DOCENDO DISCIMUS

FACULTY OF CIVIL AND TRANSPORT ENGINEERING

Modern experiments exploring advancements in protective structures engineering

The 9th International Colloquium on Performance, Protection & Strengthening of Structures Under Extreme Loading & Events (Singapore)

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www.protect2024.org | 13-16 August 2024

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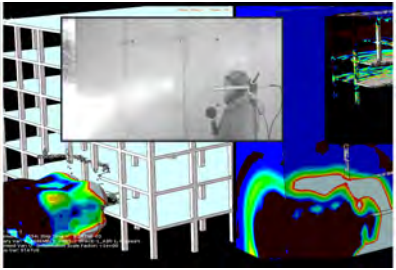
Presentation outline



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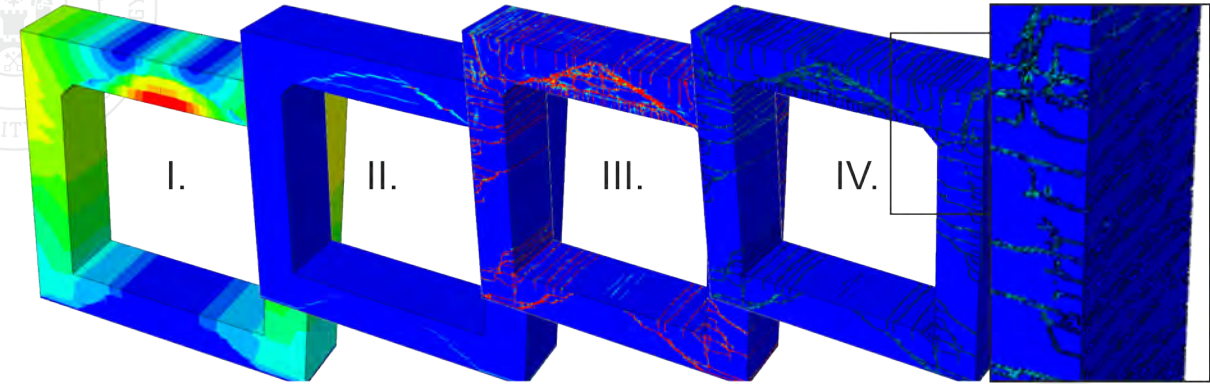
Advancements : Finite Element Methods |movie|



"We can perform whatever we only want ! How sure are we of the results ?"

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The Range (measurement capabilities) Ref. : [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13]

I. Perform the test

to validate design assumption
repeat the test
data storage and future experience

II. High-speed records

BW and full HD colour cameras
1E3 - 1E6 fps of faster..
"Go-Pro" is alwas valuable

III. Displacement in time

Digital Image Corelation (how many fps ?)
LVDT and laser tools, what frequency ?
is 10000 Hz enough ?

IV. Blastwave characteristics

Insident and reflected pressure
blastwave velocity and front temperature
is 1000 Hz enough ?

V. Combined effect

Fragments vs. blastwave front
What is faster ? What is more energetic ?

VI. CBRNE threats

Products of home made explosive mixtures : pressure, temperature, corrosion, .. or radiation..

VII. Material of specimens

Comparison of concrete mixtures : steel or welding quality

VIII. Internal damage

Penetration and perforation ettects
Is the specimen damaged inside ?
X-Ray scan up to .. cm of material

IX. PBI & TBI measurements

Different limits and cumulative criteria

X. IEDs, UAS

repeat actual scenarios and own database

XI. Underground*

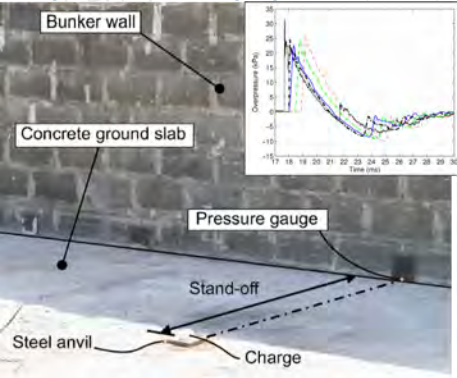
..

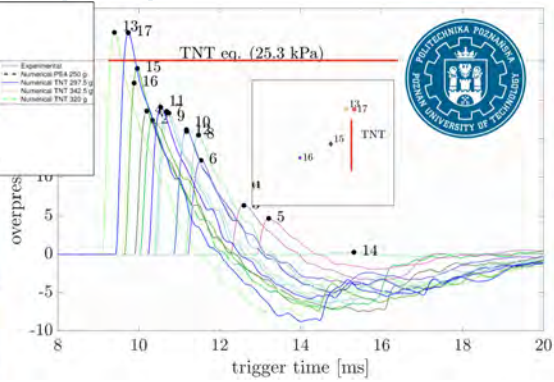
XII. Underwater*

..

Experimental testing | lvl ’basic’

Explosive mixture properties |movie| Ref. : [9, 12, 1]

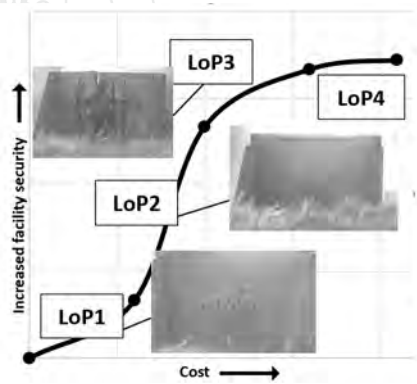


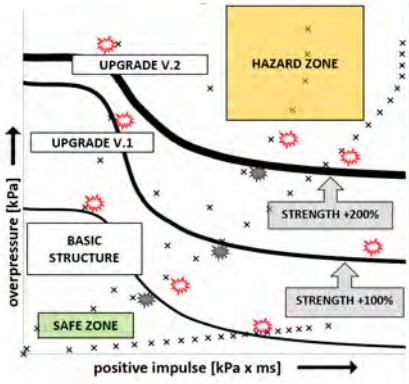


mixture 2 (17.4 kPa)
mixture 3 (6.4 kPa)
mixture 4 (18.6 kPa)
mixture 5 (4.7 kPa)
mixture 6 (12.2 kPa)
mixture 7 (18.6 kPa)
mixture 8 (15.5 kPa)
mixture 9 (18.3 kPa)
mixture 10 (16.2 kPa)
mixture 11 (19.1 kPa)
mixture 12 (16 kPa)
mixture 13 (28.8 kPa)
mixture 14 (0.3 kPa)
mixture 15 (24.1 kPa)
mixture 16 (22.3 kPa)
mixture 17 (28.8 kPa)

Rigby, Samuel E. and Sielicki, Piotr. « *An Investigation of TNT Equivalence of Hemispherical PE4 Charges* ». *en. In :* ***Engineering Transactions*** *62.4 (2014), p. 423-435.* ISSN *: 0867-888X* | Sielicki, Piotr W. and Clutter, James Keith and Sumelka, Wojciech and Gajewski, Tomasz and Malendowski, Michał and Peksa, Piotr and Studziński, Robert. « *Identification of Aluminium Powder Properties for Modelling Free Air Explosions* ». *en. In :* ***Materials*** *15.4 (2022), p. 1294-1-1294-13.* ISSN *: 1996-1944.* DOI *: 10.3390/ma15041294* | Sielicki, Piotr and Stachowski, Michał. « *Implementation of Sapper-Blast-Module, a Rapid Prediction Software for Blast Wave Properties* ». *en. In :* ***Central European Journal of Energetic Materials*** *12.3 (2015), p. 473-486.* ISSN *: 1733-7178*

Masonry wall damage modes |movie| Ref. : [14, 15]

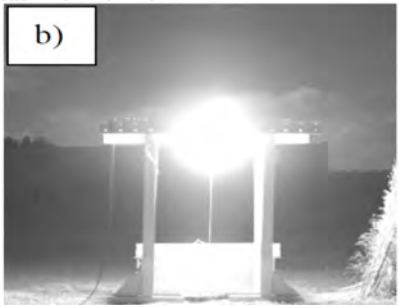


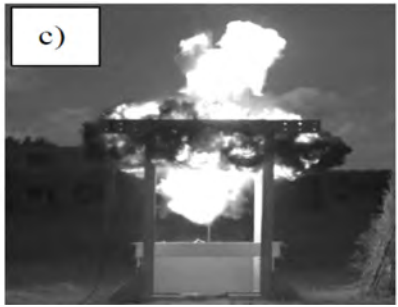


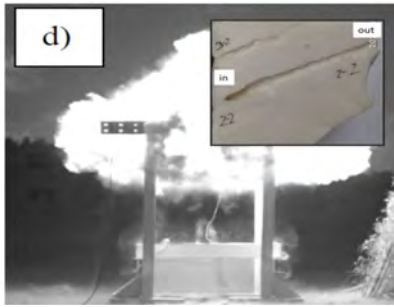
SIELICKI, PIOTR W. AND ŁODYGOWSKI, TOMASZ. « *Masonry wall behaviour under explosive loading* ». *en. In : **Engineering Failure Analysis** 104 (2019), p. 274-291.* ISSN : *1350-6307.* DOI : *10 . 1016 / j . engfailanal . 2019 . 05 . 030*

BŁASZCZYŃSKI, TOMASZ Z. AND SIELICKI, PIOTR W. « *The influence of design and contractor errors on the failure of a tenement building* ». *en. In : **Engineering Failure Analysis** 97 (2019), p. 676-689.* ISSN : *1350-6307.* DOI : *10 . 1016 / j . engfailanal . 2019 . 01 . 060.* URL : *https : // www . sciencedirect . com / science / article / pii / S1350630718312470*

Facade and elevation panels |movie| Ref. : [16, 17, 18]

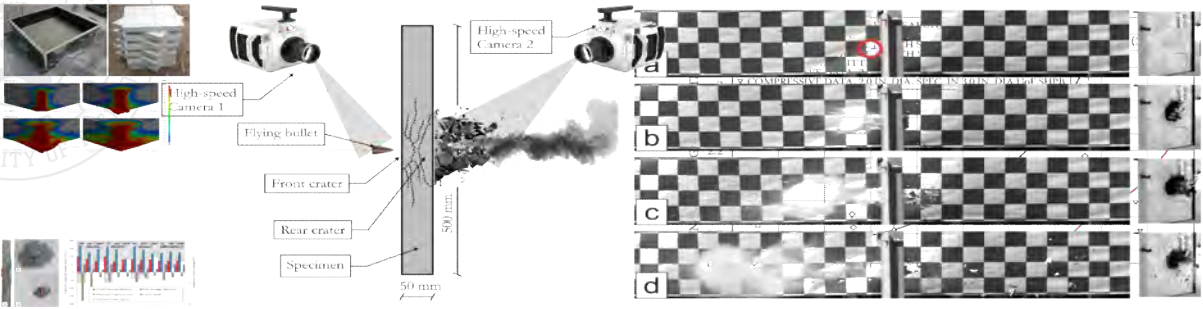






| Studziński, Robert and Malendowski, Michał and Sumelka, Wojciech and Gajewski, Tomasz and Peksa, Piotr and Sielicki, Piotr W. « *Robustness of Sandwich Panels Subjected to Blast Wave* ». *en. In : **ce/papers** 6.3-4 (2023), p. 1-4.* ISSN : *2509-7075.* DOI : *10.1002/cepa.2275.* URL : *https://onlinelibrary.wiley.com/doi/10.1002/cepa.2275* | Al-Rifaie, Hasan and Studziński, Robert and Gajewski, Tomasz and Malendowski, Michał and Sumelka, Wojciech and Sielicki, Piotr W. « *A New Blast Absorbing Sandwich Panel with Unconnected Corrugated Layers—Numerical Study* ». *en. In : **Energies** 14.1 (2021), p. 214-1-214-23.* ISSN : *1996-1073.* DOI : *10.3390/en14010214.* URL : *https://www.mdpi.com/1996-1073/14/1/214/pdf* | Studziński, Robert and Gajewski, Tomasz and Malendowski, Michał and Sumelka, Wojciech and Al-Rifaie, Hasan and Peksa, Piotr and Sielicki, Piotr W. « *Blast Test and Failure Mechanisms of Soft-Core Sandwich Panels for Storage Halls Applications* ». *en. In : **Materials** 14.1 (2021), p. 70-1-70-14.* ISSN : *1996-1944.* DOI : *10.3390/ma14010070.* URL : *https://www.mdpi.com/1996-1944/14/1/70/pdf*

Reinforced concrete structures : slab and columns under contact blast Ref. : [5, 2, 13]



Grisaro, Hezi Y. and Turygan, Scott and Sielicki, Piotr W. « *Concrete Slab Damage and Hazard from Close-In Detonation of Weaponized Commercial Unmanned Aerial Vehicles* ». *en. In : **Journal of Structural Engineering** 147.11 (2021), p. 1-13.* ISSN : *0733-9445.* DOI : *10. 1061/ (ASCE) ST. 1943 - 541X. 0003158.* URL : *https : // ascelibrary. org/ doi/ 10. 1061/ %28ASCE%29ST. 1943 - 541X. 0003158*

Baranowski, Paweł and Kucewicz, Michał and Małachowski, Jerzy and Sielicki, Piotr W. « *Failure behaviour of a concrete slab perforated by a deformable bullet* ». *en. In : **Engineering Structures** 245 (2021), p. 112832-1-112832-20.* ISSN : *0141-0296.* DOI : *10. 1016/ j. engstruct. 2021. 112832.* URL : *https : // www. sciencedirect. com/ science/ article/ pii/ S0141029621009822? via%3Dihub*

Sielicki, Piotr W. and Ślosarczyk, Agnieszka and Szulc, Dominik. « *Concrete slab fragmentation after bullet impact : An experimental study* ». *en. In : **International Journal of Protective Structures** 10.3 (2019), p. 380-389.* ISSN : *2041-4196.* DOI : *10. 1177/ 2041419619854764*

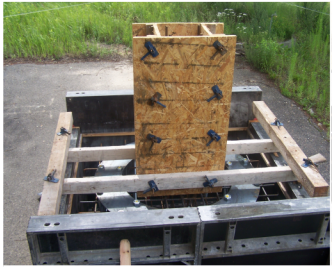
Reinrofced concrete structures : specimen quality vs. results Ref. : [13, 5, 2]

I. In-situ concrete structures

Up to fc=40 MPa is fine
Geometry accuracy for specimen 30mm at 5m ?
Time of test preparation is too long
It is hard to build-it internal gauges into the specimens in the field conditions.

II. Precast concrete

Quality vs. price both are high
Certified contractor, e.g. : NSPA–NATO Support and Procurement Agency
Geometry accuracy for specimen <5mm at 12m



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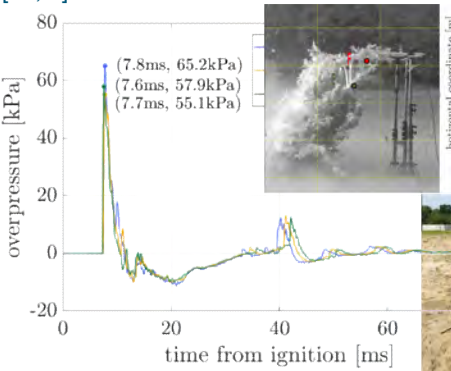
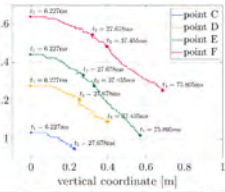
"Green structures" shielding |movie| Ref. : [19, 4]





Gajewski, Tomasz and Peksa, Piotr and Studziński, Robert and Malendowski, Michał and Sumelka, Wojciech and Sielicki, Piotr W. « *Application verification of blast mitigation through the use of thuja hedges* ». *en. In : **International Journal of Protective Structures** 13.2 (2022), p. 363-378.* ISSN : *2041-4196.* DOI : *10.1177/20414196211062927.* URL : *https://journals.sagepub.com/doi/pdf/10.1177/20414196211062927*

Gajewski, Tomasz and Szlachta, Artur and Sielicki, Piotr W. « *The influence of fracture energy on wooden structural members due to contact explosion* ». *en. In : **European Journal of Wood and Wood Products** 81.2 (2023), p. 301-314.* ISSN : *0018-3768.* DOI : *10.1007/s00107-022-01906-3.* URL : *https://link.springer.com/article/10.1007/s00107-022-01906-3*

Experimental testing | lvl ’advanced’

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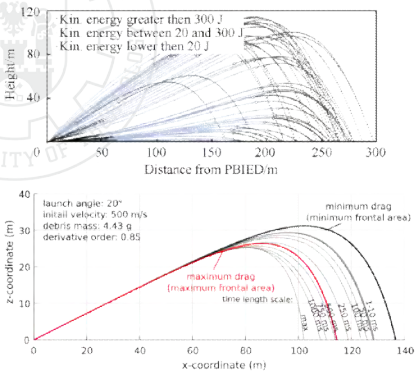
VBIED preliminary tests (based on "Suicide belt") |movie| Ref. : [11, 6]



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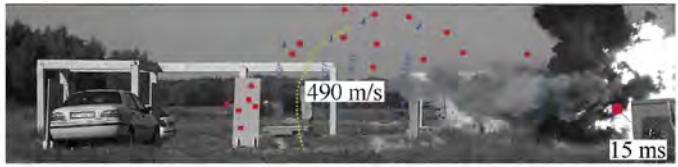
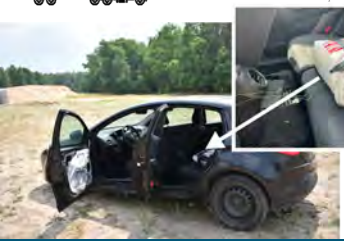


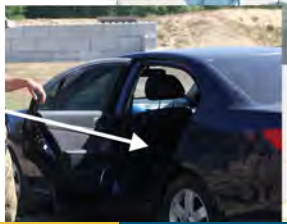
Sielicki, Piotr and Stewart, Mark G. and Gajewski, Tomasz and Malendowski, Michał and Peksa, Piotr and Al-Rifaie, Hasan and Studziński, Robert and Sumelka, Wojciech. « *Field test and probabilistic analysis of irregular steel debris casualty risks from a person-borne improvised explosive device* ». en. In : **Defence Technology** 17.6 (2021), p. 1852-1863. ISSN : 2214-9147. DOI : 10.1016/j.dt.2020.10.009. URL : https://www.sciencedirect.com/science/article/pii/S2214914720304670?via%3Dihub | Malendowski, Michał and Sumelka, Wojciech and Gajewski, Tomasz and Studziński, Robert and Peksa, Piotr and Sielicki, Piotr W. « *Prediction of high-speed debris motion in the framework of time-fractional model : theory and validation* ». en. In : **Archives of Civil and Mechanical Engineering** 23.1 (2023), p. 46-1-46-21.

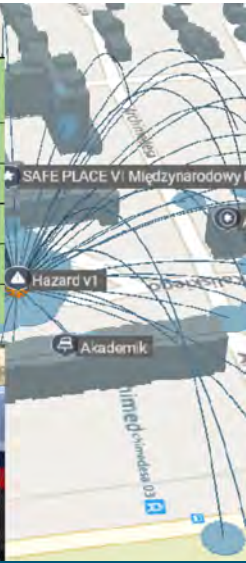
VBIED actual threat in guidelines |movie-PLAY||movie-PLAY| Ref. : [11, 6]

Vehicle Borne IED Identification: Parked Vehicles

Threat Description		Explosive Capacity [kg]	Mandatory Evacuation Distance [m]	Scaled Distance [m/kg$^{1/3}$]	Shelter-in-Place Zone [m]	Scaled Distance [m/kg$^{1/3}$]	Preferred Evacuation Distance [m]	Scaled Distance [m/kg$^{1/3}$]
	Car	<227	<98	16.0	99 - 579	94.9	>579	94.9
	SUV/Van	<454	<122	15.9	123 - 731	95.2	>731	95.2
	Small Delivery Truck	<1814	<195	16.0	196 - 1158	94.9	>1158	94.9
	Container/Water Truck	<4536	<262	15.8	263 - 1554	93.9	>1554	93.9
	Semi-Trailer	<27216	<479	15.9	480 - 2834	94.2	>2834	94.2







VBIED random fragmentation = random fragment trajectories Ref. : [11, 6]

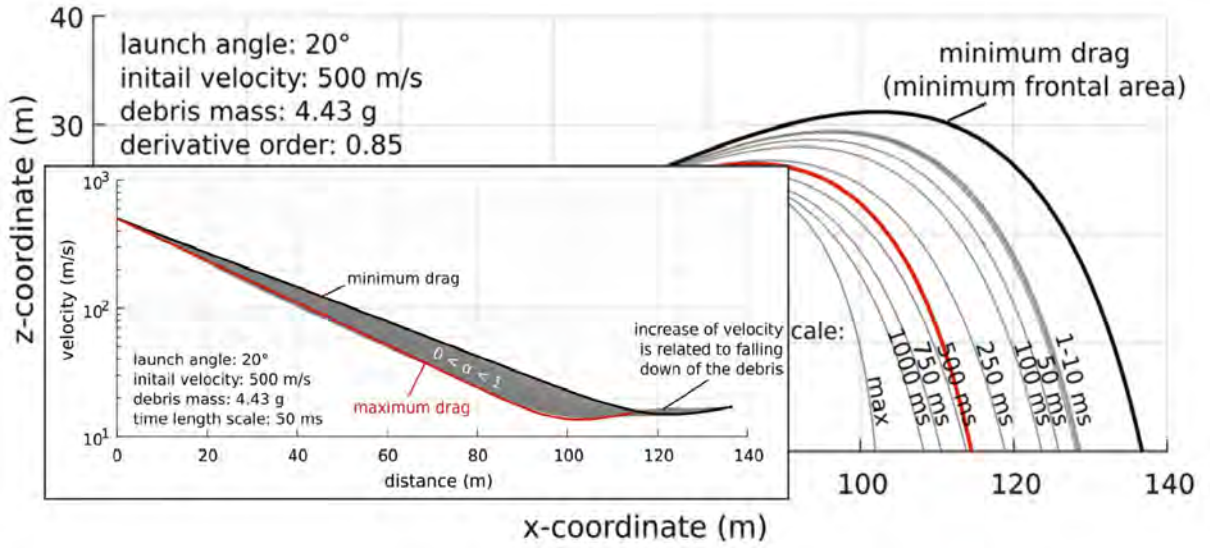
$$m\frac{d^2\mathbf{u}}{dt^2} + c\frac{d\mathbf{u}}{dt} = \mathbf{F} \quad \Rightarrow \quad m\frac{d^2\mathbf{u}_{i+1}}{dt^2} + \hat{c}\,{}_{t_{i-s}}^{C}D_{t_{i+1}}^{\alpha}\mathbf{u}_{i+1} = \mathbf{F}_{i+1}$$

with ${}_{t-\ell_t}^{C}D_t^{\alpha}\mathbf{u}$, $\left[0\ 0\ -mg\right]^T$, and $\hat{c} = c\,\ell_t^{\alpha-1}$

I. Fractional Derivative algorithm to include randomization

1| Damping term is - generalised using / proportional to - the fractional velocity of flying fragment.
2| Damping factor *c* is a function of velocity du/dt
3| The velocity du/dt (which is first-time derivative of the position vector *u*) is replaced by the fractional derivative.
4| α is an order of derivative (0,2) and *l* is a time length scale.
5| Modified damping factor $\hat{c}$ is defined as a product of the damping factor *c* and the time length scale *l*.

VBIED fragment trajectory Ref. : [11, 6]



Underwater explosion : Tallboy 12,000lb |movie-PLAY| Ref. : [7, 8]


The New York Times

World War II-Era 'Earthquake Bomb' Explodes in Polish Waters

Polish Navy divers tried to remotely neutralize a six-ton "Tallboy" dropped by the British, but the bomb had no intention of going quietly.

A 12,000-pound World War II-era bomb exploded in a shipping canal off the Polish port city of Swinoujscie on Tuesday, sending a plume of water high into the air as a team of navy divers were working to neutralize it remotely.

No one was hurt in the operation, which the Polish military forces said they considered a success because the munition, a British "Tallboy" bomb, had ultimately been destroyed.

The day before the operation, the Polish Ministry of Defense announced that the bomb was the largest yet discovered in the country and that divers from the Polish Navy's Eighth Coast Defense Flotilla would attempt to neutralize the weapon remotely through a process in which special explosive charges are used to punch holes in a bomb's thick steel case and to light the explosive material inside on fire.

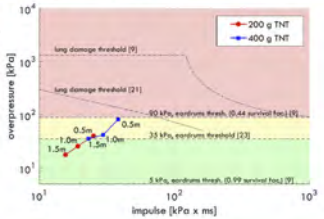
If successful, the procedure would have allowed the 5,300 pounds of energetic material inside the bomb to safely burn itself out underwater, allowing divers to raise the emptied casing out of the water or to tow it farther out to sea.

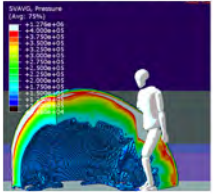
Poland has been clearing explosive remnants of war from its territory since the end of World War II, according to experts with the International Committee of the Red Cross. From 1944 to 2003, more than 96 million pieces of explosive ordnance had been removed at an estimated cost of $666 million, the experts wrote, and from 1944 to 2003, unexploded ordnance claimed the lives of more than 4,000 people in Poland.

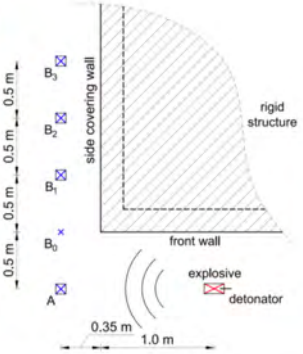
In the field of bomb disposal, any procedure taken to render a munition safe also carries the risk that the item will explode, no matter how closely and properly those procedures are followed.

For a bomb like this one, divers would most likely have surveyed the munition underwater, taking measurements and carefully sketching out key identifying features. Analyzing their findings back on land, the divers would pinpoint which types of fuses would normally be attached to such a bomb and study documented procedures for removing or safely destroying them without causing the munition to explode.

Personal safety and PBI measurement |movie| Ref. : [3]







I. Basic Assumptions

1. Find safe standoff distance for data aparature at the rangefield
2. Consider cumulative criteria for human
3. Measure the blast pressure in the command area

II. The Challenge

1. Perform tests for Z<10 [SI]
2. Pressure gauges close to human head
3. Human skull acceleration 8000 Hz
4. Different properties of "specimens"

III. Primary Results

1. Overpressure and impuls for 10<Z<20 [SI] measured close to human head
2. human skull acceperation for 10<Z<20 [SI]

Conclusions

1. In last 12 years performed hunderts experiments in more than 200 days at the PUT facility only.
2. Performing blast loading scenario testing is expensive and deals with different risks.
3. Measuring of unique data is impossible without proved planning and initial verification (e.g. by FEM or preliminary tests).

Recommendation

Start with repeating another experiments published numerically (and if is only possible at the range) to find differences.

Comment

"Only through rigorous experimental validation we explore advancements and understand complex mechanisms in protective structures engineering."

P.W.SIELICKI

Thank you ! Questions ?

References I

Sielicki, Piotr and Stachowski, Michał. « Implementation of Sapper-Blast-Module, a Rapid Prediction Software for Blast Wave Properties ». en. In : **Central European Journal of Energetic Materials** 12.3 (2015), p. 473-486. ISSN : 1733-7178.

Baranowski, Paweł and Kucewicz, Michał and Małachowski, Jerzy and Sielicki, Piotr W. « Failure behaviour of a concrete slab perforated by a deformable bullet ». en. In : **Engineering Structures** 245 (2021), p. 112832-1-112832-20. ISSN : 0141-0296. DOI : 10.1016/j.engstruct.2021.112832. URL : https://www.sciencedirect.com/science/article/pii/S0141029621009822?via%3Dihub.

Gajewski, Tomasz and Sielicki, Piotr W. « Experimental study of blast loading behind a building corner ». en. In : **Shock Waves** 30.4 (2020), p. 385-394. ISSN : 0938-1287. DOI : 10.1007/s00193-020-00936-1. URL : https://link.springer.com/article/10.1007/s00193-020-00936-1.

References II

Gajewski, Tomasz and Szlachta, Artur and Sielicki, Piotr W. « The influence of fracture energy on wooden structural members due to contact explosion ». en. In : **European Journal of Wood and Wood Products** 81.2 (2023), p. 301-314. ISSN : 0018-3768. DOI : 10.1007/s00107-022-01906-3. URL : https://link.springer.com/article/10.1007/s00107-022-01906-3.

Grisaro, Hezi Y. and Turygan, Scott and Sielicki, Piotr W. « Concrete Slab Damage and Hazard from Close-In Detonation of Weaponized Commercial Unmanned Aerial Vehicles ». en. In : **Journal of Structural Engineering** 147.11 (2021), p. 1-13. ISSN : 0733-9445. DOI : 10.1061/(ASCE)ST.1943-541X.0003158. URL : https://ascelibrary.org/doi/10.1061/%28ASCE%29ST.1943-541X.0003158.

References III

Malendowski, Michał and Sumelka, Wojciech and Gajewski, Tomasz and Studziński, Robert and Peksa, Piotr and Sielicki, Piotr W. « Prediction of high-speed debris motion in the framework of time-fractional model : theory and validation ». en. In : **Archives of Civil and Mechanical Engineering** 23.1 (2023), p. 46-1-46-21. ISSN : 1644-9665. DOI : 10.1007/s43452-022-00568-5. URL : https://link.springer.com/article/10.1007/s43452-022-00568-5.

Nowak, Piotr and Gajewski, Tomasz and Peksa, Piotr and Sielicki, Piotr. « Experimental verification of different analytical approaches for estimating underwater explosives ». en. In : **International Journal of Protective Structures** in pess (2022). ISSN : 2041-4196. DOI : 10.1177/20414196221120511. URL : https://www.researchgate.net/publication/363850585_Experimental_verification_of_different_analytical_approaches_for_estimating_underwater_explosives.

References IV

Nowak, Piotr and Szlachta, Artur and Gajewski, Tomasz and Peksa, Piotr and Sielicki, Piotr W. « Small-scale underwater explosion in shallow-water tank ». en. In : **Ocean Engineering** 288, pa 1 (2023), p. 115894-1-115894-9. ISSN : 0029-8018. DOI : 10.1016/j.oceaneng.2023.115894. URL : https://www.sciencedirect.com/science/article/pii/S0029801823022783?via%3Dihub.

Rigby, Samuel E. and Sielicki, Piotr. « An Investigation of TNT Equivalence of Hemispherical PE4 Charges ». en. In : **Engineering Transactions** 62.4 (2014), p. 423-435. ISSN : 0867-888X.

Chybiński, Marcin and Polus, Łukasz and Ratajczak, Maria and Sielicki, Piotr. « The evaluation of the fracture surface in the AW-6060 T6 aluminium alloy under a wide range of loads ». en. In : **Metals** 9.3 (2019), p. 9030324-1-9030324-17. ISSN : 2075-4701. DOI : 10.3390/met9030324.

References V

Sielicki, Piotr and Stewart, Mark G. and Gajewski, Tomasz and Malendowski, Michał and Peksa, Piotr and Al-Rifaie, Hasan and Studziński, Robert and Sumelka, Wojciech. « Field test and probabilistic analysis of irregular steel debris casualty risks from a person-borne improvised explosive device ». en. In : **Defence Technology** 17.6 (2021), p. 1852-1863. ISSN : 2214-9147. DOI : 10.1016/j.dt.2020.10.009. URL : https://www.sciencedirect.com/science/article/pii/S2214914720304670?via%3Dihub.

Sielicki, Piotr W. and Clutter, James Keith and Sumelka, Wojciech and Gajewski, Tomasz and Malendowski, Michał and Peksa, Piotr and Studziński, Robert. « Identification of Aluminium Powder Properties for Modelling Free Air Explosions ». en. In : **Materials** 15.4 (2022), p. 1294-1-1294-13. ISSN : 1996-1944. DOI : 10.3390/ma15041294.

References VI

Sielicki, Piotr W. and Ślosarczyk, Agnieszka and Szulc, Dominik. « Concrete slab fragmentation after bullet impact : An experimental study ». en. In : **International Journal of Protective Structures** 10.3 (2019), p. 380-389. ISSN : 2041-4196. DOI : 10.1177/2041419619854764.

Sielicki, Piotr W. and Łodygowski, Tomasz. « Masonry wall behaviour under explosive loading ». en. In : **Engineering Failure Analysis** 104 (2019), p. 274-291. ISSN : 1350-6307. DOI : 10.1016/j.engfailanal.2019.05.030.

Błaszczyński, Tomasz Z. and Sielicki, Piotr W. « The influence of design and contractor errors on the failure of a tenement building ». en. In : **Engineering Failure Analysis** 97 (2019), p. 676-689. ISSN : 1350-6307. DOI : 10.1016/j.engfailanal.2019.01.060. URL : https://www.sciencedirect.com/science/article/pii/S1350630718312470.

References VII

Studziński, Robert and Malendowski, Michał and Sumelka, Wojciech and Gajewski, Tomasz and Peksa, Piotr and Sielicki, Piotr W. « Robustness of Sandwich Panels Subjected to Blast Wave ». en. In : **ce/papers** 6.3-4 (2023), p. 1-4. ISSN : 2509-7075. DOI : 10.1002/cepa.2275. URL : https://onlinelibrary.wiley.com/doi/10.1002/cepa.2275.

Al-Rifaie, Hasan and Studziński, Robert and Gajewski, Tomasz and Malendowski, Michał and Sumelka, Wojciech and Sielicki, Piotr W. « A New Blast Absorbing Sandwich Panel with Unconnected Corrugated Layers—Numerical Study ». en. In : **Energies** 14.1 (2021), p. 214-1-214-23. ISSN : 1996-1073. DOI : 10.3390/en14010214. URL : https://www.mdpi.com/1996-1073/14/1/214/pdf.

References VIII

STUDZIŃSKI, ROBERT AND GAJEWSKI, TOMASZ AND MALENDOWSKI, MICHAŁ AND SUMELKA, WOJCIECH AND AL-RIFAIE, HASAN AND PEKSA, PIOTR AND SIELICKI, PIOTR W. « Blast Test and Failure Mechanisms of Soft-Core Sandwich Panels for Storage Halls Applications ». en. In : **Materials** 14.1 (2021), p. 70-1-70-14. ISSN : 1996-1944. DOI : 10.3390/ma14010070. URL : https://www.mdpi.com/1996-1944/14/1/70/pdf.

GAJEWSKI, TOMASZ AND PEKSA, PIOTR AND STUDZIŃSKI, ROBERT AND MALENDOWSKI, MICHAŁ AND SUMELKA, WOJCIECH AND SIELICKI, PIOTR W. « Application verification of blast mitigation through the use of thuja hedges ». en. In : **International Journal of Protective Structures** 13.2 (2022), p. 363-378. ISSN : 2041-4196. DOI : 10.1177/20414196211062927. URL : https://journals.sagepub.com/doi/pdf/10.1177/20414196211062927.