Hydrostatic Level Systems at Fermilab and SURF

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# Systems

<table>
<thead>
<tr>
<th>Location</th>
<th>Sensor type</th>
<th>Number of sensors</th>
<th>Separation</th>
</tr>
</thead>
<tbody>
<tr>
<td>MINOS-2 MINOS hall Fermilab</td>
<td>SAS-E</td>
<td>10</td>
<td>10 m</td>
</tr>
<tr>
<td>LaFarge North Aurora III</td>
<td>SAS</td>
<td>5</td>
<td>30 m</td>
</tr>
<tr>
<td>Array C SURF Lead South Dakota</td>
<td>SAS-E</td>
<td>6</td>
<td>30 m</td>
</tr>
<tr>
<td>NML NML Fermilab</td>
<td>SAS</td>
<td>4</td>
<td>Varies</td>
</tr>
<tr>
<td>MP7 MP7 Fermilab</td>
<td>ULSE</td>
<td>3</td>
<td>20 m</td>
</tr>
<tr>
<td>Stability test MP8 Fermilab</td>
<td>SAS</td>
<td>12</td>
<td></td>
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<tr>
<td>MT ULSE MP8 Fermilab</td>
<td>ULSE</td>
<td>12</td>
<td>1 m</td>
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</table>
# Inactive Systems

<table>
<thead>
<tr>
<th>Location</th>
<th>Sensor Type</th>
<th>Number of sensors</th>
<th>separation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Array D</td>
<td>ULSE</td>
<td>12</td>
<td>7 m</td>
</tr>
<tr>
<td>4850 ft level SURF</td>
<td></td>
<td></td>
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<tr>
<td>B0 low beta quads</td>
<td>SAS</td>
<td>9</td>
<td>Varies</td>
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<tr>
<td>B0 Tevatron</td>
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<tr>
<td>D0 low beta quads</td>
<td>SAS</td>
<td>9</td>
<td>Varies</td>
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<tr>
<td>D0 Tevatron</td>
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<tr>
<td>Tev quads</td>
<td>Balluff</td>
<td>204</td>
<td>30 m</td>
</tr>
<tr>
<td>Tevatron quads</td>
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<td></td>
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</tr>
</tbody>
</table>
MINOS Near Detector

MINOS is the Fermilab Neutrino oscillation Experiment
The near detector is Located on site
100 meters below grade
MINOS-2

Single pipe half filled system

10 m
Typical MINOS data August 2012
5 days of data

Time plot difference
Of two sensors

FFT of data

Sept 11, 2012
IWAA 2012
MINOS-2 Data Feb 2012 to August 2012

L0-2*L4 + L7
Road Header used to excavate the Nova near detector hall extension

2 24 m by 10 m by 7 meter Caverns excavated for Nova near detector
Work done by Dec 2012
LaFarge Mine
Level 1 of LaFarge Mine

34 hectares mined out Level 1
Drifts 20 meters wide by 20 meters high
Difference in two sensors 120 meters apart
Difference in two sensors 120 meters apart June 2008 to Jan 2009

Conveyor breakdown
Difference in two sensors 120 meters apart June 2008 to Jan 2009
LaFarge East West Array
Jan 2011 to Aug 2012
Tohoku Earthquake March 2011

Mine blasts

Earth Quake
Sanford Underground Research Facility

Max water level

Current level Holding 600 ft
Surface view of SURF
Array C layout

East West leg
L3, L4, L5

North South leg
L0, L1, L2
HLS at 2000 ft level on rock bolt shelf
Difference in two sensors
2000 ft level SURF
Tohoku Earthquake March 2011

Earthquake

micrometers
Difference in two sensors 60 meters apart SURF 2000 foot level
4850 ft level SURF installation
4850 ft installation SURF

Sensors 5 and 6

Sensor 9

Sensor 11

Computer and switch
Difference in two sensors 4850 ft level
Difference in two sensors
4850 ft level SURF
ATL law

The ALT law states that motion between two points goes as

\[ < ds >^2 = ATL \]

Where;
- \( T \) is the time between measurements
- \( L \) is the separation between the points
- \( A \) is a constant in \( \mu^2 \) per second per meter

By comparing the double differences for sensors

\[ (D1-D2) - (D2-D3) \]

at various time slices the \( A \) constant can be computed. Corrections are made for constant drift of sensor such as in array C.
# A values as a function of depth

<table>
<thead>
<tr>
<th>System</th>
<th>Sensors</th>
<th>Double differences</th>
<th>Separation m</th>
<th>Depth m</th>
<th>Average A $\mu^2$/s/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>LaFarge mine</td>
<td>4</td>
<td>3</td>
<td>30</td>
<td>110</td>
<td>$1.61 \times 10^{-5}$</td>
</tr>
<tr>
<td>MINOS-1</td>
<td>4</td>
<td>3</td>
<td>30</td>
<td>100</td>
<td>$3.01 \times 10^{-5}$</td>
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<td>MINOS-2</td>
<td>7</td>
<td>6</td>
<td>10</td>
<td>100</td>
<td>$3.91 \times 10^{-5}$</td>
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<tr>
<td>Array C</td>
<td>6</td>
<td>2</td>
<td>20</td>
<td>680</td>
<td>$8.85 \times 10^{-7}$</td>
</tr>
<tr>
<td>Array D</td>
<td>12</td>
<td>8</td>
<td>7</td>
<td>1650</td>
<td>$6.02 \times 10^{-7}$</td>
</tr>
</tbody>
</table>
NML system for Project X
NML Data
L0-L1

-160
-150
-140
-130
-120
-110
-100
-90
-80

micrometers

7/29/2012
8/1/2012
8/4/2012
8/7/2012
8/10/2012
8/13/2012
8/16/2012
To save construction costs a the beam will be extracted upward from the Main Injector. There will be a hill 24 meters high to cover the beam line. Pillars to bed rock will be used to support the tunnel. It is expected that the hill will settle over time. Re use the Tevatron HLS system to monitor the settlement soon after construction.
LBNE Target Hall
Cross section of LBNE tunnel

Ground level
LBNE Beam Line
Information

Hydrostatic Level Sensors as High Precision Ground Motion Instrumentation for Tevatron and Other Energy Frontier Accelerators
Published in JINST Fall of 2011 available at
http://dx.doi.org/10.1088/1748-0221/7/01/P01004
And on ArxivX
http://arxiv.org/abs/1205.1777

HLS data are available at
Conclusions

• There are 7 active HLS setups at Fermilab and DUSEL
• All are highly reliable and have taken data for years
• Most used to monitor slow ground motion
• Able to detect tides, earthquakes, and the shifting of earth
Thanks any Questions?