A method for generating spectrum-compatible earthquake ground motion time histories with permanent displacement

Jeff Bayless, AECOM

Norman Abrahamson, UC Berkeley

AECOM

Berkeley
UNIVERSITY OF CALIFORNIA

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Outline

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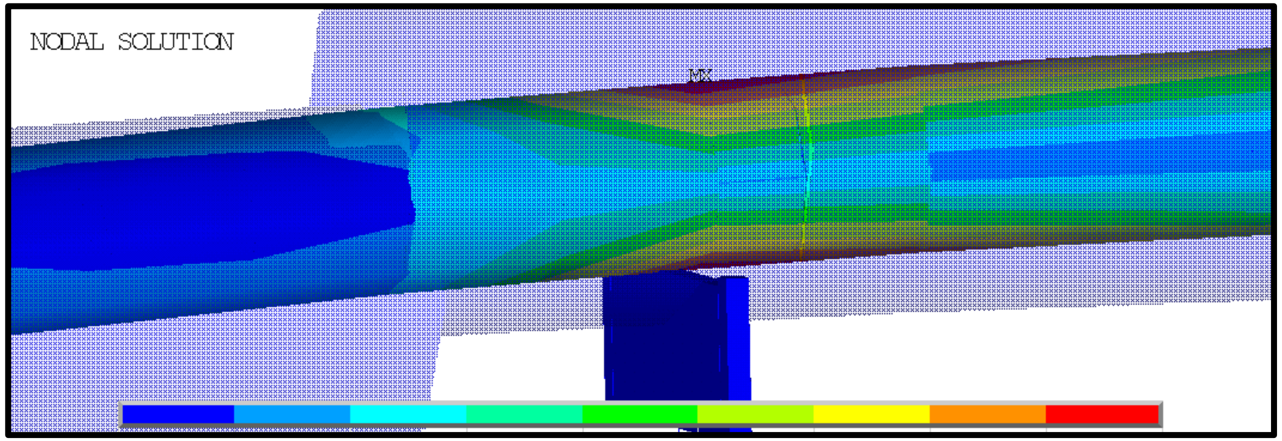
- Description of the dilemma
- Modification procedure
- Limitations
- Summary

Introduction

- Dynamic (time history) response analysis
  - involves solving the dynamic equation of motion throughout the duration of the ground shaking (or ground displacement) and the subsequent system vibration.
- Usually done by application of the earthquake ground motions in three orthogonal directions simultaneously to a finite-element model of the system.
  - obtains time history excitations of the system, including stresses, strains, and reaction forces



Finite element model of a dam outlet pipe (stresses)

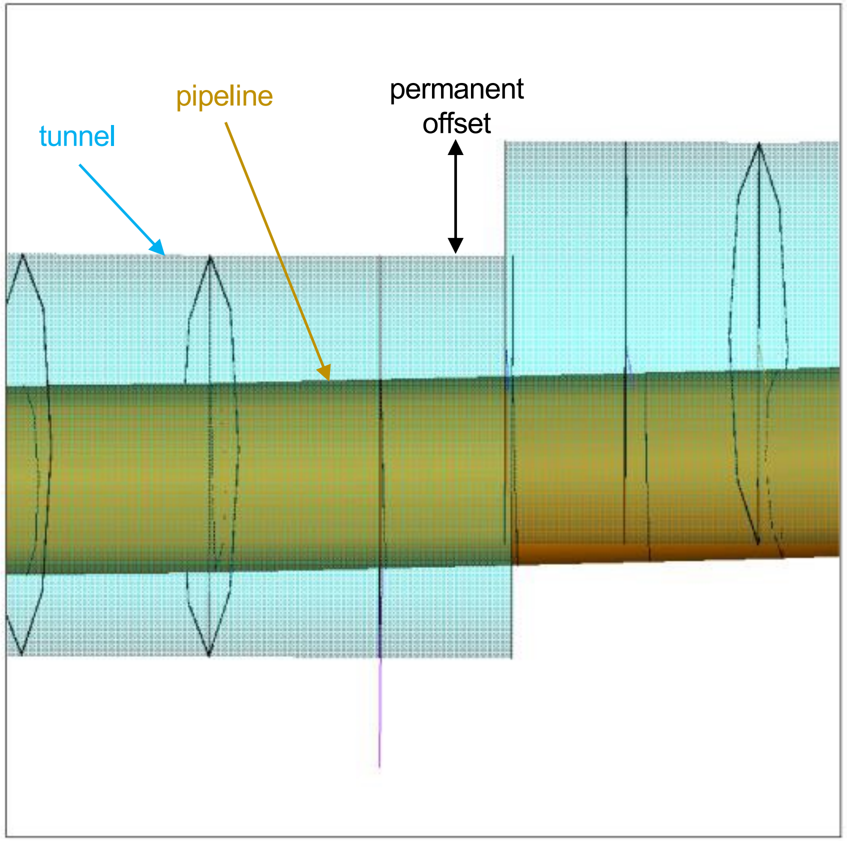
Introduction

- This method requires ground motion time histories established from a seismic hazard analysis.

- In some instances, ground shaking and dynamic displacement are both critical seismic load conditions (e.g., fault crossings).

  - Then the ground-motion time histories should match both the target **response spectrum** and contain a dynamic displacement with permanent offset (**fling-step**).

  - Until now, there is no standardized procedure for this.



Finite element model showing the tunnel (blue) and pipeline (brown) on sliding supports, subject to displacement at a fault crossing

Introduction

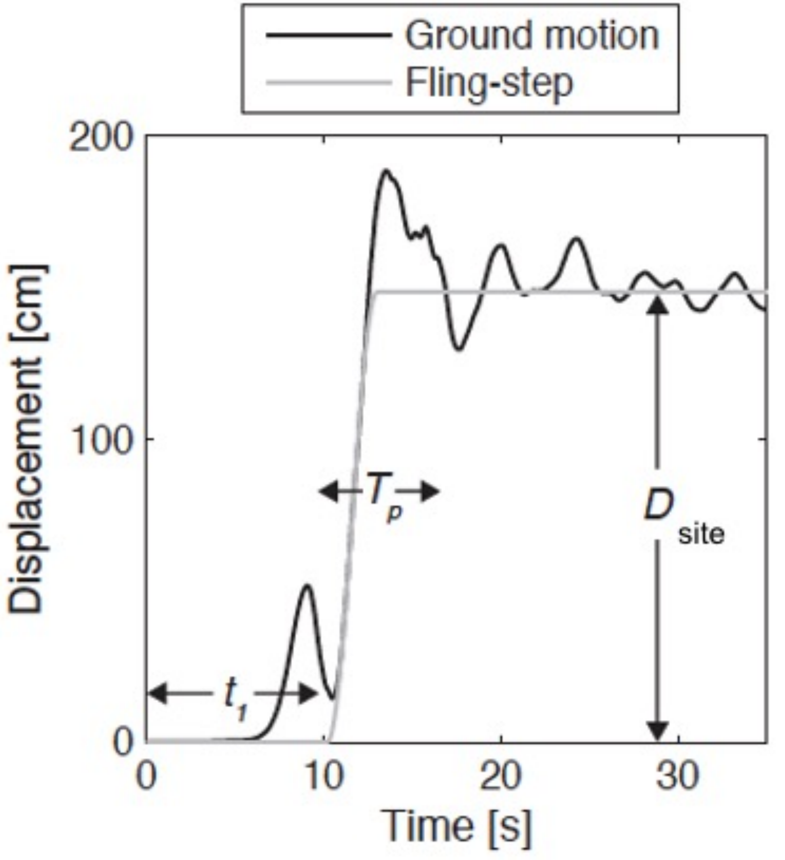
- **Fling-step**
  - engineering term for the effects of the permanent tectonic offset of a rupturing fault in the recorded ground motions near the fault.
  - expressed by a single-cycle acceleration pulse, a one-sided pulse in ground velocity and a nonzero final displacement at the end of shaking.

- The notation used by Kamai et al. (2014) is:

  D_{fault} = mean fault slip (displacement) over the rupture plane.

  D_{site} = component-specific amplitude of the tectonic displacement (fling-step) observed or modeled at a site.

  T_p = the period in seconds of the single-cycle acceleration sine wave used to model D_{site}.



Ground motion displacement from the 1999 Kocaeli, Turkey earthquake.

Figure modified from Burks and Baker (2016)

Description of the Dilemma

There are challenges in modifying time histories to contain both a fling-step (with a specified duration and amplitude) and to acceptably match a target response spectrum.

Difficulty arises due to the inherent relationship between the response spectrum and the acceleration time history.

Three potential methods are outlined next – each have significant shortcomings.

Option 1: Simple scaling of a recorded time history containing a fling-step.

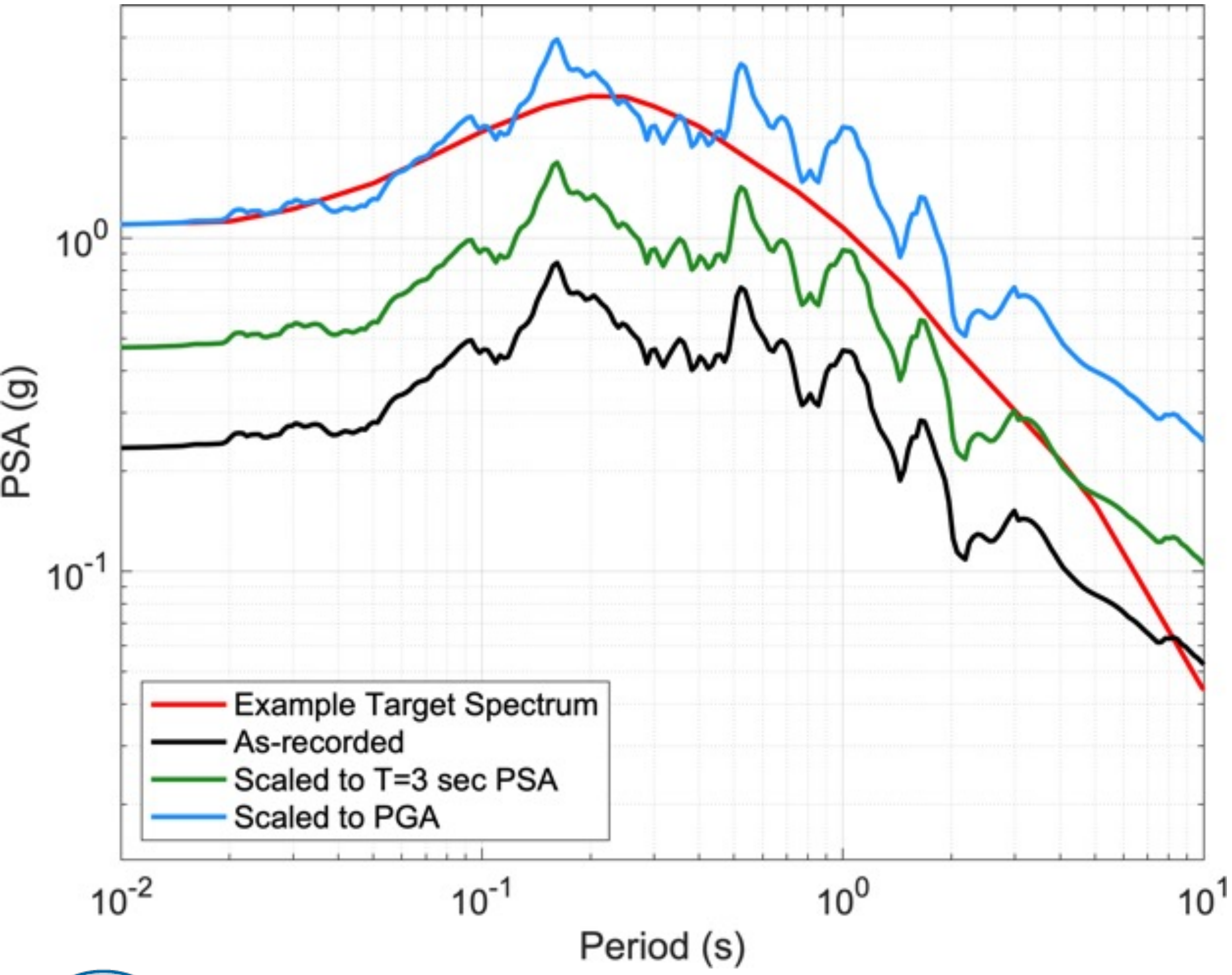
Option 2: A combination of simple scaling, followed by spectral matching.

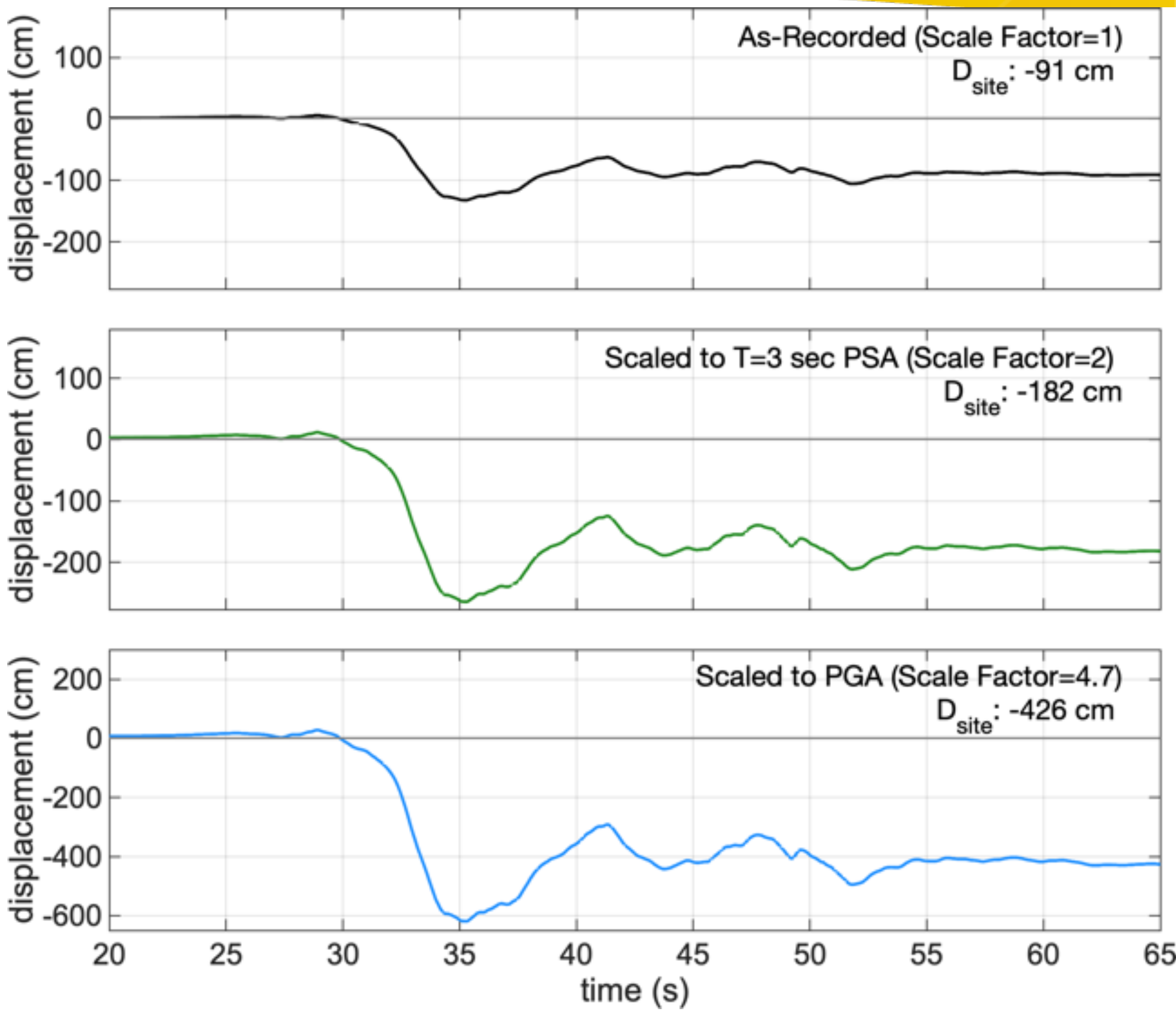
Option 3: Add the fling-step to an acceleration time history without an existing fling-step, followed by spectral matching.

Then,

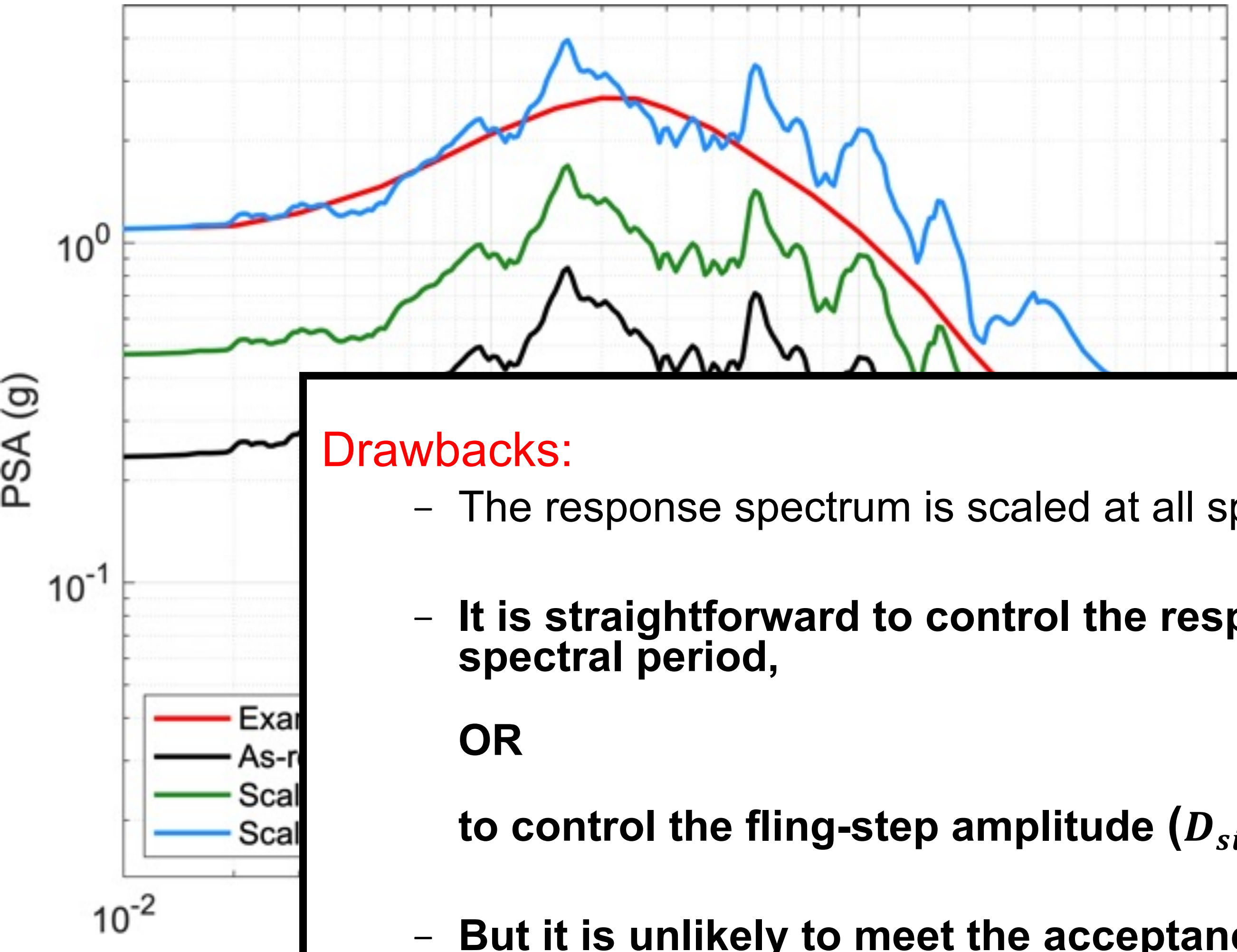
Proposed Method: Like Option 3, using a modified target response spectrum for spectral matching.

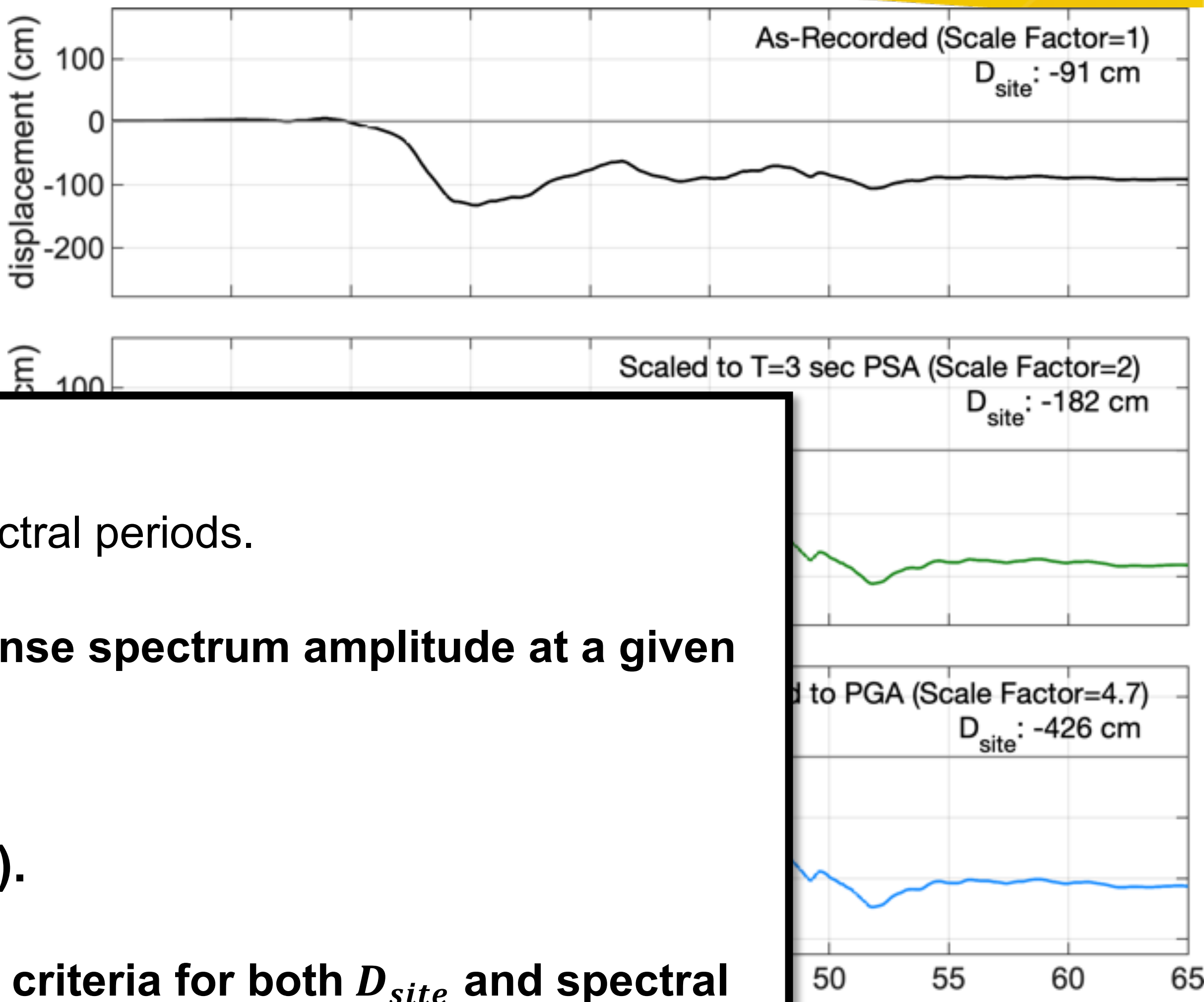
Option 1: Simple scaling





Option 1: Simple scaling





Drawbacks:

- The response spectrum is scaled at all spectral periods.
- **It is straightforward to control the response spectrum amplitude at a given spectral period,**

  OR

  to control the fling-step amplitude (D_{site}).
- **But it is unlikely to meet the acceptance criteria for both D_{site} and spectral acceleration (match to the target spectrum).**

Option 2: A combination of simple scaling (to reach the target D_{site}), followed by spectral matching.

Drawbacks:

- Does not lend itself to specifying the fling-step duration.

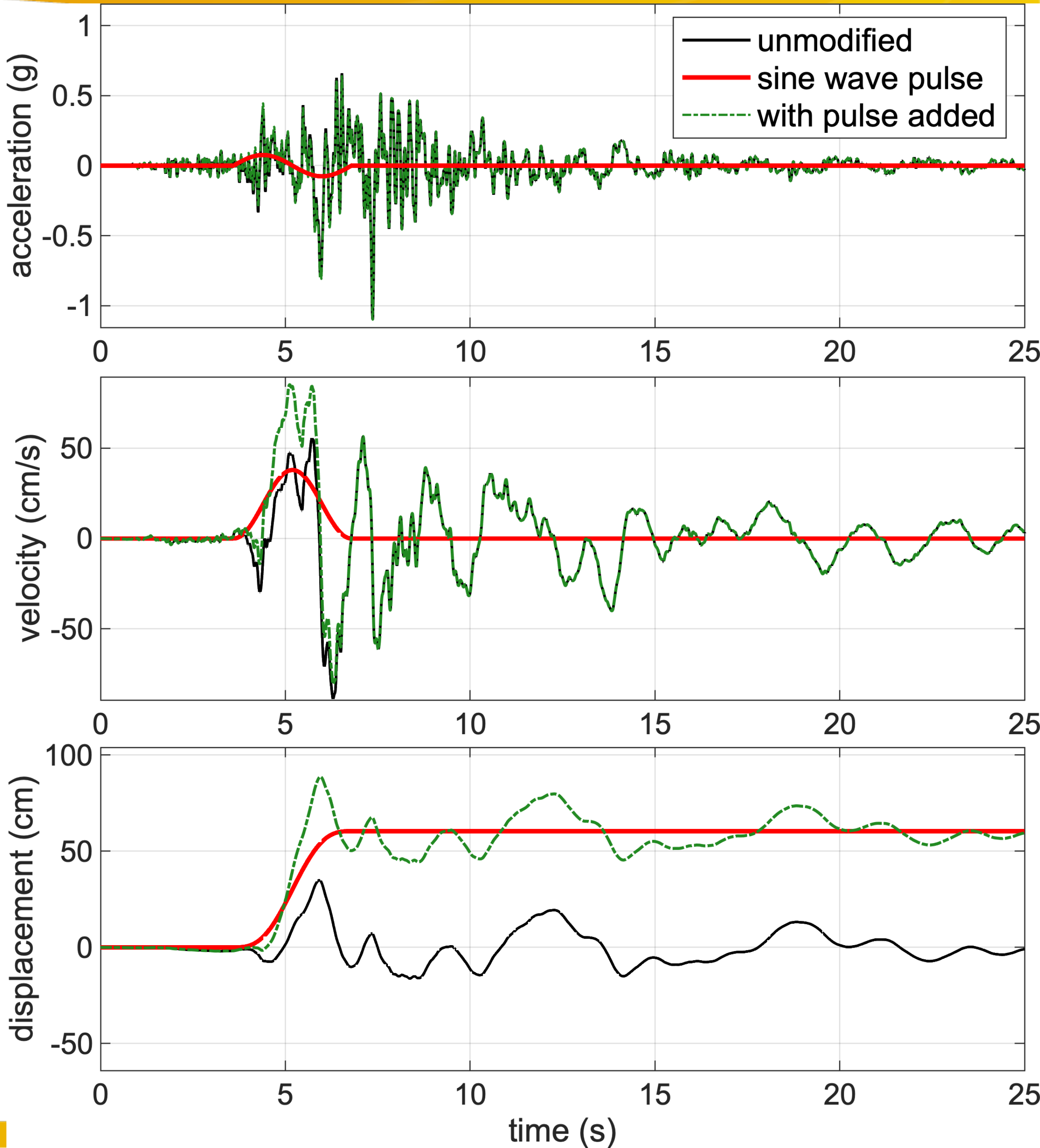
More on this next

- Has potential for destructive interference because:

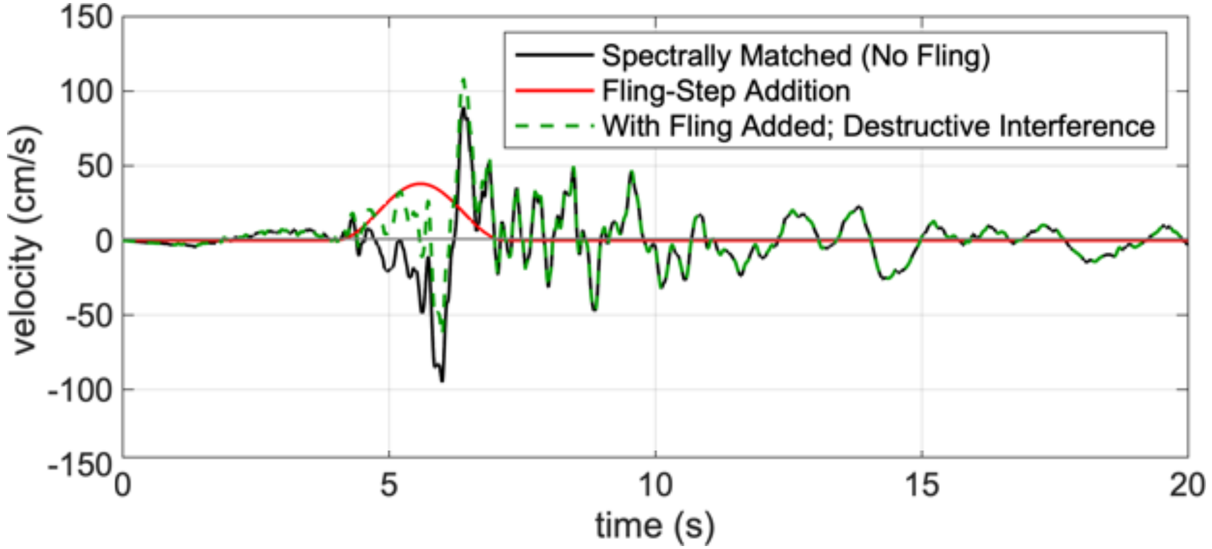
  The fling-step (with a given period and amplitude) is related to the response spectrum amplitude in that period range, and modification to one will affect the other.

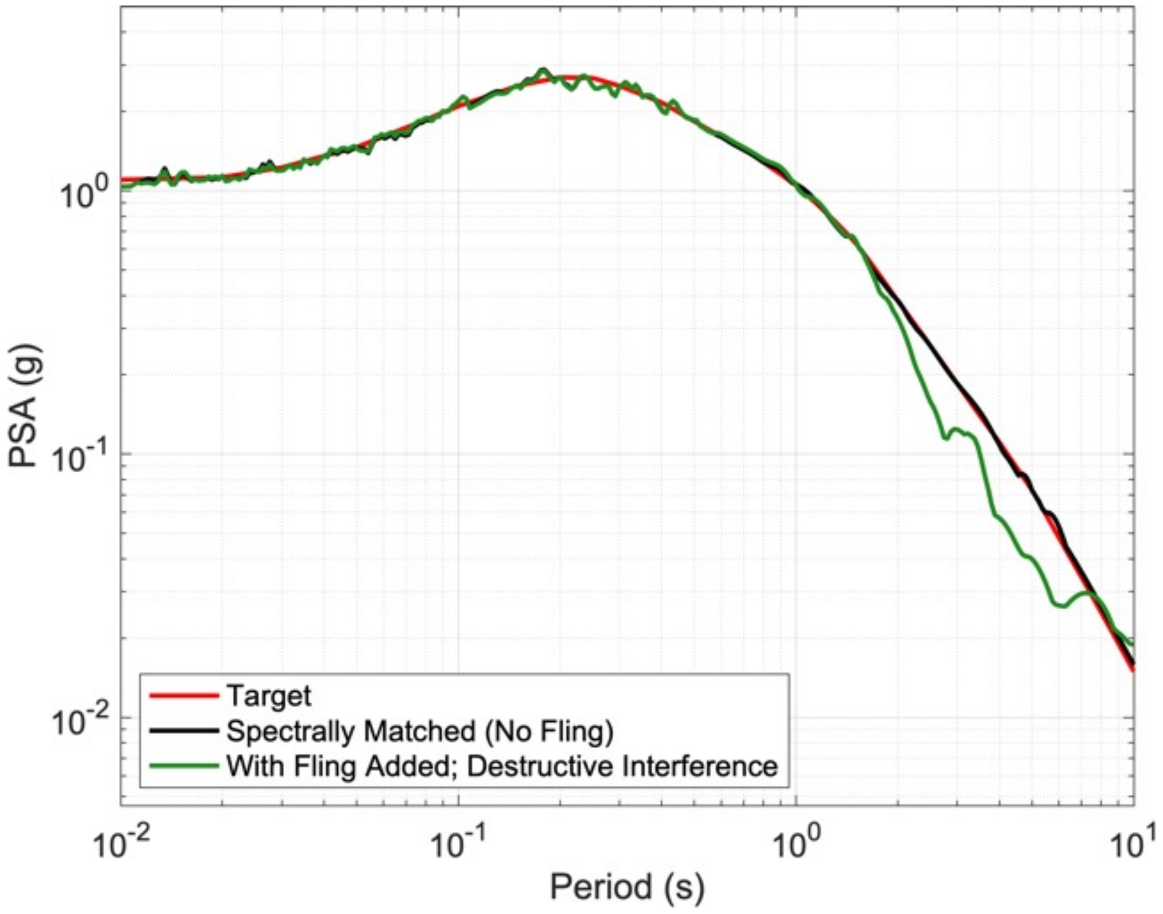
Option 3: Add the fling-step to an acceleration time history without an existing fling-step, following Kamai et al. (2014), then perform spectral matching.

- The Kamai et al. (2014) method is to add a single-cycle sine wave in acceleration.
- Allows specification of the pulse period and fling-step amplitude.
- Drawback:
  - The same potential for destructive interference, **because of the relationship between the pulse and the response spectrum**.



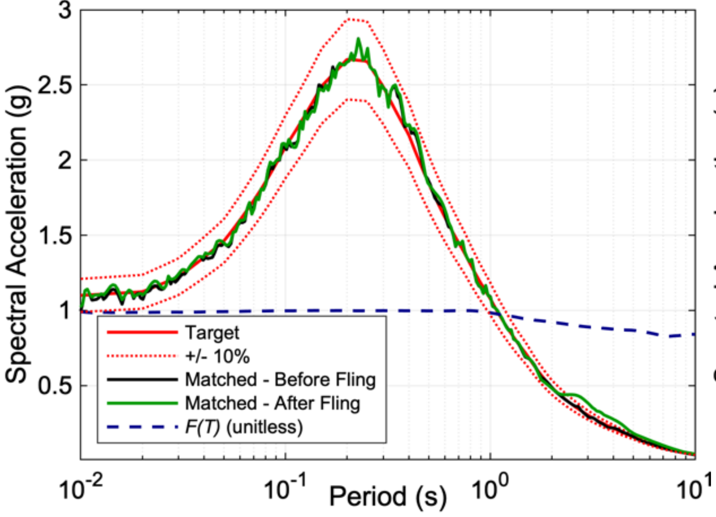
Destructive interference - example

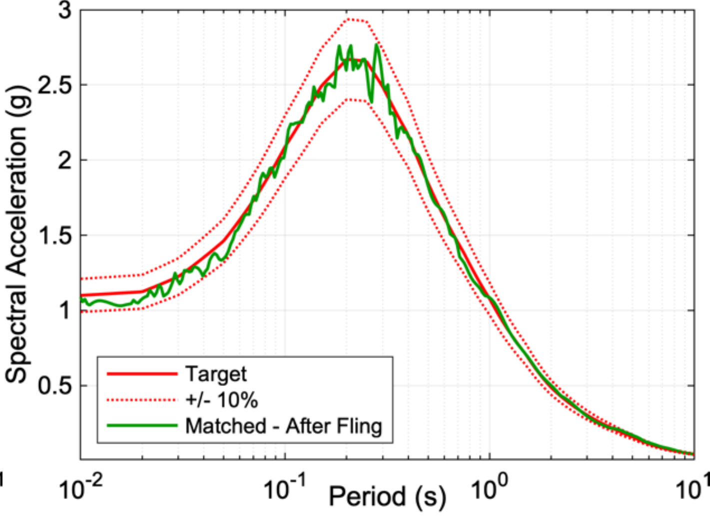


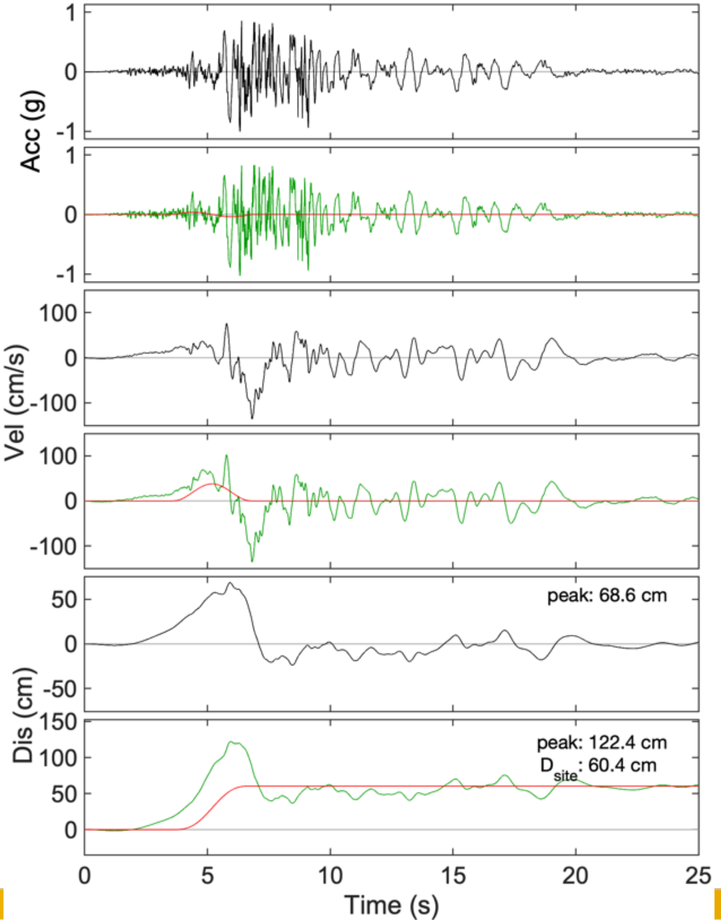


Modification Procedure

1. Select a time history without a fling step.
2. Spectrally match to the target spectrum.
3. Add the fling-step following Kamai et al. (2014).
4. Calculate F(T): the ratio of the response spectrum before and after adding the fling-step.
   Scale the target response spectrum by F(T).
5. Spectrally match the original time history to the modified target spectrum.
6. Add the fling step as in Step 3.







Modification Procedure (cont.)

7. Check the resulting time history for its non-stationary characteristics and for compatibility with the target response spectrum ($Target$) and the target permanent displacement (D_{site}).

This method *should* retain the non-stationary characteristics of the time history and maintain the physically important features of the fling step.

Limitations of the Procedure

The main limitation – it doesn't always work!

- There is potential for the addition of the fling-step (sine wave in acceleration) to destructively interfere with the vibratory ground motion, leading to the spectrum of the final time history falling below the target at long periods.
- Steps 2-4 of the procedure are intended to reduce the likelihood of destructive interference.
- **Still, users of the method will need to be cognizant of the effect each step has on the time history.**
- Troubleshooting tips are provided in the paper.

Summary

- For engineering projects in which dynamic analyses are performed, ground-motion time histories are required as input.
- In circumstances where both ground shaking and dynamic displacement are critical seismic load conditions, ground-motion time histories may be required which simultaneously match a target response spectrum and contain a fling-step with a specified duration and amplitude.
- This paper/presentation proposes a straightforward procedure for developing earthquake ground motion time histories containing both features while maintaining the physically important features of the fling-step.

Thank you

jeff.bayless@aecom.com