Discussion of “Analytical Model of Ground Motion Pulses for the Design and Assessment of Seismic Protective Systems” by W.-L. He and A.K. Agrawal

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This discussion raises a few comments on the paper by He and Agrawal (2008). The paper develops a useful mathematical model for near-field ground motions affected by directivity focusing and derives closed-form expressions for structural responses. The model accounts for nonstationarity in the ground motion by expressing the ground velocity as a steady-state function modulated by an enveloping function. The study also examines the reduction of the structural deformations using supplemental dampers. The following comments are raised:

1. The authors report that near-field phenomenon was observed first by Benioff (1955) and was studied latter by Malhotra (1999). It may be emphasized here that Housner and Hudson (1958) were the first to show that the March 18, 1957 Port Hueneme earthquake of magnitude 4.7 was the first ground motion that consisted essentially of a single pulse. Since energy was contained in one pulse, the damage caused by this earthquake was unusual for a moderate earthquake. The response spectra of this earthquake were considerably larger than for more typical Pacific Coast earthquakes of equivalent magnitude. Single-pulse earthquakes have been recorded by seismologists before 1957 but these were shocks of small magnitudes (Housner and Hudson 1958). Housner and Hudson (1958) concluded that if a pulse-like earthquake of larger magnitude could occur it would require *a revision* of engineering

thinking with possible intensities of ground motions. Furthermore, Housner and Hudson (1958) studied the response of SDOF systems with natural periods of 2.48 s and 2.50 s that are similar to the structure studied by He and Agrawal (2008). Thus, the study by Housner and Hudson is one of the first studies on pulse-like near-field earthquakes that is worth mentioning.

2. The significance of the closed-form response expressions from the proposed model is limited to elastic linear structures only. Strong ground motions, however, particularly in near-field regions, generally cause the structure to deform beyond its elastic limit (e.g., Sasani and Bertero 2000). In fact, as already noted by the authors “near-field ground motions have been observed to cause *extensive* damages to structures during Northridge (1994), Kobe (1995), Turkey (1999), and Chichi (1999)”. Damage of structures due to strong ground motions at the near-field regions is generally associated with nonlinear behavior which is not discussed in the paper. Additionally, for inelastic behavior one has no option but to use numerical methods to compute the structure response and thus the closed-form expressions for structural response is limited to linear structural behavior only.
3. The problem of modeling pulse-like near-field ground motion is essentially an optimization problem in which the model parameters (i.e., optimization variables, such as, C, a, ω_p, v) are estimated so that the theoretical model matches the actual recorded ground motion and at the same time it satisfies predefined constraints (e.g., $\omega_p, \dot{u}_{\max}$ and observed nonstationarity

trend). This is not specified explicitly in the paper. For instance, constraining the peak ground velocity and pulse or central frequency ω_p of the theoretical model to match those observed in a recorded earthquake are simply *constraints*.

4. It is observed that the model provides good match of the actual ground velocity and displacement while the match between the actual acceleration and the mathematical model is poor. This is attributed to the exclusion of *explicit* constraints on the energy (e.g. Arias intensity) and PGA which, for the model adopted by the authors, are automatically implemented once the PGV and nonstationarity constraints are imposed (see Eqs. 1-3) (Arias 1970). Additionally, the exclusion of explicit constraints on the frequency content of the ground acceleration resulted in exclusion of important frequencies (not only higher frequencies) from the ground acceleration as noted by the authors. For instance, the Fourier amplitudes of the 1992 Landers earthquake recorded at Lucerne (LCN275) and the 1994 Northridge earthquake recorded at Rinaldi (RRS228) considered by the authors show significant wide range frequency contents which cannot be represented as a single acceleration pulse (see Fig. 1). Thus, while the 1979 Imperial Valley and the 1999 Chichi accelerations (see Fig. 1) show narrow frequency range, the Fourier amplitudes of the ground accelerations of the 1992 Landers and 1994 Northridge accelerations reveal clearly that the energy is distributed across a wide frequency range. Accordingly, exclusion of these constraints led to significant difference in energy, PGA and frequency content of the actual

record and the model (see, for example, the ground accelerations in Figs. 1, 6-8).

5. As it is well known, the ground acceleration is used in computing the structural responses.

Therefore, the accurate representation of the ground acceleration is essential for obtaining acceptable structural responses from the theoretical model. The mismatch between the actual recorded accelerogram and the mathematical model resulted in significant differences in spectral responses from the actual record and the theoretical model. This is seen in the plots of the acceleration response spectra at the short period range in Fig. 9 (third column of the plots). An alternative to overcome this difficulty could be by estimating the structure response using the ground displacement. Such alternative, however, could be computationally expensive and may introduce additional errors to the solution if not used carefully (see, e.g., Wilson 2002). The other alternative is to include explicit constraints on the frequency content, energy and peak ground acceleration. It is difficult, however, to handle the problem using the model adopted by the authors. This calls for more rigorous models to account for the significant difference in the frequency contents of ground accelerations and ground velocities and displacements of near-field earthquakes (see Fig. 1). In other words, a wide frequency bandwidth for the ground acceleration needs to be assumed and the model parameters can be estimated such that the frequency content of the ground velocity and displacement are filtered (see, e.g., Abbas and Manohar 2002 and Abbas 2006).

6. There are a few typing mistakes:

- There are two horizontal records for the TCU075 station of the 1999 Chichi earthquake (see Table 1). Which component is shown in Fig. 2 ?
- The parameters n in Eqs. (1-3) and N in table 1 (later in Eq. 8) are different. The numerical values of n which is one of the model parameters are not provided in table 1 while N values are listed in table 1. In fact, Eq. (8) should have been given earlier when the table was referred first time (page 1180). Also, are the parameters a in Eqs. (1-3) and A in table 1 the same ? It is also noticed that v (Eq. 1-3) is taken as 0.
- The units of the ratios PGD/PGV and PGV/PGA and the parameter C are not provided in Table 1. These are not dimensionless quantities.
- The value of $C = -3200$ (Table 1) for the 1994 Northridge earthquake recorded at Rinaldi receiving station (RRS228) seems to be incorrect. The correct value might be -32.00. The value of $C = 432.06$ for the same earthquake recorded at Sylmar station (SYL360) needs to be checked since it is significantly different from $C = -18.29$ for the other component (SYL090) of the same earthquake. Note that the model parameters $(\omega_p, \zeta_p, N, A, t_0)$ of these two components are not significantly different.
- The reference Huang (2003) “Consideration of multimode structural response for near-field earthquakes” should be corrected to *Journal of Engineering Mechanics*, 129(4), 458-467.

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1979 Imperial Valley (El Centro, E06230)

1999 Chichi (TCU068N)

1994 Northridge (Rinaldi, RRS228)

1992 Landers (Lucerne, LCN275)

Fig. 1 Fourier amplitude spectra of near-field ground motion.