Dynamore GmbH - 2018 LS-Dyna Forum - Civil Engineering - 14 October 2018 – Raum 4- 16:20 hours

Blast Response of Slabs in Reinforced Concrete Buildings

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Outline

> The need for designing Protective Structures

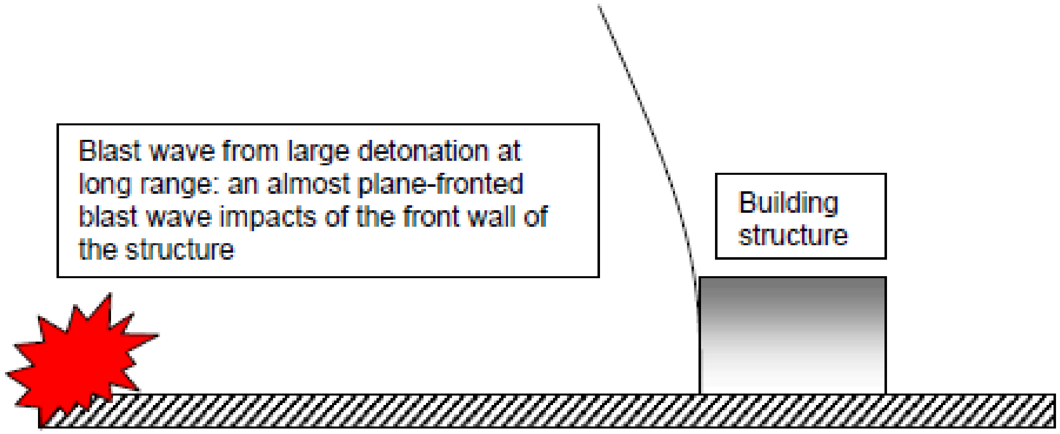
> Previous ALE studies

> Current CONWEP study for RC slabs

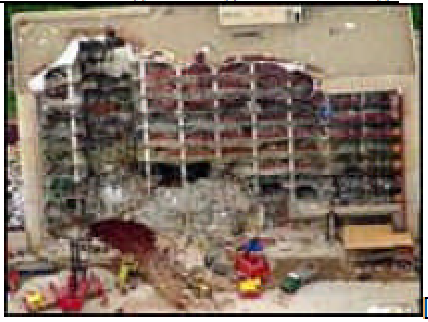
> Comparison of classical civilian design versus Protective Engineering design for RC floor slabs

> Conclusions

Why do We Need “Protective Engineering” for Structures?



Case History 6: Modern frame building with large close-in charge



[Ref 4]

Location: Alfred Murrah Building, Oklahoma City
Date: April 1995
Timing: The middle of the working day
Charge size: Approx. 1500kg ANFO (or equivalent)
Enhancement: No, a fairly uncongested urban landscape
Perpetrators: Timothy McVeigh (et al ?)
Casualties: 167 fatalities, numerous injuries of varying degrees
Damage radius: Extensive, but not generally serious other than ‘target’ building
Comment: The building was built to a US code that did not enshrine the requirement for ‘robustness’: the removal of a key structural column led to progressive collapse.

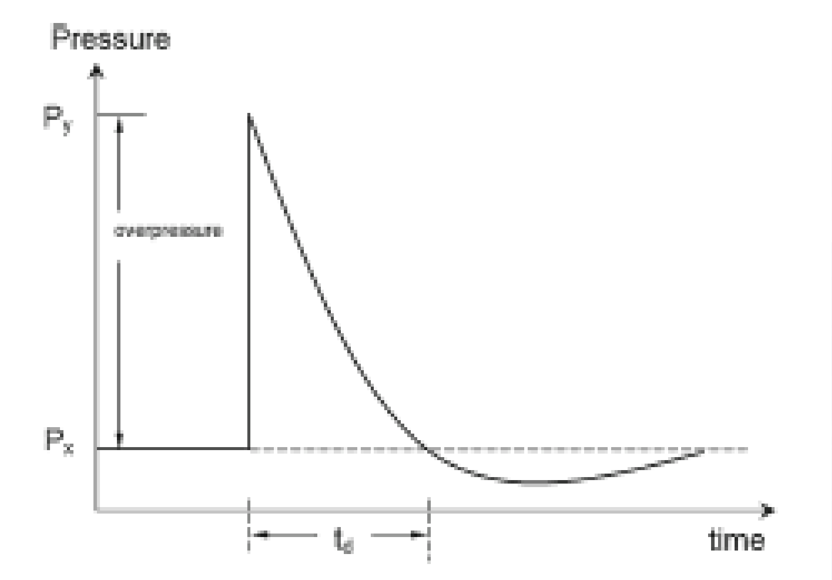
Case History 7: Modern building with large non-ideal charge partly mitigated by stand-off + wall

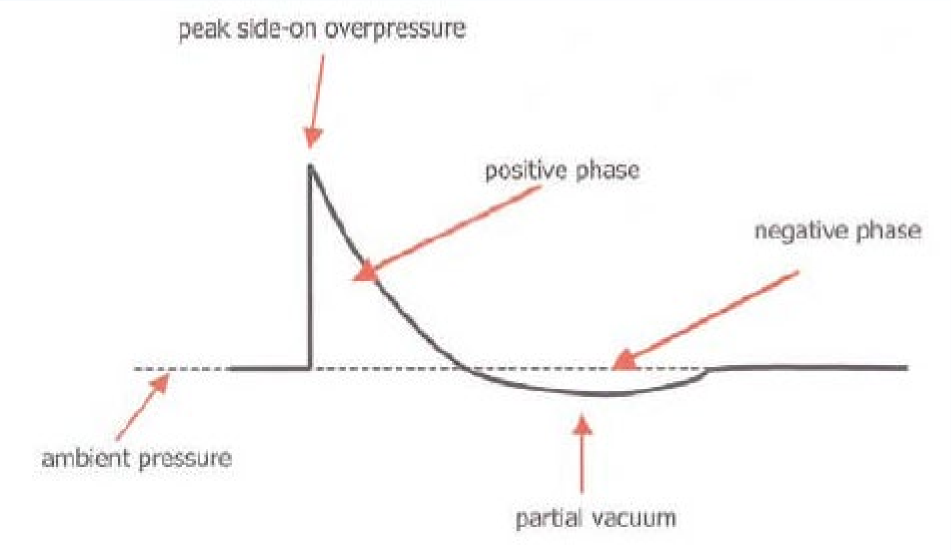
[Ref 5]

Event: Attack on Khobar Towers in Dharan, Saudi Arabia, June 1996
Consequences: 19 fatalities and 300+ injuries.
Comment: Severe façade failure though building did not collapse. The effects of the non-ideal explosion (a tanker containing 1300-2300kg ‘explosive material’) may have been mitigated by a combination of stand-off plus a Jersey barrier wall. The crater produced was unusually large, indicating the non-ideal nature of the explosion.

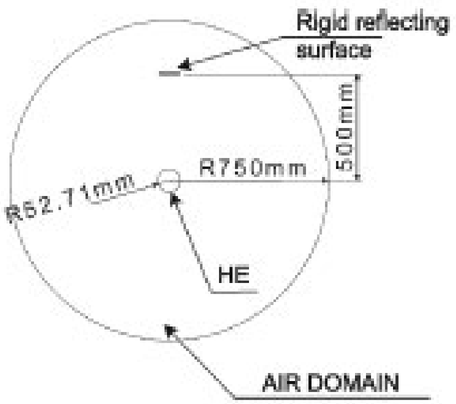
El Nogal Social Club Building <u>Car Park Internal Explosion</u>: Bogota, Colombia (2003)

Shock Waves of the HE Blast Phenomenon

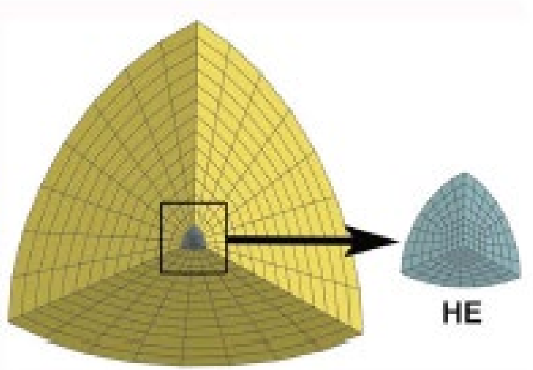




Previous Work Using Arbitrary Lagrangian Eulerian (ALE) Approach in LS-Dyna



(b) Eulerian mesh domain



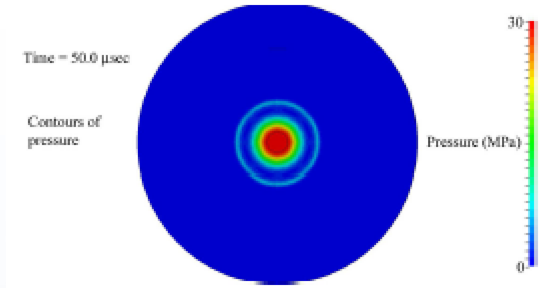


Fig. 11 Contours plots of pressure at $t = 50.0$ µsec for the S6 simulation

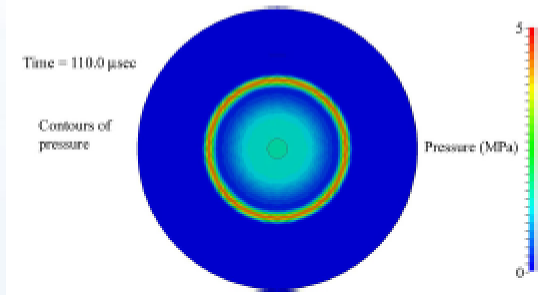


Fig. 12 Contours plots of pressure at $t = 110.0$ µsec for the S6 simulation

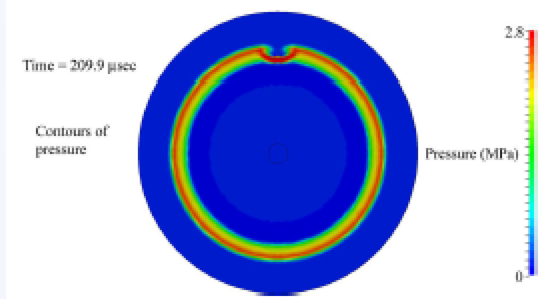
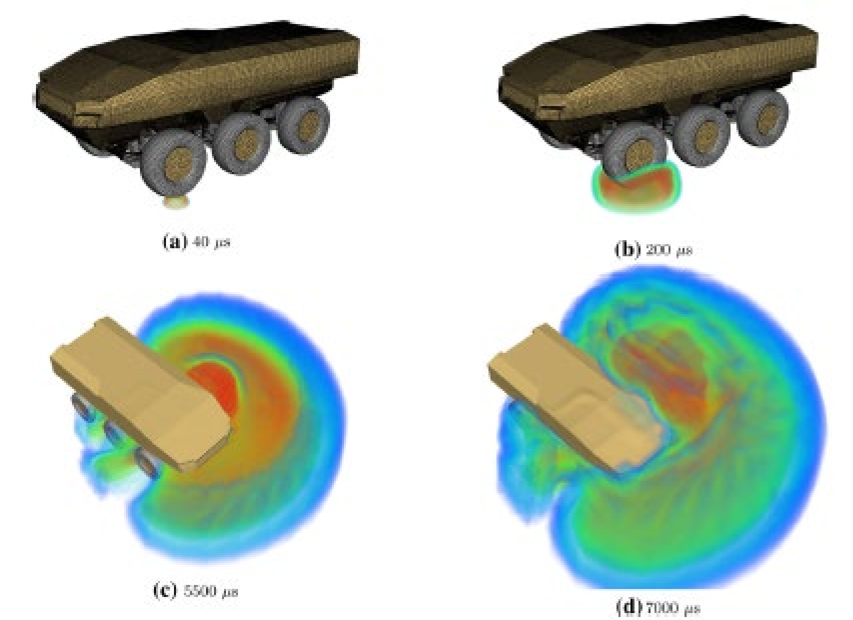
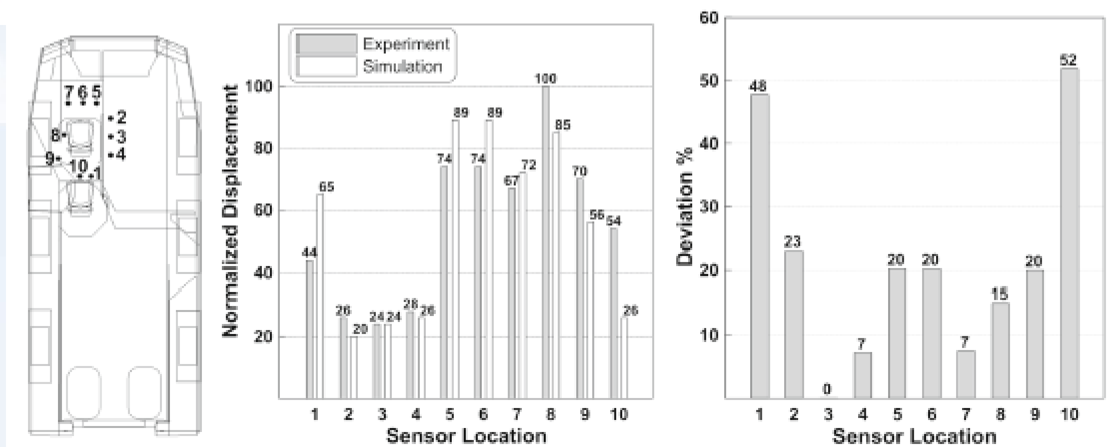


Fig. 13 Contours plots of pressure at $t = 209.9$ µsec for the S6 simulation

Joint Work with the Turkish Armored Vehicle Manufacturer Otokar Corp. (2009-2011)

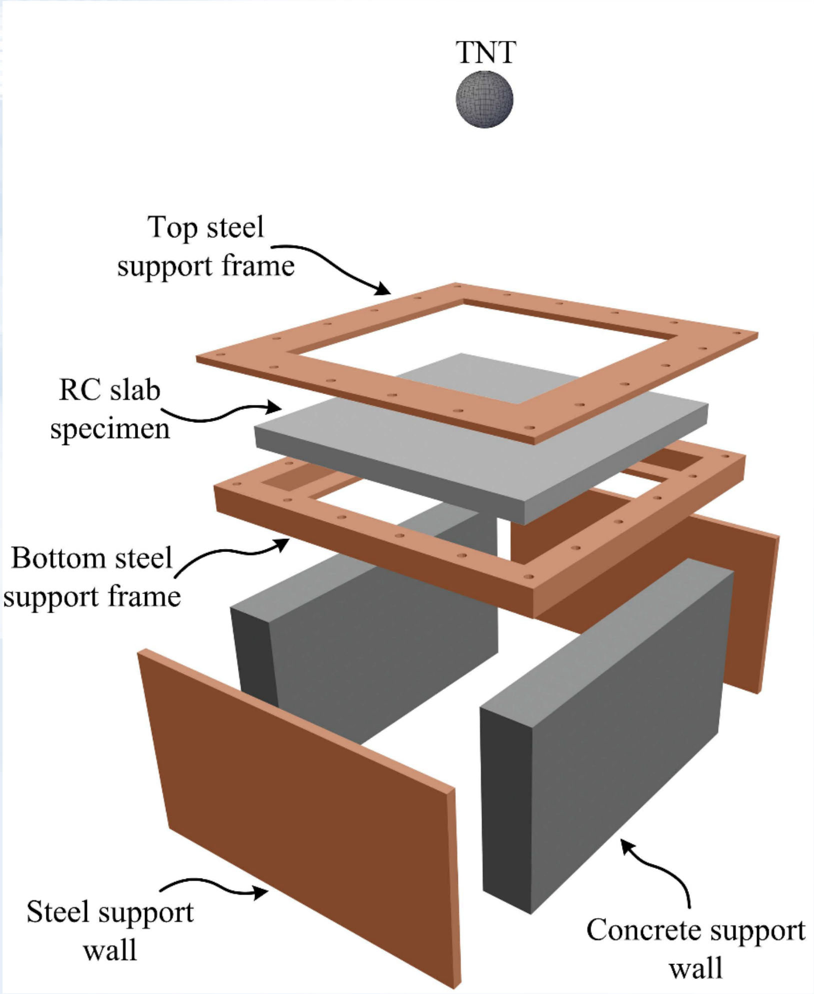
OTOKAR Corp. – NATO Mine Blast Simulation with LS-Dyna ALE Approach


(a) 40 μs
(b) 200 μs
(c) 5500 μs
(d) 7000 μs

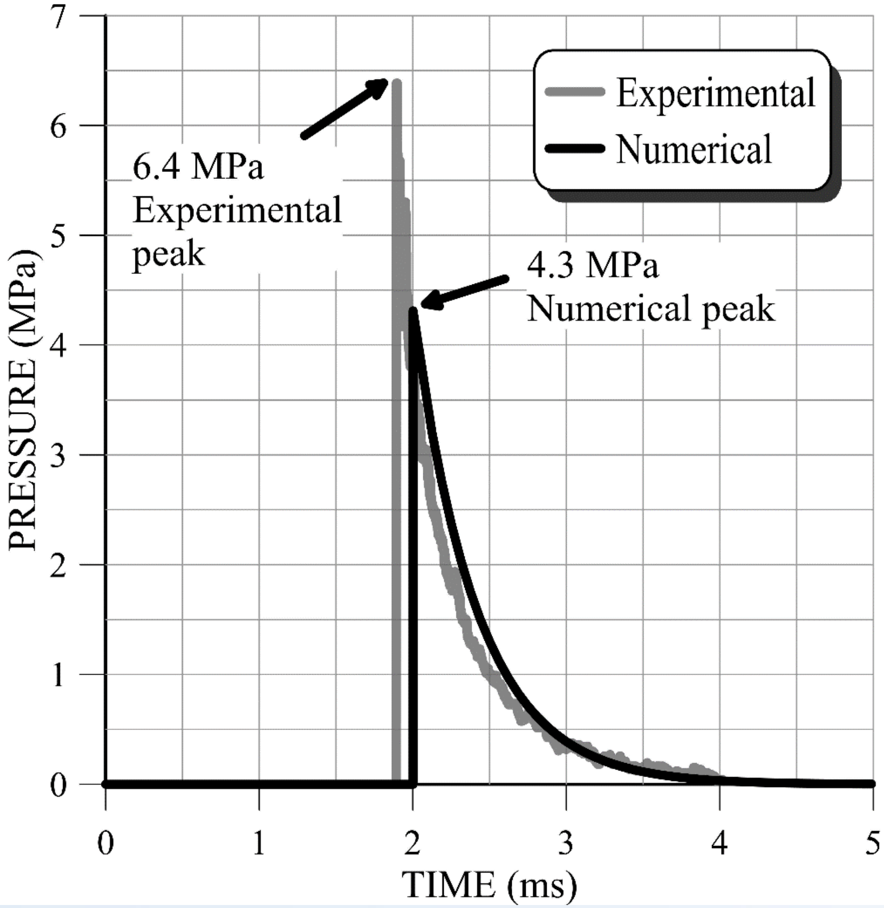


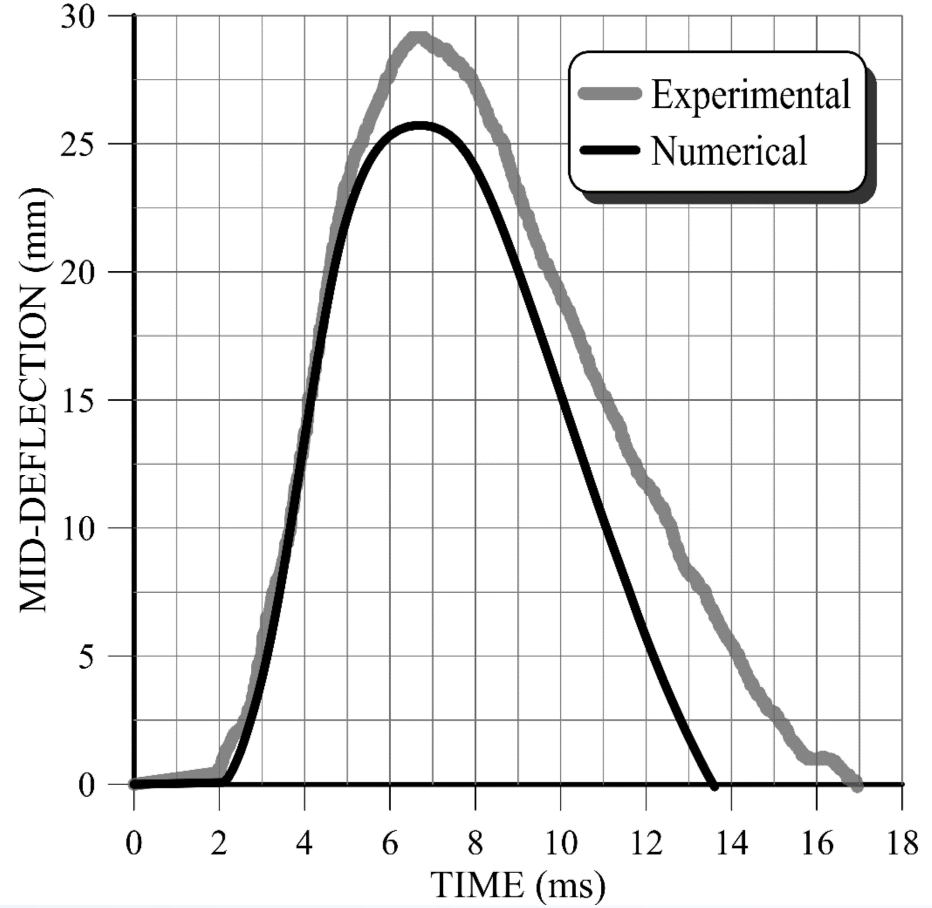
(a) (b) (c)

Validation Example: Single Slab Experiment

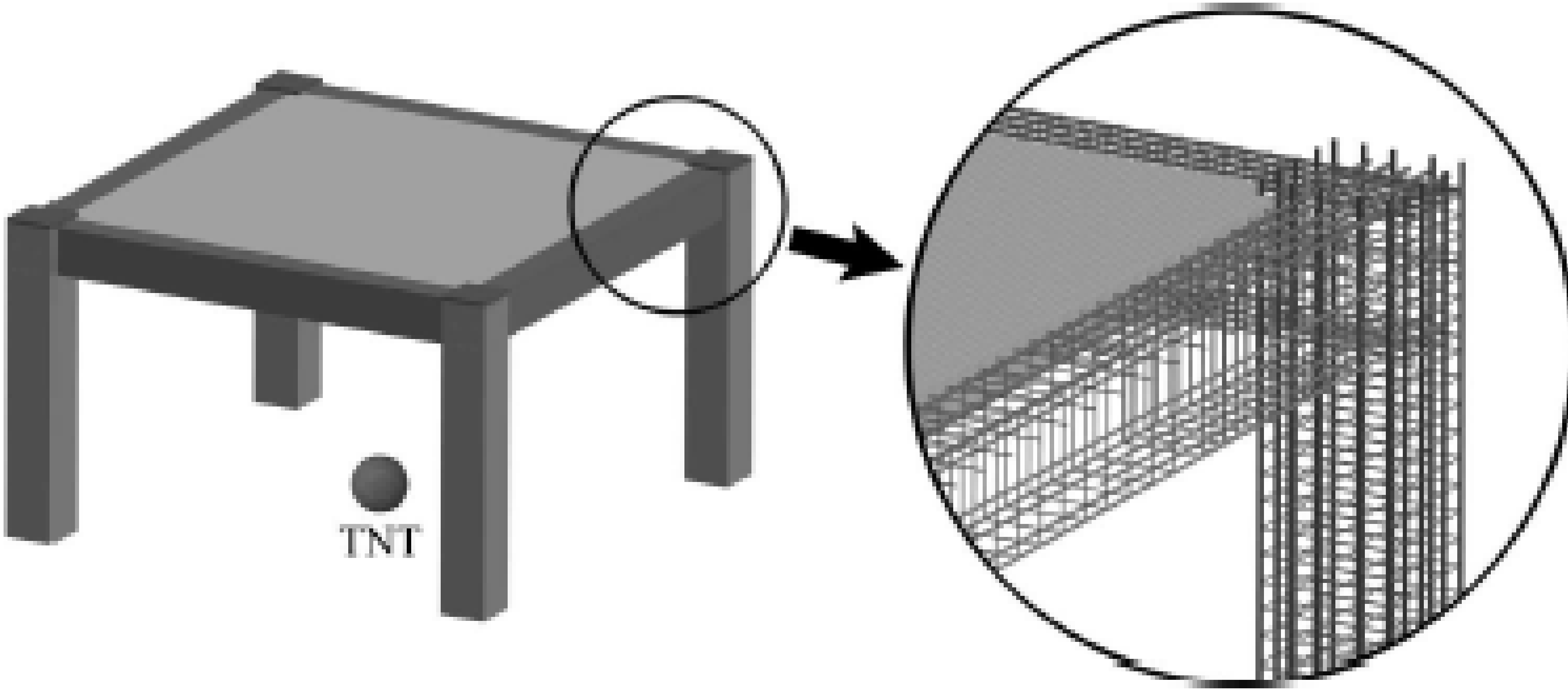


Validation Example: CONWEP Approach

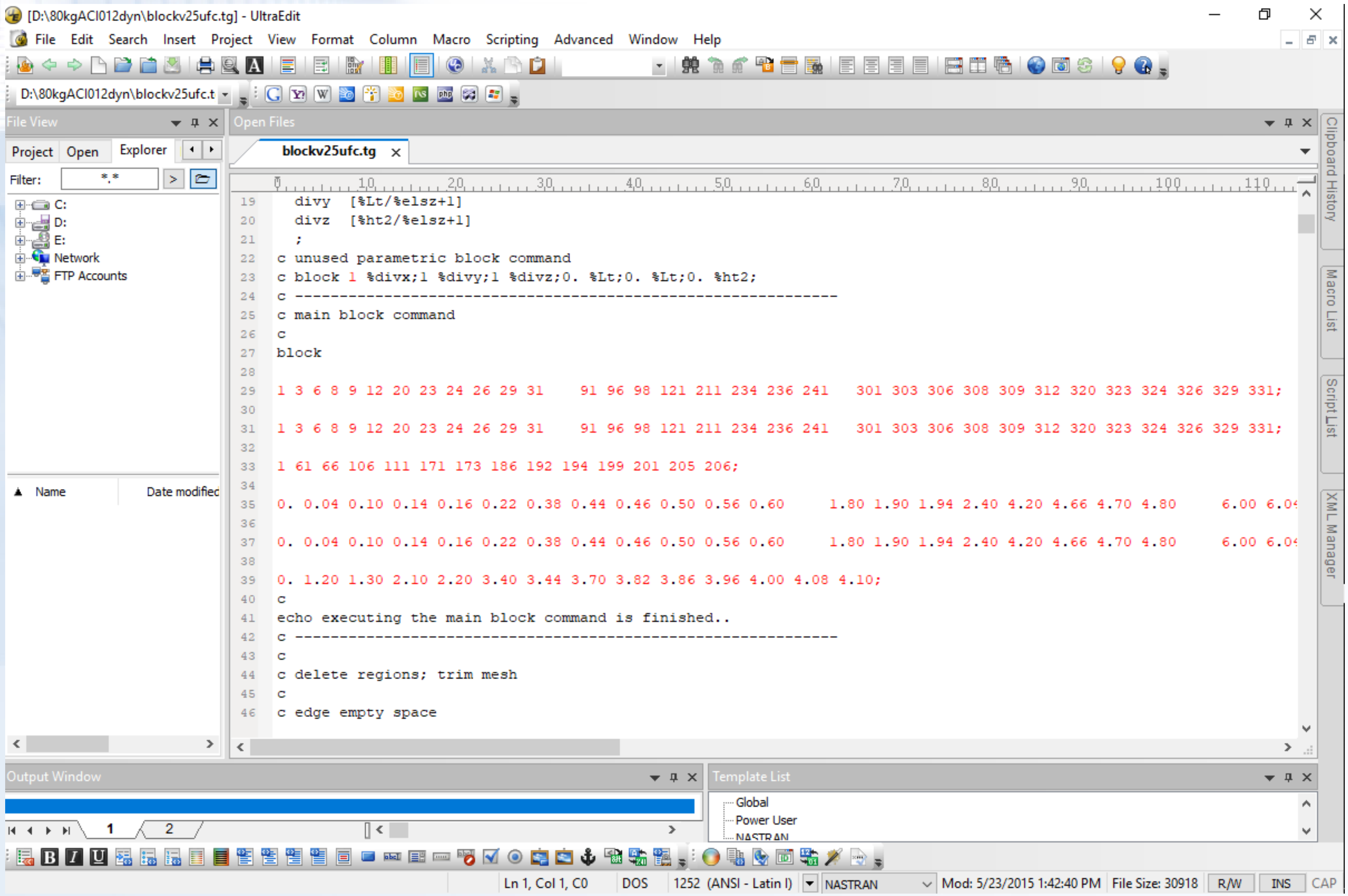




Case Study: Sample “Table Frame” with a Single Reinforced Concrete Slab



Truegrid Text-based Meshing Approach Used (Ouch!)



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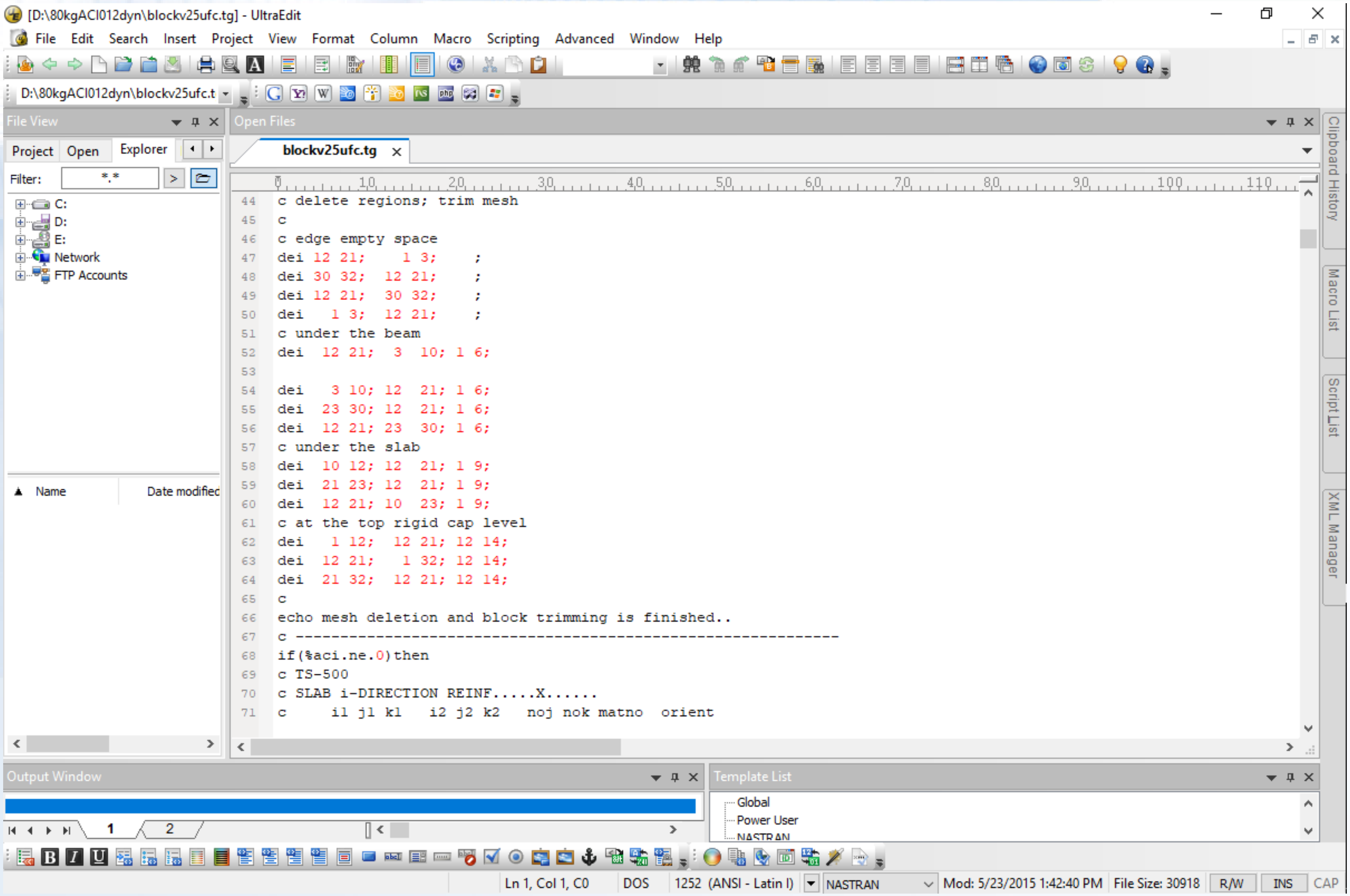
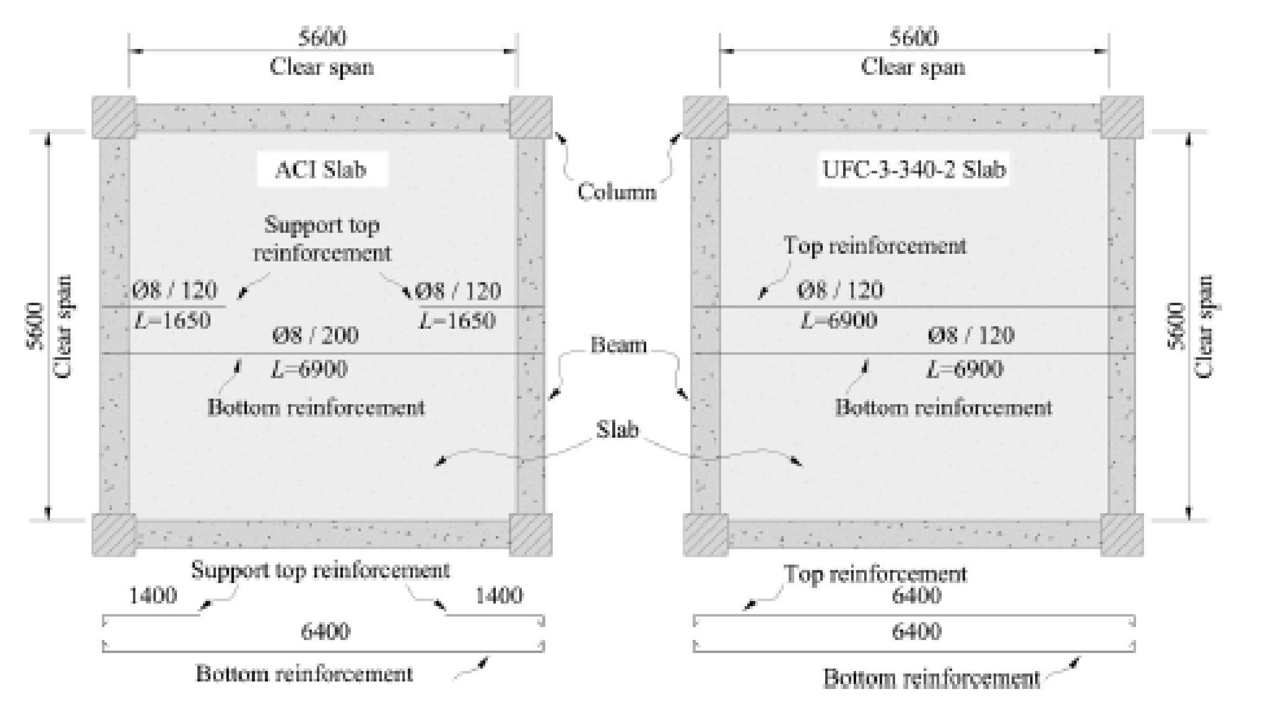
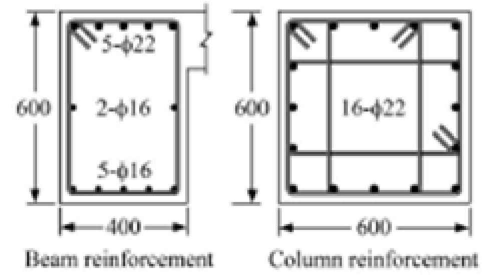
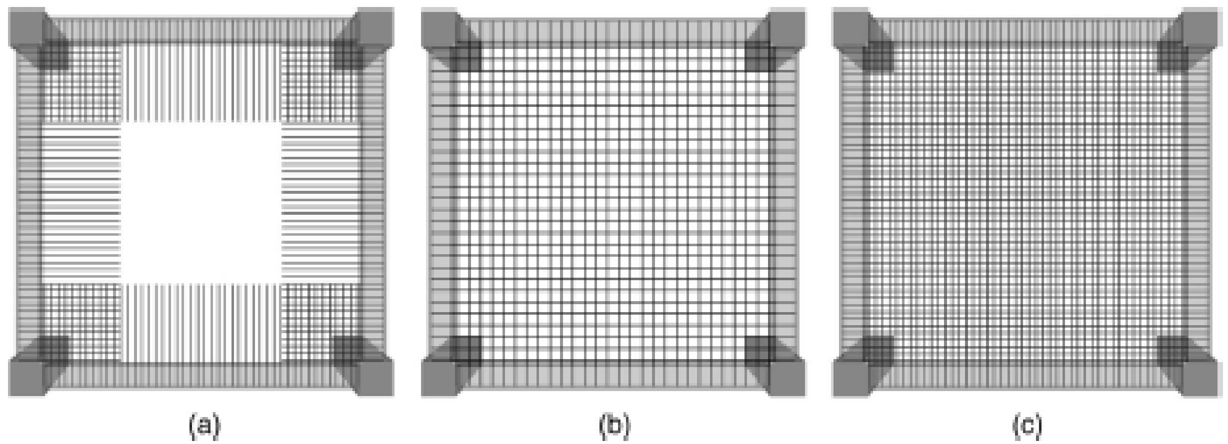


Steel Reinforcement Configurations



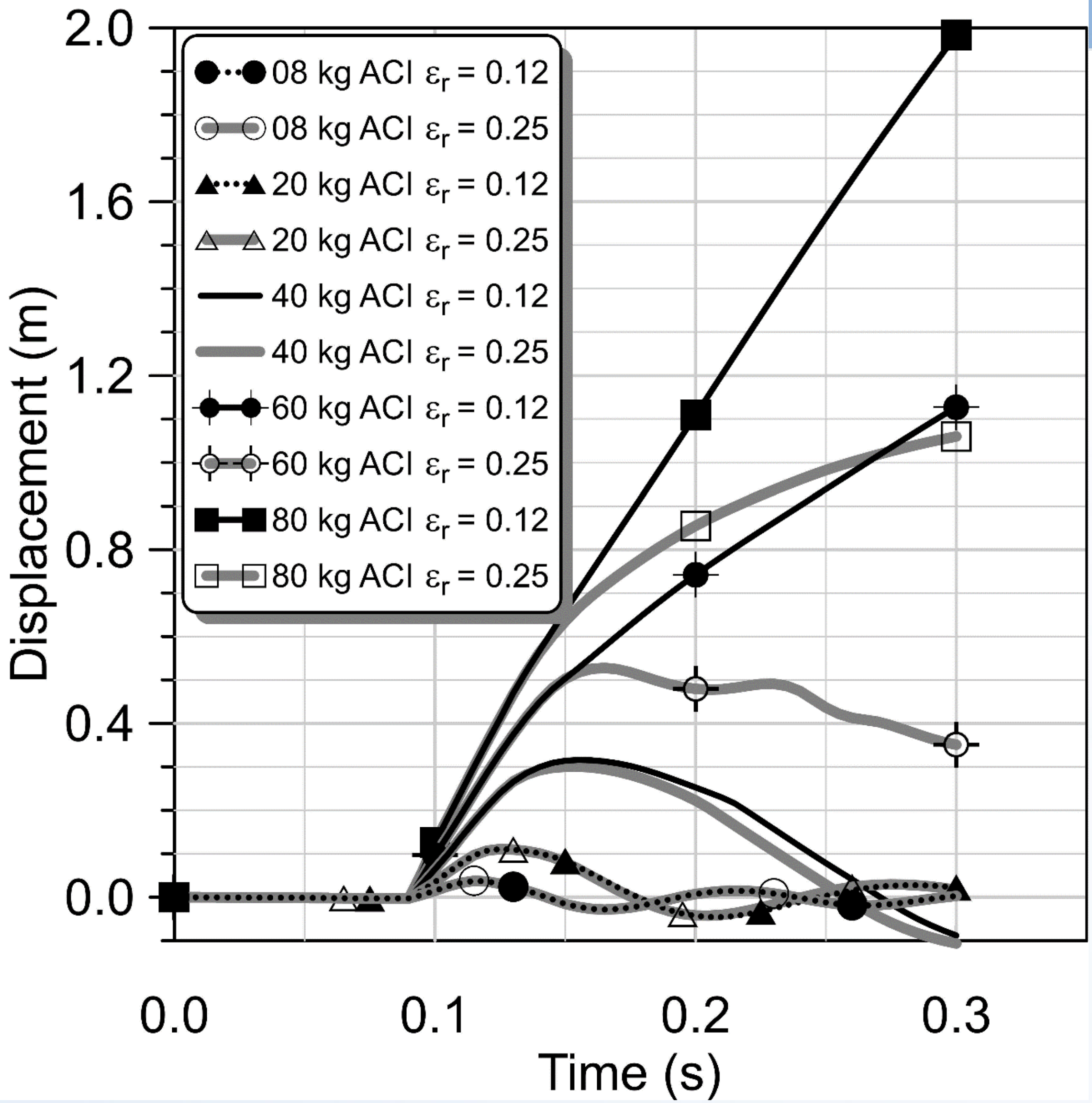




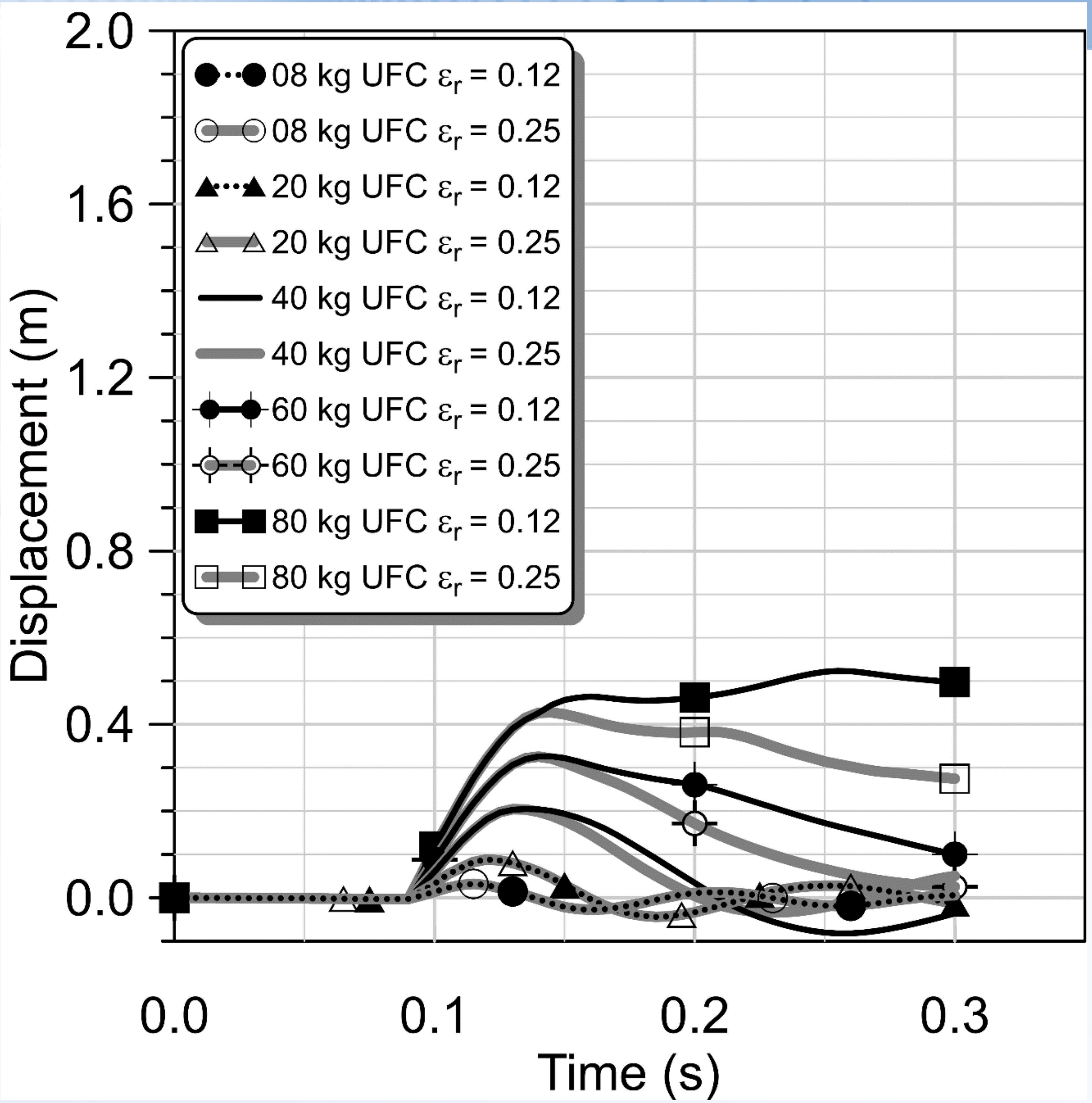
Material Data and LS-Dyna Modeling Approaches

The material properties for both slabs were assumed to be the same. The unconfined compressive strength and tangent elastic modulus of the concrete were set to 30 and 28 GPa, respectively. The concrete hexahedral elements eroded when the maximum principal strain exceeded 0.05 (based on a literature survey). The steel reinforcement yield strength and elastic modulus were set to 420 and 200 GPa, respectively. The slab thickness was 180 mm. The concrete covers at the top and bottom of the slab cross section were each 30mm thick. The strain rate effects on the rebars were included using values of 424 and 4.73 for the nondimensional constants of C and P, respectively, in the Cowper-Symonds model (Malvar and Crawford 1998). The rebar rupture was modeled defining a limiting value for the maximum principal strain.

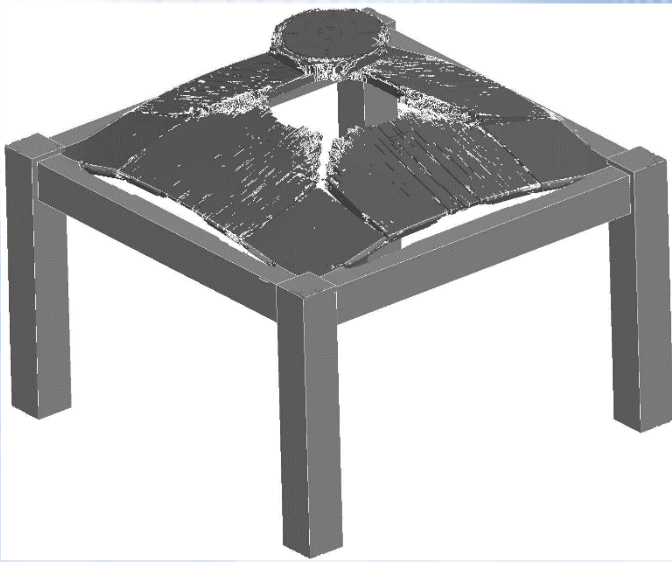
Parametric Study Results: Civilian Design



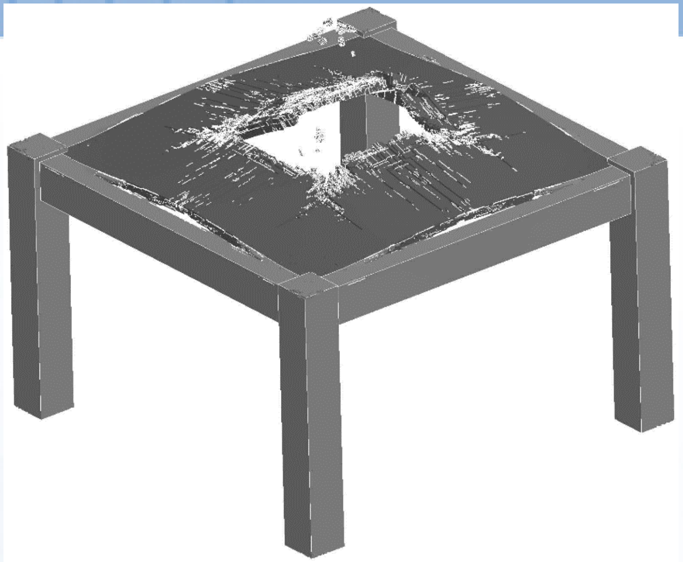
Parametric Study Results: Protective Design



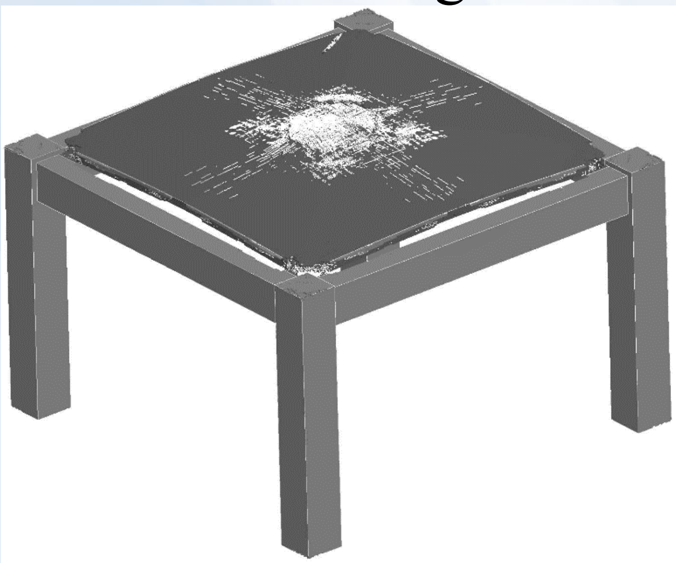
Blast Uplift Parametric Study with 80 kg TNT at 2.00 Meters of Stand-off Distance

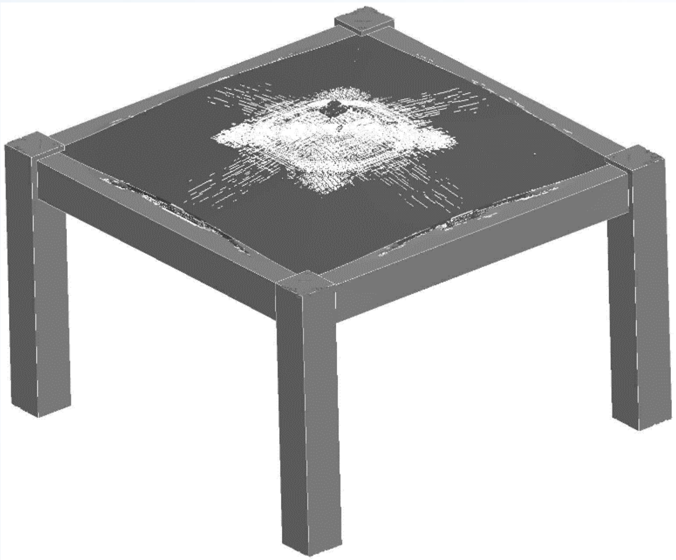


Civilian Design

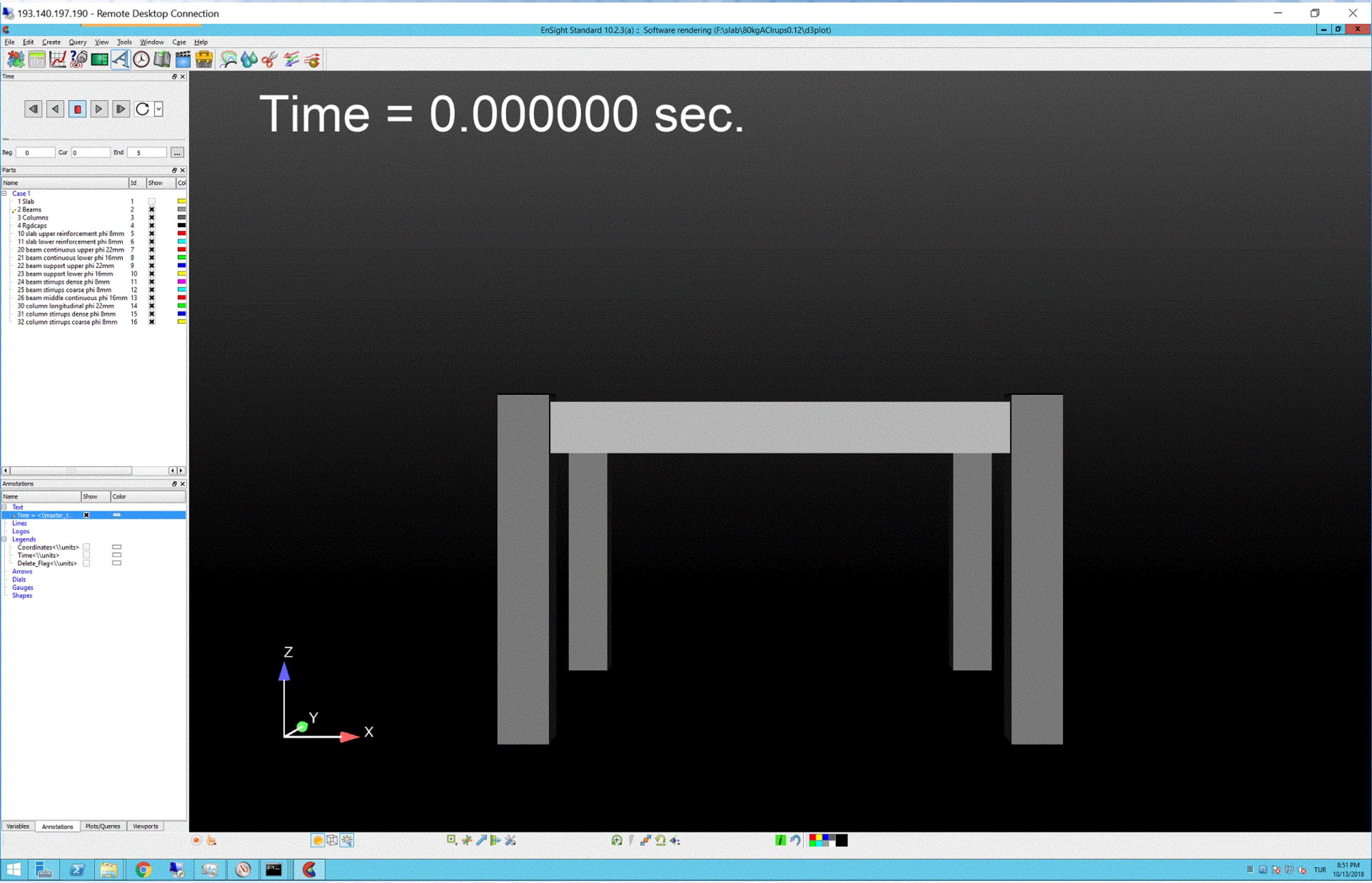


Protective Design





Civilian Design: 80 kg TNT Rups=0.12



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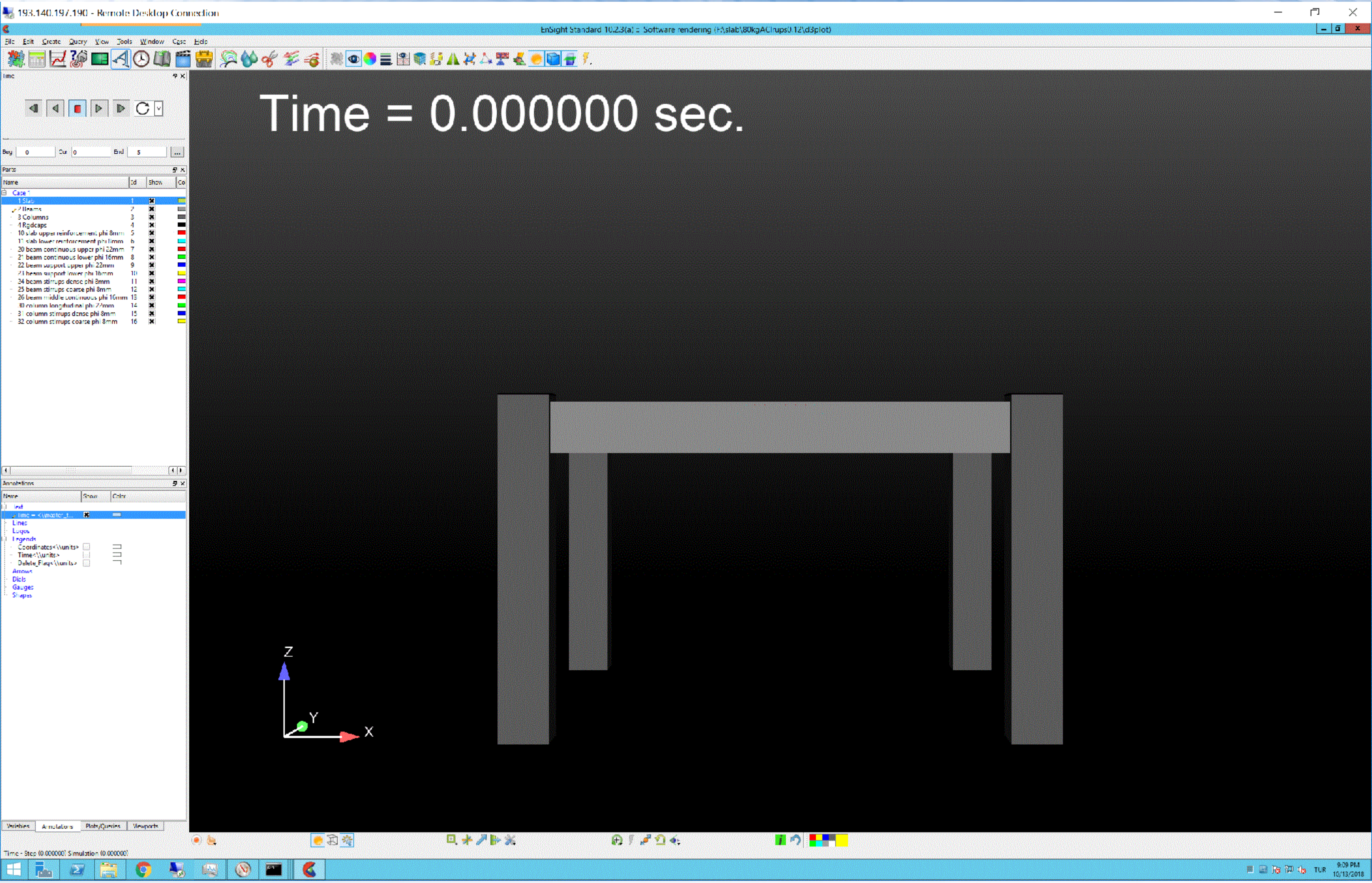

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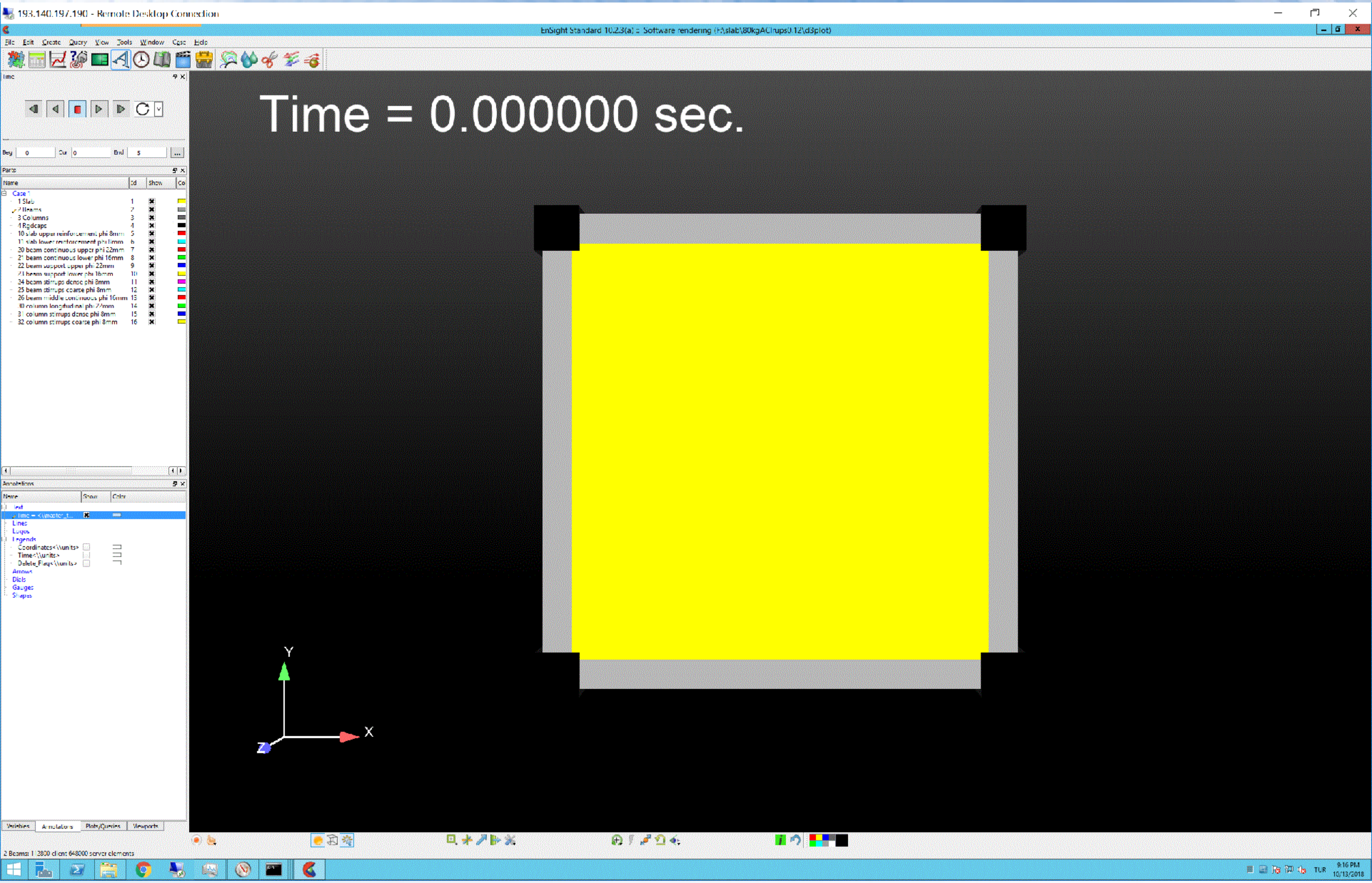

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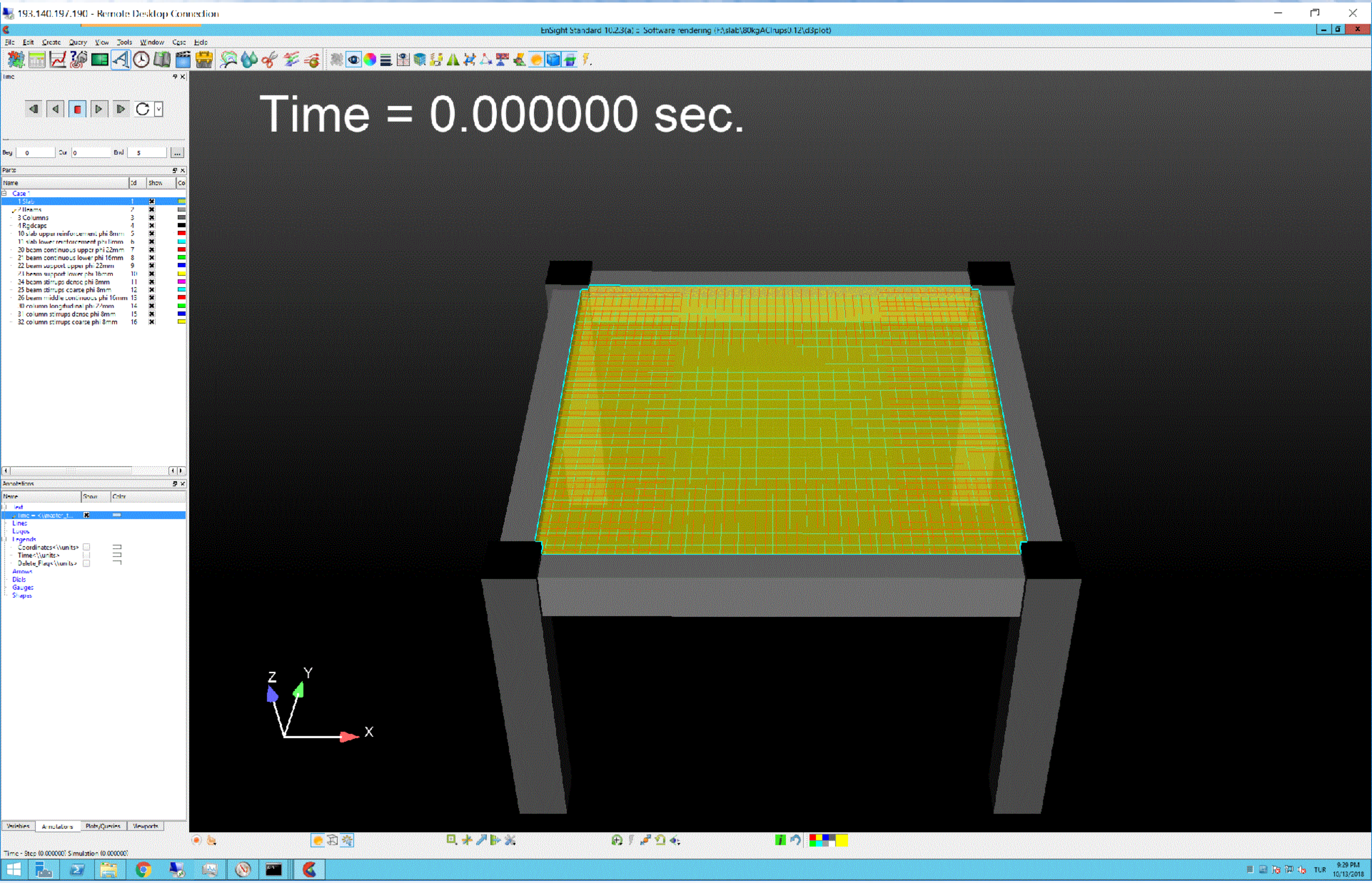

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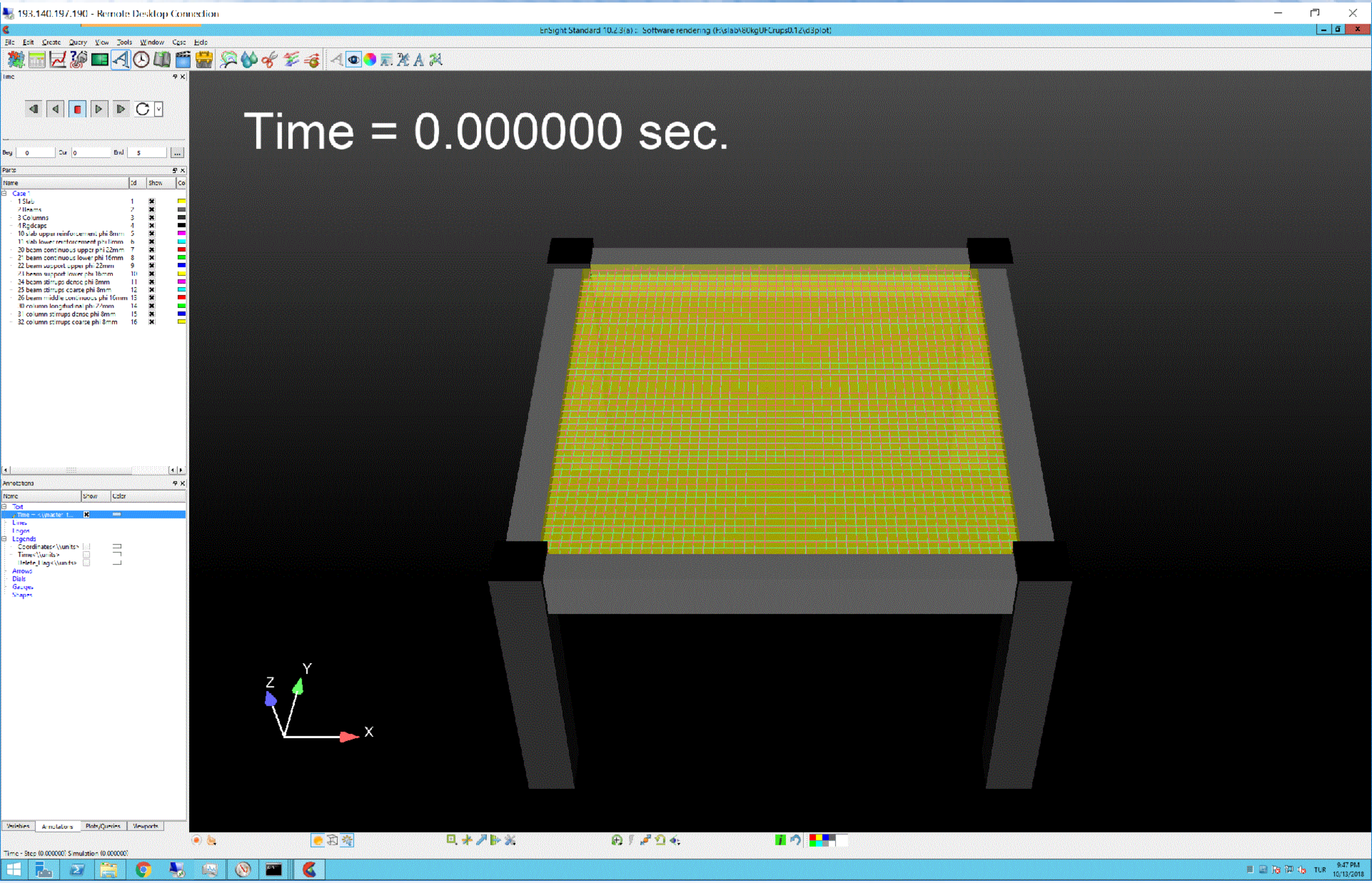

Conclusions

- **Protective Engineering design approach does make a difference in the uplift blast response of reinforced concrete slabs due to the placement of <u>continuous upper and lower reinforcing rebars</u>. The civilian design provides a poor performance as the blast situation is not taken into account in the development of civilian codes.**

- **The current Protective Engineering design codes and recommendations manuals do not take the rebar rupture strain into account. A literature survey has shown that reinforcing rebars have a garden variety of rupture strains ranging between 0.12 and 0.24. The rupture strain has a significant influence on the membrane action of the slab, which in turn directly determines the uplift blast performance. All slabs examined in this study failed in a membrane mode.**

- **Future work will involve the investigation of support strengthening with increased section dimensions. The slabs failed first at the supports, followed by rupture failure in the mid-span.**

Further Information

- **Refereed papers in an archival journals:**

Kilic, S. A., "Numerical Study on the Uplift Response of RC Slabs Subjected to Blasts", American Society of Civil Engineers, Journal of Performance of Constructed Facilities, 31(3), 1-9, June/July 2017.

Erdik, A., Kilic, S.A., Kilic, N., Bedir, S., "Numerical simulation of armored vehicles subjected to undercarriage landmine blasts", Shock Waves Journal, Springer, 26(4), 449-464, July/August 2016.

Thank you for your attention!

Questions?