



TEXAS TECH UNIVERSITY

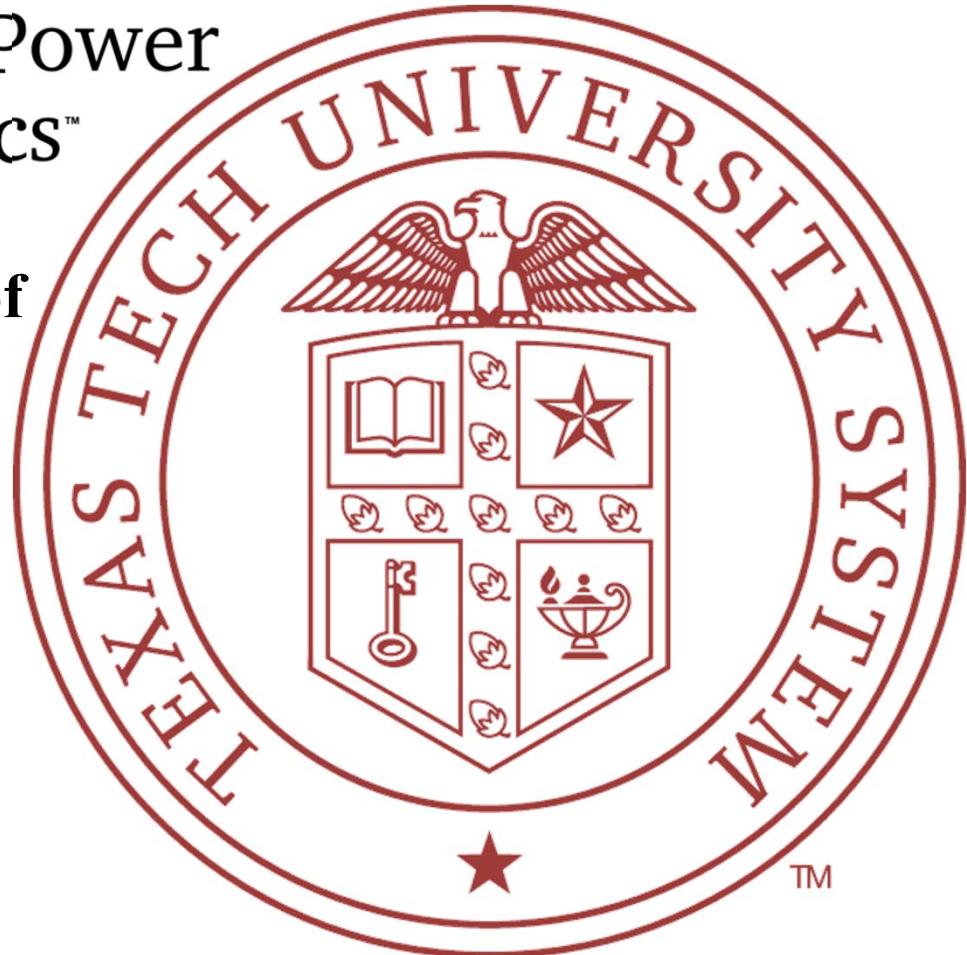
Center *for* Pulsed Power
& Power Electronics™

Interior Electromagnetic Fields of Buildings Struck by Lightning

Z.C. Shaw¹, H. Spencer¹, J. Dickens¹, D. Friesen²,
D. Hattz², N. Koone², J. Stephens¹, A. Neuber¹

¹*Center for Pulsed Power and Power Electronics*
Texas Tech University, Lubbock, Texas, USA

² *Pantex Consolidated Nuclear Security (CNS),*
Amarillo, Texas, USA





DISCLAIMER

This work of authorship and those incorporated herein were prepared by Consolidated Nuclear Security, LLC (CNS) as accounts of work sponsored by an agency of the United States Government under Contract DE-NA0001942. Neither the United States Government nor any agency thereof, nor CNS, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility to any non-governmental recipient hereof for the accuracy, completeness, use made, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency or contractor thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency or contractor (other than the authors) thereof.

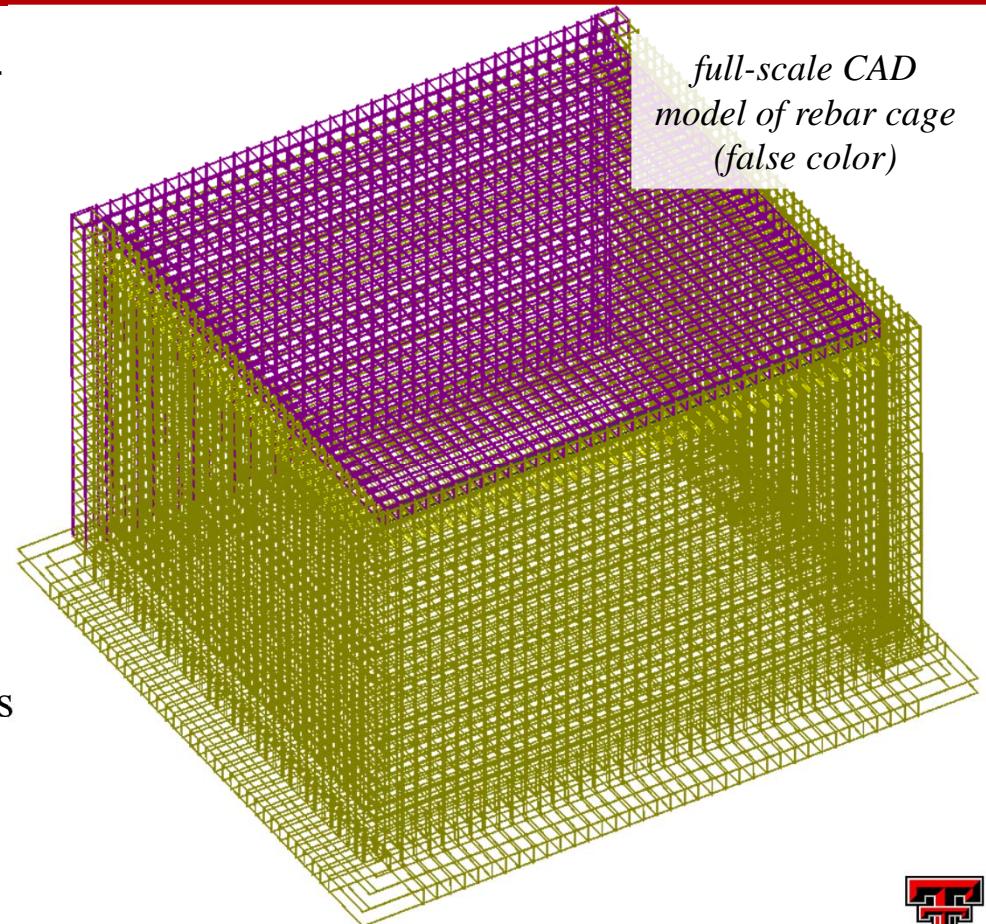
COPYRIGHT NOTICE

This document has been authored by Consolidated Nuclear Security, LLC, under Contract DE-NA-0001942 with the U.S. Department of Energy/National Nuclear Security Administration, or a subcontractor thereof. The United States Government retains and the publisher, by accepting the document for publication, acknowledges that the United States Government retains a nonexclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this document, prepare derivative works, distribute copies to the public, and perform publicly and display publicly, or allow others to do so, for United States Government purposes.



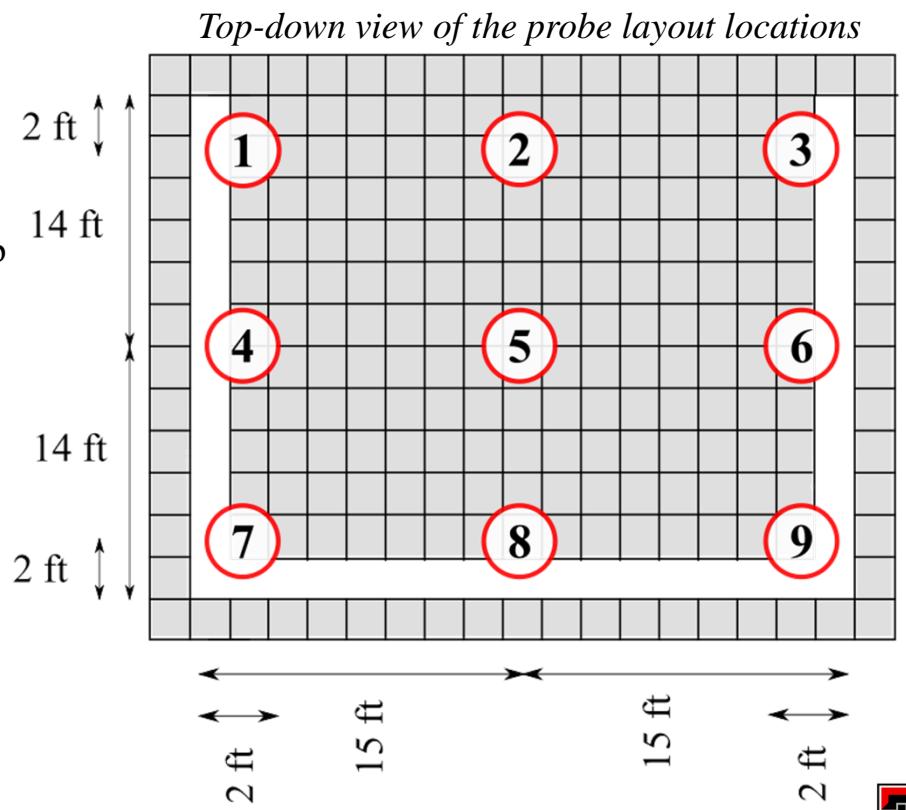
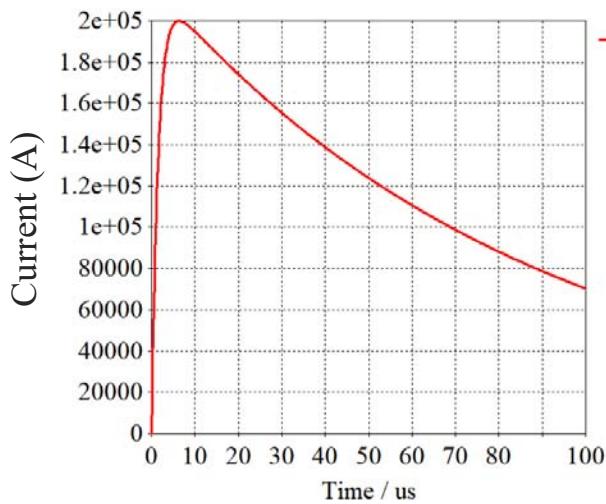
Introduction & Building Topology

- Double-layer rebar cage, common to steel-reinforced concrete structures, generally provides adequate protection against lightning strike events
 - Analogous to a Faraday cage
- The structure of interest in this study features a blast relief
 - Three walls feature no electrical connection to the roof
 - One wall is electrically connected (i.e. a hinge)
 - Does this affect induced interior fields in lightning strike events?
 - Are there more vulnerable strike locations?



Simulation Details and Probe Layout

- IEC 62305-001 LPL 1, positive strike waveform (200 kA, $\sim 6 \mu\text{s}$ rise)
 - Accounts for 99% of all lightning strike events
- Probes arranged in a 3x3 matrix
- Unless otherwise noted, probes are 3' above the foundation
 - Some instances of probes near the electrical gap are noted

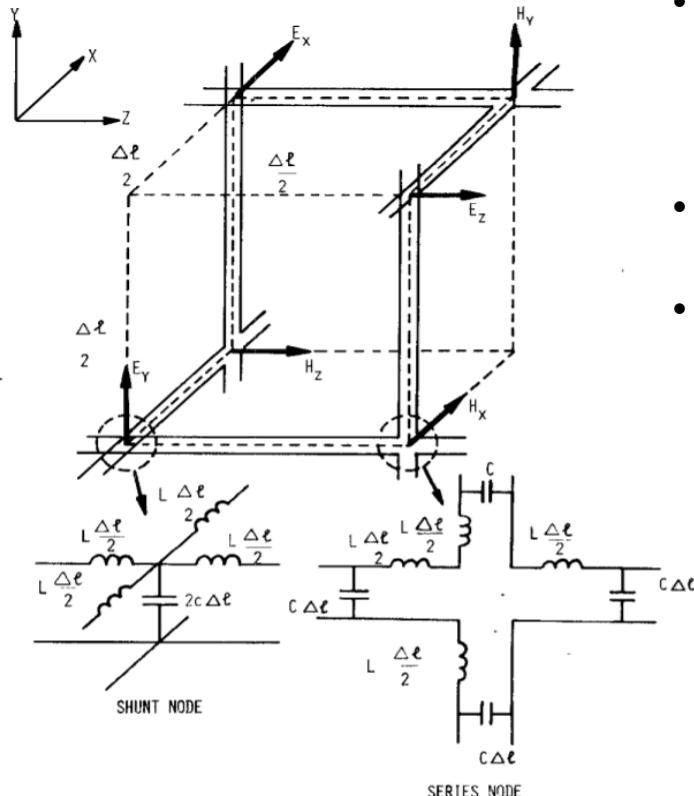


SZC6

What happened to negative strike?

Shaw, Zachary C, 11/15/2021

Algorithm and Computational Details



- Simulations incorporate a time-domain, transmission line matrix (TLM) model
 - CST Microwave Studio
- ~100M element typical mesh size
- Two, NVIDIA QUADRO RTX6000 GPUs
 - 24-48 hour typical simulation time



SPECIFICATIONS

| | |
|------------------------------|--|
| GPU Memory | 24 GB GDDR6 |
| Memory Interface | 384-bit |
| Memory Bandwidth | Up to 672 GB/s |
| ECC | Yes |
| NVIDIA CUDA Cores | 4,608 |
| NVIDIA Tensor Cores | 576 |
| NVIDIA RT Cores | 72 |
| Single-Precision Performance | 16.3 TFLOPS |
| Tensor Performance | 130.5 TFLOPS |
| NVIDIA NVLink | Connects 2 Quadro RTX 6000 GPUs ¹ |
| NVIDIA NVLink bandwidth | 100 GB/s (bidirectional) |
| System Interface | PCI Express 3.0 x 16 |

*Source: NVIDIA QUADRO RTX6000 Datasheet

Hoefer, Wolfgang JR. "The transmission-line matrix method-theory and applications." *IEEE Transactions on Microwave Theory and Techniques* 33.10 (1985): 882-893.

Slide 5

SZC1

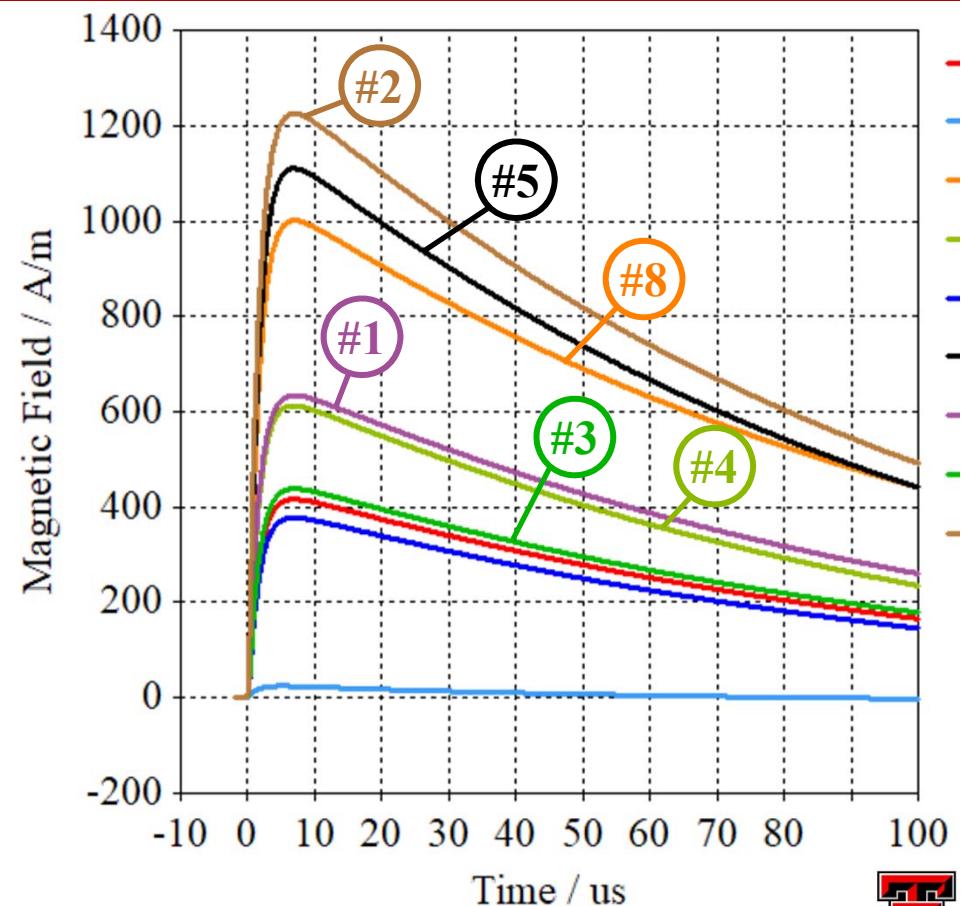
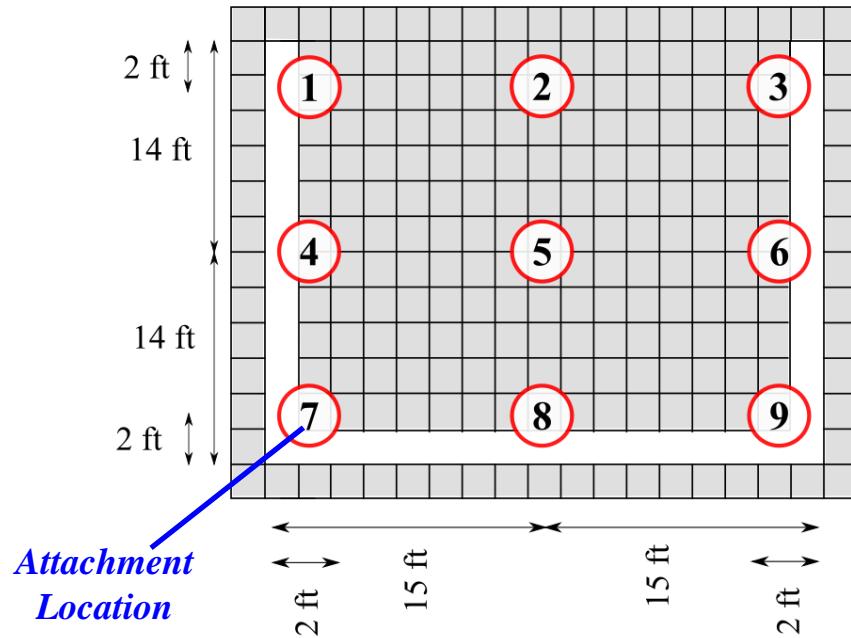
New Figure

Shaw, Zachary C, 11/15/2021



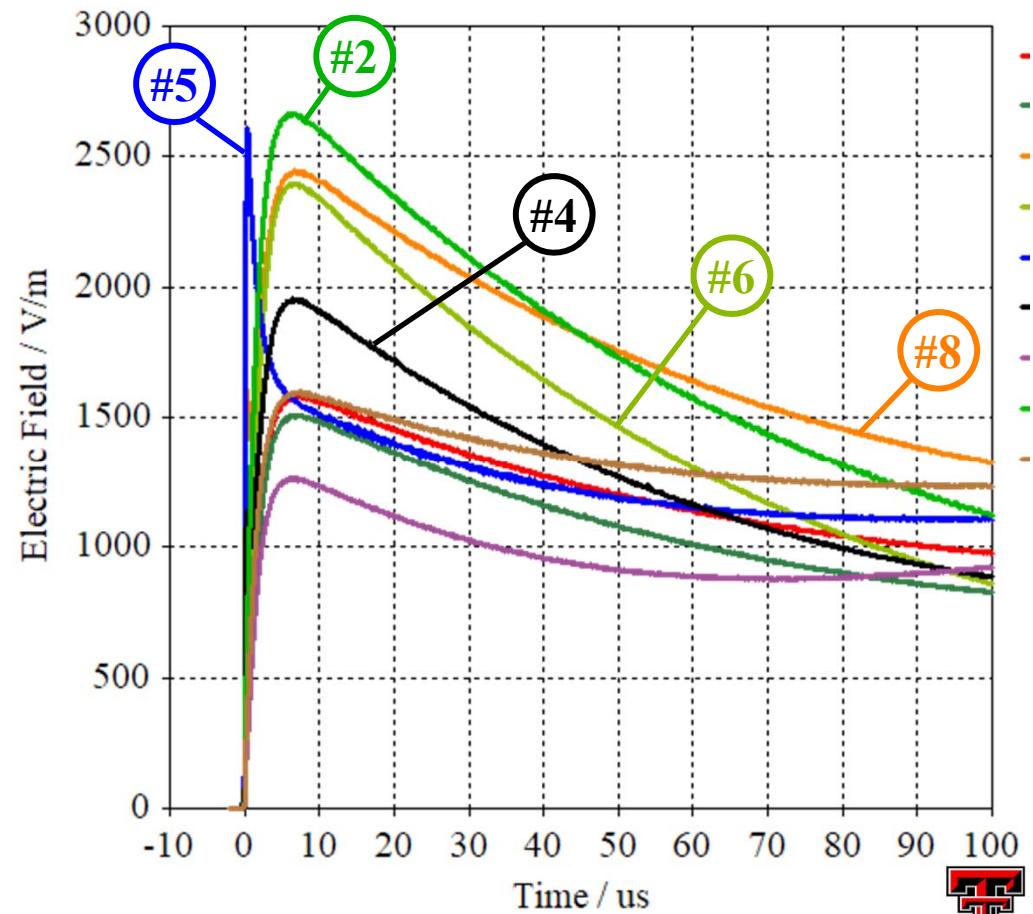
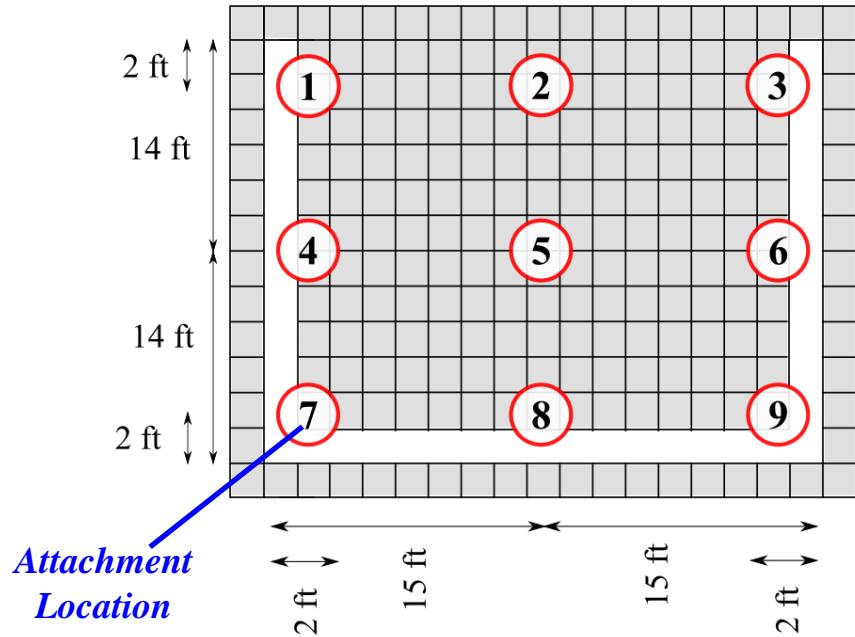
Roof-Corner Strike, H-field

- Roof-Corner strikes yield the highest interior H-fields, but not necessarily E-fields



Roof-Corner Strike, E-field

- Roof-Corner strikes yield the highest interior H-fields, but not necessarily E-fields

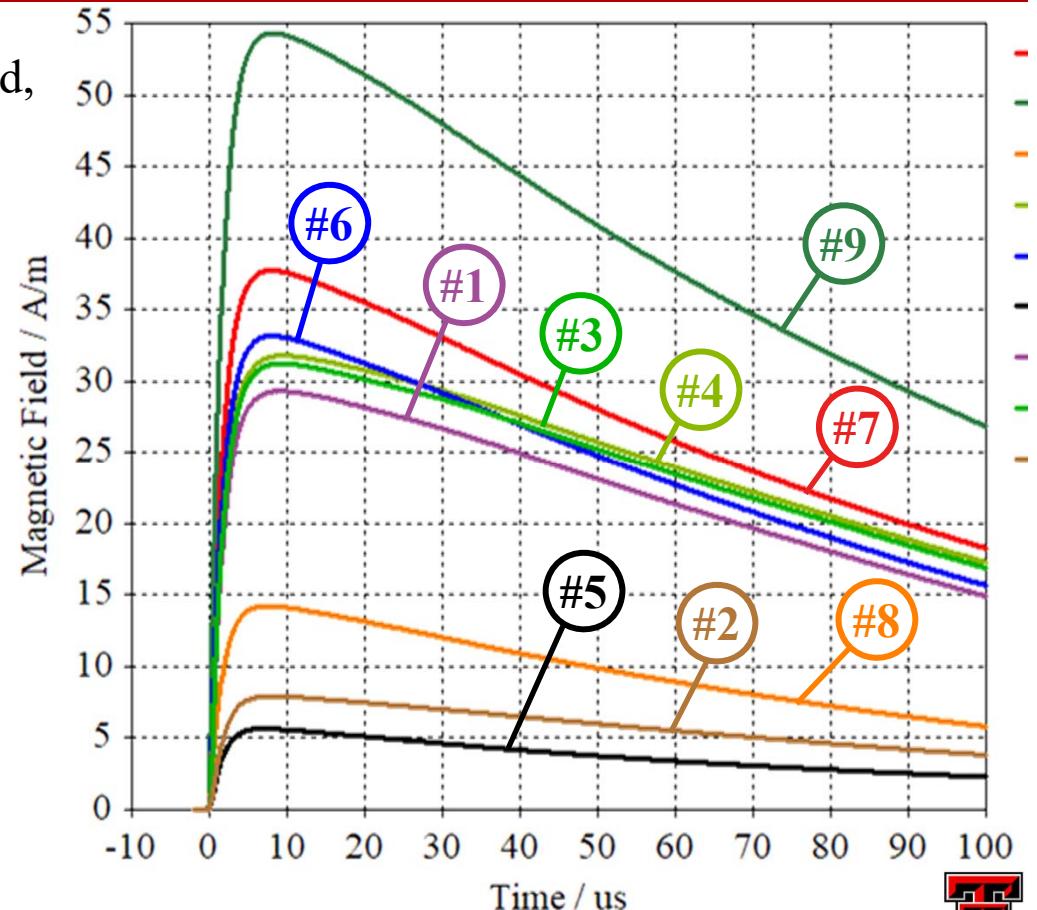
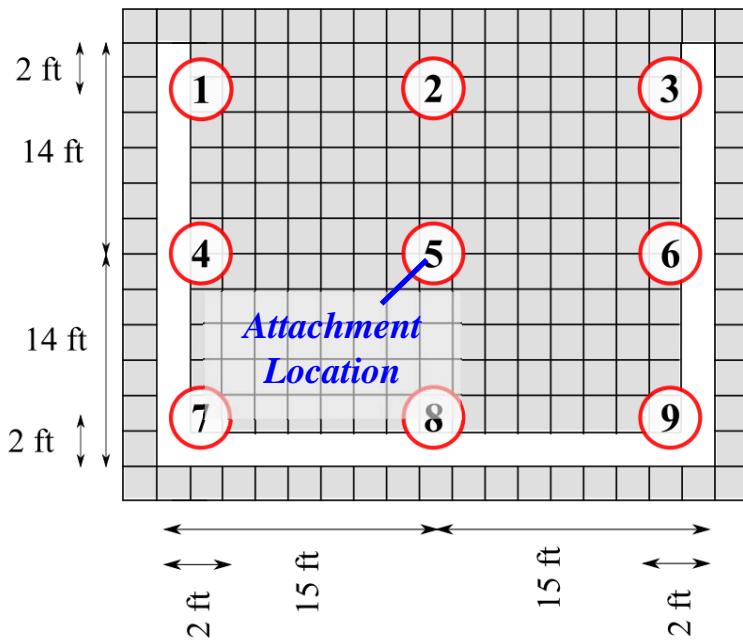


SZC4 do we know why #5 does not follow the other waveforms? Interesting.

Shaw, Zachary C, 11/15/2021

Roof-Center Strike, H-field

- Roof-Center strikes yield a higher E-field, but much lower H-field

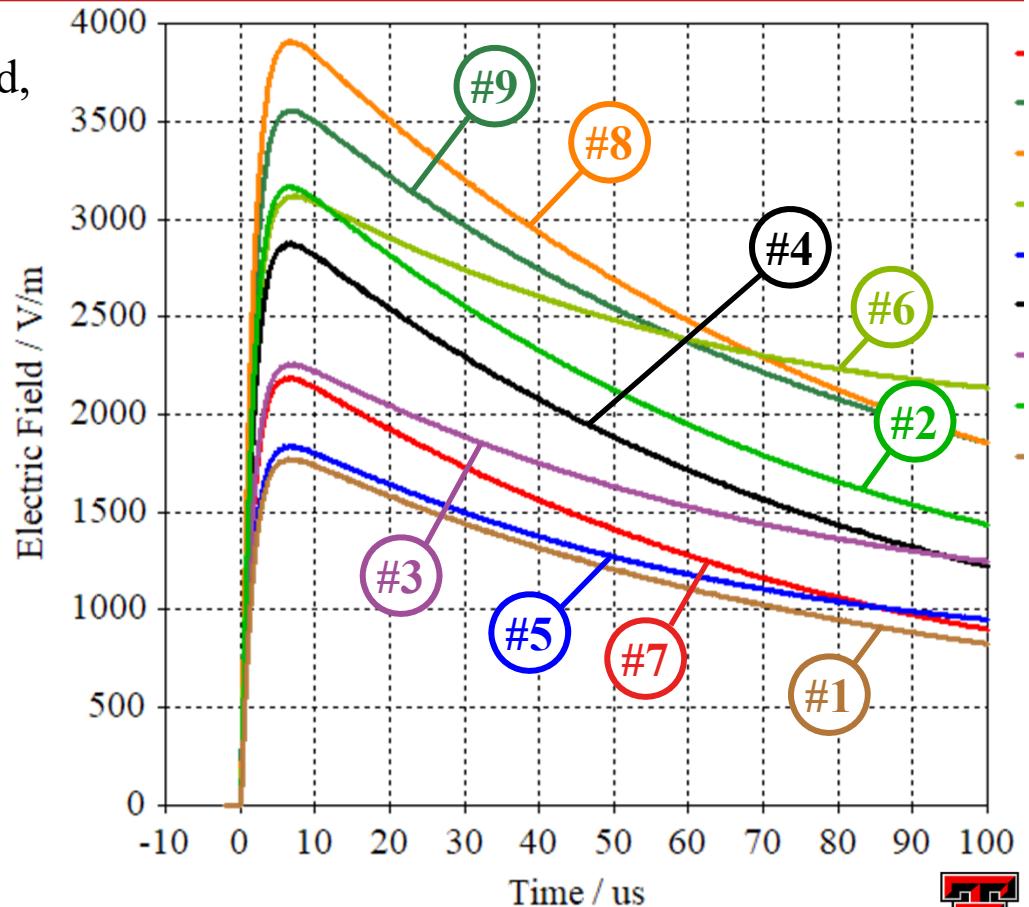
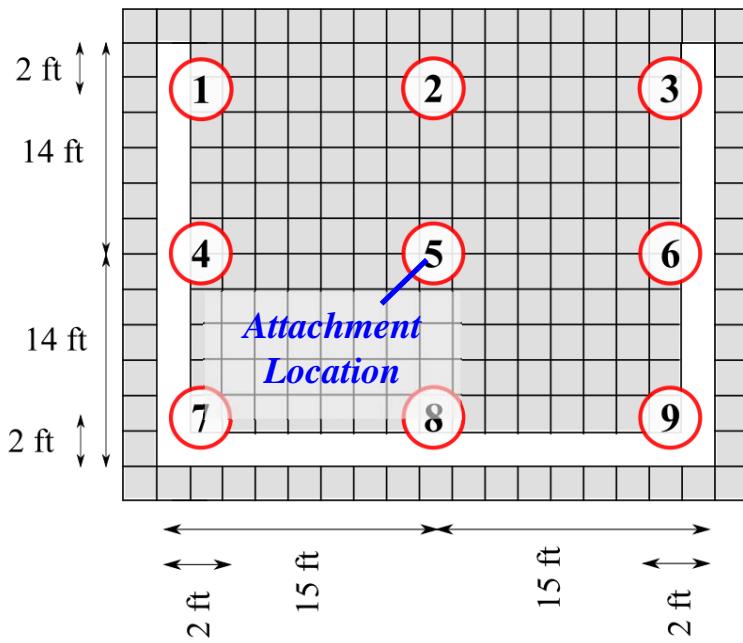


Slide 8

SZC3 Might recommend changing scale if there is time. At first glance this looks like this produces higher magnetic field
Shaw, Zachary C, 11/15/2021

Roof-Center Strike, E-field

- Roof-Center strikes yield a higher E-field, but much lower H-field



Slide 9

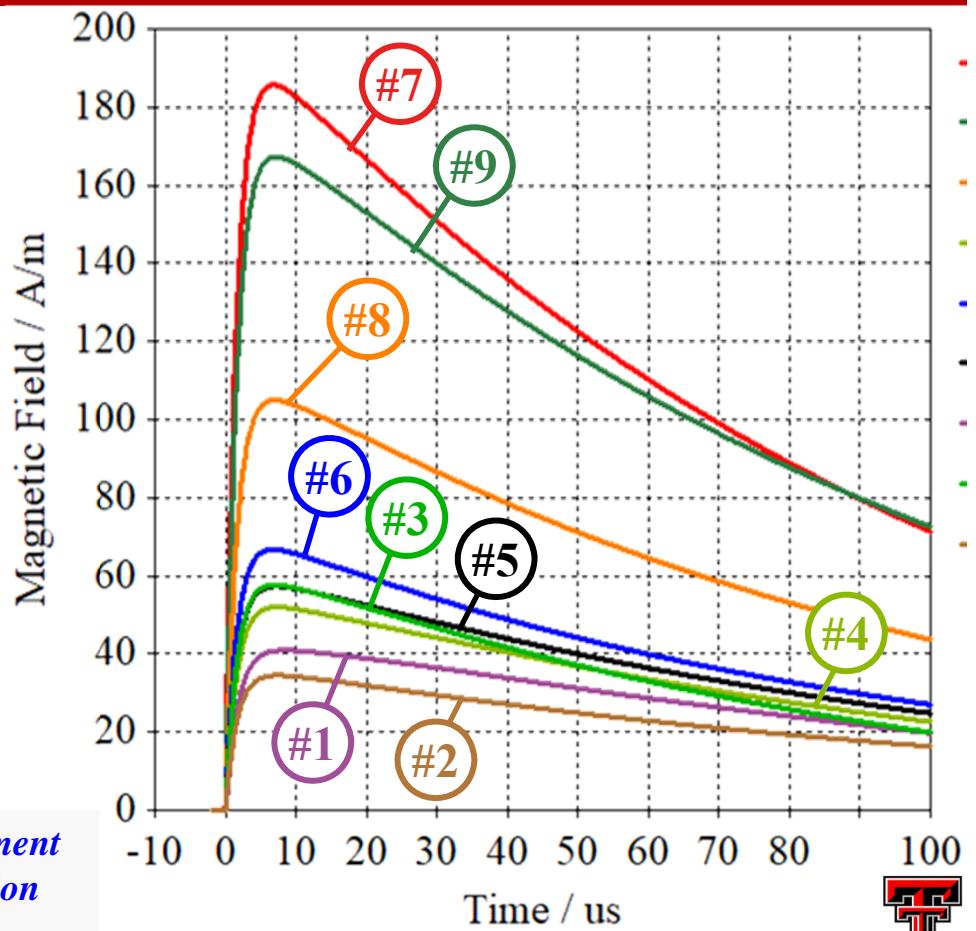
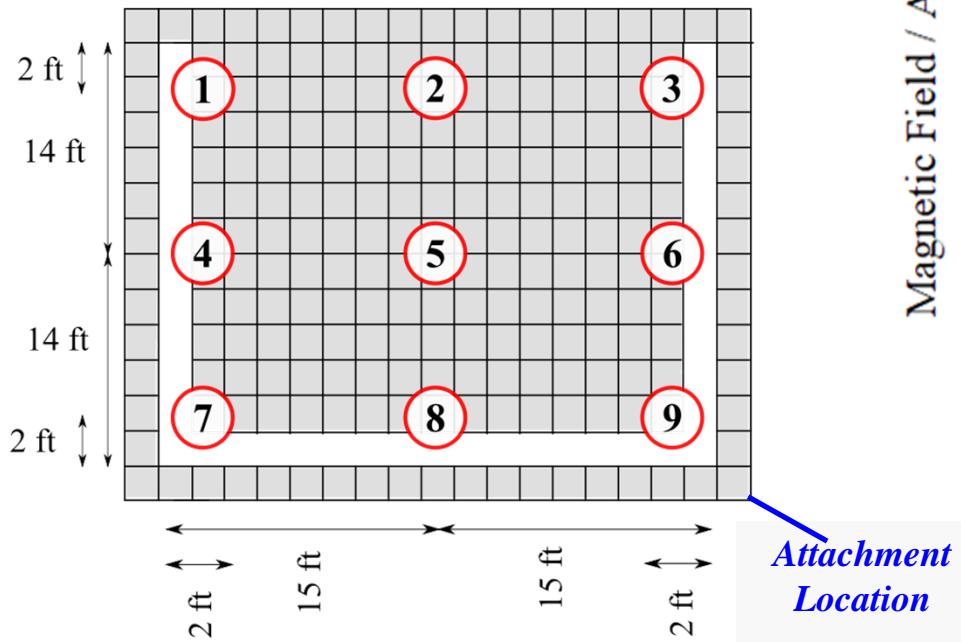
SZC5 No figures here follow what #5 did on corner strike. Interesting.

Shaw, Zachary C, 11/15/2021



Wall-Corner Strike, H-field

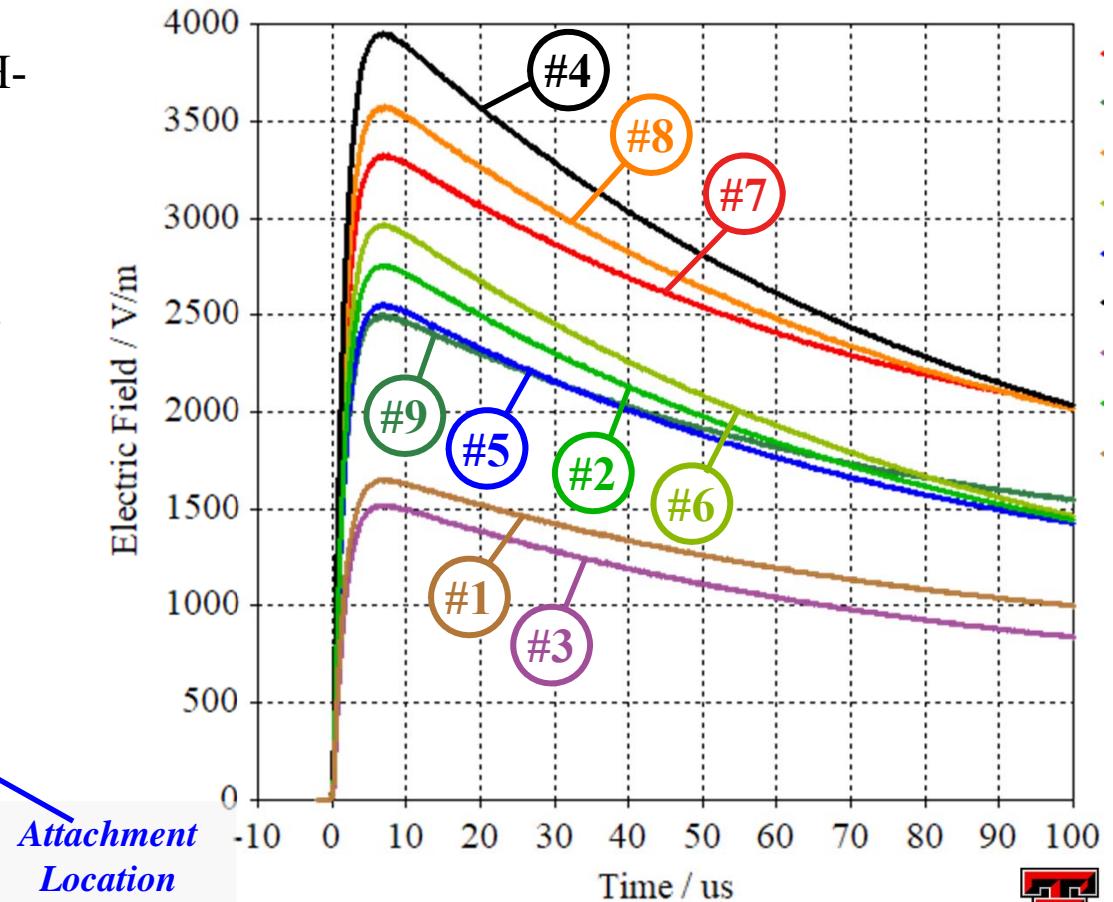
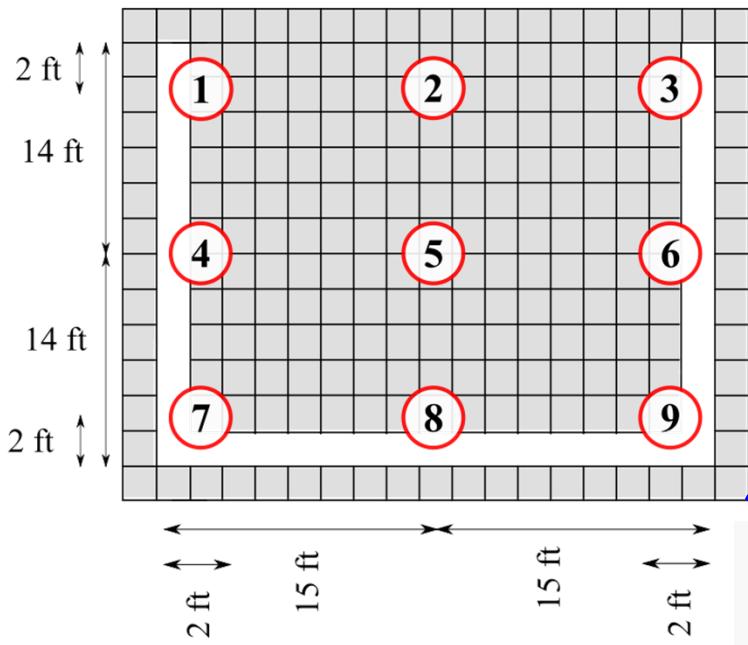
- Wall-Corner Strike yield moderate H-fields and higher E-fields





Wall-Corner Strike, E-field

- Wall-Corner Strike yield moderate H-fields and higher E-fields



Summary of Full-Scale Computational Results

- Calculated E-field and H-field magnitudes are generally consistent with published literature for conventional structures*
- Roof strikes, near the discontinuity induce significantly higher H-fields, while E-fields less dependence on the strike location

Table: Maximum field values observed for the 3x3 matrix of field probes, 3' above the foundation surface

| | Peak H-field | Peak E-field |
|--------------------|--------------|--------------|
| Roof-Corner Strike | 1200 A/m | 2600 V/m |
| Roof-Center Strike | 54 A/m | 3900 V/m |
| Wall-Corner Strike | 185 A/m | 4000 V/m |

* I.A. Metwally, F.H. Hiedler, W.J. Zischank, "Magnetic Fields and Loop Voltages Inside Reduced and Full-Scale Structures Produced by Direct Lightning Strikes" IEEE Trans. Electromag. Compat. **48**, 414 (2006).

Slide 12

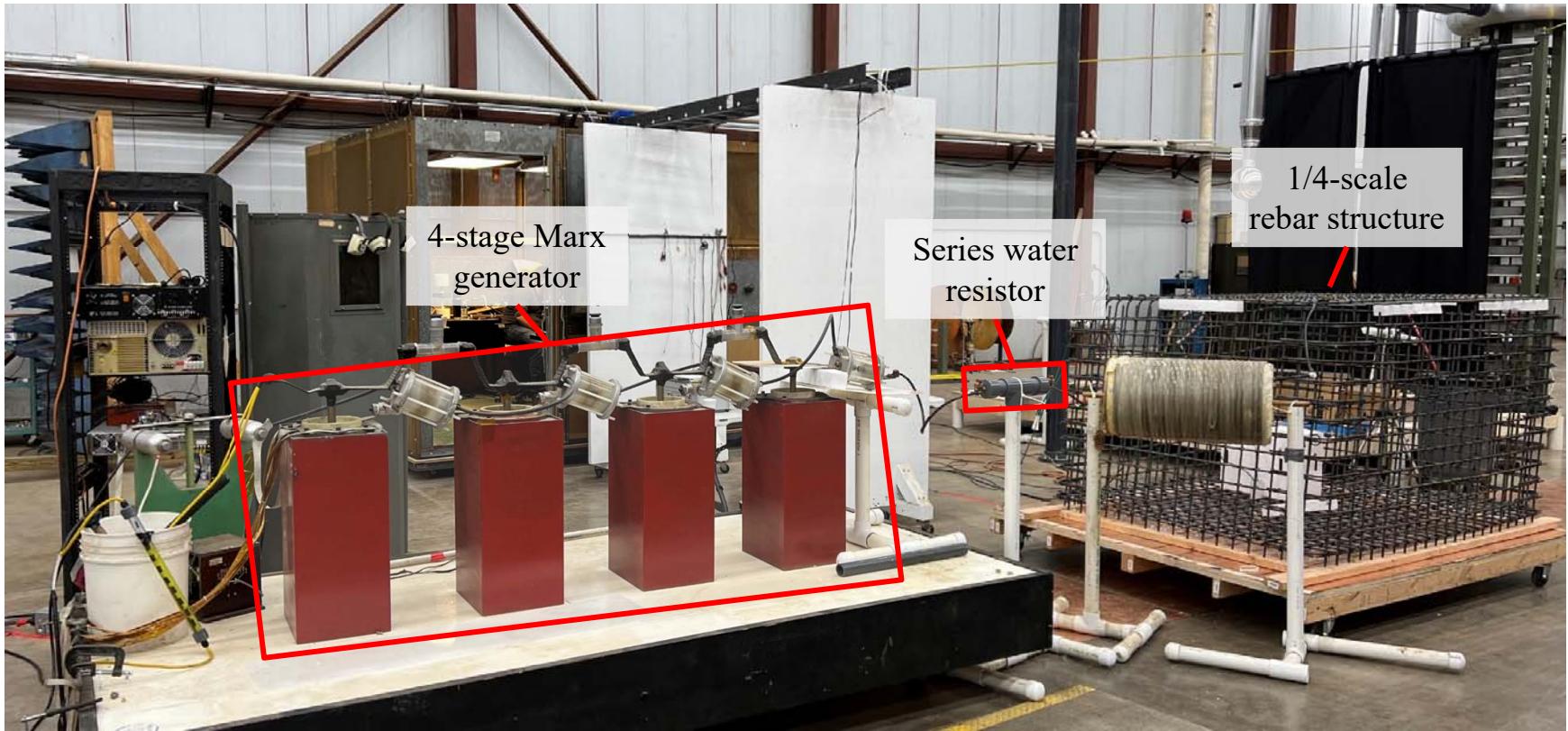
SZC7

Are there any conclusions/equations that can be drawn from this so far? Seems pretty empirical at the moment.

Shaw, Zachary C, 11/15/2021

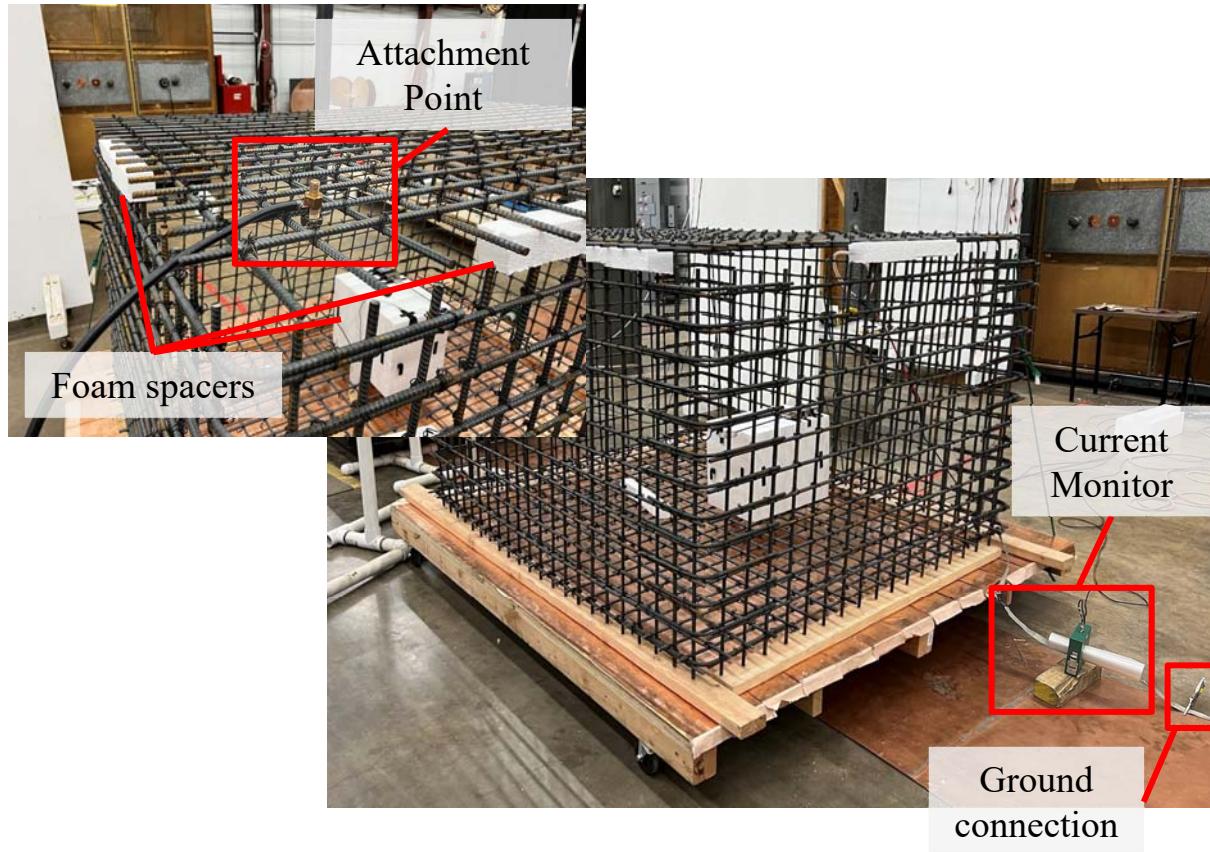


Experimental Setup





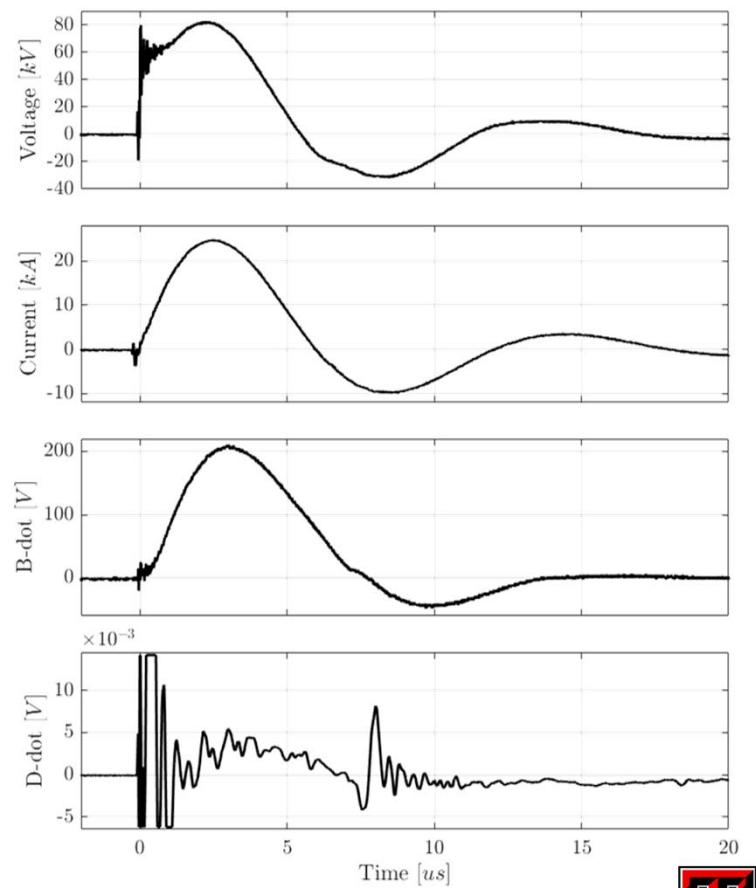
1/4-Scale Rebar Structure





First Experimental Shots

- Example shot for 30 kV marx charge voltage (~120 kV) output
- Currently collecting experimental data with varying current waveforms and strike locations
 - Voltage, Current, E-fields, B-fields





Conclusion & Future Plans

- Continue modeling effort to better understand induced fields
 - Varying attachment location, strike type (positive, negative, etc.), grounding details, etc.
- Revision of our Marx generator to provide 1/4-scale relevant peak current and pulse risetime
 - Measurement of interior magnetic and electric fields
- Reconciliation of experimental and computationally modeled fields
 - Improved confidence in computational model results

