NLC Ground Motion Characterization Program

At
SLAC

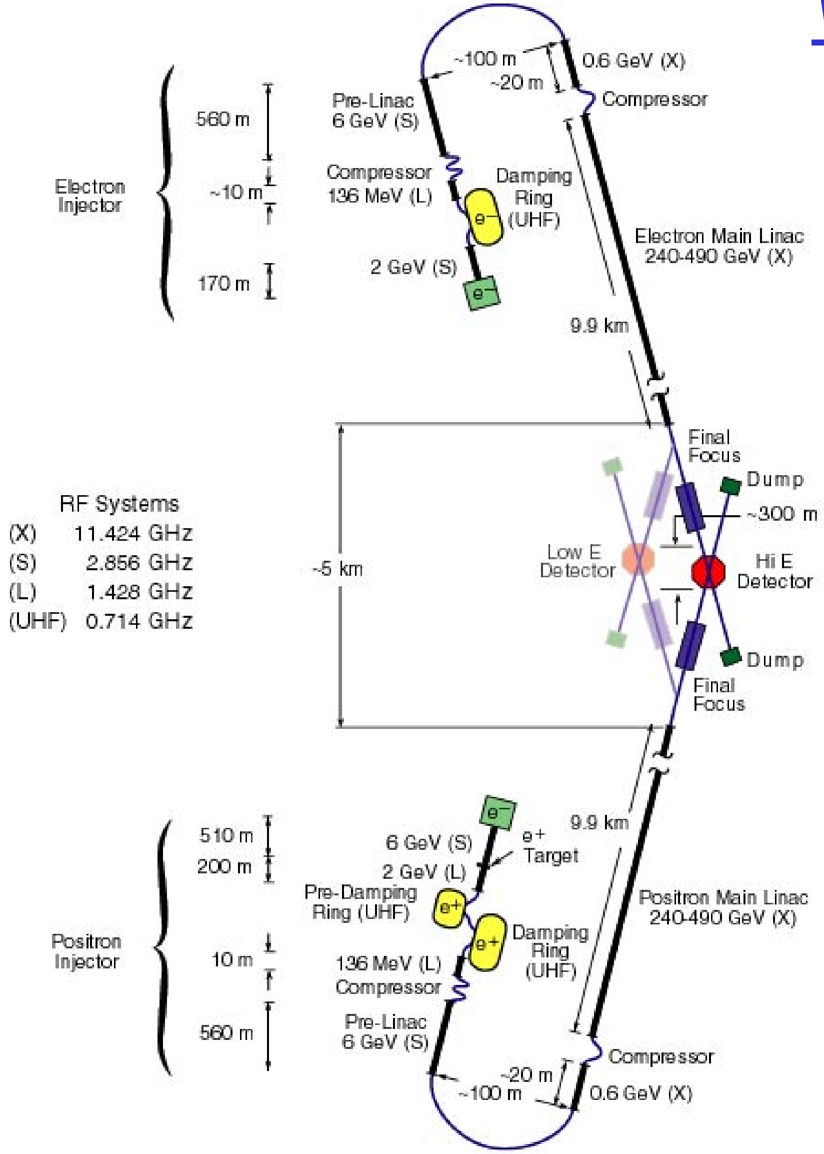
Topics Presented

Introduction

- *What, Why, Where, and How*

- Sites vibration Characterization
  - *At Site –127 CA*
  - *At Site –135 CA*
- Characterization of Vibration sources (*Site –135 CA*)
- Ground vibration characterization program at SLAC
  - *Field vibration measurement at SLAC*
  - *Planned field vibration measurement in parallel tunnel*
- Conclusions

What

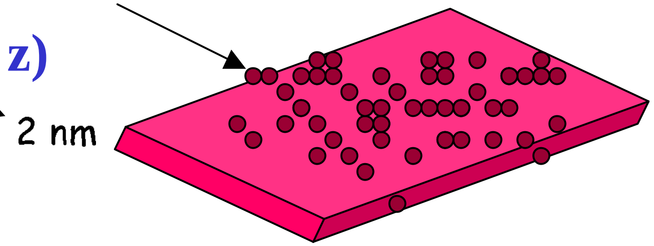


- Task is to design, build and operate a facility (NLC) with a footprint of About 30 km long and one km wide Including several buildings, each size a football field.
- General layout
  - Injectors produce electron and positron beams
  - Linac accelerates the beams to 500GeV energy
  - Final focus focuses beams to a tiny spot in a collision point
  - Detector detects products of collisions and determine their properties

Why do we care about Ground Motion

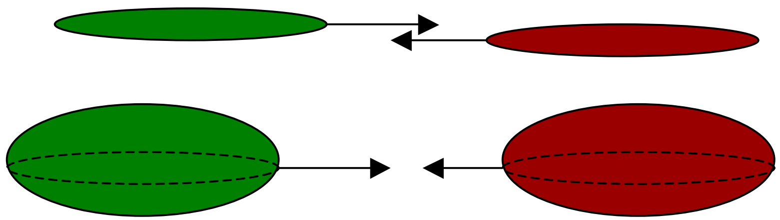
- **NLC will collide beams (swarm) of electrons and positrons**
- **To increase probability of direct collisions of e^+e^- , beam sizes must be very small**
- **NLC beam sizes just before collision; 200 * 2 * 100000 nanometers**

(x y z)



Vertical size (y) is smallest (2nm)

- **Ground Motion** and imported vibrations continuously misalign components of a collider and can result in
  - **Off-set at IP**
  - **Emittance growth**

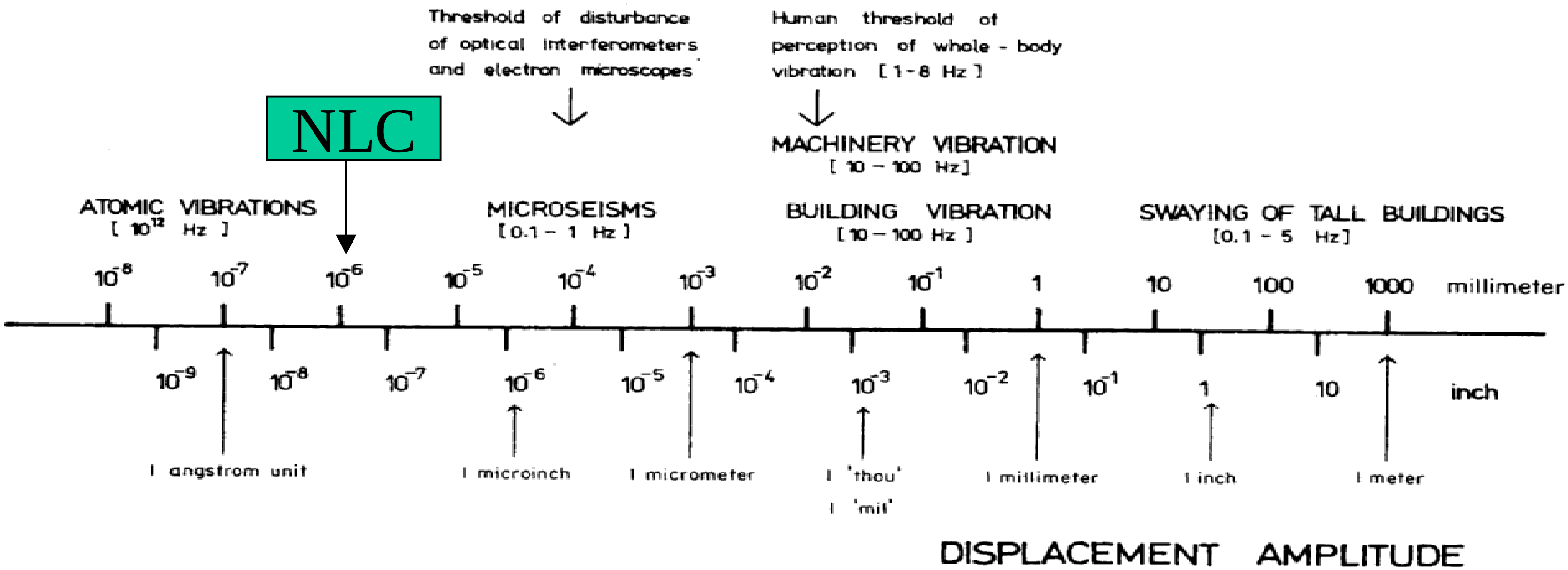


- **Goal:**

  To achieve stability of within a few nanometer above a few Hertz at the most critical region (Interaction Point).

- **Perspective:**

  Figure below, shows range of natural and man-made vibration.



Purpose of Ground Motion characterization is to estimate

vibration (e.g. frequency content, amplitude) caused by far-field and near-field sources at the Technical Foundation; denotes *where* sensitive equipment is mounted.

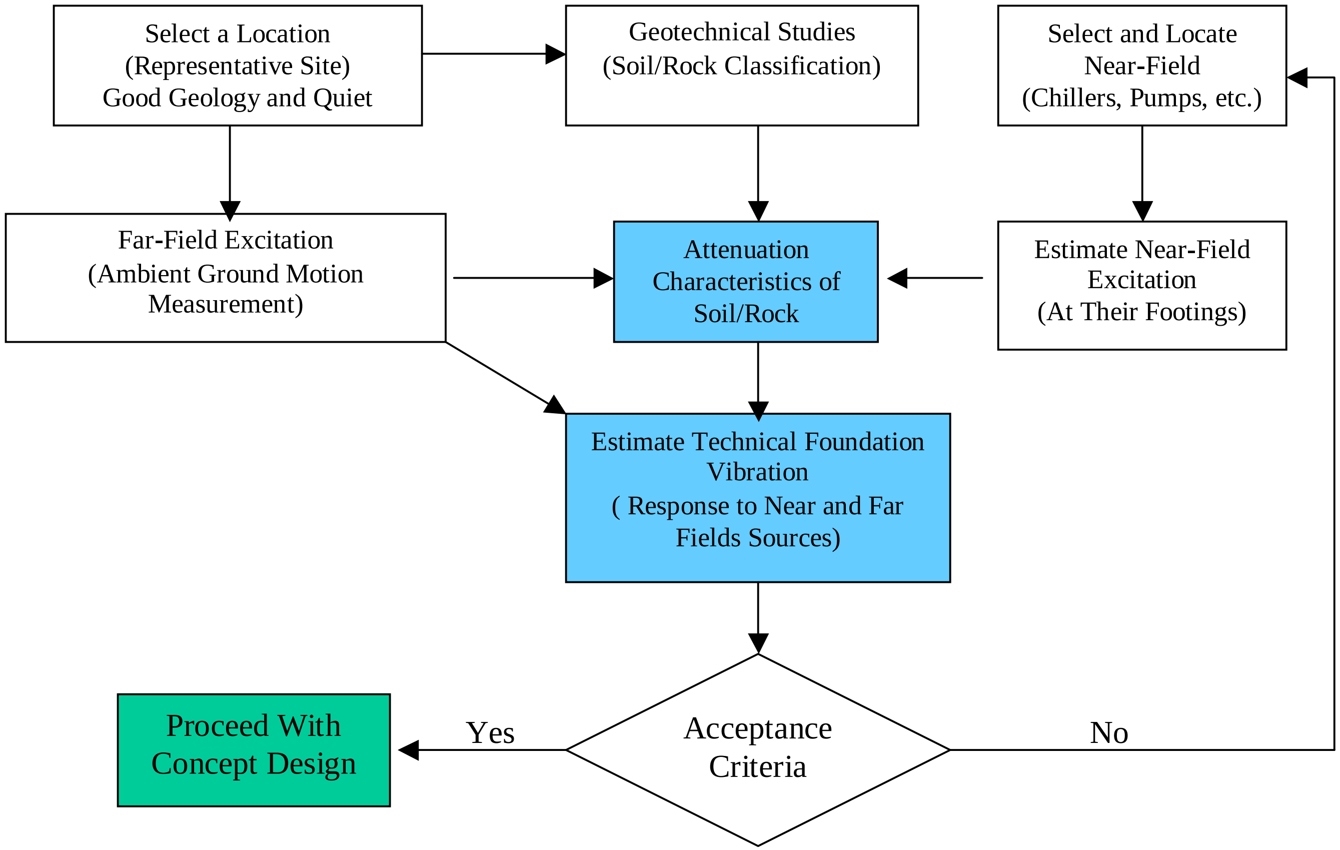
Near-field sources, Associated with compressors, HVAC equipment, pumps, fans, etc.

Far-field sources, Ground motion due to natural and cultural sources, site specifics

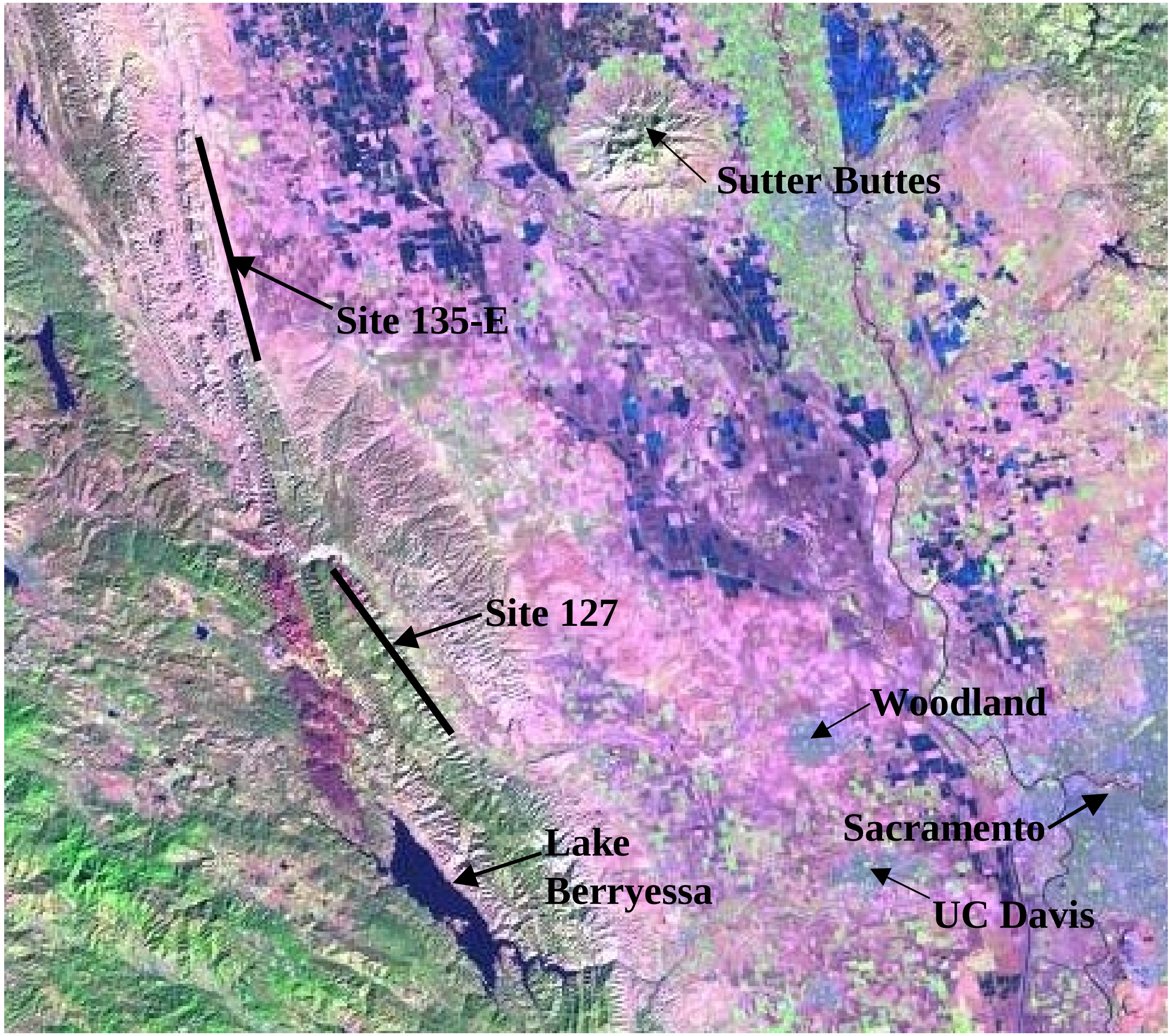
- Excitation of Technical foundation is influenced primarily by transmission properties of the soil.
- Because of the inhomogeneity and discontinuity of the soil an *estimate its transmission mechanisms are very complicated.*
- *By means of in-situ measurements and 3-D soil dynamic modeling, the reliability of such estimate can be greatly improved*.

Approach at pre-concept level

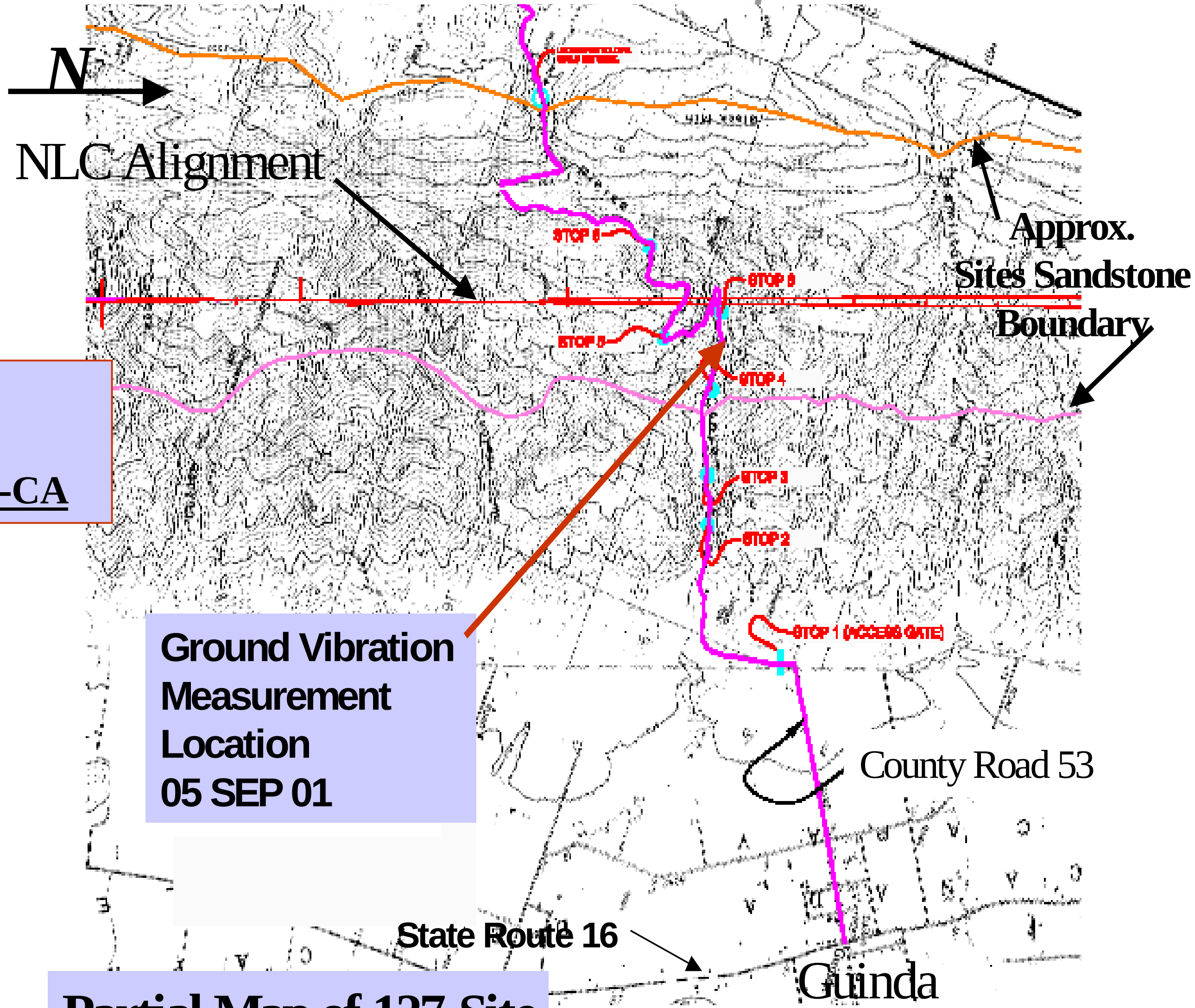
How



Northern California Representative Sites



Map showing location of ground vibration measurements at Site-127-CA



Partial Map of 127-Site

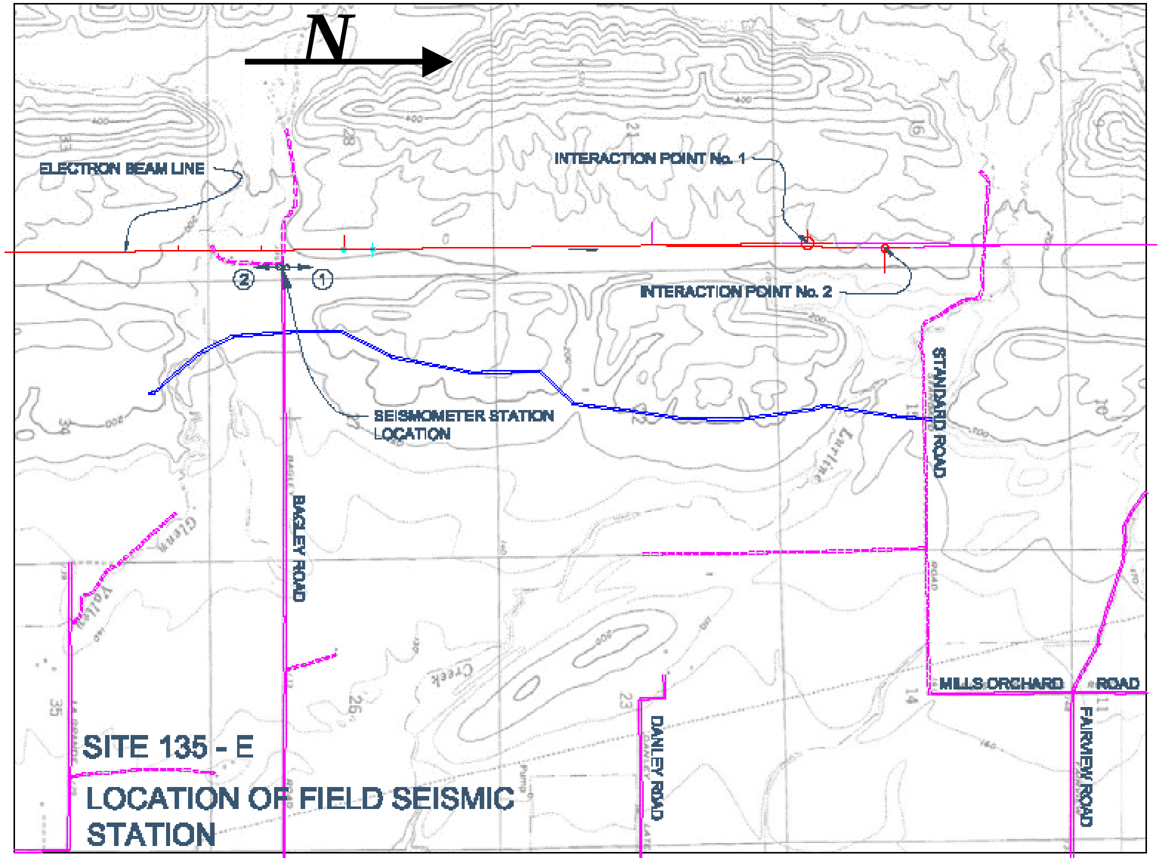
Picture showing Sites Sandstone formation near the measuring spot at CA-127 site

Probes were placed on the concrete bed at the measuring spot, then they were covered with a shielding enclosure.

Next Linear Collider – U.S. Collaboration

SLAC – FNAL – LBNL - LLNL

ICFA Nanobeams 02– Workshop Sessions 3

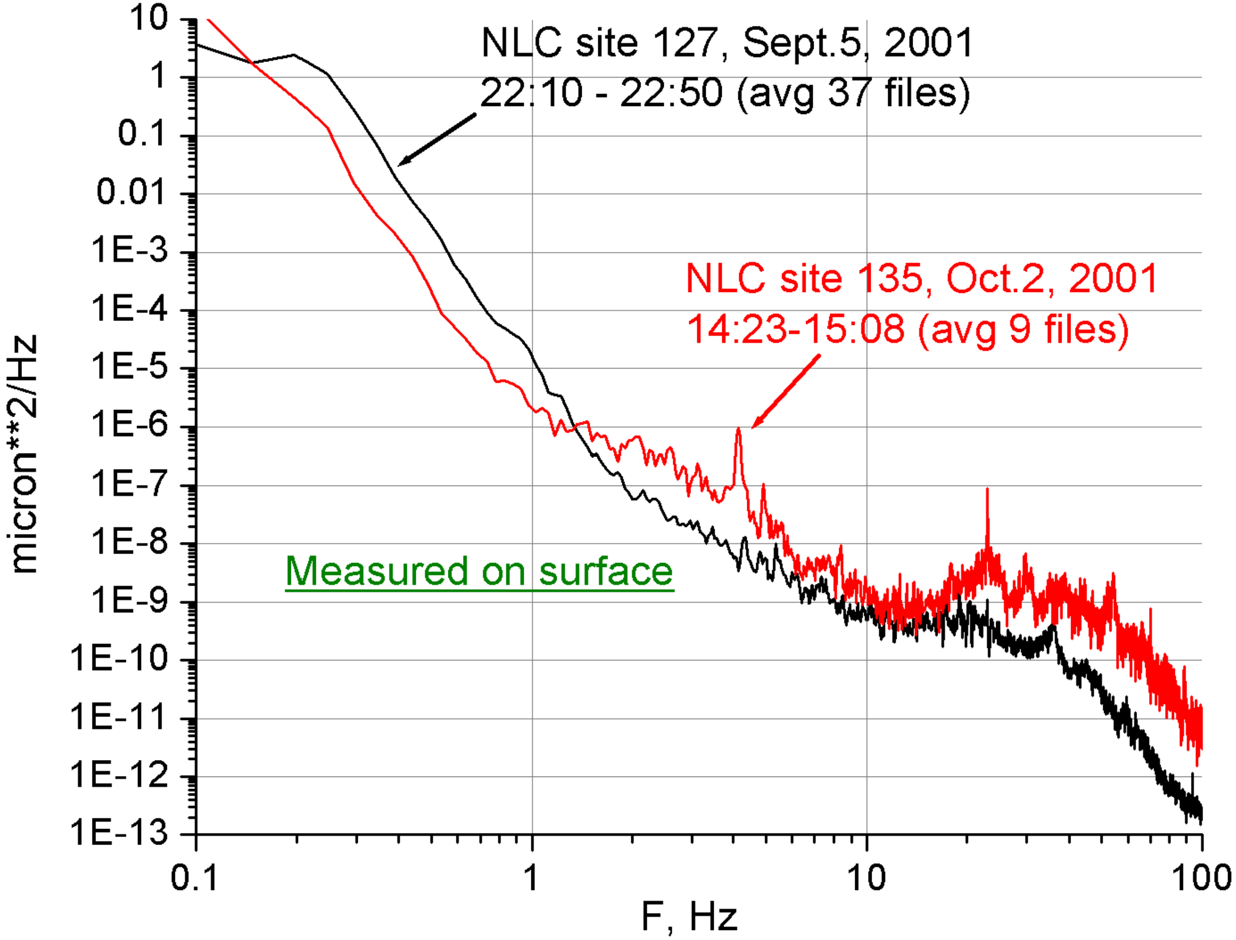


Map showing location of ground vibration measurements at Site-135-E in CA

View to the south along the future alignment of Site-135-E, taken at the end of Bagley road

View to the north along the future alignment of Site-135-E, taken at the end of Bagley road

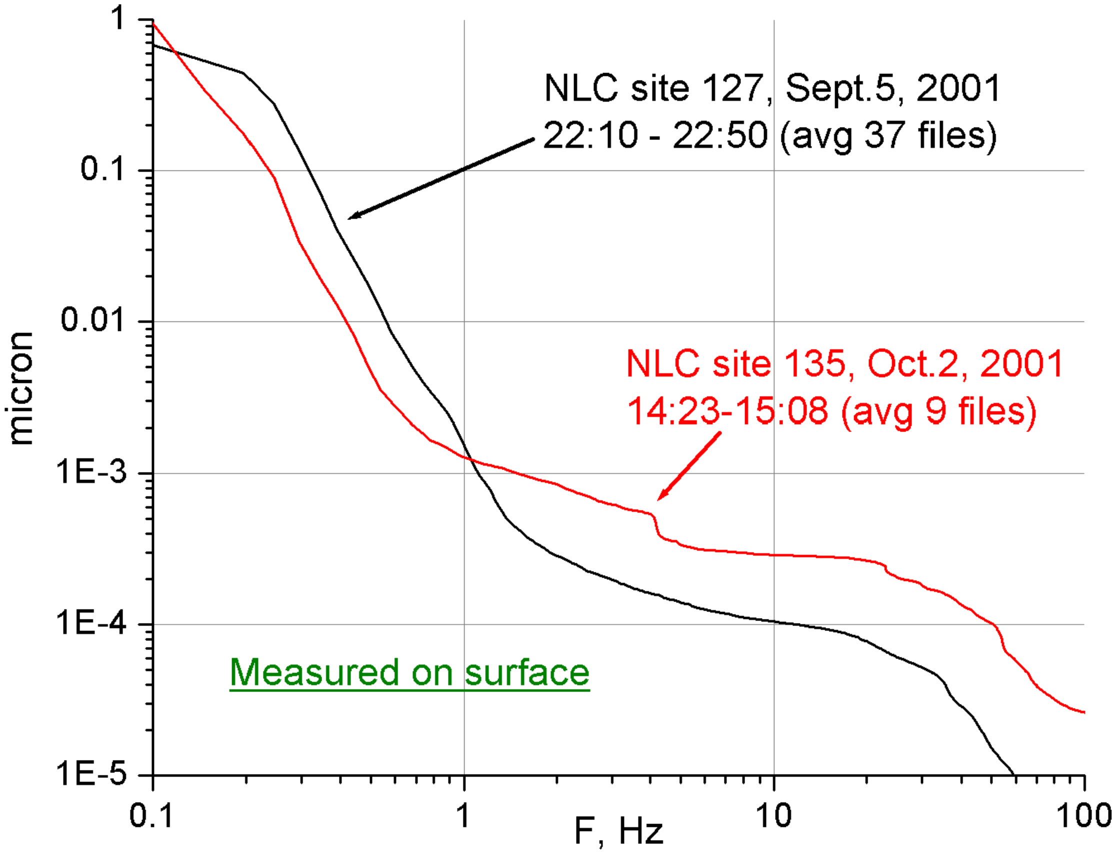
ICFA Nanobeams 02– Workshop Sessions 3



Power displacement spectrum measured at the west spot at site –135-E , as compared with data from site-127

ICFA Nanobeams 02– Workshop Sessions 3

- The noise level measured on surface is quite low
- No significant cultural noise was found
- However, if we are not care-full will be our own worst enemy
- We are the major importer of vibration and Noise



Displacement spectrum measured at the west spot at site –135-E , as compared with data from site-127

Summary for NLC 2001:

Electron : 12 access+ 33 utility+ 29 access to KG

Positron : 13 access+ 33 utility+ 30 access to KG

IR-1& IR-2 Hall: 2 access+ 2 utility

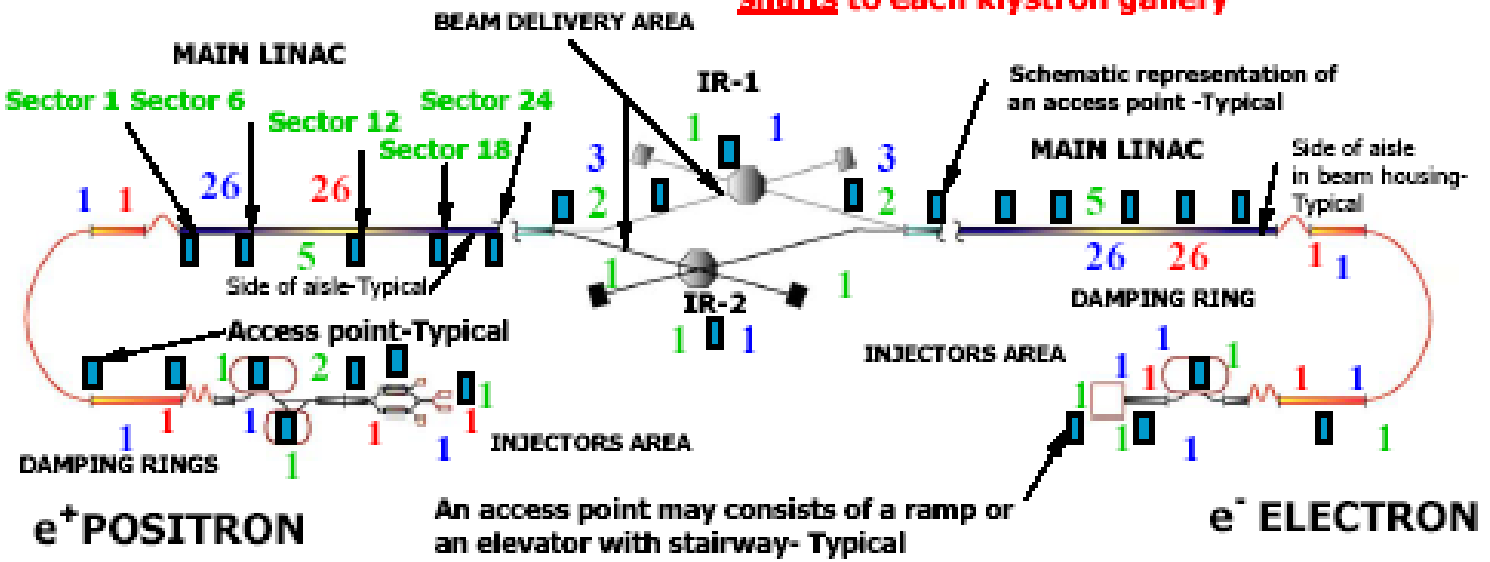
Total : 27 access+ 68 utility+ 59 access to KG

Legend:

Green figures indicate the number of access shafts or ramps(people/equipment) to Beam Housing

Blue figures indicate the number of utility shafts or ramps (mechanical equipment pads)

Red figures indicate the number of access (people/equipment) ramps or shafts to each klystron gallery



Schematic sketch Not to Scale

Subject to review

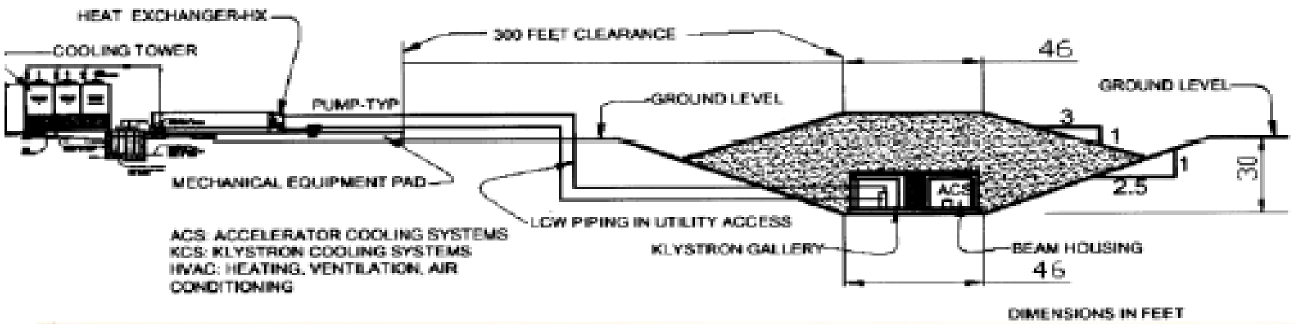
Klystron galleries are provided in the last 13 sectors of each main linac

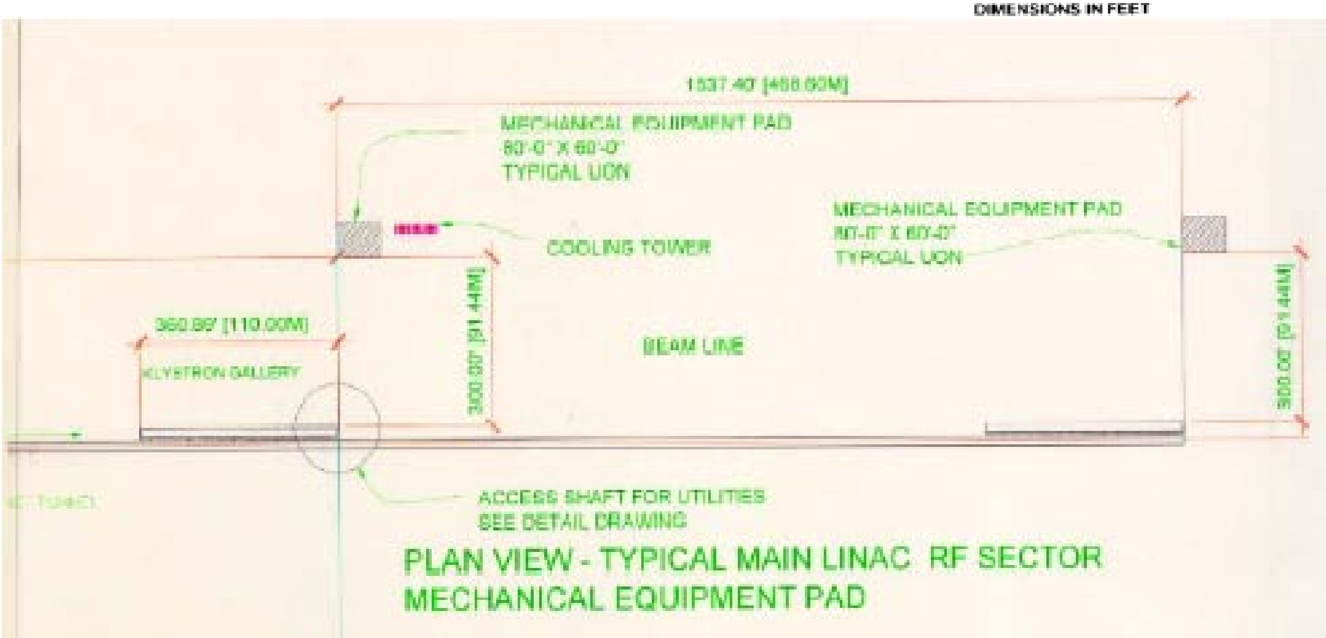
June 19, 2001

Conventional Facilities

Compiled by: J Sevilla

ICFA Nanobeams 02– Workshop Sessions 3





ICFA Nanobeams 02– Workshop Sessions 3

AREA:
Typical RF sector Main Linac

Mechanical equipment pad
ID NAME: EMLMEP-1 TO 13
Model: 500Gev, 120 Hz, NLC 2001

Equipment name/description	Quantity	Individual equipment weight LBS	Total equipment weight LBS	Rotating speed RPM	Rotating Part
<u>Equipment in Mechanical equipment pad</u>					
Beam Related systems					
LCW KLYSTRON GALLERY PUMP[1]	1	2606	2606	3600	Pump impeller and motor
LCW BEAM HOUSING PUMP[1]	1	1452	1452	3600	Pump impeller and motor
COOLING TOWER FAN[2]	2	740	1480	1800	Blades and motor
COOLING TOWER PUMPS	2	1560	3120	1800	Pump impeller and motor
Non-Beam Related systems					
CHILLED WATER PUMP	1	658	658	3600	Pump impeller and motor
CHILLERS (WATER COOLED)	1	4352	4352	1800	Compressor
Sub-total			13,670		
<u>Equipment in klystron gallery area</u>					
DRAIN SUMP PUMP	3	422	1266	1800	Pump impeller and motor
VENTILATING FANS(Utility Shafts)[3]	2	1705	3410	1014	Fan blades and motor
AIR HANDLER UNIT (Racks Alcove)[4]	2	240	480	1080	Fan blades and motor
AIR HANDLER UNITS (Kly Gallery)[4]	2	280	560	1080	Fan blades and motor
Sub-total			5,716		
Total pieces of equipment	17	-----	19,386		

-The chiller rotating equipment rotating speed is 3600 RPM (60Hz).

-The chiller equipment weighs 21,400 pounds.

-If a limit of 0.1 g is met at rotating equipment, the inertia force on skid is about 2,140 lb.

-The chiller equipment mounted on a spring isolated skid.

Generally, they have a natural frequency in the range of 4 Hz to 6 Hz which corresponds to; a reduction factor of about 1%.

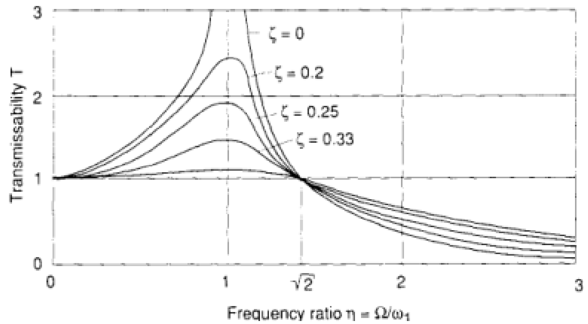
Thus, one percent of this force is transmitted to chiller equipment foundation.

Vibration Isolation (Transmissibility)

The magnitude of the force transmitted to the ground ; $\hat{F}_g = c\dot{x} + kx$

The transmissibility T, is defined as

$$T = \frac{\hat{F}_g}{\hat{F}} = \left[\frac{1+4\zeta^2\eta^2}{(1-\eta^2)^2+4\zeta^2\eta^2}\right]^{1/2}$$



Transmissibility of an isolator as a function of frequency ratio

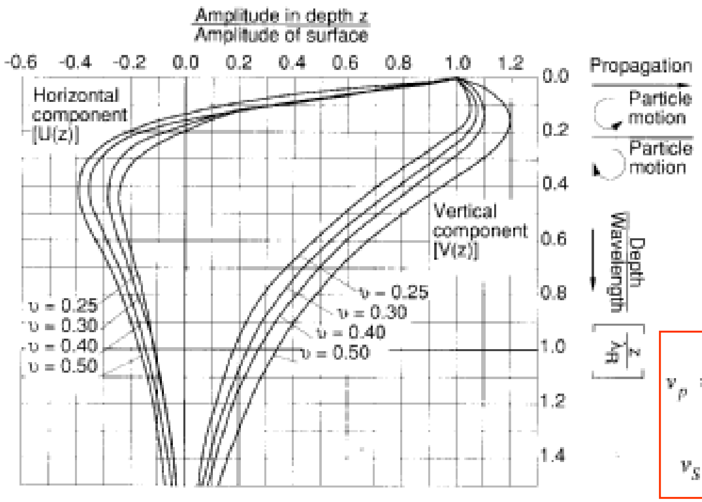
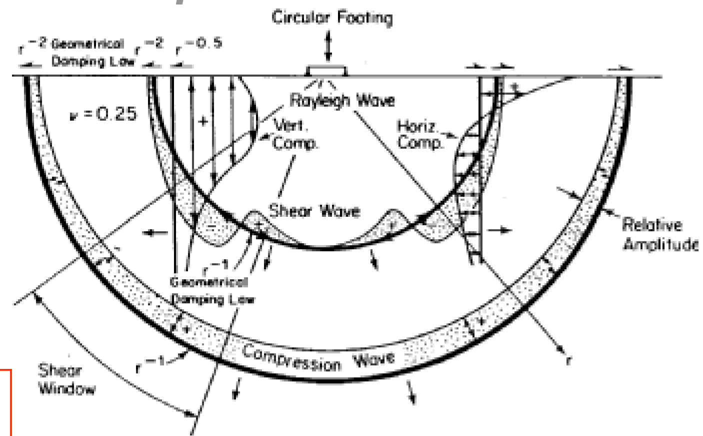


Figure E.2: Relation between amplitude ratio and dimensionless depth for Rayleigh waves with ν as parameter

$$v_p = \sqrt{\frac{(\lambda + 2\mu)}{\rho}} = \sqrt{\frac{E(1-\nu)}{\rho(1+\nu)(1-2\nu)}}$$

$$v_S = \sqrt{\mu/\rho} = \sqrt{\frac{E}{2\rho(1+\nu)}} = \sqrt{G/\rho}$$



Wave Type	Per Cent of Total Energy
Rayleigh	67
Shear	26
Compression	7

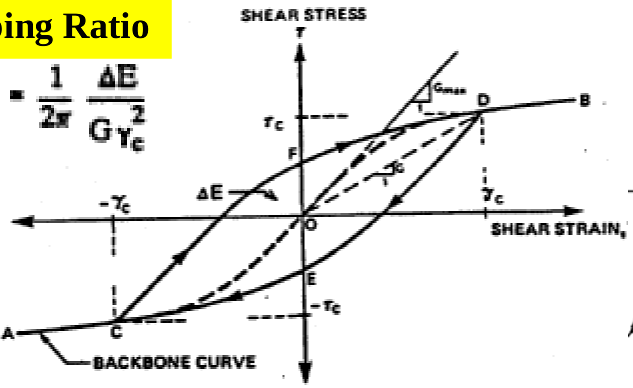
Figure 3-16. Distribution of displacement waves from a circular footing on a homogeneous, isotropic, elastic half-space (*from Woods, 1968*).

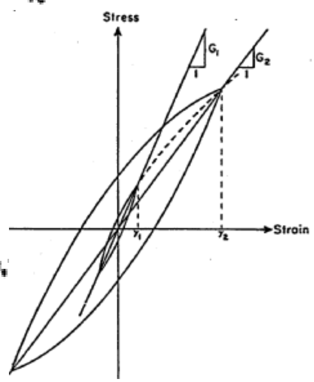
Dynamic Shear Modulus : $G = \frac{\tau_c}{\gamma_c}$

where τ_c = the cyclic stress amplitude corresponding to the strain amplitude γ_c

Soil Damping Ratio

$$\lambda = \frac{1}{2\pi}\frac{\Delta E}{G\gamma_c^2}$$





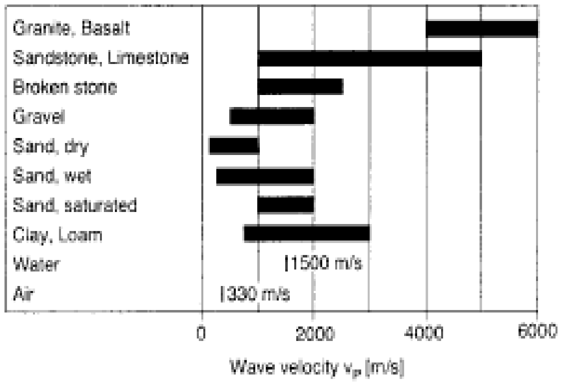
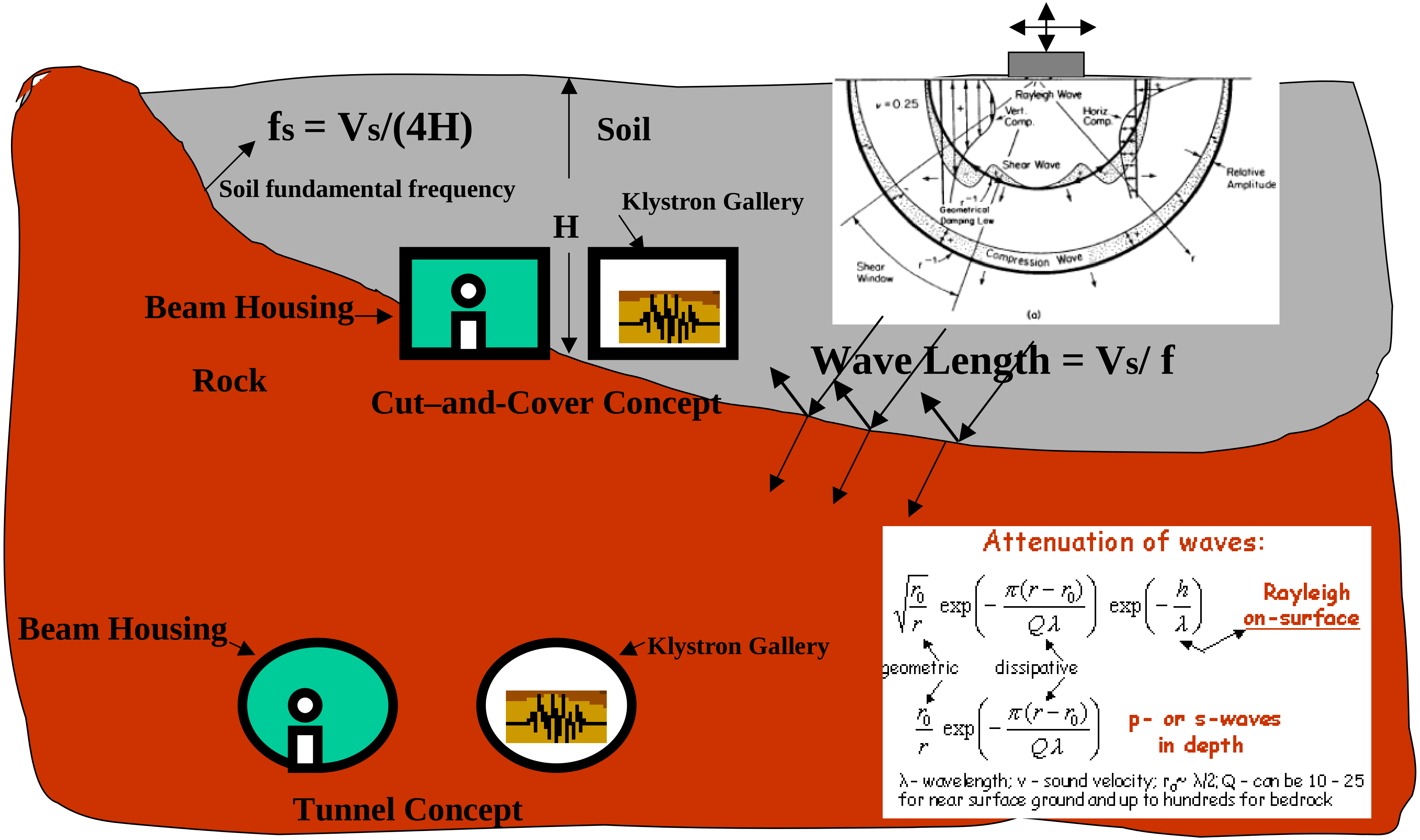


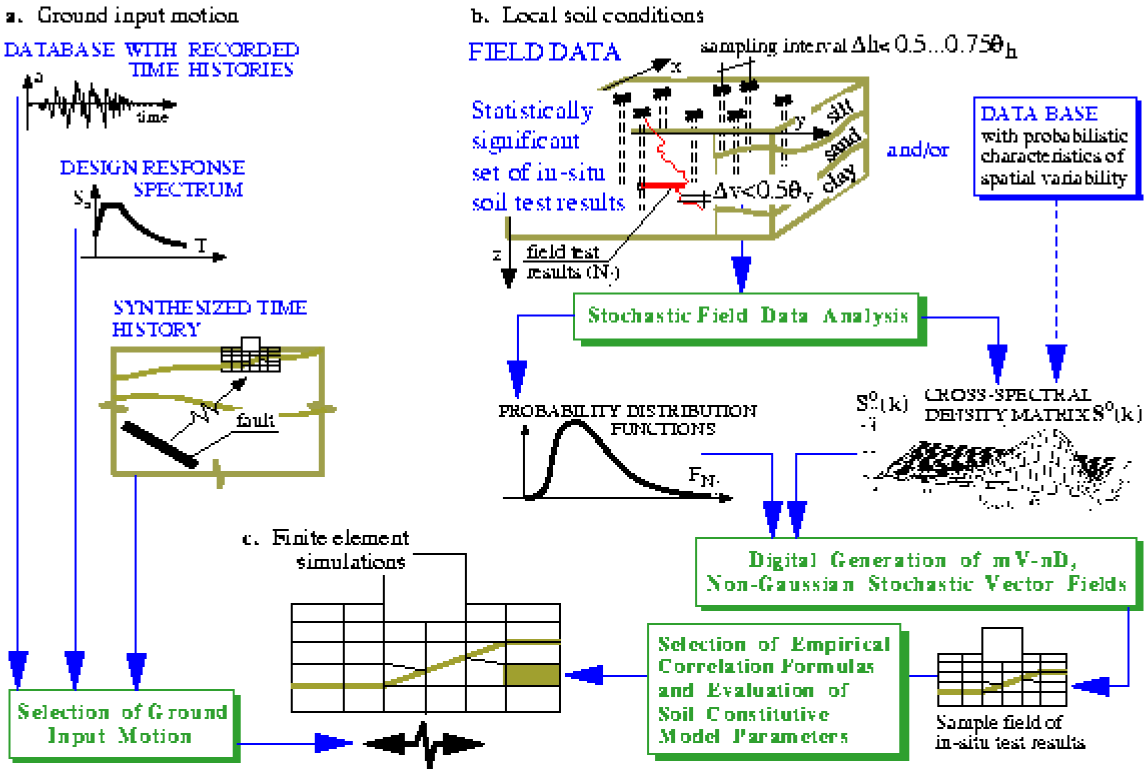
Figure E.3: Typical velocities of compression waves (P-waves) for rocks and soils



fs = Vs/(4H)
Soil fundamental frequency
Soil
H
Klystron Gallery
Beam Housing
Rock
Cut–and-Cover Concept
ν = 0.25
Rayleigh Wave
Vert. Comp.
Horiz. Comp.
Shear Wave
Relative Amplitude
Geometrical Damping Law
Compression Wave
Shear Window
(a)
Wave Length = Vs/ f
Beam Housing
Klystron Gallery
Tunnel Concept
Attenuation of waves:
$\sqrt{\frac{r_0}{r}} \exp\left(-\frac{\pi(r-r_0)}{Q\lambda}\right) \exp\left(-\frac{h}{\lambda}\right)$
Rayleigh on-surface
geometric
dissipative
$\frac{r_0}{r} \exp\left(-\frac{\pi(r-r_0)}{Q\lambda}\right)$
p- or s-waves in depth
λ - wavelength; v - sound velocity; r_0~ λ/2; Q - can be 10 - 25 for near surface ground and up to hundreds for bedrock

Goal; In collaboration with Nick Simos of BNL

- **to utilize an integrated procedure used for 3-D modeling and dynamic soil analysis of Fault-Soil-Structure interaction.**
- **to generate ground motion and spatial distribution of soil properties using spectral representation based procedure.**
- **to assess the response of technical foundation from near and far field sources.**



Field Vibration Measurement Program Why

- Experts say the 3-D modeling and analysis is :

  fancy, expensive and complex
- However, if benchmarked with reliable filed measurements it will be a great tool to assess vibration response due to source changes in ; planning, design and construction phase
- NLC Site Investigation plan for FY03 is:
  - To prepare an accurate and consistent cost comparison of all NLC representative sites (3-IL, 2-CA)
  - To identify the cost "delta" for cut-and-cover vs. tunneling construction methods for 2-CA sites (CA-135 vs. CA-127)
- Trade-Off; Tunnel Provides a More Stable and or Quiet Environment over the cut-and-cover (Insufficient data available to compare)
- Trade-Study; Perform Vibration Measurement in a Parallel Tunnel as well as for cut-and-cover

Field Vibration Measurement at SLAC Status

- Selected Sector 9 and 10 along the SLAC accelerator housing for the field measurement
  - Geological conditions at Sector 9 &10:

    Eocene sandstone and claystone (shear velocity of 720 m/sec)
  - Geological conditions at CA-135 site:

    Site Formation, sandstone with claystone (shear velocity > 760 m/sec)
- Retained services of a firm expert in field of vibration measurements.

  Colin Gordon and Associates of San Bruno, CA
- Performed Field ground measurement at Sect. 9 at SLAC on 7Aug. 02.
- Received the first draft of vibration measurement report on 27 Aug. 02.
  - Following slides are an overview of the report.

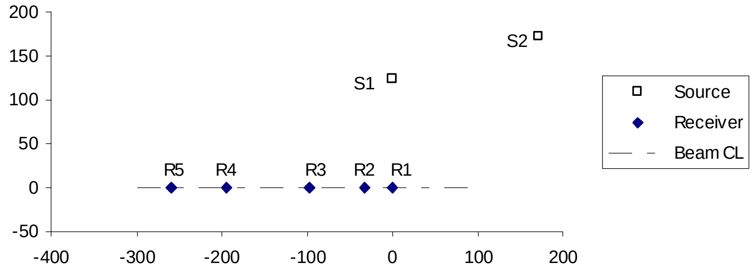
Planned Vibration Measurement Program

- Perform vibration measurement in cut-and-cover and parallel tunnel constructed with a similar configuration and in a similar geological formation as proposed for CA-135 and CA-127 sites, respectively
- To obtain relevant data associated with:
  - Transmission of vibration from the surface to the tunnel floor for cut and cover and parallel tunnel construction
  - Vibration transmission from a parallel tunnel at the same depth to the adjacent tunnel as well as along the tunnel
    - *Establish the Transfer Function (Frequency Response Function or FRF) between the "source" and the "receiver" for each case*
    - *Use the data for benchmarking of 3-D soil dynamic modeling program*

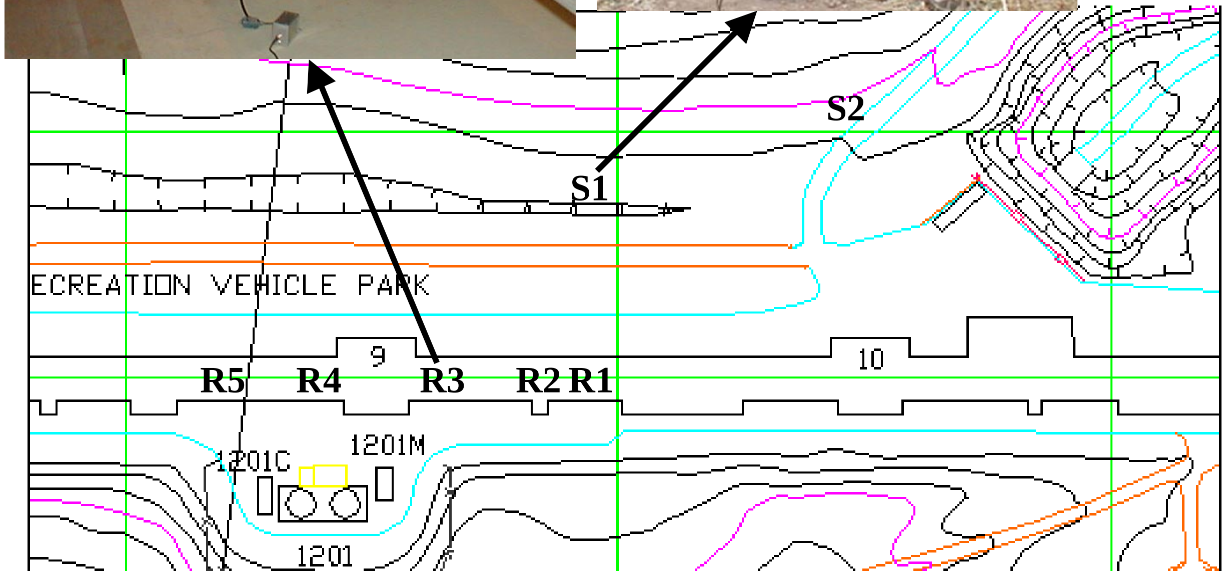
Next Linear Collider – U.S. Collaboration

SLAC – FNAL – LBNL - LLNL

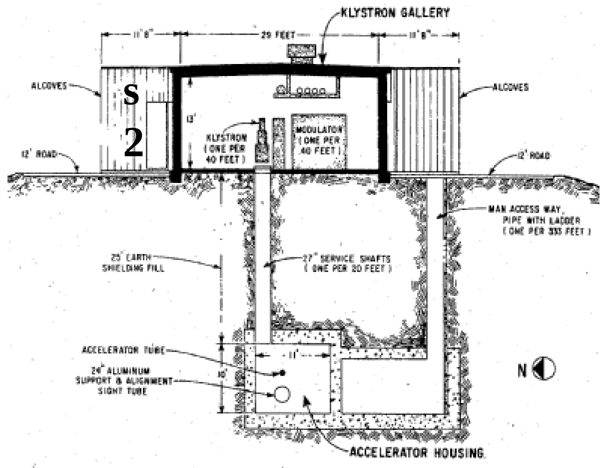
ICFA Nanobeams 02– Workshop Sessions 3



Location Plan View of Sources S# and Receptors R#



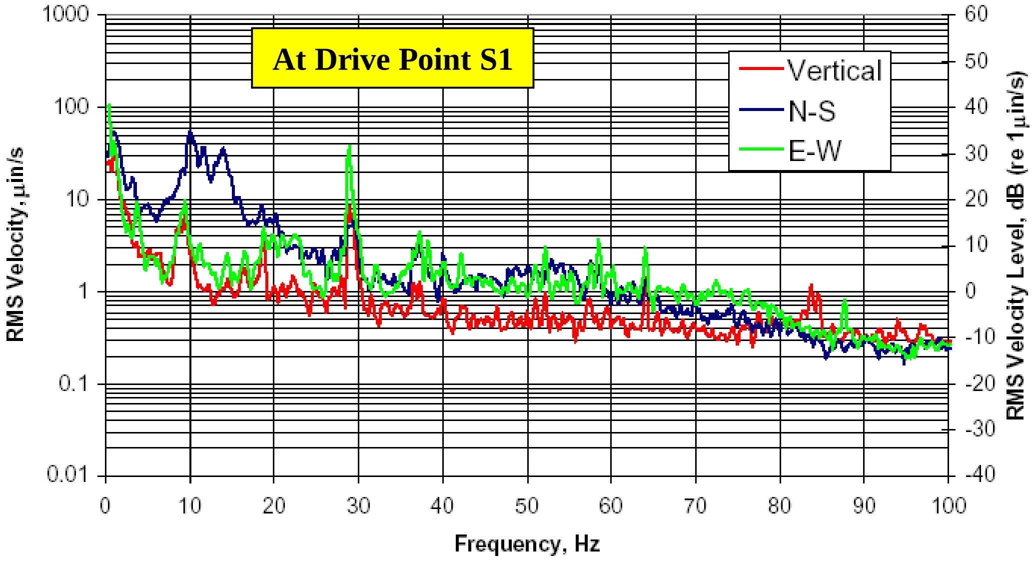
Plan Layout of Sector 9 and 10 at SLAC

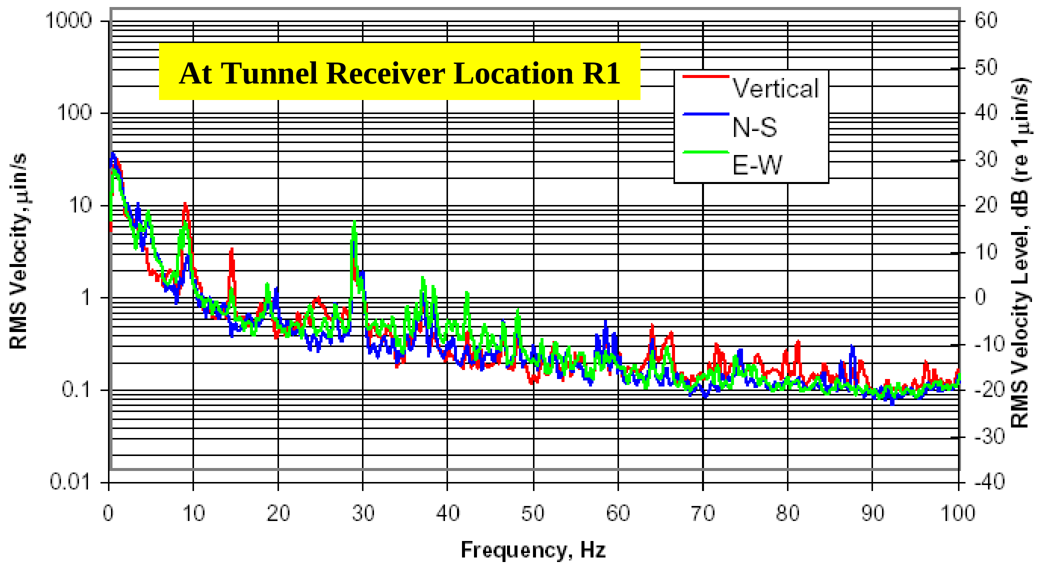


Typical Cross Section of Accelerator Housing and Klystron Gallery at SLAC

ICFA Nanobeams 02– Workshop Sessions 3

Ambient Vibrations at Drive Point S1 and Receiver Location R1 Taken on 7August 2002





ICFA Nanobeams 02– Workshop Sessions 3

Figure 5: Ground Transmission - SLAC Cut-and-Cover Tunnel - 7 Aug 2002
Drive-Point Mobility at S1

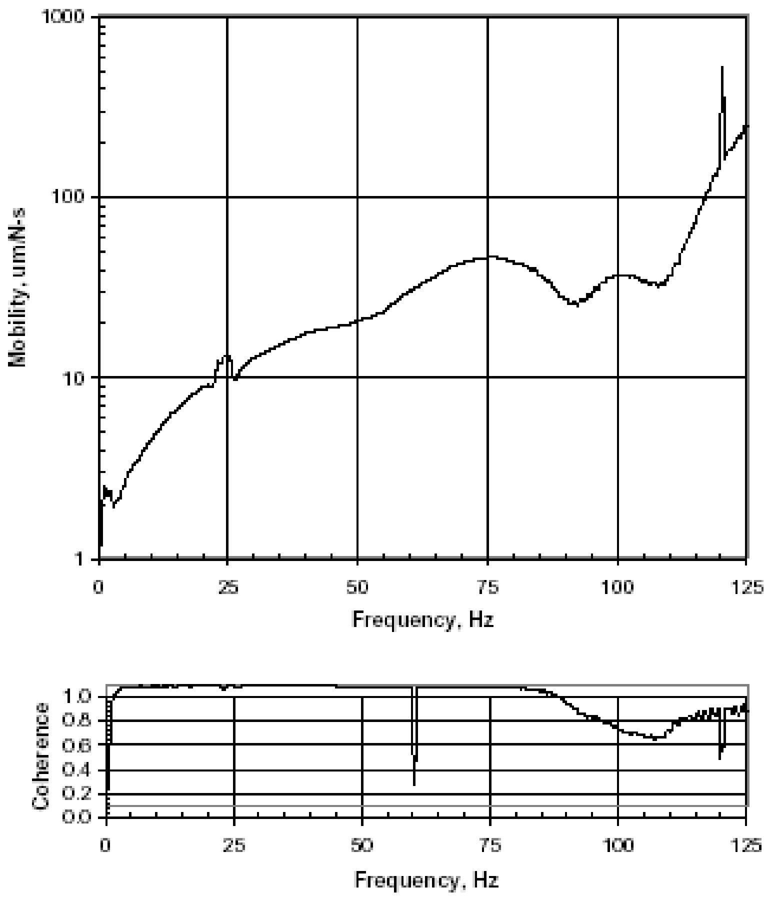
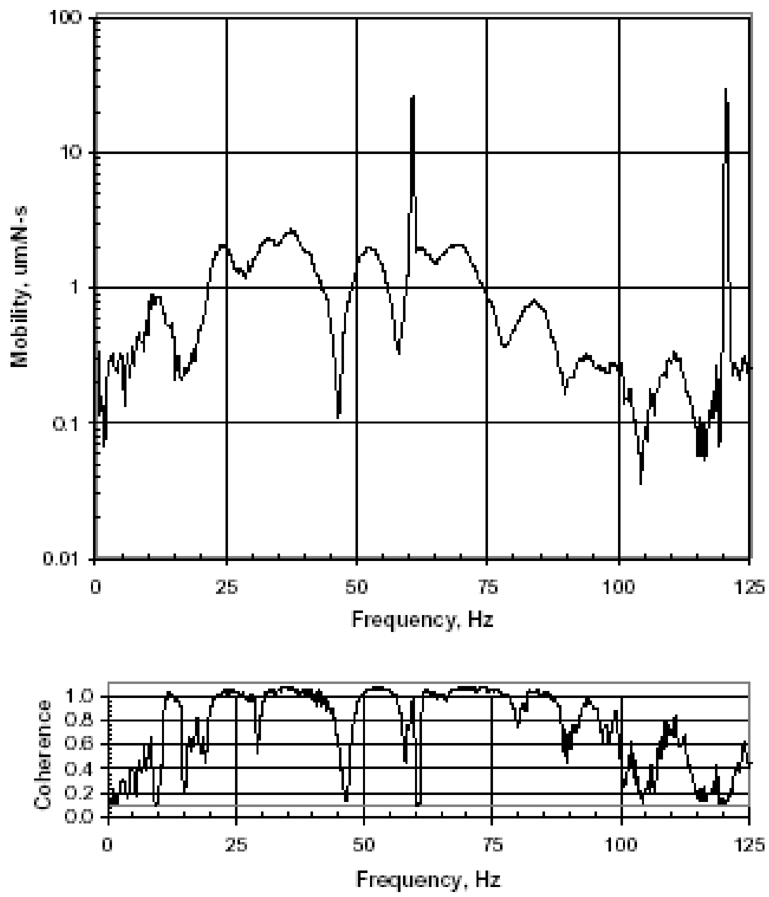
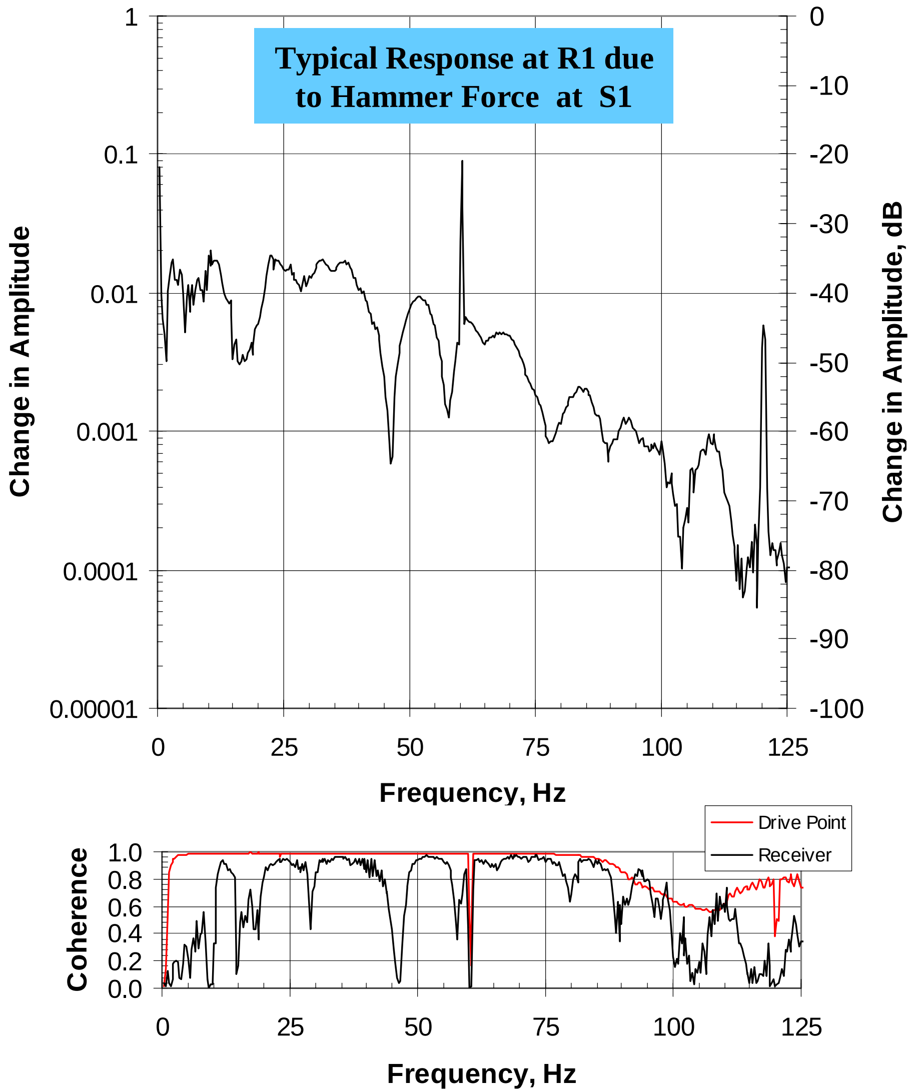
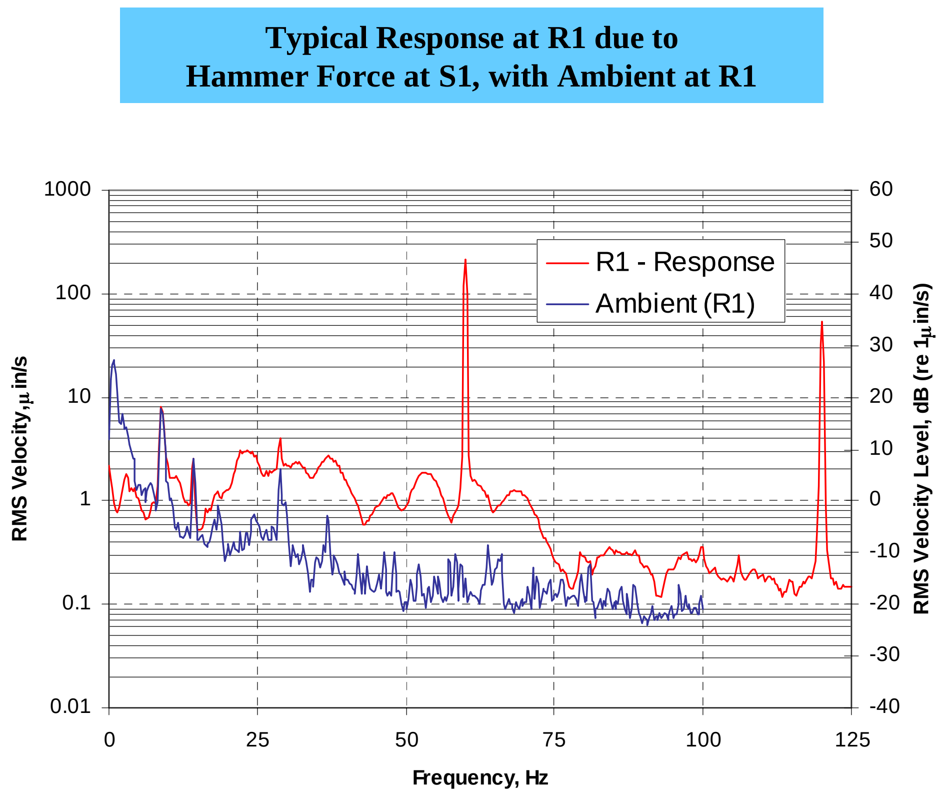


Figure 6: Ground Transmission - SLAC Cut-and-Cover Tunnel - 7 Aug 2002
Transfer Mobility - Response at R1 due to Hammer Force at S1



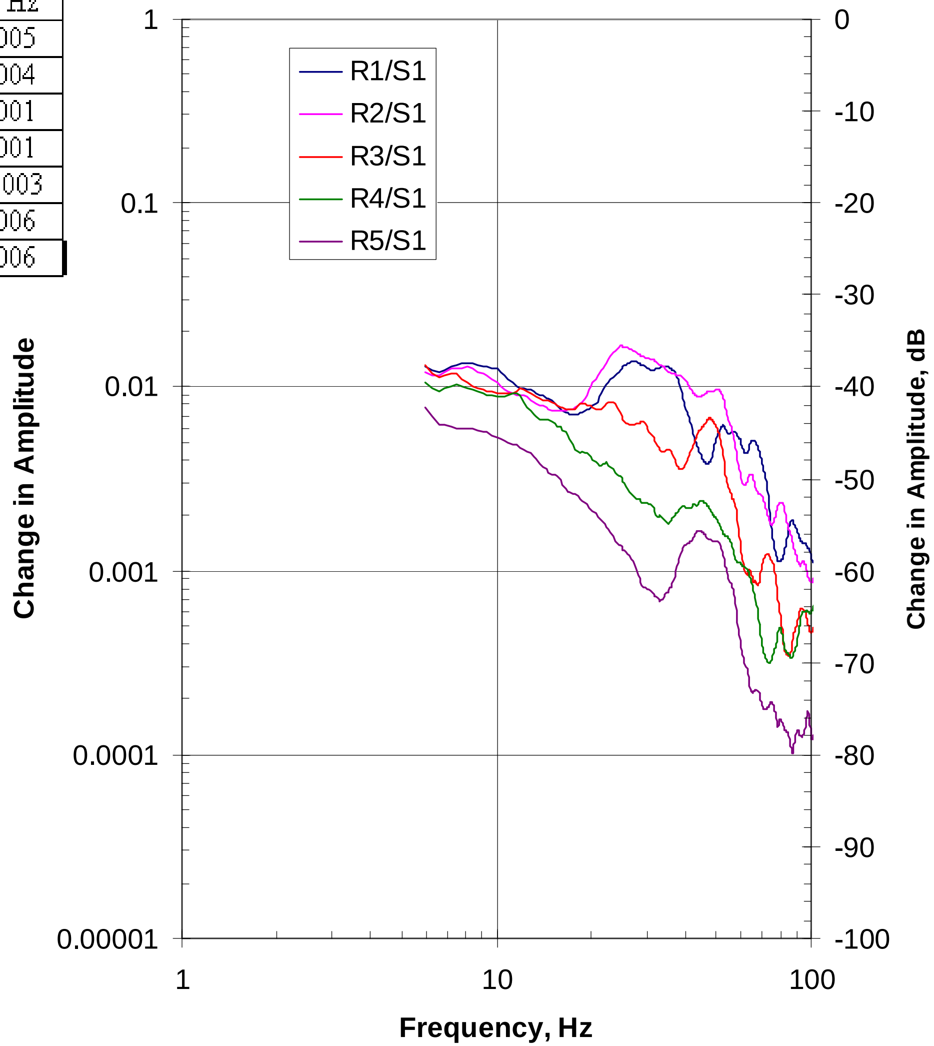
ICFA Nanobeams 02– Workshop Sessions 3





Source	Receiver	Distance, ft	Attenuation at Given Frequency			
			10 Hz	20 Hz	30 Hz	60 Hz
S1	R1	130	0.014	0.0084	0.012	0.005
	R2	134	0.012	0.012	0.014	0.004
	R3	162	0.011	0.0084	0.006	0.001
	R4	233	0.010	0.004	0.002	0.001
	R5	289	0.005	0.002	0.009	0.0003
S2	R1	248	0.023	0.011	0.007	0.006
	R2	271	0.027	0.011	0.007	0.006

Log Mean Transmission From Drive Point S!



The figures in the above table represent the attenuation
Factor A for a vibration with its source near Sn propagating along the same path.

Example 1: Suppose a pump is installed at S1, and it produces a vibration at 30 Hz with an amplitude of X.
The amplitude at 30 Hz that we measure at R5 would be the greater of either ambient or 0.009X.

Example2: If we want to place a pump at S1 and not to exceed ambient at R5 (06Mic in/sec), then we need to impose a limit on the resulting vibration at S1 of 0.6/0.009=67 Mic in /sec.

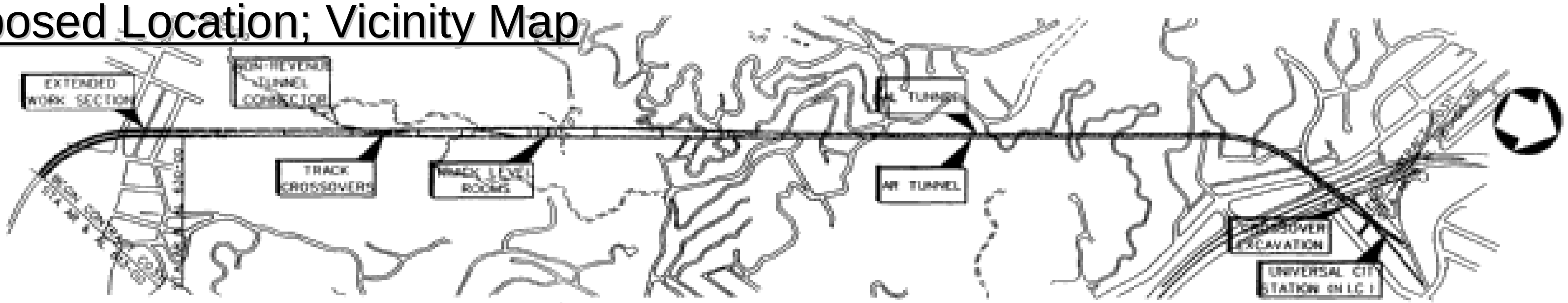
Proposed Field Vibration Measurement in a Parallel Tunnel

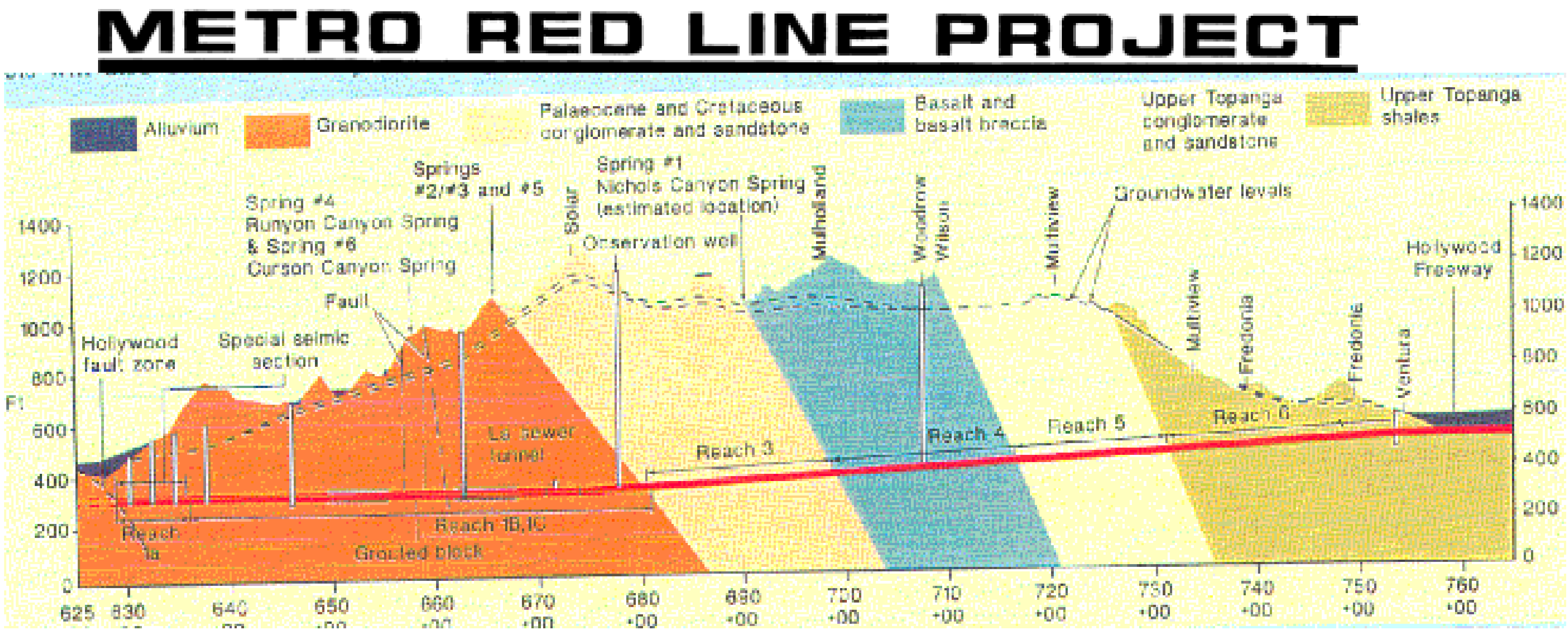
- Surface-to-depth measurement will be obtained using:
  - Traffic-as-source: It will measure the surface ambient and the tunnel simultaneously, using the excitation at surface (traffic,etc)
  - Data will be taken simultaneously over relatively long periods
  - Impulsive-source: Measurement will use the same instrument setup, using a controlled source, such as instrumented hammer
    - A "FRF" will be obtained, showing attenuation provided by ground (part of FRF is "coherence" measurement)
  - Rail-as-source: Same discussion as "Traffic-as- source", except the source and receiver would be reversed in the computations
    - Rationale: Small amount of traffic, not enough to get a signal with adequate coherence may be the case in the middle of the night (provides a check of the validity of measurement)

Proposed Field Vibration Measurement in a Parallel Tunnel

- Tunnel-to-tunnel measurement will be obtained using:
  - Electro-magnetic shaker: It will generate steady-state vibration for frequency range from 2 Hz to 100Hz (frequency sweep) in "source" tunnel with sensors placed near and along the tunnel as well as in the adjacent tunnel
  - Impulsive-source: Measurement will use the same instrument setup, using a controlled source, such as instrumented hammer
    - Shaker and hammer will simulate broad range of vibration sources in the NLC service tunnel, such as activities, ventilation equipment, cooling water, modulator, pumps, etc
  - A transfer function (FRF) will be obtained, showing attenuation or amplification of vibration between the tunnels

Proposed Location; Vicinity Map



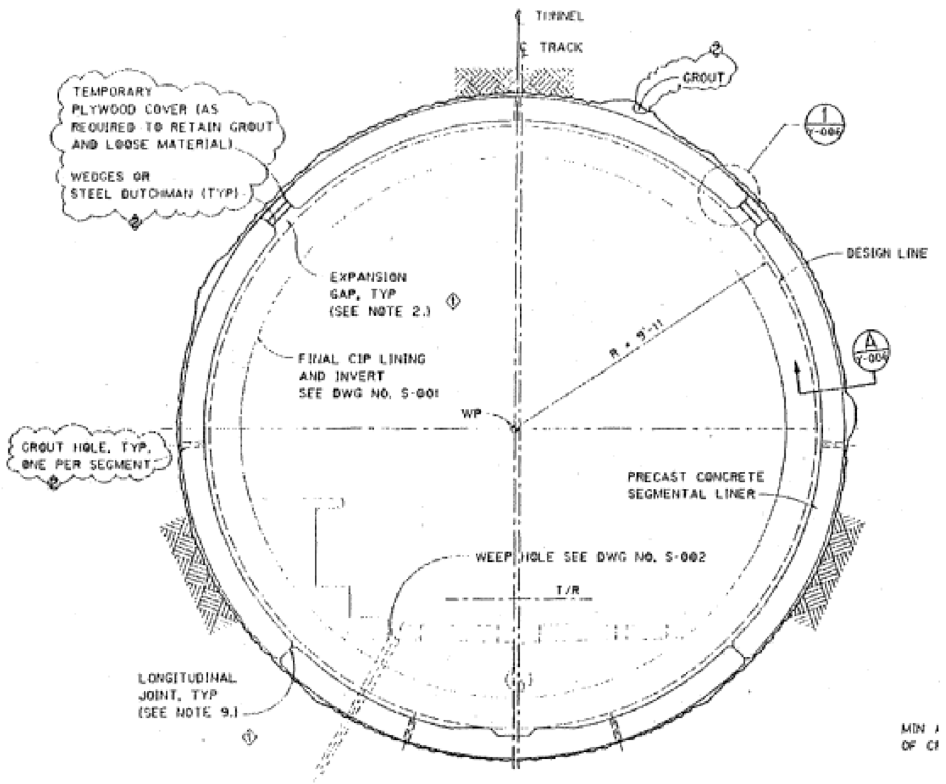


A cross-section through the Santa Monica mountains showing the different geological conditions.
Reach 6 might be a potential test site.

Geological Information

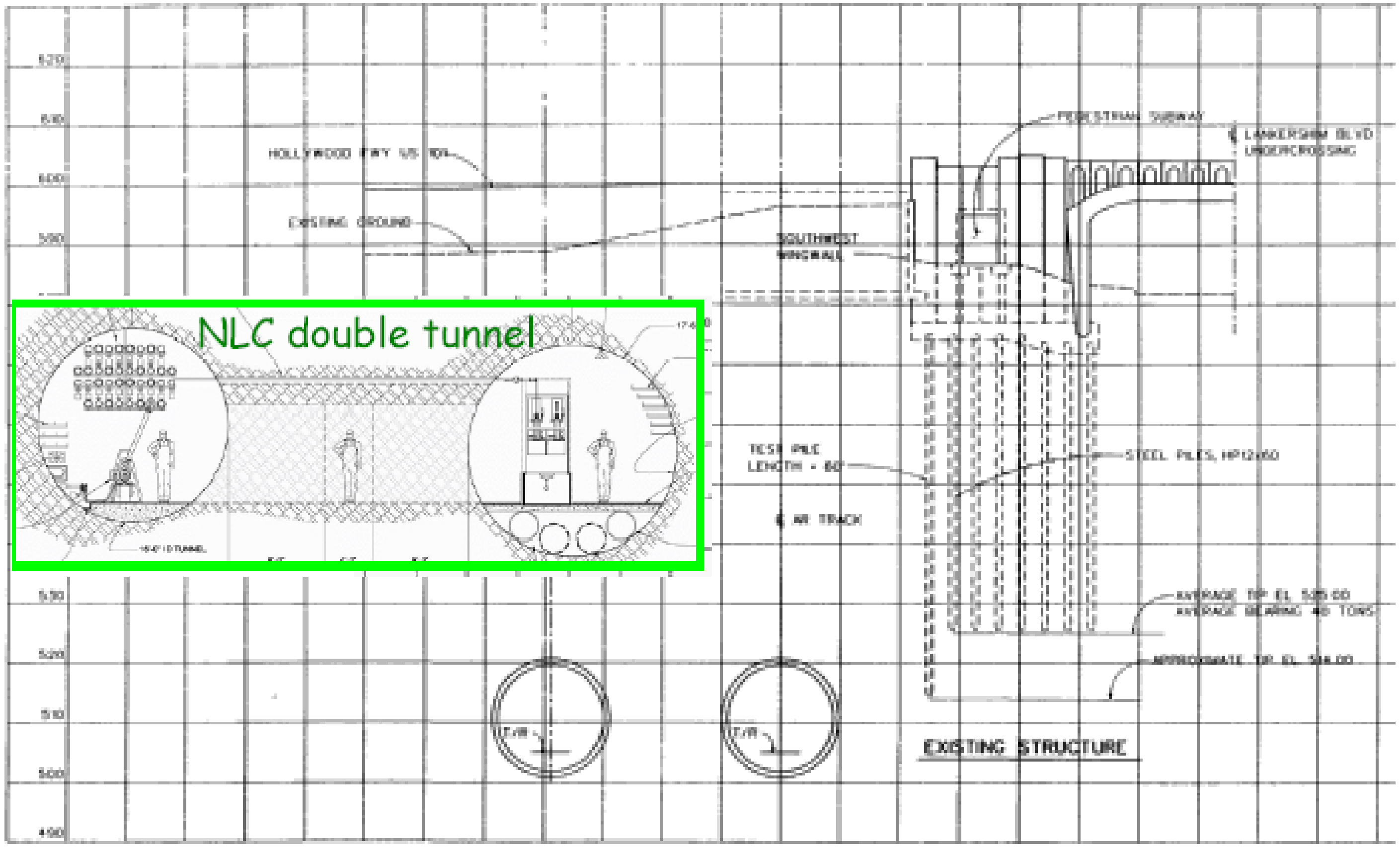
- Geologic conditions at Reach 6
  - Upper Topanga Formation; Sandstone and shale has a shear wave velocity of between 3,000 and 4,000 ft/sec
  - Further south, sandstone with conglomerate imbedded shear wave velocity of between 4,800 and 7,800 ft/sec
- Geologic conditions at CA-127 site
  - Sites Formation; Sandstone with intervals of interbedded clay-stone and siltstone (shear wave velocity > 2500 ft/sec)

CA-127 proposed tunnel is similar in configuration



Typical Cross-Section of the MTA Tunnel

Typical Cross-Section of the MTA Tunnels



Conclusions

- Ground vibration characterization program is well underway at SLAC
  - Representative sites with good geological conditions for cut-and-cover and tunnel construction have been identified.
  - The noise level measured on surface at both sites (CA-135 and CA-127) are very low and no significant cultural noise was found.
  - Near-field vibration sources for cut-and-cover are characterized.
  - Field vibration measurement at SLAC is competed.
  - Field vibration measurement in a parallel tunnel will start, soon.
  - Initial work on 3-D modeling just started.