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SASSI Subtraction Method Effects at Various DOE projects

U.S. Department of Energy
Natural Phenomena Hazards Workshop

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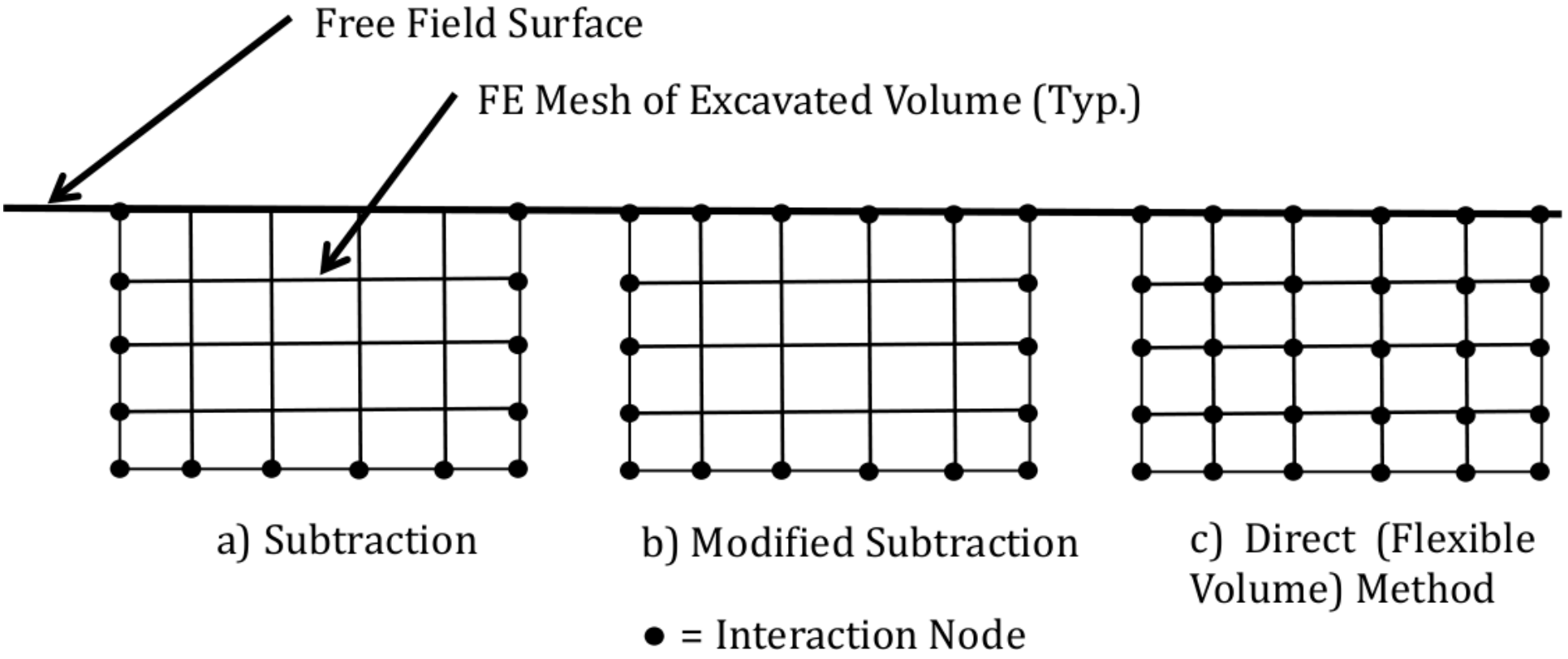
Outline

- PF-4
- CMRR
- UPF
- Generic Study
- Lessons Learned

Note: Project results represent work-in-progress and do imply regulatory acceptance

SASSI Solution Methods for Embedded Structures



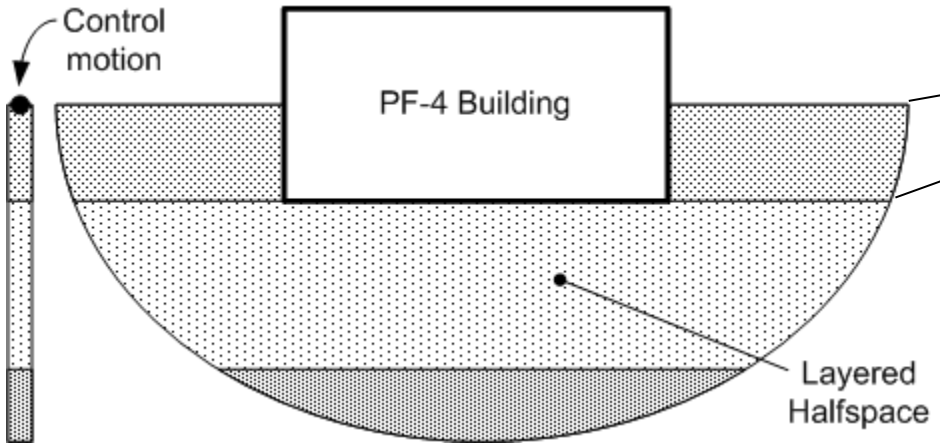
PF-4

Two story
Box-type RC Structure
284'x265'x39'
Embedded ~18'

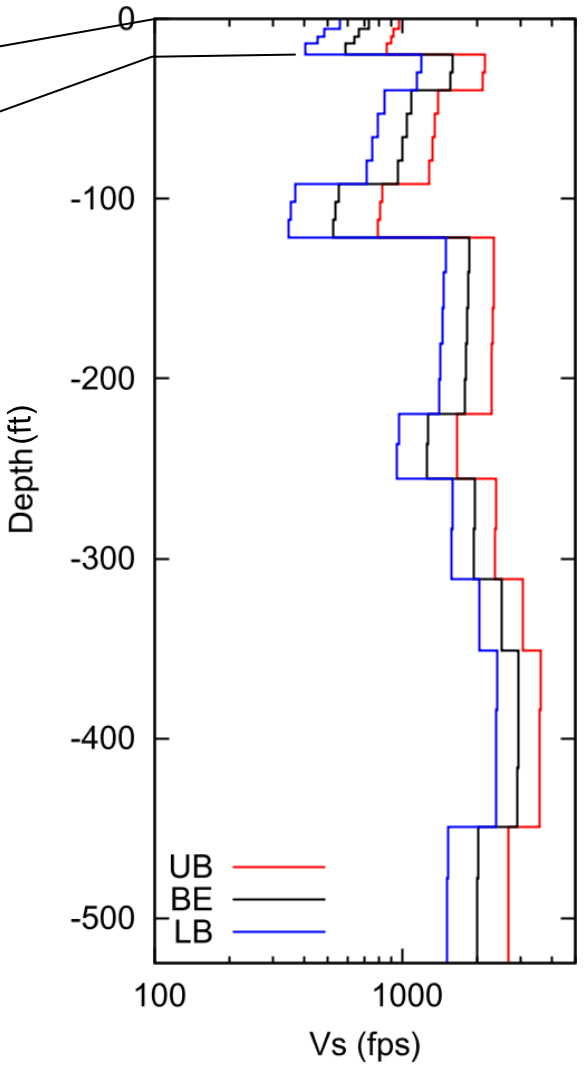
1970's construction
Thin basement floor with spread footings
Flat slab interior floor supported by columns with capitals

PF-4 SSI Analysis

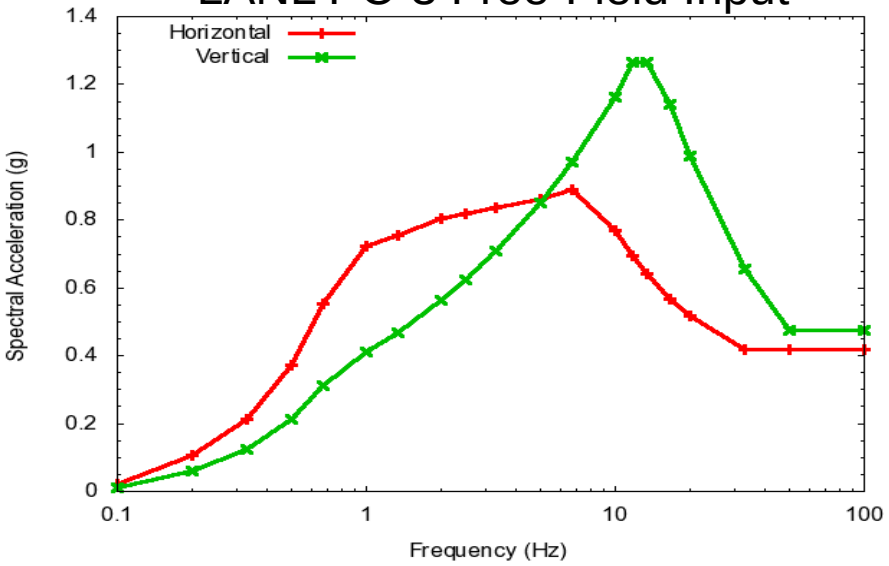
Surface Control Motion



TA-55 Soil Profile

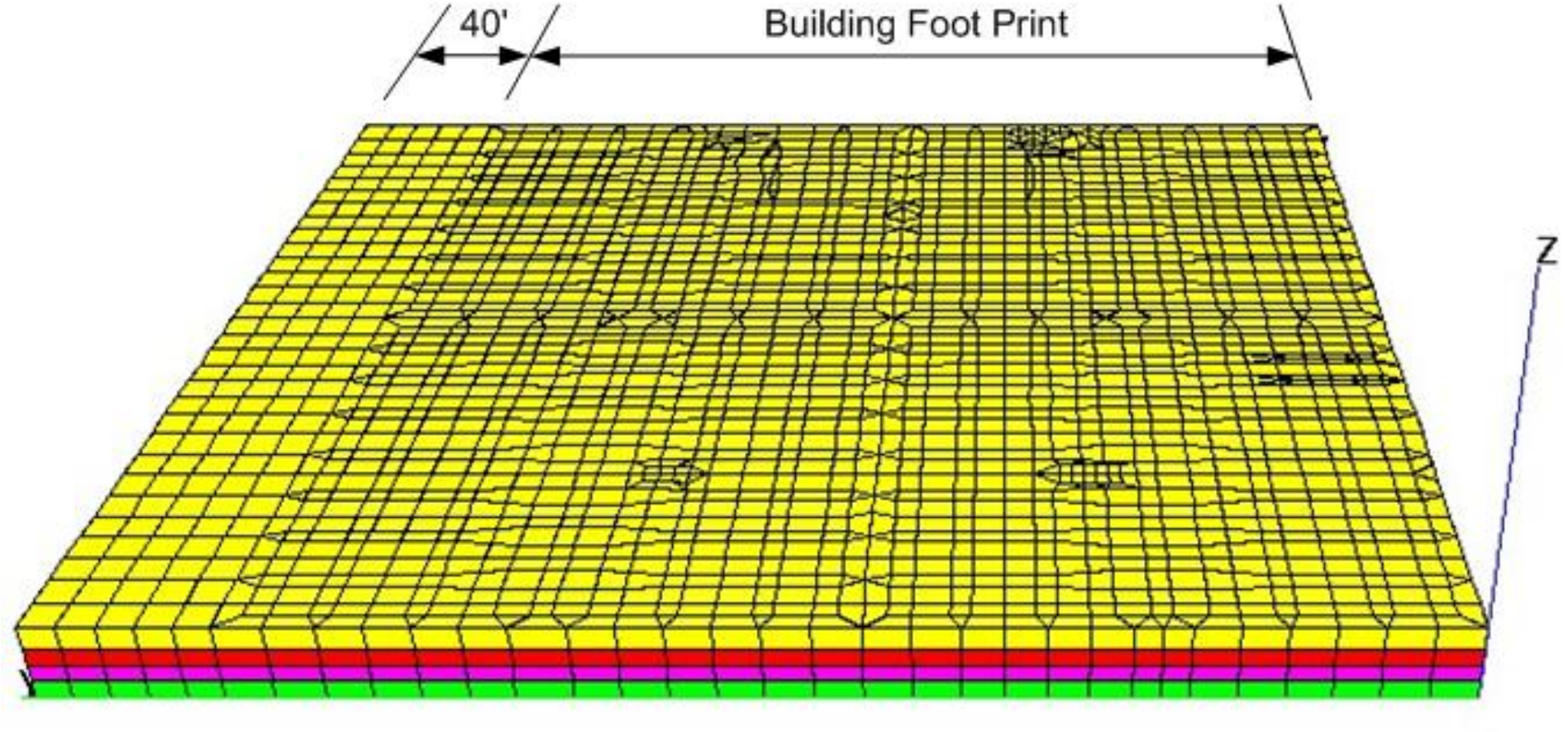


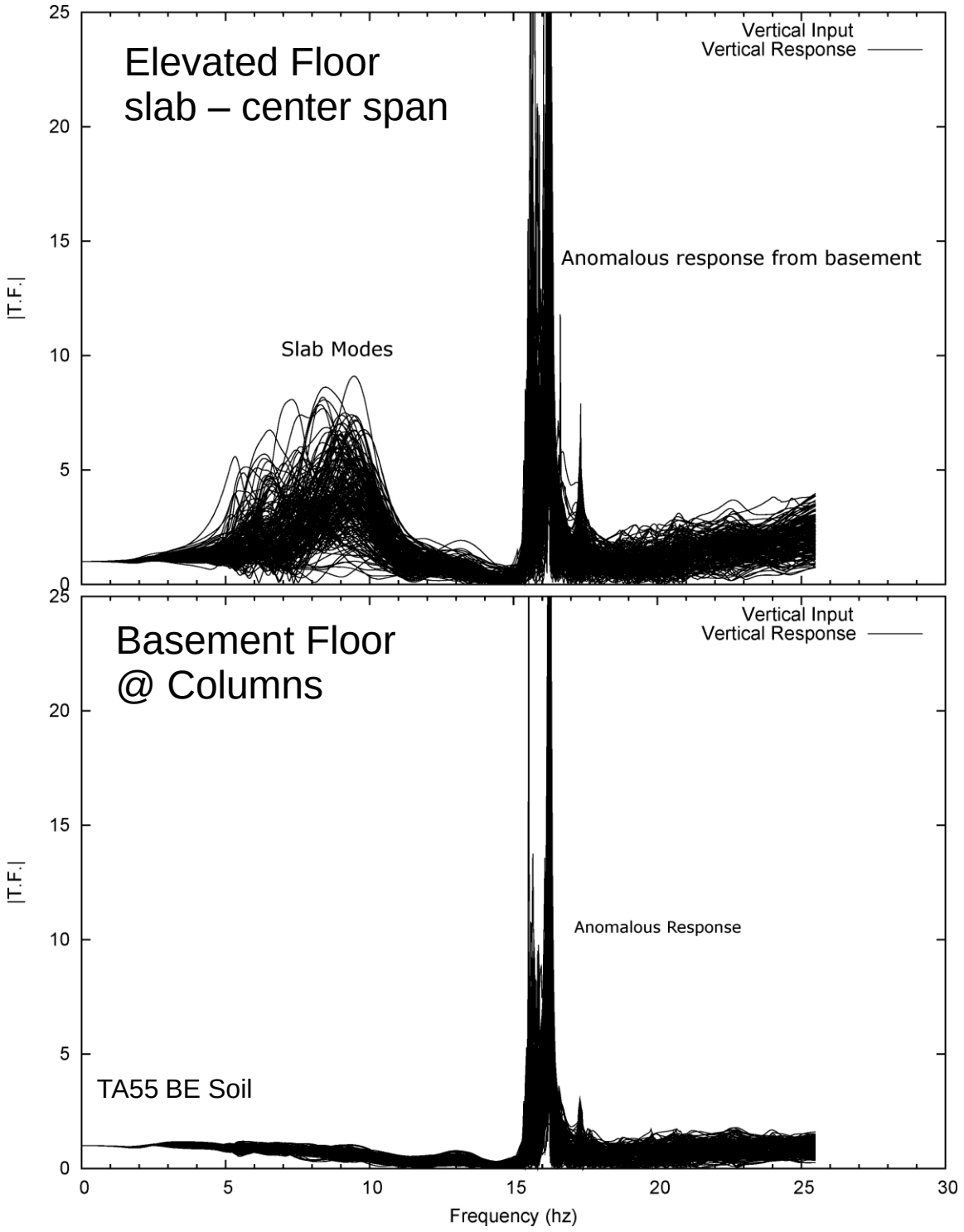
LANL PC-3 Free-Field Input



PF-4: Preliminary Analysis

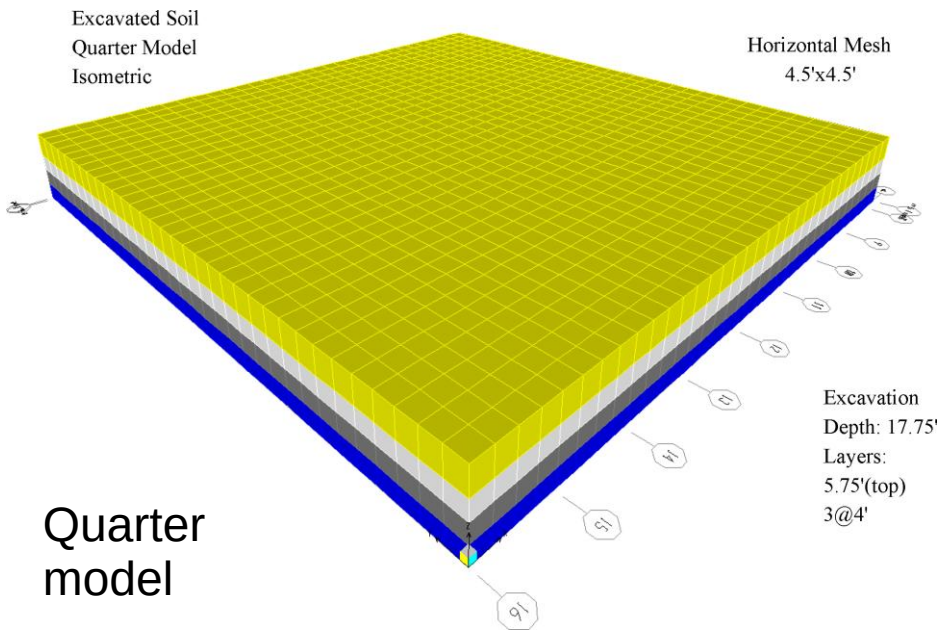
Preliminary excavated soil model
Extrusion of basement floor mesh
Building model alone has ~19,000 nodes



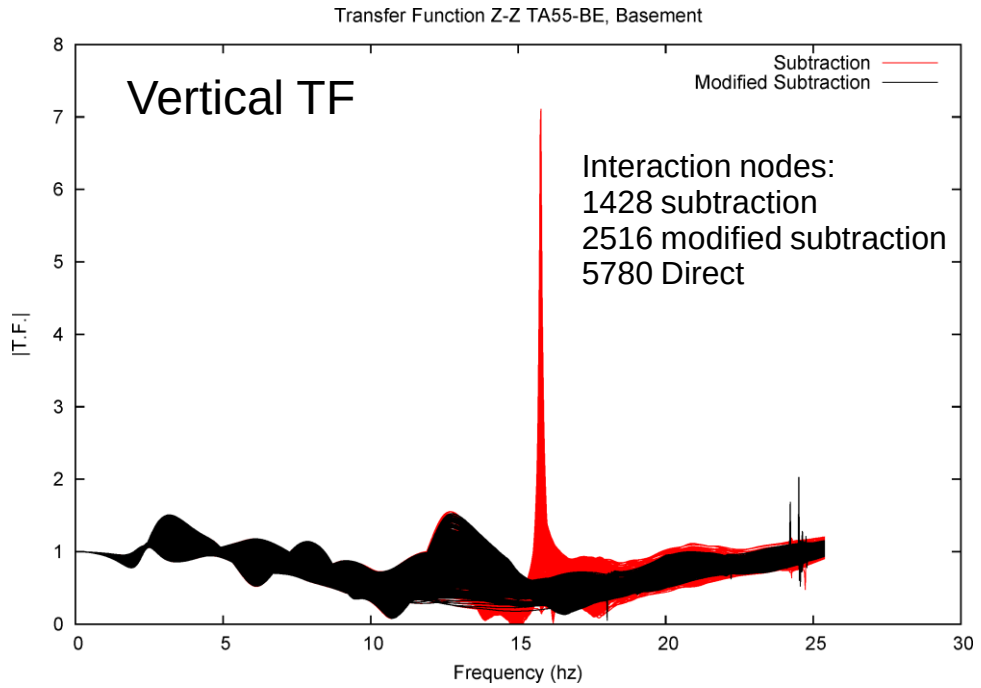


PF-4: Preliminary Analysis

- Vertical response dominated by anomalous behavior
- Anomalous response is transmitted from soil directly below building and is not caused by the structure
- Lambda/5 =25.5 Hz based on vertical element size
- Lambda/5 =19.7 Hz based on 6' average horizontal element size
- Anomalous response occurs below lambda/5



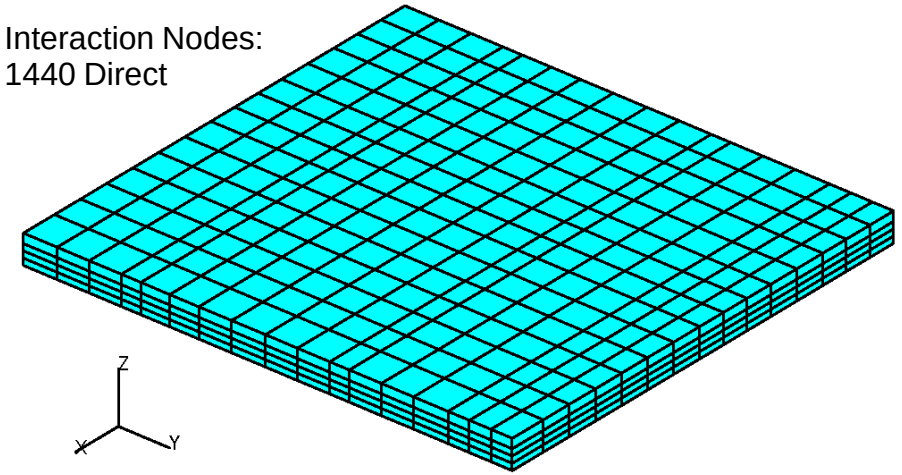
Quarter model

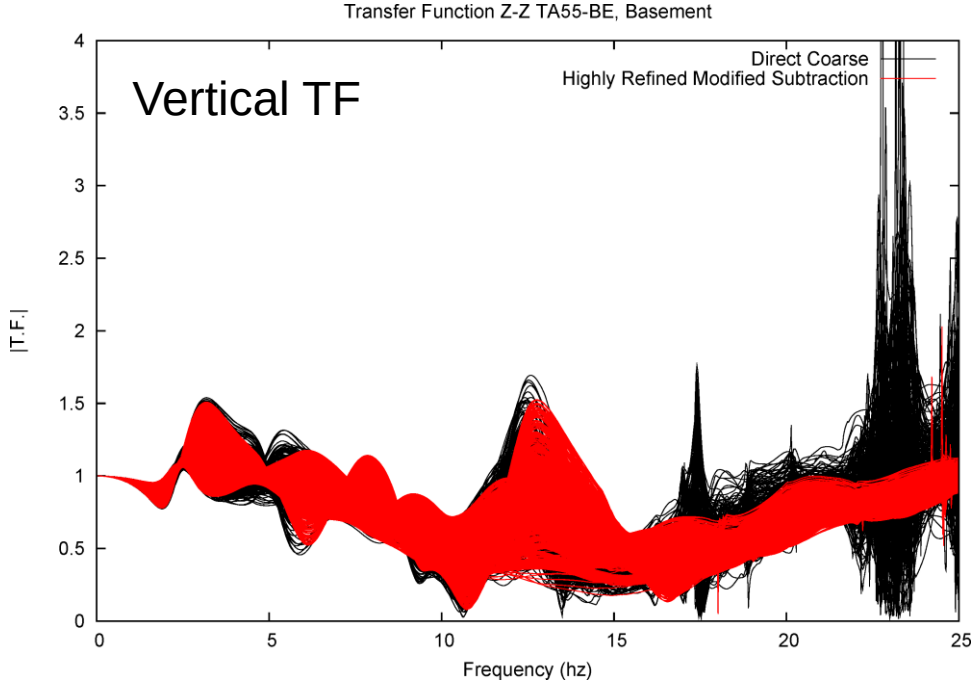


PF-4 Highly Refined Mesh

- Highly refined quarter model
  - Regular mesh geometry
  - Lambda/5=25.5 Hz
- Side studies were used to demonstrate modified subtraction approximates direct
- Regular meshing reduced anomalous response by factor of 3
- Ratio of subtraction to modified subtraction TF is as large as 9
- Highly refined mesh has too many DOF for building analysis

PF-4 Coarse Regular Mesh

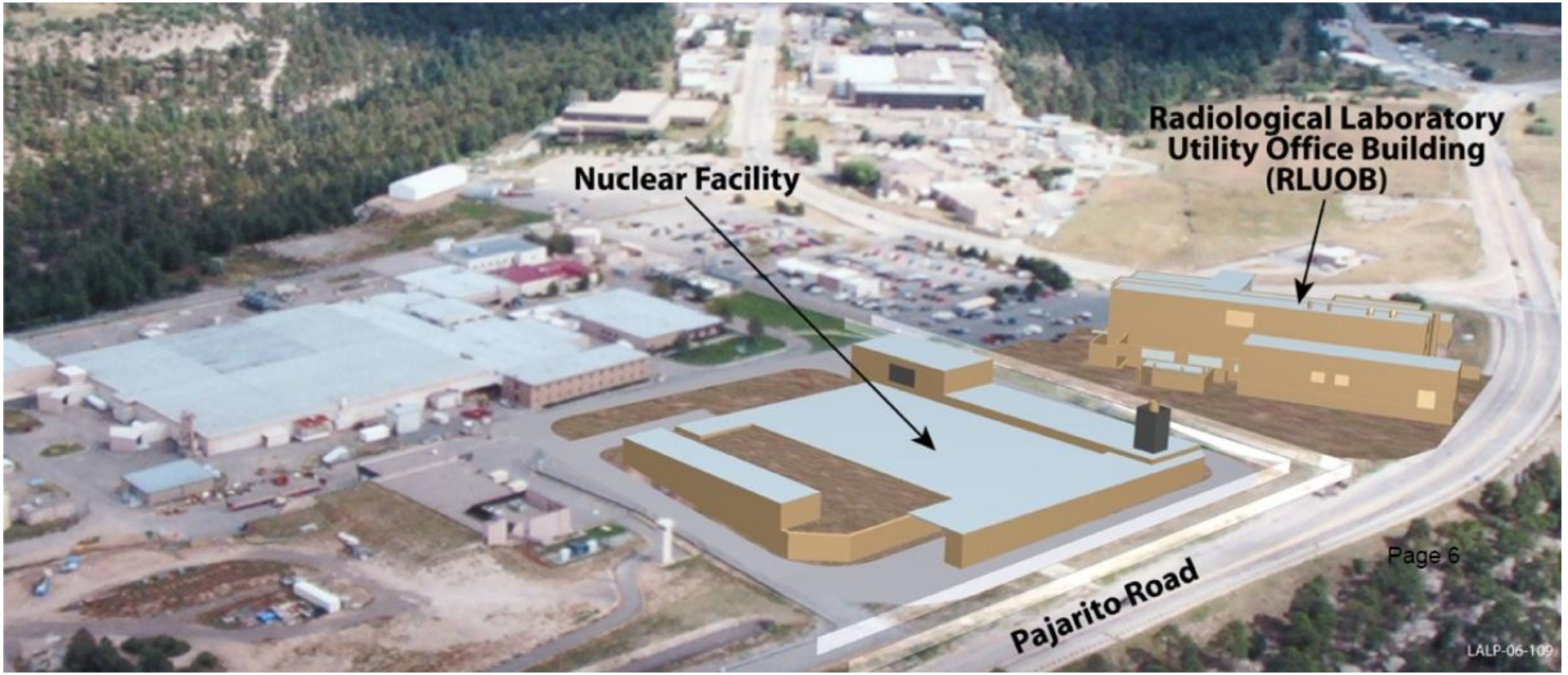




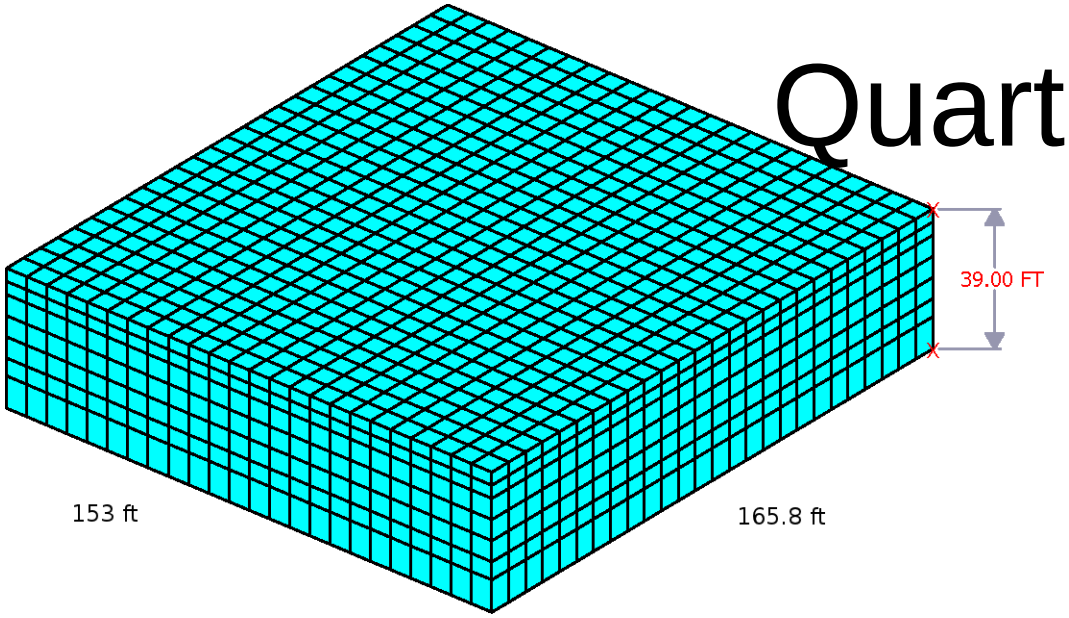
- Coarse 3D mesh
  - Direct solution
  - 1 element per bay
  - Use MPC's to constrain structural mesh to interaction nodes
  - Spurious response greatly reduced
    - Spikes @ 23 Hz due to mesh size
  - Coarse 3D mesh used for building analysis

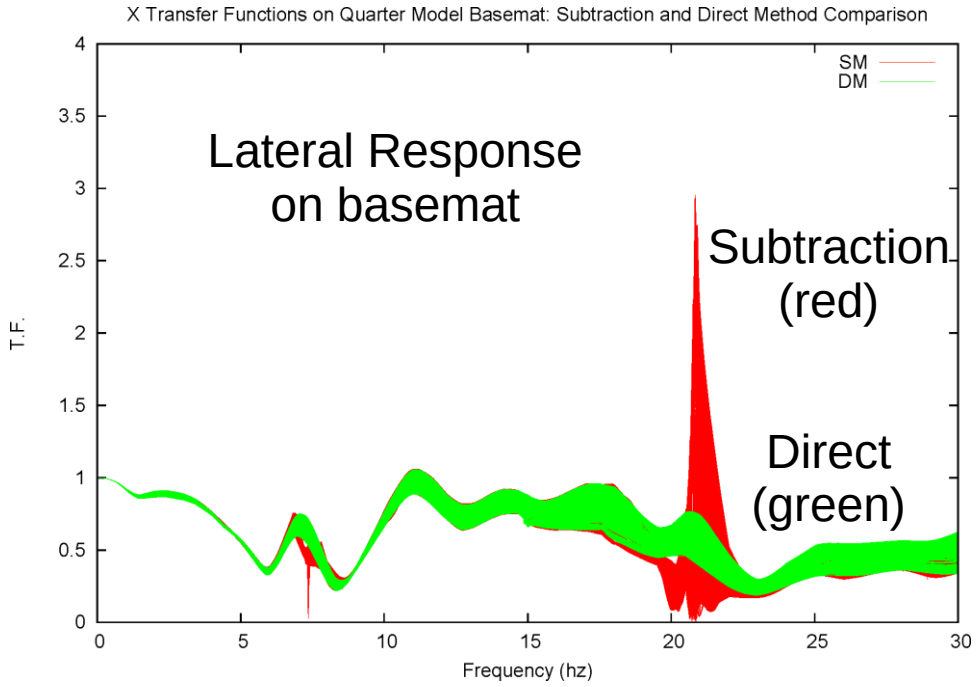
CMRR-NF

- R/C box type building
- 330' by 300' by 73'
- Embedded 39'



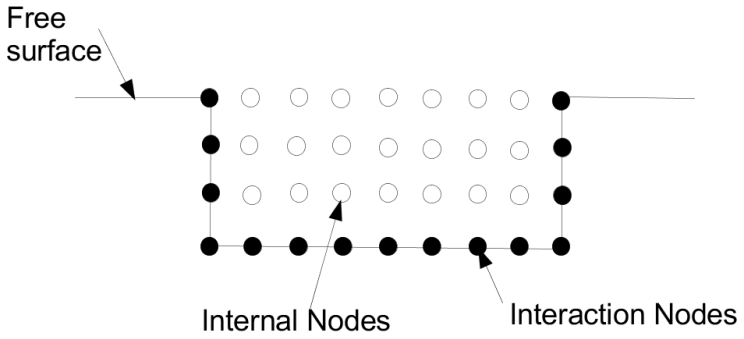
CMRR
Quarter Model Study



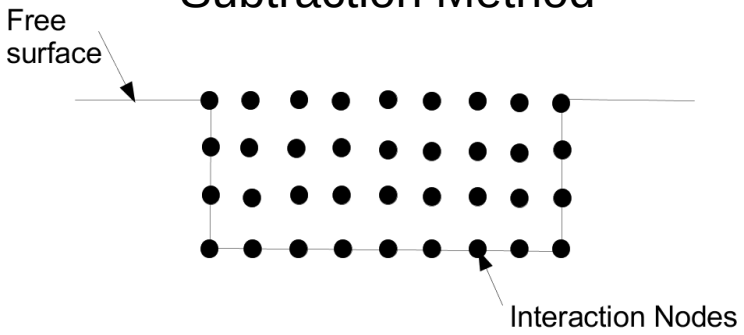


- Quarter model used to study subtraction anomaly
- Includes basemat and exterior walls
- Lateral soil column frequency is 6.4 Hz
- Lateral frequency of excavated soil volume is slightly higher
- First subtraction anomaly occurs at ~7.5 Hz
- Significant anomaly occurs at ~21 Hz

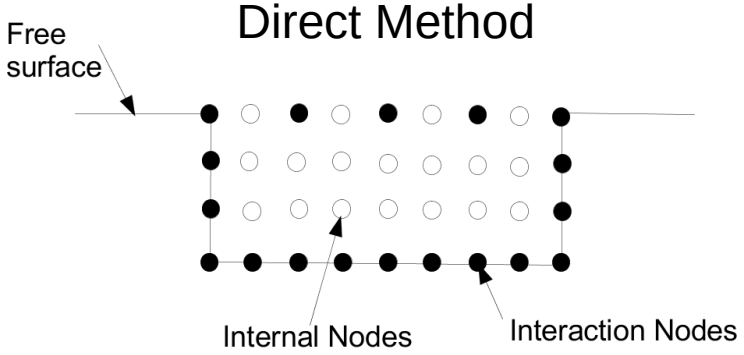
CMRR Modified* Subtraction



Subtraction Method

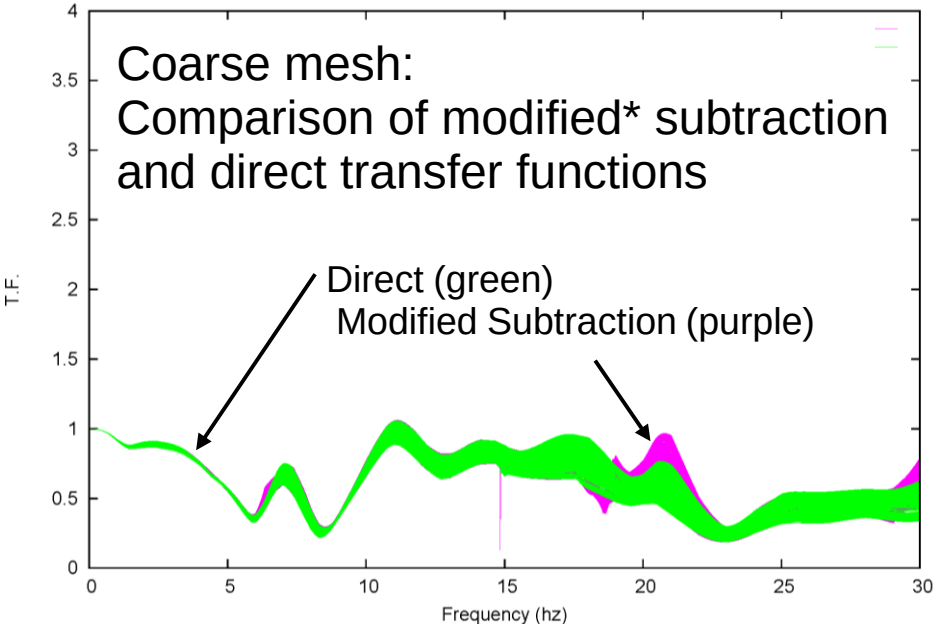


Direct Method



Modified* Subtraction Method

- Quarter model mesh is too refined for production runs
- Coarser mesh used in analysis with a variation of modified subtraction

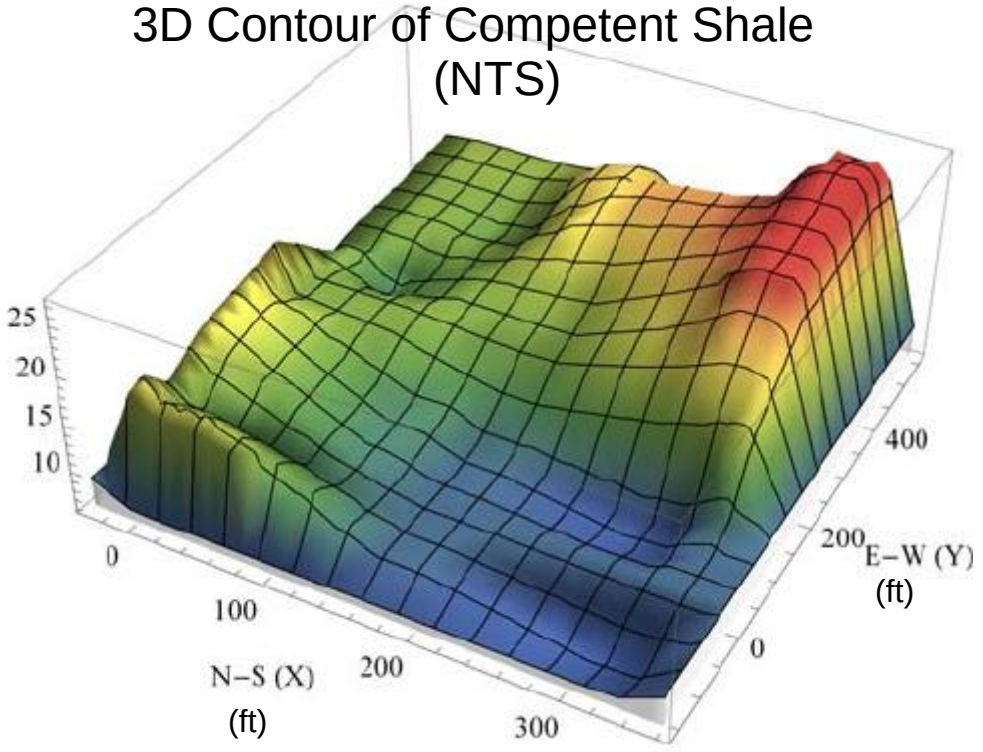


* A variation of the Modified Subtraction Method

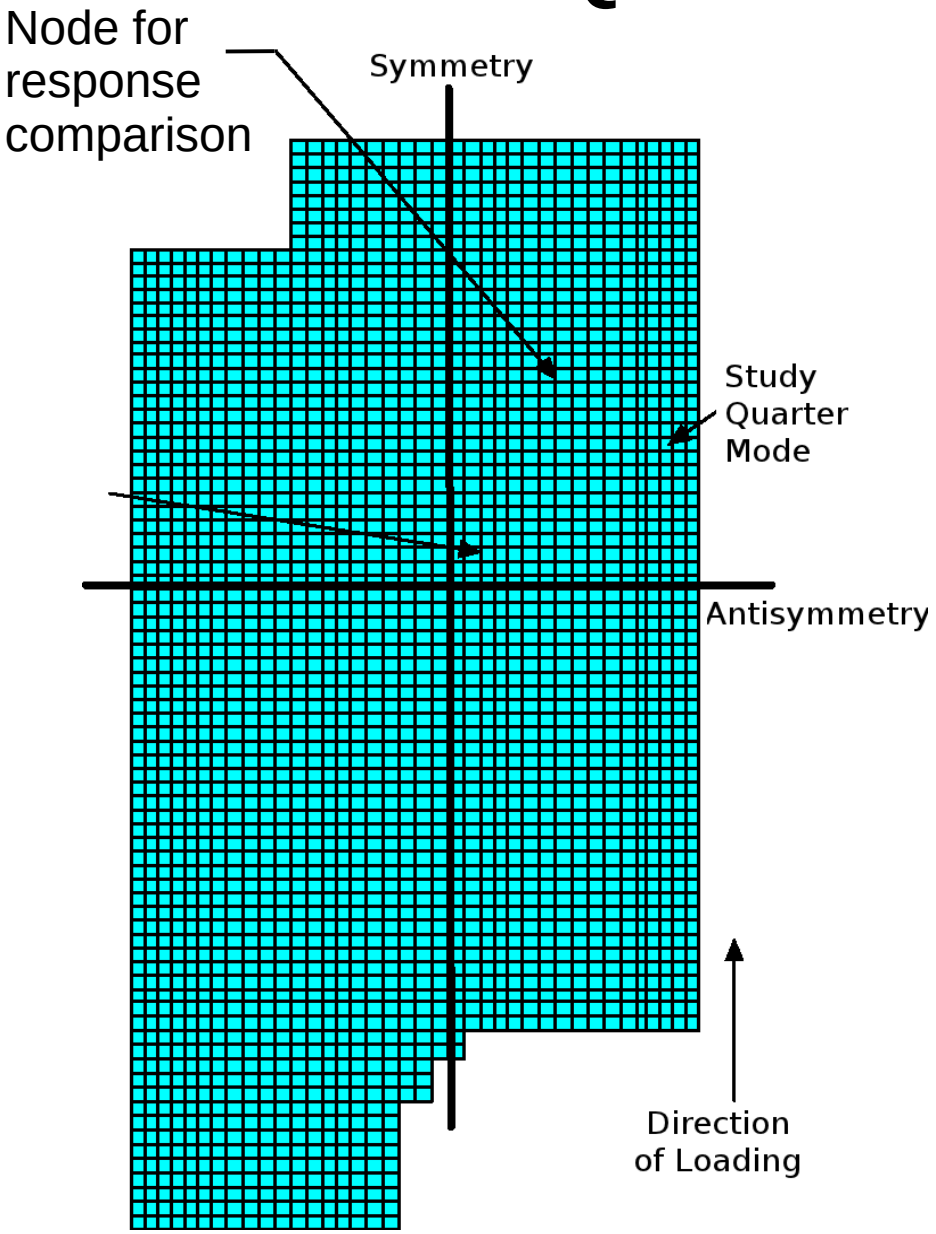
UPF

- 330'x470'x70' Surface RC building
- EUS site: High frequency input motion
- Site consists of:
  - Soil
  - Weathered shale
  - Unweathered shale
- Excavate poor soil and backfill with concrete

- SSI evaluates RC fill on competent shale

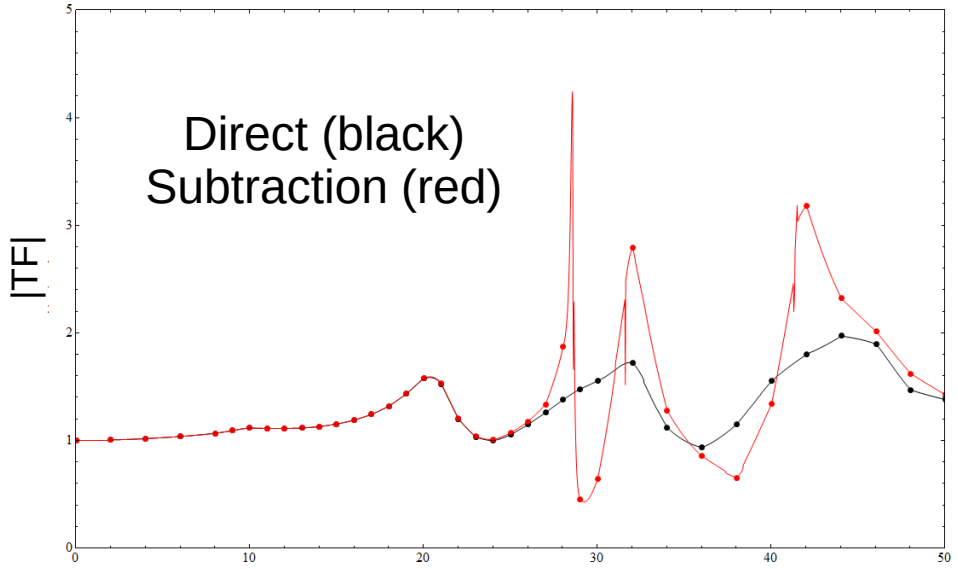


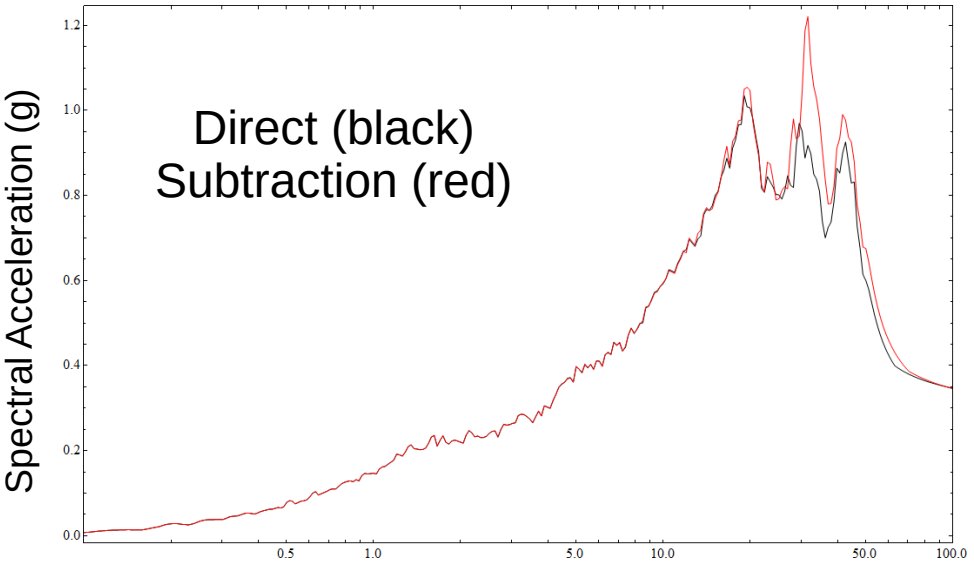
UPF Quarter Model Study

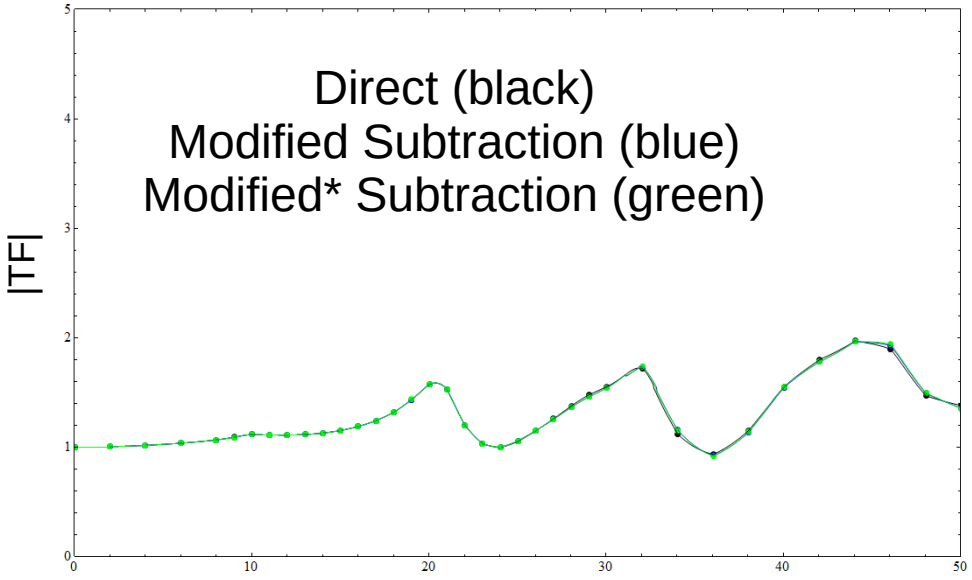


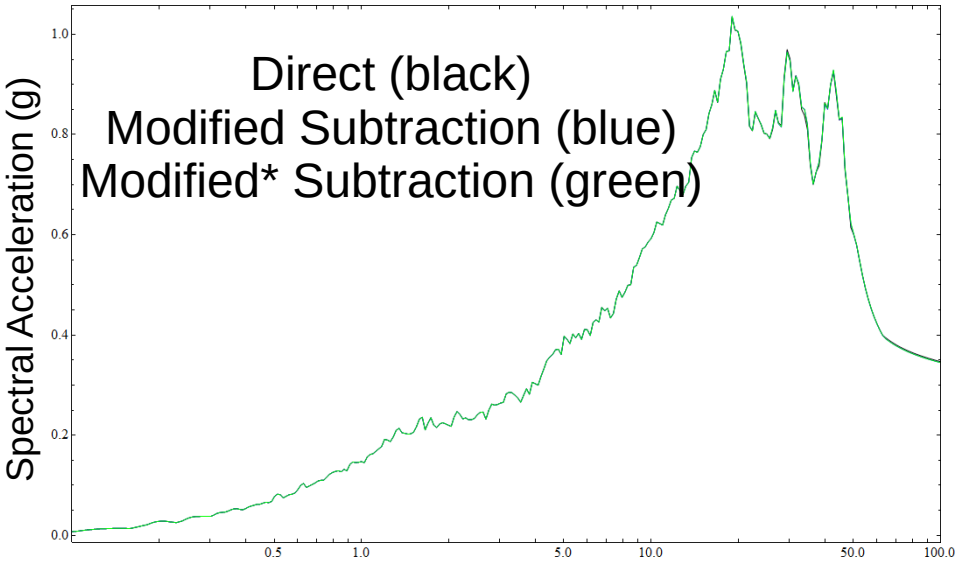
- Select a portion of the fill foot print for the quarter model study
- Compare response on top concrete fill
  - Subtract out uniform halfspace
  - Add irregular shale and concrete profile

UPF Quarter Model Study

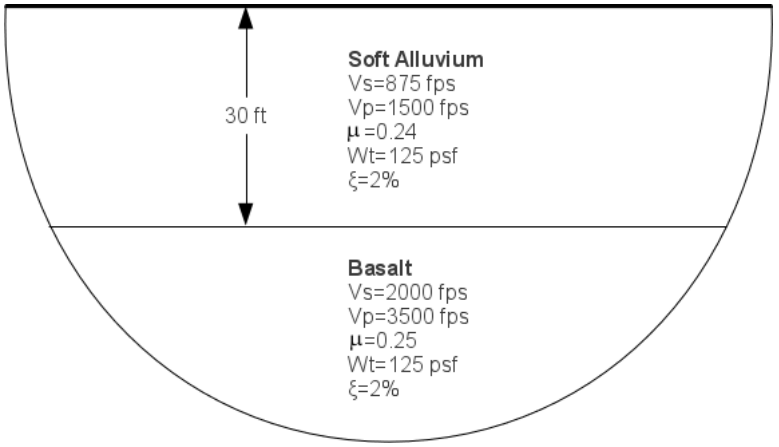


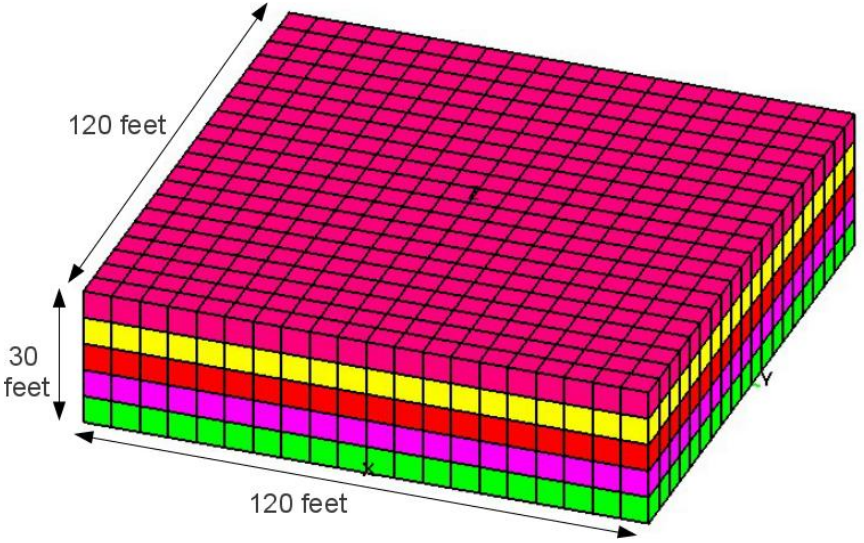






Generic Study

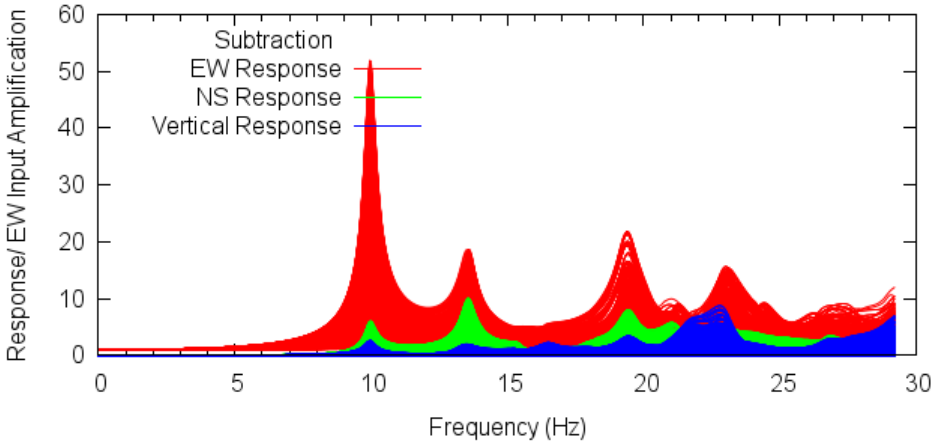


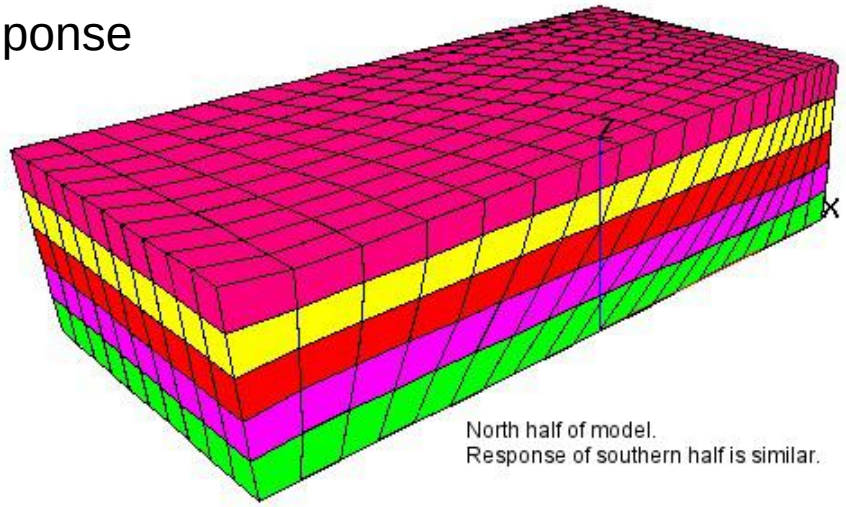


- Western US Site
- Light building
- Heavy building
- 120'x120'x30' Excavation
  - Uniform 6' bricks
  - Lambda/5=29.2 Hz

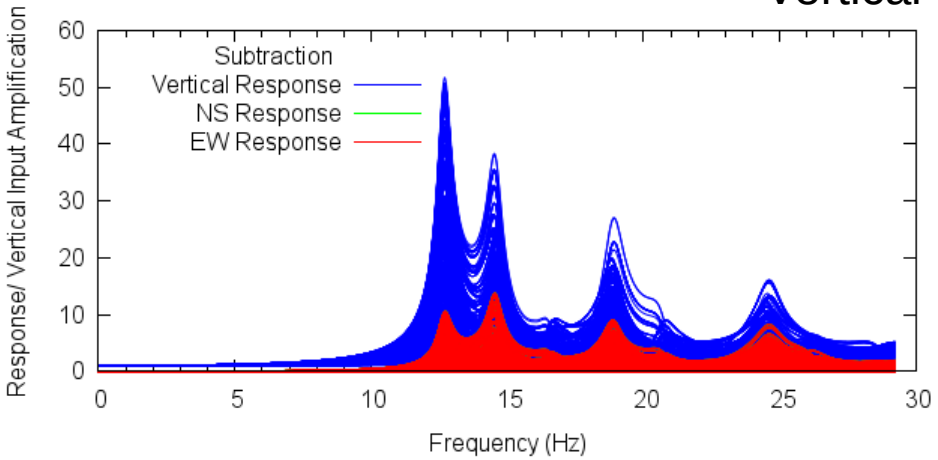
Excavated Soil Behavior for Subtraction Method

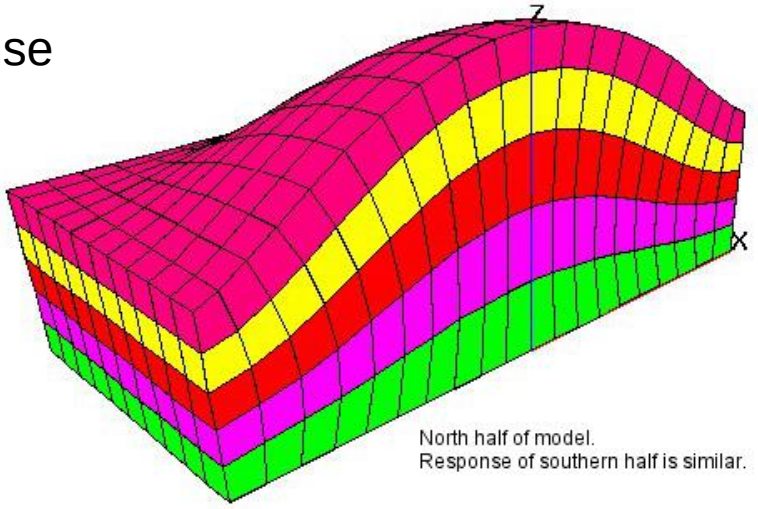
Lateral Response



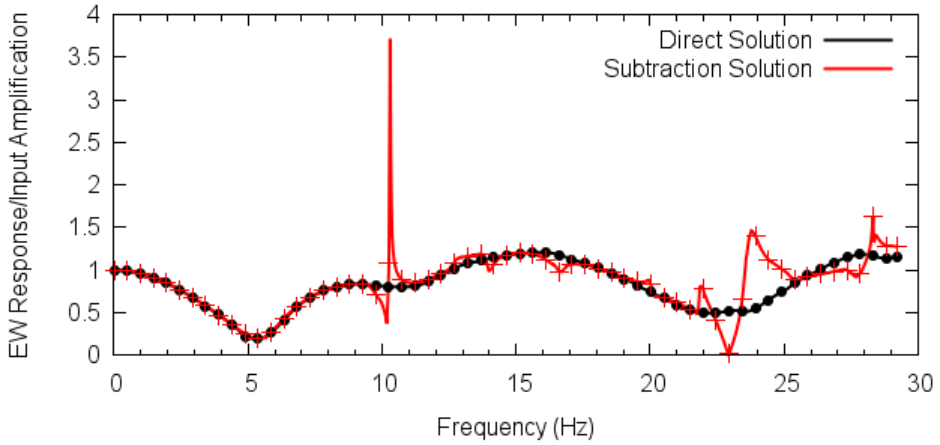


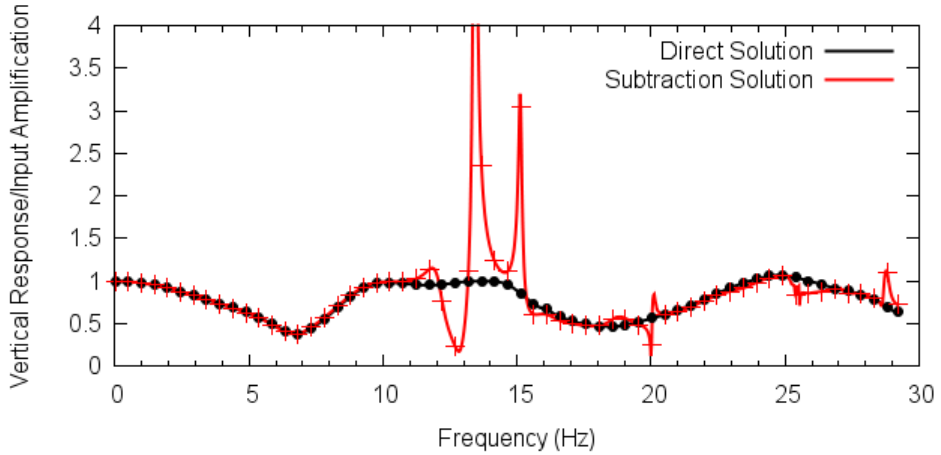
Vertical Response





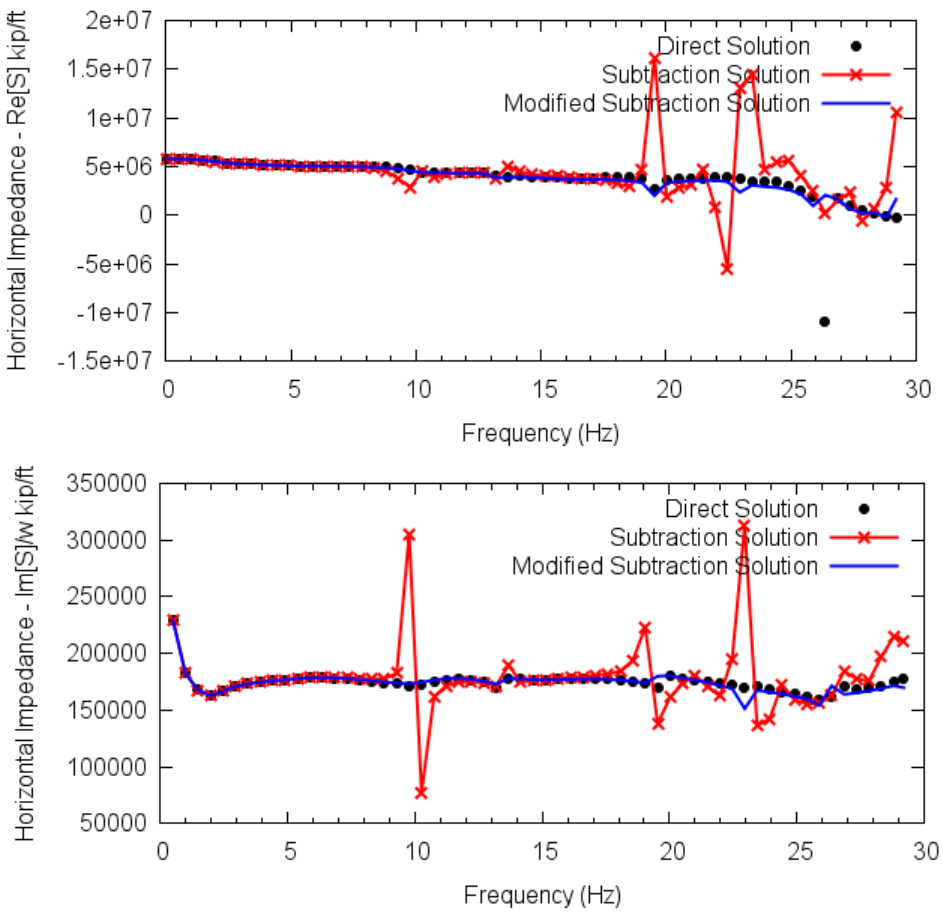
Excavation Behavior





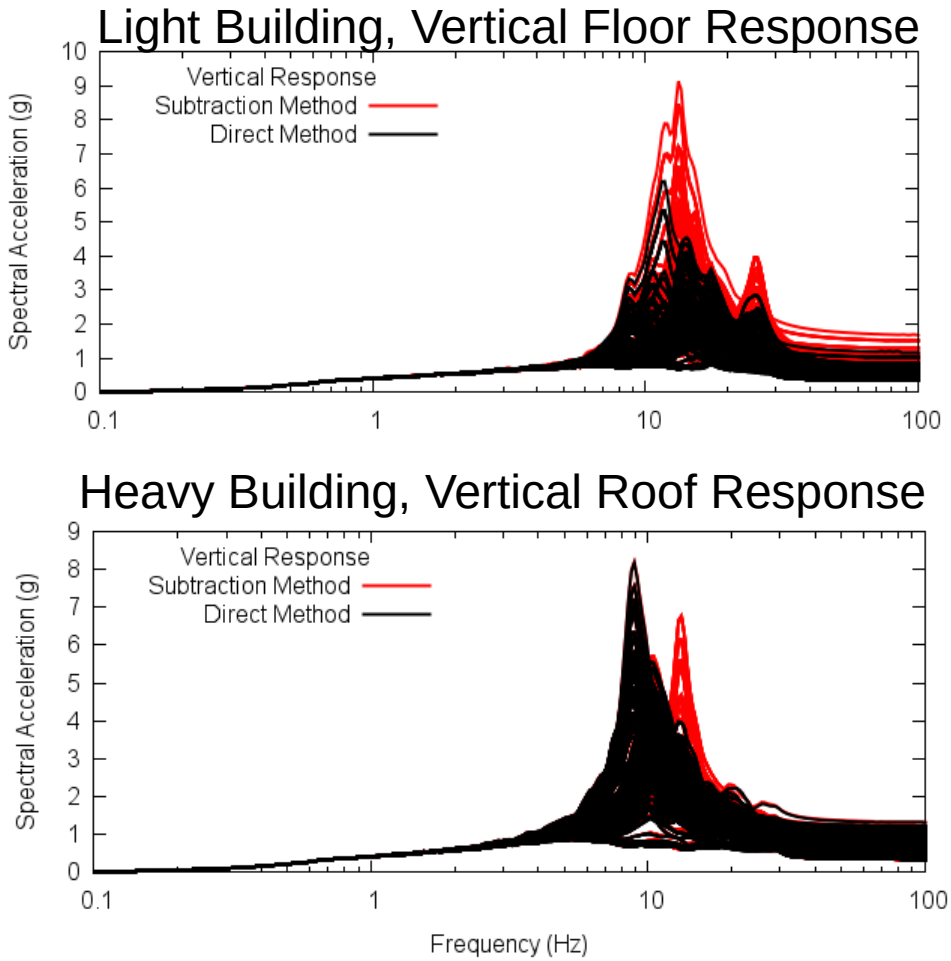
- Subtraction anomaly occurs at natural frequency of excavated soil volume
  - Anomaly at 10 Hz is at Lambda/14 << Lambda/5
  - Subtraction anomaly is NOT caused by mesh size

Rigid Massless Foundation Impedance



- Subtraction anomaly also observed in foundation impedance
- Modified subtraction also deviates from direct solution above 16 Hz
  - 16 Hz is the lateral frequency of the modified subtraction excavated soil volume

Building Response



- Light building
  - 2 story RC shear wall structure open floor plan
  - Lighter than excavated soil
- Heavy building
  - Light building on top of 60 ft rigid block of concrete
  - Weighs ~twice the excavated soil weight
- Subtraction anomaly affects ISRS in both buildings

Lessons Learned

- Subtraction can lead to anomalous response
  - Anomalous response occurs at and above the natural frequency of excavated soil volume
  - Anomalous response may not be evident in every transfer function
  - Irregular meshes can aggravate subtraction anomaly
- Subtraction anomaly is caused by independent vibration of excavated soil volume
  - Not a discretization (Lambda/5) issue
  - Not a programming error
  - Not due to numerical instabilities
  - This anomaly is a limitation of the applicability of the subtraction method

Lessons Learned (cont)

- Modified subtraction and variants, add restraint to excavated soil volume reducing independent vibration of excavated soil volume
  - Not a panacea – anomalies still occur above natural frequency of excavated soil volume
  - Modified subtraction extends the range of applicability of the subtraction method
- Strongly recommend case specific studies for individual building geometry and soil properties
  - Benchmark with direct method
- Recommend open discussion of anomalous results
  - LA-UR-10-05302
  - This workshop
  - Position Paper CJCA-004