Slow Ground Motion studies at SLAC

Snowmass 2001, July 6
Andrei Seryi
SLAC
'Slow' Ground motion at NLC and TESLA

- Diffusive or ATL motion: $\Delta x^2 \sim A_d TL$ (minutes-month)
  $(T - \text{elapsed time}, L - \text{separation between two points})$

- TESLA: Low wakes $\rightarrow$ smaller $\sigma_E \rightarrow$ smaller $\Delta \varepsilon$ ($\sim \sigma_E^2$)

<table>
<thead>
<tr>
<th>Place</th>
<th>$A$ $\mu m^2/(m.s)$</th>
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<tbody>
<tr>
<td>HERA</td>
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* Further measurements in Aurora mine, SLAC & FNAL are planned: TPAH116

TESLA: Undisruptive realignment $\sim$ every month

NLC: Undisruptive realignment $\sim$ every 5hrs

NLC: Undisruptive realignment $\sim$ every 2 days

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How to mitigate slow motion?

- Can we put more concrete into foundation and forget about slow motion? This is very unlikely:
  - we care about $L \sim \text{betatron} \lambda \sim 50\text{m}$, => would need to make strength of foundation equivalent to $\sim 50 \times 50\text{m}^2$ of soil
    - But poor foundation most probably can increase slow motion!

- Slow motion strongly depends on site and geology
  - Studies at KEK, SLAC, etc., helped to understand mechanisms and behavior of slow motion

- Careful selection of site (depth) – is a way to avoid the problem
SLAC tunnel drift studies

- **Goal:** to perform systematic studies of slow tunnel motion
- The linac alignment system working in the single Fresnel lens mode allowed submicron resolution
- First measurements of this kind were done in November 1995 by C. Adolphsen, G. Bowden and G. Mazaheri for a period of about 48hrs

**Scheme of measurements**

Signals from the quadrant photo detector were combined to determine X and Y relative motion of the tunnel center with respect to its ends.
Slow transverse relative drift of SLC tunnel

SLC tunnel deformation is correlated with atmospheric pressure

Reason: landscape and ground property vary along the linac

Motion shows diffusive or ATL character

Transverse displacement of the 3 km SLAC linac tunnel (center w. respect to ends) and atmospheric pressure.

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Tidal motion of the SLAC linac tunnel

- Observed tidal motion is ~100 times larger than expected. (N.B. the system is not sensitive to change of slope due to tides, but only to change of the curvature)
- Higher amplitudes are caused by enhancement of tides due to ocean loading in vicinity (~500km) of the shoreline.
- Tidal motion is slow, predictable, it has long wavelength and is not a serious problem for a collider.
Influence of atmospheric pressure

Very slow variation of external atmospheric pressure result in tunnel deformation. Explanations: landscape and ground property variations along the linac:

\[ \Delta h \approx \frac{\Delta P}{E} \frac{h}{E} \frac{\Delta E}{E} \]

Observed \( \Delta h = 50 \mu m \) for \( \Delta P = 1000 \) Pa is consistent with these estimations if \( \Delta E/E \sim 0.5 \), \( h \sim \lambda \sim 100 \) m, \( \alpha \sim 0.5 \) and \( E \sim 10^9 \) Pa.

Assumption \( E \sim 10^9 \) Pa is consistent with SLAC correlation measurements.

\[ v \approx \sqrt{\frac{E}{2 \rho (1 + \nu)}} \]

Taking \( v = 500 \) m/s (at \( \sim 5 \) Hz, i.e. \( \lambda \sim 100 \) m) and \( \rho = 2 \times 10^3 \) kg/m\(^3\), we get \( E = 10^9 \) Pa.
Tunnel motion. Diffusive in time

- Spectra of tunnel displacements behave as $1/\omega^2$ in wide frequency range, as for the ATL law for which $P(\omega, k) = A/(\omega^2 k^2)$

Electronic noise of the measuring system was evaluated with a light diode fixed directly to quadrant photo detector.
Parameter A found in 1999/2000 SLAC measurements.

- Fit of the spectra to ATL gives $A \approx 10^{-7} - 2 \times 10^{-6} \mu m^2/m/s$
- "A" is higher for vertical plane.
- The value "A" varies in time. Why?
- The "A" value is consistent with FFTB measurements with stretched wire over 30 m distance
Atmosphere causes “A” of ATL to vary in shallow tunnel

- Parameter $A_d$ of ATL correlates with amplitude of atmospheric pressure variation.

- For shallow tunnel, the atmospheric contribution to $A_d$ scales as $1 / E^2$, (or as $1 / v^4$, $v$ - shear velocity) => need strong ground!

- For deep tunnel, the atmospheric contribution to $A_d$ vanish.

“A” vs amplitude of atmospheric pressure spectrum $A_p$ (which behaves as $A_p / \omega^2$)
Observation of earthquakes

- Only two earthquakes detected in 3 days
- Ratio of observed absolute to relative motion is consistent with phase velocity 2.5km/s
- I.e. small earthquakes produce smooth deformation

Displacement of the tunnel and displacement measured by STS-2 seismometer during remote earthquake started January 6, 2000 at 02:49:00 local time (supposedly corresponds to 5.8MS earthquake at Alaska happened at 10:42:27 UTC). A passband filter 0.02-0.08Hz has been applied to the data.
'Slow' Diffusive Ground motion vs location

- Diffusive or ATL motion: $\Delta X^2 \sim A_T L$ (minutes-month)  
  ($T$ - elapsed time, $L$ - separation between two points)

<table>
<thead>
<tr>
<th>Place</th>
<th>$A$ $\mu m^2/(m.s)$</th>
<th>method</th>
<th>$\sim T,L$</th>
<th>geology</th>
</tr>
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<tr>
<td>HERA</td>
<td>$\sim 10^{-5}$</td>
<td>HERA beam</td>
<td>Hrs-month;30m</td>
<td>Glacial till</td>
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<td>SLAC*</td>
<td>$\sim 5\times 10^{-7}$</td>
<td>stretched wire; laser alignment system</td>
<td>Min-hrs;30m Min-days;1500m</td>
<td>Sandstone; cut and cover</td>
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<td>Esashi mine</td>
<td>$2\times 10^{-9}$</td>
<td>single tube HLS</td>
<td>Min-days;10-100m</td>
<td>Granite, TBM</td>
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* Further measurements in Aurora mine, SLAC & FNAL are planned with better HLS system

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**Diffusive Ground motion in Japan**

[S. Takeda, KEK-99-135]
range ~10-100m, min-days

<table>
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<tr>
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<th>tunneling</th>
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<tr>
<td>Tunnel of KEKB</td>
<td>$4 \times 10^{-5}$</td>
<td>Sediment</td>
<td></td>
</tr>
<tr>
<td>Kamaishi II-III</td>
<td>$1.4 \times 10^{-7}$</td>
<td>granite</td>
<td>Slow blasting</td>
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<td>granite</td>
<td>drilling</td>
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<td>Esashi No.2</td>
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“Stability time” between beam-based realignments of a colliders ~1/A
Very slow (year-to-year) motion

- **Year-to-year** motion observed in tunnels seem to be **systematic** (~linear in time). SLAC, LEP, etc., as found by Rainer Pitthan

- Settlement (SLAC); underground water (LEP)

- Extrapolation of ATL parameter “A” from year-to-year measurements to minute-hour time scale is **invalid** and result in **overestimation** of “A”.
Systematic motion of SLAC linac shallow tunnel in 1966-1983

- Year-to-year motion is dominated by systematic component
- Settlement
- Homogeneity of soil is important, but hard to achieve

Vertical displacement of SLAC linac for 17 years

[G.Fischer, M.Mayond 1988]
Example: Systematic motion at LEP
Difference of position of neighboring quads

Slow motion (minutes - years) summary

- **Diffusive or ATL motion:** \( \Delta X^2 \sim ATL \) (minutes-month)

- **Observed 'A' varies by \( \sim 5 \) orders:** \( 10^{-9} \) to \( 10^{-4} \) \( \mu m^2/(m.s) \)
  - in some cases due to inappropriate interpretation of year-to-year motion as diffusive rather than systematic
  - parameter 'A' should strongly depend on geology -- reason for the large range
  - 'A' reported to depend on tunnel construction method: blasting/TBM [Shigeru Takeda]

- **Systematic motion [R.Pitthan]:** \( \sim \)linear in time (month-years)

- **In some cases can be described as ATTL law:**
  - SLAC 17 years motion suggests \( \Delta X^2 = A_s T^2 L \) with \( A_s \sim 4 \times 10^{-12} \) \( \mu m^2/(m.s^2) \) for early SLAC
Slow motion questions and recommendations

- Reasons for slow motion
- Dependence on geology, tunneling
- Dependence of slow motion on T, L, regions of validity of models

- **Geology:** good hard rock is preferable
  - => slow motion has lower amplitude
  - => collider stability time is larger

- **Tunneling:**
  - => TBM preferable; avoid blasting