Earthquake and Structural Damage Reconnaissance with Advanced Tools

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Overview

• What’s unique? Why is a Rapid needed...
  • The Extreme Event
  • Research Questions
  • The Team / “The Fixer”
  • Contact NSF...

• Trip Planning
  • Team Logistics
  • Equipment, tools, Software, Data Collection Procedures
  • Health and Safety, Risks
  • Contact NSF...

• Example Data
  • Data Collection
  • Reports and Published Data: https://doi.org/10.17603/ds2p082

• Other potential applications
  • Other hazards: recon
  • Large-scale testing
The Extreme Event: 2015 Gorkha Earthquake

- Mainshock on April 25, 2015 with magnitude 7.8
  - Shallow earthquake, with a focal depth of 8.2 km
  - Epicenter was in Lamjung, Gorkha district, 75 km northwest of Kathmandu
- Mainshock followed by 400 aftershocks of $4.0 M_w$, including a $7.3 M_w$ east of Kathmandu (May 12)
- Measured peak ground accelerations (PGA)
  - in the E-W: $\sim 0.26g$; in the N-S $\sim 0.16g$
- Caused more than 9,000 fatalities, almost 25,000 injuries and damaged beyond repair over 500,000 buildings
- Most of the damage was on poorly engineered unreinforced masonry buildings.
- Approximately 25 per cent of the building stock consisted of reinforced concrete (RC) frames infilled with masonry walls.

Research Questions

**NSF RAPID**

1. **Post-earthquake assessment of existing RC building frames with masonry infill.** This structural system was widely used in the 1920s and 1930s in California as well as in the Pacific Northwest; hence, understanding the damage to this structural system from the Nepal earthquake has direct implications for the seismic performance of a large number of buildings in metropolitan areas in the United States.

2. **Quantitative damage measurements** performed using 3D, ground-based lidar (GBL) scans, UAS Structure from Motion (SfM).

**Additional work / Initial Wishlist**

A. **Dynamic system identification** of RC infilled buildings
   - a) Non-engineered buildings (with and without damage)
   - b) Well designed buildings (with and without damage)
   - c) Identification of frequency of infill walls (with and without damage)

B. **Damage assessment of urban/rural areas** using visual damage assessments (rapid and detailed)

C. Inform local agencies in Nepal on suggested rebuilding and recovery guidelines.
The Team / The Fixer

- **Oregon State Univ.**: Andre Barbosa, Michael Olsen, Dr. Dan Gillins, **Rajendra Soti**, Patrick Burns, Matt Gillins
- **U. Buffalo**: Andreas Stavridis, Supratik Bose
- **NSET**: Surya Shrestha, **Ramesh Guragain**, Dev Maharjan
- **PEER**: Stephen Mahin, Grace Kang, Matthew Schoettler
- **U. Chieti-Pescara**: Enrico Spacone, Giuseppe Brando, Davide Rapone
- **U. Roma-Sapienza**: Rosario Gigliotti, Marco Faggella
- **U. Nebraska**: Richard Wood
- **Tufts U.**: Babak Moaveni

Trip Planning

- Information about the existing field situation
- Main objectives/goals/focus for each group
- Research opportunities to gather, analyze and synthesize field data
- Areas of interest
- Pre-departure checklists, authorizations, and procedures
  - Examples: EERI, Masonry Society, GEER
  - Travel information: Health, Visa, embassy letters
  - Liability release forms
  - Practical/sharable data collection and uploading
    - Google Drive? Others?
    - Forms: ATC-20, NSET, Others?
- Contact information about on-site people as resources, as well as other earthquake recon teams
- Travel dates
Trip Planning

- Travel information pre-trip checklist, authorizations, and procedures
  - Logistics:
    - Base camp
      - Equipment / Work room / Debrief room
    - Transportation of people, food, water, and equipment (Rentals, Drivers, Licenses, Safety)
    - Payment methods (Cash only? Credit cards? Contingencies?)
  - Equipment:
    - List of Equipment, Special Needs, Authorizations, Carnet
  - Travel information:
    - Weather
    - Food/water safety
    - Disaster Preparedness Supplies
    - Avoiding Illness
    - Information about the existing field situation
  - Health CDC (Center Disease and Control)
  - Check with your university Risk Consultant on
    - Risk management plan and travel insurance
    - Risk mitigation plans, including training on: communication plan, knowing what to do in the event of an earthquake, plans for shelter, develop plans to avoid food/water contamination, etc.
### Team Effort

<table>
<thead>
<tr>
<th>Type of Assessment</th>
<th>Structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forms</td>
<td>RC structures with infills</td>
</tr>
<tr>
<td></td>
<td>- Three (3) tall buildings</td>
</tr>
<tr>
<td></td>
<td>- Six (6) school buildings</td>
</tr>
<tr>
<td></td>
<td>- Two (2) hospitals</td>
</tr>
<tr>
<td></td>
<td>- 25 residential buildings</td>
</tr>
<tr>
<td>Non-destructive Testing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Schmidt Hammer Testing</td>
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<tr>
<td></td>
<td>- Rebar Scanner</td>
</tr>
<tr>
<td></td>
<td>- Ultrasonic testing</td>
</tr>
<tr>
<td>Ground-based Lidar (laser scanning)</td>
<td></td>
</tr>
<tr>
<td>Unmanned Aircraft Systems (UAS)</td>
<td></td>
</tr>
</tbody>
</table>

- Two (2) Historic Centers
  - Bungamati and Bhaktapur

- Seven (7) Urban and Rural Areas
  - Kathmandu – Gongabu, Sitapaila
  - Sindulpalchowk – Chautara, Barabise, Charikot, Piskar
  - Ghorkha – Manakamana

- Three (3) historical URM structures

- Landslides and liquefaction

Full list available at: http://web.engr.oregonstate.edu/~barbosa/NEPAL/earthquake-reconnaissance/list_of_assessed_structures.htm

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**GBL and Ambient-vibration Testing at the Building Structure Scale**
18-story RC Building, Katmandu

18-story Building: Cityscape #1

- 18-story building, located in Kathmandu, Nepal.
- Extensive non-structural and moderate structural damage.
Observed damage

- Mostly infill walls
- Some beam-column joint cracks

Data Collection

- Ambient vibration using wired accelerometers
- LIDAR on the outside and inside of the structure
FE model vs System ID Correlation

- The first three natural frequencies are very closely spaced

<table>
<thead>
<tr>
<th>Frequency [Hz]</th>
<th>Mode1</th>
<th>Mode2</th>
<th>Mode3</th>
</tr>
</thead>
<tbody>
<tr>
<td>FE Model</td>
<td>0.64</td>
<td>0.72</td>
<td>0.85</td>
</tr>
<tr>
<td>System ID</td>
<td>0.61</td>
<td>0.67</td>
<td>0.73</td>
</tr>
</tbody>
</table>

FE model of Cityscape #1 building in SAP2000

Response Prediction

Linear time history analysis for mainshock (M7.8) and aftershock (M7.3)

Inter-story drift ratios of the different stories

<table>
<thead>
<tr>
<th>Story</th>
<th>Peak inter-story drift (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6th</td>
<td>Light Damage</td>
</tr>
<tr>
<td>3rd</td>
<td>Light Damage</td>
</tr>
<tr>
<td>9th</td>
<td>Moderate Damage</td>
</tr>
</tbody>
</table>

N-S Mainshock (M7.8)
E-W Mainshock (M7.8)
N-S Aftershock (M7.3)
E-W Aftershock (M7.3)
School Building, Shanku

- 4-story RC frame building with masonry infill walls
- Damaged during 2015 Gorkha EQ
- Visited by authors in 2015
- Collected post-EQ ambient vibration and laser scan data
Damage Quantification

FEM Modeling Results

<table>
<thead>
<tr>
<th>Frequencies (Hz)</th>
<th>System ID</th>
<th>Initial Model</th>
<th>Deterministic Model Updating</th>
<th>Bayesian Model Updating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model1</td>
<td>1.19</td>
<td>1.30</td>
<td>1.19</td>
<td>1.20</td>
</tr>
<tr>
<td>Model2</td>
<td>2.16</td>
<td>2.69</td>
<td>2.17</td>
<td>2.16</td>
</tr>
<tr>
<td>Model3</td>
<td>3.16</td>
<td>3.39</td>
<td>3.15</td>
<td>3.14</td>
</tr>
</tbody>
</table>

» Calibrated models from both approaches match data accurately
» Crossing of the closely spaced modes made mode-pairing challenging in the updating process
Use of GBL and UAS at the Urban Scale

Bungamati
**Bungamati: Flight Plan**

- ~1600 High-Definition Aerial Photos of Bungamati, Nepal
Bhaktapur

Post-Earthquake Reconnaissance
2015 Gorkha Earthquake (7.8 Mw)
Bhaktapur, Nepal

All field data collection occurred under National Science Foundation Grant 1545632

https://www.youtube.com/watch?v=ey7jADUWrFk&feature=youtu.be


Structural Engineering: Example Applications

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- Dr. Manjip Shakya, Dr. Ganesh Ram Nhamafuki, Dr. Hemchandra Chaulagain, Principal Chandra Kiran, Principal Sujan Maun, Sharoo Shrestha
- Several building owners in Nepal that prefer to remain anonymous
- Leica Geosystems and David Evans and Associates provided the Oregon State University laser scanning equipment and software used for this project