Technologies for Structural Damage Analysis

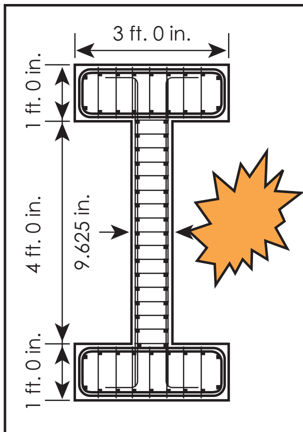
Accurately simulating the effects of reinforced concrete structures subjected to extreme events, such as blast or aircraft impact, in an efficient and timely manner continues to be extremely challenging. Many large concrete structures contain an extensive amount of rebar, which can be very time consuming for the analyst to model explicitly, using either brick or beam elements. Brick elements provide dimensionality and also allow the use of arbitrary Lagrangian-Eulerian (ALE) schemes where rebar is modeled. However, this requires a very finely resolved mesh. It is also currently difficult to model a fully-coupled blast simulation of large buildings with substantial beam and column detail. Beam element implementation in ALE3D would allow efficient detailed calculations of large buildings.

Finally, we need improved metrics of concrete damage or postprocessing techniques. In essence, when the analyst hands over a display of "damage" to the customer, there should be no guessing as to the health of the structure in question.

Project Goals

Our main objective is to enhance our ability to simulate the response of reinforced concrete structures exposed to extreme loading environments. We are also implementing codes that can handle all aspects of a blast simulation, for example, in one seamless calculation.

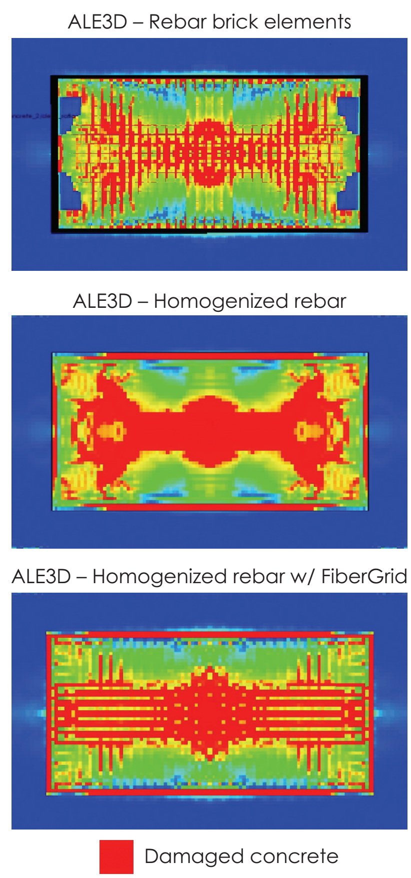
Figure 1. Comparisons among rebar brick elements, homogenized rebar, and homogenized rebar preprocessed with FiberGrid for a blast experiment.



Test wall and stubs, 6% rebar by mass (side view).

- Primary test wall reinforcing is No 3 rebar spaced at 3 in. on center.
- Secondary test wall reinforcing is size D-3 deformed wire spaced at 3 in. on center.
- Stirrups in the test wall are size D-2.5 deformed wire spaced at 3 in. on center in both directions.
- Primary and secondary reinforcing in the flanges are No. 5 rebar spaced at 4 in. on center.
- Stirrups in the flanges are No. 3 rebar spaced at 4 in. on center in both directions.
- All steel rebar reinforcing is Grade 60 and conforms to ASTM specifications A615.
- All deformed wire conforms to ASTM specification A496.

Precision test wall study: modeling a U.S. Army-ERDC test of blast loaded RC. Time comparison for mesh generation: brick rebar models ~7 days; homogenized rebar model ~ 1/2 day.



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Relevance to LLNL Mission

The computational tools implemented for this project will decrease the mesh generation time and the computation time. These tools will significantly enhance our ability to analyze the response of reinforced concrete structures for the Department of Homeland Security, the Homeland Operations and Defense Planning Systems, and Underground Analysis and Planning Systems. This project will also help LLNL programs expand their expertise in advanced computational analysis.

FY2005 Accomplishments and Results

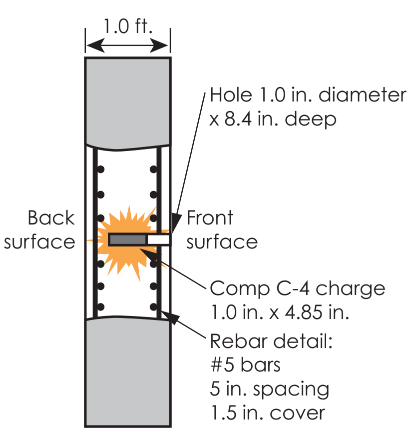
The following are the accomplishments for FY2005:

1. Implementation of DYNA3D's beam elements into ALE3D;
2. Implementation and validation of homogenized rebar model into DYNA3D;
3. Validation of homogenized rebar model for ALE3D;
4. Implementation of FiberGrid into ALE3D's generator for use with the homogenized rebar model;
5. Validation of FiberGrid;
6. Implementation of nonlinear concrete model into NIKE3D;
7. Validation of the new damage metric using VisIt.

Validation of the new homogenized rebar/concrete material model and its preprocessor, FiberGrid, has been completed using the Precision Test Wall experiments conducted by the U.S. Army Engineer Research and Development Center. In the original implementation of the homogenized rebar/concrete model, the rebar was specified as a volume fraction in an approximate region where rebar is located. FiberGrid will implement the volume fractions of rebar in the individual concrete elements (and not a whole concrete region) where rebar is located in reality. Using FiberGrid, the rebar will look and behave in a manner very similar to truss elements overlaid inside the concrete. A quick validation of FiberGrid was performed on the Precision Test Wall and the results are shown in Fig. 1. As is seen in the comparison of results, the homogenized rebar with FiberGrid simulation begins to converge very nicely towards the rebar brick element simulation. The time comparison for generating a model using brick elements for the rebar is approximately seven days, while the generation of a homogenized rebar/concrete model is only half a day.

In addition to validating that the homogenized rebar model is working properly, a new spall or damage criterion was validated against a blast experiment conducted by the U.S. Army Corps of Engineers Waterways Experiment Station (WES).

The spall or damage criterion is a very simple idea: concrete spallation might be able to be predicted in these complicated concrete plasticity models if a certain portion of a concrete structure (subjected to very large blast pressures or impact) has both tensile or compressive damage and a significant velocity. For this simulation, the concrete damage threshold was 0.85 (from a scale of 0 to 1, where 1 is complete tensile or compressive damage of concrete) and the velocity threshold was chosen to be 20 in./s. Figure 2 shows the fringe plot of this spall/damage criterion. As a result of using these two threshold values, the predicted spall was approximately 30 cm, which matches experiment reasonably well.



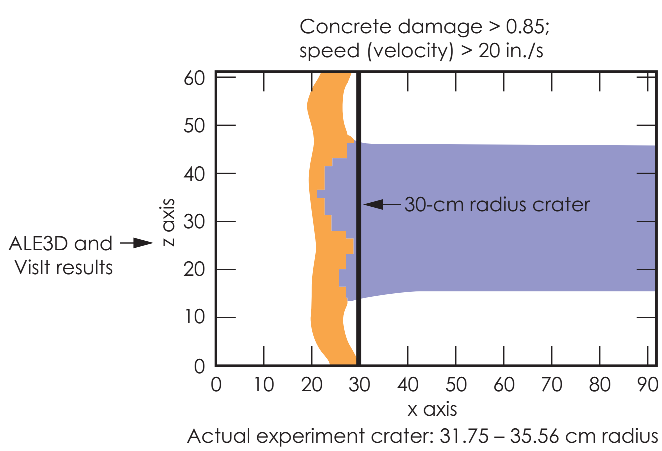


Figure 2. Validation of new concrete damage metric using the VisIt postprocessor.