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Framework for Regional Analysis of Spatially Distributed Ground Failure Displacement Hazards

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ABSTRACT

Seismic risk for spatially distributed infrastructure is driven mainly by ground failure, defined as permanent ground displacements from mechanisms such as landslides, liquefaction, and seismic compression. Most forms of ground failure are a consequence of soil responses to ground shaking, which should be evaluated on a hazard-consistent scenario basis to represent spatial correlations of intensity measures. A companion paper describes a methodology for identifying hazard-consistent event scenarios. Seismic ground failure responses are evaluated based on regionally-accessible information on geology, groundwater hydrology, and terrain. Given these inputs, liquefaction and landslide displacements are predicted point-by-point on a 10 m grid using customized analysis procedures and logic trees for each ground failure type. For each point, these analyses provide probabilities that the hazard exists, probabilistic distributions (accounting for epistemic uncertainties) of related displacements, and displacement directions (azimuths). Series of points expected to move together (e.g., in a single lateral spread) are grouped into polygons. Ground failure features (landslides, lateral spreads) of varying sizes may occur within these polygons. The output of these analyses are feature locations, sizes, displacement amounts, and displacement azimuths, which can be applied in subsequent fragility and risk analysis of distributed infrastructure systems.

Introduction

Seismic ground failure from liquefaction, landslides, and related phenomena are substantial sources of earthquake hazards to people and infrastructure. Procedures for the assessment of these hazards [1, 2] are largely derived for application to individual sites, such as a building where seismic design is to be performed. As such, these procedures are conditioned on relevant geotechnical parameters as would be derived from a site-specific geotechnical investigation (i.e., soil stratigraphy, ground water level, penetration resistance, shear

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strength, etc.). Moreover, the ground motions used with these procedures are typically derived from location-specific probabilistic seismic hazard analyses.

Studies of seismic risk to distributed infrastructure systems challenge the traditional paradigm for ground failure analysis in two key respects: (1) the infrastructure can occur across a large spatial domain, potentially involving many different geological and terrain conditions associated with different types and levels of ground failure hazards; (2) seismic ground motion hazards derived for a single site, or for a collection of sizes along the system at a consistent hazard level, fail to accurately describe the distribution of shaking demands that the distributed infrastructure systems may experience. This paper describes at a conceptual level a framework that has been developed to address the first of these issues. The focus here is on the framework and format of the model outputs, with more specific information on landslide and liquefaction modeling provided in companion papers [3-4]. The second issue above is being addressed in contemporaneous research and is described in a third companion paper [5].

The specific application for which the present work is being performed is natural gas storage and distribution infrastructure in California (Figure 1). The authors are part of a larger team developing a tool to evaluate the risk to this infrastructure system from earthquake hazards. This tool will have modules that characterize various hazards, infrastructure component fragilities, and system level risk.

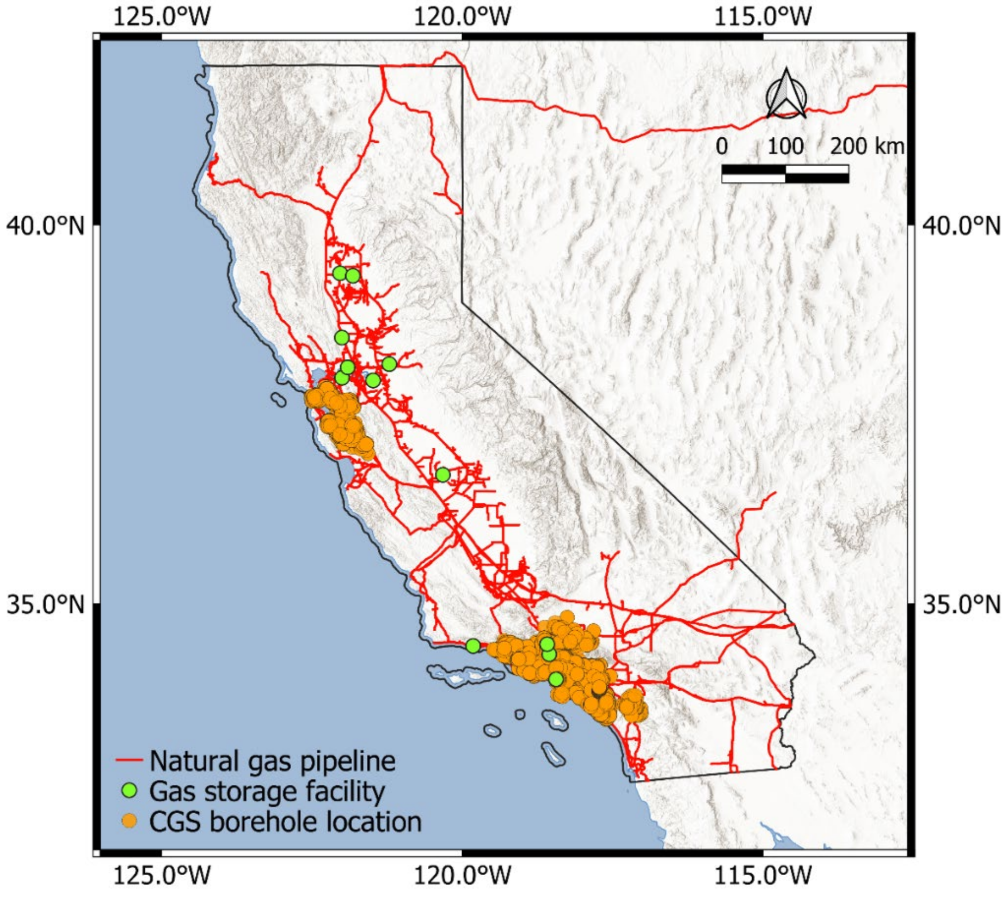

Figure 1. Natural gas pipelines, gas storage facilities, and boreholes from the California Geological Survey (CGS) within the State of California.

Framework

The proposed analysis framework takes as input the following information:

1. Scenario ground motions with realistic spatial distributions of ground shaking that are consistent with one or more relevant ground motion hazard levels [5].
2. Regional information on surface geology that is mapped in a consistent manner across the study area, which in the present case is the entire State of California. We use geologic maps prepared by the California Geological Survey [6].
3. Information on ground water depth from a global model [7], updated based on local well data [8].
4. Digital elevation models at 10 m horizontal resolution, as provided by the CGS [9].

Liquefaction and landslide displacement estimates conditioned on the above information carry large epistemic uncertainties because the information on site conditions (from 2-4) does not directly provide the information required to assess these ground failure hazards. Instead, we estimate the relevant soil properties from applicable databases conditioned on location-specific surface geology; the uncertainties associated with these soil property estimates are referred to as *parametric*. Moreover, once applicable ranges of those properties are defined, alternate methods of analysis can be applied, which is a separte source of epistemic uncertainty known as *modeling uncertainy*. These uncertainties are considered using logic tree frameworks, as described in companion papers [3-4].

The direct outcomes of both the landslide and liquefaction models are attributes of displacements for a particular ground motion scenario on a 10 m grid spacing (Figure 2). At each grid point, the following information is provided:

1. Probability that ground failure from a particular mechanism (landslide or liquefaction) occurs; in the landslide case, this is taken as the probability that a certain displacement level is exceeded, whereas for liquefaction, it is the probability of both liquefaction-susceptible soils being present and liquefaction triggering having occurred;
2. If the ground failure hazard exists, a distribution of displacement levels is provided such that a conditional probablity density function can be derived;
3. Azimuth of displacement, which is generally taken as the horizontal direction of maximum slope from the 10 m digital elevation model.

As shown in Figure 2, grid-point displacements are grouped into polygons. This grouping takes into account geomorphic features of the area as described in the companion papers [3-4]. Within the polygons, individual ground failure features (i.e., landslides or lateral spreads) of varing sizes may occur, which are estimated using empirical models. Additionally, ranges of displacement amounts and azimuths may occur within the polygons that are broader than those from (2-3) above. Within the context of the present gas infrastructure risk study, the information provided for subsequent fragility analyses are polygon locations, distributions of feature sizes within polygons, and displacement amounts and directions within polygons. As described in [3-4], in the development of the logic trees, checks are made to ensure that the cumulative sizes of features relative to the overall area of study regions are consistent with observed rates of ground failure in past earthquakes.

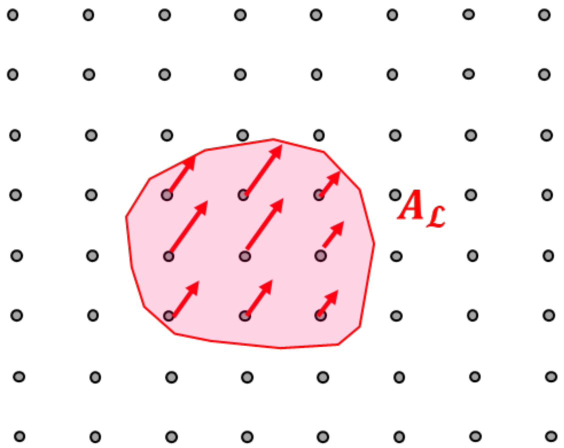

Figure 2. Schematic showing grid locations where displacements are computed. Arrows at grid points indicate displacement amounts and azimuths, which are uncertain (i.e., the amount depicted would represent a particular percentile as derived from logic tree analyses). The polygon depicted by the area marked as $A_{\mathcal{L}}$ indicates a zone where landslides or lateral spreads of varying sizes may occur.

Conclusions

In this paper and three companion papers [3-5], an analysis framework is presented for the estimation of spatially distributed seismic ground failure hazards, consisting of features having particular amounts and directions of displacement. The framework uses readily available geo-spatial information, and as such can be used without site-specific geotechnical data, which is essential for practical application. Uncertainties in the presence of these features and the amounts of displacement are evaluated using a logic tree framework in which parametric and modeling uncertainties are considered. In situations where higher-resolution site-specific information is available, substantial uncertainty reductions may be anticipated.

Acknowledgements

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