Science Application for Risk Reduction (SAFRR)

Dale Cox, Project Manager (USGS SAFRR)
Anne Wein, Keith Porter, Laurie Johnson, Kenneth Hudnut & 65+ Contributors
The SAFRR Scenarios

**ShakeOut**: San Andreas fault (southern California) earthquake scenario (2008)

**ARkStorm**: winter storm scenario impacting U.S. West Coast (2010)

**Tsunami Scenario**: tsunami generated by an Alaskan earthquake and impacting the U.S. West Coast (2013)

**HayWired**: Hayward fault (northern California) earthquake scenario (in progress; April 18, 2018 - release date)

**ARkStorm Retrospective**: 2017 ARs, disaster declarations, beach loss, extreme storms, snow pack & melt runoff
The Hayward Fault is arguably the most urbanized active fault in the United States.

It offers an informative case study of the effects of a large urban earthquake on a modern U.S. metropolis.
Building the HayWired Scenario

Integrating across disciplines...

SOCIAL SCIENCES
HayWired Volume III: Consequences

ENGINEERING
HayWired Volume II: Impacts

EARTH SCIENCE
HayWired Volume I: Hazards

POLICY
EARLY WARNING & FORECASTING
INTERNET ECONOMY
COMMUNITIES AT RISK
ENVIRONMENTAL HEALTH
FIRE FOLLOWING EARTHQUAKE
INTERDEPENDENCIES
STRUCTURES and CODES
LIFELINES
LANDSLIDES and LIQUEFACTION
AFTershocks, FAULT SLIP and AFTERSLIP
GROUND SHAKING
HayWired: Physics-Based Scenario

Hayward Mw 7.0 median

Same earthquake, bilateral rupture, physics-based model
M7.0 earthquake occurring on April 18, 2018, at 4:18 p.m, wind is mild, no rain, temperature avg.

Rupture starts under Oakland, north into San Pablo Bay and south to the city of Fremont (53 miles)

The HayWired scenario describes a M 7.0 earthquake, 83-km (51 mile) rupture, with up to 2 meters (6.5 feet) of fault offset either in the form of coseismic slip or afterslip
HayWired shaking animation
HayWired: Fault Slip, Afterslip and Aftershocks

Coseismic surface slip variability in meters

2.1m
1.7m
0.9m

HayWired mainshock
Magnitude

Aftershocks
- 2.5 – 2.9
- 3.0 – 3.9
- 4.0 – 4.9
- 5.0 – 5.9
- 6.0 – 6.9

Time Period

- Time from mainshock:
  - Within 1 day
  - Within 1 week
  - Within 1 month
  - Within 1 year
  - Within 2 years (end of modeling period)

2016 M 7.8 Kaikoura, NZ earthquake
HayWired: Hazus aftershock analysis

- Aftershocks contribute 20% of loss
  - 12% from 3 aftershocks $M_w$ 6.0 to 6.4
  - 8% to 13 aftershocks $M_w$ 5.0 to 5.9
- Some areas more damaged by aftershocks
- Repeat liquefaction is a concern
- 1st Hazus-MH analysis of entire earthquake sequence in a scenario
HayWired: Landslide & Liquefaction

2001 El Salvador earthquake-induced landslide

EXPLANATION
Probability of liquefaction in western Alameda County
- Historical liquefaction point
- Historical liquefaction line
- Historical liquefaction area
- 3-m depth to groundwater contour
- Inland waterways
- Not assessed

Area where Holzer and others (2008, 2010) methods are used to map liquefaction probability

Seismic Landslide Hazards

<table>
<thead>
<tr>
<th>Newmark Displacement (Dn) cm</th>
<th>Landslide Probability</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 1</td>
<td>L</td>
<td>0 - 2%</td>
</tr>
<tr>
<td>1 - 5</td>
<td>M</td>
<td>2 - 15%</td>
</tr>
<tr>
<td>5 - 15</td>
<td>H</td>
<td>15 - 3%</td>
</tr>
<tr>
<td>&gt; 15</td>
<td>VH</td>
<td>&gt; 32%</td>
</tr>
</tbody>
</table>

Liquefaction in San Francisco Marina, Loma Prieta Earthquake 1989
An immediate occupancy code? Build 50% stronger & stiffer; cost 1% more; reduce impairment by $\frac{3}{4}$th

Life Safety
8,000 buildings (0.4%) collapse
490,000 (24%) red or yellow tag

Immediate Occupancy
95% shelter in place, collapse, red, and yellow tags reduced by $\frac{3}{4}$

---

Preliminary information subject to revision. Do not cite.
HayWired: EEW and DCHO

Earthquake early warning (EEW) time in HayWired

Drop, cover, and hold on (DCHO) reaction time

EEW + DCHO could prevent 1,500 injuries “worth” $300M in Mw 7.0 Hayward

Preliminary information subject to revision. Do not cite.
HayWired: Water dominates EQ risk to society

- Water causes economic losses far out of proportion to the utility’s repair cost
- Some Bay Area agencies have >50% brittle pipe
- Aggressive pipe replacement: 1% per year
- Equals decades until resilient water supply

What happens in HayWired?

Preliminary information subject to revision. Do not cite.
# HayWired: New Water Network Resilience Model

- Measures lost service-days
- Lifeline interaction & resource limits
- Vetted by EBMUD & SJWC
- Requires only GIS & spreadsheet

<table>
<thead>
<tr>
<th>Condition</th>
<th>Lost service days</th>
<th>Resilience benefit (service days)</th>
<th>Avg restoration (days)</th>
<th>Resilience benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>As-is</td>
<td>17,000,000</td>
<td>0</td>
<td>44</td>
<td>0</td>
</tr>
<tr>
<td>Fuel plan</td>
<td>16,800,000</td>
<td>200,000</td>
<td>43</td>
<td>$150 million</td>
</tr>
<tr>
<td>Replace all fragile pipe</td>
<td>8,800,000</td>
<td>8,200,000</td>
<td>22</td>
<td>$6 billion</td>
</tr>
</tbody>
</table>

Preliminary information subject to revision. Do not cite.
HayWired: Fire Following Earthquake

Figure 19. Chart of fire department operations timeline. Horizontal axis is time, beginning at time of earthquake. Horizontal bars depict development of fires, from ignition through growth or increasing size (size is indicated by width or number of horizontal bars). Figure from Scawthorn and others (2005).
HayWired: Our Interconnected World
HayWired Objectives:

- Improve the communication of earthquake hazard science in risk reduction
- Advance basic knowledge of, and inform actions to reduce earthquake risks
- Help build community capacity to respond and recover from earthquakes
HayWired: Objectives

• Improve understanding of the benefits of earthquake early warning

• Facilitate conversations about lifeline restoration interdependencies (exercises on-going)

• Educate about building code performance and public preferences for the building code

• Help anticipate environmental health issues

• Engage stakeholders in the discussions about the vulnerabilities and resilience in cyber infrastructure & the internet economy

• Provide materials for emergency response, business continuity and recovery exercises
The HayWired Scenario—How Can the San Francisco Bay Region Bounce Back from or Avert an Earthquake Disaster in an Interconnected World?

By Kenneth W. Hudnut,1 Anne M. Wein,1 Dale A. Cox,1 Suzanne C. Perry,1 Keith A. Porter,2 Laurie A. Johnson,3 and Jennifer A. Strauss4

Introduction

The HayWired scenario is a hypothetical yet scientifically realistic and quantitative depiction of a moment magnitude ($M_w$) 7.0 earthquake (mainshock) occurring on April 18, 2018, at 4:18 p.m. on the Hayward Fault in the east bay part of the San Francisco Bay area, California. The hypothetical earthquake has its epicenter in Oakland, and strong ground shaking from the scenario causes a wide range of severe impacts throughout the greater bay region. In the scenario, the Hayward Fault is ruptured along its length for 83 kilometers (about 52 miles).

Building on a decades-long series of efforts to reduce earthquake risk in the San Francisco Bay region, the hypothetical HayWired earthquake is used to examine the well-known earthquake hazard of the Hayward Fault, with a focus on newly emerging vulnerabilities. After a major life-saving response functions can be compromised. For these reasons, the name HayWired was chosen for this scenario to emphasize the need to examine our interconnectedness and reliance on telecommunications and other lifelines (such as water and electricity) toward the goal of making the San Francisco Bay region more resilient in future earthquakes.

Earthquake risk in the San Francisco Bay region has been greatly reduced as a result of previous concerted efforts; for example, a roughly $50 billion investment in strengthening infrastructure was motivated in large part by the 1989 magnitude (M) 6.9 Loma Prieta earthquake. The earthquake hazard from the Hayward Fault remains high, however, and much work still needs to be done to ensure that the region is ready for a major earthquake like that modeled in the HayWired scenario. Already, there is a renewed commitment from the newly formed HayWired Coalition—consisting of numerous government, academic, utility-
ARUP—Design and Engineering Consultants
Association of Bay Area Governments
Aurecon
Bay Area Center for Regional Disaster Resilience
Bay Area Rapid Transit Authority
Boston University
California Department of Public Health
California Department of Transportation
California Earthquake Authority
California Earthquake Clearinghouse
California Geological Survey
California Governor’s Office of Business and Economic Development
California Governor's Office of Emergency Services
California Public Utilities Commission
California Resiliency Alliance
California Seismic Safety Commission
Carnegie Melon University Silicon Valley
City of Berkeley
City of Oakland
City of San Francisco, Department of Emergency Management
City of Walnut Creek

Earthquake Country Alliance
Earthquake Engineering Research Institute
East Bay Municipal Utilities District
Federal Emergency Management Agency
Joint Venture Silicon Valley
Laurie Johnson Consulting
MMI Engineering
Pacific Earthquake Engineering Research Center
Pacific Gas and Electric
Palo Alto University
Red Cross
Rockefeller Foundation—100 Resilient Cities
San Jose Water Company
Southern California Earthquake Center
SPA Risk LLC
San Francisco Bay Area Planning and Urban Research Association
Strategic Economics
Structural Engineers Association of Northern California
University of California Berkeley Seismological Laboratory
University of Colorado Boulder
University of Southern California
U.S. Geological Survey

Joint Venture Silicon Valley
PEER
ABAG
U.S.G.S.
Questions?

Dale A. Cox, dacox@usgs.gov