The Klotz Group Contribution to Explosives Safety

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Introduction

• The Klotz Group (KG) is an international group of experts on explosives safety that collaborate based on two objectives:
  • (i) to improve the knowledge base of explosion effects associated with the storage, processing and transport of ammunition and explosives, and
  • (ii) to develop engineering data bases to quantify the explosion effects that enable safety focused consequence assessments and risk analyses

• The KG is currently comprised of eight member nations: Germany, Norway, the Netherlands, Singapore, Sweden, Switzerland, the United Kingdom, and the United States

• This brief shall provide a brief overview of the group and work
Klotz Group Strategy – 2018

• To achieve the objectives, explosion effects modeling experts from member nations meet twice a year to define and update the KG research program
• Primary focus is on explosion produced debris
• Subset of tasks are
  • Discuss, plan, and execute projects of common explosives safety interest
  • Develop tools to aid in explosives risk analyses
  • Identify gaps in the knowledge of explosion effects
  • Coordinate national R&D programs within areas of common interest
• Product of research effort is the Klotz Group-Engineering Tool (KG-ET)
### Historical Overview of Klotz Group Research

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<th>Years</th>
<th>Era</th>
<th>Work Efforts</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966 – 1971</td>
<td>Pre-Klotz</td>
<td>Definition of Klotz design</td>
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<td>1971 – 1975</td>
<td>Klotz Testing</td>
<td>Test &amp; development of Klotz design; testing in Älvdalen, Sweden</td>
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<td>1975 – 1998</td>
<td>Klotz Club (KC)</td>
<td>Underground ammunition storage. Focus on experiments and gaining reliable data, numerical modeling in later years.</td>
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- A “Klotz”, German word for “Block”, is a massive closing device that acts as a gigantic blast valve in underground storage facilities
- Klotz Club avoided formal relationship with NATO in order to focus solely on technical issues
- Klotz Group reestablished formal ties with NATO, but still avoids any discussion of “acceptable risk/hazards” and discussion remains entirely technical
Highlighted Research: Klotz Club & Klotz Group

• Been multiple contributions over the years by this entity to the explosives safety community in the form of analysis, testing, and modeling

• The following slides provide a quick glimpse at just some of the work conducted in previous years
Klotz Closing Valve

• The origins of the Klotz Club, and now Klotz Group, date back to 1966 when a group of Swiss and Norwegian engineers were searching for solutions to mitigate hazards from underground storage

• The Klotz concept was envisioned as a giant blast valve

• Theoretical and experimental studies were carried out in Switzerland and Norway from 1967 to 1970

• Full-scale proof test successfully performed in Älvdalen, Sweden in 1973
  • Full size Klotz has a mass of approximately 250 tonnes
Water Mitigation

• Klotz Club started to look at water mitigation in 1993
  • Previous small scale experiments had shown reduction in pressure & impulse

• In September 1996, the Klotz Club and Singapore conducted a full-scale test using 1000 kg of 152 mm artillery shells
  • Conducted in KC-tunnel at Älvdalen range
  • Identical to test without water mitigation conducted in 1989

• Results showed reduction in explosives output, but far less than that of scaled tests

• Klotz Club conducted additional analytical studies and Singapore funded additional testing in 2000 and 2001
Debris Launch Velocity (DLV) Formula

• One of the critical parameters for determining debris throw distances from an aboveground magazine is the debris launch velocity
• The 1990s DLV test series aimed to investigate this in more detail
  • Planned by Klotz Group and Ernst Mach Institute (EMI)
  • Conducted at test sites in Germany
• Early tests had fully vented vs. enclosed conditions
  • The results of this series showed that the shock loading contributes 10% and the gas pressure 90% to the launch velocity
  • The above results are specific to loading regime and specifics of the test, but the general trend is true for confined structures
DLV Formula

- Additional tests conducted with a wide variety of loading density, structure geometry, charge placement, & fixity of corner connections
- End product was the DLV equation
- Over the years, the DLV has been proven to be accurate for a wide range of structures and loading conditions
  - Modification factors have been developed
  - The basic DLV equation is used in the KG-ET

\[ v_{\text{launch}} = 525 \sqrt{\frac{\gamma \cdot L_{\text{char}}}{m}} \]

- \( v_{\text{launch}} \) = launch velocity (m/s)
- \( \gamma \) = loading density (kg\text{TNT}/m\text{³})
- \( L_{\text{char}} \) = characteristic length; the cube root of the volume (m)
- \( M \) = aerial wall density (kg/m\text{²})
Reinforced Concrete (RC) Magazines

- After the extensive focus by the Klotz Club on underground magazines, in the 1990s the shift focused to aboveground heavy structures, such as RC, and their dominant debris throw hazard.
- DLV work used to quantify RC debris launch velocities.
- Klotz Group research range of interest for the prediction of debris hazards has been loading densities between 1 and 15 kg/m³.
- Information on mass distribution and launch angle distribution were still unknown.

<table>
<thead>
<tr>
<th>Regime</th>
<th>Shock Overloading</th>
<th>Blast Pressure Overloading</th>
<th>Gas Pressure Overloading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loading Density (kg/m³)</td>
<td>LD &gt; 15</td>
<td>1 ≤ LD ≤ 15</td>
<td>LD &lt; 1</td>
</tr>
<tr>
<td>or Scaled Distance (m/kg^{1/3})</td>
<td>Z &lt; 0.4</td>
<td>0.4 ≤ Z ≤ 1</td>
<td>Z &gt; 1</td>
</tr>
</tbody>
</table>

Illustration of Phenomena

![Illustration of Phenomena Image](image-url)
RC Magazines: Kasun Tests

- The Klotz Group conducted multiple series of tests on small RC magazines
- Type of magazine tested was the Kasun, used for small NEW storage
  - 2x2x2 m³ internal dimensions of heavily reinforced RC box
  - Wall & roof thickness of 15 cm; double layers of rebar in both directions
- Kasun test series generated extensive data on mass distribution, launch angle, and debris density as a function of distance, as well as debris launch velocity information
• A three-step procedure was developed to model the sequence of events
  • Hydrocode for pressure-time histories
  • Fragmentation prediction and jetting
  • Input into coupled simulation of Kasun
• The developed procedure and applied numerical tools enabled study of the casing effects on loading and break-up
• Methodology will be applied to other geometries, munition types, and asymmetric storage conditions
Klotz Group – Engineering Tool (KG-ET)

• Work on this debris prediction methodology and tool began about 15 years ago
• Methodology implemented in KG-ET represents state-of-the-art, physics-based engineering prediction model for debris throw hazards
• Tool implements “source function” methodology specific to each component of the donor being analyzed
  • Version 1.x is RC model, Version 2.x is ISO-container model, and Version 3 is RC model, ISO container model, and “free form” source function
• The addition of the “free form” source function is significant as it allows incredible flexibility to model any donor source if information describing debris throw phenomena are known.
KG-ET: Methodology

- KG-ET source function is defined for each component of donor and is represented as a point source.

- For example, in basic/default version, for the wall of RC magazine:
  - Mass distribution is a function of NEW & volume, launch velocity is based on DLV, and vertical/horizontal launch angles are predefined.

- Parameters based on best available date.
KG-ET: Input & Output

• Simplistic user interface in basic mode; desired complexity in expert mode

• Output is debris density by mass bin, by all debris, or by defined kinetic energy criterion, e.g., 58 ft-lb (79 joules)
  • Targets/ESs can be defined to quantify debris hazard

• Successful validation efforts with test data
Conclusion

• The Klotz Group and its predecessors have provided extensive contributions to the explosives safety community for over five decades.
• The pursuit of a fundamental understanding of explosion effects have resulted in state-of-the-art testing and research.
• The KG-ET is an integrator of extensive expertise, test data, and analytical modeling to be used for enhancing explosives safety quantity distances and supporting quantitative risk assessments.
• Future Plans
  • Develop KG-ET source functions for primary fragments & quantify stack effects.
  • Develop the KG-ET ECM source function.
  • Continue balance between testing, engineering models, and computational analysis to further develop the KG-ET to enhance explosives safety.
Thank you for your attention.

Questions?