Karagozian & Case

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STRUCTURAL RESPONSE OF AN EARTH COVERED MAGAZINE TO A SIMULATED BLAST LOADING

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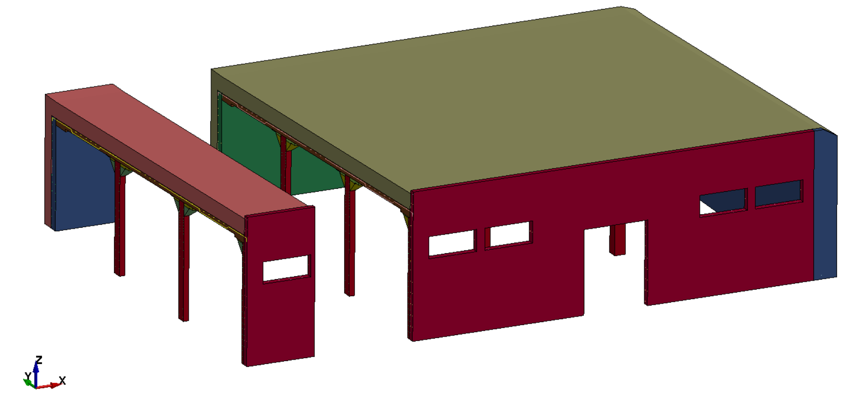
BRIEFING OUTLINE

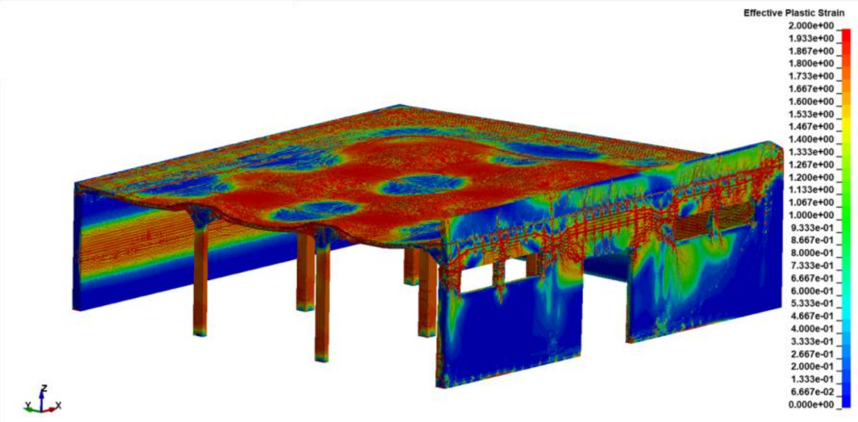
1. Background and Analytical Model Overview

1. *Geometry*
2. *Material Models*
3. *Boundary Conditions*
4. *Model Features*
   a. Reinforcing Steel Mesh
   b. Column Capital Mesh
5. *Load Application*



2. Analytical Model Results

1. *Partial Strip Model and Material Sensitivity*
2. *Half-Symmetry Model and Boundary Condition Effects*
3. *Half-Symmetry & Partial Strip Model Comparison*



3. Summary & Conclusions

1.0 BACKGROUND & MOTIVATION

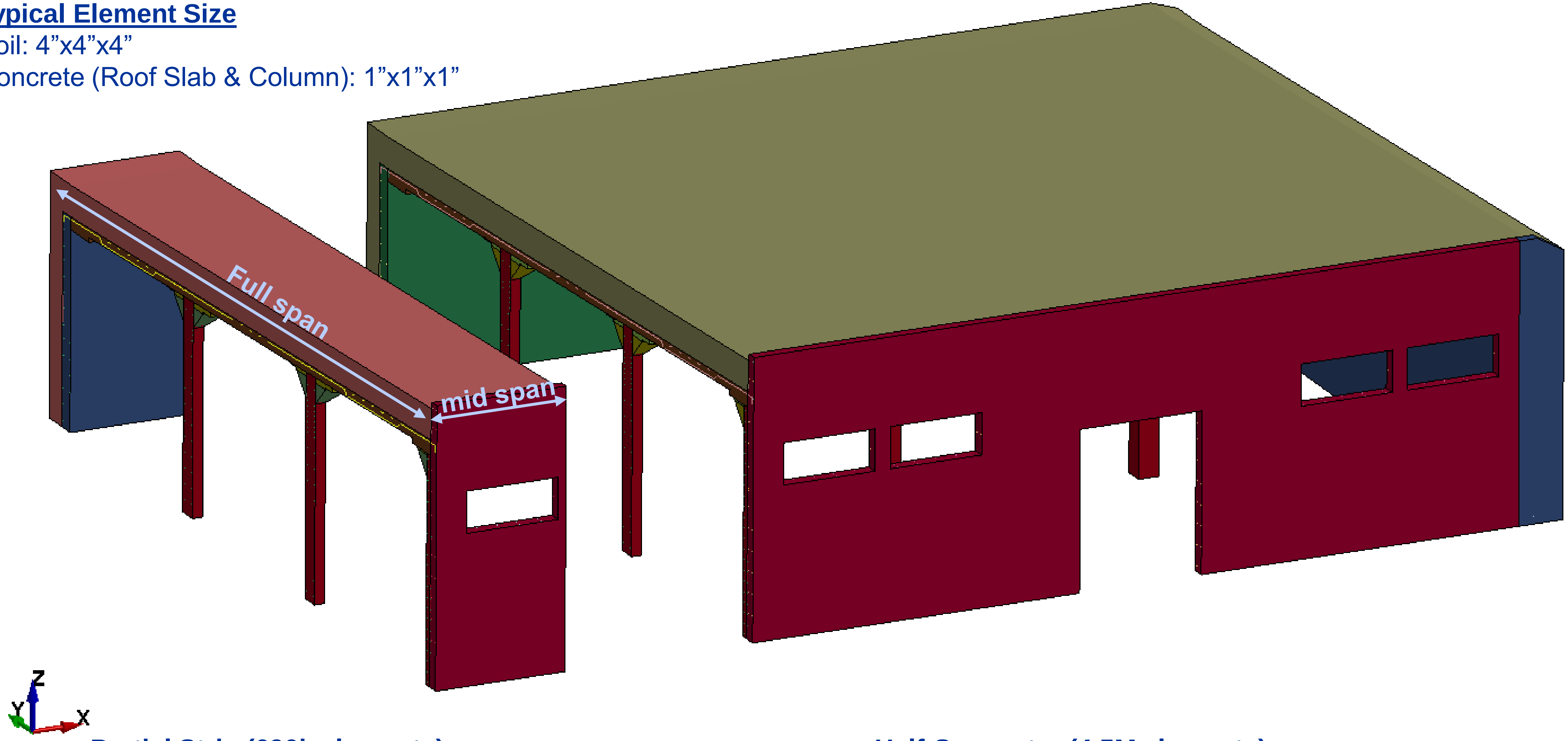
- Earth Covered Magazines (ECM) are used for storing ammunition and explosive materials
  - *Intended purpose is to mitigate sympathetic detonation risk*
  - *Need to meet loading criteria of DoD 6055.09-M*
  - *Some ECM designs may have been validated with field tests, while others may need additional analysis*
  - *Older ECM designs may need additional modern analysis to demonstrate their roof can withstand loads from external explosions*

- The project this work was a part of was an effort to better understand the response of a representative ECM to a roof-applied air-blast load
  - *Previous SDOF calculations gave failure capacity of columns and roof slab*
  - *Desire to predict roof slab or debris velocity in the event of failure*

- This presentation covers a portion of the modeling effort
  - *Challenges of modeling this problem with FEA*
  - *Material strength effects*
  - *Boundary condition effects*

1.1 ANALYTICAL MODEL GEOMETRY

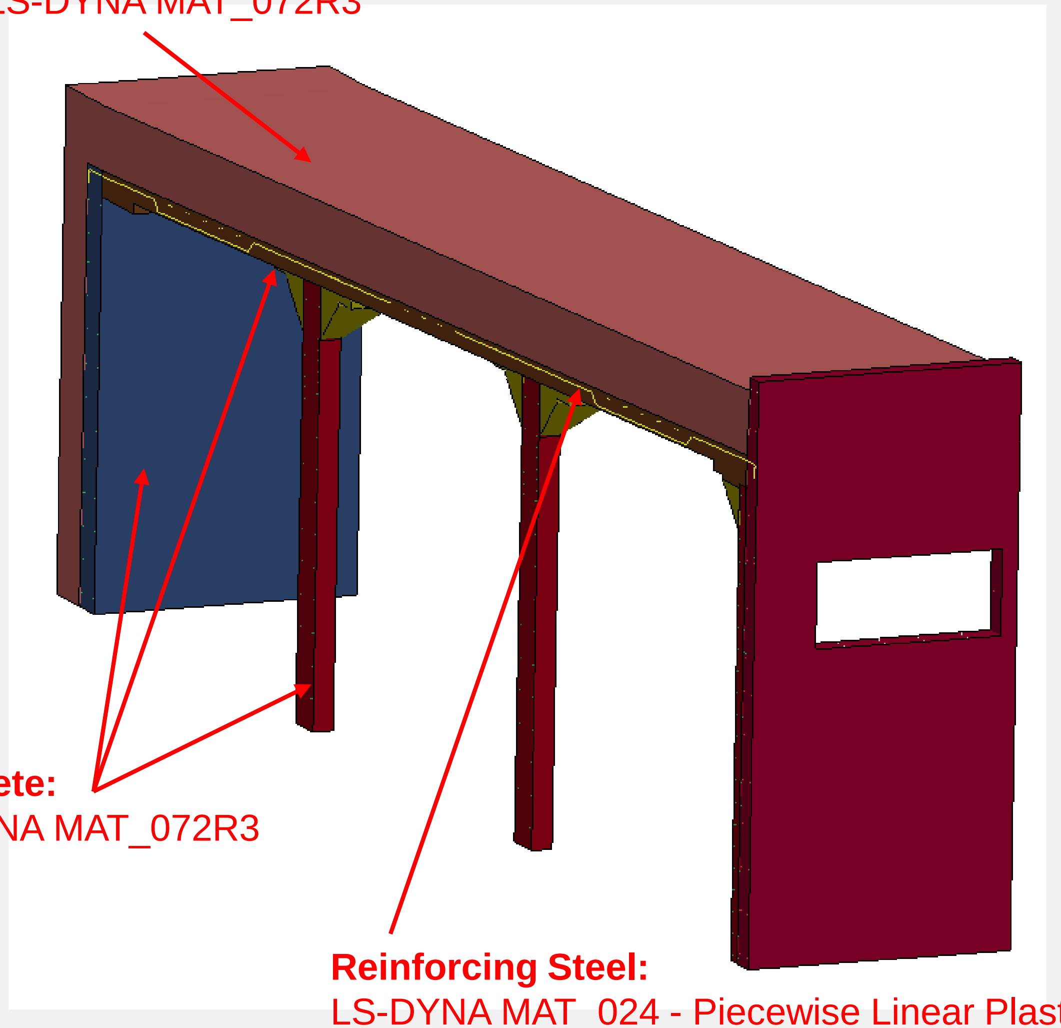
Typical Element Size
Soil: 4”x4”x4”
Concrete (Roof Slab & Column): 1”x1”x1”



Partial Strip (690k elements)
Identify load at which ECM collapses & assess sensitivity of ECM response to material properties

Half-Symmetry (4.5M elements)
Assess ECM response for critical load and material property combinations identified by partial strip model

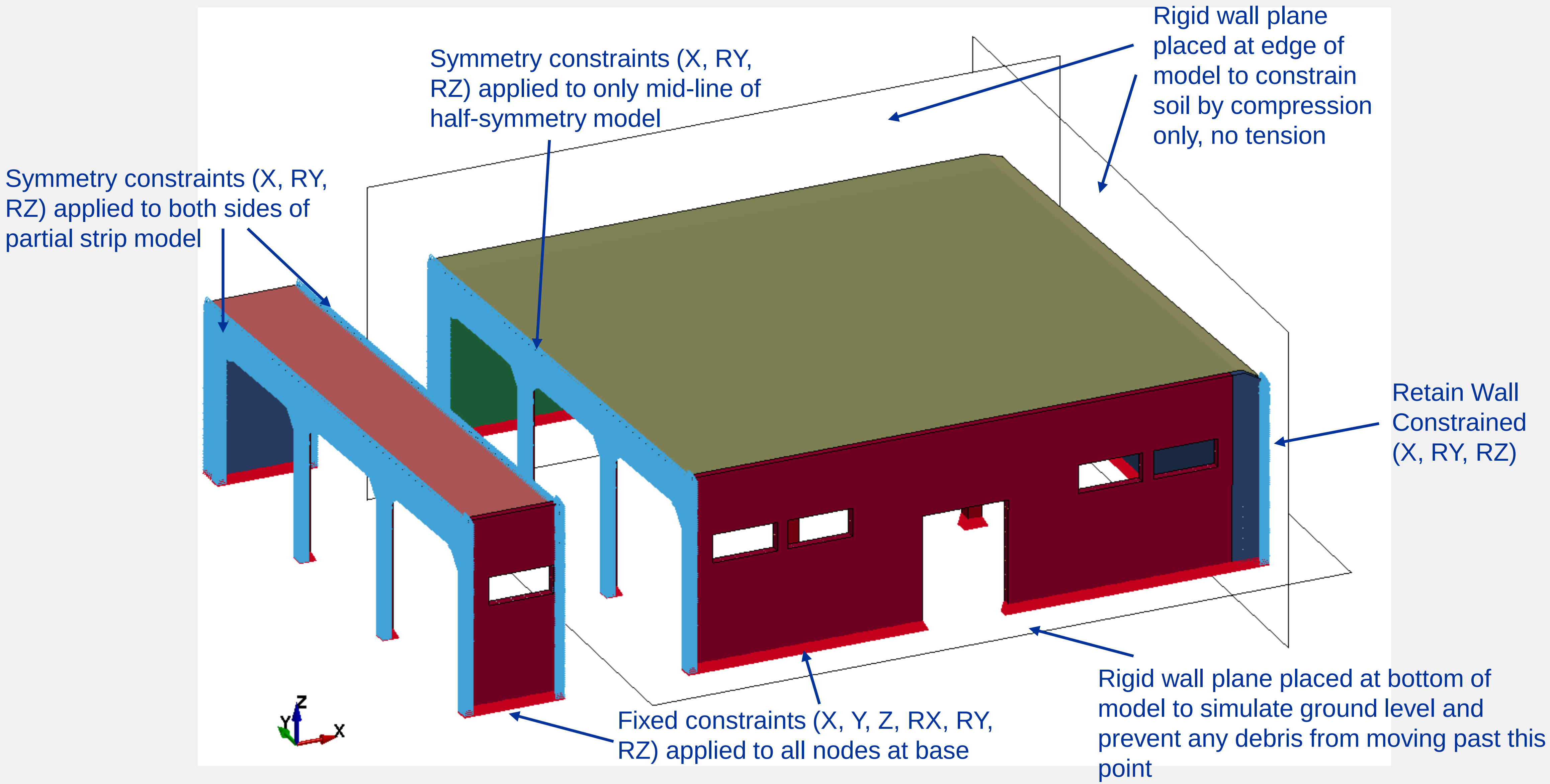
1.2 MATERIAL MODEL INFORMATION



	Target Material Strength	Notes
Concrete	f'_c = **2,500 psi**	K&C Concrete, Release 3, Fit 6 Principal strain @ failure: 0.8
	f'_c = **8,000 psi**	K&C Concrete, Release 3, Fit 6 Principal strain @ failure: 0.8
Steel	F_y = **40 ksi**	ASTM A36 steel basis for material model fit
	F_y = **50 ksi**	ASTM A572, Gr. 50 steel basis for material model fit
Soil		K&C Concrete, Release 3; fit based on characterization tests for soil classified as silty sand with some gravel; average dry bulk density of 114.9 pcf

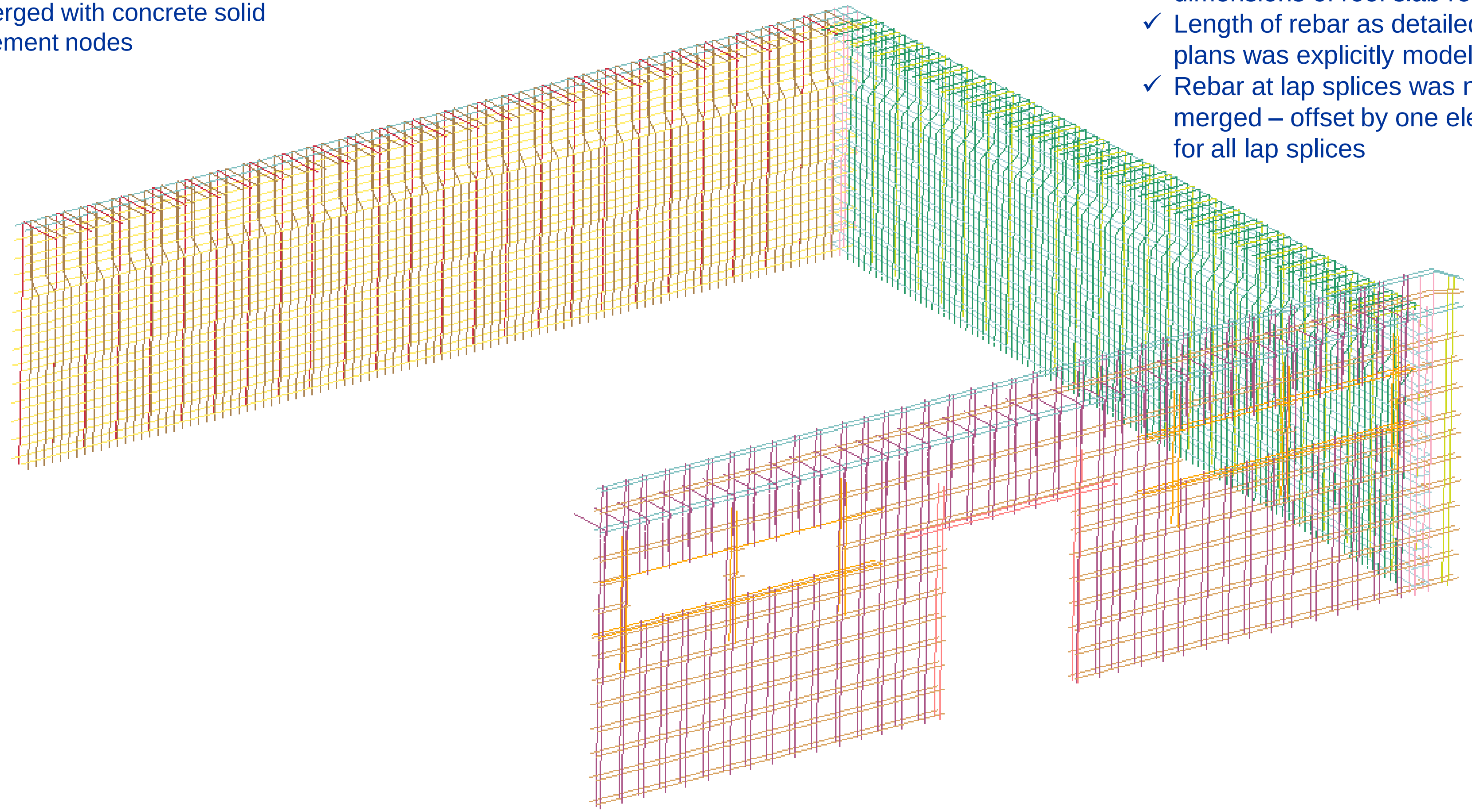
- ✓ Concrete upper bound strength based on in-situ testing performed by NAVFAC
- ✓ Concrete lower bound strength is specified unconfined compressive strength from drawings
- ✓ Basis of design drawings indicate reinforcing steel permissible tensile stress is 20 ksi, which per Section A.3.2 of ACI 318-89 correlates to either Grade 40 or Grade 50 reinforcement
- ✓ Previous studies done with MAT_072R3 (MAT_CONCRETE_DAMAGE_REL3) used to validate material fit for both soil and concrete models

1.3 ANALYTICAL MODEL BOUNDARY CONDITIONS



1.4.1 REBAR DETAILS

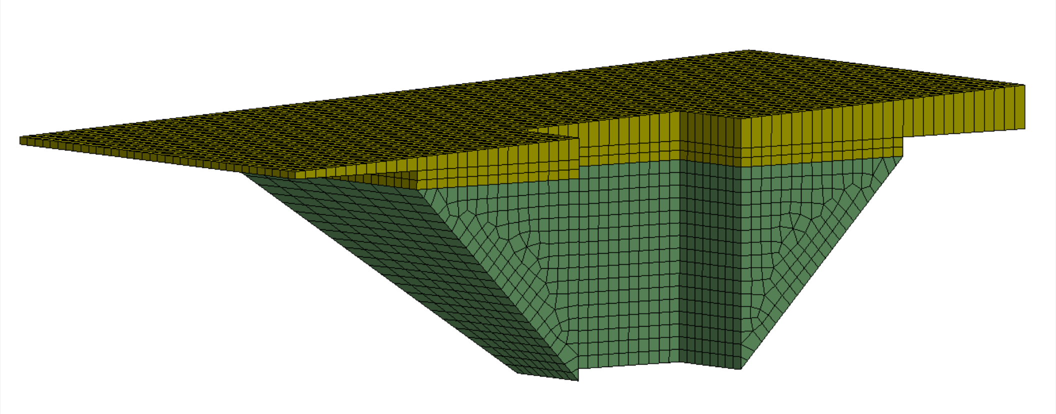
Rebar beam elements merged with concrete solid element nodes

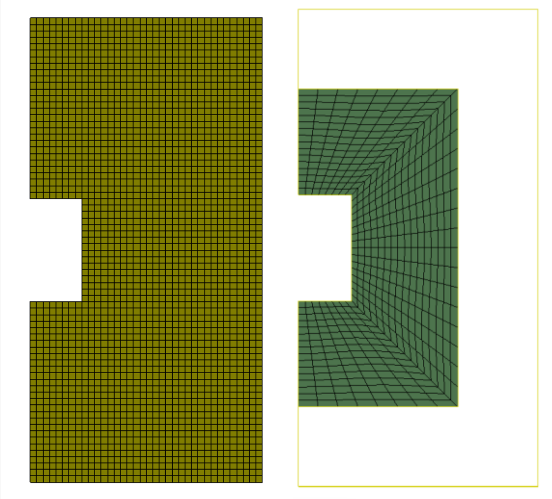


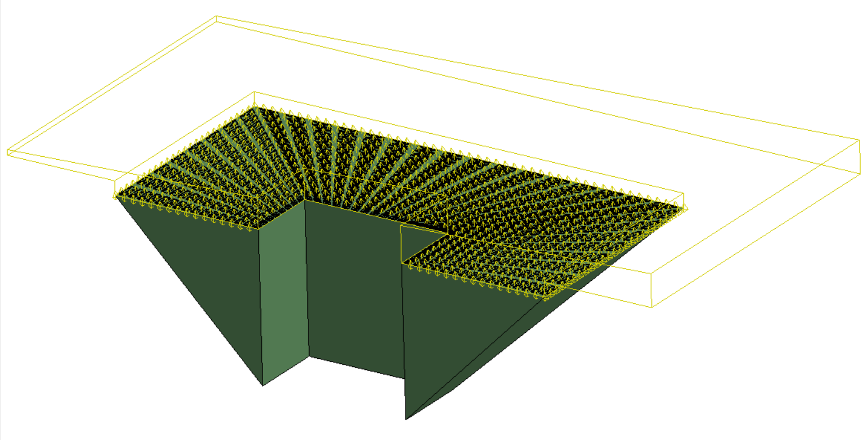
- ✓ Details from floor plan used to determine spacing and dimensions of roof slab rebar
- ✓ Length of rebar as detailed on plans was explicitly modeled
- ✓ Rebar at lap splices was not merged – offset by one element for all lap splices

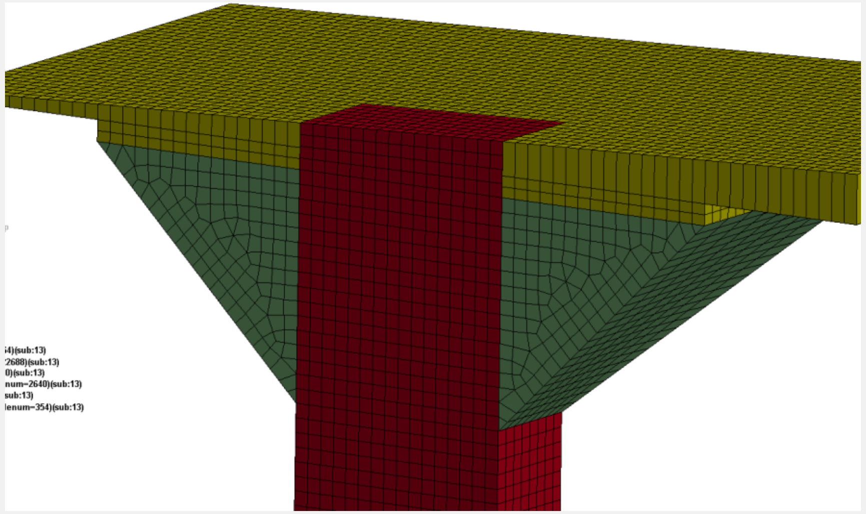
1.4.2 COLUMN CAPITAL MESHING

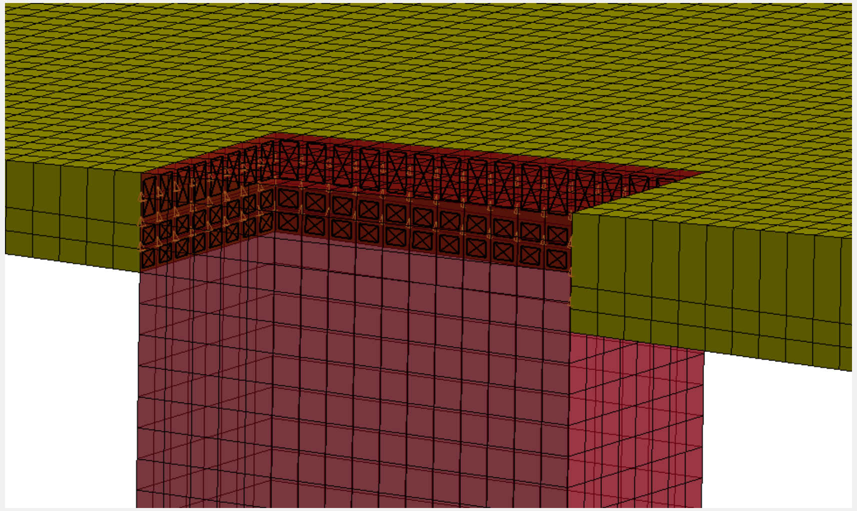
- Nodes typically merged, except drop panel connection used tied contact due to geometry





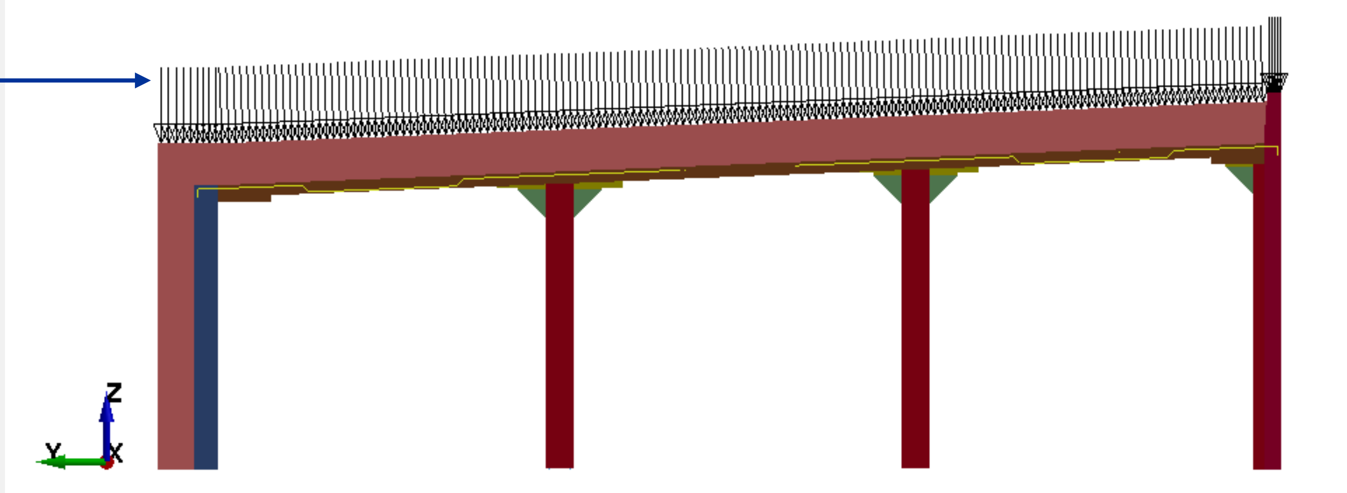




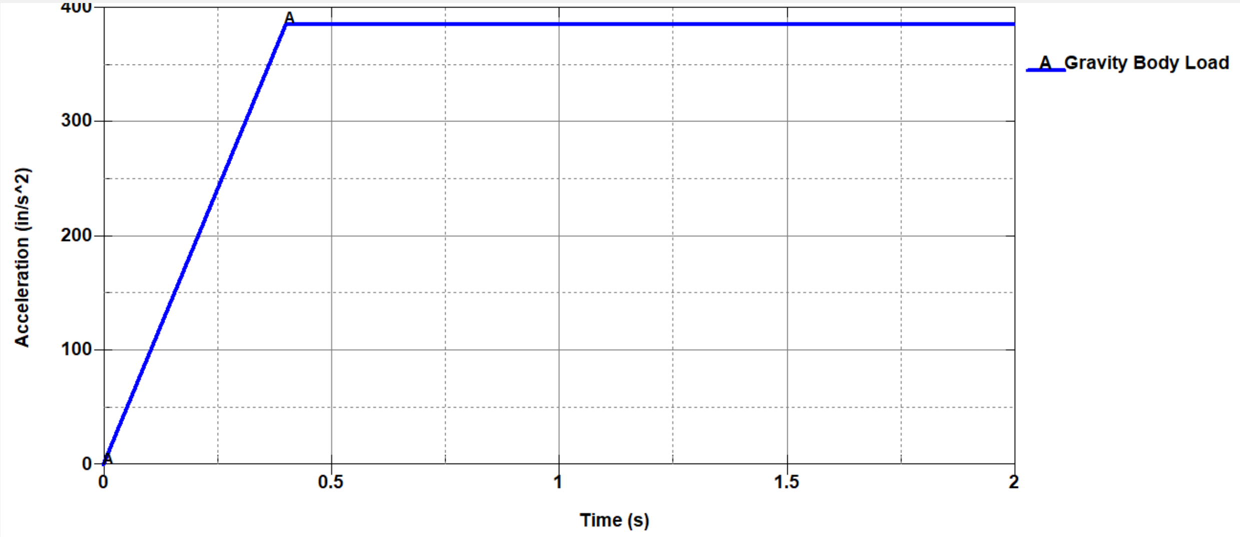


1.5 LOAD APPLICATION

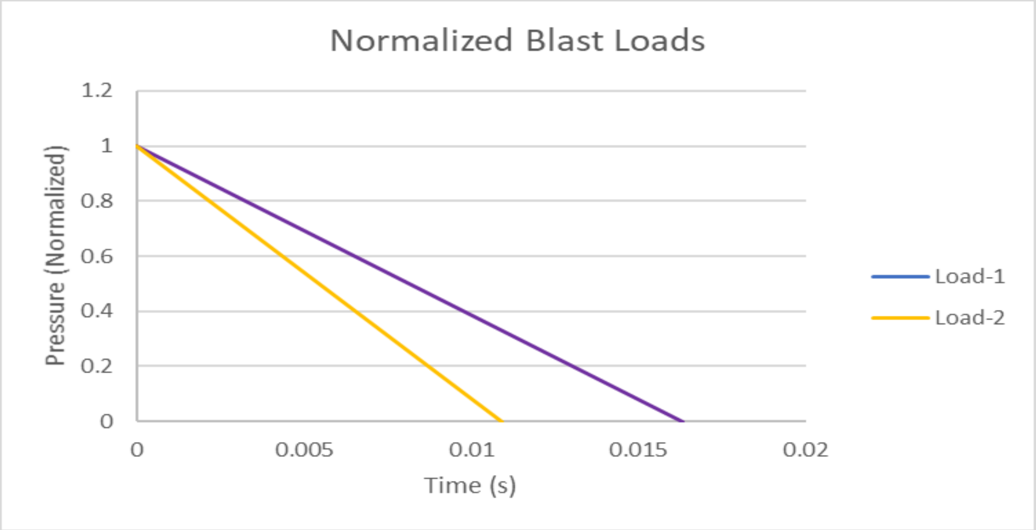
Blast load was applied to top of soil



Simplified blast load allows comparison to previous SDOF studies and is required for design of magazines. This simplified load increases overall impulse seen during loading.



Gravity load was applied to all bodies, ramped up to 386.1 in/s^2 during the first 400ms of simulation, and then held steady

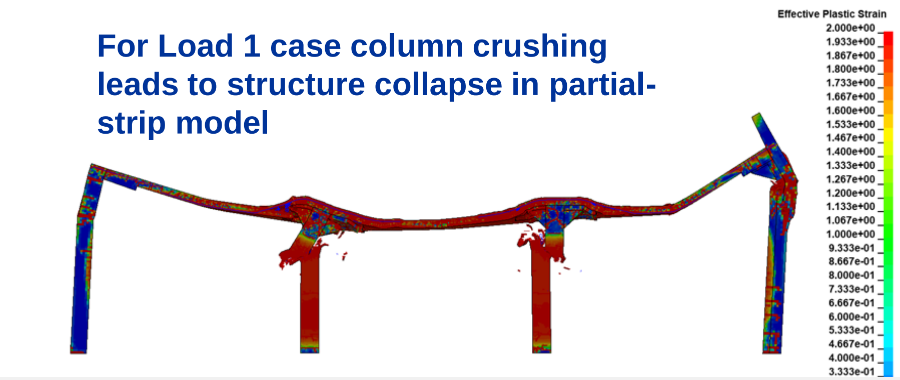


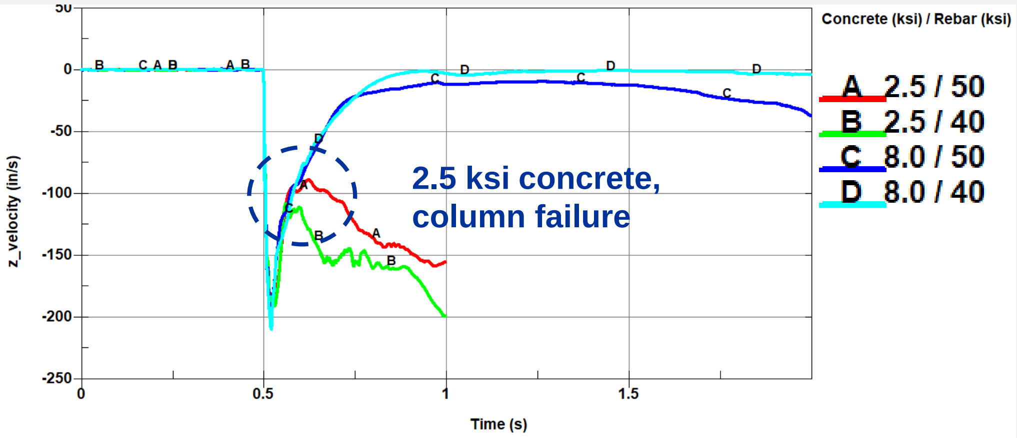
The structure dynamic response was given 100ms to settle after the gravity load was ramped up, and then at 500ms the blast load was applied

2.1 PARTIAL STRIP MODEL RESULTS & SENSITIVITY TO MATERIAL PROPERTIES

Load 1

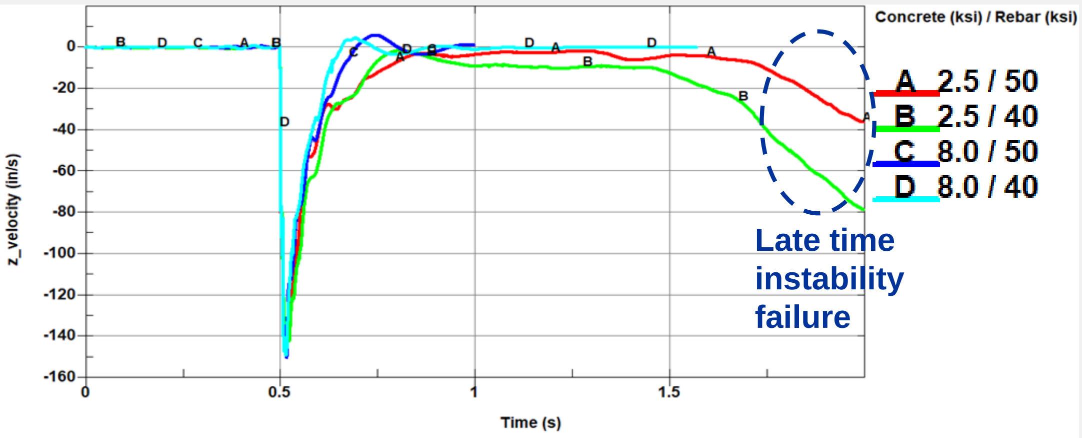
For Load 1 case column crushing leads to structure collapse in partial-strip model





Load 2

For some Load 2 cases, structure collapse occurred at late time following rotation of column / wall



Load 1: Cases w/ 2.5 ksi concrete exhibit column crushing and subsequent structure collapse early in simulation time

Load 2: Both cases w/ 2.5ksi concrete rack at late time and ultimately collapse, indicating insufficient lateral resistance of structure (i.e., artifice of partial strip model boundary conditions)

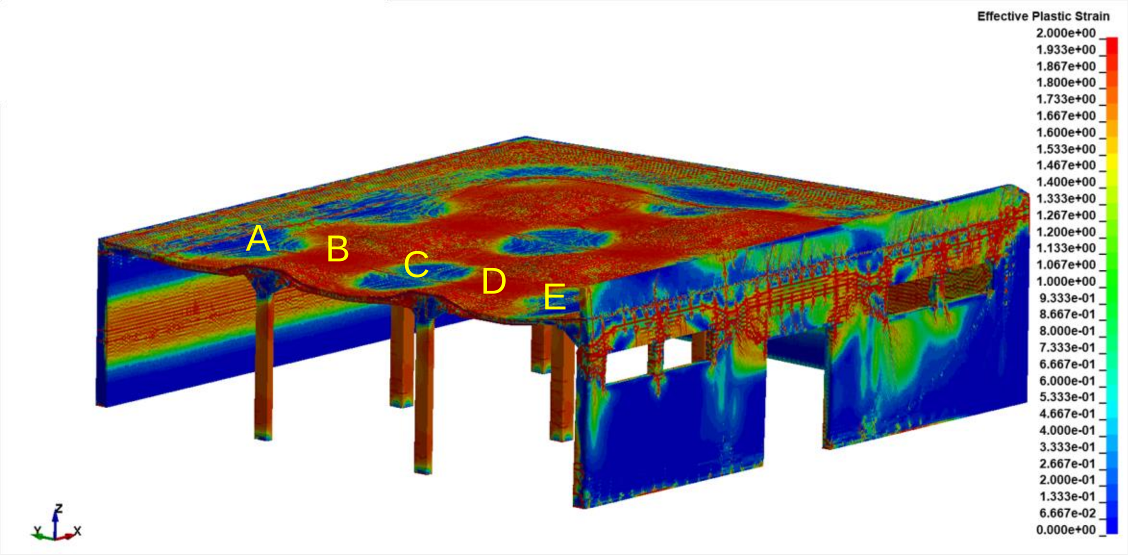
Structure response shows greater sensitivity to concrete unconfined compressive strength than rebar yield strength

2.2 HALF-SYMMETRY MODEL RESULTS & BOUNDARY CONDITION EFFECTS

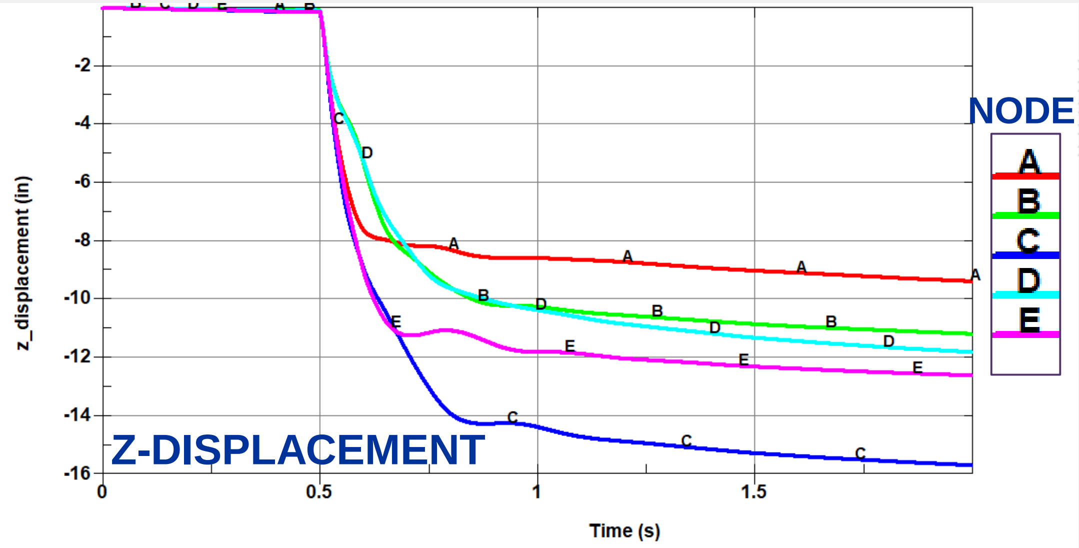
Load 2 (2.5 ksi concrete / 50 ksi reinforcement)

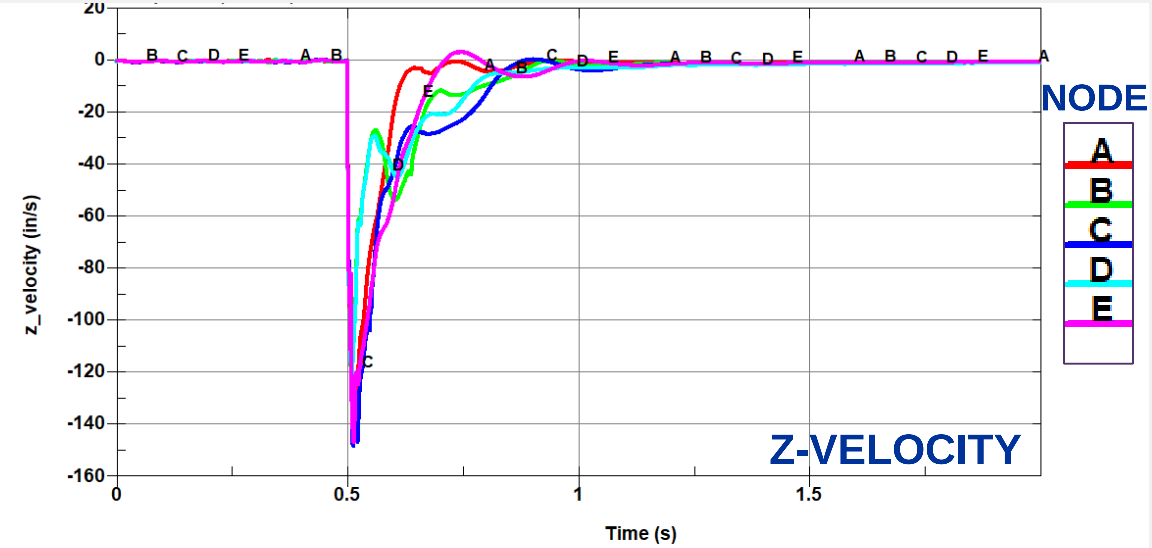
This material configuration with the partial-strip model showed late-time instability and failure, but here with the half-symmetry model there was stability and no failure

Nodes A, B, C, D, E in the plots below correspond to nodes in image to the right

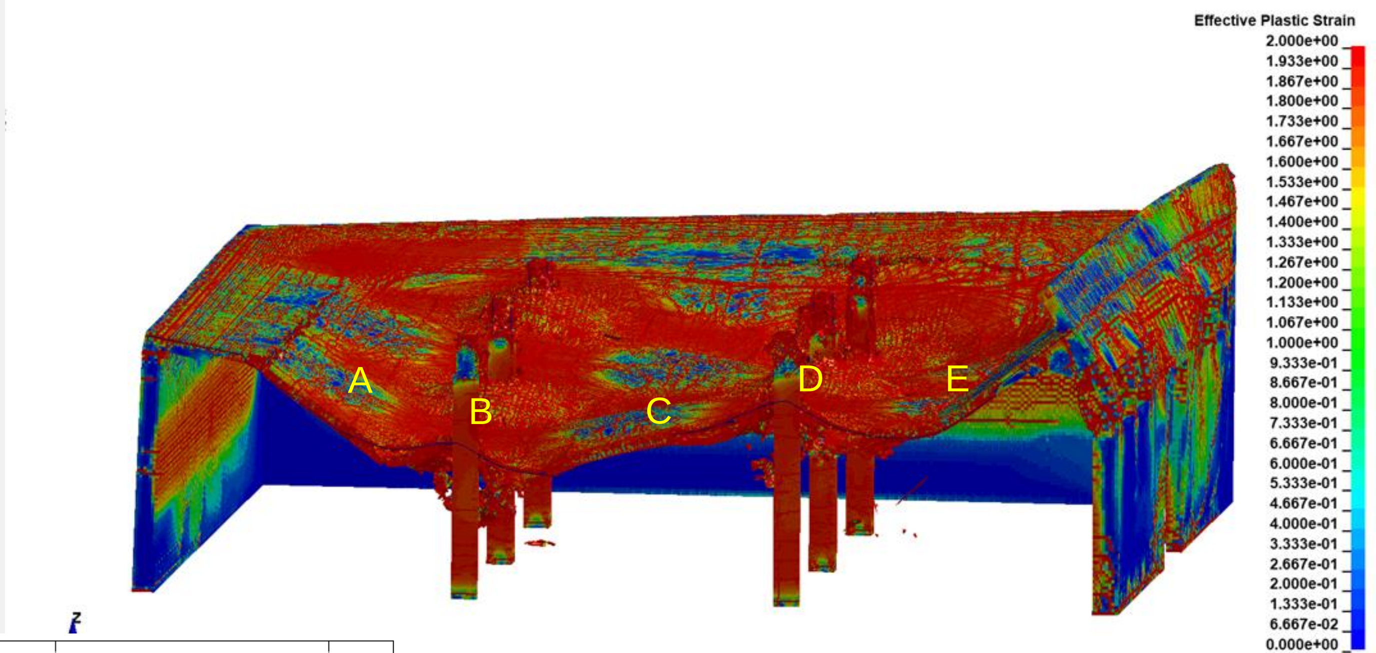


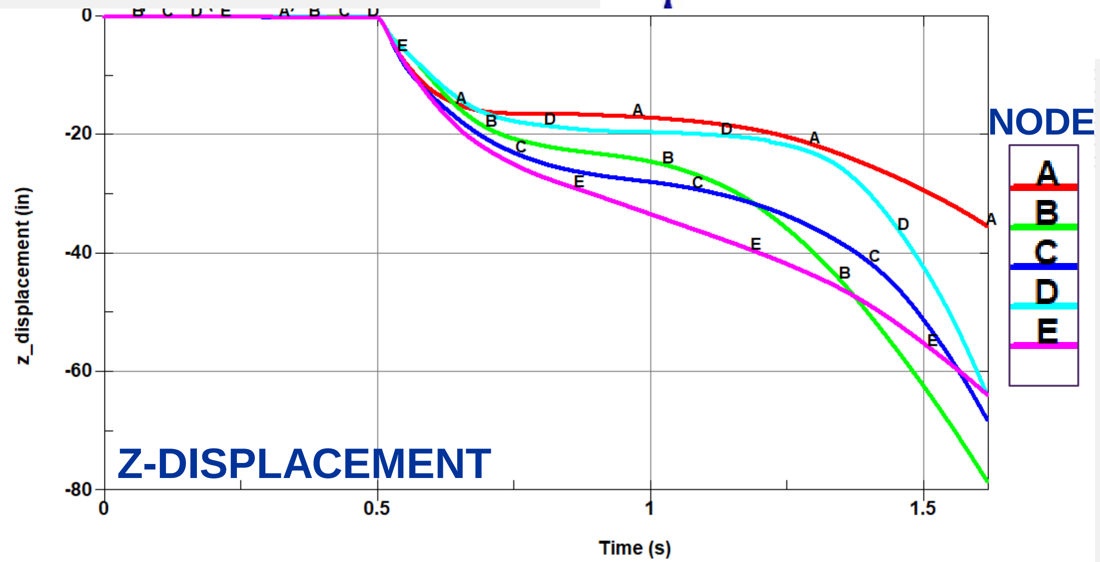
Roof slab nodal velocity settles at 0 in/s w/o roof slab being thrown in

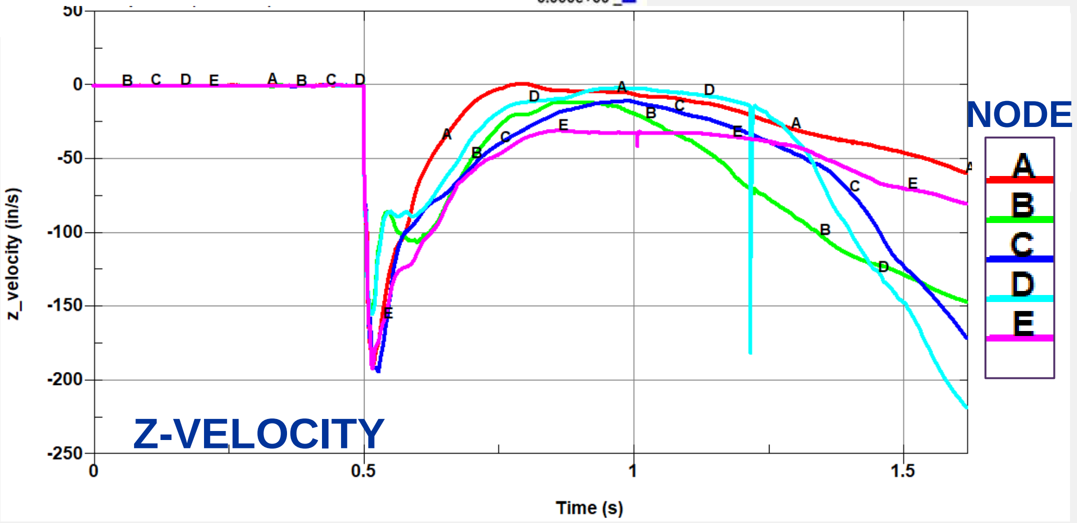




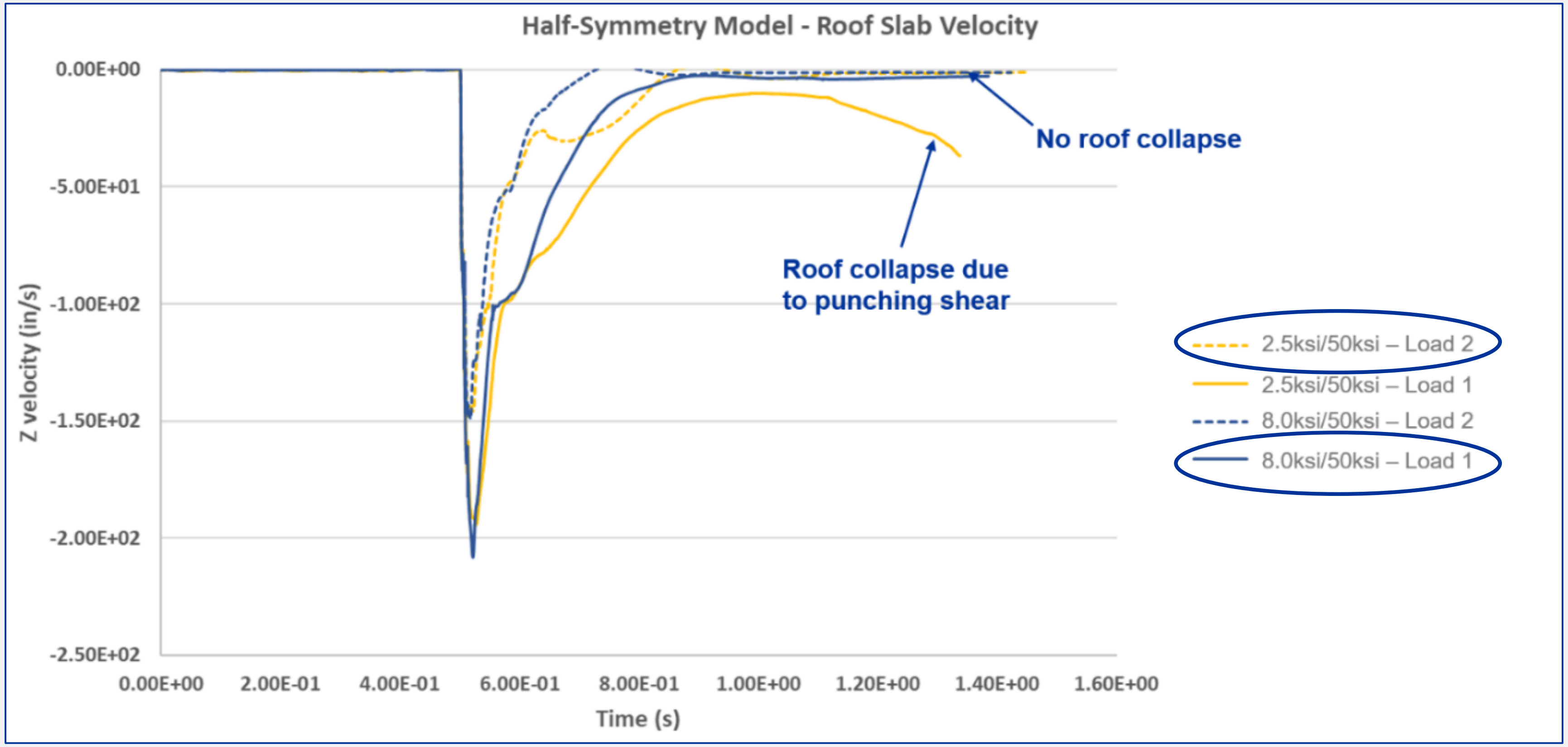
LOAD 1 (2.5 KSI CONCRETE / 50KSI REBAR) ROOF SLAB DISPLACEMENT & VELOCITY







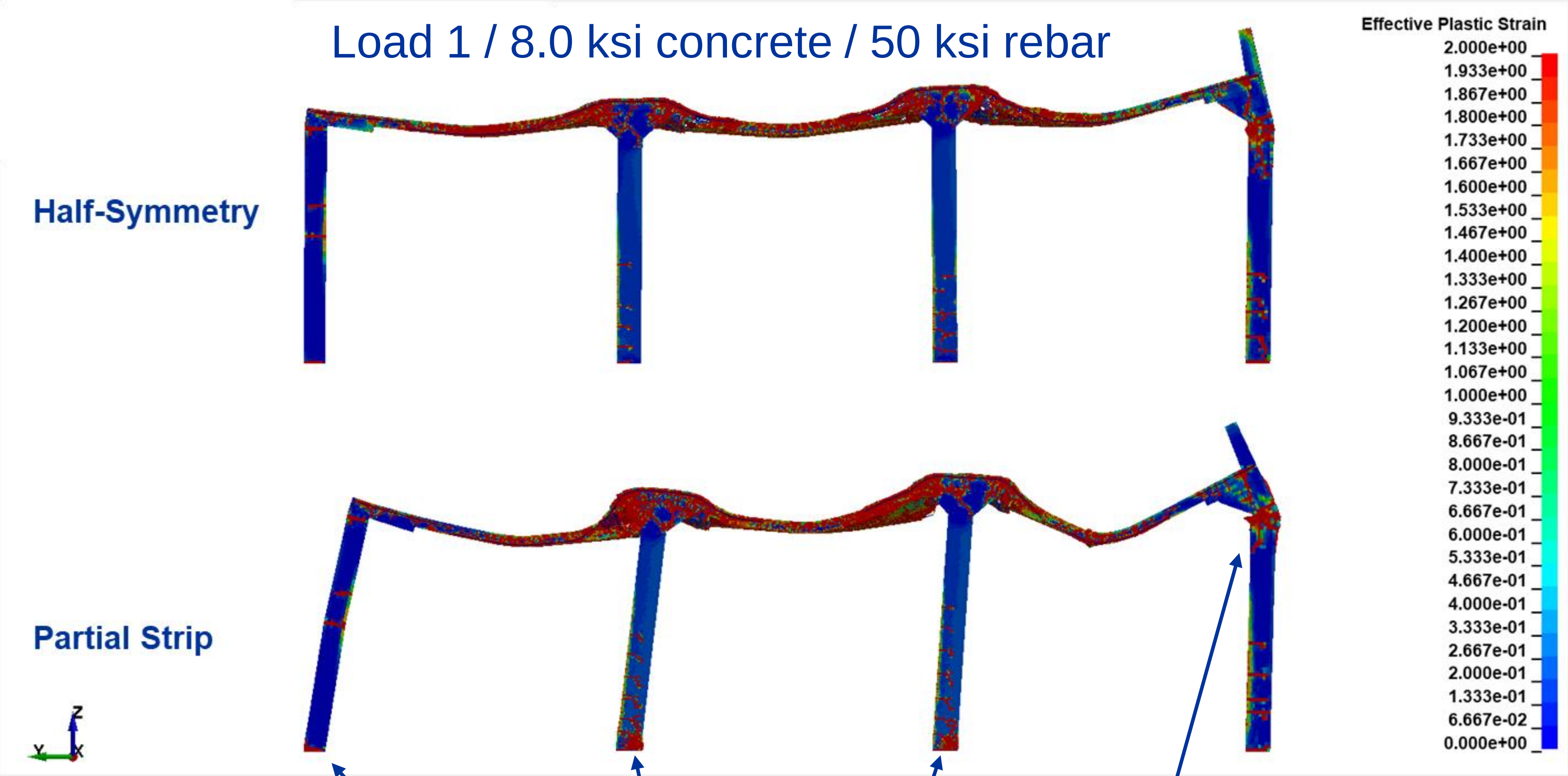
HALF-SYMMETRY MODEL ROOF SLAB VELOCITY SUMMARY



These cases showed instability and failure with the partial-strip model, but with the half-symmetry model showed stability and no roof collapse

2.3 HALF-SYMMETRY & PARTIAL STRIP MODEL COMPARISON

DEMONSTRATE LATE TIME INSTABILITY OF PARTIAL-STRIP COMPARED TO STABILITY OF HALF-SYMMETRY

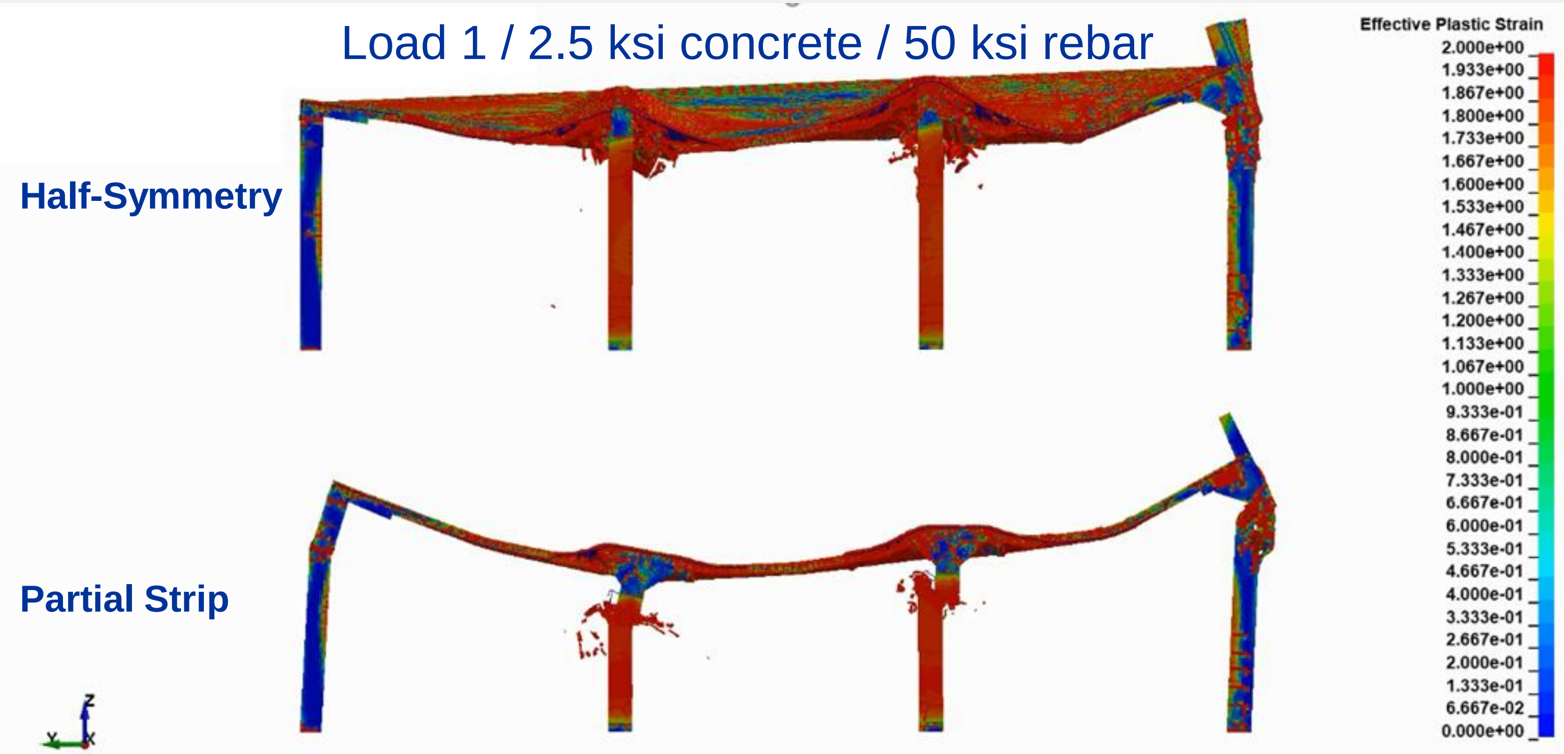


Boundary instability at column base

Bending of rear and front walls in partial-strip model

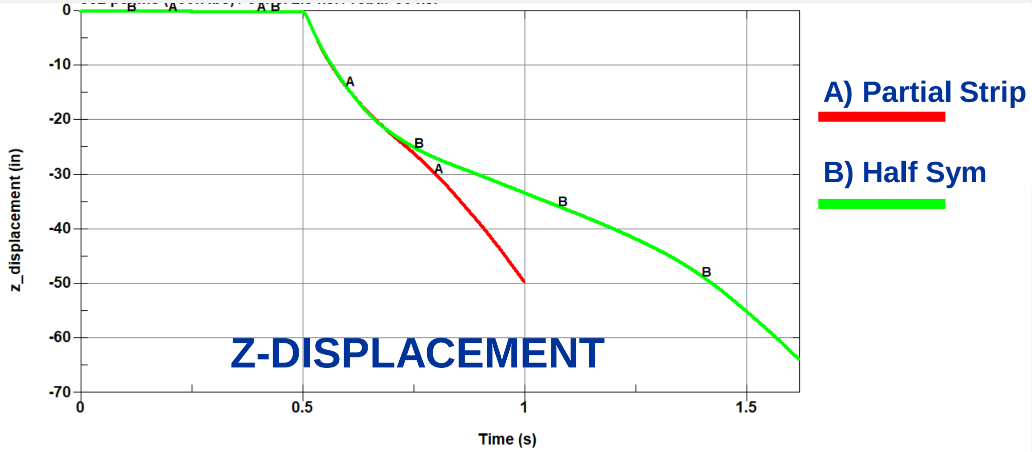
The presence of the side wall in half-symmetry model serves to preclude the late time racking failure observed in partial strip model

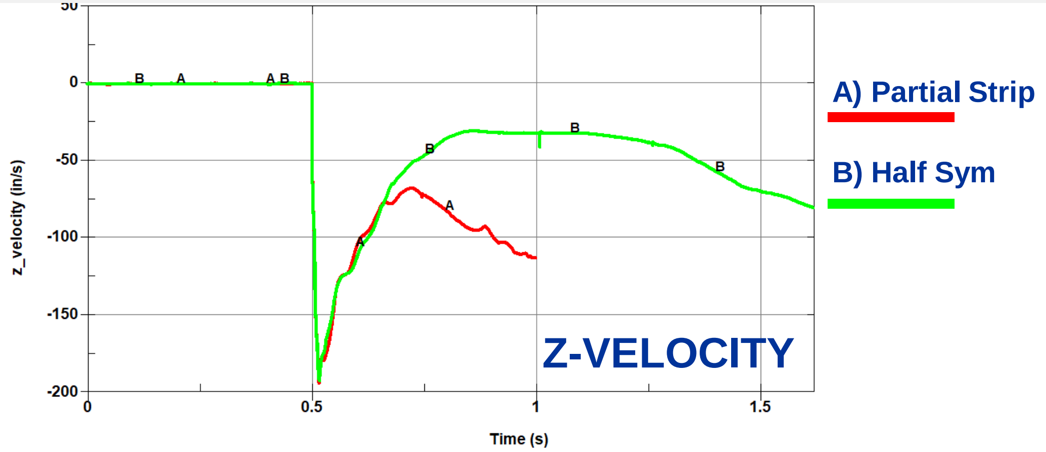
FAILURE MECHANISM DIFFERENCES BETWEEN HALF-SYMMETRY AND PARTIAL-STRIP



Partial strip model exhibited column crushing failure as governing failure mode while half-symmetry model exhibited punching shear failure in roof slab

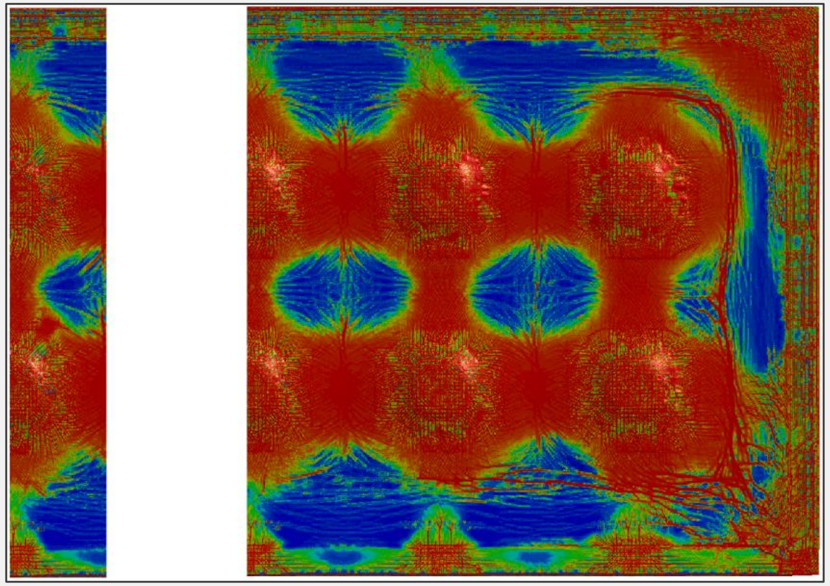
Both models led to complete structure collapse





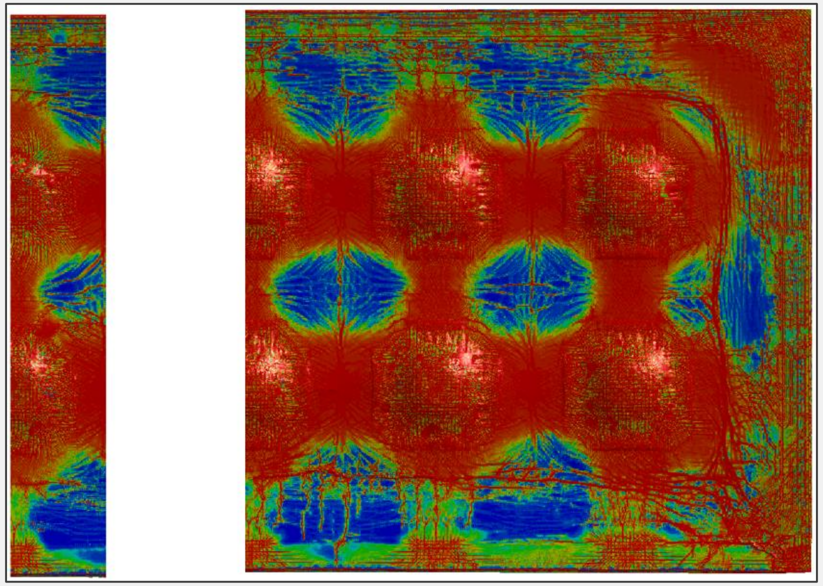
LOAD 1 WITH 2.5 KSI CONCRETE / 50 KSI REBAR: TOP SLAB DAMAGE PROGRESSION

Partial Strip | Half-Symmetry



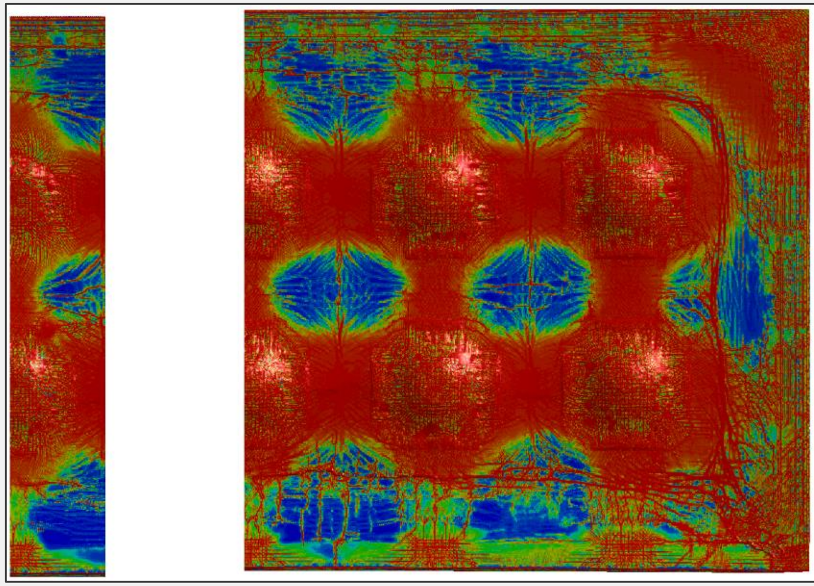
600ms

Partial Strip | Half-Symmetry

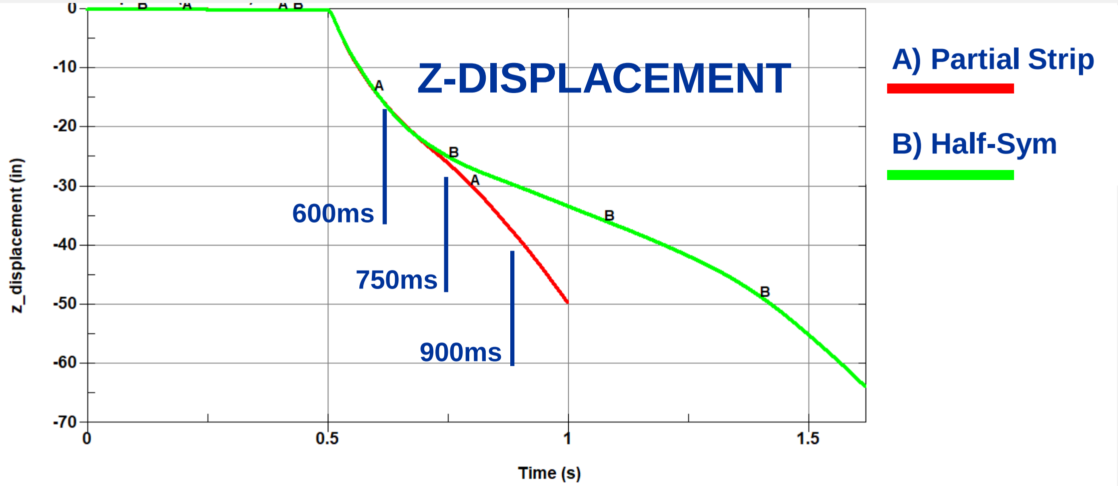


750ms

Partial Strip | Half-Symmetry



900ms

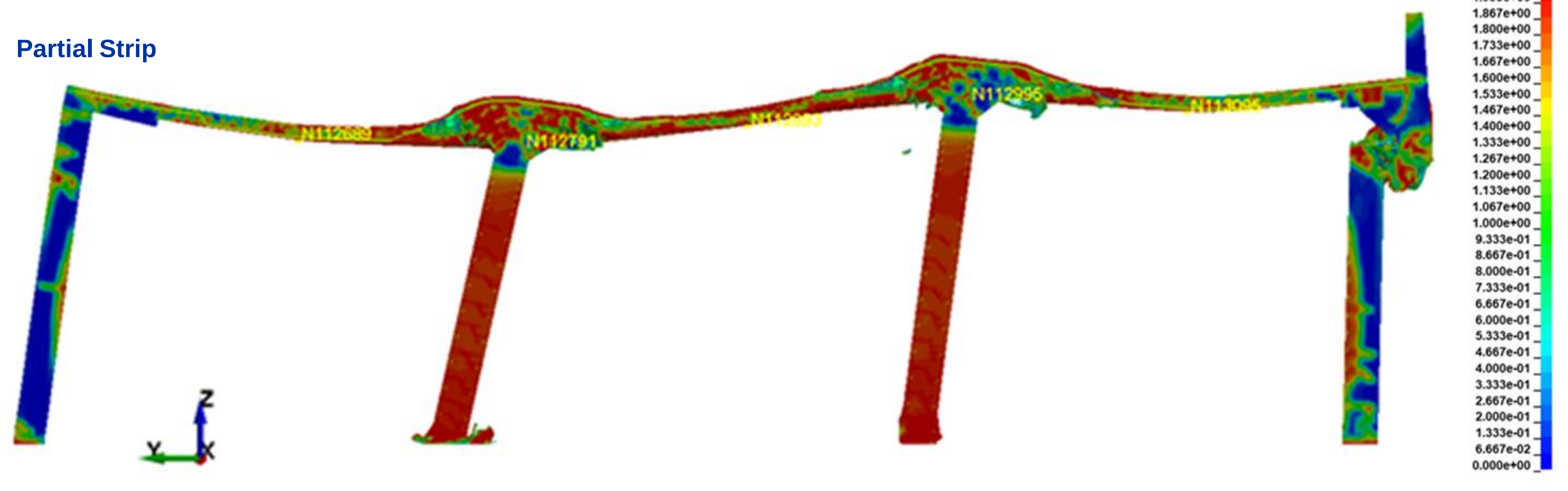


Half-symmetry model response begins to diverge from partial-strip model at approximately 700ms.

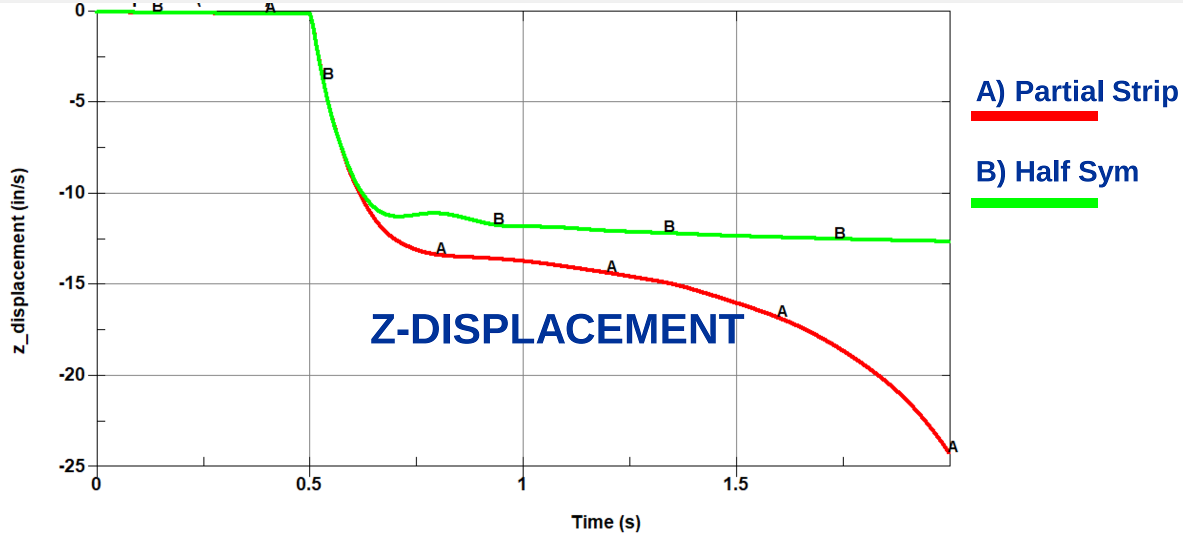
In half-symmetry model, front/back walls are restrained from moving inward by side wall, the effects of which are not accounted for in partial strip model. This front/back wall restraint serves to augment tension force in roof slab, which further damages the slab and makes it more susceptible to failing in punching shear.

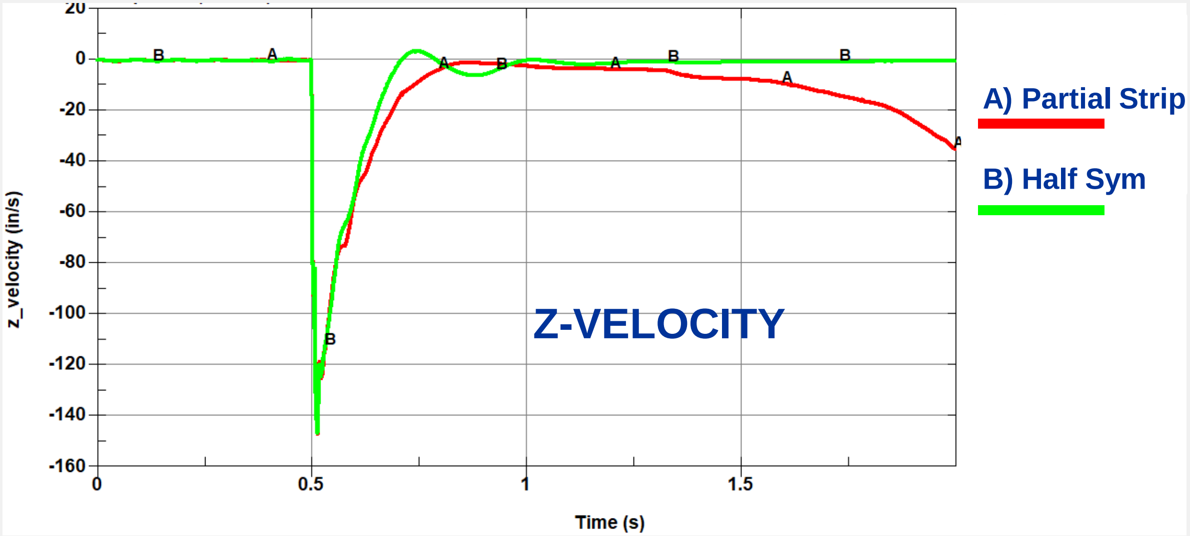
STABILITY DIFFERENCES AT LOWER LOADING BOUND

Load 2 / 2.5 ksi concrete / 50 ksi rebar



Partial strip model exhibited racking at late time (see figure to left) while half-symmetry model was stable. This indicates the importance of modeling the side wall which provides an additional membrane to tie the front and rear walls together.





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4.0 SUMMARY & CONCLUSIONS

- 12 HFPB calculations for ECM performed
  - *(8) partial strip models*
    - Identify load at which ECM collapses
    - Assess sensitivity of ECM response to material properties
  - *(4) half-symmetry models*
    - Assess ECM response for critical load and material property combinations identified by partial strip models
- Conclusions
  - *ECM structure collapse load is heavily dependent on f'c*
    - @ f'c = 2.5ksi: Stable at Load 2 but collapses at Load 1
    - @ f'c = 8 ksi: Stable at Load 1
    - Material properties critical for effective modeling
  - *Importance of modeling side wall to simulate ECM failure mechanism*
    - Lack of side wall results in spurious late time instability of structure
  - *Partial-strip model allowed faster run times and early identification of critical parameters but the half-symmetry model was necessary for better understanding of failure mechanisms and overall structural response of ECM*
- Future Efforts
  - *Modeling of air-blast load using coupled fluid-structure interaction*
  - *Blast testing of ECM structure*

	Case	Concrete f'_c [ksi]	Rebar F_y [ksi]	Load	Result Summary
Partial Strip	P1	2.5	50	Load-1	Column crushing; roof slab collapse
	P2	2.5	50	Load-2	Late time column/wall rotation leads to structure collapse
	P3	2.5	40	Load-1	Column crushing; roof slab collapse
	P4	2.5	40	Load-2	Late time column/wall rotation leads to structure collapse
	P5	8	50	Load-1	Late time column/wall rotation leads to structure collapse
	P6	8	50	Load-2	No roof slab collapse
	P7	8	40	Load-1	Late time column/wall rotation leads to structure collapse
	P8	8	40	Load-2	No roof slab collapse
Half-Symmetry	H1	2.5	50	Load-1	Roof slab punching shear; roof slab collapse
	H2	2.5	50	Load-2	No roof slab collapse
	H5	8	50	Load-1	No roof slab collapse
	H6	8	50	Load-2	No roof slab collapse

Explosives Safety Board · Department of Defense

NAVFAC Naval Facilities Engineering Command
EXWC Engineering & Expeditionary Warfare Center

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