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Low Cost Seismic Test Platform

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1. Introduction

Only a few wealthy countries can afford sophisticated seismic test facilities, and even these often have fairly limited capabilities. In most cases tests have to be run at partial scale (full scale buildings won't fit), and the earthquake forces which are created by hydraulic rams operating against a reaction wall, provide only back and forth motion at slow speed. The rigid floor of the facility further limits realism.

Buildings and building components are tested in a very artificial environment instead of the chaotic multi-directional movement experienced in a real earthquake. Even these simplified tests are very expensive, running into the tens of thousands of dollars. Yet, despite the high costs the facilities are often booked for months or years in advance due to the large demand for testing.

For example, the new earthquake simulator now being built at the University of California, San Diego will improve testing capability on a larger platform, 8 m x 13 m, but at a cost of more
than $10 million dollars. Testing on this innovative facility will be very expensive, but will provide new insight and understanding.

This cost is far out of reach of universities and engineering test labs in most countries where seismic risks are high or extremely high. As a result buildings and other facilities remain very vulnerable to earthquake damage. Improved testing to refine low cost retrofitting is urgently needed. New methods for low cost testing of earthquake proofing for non-scalable materials such as adobe, straw clay, straw bales, and stone are also urgently needed. Improved testing for infrastructure is also needed. As the Izmit earthquake in Turkey showed, damage to refineries and other facilities can be very dangerous and costly. The risks are spread around the world, with millions at risk.

I believe the new seismic testing approach presented here will help meet this need. It can provide low cost, large scale testing and evaluation well within the budgets of universities, test labs, and even engineering firms in most parts of the world. For the first time, engineers (and students) in countries around the world should be able to simulate the complex strong motion of significant earthquakes. In addition the test platform can incorporate ground movement, a factor lacking in existing test facilities, but often an important factor in structural failures. It can also provide a rapid assessment of response to a series of shaking intensities. It will help make housing, commercial buildings, industrial facilities, and infrastructure more earthquake resistant. It will also enable engineering students and faculty to hone their design skills and strategies to save lives and reduce property loss.

The need for this type of facility is demonstrated every year as earthquakes kill and maim people and damage property around the world. Mexico City (1985), Northridge, California (1994), Kobe, Japan (1995), Izmit, Turkey (1999), Bam, Iran (2003) and many other earthquakes have revealed the risks even in industrialized countries with well developed engineering capability. Damage in the Izmit earthquake (magnitude 7.4) was much greater than expected in residential, commercial, and industrial facilities, and infrastructure. The long duration of shaking and the frequency are likely to be important factors, but some of the damage may reflect weaknesses in current understanding resulting from simplified test procedures. It is very costly to learn these lessons only from earthquakes.

The risks in more rural areas are even higher, and thousands of people die each year in small to moderate earthquakes. Retrofit strategies for un-reinforced mud, masonry, and stone buildings are urgently needed, but little research has been done because the clients can't afford it and these indigenous materials are not easily scalable for model tests. Full scale testing of retrofit strategies is urgently needed for a wide range of low cost, widely used building systems. Retrofit solutions that can be easily installed with available materials are critically needed and can save thousands or tens of thousands of lives.

A large earthquake in a big city with high seismic risk could cost tens or hundreds of thousands of lives if retrofit solutions are not developed and installed. The new testing system proposed here should allow this to be done. The goal is developing much better understanding of the dynamic response of building systems and facilities under the complex motions experienced in real earthquakes. Joints that may respond well to simple back and forth motion may fail when twisted, lifted and moved back and forth at the same time.

Seismic risk is a global problem, highlighted in red on the following map.
Table 1. Large cities with very high seismic risk

<table>
<thead>
<tr>
<th>Country</th>
<th>Key cities</th>
<th>Million people</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turkey</td>
<td>Istanbul</td>
<td>8.3</td>
</tr>
<tr>
<td></td>
<td>Ankara</td>
<td>2.9</td>
</tr>
<tr>
<td>Iran</td>
<td>Tehran</td>
<td>6.7</td>
</tr>
<tr>
<td></td>
<td>Mashhad</td>
<td>1.8</td>
</tr>
<tr>
<td>Pakistan</td>
<td>Karachi</td>
<td>9.3</td>
</tr>
<tr>
<td></td>
<td>Lahore</td>
<td>5</td>
</tr>
<tr>
<td>Mexico</td>
<td>Mexico City</td>
<td>8.6</td>
</tr>
<tr>
<td></td>
<td>Guadalajara</td>
<td>1.6</td>
</tr>
<tr>
<td>Peru</td>
<td>Lima</td>
<td>7</td>
</tr>
<tr>
<td>Chile</td>
<td>Santiago</td>
<td>4.6</td>
</tr>
<tr>
<td>Columbia</td>
<td>Bogota</td>
<td>6.2</td>
</tr>
<tr>
<td></td>
<td>Medellin</td>
<td>1.9</td>
</tr>
<tr>
<td>Philippines</td>
<td>Quezon City</td>
<td>2.2</td>
</tr>
<tr>
<td></td>
<td>Manila</td>
<td>1.6</td>
</tr>
<tr>
<td>Iraq</td>
<td>Baghdad</td>
<td>4.6</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>Dhaka</td>
<td>6</td>
</tr>
<tr>
<td>India</td>
<td>Calcutta</td>
<td>4.3</td>
</tr>
</tbody>
</table>

Several of these cities have the potential for loss of life in the tens or hundreds of thousands in a large earthquake.

2. The approach

The problem in conventional testing is the application of sufficient force to deform a building. This is usually done with hydraulic rams, but the forces can be applied in only one or at most a couple of directions and only at slow speed unless very large investments are made. In this new Mobile Seismic Evaluation System the forces are created by moving a platform across a test bed with ridges shaped to create up and down and side to side movement. The speed, angle of attack, and shape of the ridges can be varied to create desired forces and movement. Adjustable spring rates and shock absorbers on platform wheel assemblies can be used to fine tune motion. With some experience it should be possible to closely mimic historic earthquakes.

The size of the test platform is limited only by motive power, which might be a tractor, large truck, locomotive, winch, or a specially developed prime mover. This would allow full scale testing for buildings and building components.

For low cost testing a semi-rigid platform could be used, with wheels spaced in relation to the strength of the platform. To further improve capability and test realism the test platform would be
created with a series of linked modules connected with high strength steel cable in a bi-
directional grid. Tension in the cables would be adjusted with hydraulic rams to control platform flex.

It should even be feasible to build a test facility that would allow sufficient soil to be placed and compacted on the platform to add further reality to tests by comparing foundation response on different soil types and soil moisture levels. It may also make full scale testing of liquefaction response feasible. With experience the platform could be set to experience wave forms and deformation much like real ground surfaces in severe earthquakes. This would allow for much more realistic testing of buildings and facilities on soft ground.

This new approach was first imagined after a visit to a state university to explore the use of their test facility for evaluation of straw bale building systems. Discussions with the site manager revealed that testing would have been expensive for even a basic reaction wall test. But the real stopper was the fact the facility was required to be operational, but had no funding for repairs. Therefore users were required to agree to cover any possible damage to the facility from testing.

The first field tests were done with a homebuilt mechanical accelerometer in 1998. This was mounted on a truck and tested over the road and a variety of speed bumps. The range of accelerations was very appropriate for testing, reaching about 1+ g vertical. As we have learned this is similar to acceleration in many earthquakes.

In 1998 a simple biaxial mechanical accelerometer was also created and tested. This provided data that was equally encouraging.

San Fernando earthquake MoSES prototype

In 2000 and 2001 a series of tests were undertaken to evaluate speed and ridge configuration effects. These confirmed earlier data helped validate the current MoSES design.

Test data from mechanical accelerometer attached to the bumber of a 1966 carryall driven briskly across a speed bump.
3. Next steps

The next step is moving to electronic instrumentation and a larger platform. The platforms would not be very expensive and a series could be built for each test facility. This would allow for construction of buildings and industrial facilities for testing at a more leisurely pace. It would also allow materials to cure and develop strength before testing without tying up expensive facilities.

Only one or two sets of sensors and cameras and one prime mover would be needed. This would reduce costs and enable a range of retrofit approaches to be sequentially tested on identical buildings. It would also allow building materials such as concrete, mud, or plaster to reach close to full strength before testing without tying up expensive facility space. Set in a series of airplane hangers the facilities could provide the opportunity for classes of engineering students to test a range of retrofit solutions over a semester or year.

Data collection and analysis would have been challenging in the past, but today the building or components can be instrumented with low cost accelerometers, strain gauges, and position recorders. The lowest cost approach would often be a simple wire net, but a wireless network would be more flexible and less costly to install and reuse. It would also be less vulnerable during failure events and collapses, so data streams would be more comprehensive for better failure analysis. Relative motion between several positions on the platform and a range of locations on the building or component being tested could be determined using graphical programs. In addition video recorders and high speed cameras would be positioned on the platform to monitor and record behavior of the building or system being tested. This videographic record would help engineers understand failure modes.

An abandoned runway or road section would be well suited for the test facility, but it could also be set up in a compacted dirt field or on a purpose built roadway or pad. Ridges could be graded in place on dirt, but would preferably be shaped in concrete and then pinned or bolted down to a concrete or asphalt test pad. The shape of the ridges would provide both vertical and horizontal earthquake motions. It should even be feasible to set up a series of ridge fields to simulate an earthquake series that increases in intensity and duration, perhaps beginning at Mercalli Intensity 4 and working up to Mercalli Intensity 9 or 10.

It would then be possible to run a building or component through a series of earthquakes in a matter of hours, or minutes if the data handling and storage package was sophisticated. If no
damage occurs at MI 4, then the test platform could be run through MI 5, MI 6, and MI 7 until damage or failure occurs.

The cost of a complete system could hopefully be kept below $5,000 for a rudimentary system, but might reach $500,000 for a fully developed installation. This is still far below conventional testing systems with more limited capability.

The most important part of the MoSES testing program is a well integrated and reliable data collection system. This would require engineering by an experienced sensor technology firm. The data analysis could be done with a PC running a graphical motion system. This might be similar to some of the proprietary multi-channel software systems now sold to analyze race car performance. The goal would be to develop a modular, upgrade-able system that would fit in a box and be "plug and play" even under less than ideal conditions. This should not be too difficult or costly, with investment covered by return on licensing or patents.

Sensor and software companies:
Pi Research       www.piresearch.com
Crossbow Technology  www.xbow.com
Active Sensors    www.activesensors.com
Honeywell  www.sensotec.com
Stack  www.stackinc.com
Memsic  www.memsic.com

Field validation is desirable, perhaps providing test data on a difficult to model building system like light-straw clay or straw bales with natural plaster. If the field tests are completed successfully the system could be refined for sale or distribution.

MoSES Details

The challenge
Who is willing to take up the challenge?

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