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

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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
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
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
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
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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Car Shop within the Central Shops Historic District
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 7⅜” long
- ⅜” lime mortar joint
CSI ETABS FEA Model of Unreinforced Masonry Bearing Wall
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
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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Wind Load Applied to Wall

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

Shell Element

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

Distributed Wind Load

14.5 PSF

7.3 PSF
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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
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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 \textit{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