NCHRP 25-25 Task 72
Construction Vibration and Historic Buildings
A Case Study

Presented to

TRB ADC40 Committee Summer Meeting

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Engineering of Structures and Building Enclosures

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- Relevance to NCHRP 25-25 Task 72
  - One of several case studies in Project Report
  - Illustrates steps taken when risk is high enough
  - Operational vibration, but similar steps for construction
- General procedure
  - Screening – conservative distance to minimize risk
  - General analysis – generic (typical) parameters
  - Detailed analysis – highly focused and case-specific
- Focused study
  - Evaluation of susceptibility – field observations
  - Well defined ground motion – field measurements
  - Structural analysis – determine stresses and/or strains

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- Background on Case Study – Sacramento Railyards
  - Relocation of freight and passenger tracks
  - Area planned for massive redevelopment
  - Several historic buildings in historic district involved
  - Buildings part of the *Central Shops* of the old SP RR
  - Built contemporary with the Transcontinental RR in 1869
- Buildings will house the *Museum of Railroad Technology* when project completed
  - Central Shop buildings unreinforced masonry construction
  - Buildings in various states of maintenance and repair

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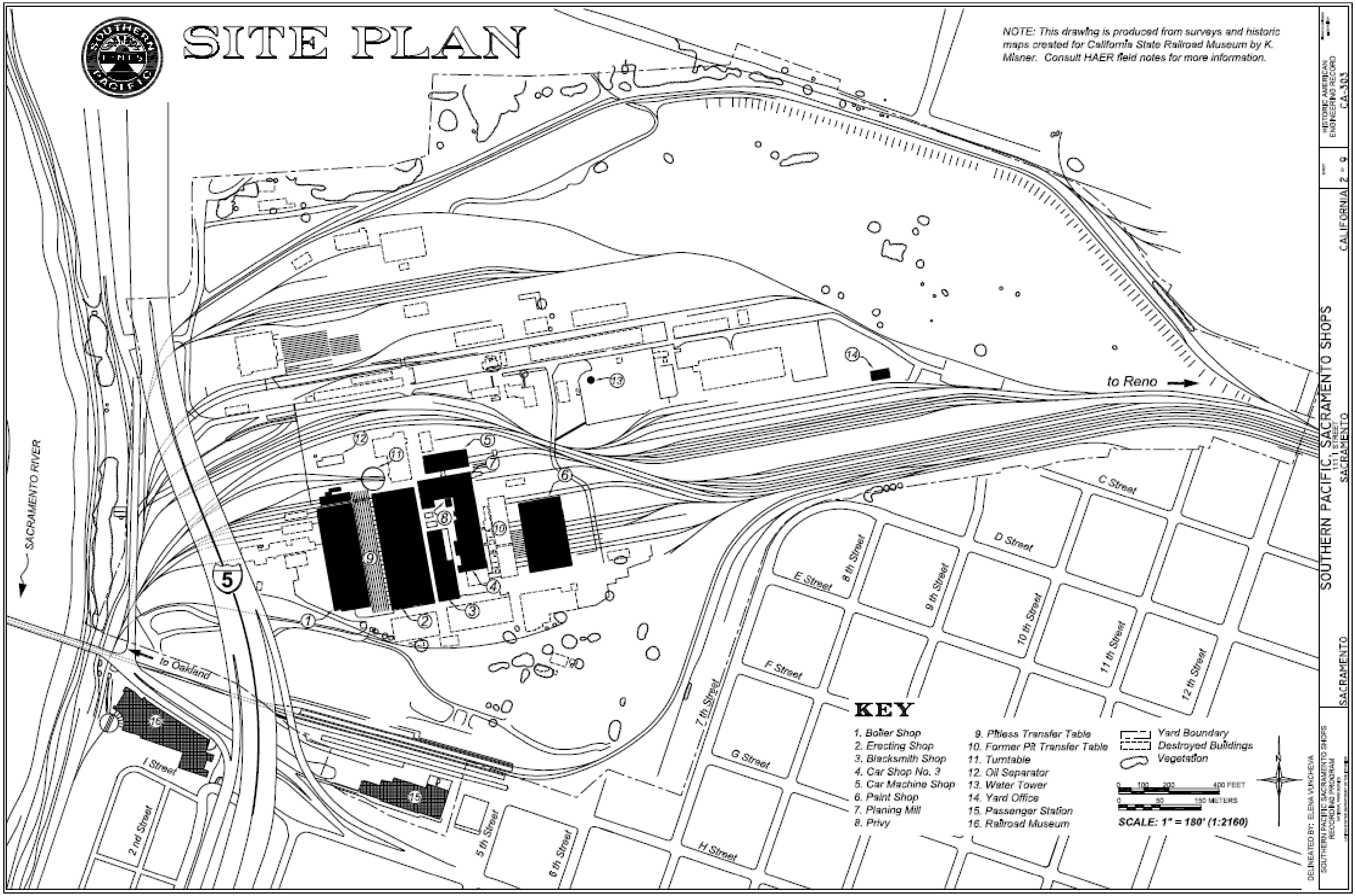

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- Environmental Phase Study - 2006
  - Predictions of groundborne vibration due to trains
  - Considered human response as well as building damage
  - FTA Guidance Manual methodology
  - Measurements of soil vibration characteristics in area
  - Ground excitation from previous projects involving freight and passenger trains
  - Vertical vibration levels predicted at building foundations of from 0.13 to 0.45 in/sec PPV (vertical) for freight
  - FTA criterion is 0.12 in/sec PPV for buildings extremely susceptible to vibration
  - Recommended further study in engineering phase to refine predictions and better evaluate building susceptibility

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- Engineering Phase Study - 2009
  - Predictions made of groundborne vibration from freight rail
  - FTA Guidance Manual - *Detailed Analysis* methodology
  - Additional measurements of site characteristics
  - Detailed measurements for freight and passenger trains
  - Peak vertical vibration of 0.32 in/sec predicted at building foundation 32 feet from freight train track
  - Corresponding peak lateral vibration is 0.24 in/sec
  - Obtained acceleration waveform of ground motion for typical freight train excitation
  - Structural engineering analysis – Finite Element Method
  - Reached conclusions based on induced strains

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- SGH conducted a site investigation of buildings and assessed susceptibility to groundborne vibration damage
  - Concern for 100+ year old unreinforced masonry construction building (Car Shop 3) with freestanding wall
- WIA conducted detailed analysis
  - Additional LSR’s measured
  - Measured FDL for freight and passenger trains
- WIA provided representative acceleration waveform to SGH, scaled to reflect expected vibration at site
- SGH performed an FEA with model of the Car Shop freestanding wall

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- Local soil conditions
  - Site is adjacent to Sacramento River
  - River used to flood regularly until levees were built
  - Surface layers consist of two fluvial-deposited sediments
  - Sedimentary layer of rock is at a depth of 3,000 feet
- 2009 Vibration predictions
  - Site LSRs indicate soil conducive to high vibration
  - LSR includes building foundation
  - Distance to the most sensitive building is 32 feet
  - Train speed of 30 mph
  - Measured freight FDL appears to include some wheel flats
  - Peak vertical vibration of 0.32 in/sec

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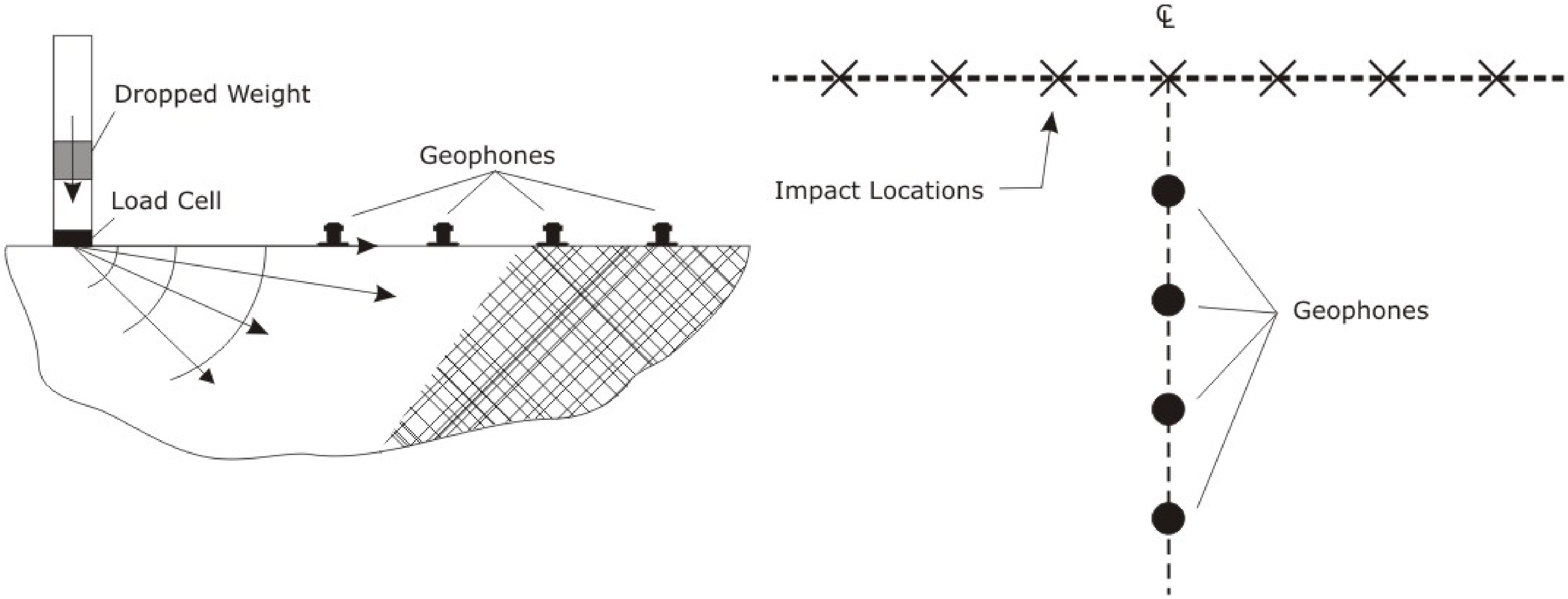

Vibration Propagation Measurements at Site

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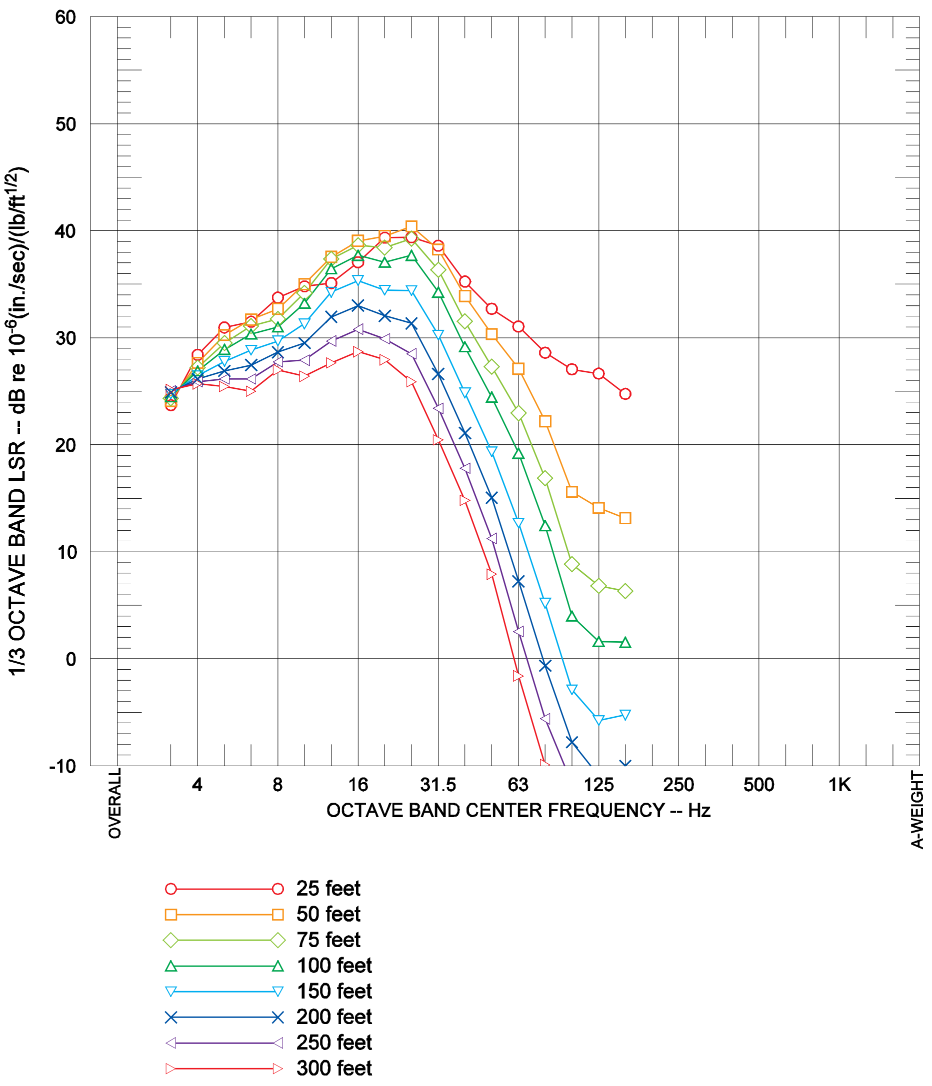

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Car Shop within the Central Shops Historic District

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- Findings of SGH building investigation
  - State of masonry walls varies considerably
  - Localized areas of large cracks due to foundation settlement
  - Some exterior masonry repointed and in relatively good condition
  - Where no repointing, exposed lime mortar in bad shape with little or no adhesion to brick
  - 1850 building worse than 1880 vintage buildings
  - Masonry walls either 3 or 4 wythes
  - Brick size: 2 ¼ ” high x 4” wide x 7⅞” long
  - ⅜” lime mortar joint

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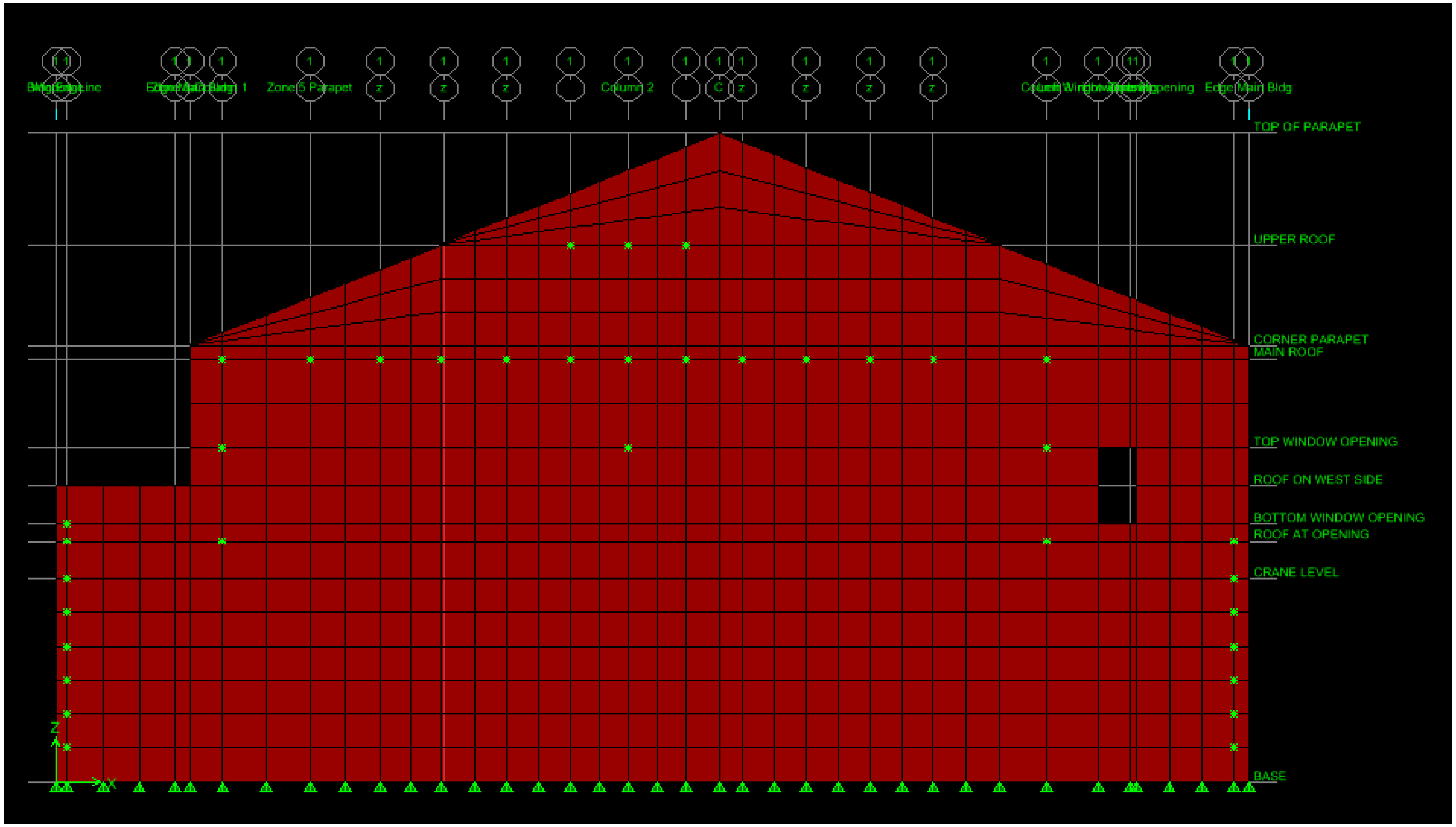

CSI ETABS FEA Model of Unreinforced Masonry Bearing Wall

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- SGH evaluated the unreinforced masonry bearing wall of the Car Shop for two load conditions:
  - Condition 1 : Out-of-plane loading of the wall due to lateral vibrations from a passing freight train traveling 30 mph, corresponding to a peak vertical particle velocity of 0.32 in/sec (wheel flats)
  - Condition 2 : Out-of-plane loading of the wall due to wind pressures based on historic wind speeds at local airport

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- Structural Evaluation Steps:
  - Create FEA model with elastic shell elements representing unreinforced masonry bearing wall in CSI ETABS
  - Condition 1: Freight train loads modeled as scaled, lateral ground acceleration time history
  - Condition 2: Typical maximum static wind loads
  - Run FEA model to analyze the building
  - Compare output from Conditions 1 & 2 and determine which loading is more severe on the wall
  - Check demands versus existing wall capacity for the more severe condition

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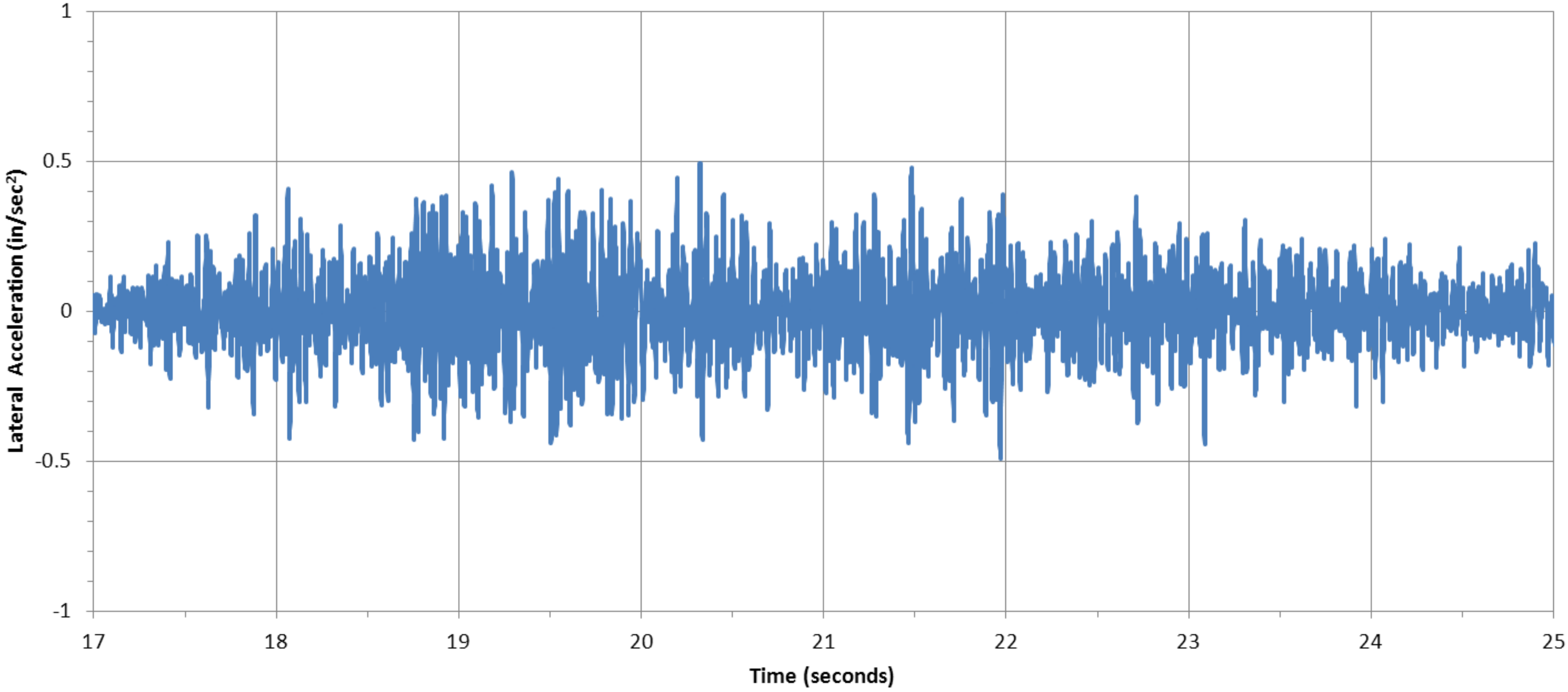

Typical (Un-scaled) Freight Train Lateral Acceleration Waveform

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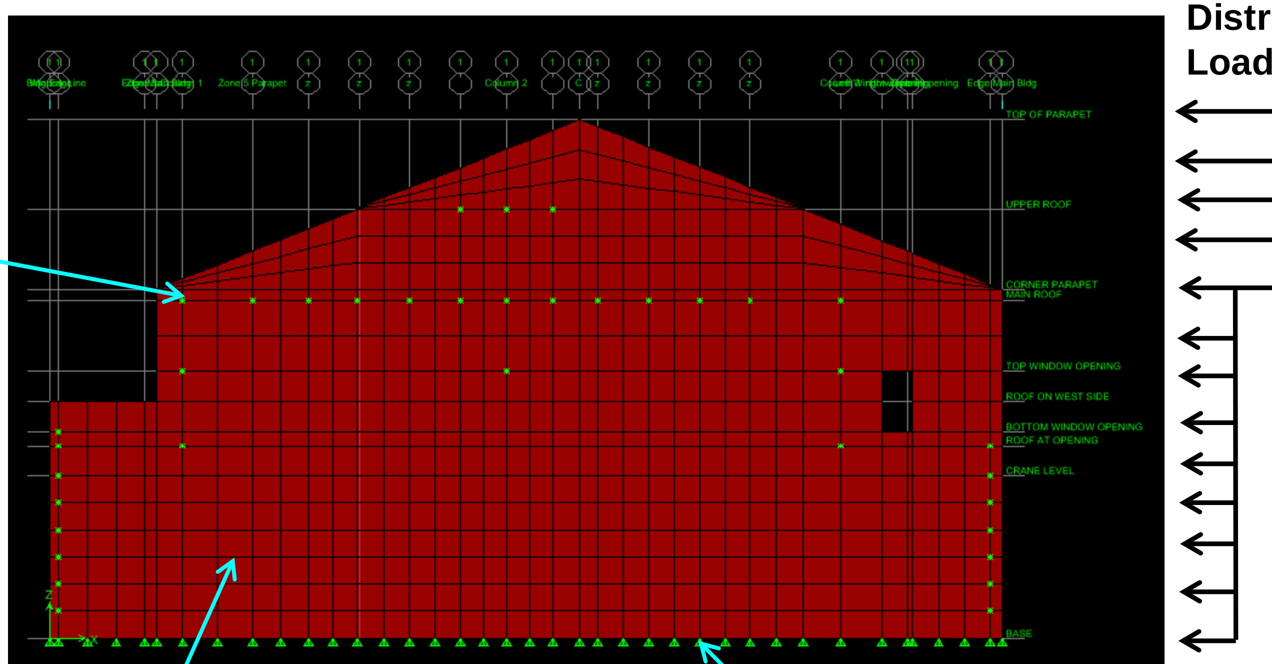
Distributed Wind Load

Out-of-Plane Restraint (Interface between masonry wall and roof framing)

X



14.5 PSF

7.3 PSF

Shell Element

Vertical and Out-of-Plane Restraint (Interface between masonry wall and foundation)

Wind Load Applied to Wall

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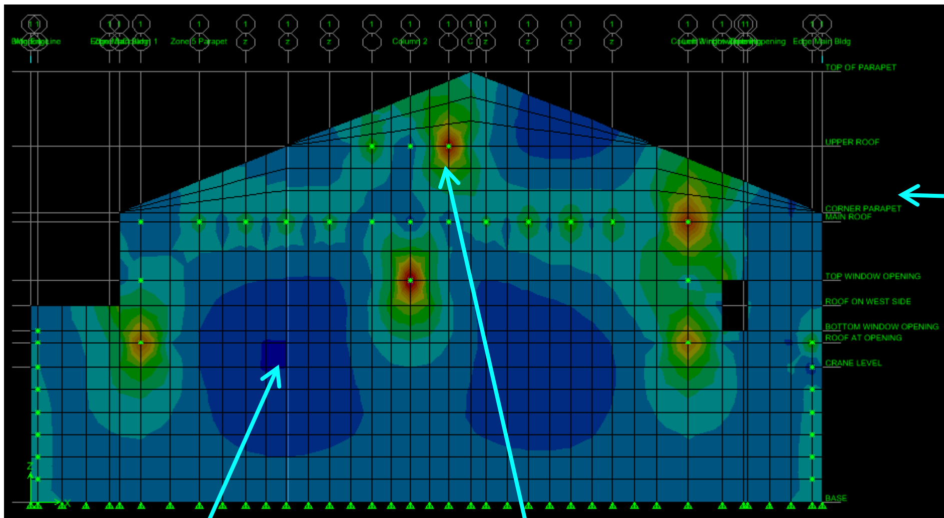
“Static” Wind Load FEA Model Response



Bending about Vertical Axis

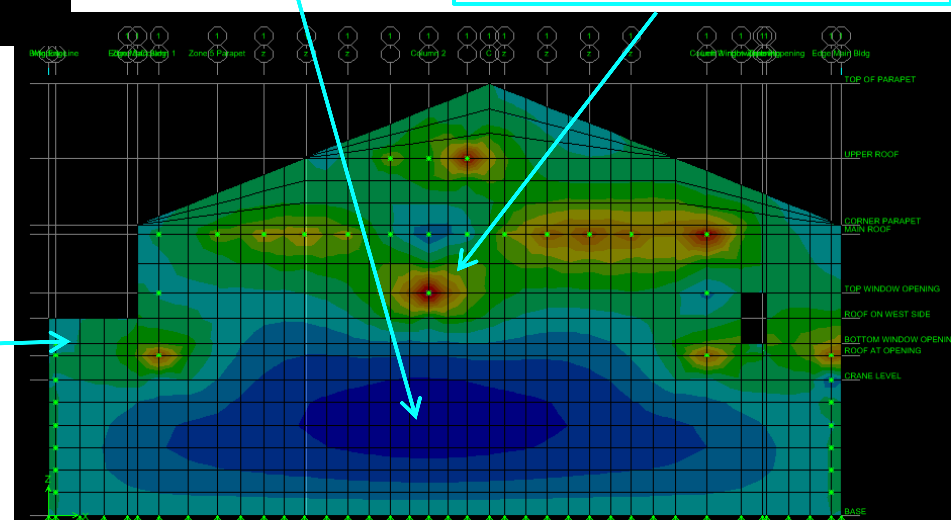
Peak Positive Curvature

Peak Negative Curvature

Peak Positive Curvature

Peak Negative Curvature

Bending about Horizontal Axis



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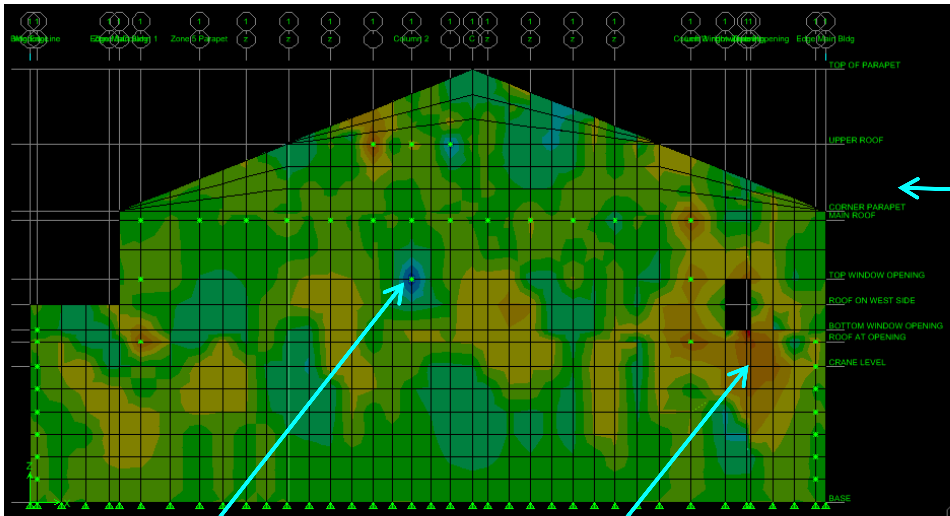
“Transient” Freight Train Load FEA Model Response



Bending about Vertical Axis

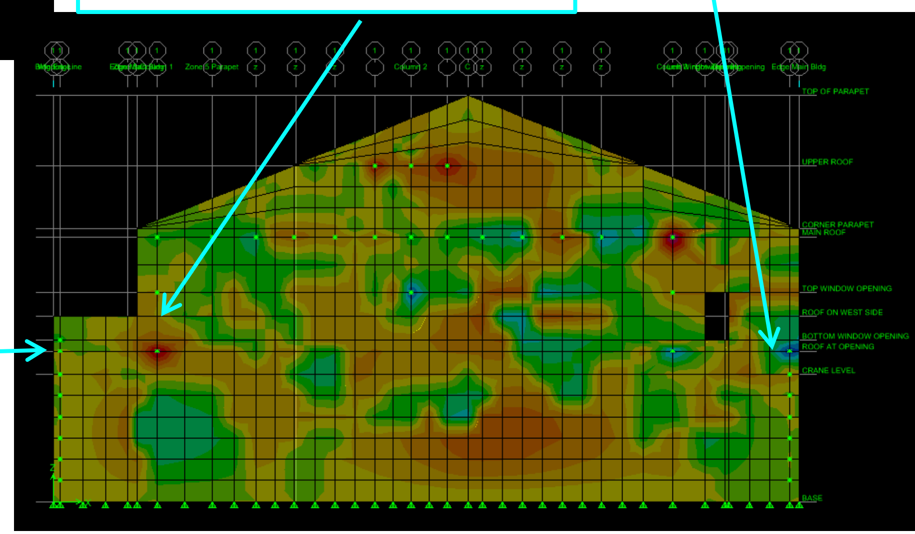
Peak Positive Curvature

Peak Negative Curvature

Bending about Horizontal Axis

Peak Positive Curvature

Peak Negative Curvature



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- Structural Evaluation Results:
  - Out-of-plane forces due to lateral train vibrations are smaller than historic based wind load demands at the site
  - Existing wall has been capable of withstanding wind loads over its 130 year existence
  - Existing wall is stable for the anticipated train induced ground vibrations predicted for the site

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- SGH Concluded:
  - Remedial work required for Car Shop structure to meet local codes and become serviceable to the public
  - If peak vertical vibrations are below 0.32 inches/sec at Car Shop then there should be no risk of masonry wall becoming unstable
  - Other building walls in Central Shops complex capable of withstanding this level of vibration in their current condition