High Speed Rail and Earthquakes

PEER Annual Meeting
Transportation Systems Research Program

Jean-Pierre Bardet & Tat S. Fu @ USC
Oct 16, 2009
California High Speed Rail (HSR)

Proposition 1A (2008)
Safe, Reliable High-Speed Passenger Train

Reinvestment and Recovery Act
“faster, cheaper & easier than building more freeways or adding to an overburdened aviation system”

http://en.wikipedia.org/wiki/California_Proposition_1A_%282008%29
HIGH-SPEED RAIL BOOM:
HOW DO THE WORLD’S MOST AMBITIOUS NEW PROJECTS MEASURE UP?

**Tel Aviv-Jerusalem**
Opening: 2015
Cost: $1.4 billion
Route between Israel’s biggest cities will be the first high-speed line in the Middle East.

**HSI-Zuid**
Opening: 2009
Cost: $3.6 billion
The Netherlands’ first fast rail line will speed travel to Belgium and Paris by an hour.

**Lyon-Torino**
Opening: 2020
Cost: $9.4 billion
Connection between France and Italy; includes 32-mile base tunnel under the Alps.

**Haramain**
Opening: 2012
Cost: $1.8 billion
Link between Saudi Arabia’s big western port, Jeddah, and the two religious centers.

**TAVE**
Opening: TBD
Cost: $4 billion
TAVE will be South America’s first fast rail line and serve 1/3 of Argentina’s population.

**CA HSR**
Opening: 2018
Cost: $30 billion
First phase of future 800-mile network will connect California’s two biggest metro areas.

**Beijing-Shanghai**
Opening: 2012
Cost: $12 billion
The world’s longest high-speed rail line will speed along China’s east coast at 220 mph.
Earlier Today:

Burbank to SF with United Air:

Check in: 45 min
DELAY (fog): 1 h 20 min
Flight: 1 h 19 min
SFO – Downtown: 30 min
Total: 3 h 54 min

Fare: $230
Outline

• Introduction
  o CA High Speed Rail (HSR)
  o HSR systems around the world

• Earthquakes and HSR

• Earthquake hazards for CA HSR
  o Earthquake faults
  o Liquefaction

• Solution example
CA HSR Routes (Google Map)
CA HSR Routes (Google Earth)
around the World

JAPAN
• Shinkansen (新幹線)
• 1528 miles
• EQ regions
• Good track record

Contact:
• Railway Technical Research Institute (RTRI) – Dr. Yoshitaka Murono; Dr. Xiu Luo; Dr. Kimitoshi Ashiya, ...
• JR Soken Engineering – Dr. Akihiko Nishimura
• Universities – Prof. Masa Hamada; Prof. Junichi Koseki
China

- Under construction
- 16,000 miles (by 2020)
- $50B (2009 alone)

Contact:

- China Railway Eryuan Engineering Group (CREEGC) – Anhong Li
- Southwest Jiaotong University (SWJU) – Prof. Jianlin Ma; Prof. Renda Zhao; Prof. Sirong Yi, ...
France

- TGV (Train à Grande Vitesse)
- Fastest in the world
- Systra
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• **Solution example**
Earthquakes and HSR

M6.6 EQ
Niigata-ken Chuetsu Japan
October 23, 2004

M8.0 EQ
Wenchuan, Sichuan, China
May 12, 2008
Fault Crossing

The Chichi, Taiwan, Earthquake of September 21, 1999
Keyword search on “Web of Science”
### Literature Review

<table>
<thead>
<tr>
<th>keywords</th>
<th># of Results</th>
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<tbody>
<tr>
<td></td>
<td>high speed rail +</td>
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<tr>
<td>(nothing)</td>
<td>93400</td>
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<tr>
<td>earthquake</td>
<td>3720</td>
</tr>
<tr>
<td>seismic</td>
<td>4960</td>
</tr>
<tr>
<td>structure</td>
<td>50300</td>
</tr>
<tr>
<td>bridge</td>
<td>20000</td>
</tr>
<tr>
<td>tunnel</td>
<td>9350</td>
</tr>
<tr>
<td>embankment</td>
<td>1320</td>
</tr>
<tr>
<td>vibration</td>
<td>19600</td>
</tr>
<tr>
<td>sensor</td>
<td>26900</td>
</tr>
<tr>
<td>noise</td>
<td>29900</td>
</tr>
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</table>

Keyword search on “Google Scholar (Engineering, Computer Science, and Mathematics)”
Railway Technical Research Institute (RTRI)
III SEISMIC DESIGN PROCEDURE .................................................................................................................. 3

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  2. Evaluation of Surface Ground .............................................................................................................. 7
  3. Computation of Structural Response Values ...................................................................................... 10
  4. Verification of Seismic Performance .................................................................................................. 12
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  1. Design Guidebook and Design Examples ...................................................................................... 26
  2. Design Software ................................................................................................................................. 26
### Table 12 Limit Values of Differential Displacement of Track Surfaces in a Seismic Condition

<table>
<thead>
<tr>
<th>Direction</th>
<th>Maximum Speed (km/h)</th>
<th>Angular rotation $\theta$ (°/1000)</th>
<th>Alignment Irregularity (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$L_b=10m$</td>
<td>$L_b=30m$</td>
</tr>
<tr>
<td>Lateral</td>
<td>130</td>
<td>7.0</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td>160</td>
<td>6.0</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td>210</td>
<td>5.5</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>260</td>
<td>5.0</td>
<td>3.0</td>
</tr>
<tr>
<td></td>
<td>300</td>
<td>4.5</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>360</td>
<td>4.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>
Design Standards for Railway Structures and Commentary (Seismic Design)

- Setting of design earthquake conditions
  - Structure dimensions/section
- Evaluation of deformability of wall body (modeled by cantilever slab)
- Load-displacement relationship of wall body
- Computation of response values of wall body (earth pressure for wall body during an earthquake)
- Verification of seismic performance of wall body
- Seismic performance satisfied?
  - Yes
    - Changes to structure dimensions/enforcement amount
  - No
- Evaluation of deformability of foundation (Wall body is assumed elastic)
- Load-displacement curve of foundation (earth pressure for stability during an earthquake)
- Yield seismic coefficient of foundation
- Yield seismic coefficient of wall body
- Computation of response values by maximum seismic coefficient of wall body
- Verification of seismic performance of foundation
- Seismic performance satisfied?
  - Yes
    - Seismic structural details
  - No
    - Changes of foundation dimensions

Figure 23 Flow of Structural Analysis for Retaining Wall subjected to Level-2 Earthquake Motion
Figure 19 Flow Chart for Computing the Response Value of Foundation Structures by Seismic Deformation Method
Design Standards for Railway Structures and Commentary
(Seismic Design)

To be constructed based on the Design Standards for Railway Structures and commentary (Earth Structures)

Seismic design required?
- Geographical features that are susceptible to the influence of earthquakes
- In particular, ground configuration that is likely to shake
- Difficulty of recovery

Setting of design conditions
- Design earthquake motion
- Ground conditions, etc.

Assumption of seismic resistant members
- Embankment materials used
- Arrangement of reinforcing materials
- Embankment shape
- Soil-improvement, etc.

Evaluation of stability
- Slip circle safety factor with respect to Level 1 earthquake motion at required safety factor or higher?

Evaluation of deformation
- Deformation amount within allowable value in respect to Level 2 earthquake motion?

Consideration of seismic performance in accordance with structural details

End

Figure 20 Flow Chart for Seismic Design of Embankments
<table>
<thead>
<tr>
<th>Items in Seismic Design</th>
<th>Time-history Dynamic Analysis Method</th>
<th>Nonlinear Spectrum Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setting input earthquake motions</td>
<td>Selection of Level 1, Level 2 earthquake motions (spectra I, II and III)</td>
<td>Selection of earthquake motions according to ground classification (from G0 to G7)</td>
</tr>
<tr>
<td>Evaluation of surface ground</td>
<td>Dynamic analysis of surface ground</td>
<td>Detailed dynamic analysis (Time-history dynamic analysis method)</td>
</tr>
<tr>
<td>Computation of structural response values</td>
<td>Selection of earthquake motions according to ground classification (from G0 to G7)</td>
<td>Simplified dynamic analysis (Non-linear spectrum method)</td>
</tr>
<tr>
<td>Verification of seismic performance</td>
<td>Member......Damage level</td>
<td>Foundation......Stability level</td>
</tr>
</tbody>
</table>

Figure 2 Seismic Design Procedure for Bridges and Viaducts
Liquefaction

Figure 11: Consideration of Ground Displacement Caused by Lateral Flow of Soil
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• **Earthquakes and HSR**

• **Earthquake hazards for CA HSR**
  o Earthquake faults
  o Liquefaction
  o Major earthquakes in CA

• **Solution example**
<table>
<thead>
<tr>
<th>Segment Type</th>
<th>Length (km)</th>
<th>Length (miles)</th>
<th>Fault Crossing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerial</td>
<td>201.7</td>
<td>125.2</td>
<td>1</td>
</tr>
<tr>
<td>At Grade</td>
<td>703.7</td>
<td>437.0</td>
<td>5</td>
</tr>
<tr>
<td>Cut &amp; Fill</td>
<td>195.9</td>
<td>121.6</td>
<td>2</td>
</tr>
<tr>
<td>Embankment</td>
<td>2.1</td>
<td>1.3</td>
<td>0</td>
</tr>
<tr>
<td>Retaining Wall</td>
<td>28.8</td>
<td>17.9</td>
<td>0</td>
</tr>
<tr>
<td>Trench</td>
<td>11.6</td>
<td>7.2</td>
<td>1</td>
</tr>
<tr>
<td>Tunnel</td>
<td>67.6</td>
<td>42.0</td>
<td>3</td>
</tr>
<tr>
<td>Under Consideration</td>
<td>168.3</td>
<td>104.5</td>
<td>6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1379.7</strong></td>
<td><strong>856.8</strong></td>
<td><strong>18</strong></td>
</tr>
</tbody>
</table>
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Caltrans ARS Online

This web-based tool calculates both deterministic and probabilistic acceleration response spectra for any location in California. To begin an analysis, identify your site using the site selection tool. You can select a new site, or modify your previously selected site location by clicking this button again. You can also enter or modify your site location at any time by entering coordinates in the fields at the bottom of the map.
Response Spectra
Response Spectra

Location: LAT=35.073878 LONG=-118.289795 Vs30=500m/s

- Garlock fault zone (Western section) (With Near Fault Factor Applied)
- USGS 5% in 50 years hazard (2008) (With Near Fault Factor Applied)
Response Spectra

Location: LAT=36.991054 LONG=-121.387939 Vs30=500m/s

Calaveras fault zone (Southern Calaveras section) (With Near Fault Factor Applied)
USGS 5% in 50 years hazard (2008) (With Near Fault Factor Applied)
Summary

- Japan, China, France, and a few other countries have had HSR systems for some time.
- U.S. launched an ambitious HSR program, but it is its first HSRs.
- Earthquakes have damaged HSR abroad.
- CA HSR will have to be designed to resist earthquakes.
- The Pacific Earthquake Engineering Research Center (PEER) has developed a large body of knowledge in seismic transportation research applicable to HSR.
Figure 8 Model for Setting Limit Values for Angular Rotation on Track Surfaces