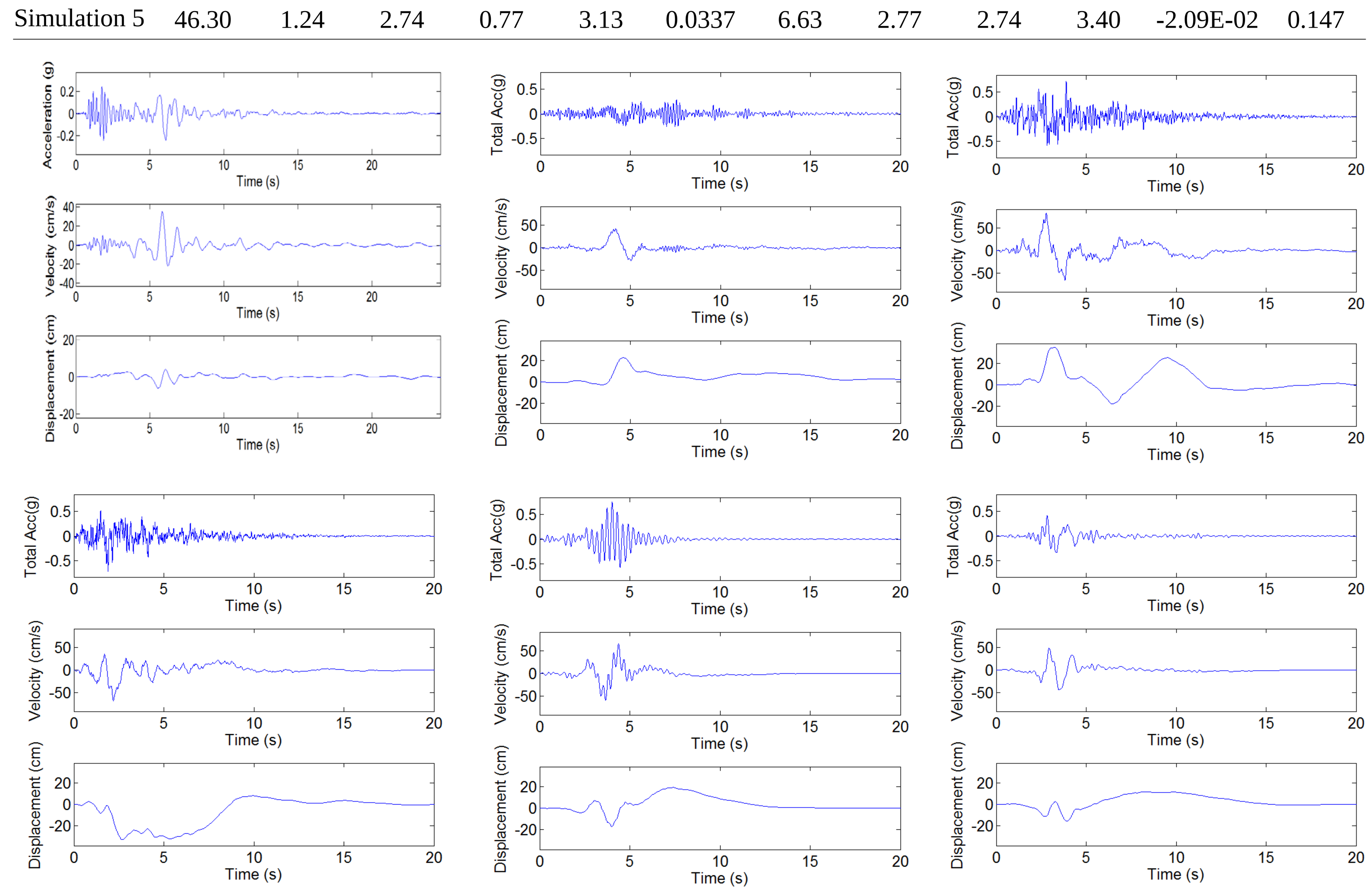
## Simulation of Near-Fault Ground Motions for Specified Earthquake Source and Site Characteristics

For each ground motion simulation:

1. Simulate model parameters using the predictive equations and the correlation matrix of the error terms
2. Simulate a white noise process
3. Plug into the model

**Predicted (median), recorded and simulated model parameters for fixed earthquake source and site characteristics: $F = 1, M_w = 6.2, R = 10$km, $V_{s30} = 660$ m/s, $\theta = 1.0^o$, $s = 27$ km**

| | $V_p$ | $T_p$ | $\gamma$ | $\nu/\pi$ | $t_{max,p}$ | $\frac{I_a}{\pi/2g}$ | $D_{5-95}$ | $t_{30}$ | $t_{max,r}$ | $\omega_{mid}$ | $\omega'$ | $\zeta_f$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | cm/s | s | | rad | s | $g^2s$ | s | s | s | Hz | Hz/s | |
| Median | 37.58 | 1.43 | 2.26 | 1.00 | 3.06 | 0.0617 | 7.20 | 2.78 | 2.89 | 4.26 | -7.17E-02 | 0.197 |
| Recorded | 32.09 | 1.02 | 2.44 | 0.52 | 5.91 | 0.0367 | 8.21 | 1.25 | 1.20 | 3.80 | -2.20E-01 | 0.035 |
| Simulation 1 | 29.10 | 1.82 | 2.24 | 0.39 | 4.40 | 0.0556 | 11.48 | 4.02 | 5.18 | 6.54 | -1.72E-01 | 0.114 |
| Simulation 2 | 45.87 | 1.65 | 2.52 | 0.10 | 2.71 | 0.2179 | 8.07 | 2.84 | 2.93 | 6.97 | -7.07E-03 | 0.407 |
| Simulation 3 | 39.73 | 1.23 | 2.20 | 0.43 | 1.94 | 0.1486 | 6.64 | 1.93 | 1.80 | 8.55 | -1.09E-01 | 0.874 |
| Simulation 4 | 43.83 | 1.66 | 2.65 | 1.50 | 3.73 | 0.1252 | 5.54 | 3.11 | 3.80 | 3.37 | -9.69E-02 | 0.027 |
| Simulation 5 | 46.30 | 1.24 | 2.74 | 0.77 | 3.13 | 0.0337 | 6.63 | 2.77 | 2.74 | 3.40 | -2.09E-02 | 0.147 |




**GM realizations for fixed earthquake source and site characteristics: F = 1, $M_w = 6.2$, $R$ = 10km, $V_{s30}$ = 660 m/s, $\theta = 1.0^o$, $s$ = 27 km; one recorded (top left) and three simulated pulselike near-fault GMs**

## Conclusions

Simple stochastic model of NF GM in the FN direction.

The model is formulated in terms of physically meaningful parameters.

Predictive equations for the model parameters in terms of earthquake source and site characteristics

Can generate an ensemble of synthetic NF ground motions

The resulting motions have the same statistical characteristics as the motions in the database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