Construction Ground-Borne Noise & Vibration

Presenter: Don Davis, Project Executive Director
Kane Hall (UW), November 7th, 2012
Tunneling Sequence:

- 3 tunnel boring machines (TBMs) launched north to south
  - Shield rotation, excavated material removed by conveyor
  - Push forward
  - Erect tunnel liners, 5’ increments
  - Install another 33’ long segment of temporary track
- Supply trains deliver materials and liner segments
  - 33 ton locomotives, typically travel ~16 mph
  - 4 to 8 trips / hour; less when removing x-passage material
- Work schedule, three shifts – 24 hrs/day, six days/week
Cross Passage Excavation

SEM Work Sequence:

• Install propping of mined tunnel
• Dewatering, grouting ground between the tunnels as needed
• Sawcut opening in liner, two rings wide
• Excavate with small mechanized and hand tools; install temporary support incrementally
• Install waterproofing, permanent concrete passageway
Supply Train and TBM launch area

Example from UW Station staging area, first 300 feet of 2nd TBM launch
U District station – UW station
Construction Schedule

- TBM launches staggered by ~3 weeks to maintain safe separation distance
- TBM shield inspection stop at 15th Avenue NE
- Cross-passage excavation likely supported by supply train hauled muck bins
Phase 1 -
Pre-Tunnel Campus Activities (Surface)
Phase 2 – TBM Drives & Supply Train
15th Ave to STA 1225+00
(FEB – MAY 2016)
Phase 3 – Tunneling TBM Drives & Supply Train

STA 1225+00 to STA 1210+25

(MAY – AUG 2016)
# North Link UW Groundborne Noise and Vibration

## Impact Durations for TBM Tunneling Operations

<table>
<thead>
<tr>
<th>Distance from 15th Ave (ft)</th>
<th>NB Station</th>
<th>Address</th>
<th>Impact Duration (weeks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1248+00</td>
<td>15th Ave/Campus Boundary</td>
<td>24</td>
</tr>
<tr>
<td>350</td>
<td>1244+50</td>
<td>Cunningham Hall</td>
<td>22</td>
</tr>
<tr>
<td>500</td>
<td>1243+00</td>
<td>Odegaard Library</td>
<td>22</td>
</tr>
<tr>
<td>500</td>
<td>1243+00</td>
<td>Parrington Hall</td>
<td>22</td>
</tr>
<tr>
<td>800</td>
<td>1240+00</td>
<td>Kane Hall</td>
<td>20</td>
</tr>
<tr>
<td>950</td>
<td>1238+50</td>
<td>Savery Hall</td>
<td>19</td>
</tr>
<tr>
<td>1300</td>
<td>1235+00</td>
<td>Smith and Gowen Halls</td>
<td>18</td>
</tr>
<tr>
<td>1300</td>
<td>1235+00</td>
<td>Suzallo Library</td>
<td>18</td>
</tr>
<tr>
<td>1600</td>
<td>1232+00</td>
<td>Thompson Hall</td>
<td>16</td>
</tr>
<tr>
<td>1600</td>
<td>1232+00</td>
<td>Allen Library</td>
<td>16</td>
</tr>
<tr>
<td>2000</td>
<td>1228+00</td>
<td>Husky Union Building</td>
<td>14</td>
</tr>
<tr>
<td>2200</td>
<td>1226+00</td>
<td>Facilities Service Administration</td>
<td>13</td>
</tr>
<tr>
<td>2300</td>
<td>1225+00</td>
<td>Annex 1</td>
<td>13</td>
</tr>
<tr>
<td>2300</td>
<td>1255+00</td>
<td>Engineering Library</td>
<td>13</td>
</tr>
<tr>
<td>2400</td>
<td>1224+00</td>
<td>Loew Hall</td>
<td>12</td>
</tr>
<tr>
<td>2600</td>
<td>1222+00</td>
<td>Engineering Annex</td>
<td>11</td>
</tr>
<tr>
<td>2800</td>
<td>1220+00</td>
<td>Power Plant</td>
<td>10</td>
</tr>
<tr>
<td>3000</td>
<td>1218+00</td>
<td>Annex 7</td>
<td>9</td>
</tr>
<tr>
<td>3000</td>
<td>1218+00</td>
<td>More Annex</td>
<td>9</td>
</tr>
<tr>
<td>3100</td>
<td>1217+00</td>
<td>More Hall</td>
<td>9</td>
</tr>
<tr>
<td>3200</td>
<td>1216+00</td>
<td>Roberts Annex</td>
<td>8</td>
</tr>
<tr>
<td>3300</td>
<td>1215+00</td>
<td>Wilcox Hall</td>
<td>8</td>
</tr>
<tr>
<td>3700</td>
<td>1211+00</td>
<td>End - UWS TBM Extraction Pit</td>
<td>6</td>
</tr>
</tbody>
</table>

Impact Durations (weeks):
- **40 ft/day**
- **60 ft/day**
- **200 ft/week**
- **300 ft/week**
Phase 4 – Cross Passage Excavation, Lining & Tunnel Concrete

15th Ave to UWS

(AUG 2016 – APR 2017)
Predictions during Construction

- Presenter: Derek Watry, Principal
Background: U-Link Measurements

- **July 2011 – April 2012**
  - Surface vibration during U-Link tunneling measured at 7 locations in Montlake and Capitol Hill neighborhoods
  - Purpose was to collect data for UW tunnel construction vibration assessment

- **Data**
  - Collected within 200 ft. offset of tunnel centerline
  - Upper bound range of 1/3 octave band RMS vibration levels

- **Tunnel construction vibration sources included:**
  - TBM cutterhead
  - Thrust jack impacts
  - Supply trains (Supply trains on jointed track were by far the dominant vibration source)
UW Construction Prediction Methodology

- Vibration prediction for UW receivers determined from
  - Source vibration levels (Direct measurements)
  - Source/receiver propagation models

- Source vibrations:
  - Auger drilling:
    - Source assumed to be point source at the surface
    - -6 dB per doubling of distance attenuation
  - Tunnel sources: TBM Cutterhead; Thrust jacks; Supply Train
    - Surface vibration levels taken to be constant within 200 ft. offset of tunnel centerline
    - Beyond 200 ft., frequency-dependent attenuation factor calculated using soil model by C.H. Dowding (Construction Vibrations, 1996)
## Mitigation Approach

<table>
<thead>
<tr>
<th>TBM Mining</th>
<th>• None</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thrust Jacks:</td>
<td>• Specify TBM to eliminate</td>
</tr>
<tr>
<td>Tunnel Rails</td>
<td>• Uniform profile, undamaged</td>
</tr>
<tr>
<td></td>
<td>• Rail joints:</td>
</tr>
<tr>
<td></td>
<td>Staggered</td>
</tr>
<tr>
<td></td>
<td>Gaps &lt; 1/8”</td>
</tr>
<tr>
<td></td>
<td>Offset &lt; 1/16”</td>
</tr>
<tr>
<td></td>
<td>• Rail maintenance Program</td>
</tr>
<tr>
<td></td>
<td>• Rail Support:</td>
</tr>
<tr>
<td></td>
<td>Wood Ties Spaced ≤ 30” Centered</td>
</tr>
<tr>
<td>Locomotive</td>
<td>• Wheels new or reconditioned maintenance program limit speed 5-8 mph, last 2000 ft. of drive</td>
</tr>
<tr>
<td>Surface Work (Drilling)</td>
<td>• Mutually agreed schedule windows</td>
</tr>
</tbody>
</table>
Temporary rail example: U-Link
### Prediction Results

<table>
<thead>
<tr>
<th>Building</th>
<th>Offset (ft.)</th>
<th>Basement to tunnel Crown (ft.)</th>
<th>VC Curve met by Supply Trains with Mitigation (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EE/CC</td>
<td>290</td>
<td>107</td>
<td>VC-E</td>
</tr>
<tr>
<td>Wilcox</td>
<td>75</td>
<td>83</td>
<td>VC-C</td>
</tr>
<tr>
<td>Roberts</td>
<td>213</td>
<td>99</td>
<td>VC-C</td>
</tr>
<tr>
<td>More</td>
<td>89</td>
<td>100</td>
<td>VC-C</td>
</tr>
<tr>
<td>Mech Eng.</td>
<td>59</td>
<td>118</td>
<td>VC-D</td>
</tr>
<tr>
<td>Mech Eng. Annex</td>
<td>33</td>
<td>115</td>
<td>VC-D</td>
</tr>
<tr>
<td>Winkenwerder</td>
<td>660</td>
<td>72</td>
<td>VC-F</td>
</tr>
<tr>
<td>UWMC-Cyclotron</td>
<td>916</td>
<td>83</td>
<td>VC-G</td>
</tr>
</tbody>
</table>

(1) Includes effects of matched rail, tight joints, and speed limits during the final 2000 feet of tunneling.
Summary of Impacts

- MIA limit on TBM operations – 43 weeks (304 days)

- Current schedule (Tunneling @ 40’/day)
  - TBM under campus about 24 weeks

- Target Schedule (Tunneling @ 60’/day)
  - TBM under campus about 19 weeks

- 8 Sensitive Buildings are in final 1,600 Ft. of tunnel alignment
  - Speed limit enforced
  - Duration of tunneling work in this segment is 12 – 14 weeks
  - Cross-passage & tunnel concrete construction scheduled for 30 weeks after tunnel completion

- Monitoring of vibration levels
  - updated predictions based on measurements made off-campus, actual progress
PREDICTED UNMITIGATED TUNNEL CONSTRUCTION VIBRATION LEVELS AT MECHANICAL ENGINEERING BUILDING

(Refer to figure 29)
Predicted unmitigated tunnel construction vibration levels at mechanical engineering annex.

Refer to figure 30.
PREDICTED UNMITIGATED TUNNEL CONSTRUCTION VIBRATION LEVELS AT EE/CS BUILDING

(Refer to figure 22)
Wilcox Hall

PREDICTED UNMITIGATED TUNNEL CONSTRUCTION VIBRATION LEVELS AT WILCOX HALL

(Refer to figure 23)

- Supply Trains
- Thrust Jacks
- TBM Cutterhead
- Y) Wilcox - MIA levels
- 60 dBV - VC-B
More Hall

PREDICTED UNMITIGATED TUNNEL CONSTRUCTION VIBRATION LEVELS AT MORE HALL

(Refer to figure 27)
Roberts Hall

PREDICTED UNMITIGATED TUNNEL CONSTRUCTION VIBRATION LEVELS AT ROBERTS HALL

(Refer to figure 25)

- SUPPLY TRAINS
- THRUST JACKS
- TBM CUTTERHEAD
- Roberts - MIA levels
- 60 dBV - VC-B
PREDICTED UNMITIGATED TUNNEL CONSTRUCTION VIBRATION LEVELS AT WINKENWERDER HALL

(Refer to figure 12)
PREDICTED UNMITIGATED TUNNEL CONSTRUCTION VIBRATION LEVELS AT UWMC-CYCLOTRON

(Refer to figure 26)