

# Blast Response of Slabs in Reinforced Concrete Buildings



**SAMI A. KILIC**

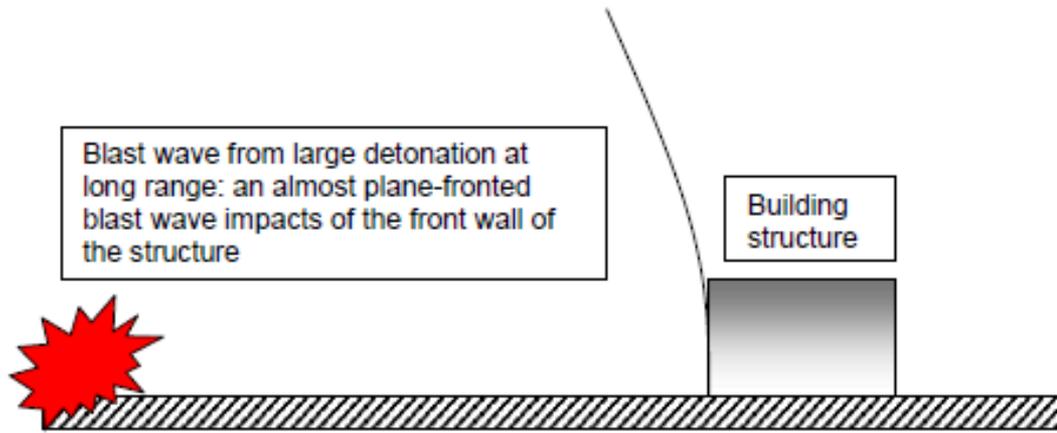


**GOKHAN YAZICI**

# 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



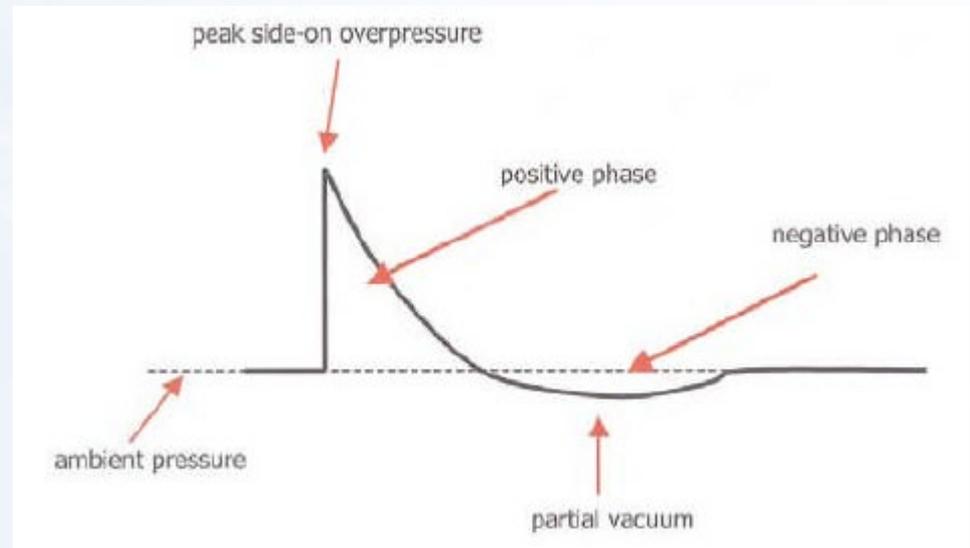
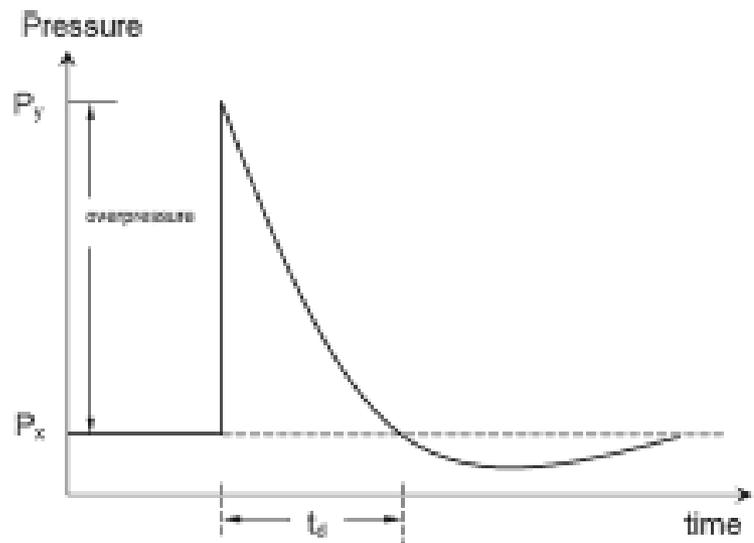
[Ref 5]

**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 Car Park Internal Explosion: Bogota, Colombia (2003)



# Shock Waves of the HE Blast Phenomenon



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

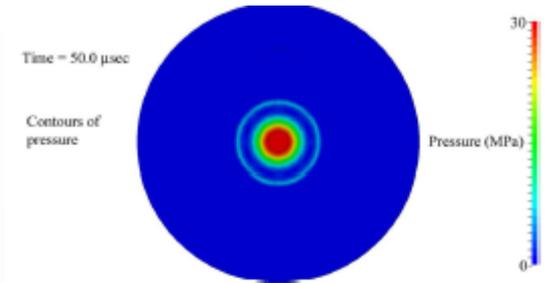
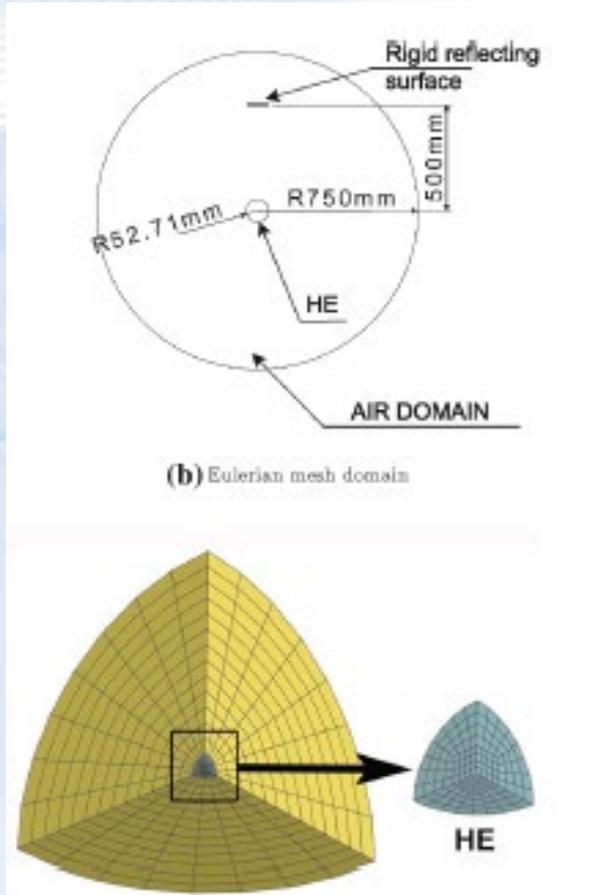


Fig. 11 Contours plots of pressure at  $t = 50.0 \mu\text{sec}$  for the S6 simulation

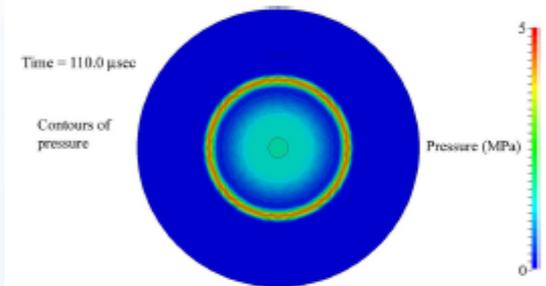


Fig. 12 Contours plots of pressure at  $t = 110.0 \mu\text{sec}$  for the S6 simulation

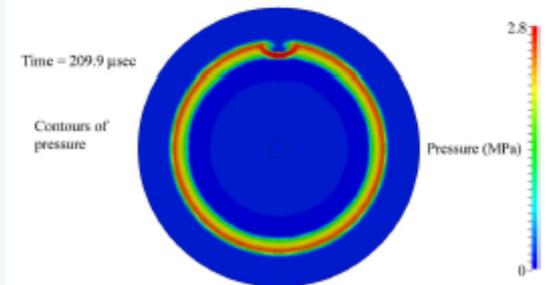
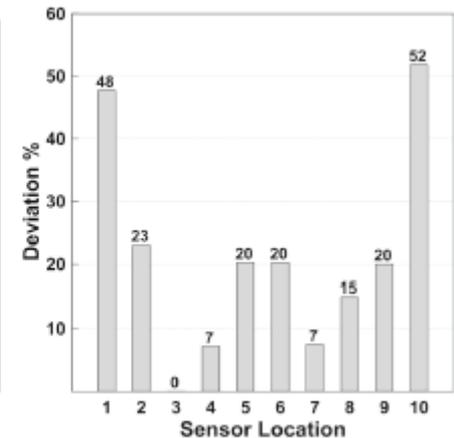
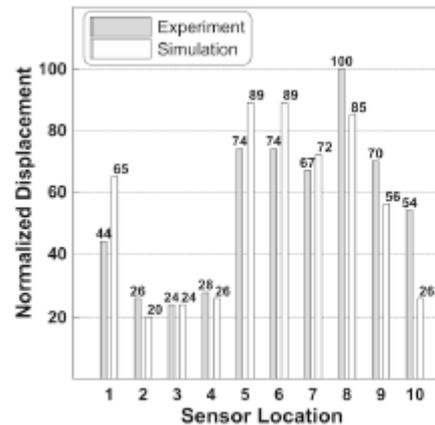
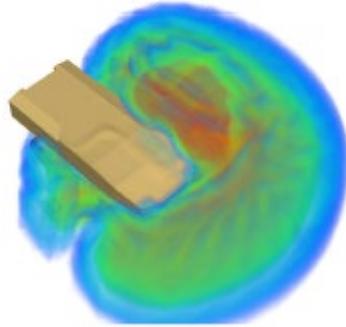
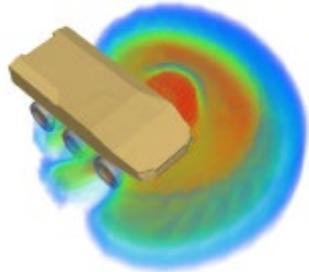
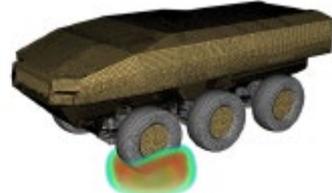


Fig. 13 Contours plots of pressure at  $t = 209.9 \mu\text{sec}$  for the S6 simulation

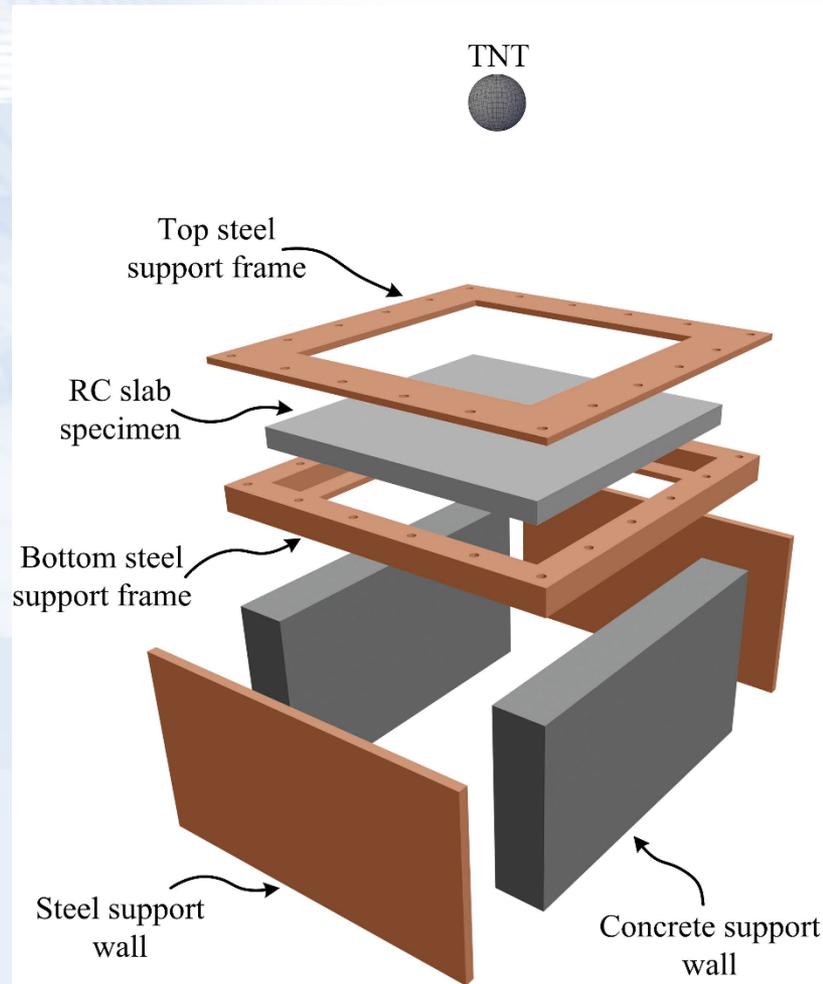
# Joint Work with the Turkish Armored Vehicle Manufacturer Otokar Corp. (2009-2011)



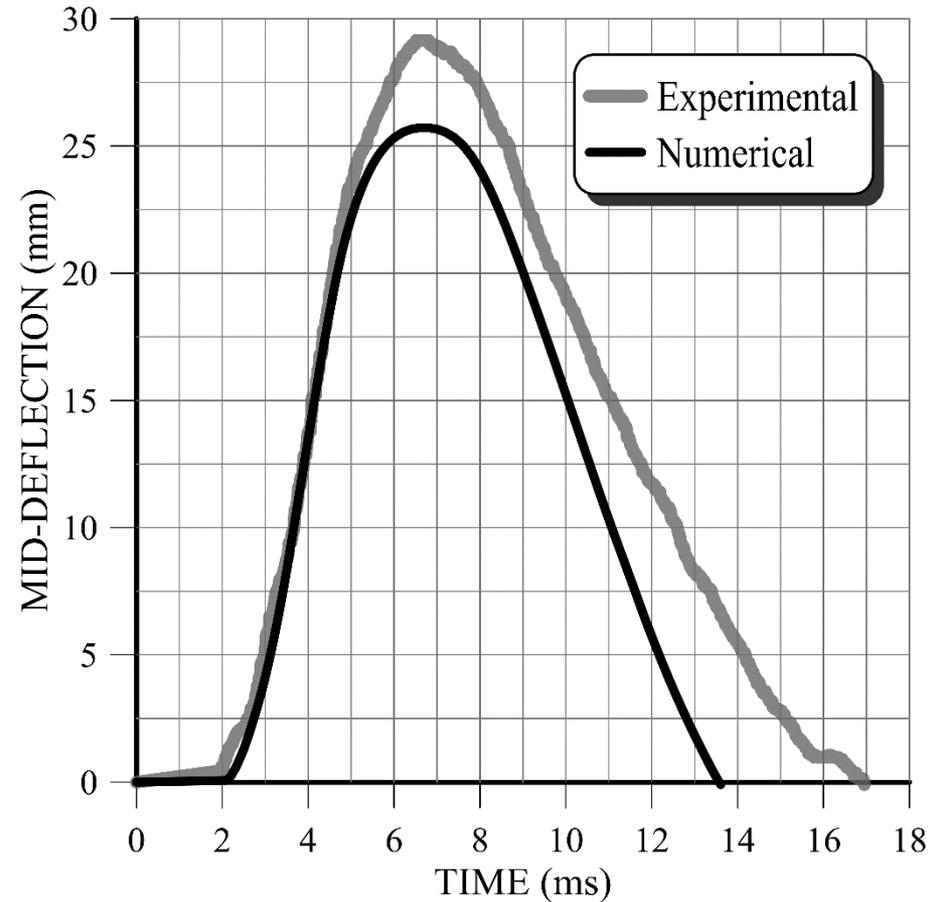
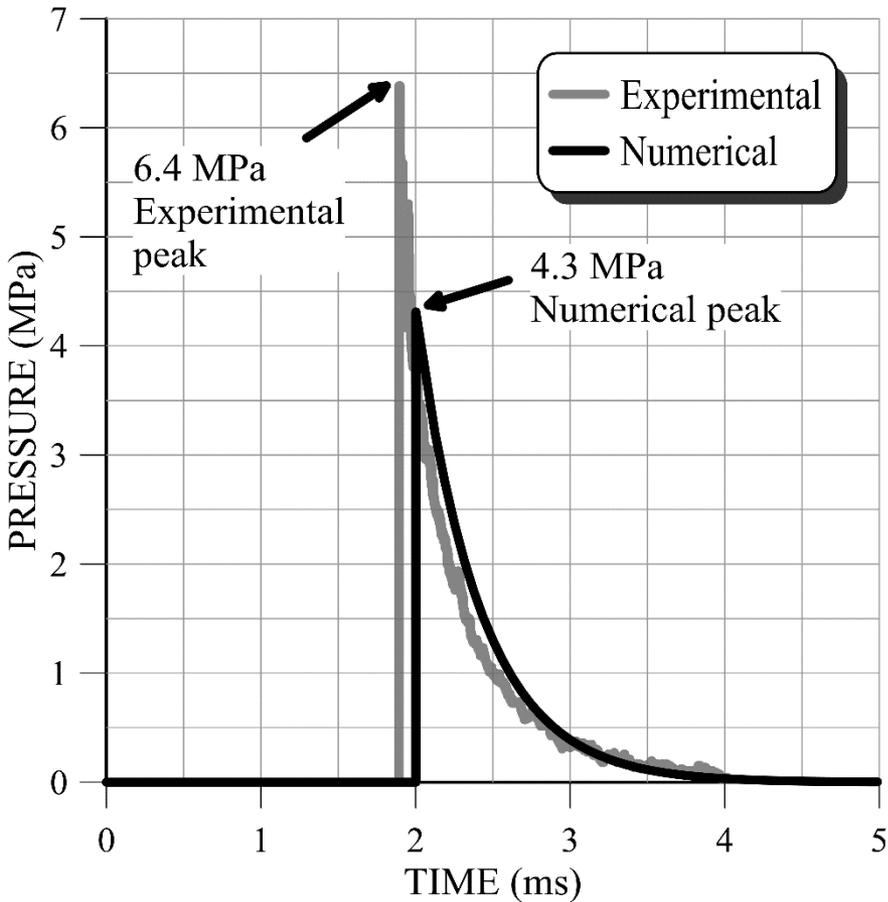
# OTOKAR Corp. – NATO Mine Blast Simulation with LS-Dyna ALE Approach



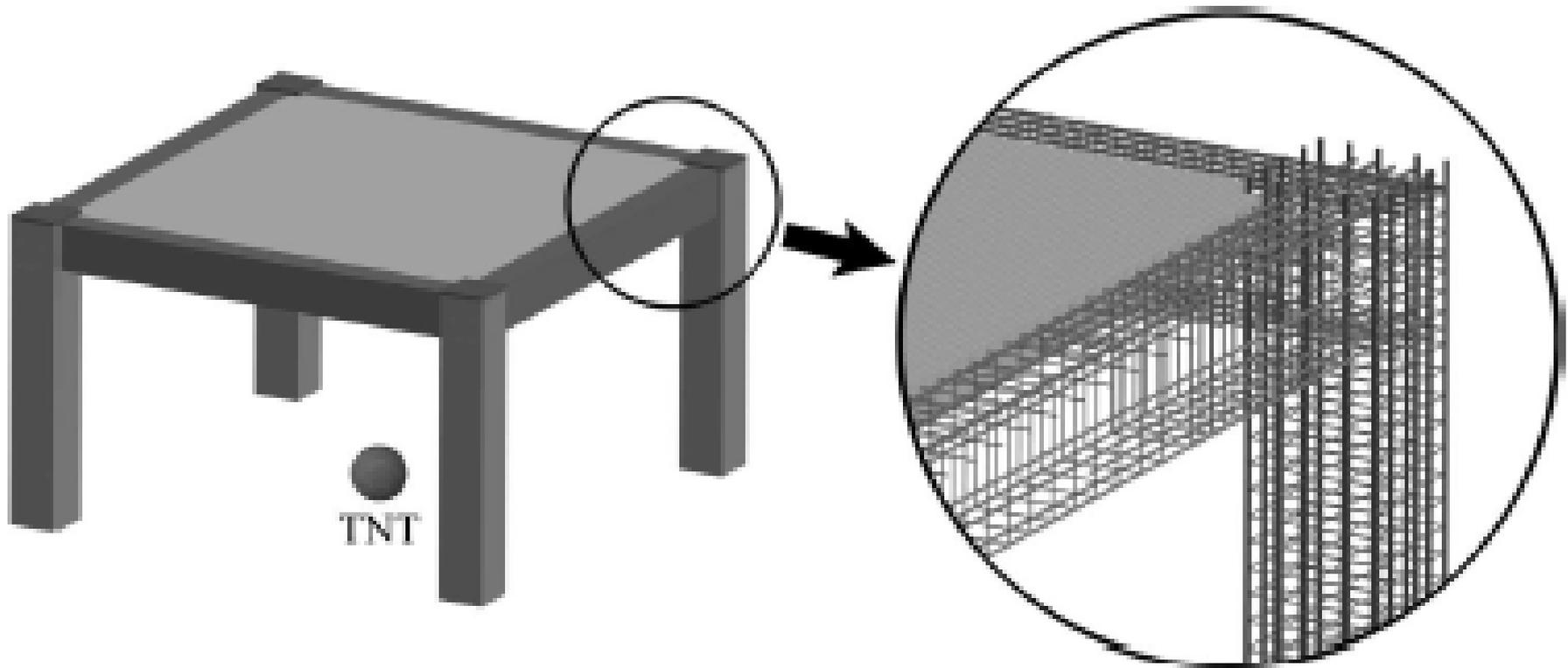
# Validation Example: Single Slab Experiment



# Validation Example: CONWEP Approach



# Case Study: Sample "Table Frame" with a Single Reinforced Concrete Slab



# Truegrid Text-based Meshing Approach Used (Ouch!)

[D:\80kgACI012dyn\blockv25ufc.tg] - UltraEdit

File Edit Search Insert Project View Format Column Macro Scripting Advanced Window Help

D:\80kgACI012dyn\blockv25ufc.tg

File View Open Explorer

Project Open Explorer

Filter: \*.\*

Open Files

blockv25ufc.tg x

```
19  divy [%Lt/%elsz+1]
20  divz [%ht2/%elsz+1]
21  ;
22  c unused parametric block command
23  c block 1 %divx;1 %divy;1 %divz;0. %Lt;0. %Lt;0. %ht2;
24  -----
25  c main block command
26  c
27  block
28
29  1 3 6 8 9 12 20 23 24 26 29 31    91 96 98 121 211 234 236 241    301 303 306 308 309 312 320 323 324 326 329 331;
30
31  1 3 6 8 9 12 20 23 24 26 29 31    91 96 98 121 211 234 236 241    301 303 306 308 309 312 320 323 324 326 329 331;
32
33  1 61 66 106 111 171 173 186 192 194 199 201 205 206;
34
35  0. 0.04 0.10 0.14 0.16 0.22 0.38 0.44 0.46 0.50 0.56 0.60    1.80 1.90 1.94 2.40 4.20 4.66 4.70 4.80    6.00 6.04
36
37  0. 0.04 0.10 0.14 0.16 0.22 0.38 0.44 0.46 0.50 0.56 0.60    1.80 1.90 1.94 2.40 4.20 4.66 4.70 4.80    6.00 6.04
38
39  0. 1.20 1.30 2.10 2.20 3.40 3.44 3.70 3.82 3.86 3.96 4.00 4.08 4.10;
40  c
41  echo executing the main block command is finished..
42  c -----
43  c
44  c delete regions; trim mesh
45  c
46  c edge empty space
```

Output Window

Template List

- Global
- Power User
- NASTRAN

Ln 1, Col 1, C0 DOS 1252 (ANSI - Latin I) NASTRAN Mod: 5/23/2015 1:42:40 PM File Size: 30918 R/W INS CAP

# Truegrid Text-based Meshing Approach Used (Ouch!)

[D:\80kgACI012dyn\blockv25ufc.tg] - UltraEdit

File Edit Search Insert Project View Format Column Macro Scripting Advanced Window Help

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File View Open Explorer Filter: \*.\*

Open Files blockv25ufc.tg x

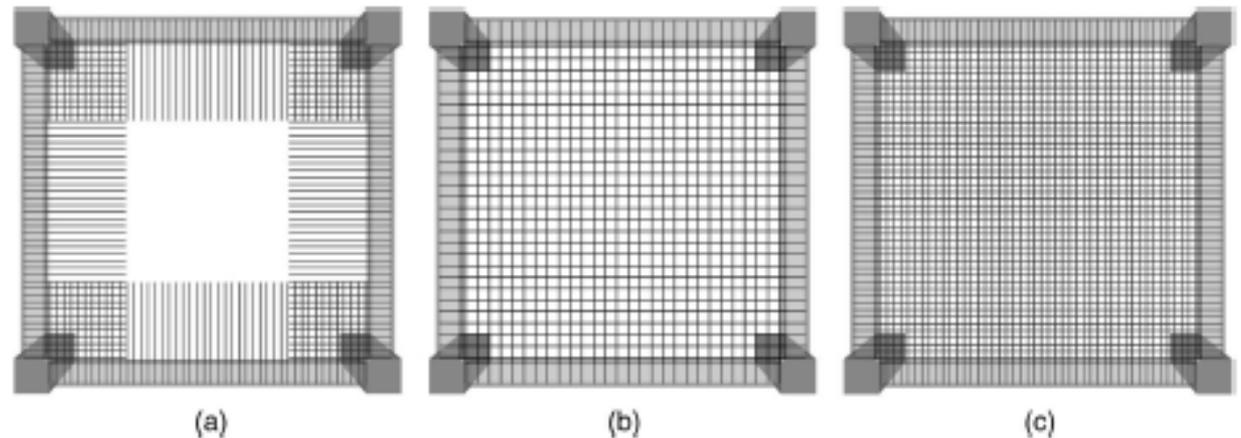
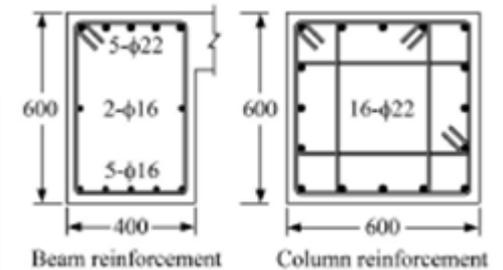
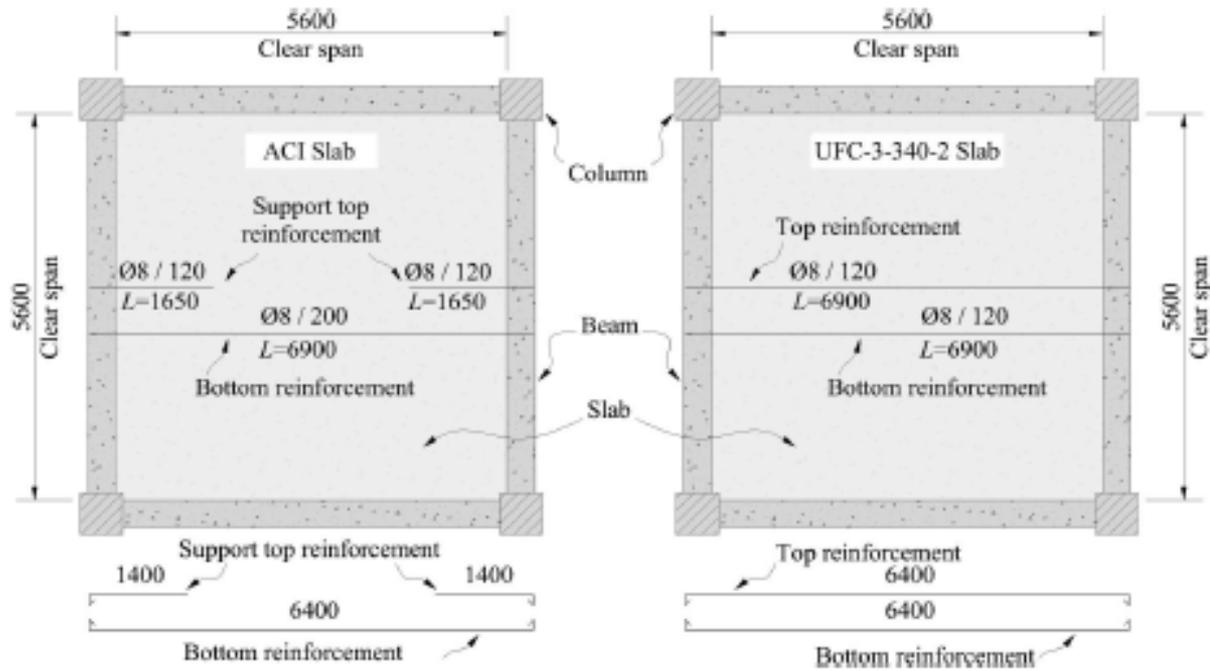
```
44 c delete regions; trim mesh
45 c
46 c edge empty space
47 dei 12 21; 1 3; ;
48 dei 30 32; 12 21; ;
49 dei 12 21; 30 32; ;
50 dei 1 3; 12 21; ;
51 c under the beam
52 dei 12 21; 3 10; 1 6;
53
54 dei 3 10; 12 21; 1 6;
55 dei 23 30; 12 21; 1 6;
56 dei 12 21; 23 30; 1 6;
57 c under the slab
58 dei 10 12; 12 21; 1 9;
59 dei 21 23; 12 21; 1 9;
60 dei 12 21; 10 23; 1 9;
61 c at the top rigid cap level
62 dei 1 12; 12 21; 12 14;
63 dei 12 21; 1 32; 12 14;
64 dei 21 32; 12 21; 12 14;
65 c
66 echo mesh deletion and block trimming is finished..
67 c -----
68 if(%aci.ne.0)then
69 c TS-500
70 c SLAB i-DIRECTION REINF.....X.....
71 c il j1 k1 i2 j2 k2 noj nok matno orient
```

Output Window

Template List Global Power User NASTRAN

Ln 1, Col 1, C0 DOS 1252 (ANSI - Latin I) NASTRAN Mod: 5/23/2015 1:42:40 PM File Size: 30918 R/W INS CAP

# Steel Reinforcement Configurations



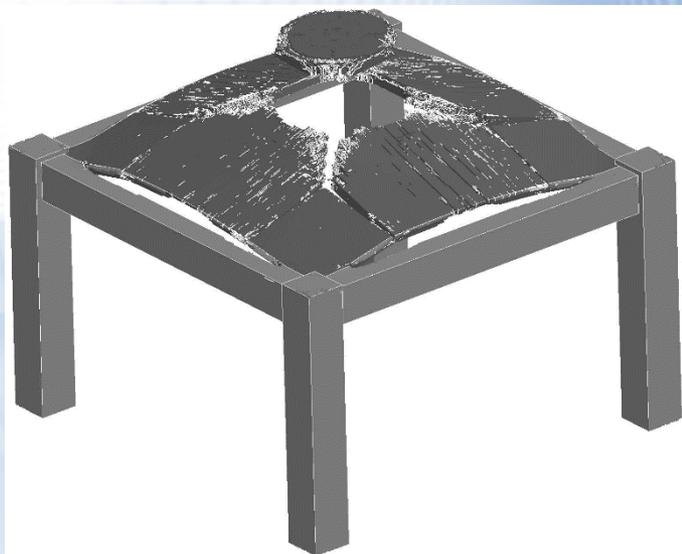
# Material Data and LS-Dyna Modeling Approaches

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.

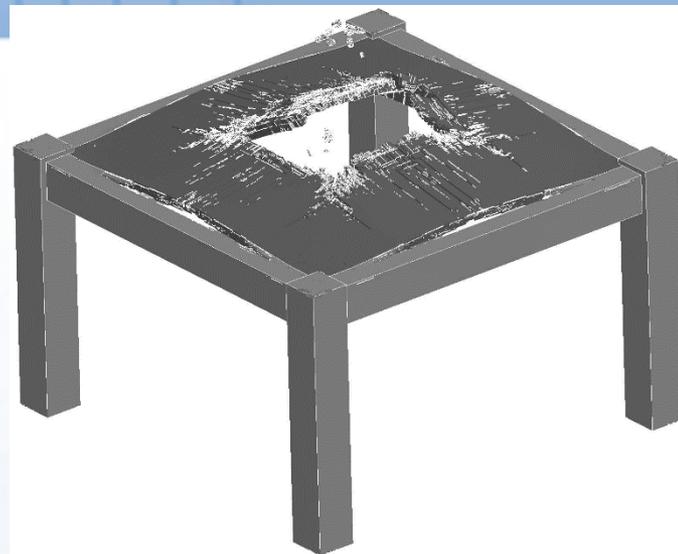




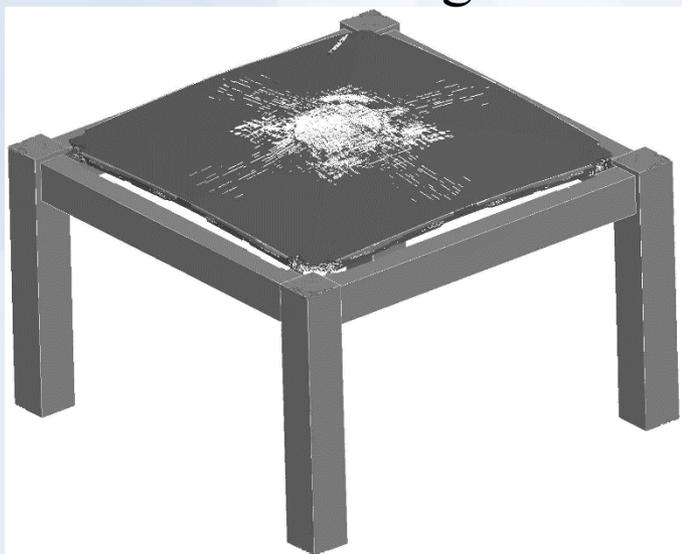
# Blast Uplift Parametric Study with 80 kg TNT at 2.00 Meters of Stand-off Distance



Civilian Design



Protective Design



# Civilian Design: 80 kg TNT Rups=0.12

193.140.197.190 - Remote Desktop Connection

EnSight Standard 10.2.3(a) - Software rendering (F:\stab\80kgAClrups0.12\d3plot)

File Edit Create Query View Tools Window Case Help

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Parts

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Case 1			
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2 Beams	2	<input checked="" type="checkbox"/>	
3 Columns	3	<input checked="" type="checkbox"/>	
4 RgdCaps	4	<input checked="" type="checkbox"/>	
10 slab upper reinforcement phi 8mm	5	<input checked="" type="checkbox"/>	
11 slab lower reinforcement phi 8mm	6	<input checked="" type="checkbox"/>	
20 beam continuous upper phi 22mm	7	<input checked="" type="checkbox"/>	
21 beam continuous lower phi 16mm	8	<input checked="" type="checkbox"/>	
22 beam support upper phi 22mm	9	<input checked="" type="checkbox"/>	
23 beam support lower phi 16mm	10	<input checked="" type="checkbox"/>	
24 beam stirrups dense phi 8mm	11	<input checked="" type="checkbox"/>	
25 beam stirrups coarse phi 8mm	12	<input checked="" type="checkbox"/>	
26 beam middle continuous phi 16mm	13	<input checked="" type="checkbox"/>	
30 column longitudinal phi 22mm	14	<input checked="" type="checkbox"/>	
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32 column stirrups coarse phi 8mm	16	<input checked="" type="checkbox"/>	

Annotations

Annotations

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Legends

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Arrows

Dials

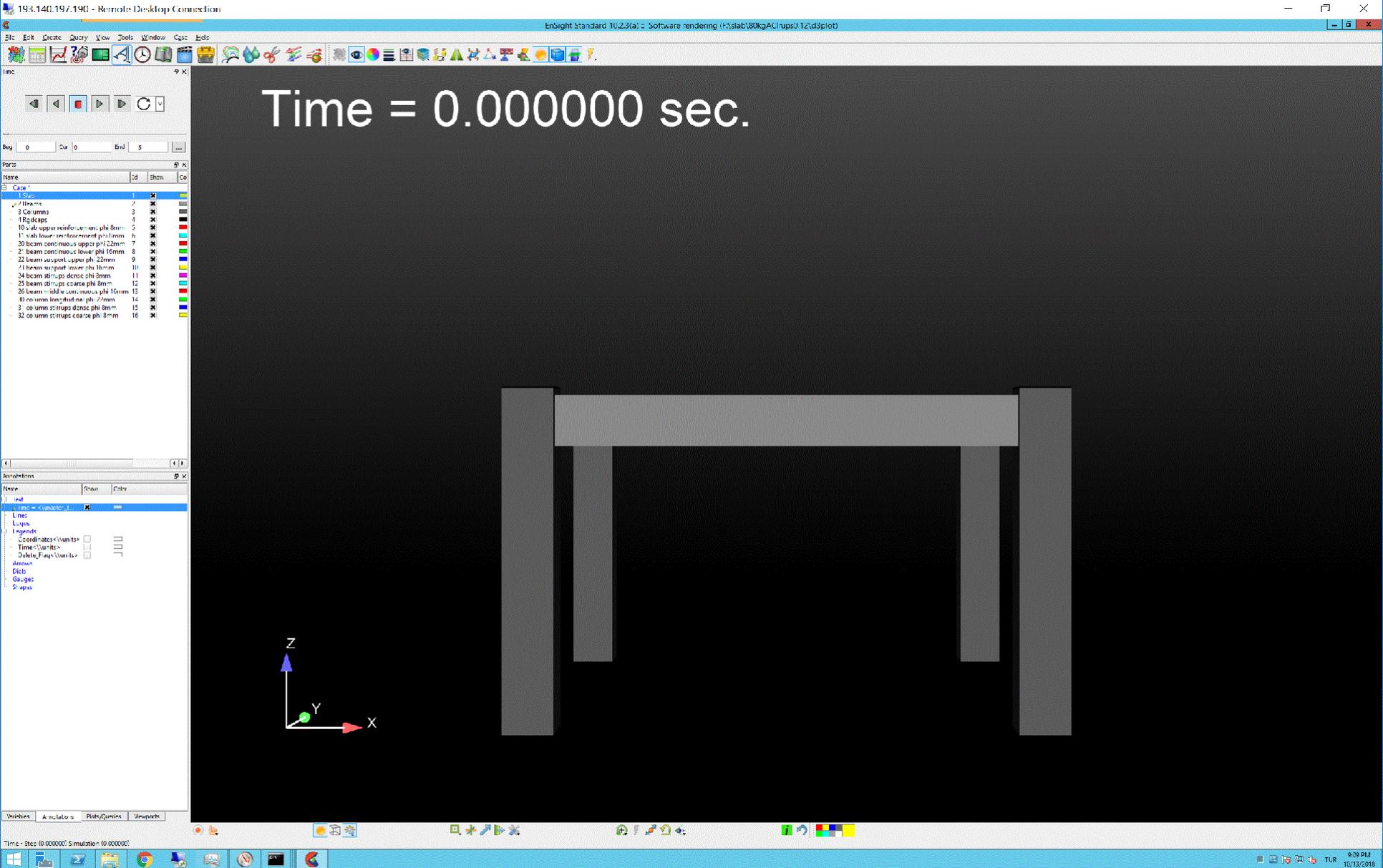
Gauges

Shapes

Variables Annotations Plots/Queries Viewports

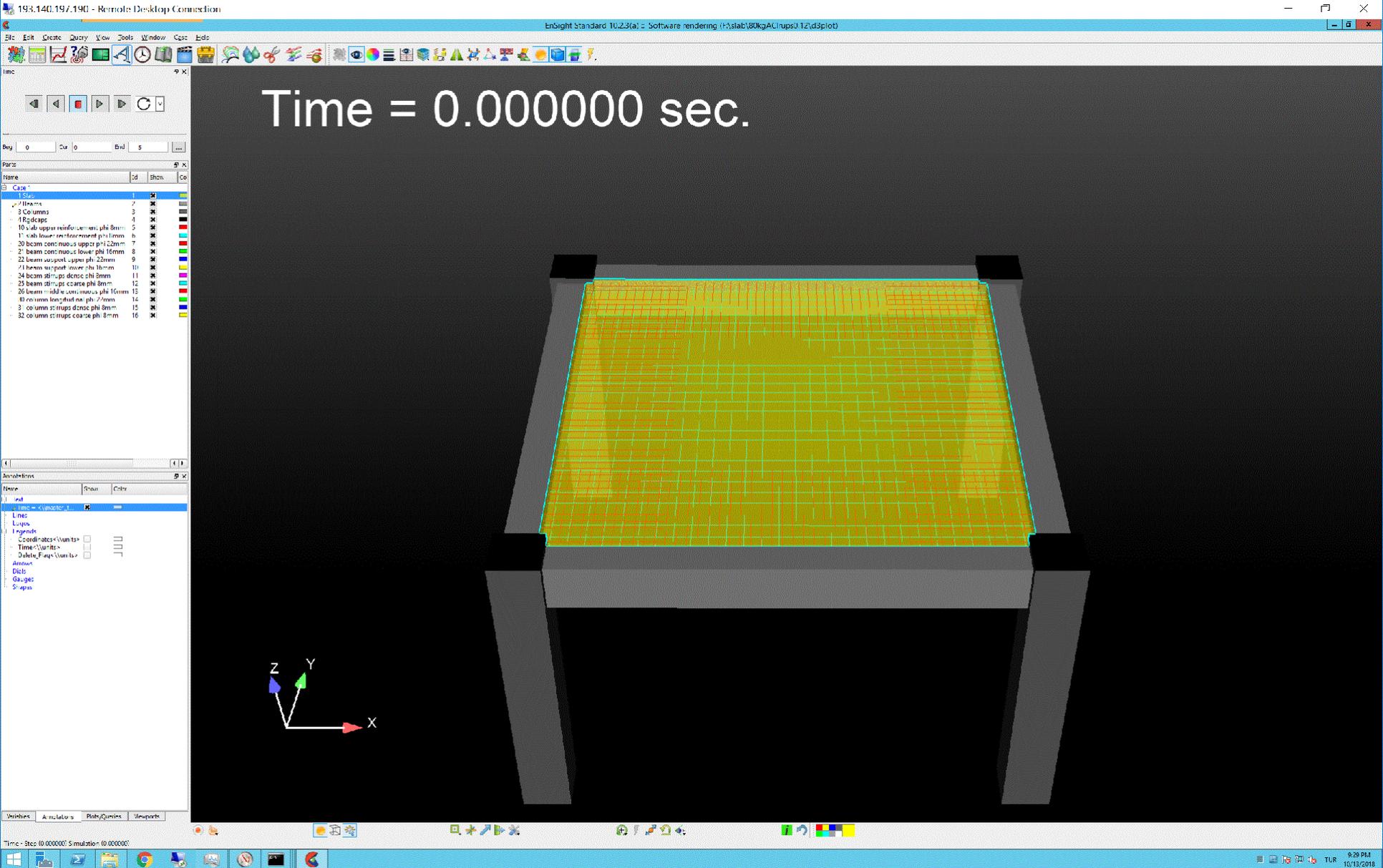


# Civilian Design: 80 kg TNT rups=0.12





# Civilian Design: 80 kg TNT rups=0.12





# Conclusions

- **Protective Engineering design approach does make a difference in the uplift blast response of reinforced concrete slabs due to the placement of continuous upper and lower reinforcing rebars. 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?**