Final Project Summary — PEER Lifelines Program

Project Title—**ID Number**	*Ground Motion Models for Fling step*—**1L06**		
Start/End Dates	5/1/03 – 6/30/04	Budget/ Funding Source	$64,603 / PG&E
Project Leader (boldface) and Other Team Members	**Graves (URS Corporation)**		

1. Project goals and objectives

The objective of this project is to develop a parametric description of the fling step behavior expected for dip-slip faulting using numerical simulations of scenario earthquakes. The earthquake magnitude range is Mw 6.5-7.9. Our goal is to use these numerical results along with existing recorded ground motions to help guide and develop a model of fling step behavior that can be used for engineering purposes, specifically in the NGA program.

Another component of this project will support the participation of Robert Graves in the NGA program. The analysis and characterization of fling effects form a component of the NGA program in Working Group 1 (task 2). This work will entail the coordination of a panel of experts to provide input and guidance on the characterization of fling effects. We will solicit input from these experts on two key questions: 1) Are the characteristics of fling effects fundamentally different than the characteristics of more general ground shaking (e.g. different distance dependence)? 2) Do fling effects behave in a systematic manner that can be adequately represented using a regression model? The input from these experts will be documented and a summary report describing our recommendations will be provide to NGA.

2. Benefits of the results of this project to develop technologies and protocols to mitigate the vulnerability of electric systems and other lifelines to damage directly and indirectly caused by earthquakes. Also, benefits to develop assessment techniques to evaluate damage to electric systems caused by earthquakes and to assess fiscal impacts due to the loss of electric service to the community.

The results of this project will be directly incorporated in the NGA program. The goal of NGA is to develop the Next Generation of Ground Motion Attenuation relations. It is expected that these ground motion models will be used extensively in engineering practice in the years to come.

3. Brief description of the accomplishments of the project

Using a combination of empirical analysis and numerical simulations, we have developed a preliminary model of fling step behavior expected very close to large earthquakes. The fling model is parameterized by start time, final residual displacement, and pulse period. These parameters are constrained by modeling the ground motion records from recent large earthquakes, including Chi-chi (Taiwan), Izmit (Turkey), and Landers.

4. Describe any instances where you are aware that your results have been used in industry

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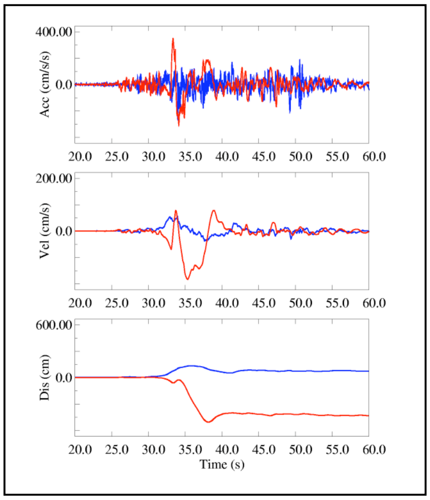
5. Methodology employed

This project employs a combination of empirical data analysis and numerical simulation techniques to develop the fling ground motion model. The numerical simulations consist of a theoretically rigorous representation of heterogeneous fault rupture within a plane-layered visco-elastic velocity structure. Full waveform ground motions in the frequency range 0 – 2 Hz (including residual displacement) are computed. From the suite of empirical and simulated ground motion time histories, fling parameters including pulse start time, pulse period and residual displacement amplitude are measured. These parameters are used to develop a regression model to be used for estimating expected fling behavior.

The deployment in recent years of broadband, high dynamic range, digital seismometers has resulted in a wealth of strong ground motion data. The nature of the modern instrumentation has allowed recovery, in several instances, of ground motion records covering a continuous frequency range from several tens of Hertz down to zero frequency. These records provide an unprecedented opportunity to examine not only the dynamic ground shaking characteristics, but also the growth and temporal evolution of static ground displacements. These static displacements represent the effects of tectonic deformation associated with the fault rupture. Recent earthquakes generating such recordings include the 1992 Landers, 1999 Izmit, and 1999 Chi-Chi events.

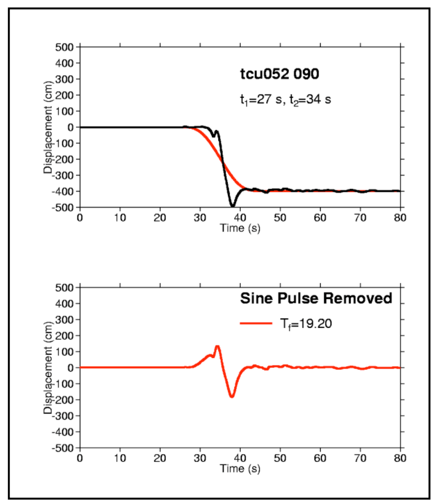
Figure 1 shows an example of the significance of fling effects. These two records are obtained on opposite sides (foot- / hanging-wall) of the fault during the Chi-Chi earthquake. Both sites are within 2 km of the fault rupture and they are directly across the fault from one another.



The blue traces are from the footwall site and the red traces are from the hanging wall. At longer periods (velocity and displacement) the hanging wall motions are much larger than the footwall. This is due to fling effects (growth of residual displacement). However, this can have a significant effect on PGV as well. These effects are accurately reproduced with the numerical simulations.

From a theoretical standpoint, one may expect the frequency and distance dependence of the static deformation field to exhibit somewhat different characteristics than the dynamic ground shaking. This is because the static field is generated from the near- and intermediate-field terms, while the dynamic motions are also controlled by the far-field terms. However, the contribution of the near- and intermediate-field terms to the dynamic motions may also be important in the near-fault region. Unfortunately, the currently available set of recorded motions is not sufficient to adequately parameterize these effects. Thus, we propose to use numerical simulations to augment the existing recorded motions.

The tabulated fling parameters from the dip slip faulting simulations will be combined with those from the strike slip simulations into a database that will then be used to develop the fling model. Norm Abrahamson will be responsible for the development of the fling model. The model will be built using regressions on the tabulated parameters. We expect the model will explicitly include dependencies on earthquake magnitude and closest distance; however, we will also test the sensitivity of the model to other parameters such as hypocenter location and slip distribution to quantify the expected uncertainty in the estimates of the model parameters.



The fling pulse is modeled using the double integral of a single cycle of a sine function. The parameters controlling the shape of the pulse are start time (t_1), final residual displacement (D), and pulse period (T_f). The start time can be estimated from the theoretical S-wave arrival time and the final displacement can be directly measured (or inferred). We estimate the pulse period using numerical simulation of fault rupture. Following this procedure, we have developed a fling pulse for the TCU052 record shown in Figure 1. The original displacement record is plotted against the fling pulse displacement in Figure 2. Shown at the bottom of Figure 2 is the result of removing the fling pulse from the recorded displacement.

6. Other related work conducted within and/or outside PEER

Previously, we have calculated a suite of numerical simulations to investigate the fling step behavior for strike slip faulting. That study examined a suite of rupture scenarios and a suite of rupture magnitudes. This project will augment that study be extending the analysis to dip slip faulting. We will incorporate the strike slip results with the dip slip results in our final fling model.

7. Recommendations for the future work: what do you think should be done next?

The preliminary fling pulse model developed here needs further testing against both recorded and simulated data. In particular, the pulse period is not well constrained by current information. It is most certainly related to the rupture propagation speed along the fault and the fault slip rise time. More sophisticated numerical experiments utilizing dynamic rupture simulations would probably help to better understand the relationship between the faulting parameters and the fling pulse period.

8. <u>Author(s), Title, and Date</u> for the final report for this project

Robert W. Graves and Norm Abrahamson "Ground Motion Models for Fling Step", 2004