FINAL REPORT

Professorship SFI CASA 2017-2022

HOW SAFE IS SAFE ENOUGH?

CASA
Centre for Advanced Structural Analysis

Norwegian Ministry of Justice and Public Security

NTNU

Knowledge for a Safer Society

On 7th April 2017, the Norwegian Ministry of Justice and Public Security granted NOK 8 million to SFI CASA at NTNU's Department of Structural Engineering.The funds were intended to establish a professorship in societal security for the duration of five years.Vegard Aune was appointed to the position, which focused on physical security.

The Assignment:

- Conduct teaching and research at NTNU.
- The tasks will contribute to improving knowledge surrounding the safe and secure design of civil engineering buildings, as well as physical security of critical infrastructure and societal functions.
- Promote effective cooperation with industrial players, related professional circles nationally and internationally, as well as relevant authorities.
- Active dissemination of results and regular contact with the user community.
- Scientific results will be made public to the greatest extent possible.
- Initiate and participate in research and development work.

CONTENTS:

SUMMARY

COOPERATION ON PHYSICAL SECURITY

Norway is under mounting pressure to protect vital infrastructure against the threat of terrorism (ref. National Security Act of 01 January 2019). At the same time, work is underway to tackle the consequences of accidents along Norwegian roads linked to the land-based and oil and gas industries. A rational mitigation to prevent accidents, and thus the extent of any damage, is to carry out risk and vulnerability assessments. However, risk assessments require that the consequences for a given action or accident are known. To define such a set of consequences, comprehensive knowledge on the behaviour of materials and structures exposed to extreme loads exerted during an incident is first required.

It is for this reason that NTNU, with support from the Ministry of Justice and Public Security (JD), created a professorship in societal security linked to SFI CASA (Centre for Advanced Structural Analysis). CASA is a centre for research-based innovation, hosted by the SIMLab research group (Structural Impact Laboratory). The position contributes to the effort of becoming better equipped to face future challenges that concern structures exposed to extreme loads. The position entails responsibility for establishing international cooperation, as well as conducting teaching and research in the field.

In a letter of commitment (ref. 17/2411 MKE) dated 7th April 2017, the JD granted NOK 8 million over a five-year (5) period to SFI CASA at NTNU. The funds finance the establishment of a professorship in societal security with a focus on physical security. The funds add value to the support that the National Security Authority (NSM) provides to SFI CASA at NTNU. NTNU will take over all obligations for the position after the five-year period.

The undersigned was employed in the position on 1st December 2017.

Thanks to the professorship the JD has strengthened SFI CASA's and NTNU's contribution towards raising the level of physical security education and research in Norway. The activity and resources at SFI CASA have also provided a profitable return on the support from the JD. The result is that we are better equipped to face future challenges related to structures that are exposed to extreme loads.

In general, the project period (2017-2022) has seen continuous activity and produced useful results. Dialogue with the user community has been positive, and we have made many new points of contact. There has been a carefully considered balance between teaching master's students, research activities and communication. The already thriving cooperation with industrial players has been strengthened. We have had positive national and international contact with academic groups and dialogue with relevant authorities in the field. This has triggered new applications for projects and new collaborative constellations. The SFI CASA and KPN SLADE projects, as well as new collaborative work with academic groups in England, Italy, Spain and France, have been central to the research and development work. We have contributed to discussions and provided input to the Research Council of Norway's national reference group for Civil Security for Society. Dissemination of research activities has been well received and paid dividends in popular science forums, both nationally and internationally, which is gratifying.

The COVID19 pandemic impacted the project at times, posing some challenges but at the same time creating opportunities. Most conferences were either held digitally or postponed and most meetings were remote. Teaching took place both physically and digitally, depending on the current guidelines from the authorities. Less travel freed up time to prioritise other activities, in particular writing project proposals and reporting scientific results. This effort has already paid off in the form of publications and new projects and further returns may be expected in the coming years.

Thirteen (13) master's theses, one (1) doctoral thesis, and thirty-eight (38) scientific publications were written and disseminated as articles in recognized journals, conference contributions, technical reports and datasets. Scientific results have been published to the greatest extent possible.

Financially, the project has remained within the annual allocation from the JD. Costs beyond the allocation were covered by the SFI CASA and KPN SLADE projects and are not documented in this report.

Additional descriptions of activities can be found in annual reports sent to the JD for the respective calendar years.

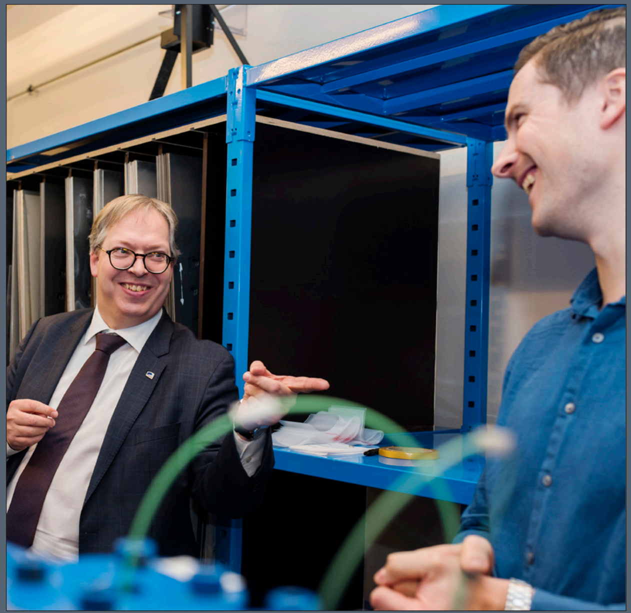
In my opinion, we can count this project a success!

Trondheim, February 1, 2023

Vegard Aune

Vegard Aune

Associate Professor
Department of Structural Engineering
SIMLab/SFI CASA, NTNU



A DAY FOR THE HISTORY BOOKS

On 2nd January 2018, Thor Kleppen Sættem, the then State Secretary for the Ministry of Justice and Public Security (JD), visited SFI CASA and the management at NTNU to mark the establishment of Vegard Aune´s professorship.

The new position was made possible by a 5-year grant of NOK 8 million from the Ministry. The university also granted fresh funds to employ a Ph.D. candidate who will cooperate closely with Aune. Benjamin Stavnar Elveli took up the post in August 2018.

Part of the ministry's strategy was to foster more cooperation between business and research environments in civil infrastructure security. A particular priority was to seek partnerships within education and research with the aim to build competence and improve teaching and research quality.

«We need more experts on the behaviour of materials and structures subjected to blast loadings. I will have the opportunity to continue my research. We will also work and build further on our international partner network», Dr. Aune said in an interview .

Vegard Aune's name will forever be linked to the acquisition of one of SIMLab's most essential test facilities: the shock tube. His Ph.D. thesis was dedicated to the 20-meter long custom-made tube with innumerable possibilities for recording and measuring blast loads.

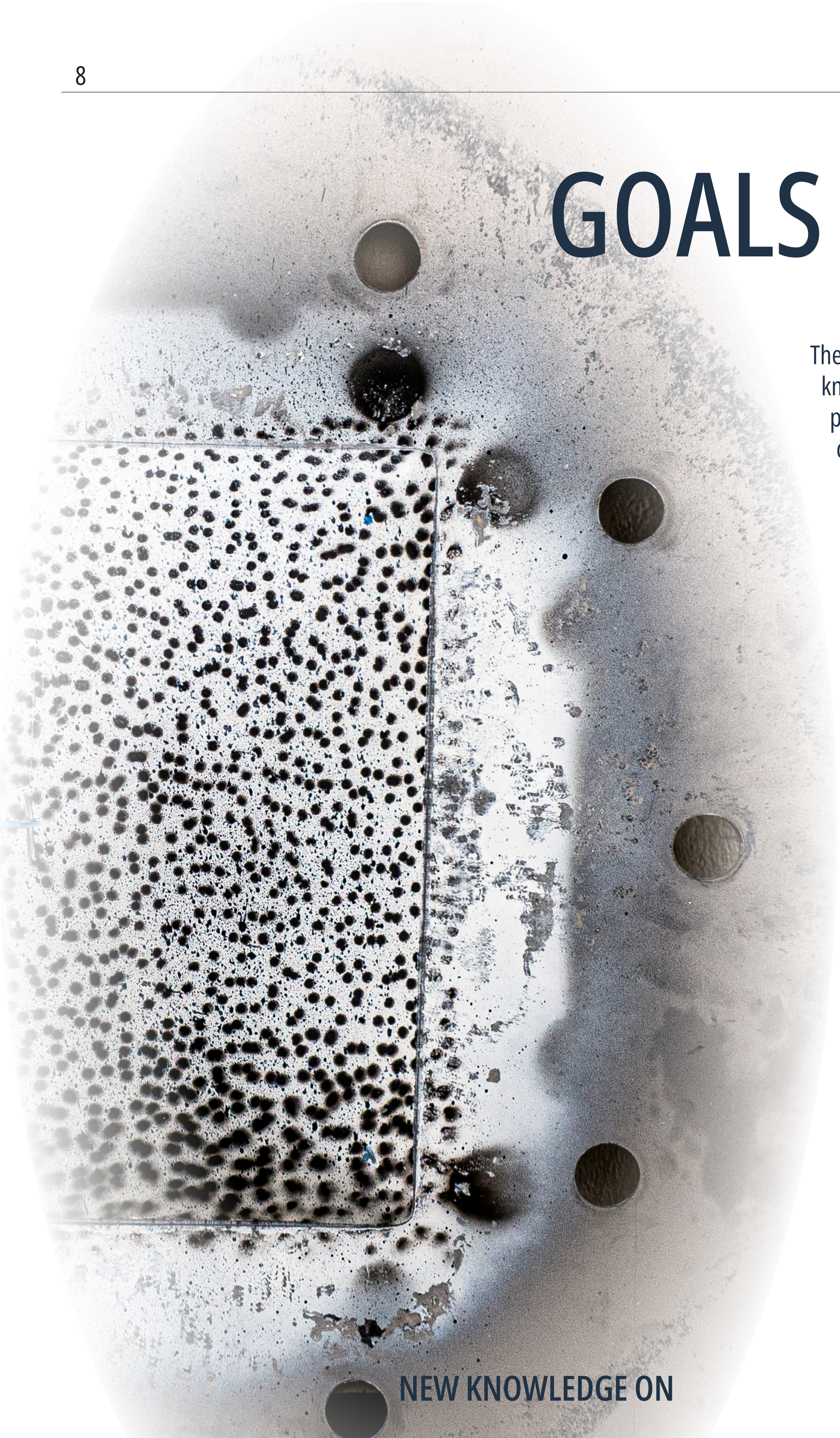
From 2023 NTNU will take over responsibility for the position.

When the Worst Happens

Change in the society around us has exposed a growing risk of extreme loading events on civilian buildings and structures. Destructive, extreme weather and landslides are also occurring more frequently than ever before. The standards for securing vital operations and infrastructure in Norway have risen; the requirements for safety in transport, industry, and especially energy supply, have become stricter. Important buildings, facilities and infrastructure must be protected against catastrophes, sabotage and terrorism. The threats are growing ever closer to civilian structures and urban areas; physical security is no longer reserved for fortifications and military installations. Current regulations on resistance to extreme loads for civilian infrastructure – whether caused by sabotage, terror, extreme weather or a natural disaster – require entirely different considerations compared to those intended for military installations. Current protocol regarding security in urban areas was founded on a set of military regulations, but times have changed along with the nature and severity of the threats posed. A major challenge for physical security remains: there are no such design standards in existence for the protection of civilian infrastructure. The starting point for a safer and more secure society is the Norwegian Security Act. The Security Act specifies physical security requirements but does not set out how protective measures are to be implemented. Our shared security culture must be diligently revaluated and strengthened; the extent of our knowledge will determine how vulnerable we are. We all have a responsibility in the race against future threats.

Better security requires an increased research effort. We need to know the consequences of a given action or accident in order to protect ourselves in the most effective way. Research enables us to prepare for future societal challenges related to physical security.

GOALS



The overall goal is to generate new knowledge that contributes to our preparedness for future challenges concerning structures prone to extreme loads.

Controlled, laboratory environments are used to expose steel, aluminium, concrete, and composite structures to extreme loading conditions.

Detailed studies on components and materials are conducted to evaluate the performance of methods and tools for the protective design of civil engineering structures.

Research is centred around understanding how materials and structures react to extreme loading events.

The more we understand, the safer industry can design cars, pipelines, and buildings.

NEW KNOWLEDGE ON

- How civil engineering structures react to extreme surface pressure loadings
- Interaction between blast loading and structural response
- Behaviour of structures exposed to combined fragment impact and blast loads
- Violent wave impacts against offshore structures
- Drones posing the threat of collisions and explosions against structures, critical infrastructure, and societal functions

METHODOLOGY

Activities conducted during the professorship have pertained to the methodology of SFI CASA, NTNU, which follows a top-down/bottom-up approach to research. The objective of this methodology is the generation of new knowledge within advanced structural analysis to inform guidelines and recommended practices for industrial applications. Research questions are top-down, while methods and tools are bottom-up; new knowledge is sought in obtaining solutions to the questions. Existing methods and tools are used where sufficient, and new methods are developed where a novel approach is required.

The research methodology adopted to meet the overall objective is presented in Figure 1. As illustrated, a structure can be studied on different physical and modelling scales. In some cases, microstructural modelling or even modelling on an atomic scale may be required to understand the underlying physical mechanisms of the observed material response to loading. For joints or components, however, the behaviour may be sufficiently well understood on the continuum scale. In all cases, the research is designed to obtain modelling frameworks on material and structural levels that are suitable for industrial applications.

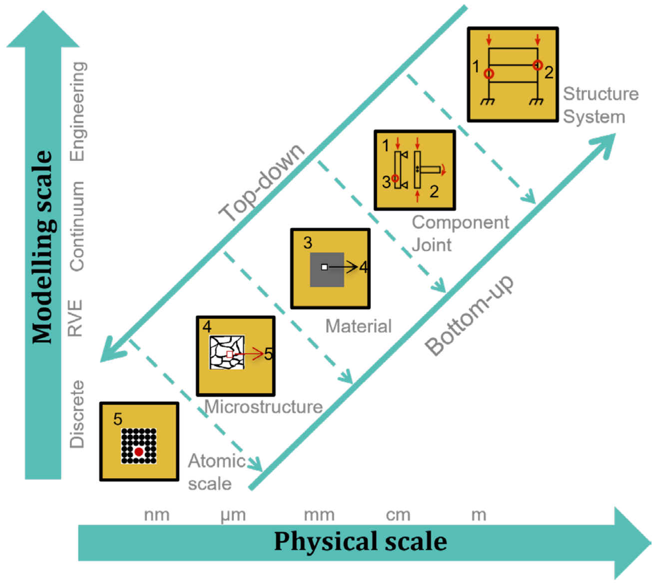


Figure 1: Research methodology

The professorship has placed particular focus on one of the main research questions in SFI CASA;
How can we describe the interaction between the load and the deformable structure under extreme loading? To design the next generation of resilient structures, new knowledge is required of the interaction between different media in contact. Such interactions may take place in a variety of scenarios: the blast loading of lightweight structures, a violent ocean wave slamming into offshore structures, the combined blast and fragment loading against a structure caused by a terrorist act, or the collision between vehicles or any other bodies. A better understanding of interaction effects is a crucial step towards resilient and sustainable structures, e.g., in the safety and security design of building facades and large ocean structures.

The research topics and activities under consideration have been approached through the testing, modelling and simulation of materials and structures, numerical solution techniques, experimental techniques, verification and validation approaches, optimisation methods and parametric studies. The performance of computational models and simulations has been measured by their ability to predict the physical reality observed in experiments.

The work is in alignment with the research and implementation strategy of SFI CASA. This is illustrated in Figure 2 starting with basic research, from which methods and tools lead to technology transfer, and finally resulting in industry applications. The professorship has primarily focussed on testing, modelling and simulations by evaluating and developing new methods and tools. However, the work has also brought about new guidelines and recommended practices for credible numerical simulations in industrial applications.

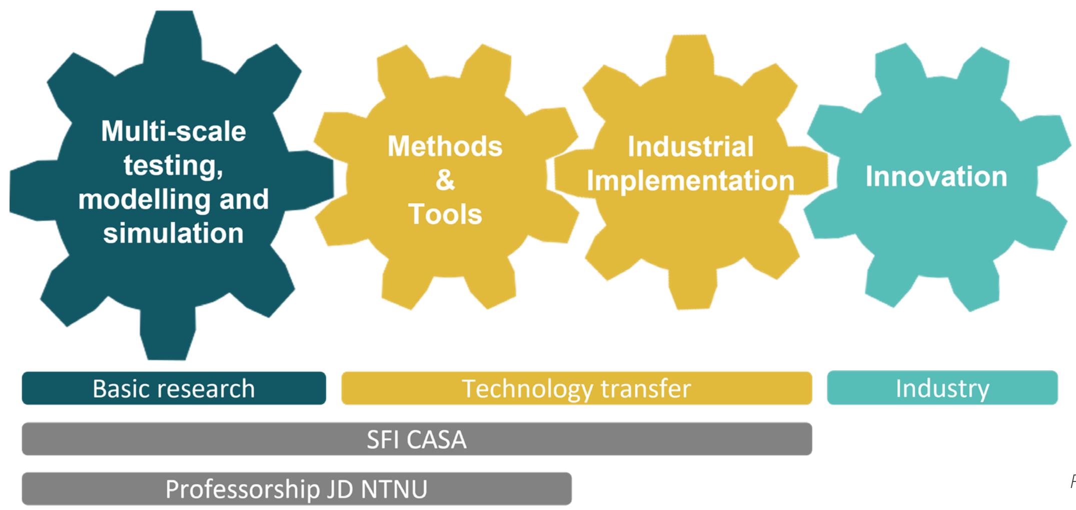
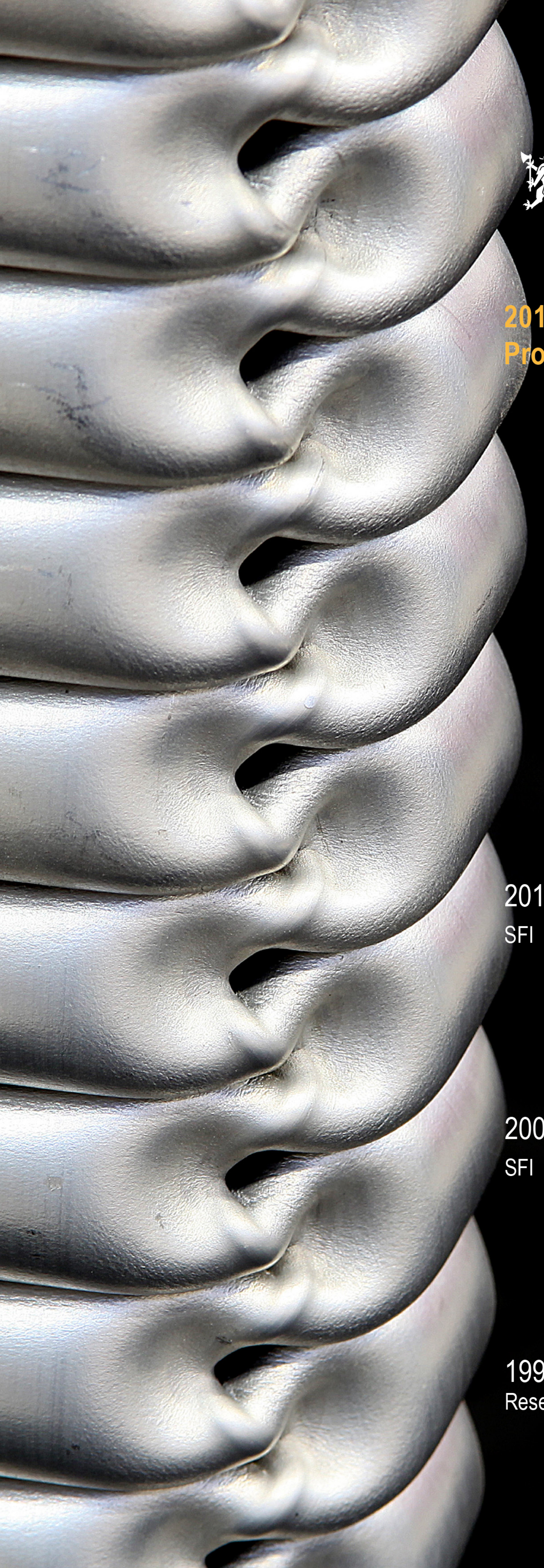


Figure 2: Research and implementation



Norwegian Ministry
of Justice and Public Security

2018 - 2022
Professorship

CASA
Centre for Advanced Structural Analysis

SIMLab

NTNU

2015 - 2023
SFI

Norwegian Centre
for Research-based
Innovation

CASA
Centre for Advanced Structural Analysis

2007 - 2014
SFI

Norwegian Centre
for Research-based
Innovation

SIMLab

1998
Research group

SIMLab

On the SHOULDERS of SIMLab

For almost 30 years, the research group SIMLab (Structural Impact Laboratory) at NTNU's Department of Structural Engineering has built up internationally leading expertise on the behaviour of materials and structures subject to impact, collisions, explosions, terminal ballistics and other extreme loads. This knowledge has great utility in the effort to improve physical security. The more we understand, the safer industry can design cars, pipelines and buildings.

The research group has achieved its world-leading position through perseverance, persistent research efforts and the development of unique laboratory facilities. Tailor-made experiments are paired with mathematical modelling and computer simulations, all the way down to the nanoscale if necessary. The research started with steel and eventually the portfolio was broadened to include aluminium and polymers.

SIMLab has been awarded two centres for research-based innovation (SFI) in the past 16 years. SFI is a programme under the auspices of the Research Council of Norway. The aim of the scheme is to accelerate businesses' ability to innovate through investing in long-term research. From 2007 to 2014, the group hosted an eponymous SFI, SIMLab, and was subsequently assigned a new SFI, the Centre for Advanced Structural Analysis (CASA), for the period 2015 to 2023. The research was further extended to include glass and concrete.

At its inception in 2015, CASA set out a vision: "To establish a world-leading centre for multi-scale testing, modelling and simulation of materials and structures for industrial applications." CASA expanded its breadth of activity and went to further depths of detail than its predecessor SFI SIMLab (2007-2015). Where necessary, the researchers studied materials at scales as small as one thousandth the thickness of a strand of hair. This is the size of the smallest building blocks in aluminium and steel, which are among the favourite materials of civil engineers and architects.

The objective of the centres has been to research and develop computer simulations that can predict material and structural behaviour under extreme loads. This research forms the basis for innovation and value creation by the partners: Hydro, DNV, Benteler Automotive Raufoss, Equinor, the Norwegian Defence Estates Agency (FB), the National Security Authority (NSM), the Norwegian Ministry of Local Government and Regional Development (KDD), the Norwegian Public Roads Administration (NPRA), Multiconsult, BMW, Audi, Honda, Renault and SINTEF.

SIMLab's long-term, targeted investment and well-established position in physical security provided excellent grounds for the Ministry of Justice and Public Security's (JD) endowed professorship in 2017. The parties have mutually strengthened each other. With willingness to invest, the JD has facilitated SFI CASA's work to raise the level of education and research on physical security in Norway. Likewise, the activity and resources at SFI CASA have given the JD a good return on its investment.

SFI CASA will end in 2023. The research group is pursuing several potential avenues to ensure a continued high level of activity and to retain its position as a world-leading research environment for physical security.

THE MINISTER PAID A VISIT

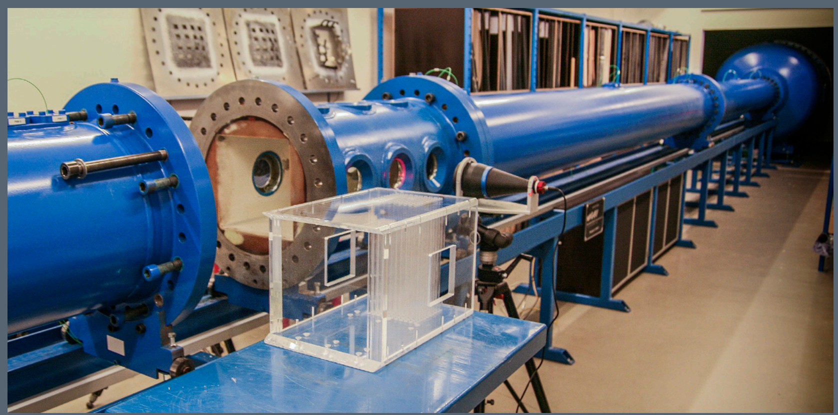
On 13th May 2019, The Minister of public security Ingvil Smines Tybring-Gjedde received a crash course on how CASA contributes to improving societal security. She took up The Centre's invitation to learn more about the research that aims to ensure human survivability of any threat against vital infrastructure. The guests were shown a crash test of an aluminium profile in the kicking machine. They also paid a visit to the shock tube facilities.

«This was very, very exciting», the Minister of Public Security summed up. She also commented that it is essential for final decision-makers to be aware of the challenges that society faces. At the same time, they must know of the solutions that are available to solve such challenges.

«Besides», the Minister added with a smile and a nod towards Associate Professor Vegard Aune: «It was very nice to meet our expense item».

Thanks to funds from the Ministry of Justice and Public Security, NTNU and SFI CASA stepped up the work on physical security. Vegard Aune's position as an Associate Professor results from this funding. He is an expert on the behaviour of materials and structures subjected to blast loadings.

«It is good to see where the budget goes, and I am sure that this is money well spent» the Minister of Public Security said.



NUCLEAR FUEL RODS IN THE SHOCKTUBE

In France, earthquake and depressurisation effects are considered reference accidents when engineers design the interior of nuclear power plants. That explains why French researchers subjected nuclear fuel rods to shock waves in the SIMLab Shock Tube Facilities in December 2019. It was Dr. Vincent Faucher's second visit to Trondheim during that year. He is a Senior Expert at the French Alternative Energies and Atomic Energy Commission (CEA). This time, he was accompanied by Ph.D. candidate Samy Mokhtari.

The backdrop of their visit was a so-called loss-of-coolant accident (LOCA) in a Pressurized Water Nuclear Reactor (PWR) reactor. If not managed effectively, a LOCA could lead to severe damage. Each nuclear plant has an emergency cooling system to cope with such incidents. Faucher and Mokhtari brought a specimen representative of a PWR fuel assembly for the experiments. The sample appears as a bundle of fuel rods.

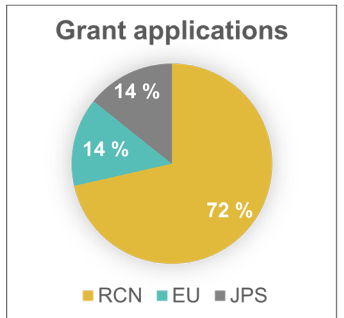
The tests addressed the dynamic response of nuclear fuel rods to a transverse pressure wave. The scientists aimed to provide reference data for code validation of the response of a simple bundle subjected to such a wave. According to Dr. Faucher and Associate professor Aune, the visit arouse from their collaborative work on fast transient fluid-structure dynamics. At the same time, NTNU's long history of collaboration continues through a partnership with SIMLab and CEA's development team in the Europlexus (EPX) programme, which is co-owned jointly between CEA and the EU Commisions Joint Research Centre (EU-JRC) in Ispra, Italy.

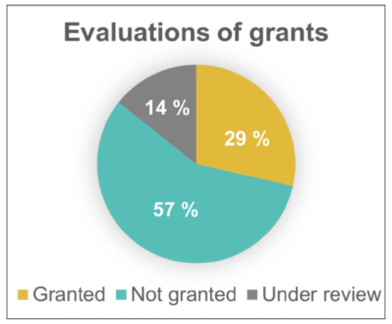
FACTS FIGURES VISIBILITY & INTERNATIONAL COOPERATION

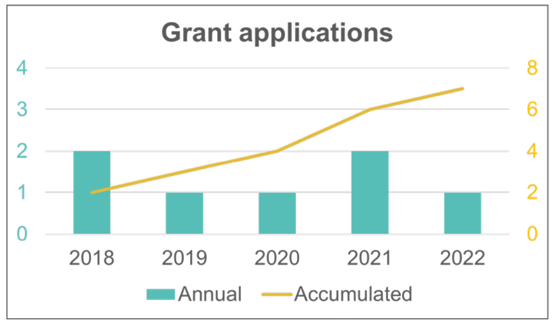
INTERNATIONAL COOPERATION:

- French Aerospace Lab (Onera), Lille, France (Bertrand Langrand)
  French Commissariat à l'Energie Atomique et aux Energies Alternatives (CEA), Cadarache, France (Vincent Faucher)
- Royal Military Academy, Brussels, Belgium (David Lecompte)
- University Carlos III, Spain (Ramón del Cuvillo Mezquita)
- Joint Research Centre (JRC), European Commission, Directorate for Space, Security and Migration, Safety and Security of Buildings Unit, Ispra, Italy (Martin Larcher, Georgios Valsamos and Folco Casadei)
  Politecnico di Milano, Italy (Luca Lomazzi and Andrea Manes)
- University of Cambridge, UK (Vikram S. Deshpande)
  Sheffield University, UK (Sam Rigby)
  University College London, UK (PJ Tan)
- SINTEF Ocean, Trondheim, Norway
  (Øyvind Helland and Bjørn Christian Abrahamsen)

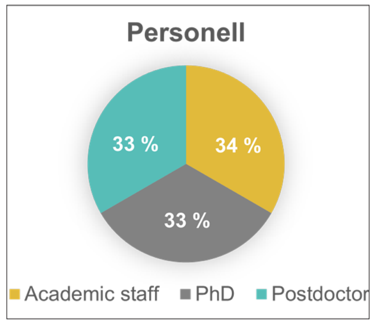
APPLICATIONS:

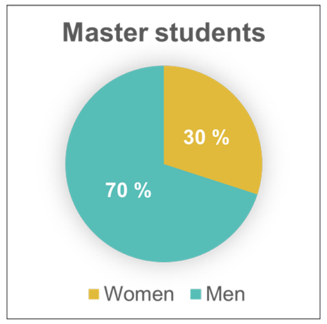


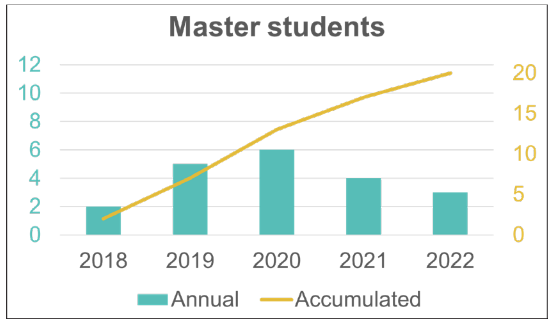




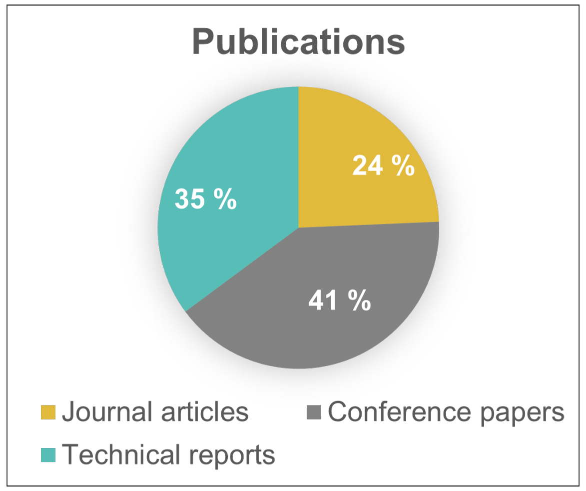
PEOPLE:

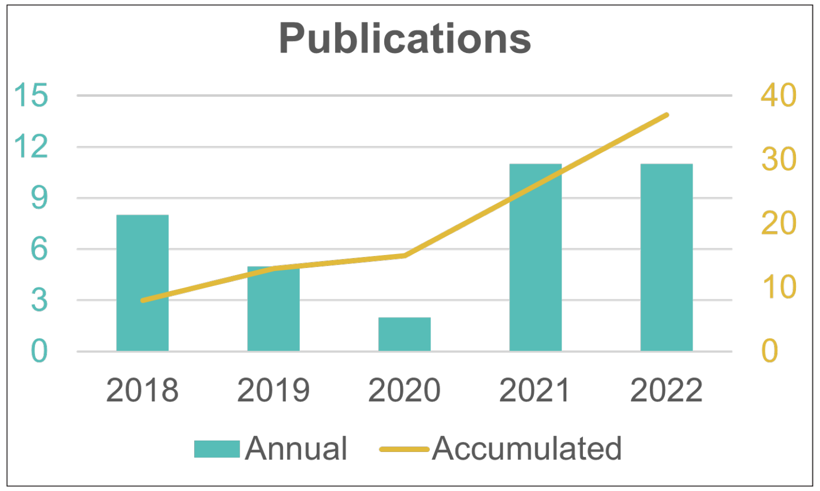






PUBLICATIONS





ANNUAL ACCOUNTS

ANNUAL ACCOUNTS 2017-2022 (NOK)					
Revenues	2018	2019	2020	2021	2022
Allocation from the Ministry of Justice and Public Security	1 600 000	1 600 000	1 600 000	1 600 000	1 600 000
Total income	1 600 000	1 600 000	1 600 000	1 600 000	1 600 000
Expenditures					
Wages and social costs	811 829	714 707	950 864	1 000 077	901 847
Indirect costs	435 000	435 000	459 000	451 000	490 000
Travel, accomodation and meeting costs	40 492	65 442	3 304	13 069	71 076
Operating costs	388 880	308 650	182 032	84 327	193 318
Operating Expenditures	1 676 201	1 523 799	1 595 200	1 548 473	1 656 241
Result	-76 201	76 201	4 800	51 527	-56 327

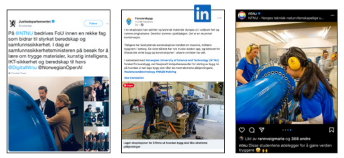
In addition to the grant from the Ministry of Justice and Public Security, NTNU funded one Ph.D. candidate in the period 2018-2022. The Ph.D. candidate is associated with SFI CASA, where the centre contributes operating funds. One postdoctoral researcher is also associated with this professorship. The funding is provided by the Research Council of Norway (NFR) through the KPN SLADE project. Income and costs related to these projects are not shown in the accounts.

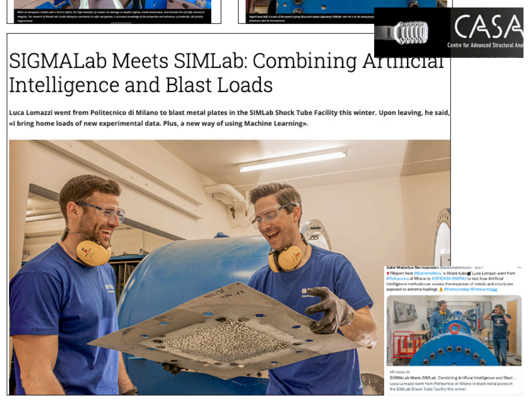
VISIBILITY:

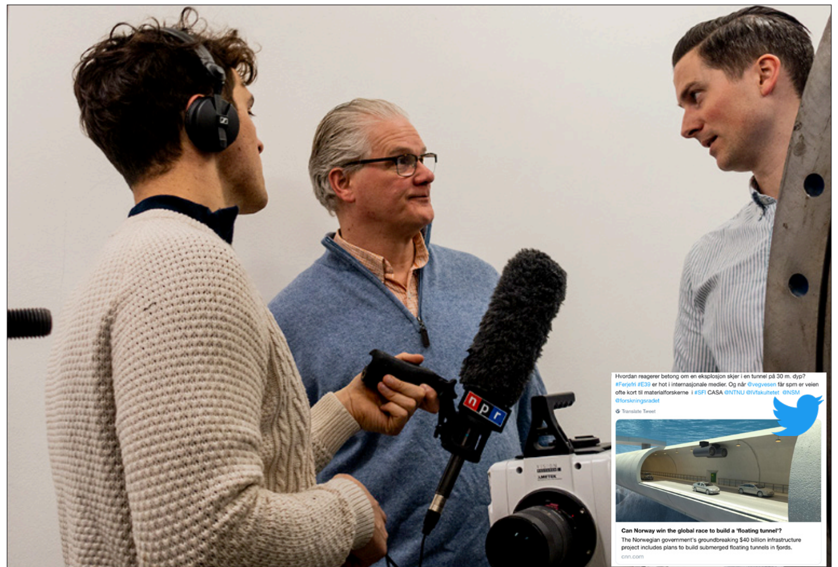
The essential tool to make the research activities connected to SFI CASA visible is the website sfi-casa.no. Here, research news, feature stories, videos, and in-depth interviews with key personnel working with or related to the Centre are published regularly. As the professorship's activities are closely linked to the research in CASA, they are reported and disseminated in the same way.

The site works as a platform for sharing and spreading content in social and mainstream media. The content is distributed in newsletters to partners, contacts, and subscribers in the Centre´s social and professional network. In addition, a Technical Newsletter is allocated to the partners.

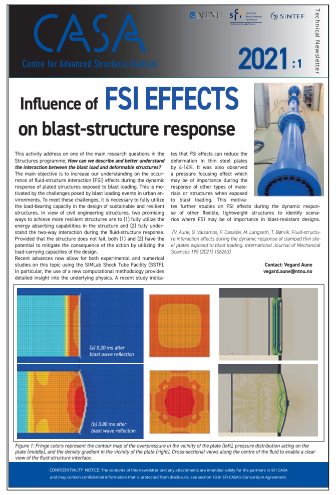
The Centre collaborates well with the communication divisions at the Norwegian University of Science and Technology and the Faculty of Engineering. Thus, content is shared and disseminated on social media accounts and sites with a substantial outreach, such as NTNU News, Norwegian SciTech News/Gemini, YouTube, Instagram, Twitter, LinkedIn and Facebook.

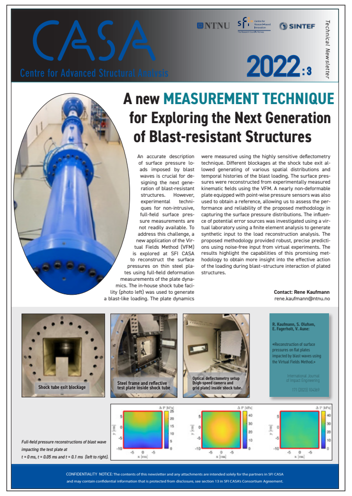


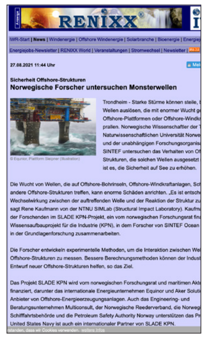




BBC World Radio popped into the Shock Tube







BLAST LOADS ON FLEXIBLE STRUCTURES

During the past two decades, the heightened threat of deliberate use of high explosives against civilian targets has accelerated research activity on blast-loaded structures. Ayesha Syed and Ingrid Gisnås collaborated on their MSc thesis in spring 2021. The thesis was entitled «Dynamic response of flexible structures subjected to blast loading». Blast events situated in urban environments introduce new materials and lightweight, flexible structures to the scope of protective design. Depending on the blast intensity and the structural properties, the dynamic response of a structure may undergo significant changes. Various methods have been proposed to predict both the loading and structural response in these extreme situations. The capabilities of current computational methods to predict the response of flexible structures subjected to blast loading must therefore be reviewed. This is necessary for the development of safe and cost-effective protective structures.

Associate professor Vegard Aune, Professor Magnus Langseth, and Nicolas Neumann from SFI CASA's partner Multiconsult supervised the students. Syed and Gisnås performed blast experiments on flexible beams. They used the data to evaluate the performance of commonly used computational methods in blast-resistant design.

COMPOSITES UNDER EXTREME LOADS

Composites are essential materials in the design and manufacture of aeronautical structures. More than 50 percent of a modern aircraft consist of these lightweight and high-temperature resistant materials. Ramón del Cuvillo Mezquita, who was a visiting scientist at SIMLab in 2021, tests and models composites under extreme loads.

«Despite their high stiffness and strength-to-weight ratio, these materials are quite vulnerable to impact loading. The impact loads could be anything from bird strikes to hail, tire rubber, or metal fragments. Therefore, damage tolerance is a critical safety issue for the design of primary aircraft structures», del Cuvillo explains.

He is a Ph.D. candidate at the University Carlos III de Madrid. He believes he is lucky to have been able to carry out a series of tests in the SIMLab Shock tube facility (SSTF) at NTNU. «Beforehand, we did not know what to expect we would obtain in the SSTF. Until now, we have tested 15 plates, which has provided us with a lot of information. All of us are very happy with the outcome», Del Cuvillo said.

Associate professor Vegard Aune agrees: «It is great that the SSTF attracts scholars from outside Norway. We built it precisely for tests like Ramon's, namely small-scale blast testing of flexible structures in controlled laboratory environments. This campaign turned out to be very useful».

These tests represented a new milestone as they were the first ever experiments with composite materials at the SSTF.

COMBINING ARTIFICIAL INTELLIGENCE AND BLAST LOADS

In the winter of 2022, Luca Lomazzi arrived from Politecnico di Milano to blast metal plates in the SIMLab Shock Tube Facility. His doctoral work uses artificial intelligence methods to predict how structural damage evolves in metals and structures exposed to severe blasts and assess the response. Well into his 2nd year of doctoral studies at the SIGMALab research group in Italy, he began searching for a test facility. He needed access to new experimental data and wanted to develop novel data-driven approaches to enhance numerical models.

The ball started rolling when he came across SIMLab's Associate professor Vegard Aune´s work. Eventually, the two of them teamed up with SIMLab's Associate professor David Morin, colloquially known as Mr. Machine Learning.

During his stay, Lomazzi tested steel, aluminium, and titanium plates under blast loads. He worked in close collaboration and under the supervision of Vegard Aune.

«I will bring home loads of new experimental data. Plus, a new way of using Machine Learning. I think the stay at the SIMLab group will make up the most important part of my doctoral work,» Lomazzi said when he headed back to Italy in April.

At the ICILSM 2022 conference in Trondheim, the Ph.D. candidate presented a lecture titled «A Data-driven approach to account for fluid-structure interaction effects on blast loaded steel plates». The lecture extracted a joint conference paper with Lomazzi's supervisors, Professor Andrea Manes, Francesco Cadini, David Morin, and Vegard Aune.

SCIENCE FOR A SAFER SOCIETY

Photo: Colourbox

Measuring the Impact of Extreme WAVES

Heavy storms can cause steep and violent waves to slam into platforms and offshore wind turbines. SIMLab's Rene Kaufmann measures the pressure and deformations from such massive loads – to improve safety at sea.

Large photo: The Sleipner platform (Øyvind Hagen, Equinor) Small photo: Rene Kaufmann (Vegard Aune, SIMLab)

Wave slamming has the potential to cause catastrophic damage. At risk are offshore rigs, wind turbine pillars, ships, or any other structures at sea. The accurate prediction of structural response due to wave slamming remains a challenge. In fact, it is one of the fundamental – and unresolved – problems in designing such large ocean structures. The solution for safer and more cost-efficient marine operations lies in addressing these challenges.

UNDERSTANDING THE MUTUAL INTERACTION

«It is crucial to understand the mutual interaction between the impacting wave and the structure's response», says Rene Kaufmann (photo right). The post-doctoral fellow at SIMLab is involved in the SLADE KPN project.

Here, scientists from SINTEF Ocean and NTNU join forces on fundamental investigations. SLADE is a knowledge building project (KPN) financed by the Norwegian Research Council (NRC) and prominent maritime players. Among them is the leading international offshore operator Equinor, plus Aker Solutions, a global leader in the delivery of offshore energy production facilities. Consulting engineers Multiconsult, the Norwegian Shipowner's Association, the Norwegian Maritime Authority and the Norwegian Petroleum Safety Authority also support the project. The United States Navy is an international partner.

BRIDGE THE GAP AND BUILD BETTER DESIGNS

The path to new knowledge begins with systematic experimental studies of relevant wave-impact scenarios. These experiments must be combined with the development of numerical and analytical methods. Thus, SLADE aims to bridge the gap between physical tests and reliable computer simulations.

SIMLab's task is to measure the full-field surface deformations. To do so, Kaufmann uses powerful, non-intrusive optical techniques. The measurements provide new insight into the actual loading during violent wave impacts. He records the experiments with high-speed cameras able to film several thousand frames per second. Also, for the first time, he extracts loading information from the deformation measurements during wave impact. More details on SLADE and Kaufmann's measuring techniques comes later. First, we take a trip into the Norwegian Sea.

«A VERY LARGE WAVE COMING»

In 1995, the offshore oil and gas platform «Draugen» was put to a severe test in the Haltenbanken area. On 12th March, a hurricane raged in the Norwegian Sea. Suddenly, the Platform Manager, Mr Gundersen, received an unexpected call from the Aberdeen Weather Center. They warned him of a massive wave heading in their direction. 30 minutes was all they had to prepare. All production was halted. Mr Gundersen summoned the crew of 134 people to the gymnasium in front of the platform's inner walls. There, he reassured everyone present on his unconditional faith in the platform designers' work.

«INCREASINGLY LARGE MOTIONS»

«After I had finished my speech, the loudest, most shivery and violent "BANG" I have ever heard rang out in the gymnasium», he said in an interview later. «We started to feel increasingly large motions under our feet. (...) The room kept on pitching. I could not tell exactly how long it lasted, but my guess would be more than a minute».

First, the monstrous wave had hit the shaft and then lifted itself up under the deck with a violent force. The air gap on Draugen, from still water level to cellar deck, is 30 meters.

INTO THE PHYSICS OF VIOLENT WAVE SLAMMING

A key question for SLADE is: What is the effective action of such loading conditions? «We must understand this before we can study the details in the structures behaviour», says Vegard Aune, Associate professor at SIMLab. Another incident that contributes to the project's motivation occurred in the North Sea in December 2015. A big, steep wave struck into the deep-water drilling rig COSL Innovator. The platform was designed according to the regulations. Still, it failed to withstand the load. The incident caused one fatality, four people injured and extensive damage.

UNDERSTANDING AND PREDICTING RESPONSE

«Accidents like COSL Innovator raise the question: Do we fully understand the underlying physics of the loading during violent wave slamming? It is of utmost importance to provide structural engineers with detailed knowledge. About loads, underlying physics, and materials. All to understand and predict how structures respond during extreme loading events», says Aune.

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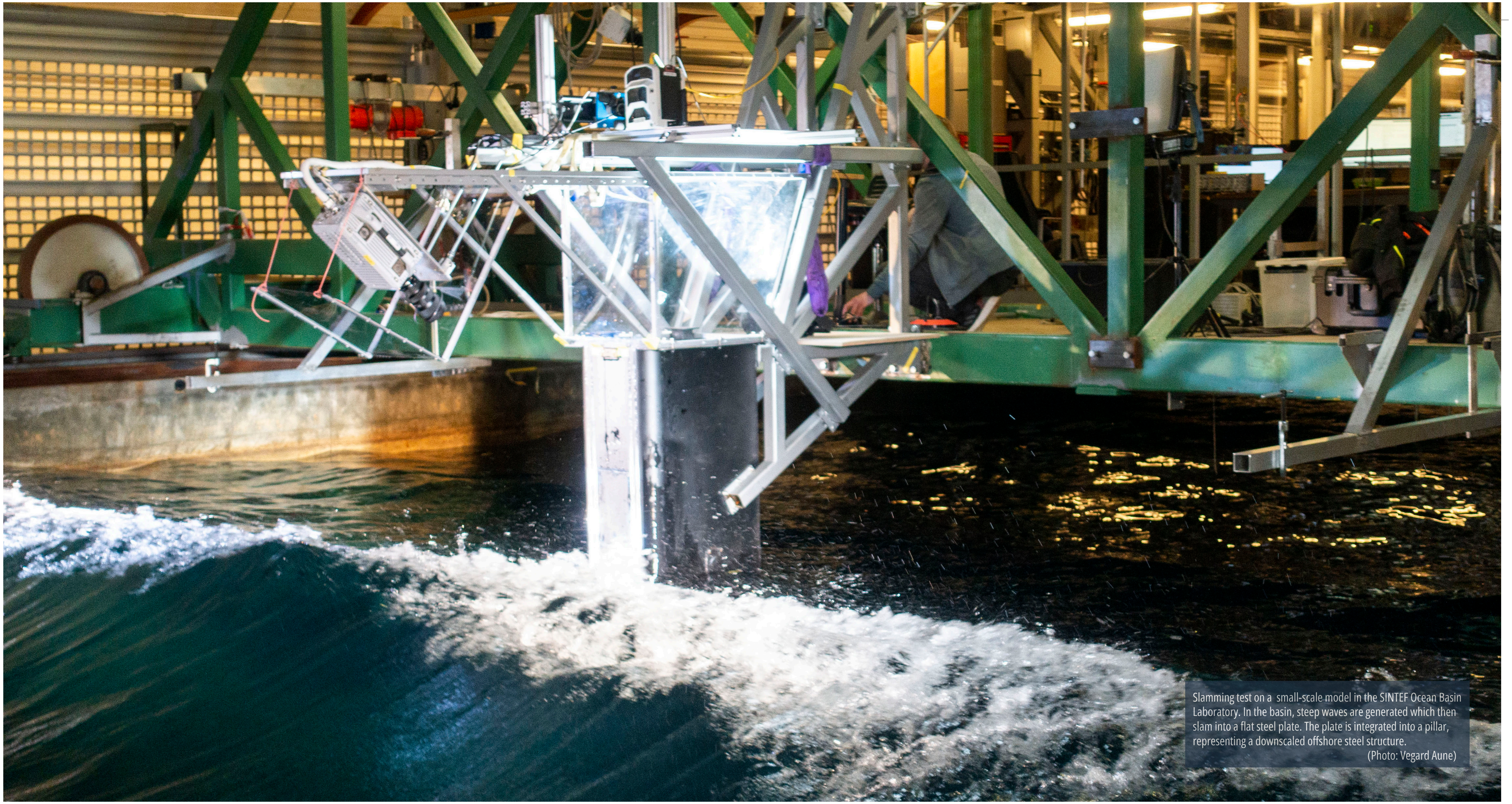


Slamming test on a small-scale model in the SINTEF Ocean Basin Laboratory. In the basin, steep waves are generated which then slam into a flat steel plate. The plate is integrated into a pillar, representing a downscaled offshore steel structure.
(Photo: Vegard Aune)

CONTROLLED SMALL-SCALE MODEL TESTS

In spring 2021, Rene Kaufmann and fellow SLADE researchers spent several days performing slamming tests on small-scale models in the SINTEF Ocean Basin Laboratory.

In the basin, they generated steep waves slamming into a flat steel plate. The plate was integrated into a pillar, representing a downscaled offshore steel structure. It has been assumed that the loading could be obtained from force panel measurements on massive, non-deformable structures. Techniques to determine the full-field surface pressures and the mutual interaction between the load and the structure's response have been lacking.

FULL-FIELD SURFACE SLOPE MEASUREMENTS

Kaufmann would like to change this. He uses the full-field deformation measurements of flexible, plated structures to access the surface pressure distributions acting on the plate.

SIMLab's post-doc has a background in fluid mechanics and is an expert in deflectometry. He describes it as «a full-field surface slope measurement technique». It is highly sensitive and allows measuring deformations down to the micrometre level. Kaufmann earned his PhD in 2019 at the University of Southampton, UK. The technique he uses in SLADE relates to his thesis titled «Full-Field Surface Pressure Reconstruction Using Deflectometry and the Virtual Fields Method» (VFM).

BLASTS, DROP-TESTS AND SLAMMING TESTS

At SIMLab, Kaufmann works closely with Associate Professor Vegard Aune and Senior Researcher Egil Fagerholt. He entered SLADE in autumn 2019 when the project was well underway. In addition to the recent wave slamming tests, some initial experiments in SIMLab's shock tube have been performed. In 2021, the researchers also conducted a series of drop tests in one of the basins at SINTEF Ocean. They dropped a 3D-printed stiffened panel from different heights into the water. They used 3D Digital Image Correlation, Egil Fagerholt's field of expertise, to measure the dynamic deformations.

SCIENTISTS COMPLEMENTING EACH OTHER

The project manager of SLADE KPN, Dr Øyvind Hellan, describes the project as an «inspiring collaboration between research environments that complement each other». Hellan is Vice President for Research at SINTEF Ocean. He says that, when they launched SLADE, they only set out to assemble a top Norwegian national team. SINTEF Ocean, a world leader in marine technology and marine bioresearch, teamed up with NTNUs Department of marine technology (IMT) and SIMLab at the Department of Structural Engineering (KT). IMT is a world leader in education, research, and innovation for engineering systems in the marine environment. SIMLab holds the same status within the field of structures subjected to extreme loads.

A LONG HISTORY OF COLLABORATION

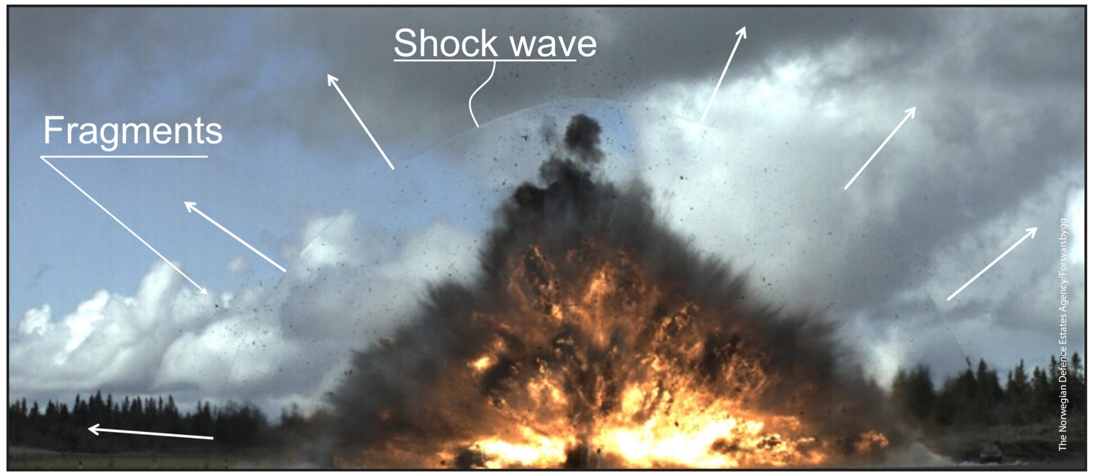
«These are the two academic environments at NTNU that rank highest in the RCN´s international evaluations within their respective fields», Hellan says.

Although SLADE KPN was launched in 2019, the involved partners have a history of collaboration dating far back. «I think the people involved in this project hold the same attitude, concerning both basic research and the value creation and innovation that must come out of the research. Also, we share a common curiosity for the possibilities that new technology offers. Frequent and fruitful professional discussions unite the people of KPN SLADE», says Dr Øyvind Hellan.

This article was published at sfi-casa.no in June 2021.

On 14th December 2022, Benjamin Stavnar Elveli (right) defended his thesis at NTNU. The title is «Behaviour, modelling, and simulation of thin steel plates subjected to combined blast and impact loading». His supervisors are Associate professor Vegard Aune (main), and Professor Tore Børvik. During spring 2022, several tests were perfomed in collaboration with CASA´s partner the Norwegian Defence Estates Agency (NDEA). On the photo Elveli, Aune (to the left) and NDEA-researcher Ole Vestrum prepare NDEA´s testing rig for experiments on partially confined detonations.

Studying the SCARIEST Loads



The shock wave produced by an explosion may be accompanied by fragments accelerating to immense speeds. This devastating combination is a massive challenge for those working with blast-resistant designs.

When blast and impact loading combine, the projectile-like fragments often strike before the blast wave arrives. The damage caused by the fragments introduces the risk of more significant structural failure. Buildings, cars, and other infrastructure close to the detonation will be subject to a load case more severe than if either load acted alone. Despite the high risk, loading scenarios such as these are not considered by design codes and few studies are available in the open literature. Benjamin Stavnar Elveli's PhD is a step in the right direction for better protection and safer solutions.

THE SCARIEST LOAD

«This is the scariest load out there. It works the same way as shrapnel bombs», says Benjamin Stavnar Elveli, a PhD student from Gjøvik in the eastern part of Norway.

It was in 2018 that the busy skateboarder, surfer, climber, and snowboarder was offered a doctorate in severe blast events at SFI CASA. He had just completed a master's degree in blast loading. The task was to investigate how combined fragment impact and blast loading affect thin steel plates.

« I can´t claim that I was a straight-A student during my masters. It has always been important for me to spend time on my hobbies outside of working hours. So, I was unsure if I would fit the typical PhD candidate profile. However, I am very happy that I decided to give it a try».

SAFER STRUCTURES, SAFER SOCIETIES

Elveli submitted his PhD thesis in October 2022. His work consists of more than 80 small-scale blast experiments on target plates of three different steel types with holes that mimic fragment impact. By combining information from physical blast tests with theory and mathematics, he recreated the blast loads in computer simulations. The end goal is the accurate prediction and control of how civil engineering structures respond to combined loading.

Understanding the physics of the load will enable future generations of engineers to design safer and more sustainable structures. This is science for a safer society.

FRAGMENTS BEFORE THE BLAST LOAD

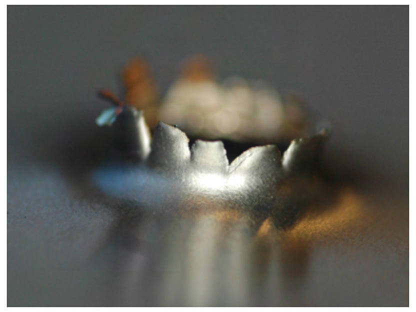
Whether accidental or intentional, explosions can cause extensive destruction. Fragments can originate from an explosive device such as a ruptured casing or ball bearings, from gravel, rocks, or debris from surrounding structures.

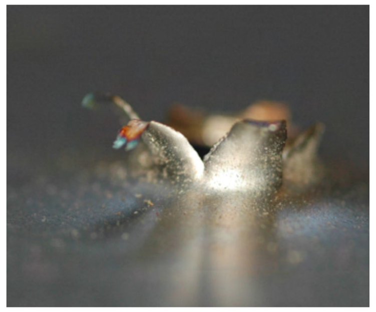
Depending on the proximity to the detonation, fragments can strike a structure before, during, or after the blast wave arrives. If they hit before, a structural engineer may say they have «compromised the structural integrity of the target». This means that they introduce areas of weakness in, for example, thin-walled façadic elements, which must then withstand the incoming blast load. It is most often in these weak points that fracture starts.

According to Benjamin Stavnar Elveli, scenarios like this, where the structure contains a defect prior to blast loading, are assumed to have the highest potential for severe damage.

DESCRIBING BALLISTIC IMPACT AND BLAST LOADING – AT THE SAME TIME

The pressure from a blast wave can last for several milliseconds and cause deformation over a large area. A fragment moves at high speed and causes concentrated damage. Modeling the combined effects means describing two very different, damaging loads within the same model. To label it a complex modelling task is an understatement.





> Idealized defects are easier to test and to simulate. However, since they lack the deformations and damage occurring in real explosions, there is a risk of exaggerating the strength of the materials in these models.
>
> (Benjamin Stavnar Elveli)

«You will often have to reach a compromise. To capture the locally reduced fracture resistance during the explosion, you must decide how accurate the descriptions of the fragment impact need to be. If you do not have full control of this, you could overestimate the structure's capacity during the blast loading».

Overestimating the strength of a component or structure may have fatal consequences. Structural engineers must deliver reliable designs. Elveli's work has largely been focused on investigating how accurate the models must be to ensure safe and reliable structures.

FROM MASSIVE MILITARY TO LIGHTWEIGHT CIVILIAN

Historically, those working on blast-resistant design have focused on massive military concrete structures. However, new threats have emerged over recent decades and the need to protect civilian infrastructure in urban areas has intensified. As a result, the interest in blast-resistant, thin-walled structures capable of withstanding large deformations without fracture has peaked. There is an increasingly critical need to establish universal design guidelines for blast-resistant, lightweight structures. This trend explains Mr. Elveli's test material choice of various types of steel.

AN APPROACH WITH A DOWNSIDE

One common approach is to assume that the fragments strike before the arrival of the blast wave and split the load case into two sequential loading events. Often, such studies rely upon structures with pre-cut defects to mimic flaws or weaknesses from fragment impact prior the explosion. The downside of this simplified approach is that it overlooks all uncertainties related to real fragment impact.

«For instance, manufactured defects lack the small cracks that lead to fracture under blast load», according to Elveli, who tested plates with idealised pre-cut defects during his master's thesis and in the first study of his PhD.

COMPARING FRACTURE STRENGTH

This leads to several essential questions and the main aspect of originality in Benjamin Elveli's doctoral work: Do the plates with idealised holes behave differently from target plates with authentic holes? If yes: How does the simplified approach affect the reliability of the models when predicting the structure's blast resistance – and behaviour?

Elveli compared the pre-cut plates with plates subjected to real ballistic impact in the search for answers. High-velocity fragment impact is very similar to ballistic impact; he fired small-arm projectiles at the target plates in SIMLab's ballistic lab. Afterwards, he subjected the plates to blast loading in the SIMLab Shock Tube Facility.

OVERESTIMATING CAPACITY

The pre-cut holes and ballistic impact holes were both circular with similar diameters, but where the former had «clean» edges, the latter had small petalling cracks and plastic deformation around the perforation hole where the projectile struck (photo above). Under the blast loads, propagation was initiated in these small cracks. Thus, Elveli's work demonstrates that the simplified approach may lead to an overestimation of the structure's ability to withstand combined loads.

«Idealized defects are easier to test and to simulate. However, since they lack the deformation and damage present in real explosions, there is a risk of exaggerating the strength of the materials in these models».

THE PUSH FOR COMPUTER SIMULATIONS

The push for accurate computer simulations of blast-loading events is understandable. Experimental testing on real-size structures to investigate their blast resistance is costly, wasteful and limited in its utility. Detonating cased explosives in full-scale would, for instance, create a dense cloud of flying fragments that could destroy sensors and camera set up to record the event.

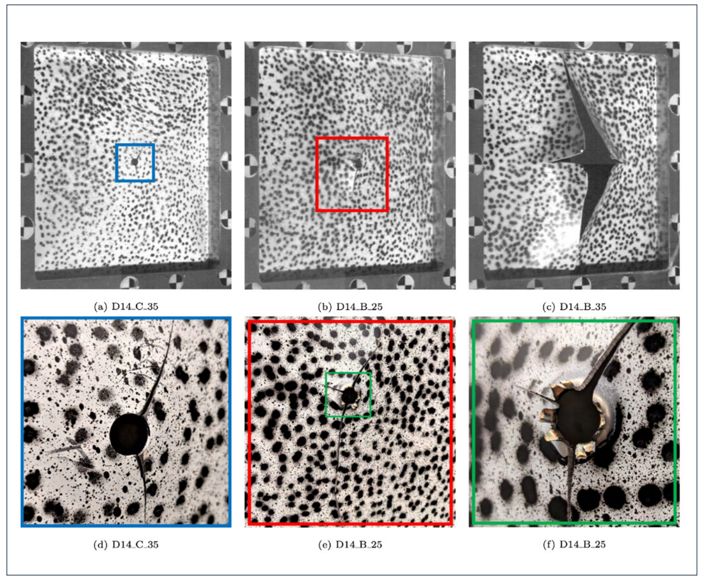
Benjamin Elveli has dedicated a remarkable amount of effort to designing controlled and reliable small-scale experiments. He has performed 110 tests in total, 82 of which involved blast loading. Cameras filming at 37 000 frames per second have captured the combined loads.

EXTENSIVE, EXPENSIVE – AND HOPEFULLY USEFUL

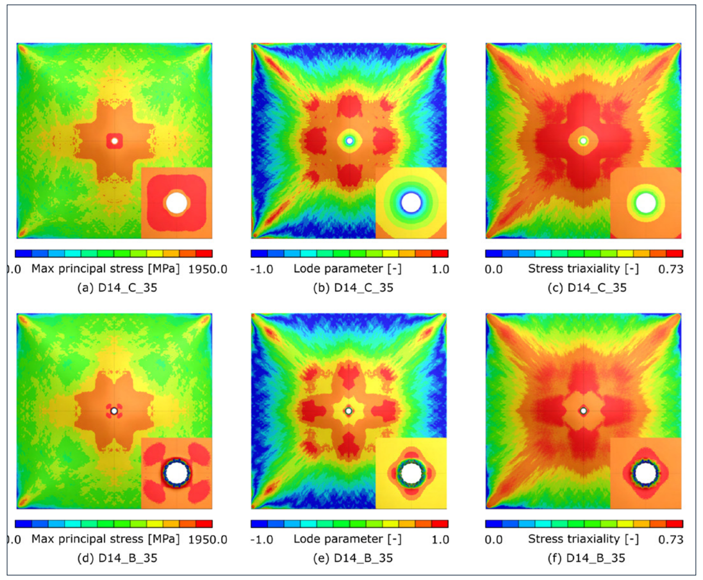
«It has become an expensive doctorate, so I hope the new knowledge will be useful to more people than just me», he jokes.

When asked whom he hopes will benefit from his work, he nods to the scientific community, both military and civilian. Through experiments, Elveli has generated enormous amounts of data that would be of interest to researchers working in this field, as well as engineers in the research and development departments of large companies.

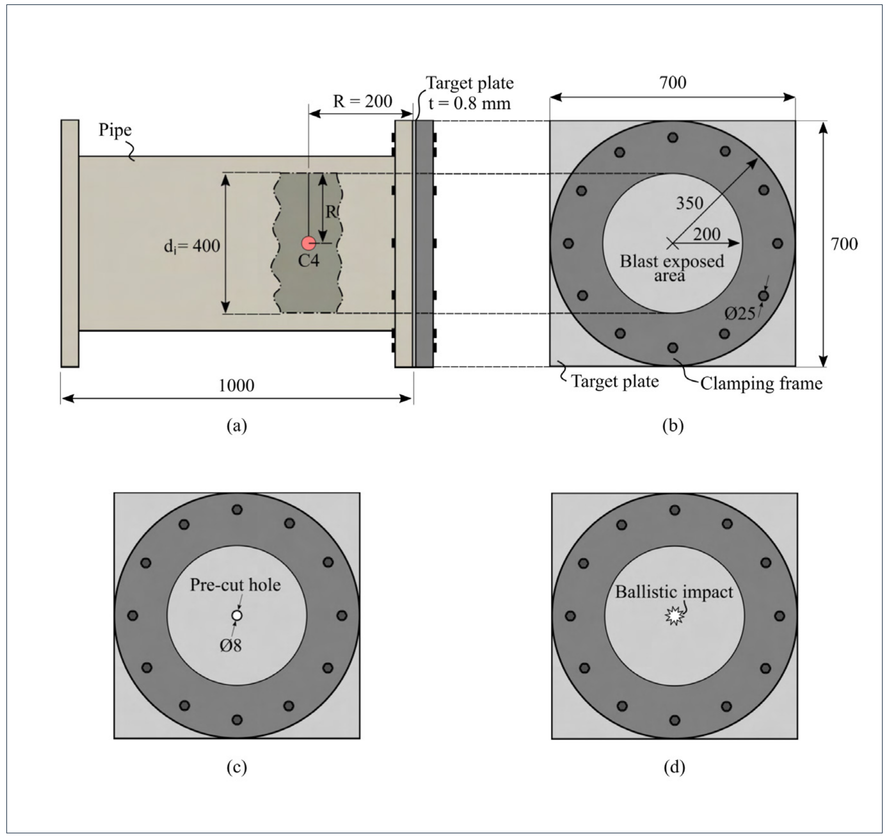
«The extensive dataset is well suited to further evaluate numerical methods and develop new computational tools in the future. It may also be useful for engineers working with Finite element software. The complicated load cases enable the various numerical methods in use today to be put to the test», he says.



Left: Pictures of the final state after blast loading for all tests on tests on high strength plates (D14) experiencing cracking. The full blast exposed area is shown in (a)-(c), and zoomed-in views of the arrested cracks are presented in (d)-(f).



Field plots of the major principal stress 1, the Lode parameter, and the stress triaxiality right before the crack initiation occurred. The high-strength plate with pre-cut hole (D14 C 35) simulation is presented in (a)-(c) and the high-strength plate with ballistic hole (D14 B 35) simulation in (d)-(f). All field plots are taken from the unloaded surface of the target plates.



Schematic of the experimental setup in NDEA´s testing rig for partially confined detonations: (a) The dimensions of the test rig and the position of the explosive charge, (b) the dimensions of the clamping frame and target plates, and the plate geometries containing (c) pre-cut circular holes and (d) pre-formed ballistic holes. All dimensions are in mm.

THE MOST IMPORTANT ACTIVITIES:

- Interaction between blast load and structural response
- Behaviour of structures exposed to combined fragment impact and blast loads
- Violent wave impacts against offshore structures
- Drones as a threat for collisions and explosions against structures, critical infrastructure and societal functions
- Temporary vehicle barriers to prevent attacks from vehicles
- Identify and achieve innovation potential in research results
- Proposal writing and work to secure new research projects

INTERACTION BETWEEN BLAST LOAD AND STRUCTURAL RESPONSE

The interaction between the response to a load and the load itself does not currently form part of the analyses conducted when designing structures to withstand explosions, despite that this interaction could be crucial to understanding damage to buildings and personnel. Recent research findings have revealed that the traditional approach in blast-resistant design fails to capture accurate structural behaviour. Therefore, further research and education to develop competence in this area is of critical importance.

BEHAVIOUR OF STRUCTURES EXPOSED TO COMBINED FRAGMENT IMPACT AND BLAST LOADS

Structures are exposed to combined blast loads and ballistic impact when an explosion occurs during an accident or terrorist act. Ballistics can take the form of projectiles from typical small -arms or fragments that are created as a result of explosions. Experience shows that the combined effect of ballistic impact and blast loads is more critical than either of these loads acting alone. Even so, neither regulations nor guidelines are currently available for such loading cases. The aim of the project is to shed light on the scenarios where it may be necessary to consider the combination of these loading effects. The extent of any damage typically depends on whether the blast pressure or the fragment impacts the structure first, as well as the distance from the explosion itself and the properties of the structure.

VIOLENT WAVE IMPACTS AGAINST OFFSHORE STRUCTURES

This activity was initiated by SINTEF Ocean, Marine Technical Centre at Tyholt in Trondheim. Limited regulations and guidelines regarding the design of offshore structures exposed to violent wave slamming formed the starting point for the activity. The need for such knowledge became particularly evident after an accident on the COSL Innovator on 30th December 2015. The housing module of the drilling rig was heavily damaged when violent waves hit the platform. One human life was lost and several people were injured.

The activity has resulted in a KPN project. The SLADE project (Slamming loads in design, fundamental investigations of violent wave actions and impact response) is led by SINTEF Ocean. The goal of KPN SLADE is to improve safety at sea through new insight into the forces acting on marine structures. The project is funded by the Research Council of Norway (NFR) and the competence and cooperation projects for business (KPN) programme. The KPN programme contributes to industry-oriented research training and long-term competence building in Norwegian research environments. The academic topics are required to be of high importance for the development of Norwegian companies.

DRONES AS A THREAT FOR COLLISIONS AND EXPLOSIONS AGAINST STRUCTURES, CRITICAL INFRASTRUCTURE AND SOCIETAL FUNCTIONS

The increasing prevalence and range of drones has brought to light issues with their use that are of national safety concern. Drones are here to stay, and the consequences they could have on physical security are immediate and severe enough to require action. So far, few studies have addressed the impact and conceivable extent of damage from drones. Traditionally, threats to infrastructure have consisted of large quantities of explosives placed at ground level. The way we think about security measures must transform to account for drone technology; it is now possible for relatively small charges of explosives to be brought in close proximity to buildings and structures and at height. Owners of critical national objects must therefore rethink what should define a perimeter. The technology has exposed vulnerabilities that can be exploited by individuals with treacherous intentions. The technology is not merely a threat; it is a very effective weapon in the wrong hands.

In 2019, SIMLab established an international collaboration concerning the intentional use of drones against people, civilian structures, critical infrastructure and societal functions. The project was named VOLCANO (Vulnerability of public spaces subjected to exploding drones) and was conceived as a collaboration between the French aerospace research centre (ONERA) in Lille, the EU research centre EU-JRC in Ispra (Italy), the Royal Military Academy (RMA) in Brussels (Belgium) and SIMLab. The objective is twofold: to investigate the consequence of (1) drones themselves as weapons intended to cause damage to people and structures (in the form of collisions) and (2) drones as a means of transportation for explosives to be brought close to structures and civilians. VOLCANO is highly relevant to our race against evolving threats, but attempts to secure research funding to follow up on this issue have not been successful.

TEMPORARY VEHICLE BARRIERS TO PREVENT ATTACKS FROM VEHICLES

This activity was initiated by the National Security Authority (NSM) due to the limited regulations and guidelines around the use of temporary vehicle barriers as protection against attacks from vehicles. "Temporary" implies vehicle barriers that are not anchored in the ground. Such barriers can therefore only withstand the vehicle to the extent of the barrier's own weight and resulting friction against the ground. Initial efforts have focussed on a systematic mapping of current protocol and regulations for the use of temporary vehicle barriers. Preliminary studies initiated by NSM have been carried out to investigate the resistance capability of this type of vehicle barrier.

In connection with this work, a national working meeting was organised in collaboration with the Ministry of Justice and Public Security (JD) (6th June 2018). Vegard Aune also participated in an international working meeting at the EU-JRC in Italy (20-21 June 2018) on the topic of temporary barriers. Experience from these activities has been transferred to the Norwegian Defence Estates Agency (FB) and the National Centre for Protection of Buildings (NKSB).

IDENTIFY AND ACHIEVE INNOVATION POTENTIAL IN RESEARCH RESULTS

This project was linked to the Research Council of Norway's programme for research-based innovation (FORNY). SFI CASA was awarded funding for the Matcards project as part of the FORNY2020 programme. The aim was to identify and achieve innovation potential in research results and the project was completed at the end of 2019.

PROPOSAL WRITING AND WORK TO SECURE NEW RESEARCH PROJECTS

Grant applications have been submitted to the Research Council's (NFR) Research Project for Young Talents (FRIPRO) programme and to the European Research Council for the ERC Starting Grant (ERC StG). Both submissions are in the ground-breaking research category. ERC StG is aimed at Excellent Science and is part of Pillar I in Horizon Europe.

The aim of these applications is to develop new measurement techniques that can provide better insight into data from tests on structures that are exposed to extreme loading events. This new and ground-breaking technology will give rise to opportunities for better understanding the forces that act on structures exposed to extreme loads. Our ability to plan safe and sustainable structures in the future is dependent on the type of knowledge generated by this research. The technology to be developed is also intended for new project proposals that aim higher on the TRL scale.

The submissions received top marks, but did not progress in the competition to receive funding.

The rejection confirms that the funding competition for ground-breaking research is fierce and intensifying. It underlines the importance of predictable and long-term support for research which is necessary to increase national competitiveness in our field. Research on physical security is at present left to compete in the same category as generic excellent research - that seems questionable.

SIMLab at NTNU has applied to the Ministry of Justice and Public Security (JD) for financial support to establish a national centre of societal security, with a focus on teaching and research related to the physical security of buildings and infrastructure. The application was submitted in May 2019, and the centre is proposed to be a ten-year research and education programme in societal security. SIMLab is in ongoing dialogue with the JD regarding a response to this application.

HOW SAFE IS SAFE ENOUGH?

Photo: Colourbox

The Norwegian Security Act oversees the standard of our national security. The law, however, is not all-encompassing: a critical burden is placed upon all business owners responsible for “critical national objects” – facilities that must be protected against threats to national security, such as power and water supply plants, data centres, and oil and gas installations. Business owners must assess the risks and ensure the proper security measures themselves.

But how safe is safe enough?

RISK AND VULNERABILITY ARE PASSED ON

Significant weaknesses can be identified in national security management at present. While the requirements for securing information systems are clear, the requirements for physical objects have major shortcomings. The Security Act is clear on what constitutes a critical national object: law enforcement and armed forces buildings, for example. The law is also clear on what constitutes a reasonable security level. The problem lies in the lack of regulation and guidance for how business owners should achieve the required levels of security. Thus, risks of the most serious nature are left unanalysed and vulnerability is passed onto the general population.

BASED ON MILITARY REGULATIONS

The Norwegian Security Act and associated regulations lack clarity and leave considerable room for interpretation to those who implement the Act. The law uses both a functional and a trust-based approach. A functional approach implies that design is based on design standards which ensure that the fundamental requirements are met, but are nevertheless voluntary to uphold. Current protocol regarding security in urban areas was founded on a set of military regulations, but times have changed along with the nature and severity of the threats posed. Today’s civilian buildings and infrastructure have a completely different capacity for withstanding extreme loads compared to military installations – whether they are caused by sabotage, terror, extreme weather or natural disasters. The biggest challenge for physical security remains: there are no such standards in existence for the protection of civilian infrastructure.

LACK OF TECHNICAL REQUIREMENTS FOR PHYSICAL SECURITY

Requirements for how to achieve an appropriate level of security are lacking and instead, responsibility for safety measures falls to the competence of individual engineers. There is inherent risk in basing security standards on the knowledge and experience of the very engineer responsible for designing the protection. Security culture at present therefore has clear deficiencies.

ACTING ON OUR FEELINGS

History demonstrates that steps are taken in the right direction whenever threats and discomfort come close to home. The attacks against the USA on 11th September 2001 triggered the greatest shift in global societal security operations to date. In Norway, 22nd July 2011 transformed our national approach to physical security. NOK 30 billion has been allocated to protection against identical threats, despite that the events of 22nd July will likely never be repeated in exactly the same way they unfolded in 2011.

RUNNING AFTER THE THREATS

In autumn 2022, evidence was again seen that sudden events govern the level of commitment to our own safety. When threats and discomfort get close enough, we act. At present we harbour strong suspicions of sabotage in the Baltic Sea, resulting in a high awareness to secure oil and gas installations at the Norwegian continental shelf. Drones have become ubiquitous and incidents of trespass are becoming ever more frequent. As the number of observations increases, more and more resources are directed to regulating their use.

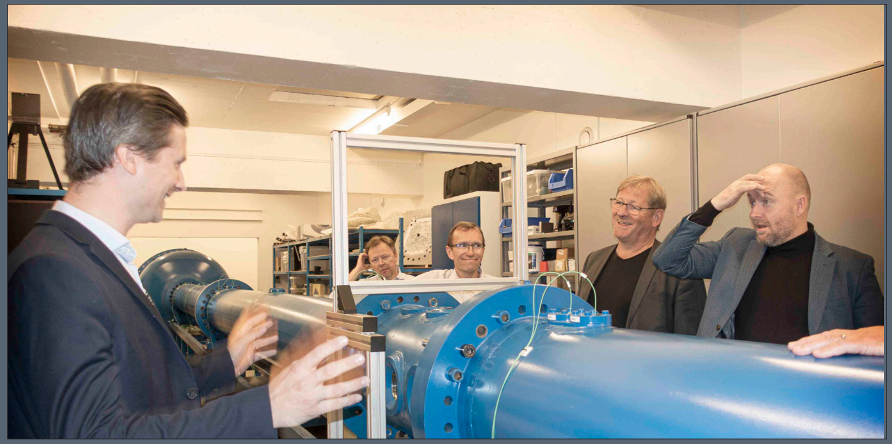
NO WAY BUT PHYSICAL SECURITY

The time for addressing modern challenges in physical security is overdue. We need fresh efforts to bolster the national level of competence and set stricter regulations on how to ensure proper security measures for critical national objects; their resilience is the last barrier of protection. When all other measures fail, it is physical security that defines the consequences in terms of loss of assets, and worse, human life. The sum of all security measures determines how vulnerable we are.

LEGAL LOOPHOLES MUST BE CLOSED

Upgrading the oil and gas network with 9 000 kilometres of bomb-proof pipelines is of course not a viable solution. Office buildings cannot be replaced with windowless bunkers. A holistic approach must be taken. Balanced security measures must form a central component in major construction and decision-making processes from the outset. The critical questions must be addressed: What technical requirements must a risk assessment fulfil for critical national objects? How do we ensure that assessments are properly carried out and measures implemented? Should controls only be enforced once the threat level becomes severe? Where do we stand in the race against evolving threats?

Our shared security culture must be diligently revaluated and strengthened; the extent of our knowledge will determine how vulnerable we are. The requirements for competence must be tightened, and we must eliminate any shortcomings and unpremeditated risks in the legislation that is designed to protect us.



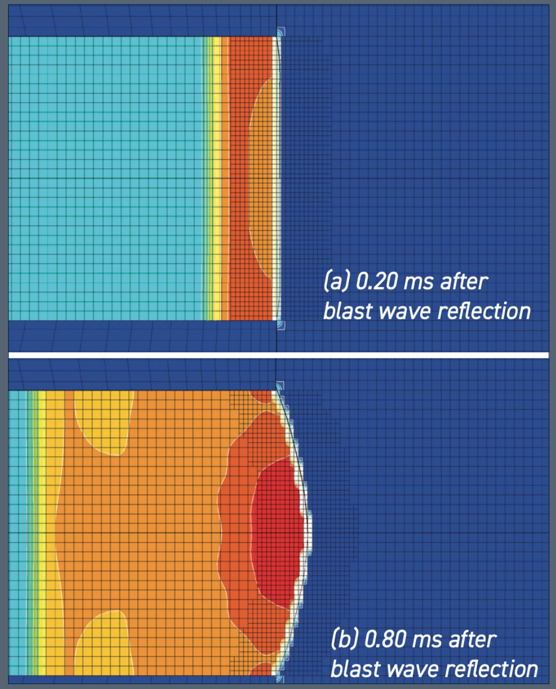
A CRASH COURSE FOR MPS

When politicians knock, the staff at CASA are always prepared and proud to present how the Centre works with physical security. On 1st September 2021, Parliament politicians Espen Barth Eide, Jorodd Asphjell and Eirik Sivertsen from the Labour Party were introduced to CASA's research activities. Professor Magnus Langseth gave his presentation in the large hall next to the impressive Pendulum Impactor – also known as the Kicking Machine. Here, the engaged politicians were shown a quick demonstration of a 40 kph crash test of an aluminium profile. Afterwards, researchers and politicians took the opportunity to discuss future initiatives for CASA.
Next, the group moved to the Ballistic Impact lab for a presentation on the Gas gun and ballistic impact studies. The last stop was the Shock tube facility,where Associate professor Vegard Aune explained the nearly 20-meter-long custom-made tube´s possibilities for recording and measuring blast loads. SIMLab and SFI CASA researchers subject aluminum, steel, glass, and concrete plates to blast loads using this rig. During the visit, the research group's essential role in education was an important topic. The group is world leading in the field of extreme loading on materials and structures. Civil and doctoral engineers from SIMLab are trained to use the latest tools and think holistically about physical security; the group produces not only research but candidates for public and private sector roles.

NEW CLOSE-RANGE DETONATION STUDIES

Over a few days in spring 2022, 30 blast loads detonated inside one of the Norwegian Defence Agency's (NDEA) test facilities.
Behind the destruction lies CASA and partner NDEA's shared aim to address the complexity of close-range detonations. Several studies show how near- and far-field blast events affect blast-loaded structures. «Thus, we know quite a bit about what happens when significant explosive charges detonate at some distance from critical infrastructure. Such incidents have been the main threat in historical explosive events», says Associate professor Vegard Aune.
Close-range detonations introduce complex interactions between the blast overpressure and expanding detonation products such as fireballs. Today's computational tools enable advanced simulations.
«We must challenge the existing modelling methods for near- and far-field events and see how they perform for the effects of blasts in small, confined spaces,» Aune says. The actual loading environment is not yet fully understood. The core question is, «what is the load». This is a critical uncertainty because how the load is defined directly influences the material's and the structure's behaviour. We want to answer this question to provide models with reliable predictions».

NEWS ON EXTREME BLAST-STRUCTURE INTERACTION



At the 13th International DYMAT conference (2021), Associate professor Vegard Aune shared new insight on the underlying physics of extreme blast-structure interaction. He presented recently published work on the influence of fluid-structure interaction (FSI) effects on the ductile fracture of blast-loaded steel plates. FSI occurs when a movable or deformable structure interacts with an internal or surrounding fluid flow. In this case, the fluid is air from the pressure waves generated by an explosion. According to Aune, we do not fully understand the importance of FSI effects during the dynamic response of blast-loaded structures. Therefore, developing a methodology for identifying scenarios where FSI is essential in designing civil engineering structures is necessary. His team has dedicated a lot of effort to establishing such a methodology. The aim is to gain a deeper insight into the underlying physics during extreme blast-structure interaction.
The first step of the methodology is to use experimental data as a reference to validate the predicitve capabilities of numerical simulations. Next, numerical simulations are used to study the FSI effects. This novel approach allows for detailed studies on the dynamic response of the blast-loaded steel plates. Dr. Aune's fellow authors on the study presented at DYMAT are Professors Magnus Langseth and Tore Børvik (SIMLab and SFI CASA) and Georgios Valsamos and Folco Casadei (European Commission, Joint Research Centre (JRC), Ispra (VA), Italy).

VEGARD AUNE JOINS EXCLUSIVE GROUP

In 2022, Vegard Aune was appointed among 25 carefully selected participants in NTNU's Outstanding Academic Fellows Programme (OAFP).
The scheme aims to accelerate the international career of the university's top talented young researchers.
«This is a truly great and unique opportunity to concentrate on research over the next four years,» Dr. Aune said after the news broke.
Since 2014, NTNU has facilitated academic development and merit through the OAFP for more than 90 researchers. All those selected are already internationally outstanding in their field. One important contribution of the scheme is to qualify participants for excellence grants, such as the European Research Council (ERC) Grants.
Further, the participants must set aside all engagements and activities that do not support the development of ground-breaking research.
«I see this as a parallel to top-level sport. You are supported in managing your time effectively and concentrating on the research. It is all about performing your best by prioritizing correctly and clearing space for what is important», Aune says.
Dr. Aune's selected mentor is Cambridge Professor Vikram S. Deshpande. Deshpande is the head of the Cambridge Solid Mechanics Group. The two are expected to work closely: together they must establish a career and research plan for publications, collaborations, grants, projects, and research stays. The plan must also detail concrete actions for Dr. Aune to prove himself as an independent international leader in his field.

FUTURE OUTLOOK

Research excellence and elite sport have many close comparisons. Both fields require continuous improvement, strong ambitions, perseverance and – not least – resources and targeted investment for extended periods of time. Over several decades, the SIMLab (Structural Impact Laboratory) research group has built up internationally leading expertise in the behaviour of materials and structures exposed to impact and and other extreme loads. In the last 16 years, the group has run two Centres for Research-based Innovation (SFI). SFI CASA, the second Centre, ends in 2023.

Many people have contributed to the world-leading position of SIMLab when it comes to research on physical security. The collaboration with JD has consolidated the academic environment in physical security at SIMLab. The JD has facilitated SFI CASA's contribution to raising the level of education and research on physical security in Norway. At the same time, the activity and resources in SFI CASA have yielded a gainful return on the support from the JD. The result is that we are better equipped to face future challenges related to structures that are exposed to extreme loads.

The question now is how the knowledge will be maintained and developed. The answer quickly points to research funding.

STRONG COMPETITION FOR FUNDING

In elite sports it is the miniscule and often trivial margins in funding decisions that determine whether an athlete is successful, or the door is closed. Public research funding schemes can all too easily create the same obstacles; the processes to apply for funding from the Research Council of Norway and the EU is one example. Only applications with top marks survive the tough competition. However, there may well be more outstanding project proposals than there is funding available, leaving many top tier applications on the rejected pile. Luck, as well as the nuances of decision makers, can play all too great a role in funding success.

PHYSICAL SECURITY FALLS BETWEEN THE CRACKS

We live in troubled and challenging times. New threats, new technology and turbulent politics are discernibly making their mark in the fields of protection, security and safety. At the same time, extreme weather and landslides are occurring more frequently, becoming more powerful and causing greater destruction. The transport industry and energy sectors are also facing stricter requirements for physical security.

The latest Long-Term Plan for Research and Higher Education (LTP) (2023-2032) shows the importance of physical security: One of six Norwegian priorities is civil protection and emergency preparedness. Yet, this priority has not been evidenced in funding scheme announcements to date. Physical security appears to fall between the cracks when funding is assigned to strategic research areas.

PHYSICAL SECURITY IS A PUBLIC RESPONSIBILITY

Physical security is a public responsibility. Civil engineers of the future need to be trained. Research must be conducted on the resilience of exposed structures. The authorities must ensure long-term funding for academic environments to flourish. Future decisions must be informed by science and build on first-hand expertise in security design and management. Appropriate security measures must be a central component in major construction and decision-making processes from the outset. Reliable expertise is required to ensure that the cost of a given security measure is in reasonable proportion to what can be achieved by the measure.

Funding schemes are becoming increasingly targeted toward research and innovation endeavours, such as the EU's Horizon Europe programme. Such projects mandate that clearly defined and ambitious objectives are addressed over a short time period of 2-3 years. In certain circumstances it is appropriate that research is directed towards achieving tangible results in specific time frames. However, the importance of basic research and education must not be overlooked if a strong position to adapt to future challenges is to be maintained.

NO FUNDING = NO EDUCATION OR RESEARCH

The master's and doctoral candidates from SIMLab

FUTURE OUTLOOK continued...

are bridge builders between academia and industry; they translate research efforts into innovation. Without fresh funding, the academic environment will need to start preparing to downsize. The reorganisation would simultaneously require a time- and resource-consuming process of building capacity in new areas. The planned continuing education and professional development programmes, which foster competence in the private and public sector, would need to be shelved. Large investments would be lost. Well-equipped and unique laboratories would need to be dismantled because space at NTNU is at a premium.

Without laboratories, there is no teaching and no research. The consequence is a greatly reduced offering for educating civil engineers in the field of security. The research environment would lose competitiveness in the increasingly tough battle for research funding.

THE STATE´S RESPONSIBILITY
FOR BASIC RESEARCH

We must have stable and competent research environments that maintain a high international level in both applied research and basic research. Basic research builds foundations which, in the longer term, are necessary to give rise to successful innovations in the future.

Investing in high quality research environments is the only way to foster the expertise that we rely upon to meet major societal challenges, both those faced at present and the unknowns yet to come. Basic, curiosity-driven research builds knowledge on which the society of the future depends.

MINISTRIES MUST FUND
EXCELLENT RESEARCH GROUPS

The various ministries are responsible for research within their areas. Long-term funding for outstanding research groups is crucial to achieving the strategic goal of preserving and further developing internationally renowned academic environments. Direct, basic funding from the ministries is common practice in Europe and elsewhere in the world. The purpose is to facilitate competence building, education and research.

The ministry must ensure continuous calls in the Research Council that address physical security. Furthermore, such funding schemes must be considered as additional top-up funding sources of support for research. When funding allocations are inconsistent, academic environments become tenuous and unstable; conditions which, in turn, inhibit performance and the quality of output. Long-term basic funding from the ministries guarantees continuous teaching and research in our field.

LONG-TERM FUNDING IS A
PREREQUISITE FOR RECRUITMENT

For security clearance reasons Norway is reliant on an increase in uptake of Norwegian citizens to master's degrees and doctorates in physical security. Throughout two SFIs, the research group SIMLab has trained 20-30 Norwegian master's candidates each year.

In addition, the academic environment has educated more than 60 doctoral candidates, over 70 percent of whom have been Norwegian citizens. The latter statistic stands in strong contrast to comparable academic environments that have struggled to recruit Norwegian candidates.

Long-term funding has been crucial; with consistent funding, the work to recruit the best students can start early, often 1-2 years before they are hired as doctoral candidates. This strategy becomes unfeasible for short-term funding and smaller research projects. Educating Norwegian citizens ensures that we retain expertise in Norwegian companies and stakeholders. On top of this, long-term financing promotes continuity of investment in younger research talents and enhances competitiveness in the pursuit of new projects.

QUALITY BECOMES APPARENT OVER TIME

The best indicator of a high quality research group is consistent, internationally recognized research output over an extended period of time. Publications in leading journals or by renowned publishers are the best proof of scientific quality. Scientific quality is crucial for cooperation with world-leading research groups and renowned scientists.

SIMLab at NTNU is an international leader in its field. For several years, efforts have been made to establish a National centre for physical security. The centre will have overall responsibility for teaching and research related to the physical security of buildings and infrastructure.

The Ministry of Justice and Public Security (JD) is urged to continue its national commitment to physical security. This investment will ensure knowledge readiness to meet future societal challenges related to physical security.

Photo: Colourbox

CONTRIBUTORS
PUBLICATIONS
INVITED TALKS
SELECTED WORKSHOPS

Contributors, publications, selected workshops and invited talks

Permanent academic staff
Tore Børvik (Professor NTNU, SFI CASA)
Magnus Langseth (Professor NTNU, SFI CASA)
Vegard Aune (Project leader, Associate Professor NTNU, SFI CASA)

Communications
Sølvi Marie Waterloo Normannsen
(Informasjonsmedarbeider NTNU, SFI CASA)

Master students	Topic
2018 B. S. Elveli, M. B. Iddberg.	Experimental and numerical study on perforated steel plates subjected to blast loading.
2019 A. Hald.	Dynamic response of steel plates subjected to combined impact and blast loading.
2019 A. Berrum, C.-M. R. Bjorvand.	Dynamic response of flexible structures subjected to blast loading.
2019 H. H. Kristiansen, G. Sigstad.	Dynamic response of blast-loaded steel plates with and without pre-formed holes.
2020 J. Sørbøl.	Performance of perforated aluminium plates subjected to blast loading.
2020 O. Celius, M. L. Knoph.	Plated aluminium structures exposed to extreme pressure loads.
2020 A. M. Gahre, R. H. Haug.	Dynamic response of steel plates subjected to combined blast and impact loading.
2020 S. H. L. Johansen.	Plated aluminium structures exposed to extreme pressure loads.
2021 V. S. Hjelmeland.	Fluid-structure interaction effects during the dynamic response of blast-loaded plated structures.
2021 I. Gisnås, A. B. A. B. A. Syed.	Dynamic response of flexible beams subjected to blast loading.
2021 H. Næss.	Plated offshore structures exposed to violent wave impact – Slamming structural response.
2022 M. Bacher, A. M. Larsen.	Thin steel plates subjected to confined, close-range blast loading.
2022 A. A. Resell.	Modelling of fluid-structure interaction with a cartesian grid method: Application to shock tube simulations

PhD candidate
2018-2022 B. S. Elveli. Behaviour and modelling of steel plates subjected to combined blast and impact loading.

Postdoctoral research fellow
2019-2021 R. Kaufmann. Fluid-structure interaction during violent wave impact – Slamming structural response.

Researchers
2021-2023 R. Kaufmann. Reconstruction of surface pressures on plated structures impacted by extreme loading events.

Visiting scientists
2019 Vincent Faucher, Research and senior expert, CEA, Cadarache, France.
2021 Ramón del Cuvillo Mezquita, PhD candidate, University Carlos III de Madrid, Spain.
2022 Luca Lomazzi, PhD candidate, Politecnico di Milano, Italy.

Invited talks and selected workshops
2018 Magnus Langseth, Vegard Aune (both NTNU, SFI CASA) og Geir Paulsrud (JD) organized a national workshop on challenges within safe design in urban planning and securing the public space. The meeting was held on 6th June in JD's premises at Gullhaug Torg in Oslo. The goal was to collect useful input and experiences among national players regarding vehicle barriers aimed at physical security of public spaces.
2018 Vegard Aune (NTNU, SFI CASA) attended a workshop at the European Commission's Joint Research Centre (EU-JRC) in Ispra in Italy 20th-21th June. The agenda was physical security of public spaces with a particular focus on the use of vehicle barriers. Vegard Aune presented the results from the discussion in the national workshop held at JD on 6th June.
2019 Magnus Langseth og Vegard Aune (both NTNU, SFI CASA) attended a workshop aimed at establishing an application for an EU project targeting drones as a threat for collisions and explosions against structures, critical infrastructure and societal functions. The project was named VOLCANO and the meeting took place in Onera, Lille, France, on 20th February.
2020 Vegard Aune (NTNU, SFI CASA) attended the 1st workshop on "Numerical simulation for hostile vehicle mitigation". This was a digital workshop hosted by the European Commission's Joint Research Centre (EU-JRC) in Ispra in Italy 7th July.
2020 Vegard Aune (NTNU, SFI CASA) attended the 2nd workshop on "Numerical simulation for hostile vehicle mitigation". This was a digital workshop hosted by the European Commission's Joint Research Centre (EU-JRC) in Ispra in Italy 25th November.
2021 Vegard Aune (NTNU, SFI CASA) attended the 3rd workshop on "Numerical simulation for hostile vehicle mitigation". This was a digital workshop hosted by the European Commission's Joint Research Centre (EU-JRC) in Ispra in Italy 10th February.
2021 Vegard Aune (NTNU, SFI CASA) attended the 4th workshop on "Numerical simulation for hostile vehicle mitigation". This was a digital workshop hosted by the European Commission's Joint Research Centre (EU-JRC) in Ispra in Italy 14th December.
2022 Vegard Aune (NTNU, SFI CASA) was examinator of the PhD thesis of Tristan Julien, CEA Cadarache, France 29th March.
2022 Vegard Aune (NTNU, SFI CASA) attended the 5th workshop on "Numerical simulation for hostile vehicle mitigation". This was a digital workshop hosted by the European Commission's Joint Research Centre (EU-JRC) in Ispra in Italy 31th March.
2022 Vegard Aune (NTNU, SFI CASA) attended the 6th workshop on "Numerical simulation for hostile vehicle mitigation". This was a digital workshop hosted by the European Commission's Joint Research Centre (EU-JRC) in Ispra in Italy 21th September.
2023 Vegard Aune (NTNU, SFI CASA) was invited to give a talk at the Micromechanics seminar at the University of Cambridge, 3rd March.

Peer-reviewed journal articles

M. Kristoffersen, J.E. Pettersen, V. Aune, T. Børvik. Experimental and numerical studies on the structural response of normal strength concrete slabs subjected to blast loading. Engineering Structures 174 (2018) 242-255.
H. Granum, V. Aune, T. Børvik, O. S. Hopperstad. Effect of heat-treatment on the structural response of blast-loaded aluminium plates with pre-cut slits. International Journal of Impact Engineering 132 (2019) 103306.
B. C. Abrahamsen, H. S. Alsos, V. Aune, E. Fagerholt, O. M. Faltinsen, Ø. Hellan. Hydroplastic response of a square plate due to impact on calm water. Physics of Fluids 32 (2020) 082103.
V. Aune, G. Valsamos, F. Casadei, M. Langseth, T. Børvik. Fluid-structure interaction effects during the dynamic response of clamped thin steel plates exposed to blast loading. International Journal of Mechanical Sciences 195 (2021) 106263.
B. S. Elveli, M. B. Iddberg, T. Børvik, V. Aune. On the strength-ductility trade-off in thin blast-loaded steel plates with and without initial defects – An experimental study. Thin-Walled Structures 171 (2022) 108787.
S. Olufsen, R. Kaufmann, E. Fagerholt, V. Aune. RECOLO: A python package for the reconstruction of surface pressure loads from kinematic fields using the virtual fields method. Journal of Open Source Software 7 (71) (2022) 3980. doi: 10.21105/joss.03980.
R. Kaufmann, S. Olufsen, E. Fagerholt, V. Aune. Reconstruction of surface pressures on flat plates impacted by blast waves using the Virtual Fields Method. International Journal of Impact Engineering 171 (2023) 104369. doi: 10.1016/j.ijimpeng.2022.104369.
B. S. Elveli, T. Berstad, T. Børvik, V. Aune. Performance of thin blast-loaded steel plates after ballistic impact from small-arms projectiles. International Journal of Impact Engineering 173 (2023) 104437.
B. S. Elveli, O. Vestrum, K. O. Hauge, T. Berstad, T. Børvik, V. Aune. Thin steel plates exposed to combined ballistic impact and partially confined airblast loading. Engineering Failure Analysis 144 (2023) 106943.

Presentations at international conferences

R. Kaufmann, S. N. Olufsen, E. Fagerholt, V. Aune. Application of the Virtual Fields Method to Reconstruct Full-Field Surface Pressures During the Dynamic Response of Blast Loaded Steel Plates. Presented at the 16th International Conference on Advances in Experimental Mechanics - BSSM2022 (2022) Oxford, United Kingdom.
del Cuvillo, M. Costas, V. Aune, T. Børvik, J. A. Artero-Guerrero, J. Parnas-Sánchez, J. López-Puente, Carbon fibre composite exposed to blast loading: A preliminary study, Presented at the 3rd International Conference on Impact Loading of Structures and Materials - ICILSM 2022 (2022) Trondheim, Norway.
B. S. Elveli, T. Børvik, V. Aune. Blast resistance of perforated steel plates. Presented at the 3rd International Conference on Impact Loading of Structures and Materials - ICILSM 2022 (2022) Trondheim, Norway.
R. Kaufmann, S. N. Olufsen, E. Fagerholt, V. Aune. The Virtual Fields Method for Reconstruction of Impact and Blast Loading. Presented at the 3rd International Conference on Impact Loading of Structures and Materials - ICILSM 2022 (2022) Trondheim, Norway.
L. Lomazzi, A, Manes, F. Cadini, D. Morin, V. Aune. Data-driven approach to account for fluid-structure interaction effects on blast loaded steel plates. Presented at the 3rd International Conference on Impact Loading of Structures and Materials - ICILSM 2022 (2022) Trondheim, Norway.
R. Kaufmann, B. C. Abrahamsen, Ø. Hellan, E. Fagerholt, V. Aune. Full-field reconstruction of wave slamming pressures. Presented at the 74th Annual Meeting of the APS Division of Fluid Dynamics – APS DFD (2021) Phoenix, Arizona, USA.
K. A. Brekken, R. Kaufmann, V. Aune, M. Langseth, T. Børvik. Shock tube testing of deformable structures: A novel experimental set-up. Presented at the 15th International Conference on Advances in Experimental Mechanics for the British Society for Strain Measurement – BSSM (2021) Virtual, Online.
V. Aune, G. Valsamos, F. Casadei, M. Langseth, T. Børvik. Influence of fluid-structure interaction effects on the ductile fracture of blast-loaded steel plates. Presented at the 13th International Conference on the Mechanical and Physical Behaviour of Materials under Dynamic Loading – DYMAT (2021) Madrid, Spain.
B. S. Elveli, T. Børvik, V. Aune. Influence of material properties on the performance of blast-loaded steel plates with pre-cut defects. Presented at the 13th International Conference on the Mechanical and Physical Behaviour of Materials under Dynamic Loading – DYMAT (2021) Madrid, Spain.
R. Kaufmann, E. Fagerholt, V. Aune. Surface pressure reconstruction in shock tube tests using the Virtual Fields Method. Presented at the annual conference for the Society for Experimental Mechanics – SEM Annual (2021) Virtual, Online.
B. S. Elveli, T. Børvik, V. Aune. Blast-load response of thin steel plates after ballistic impact from small-arms projectiles. Presented at the conference of Light-Weight Armour for Defense & Security, LWAG (2019), Roubaix, France.
V. Aune, G. Valsamos, F. Casadei, T. Børvik. Aspects of fluid-structure interaction on the dynamic response of blast-loaded metallic plates. Presented at the conference of Light-Weight Armour for Defense & Security, LWAG (2019), Roubaix, France.
H. Granum, V. Aune, T. Børvik, O.S. Hopperstad. Aluminium plates with pre-formed slits subjected to blast loading. Aluminium Innovation Workshop, European Aluminium (2019), Trondheim, Norway.
H. Granum, V. Aune, T. Børvik, O. S. Hopperstad. Aluminium plates with pre-formed slits subjected to blast loading. Presented at the 12th International Conference on the Mechanical and Physical Behaviour of Materials under Dynamic Loading – DYMAT (2018) Arcachon, France.
V. Aune, F. Casadei, G. Valsamos, M. Langseth, T. Børvik. A shock tube used to study the dynamic response of blast-loaded plates. Presented at the 18th International Conference on Experimental Mechanics – ICEM18 (2018), Brussels, Belgium.

Dataset publications

R. Kaufmann, S. N. Olufsen, E. Fagerholt, V. Aune. Experimental data for force reconstruction using impact hammer and deflectometry. DataverseNO (2021) https://doi.org/10.18710/TKS7SI
R. Kaufmann, V. Aune. Experimental data for Reconstruction of Surface Pressures on Flat Plates Impacted by Blast Waves Using the Virtual Fields Method, DataverseNO (2022) http://dx.doi.org/10.18710/GXKVUR

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F. Casadei, M. Larcher, G. Valsamos, V. Aune. A solution mapping algorithm in EUROPLEXUS. EUR – Scientific and Technical Research Reports, EUR 29259 EN. European Commission, Luxembourg (2018). ISBN: 978-92-79-86762-0.
F. Casadei, G. Valsamos, M. Larcher, V. Aune. Scoping calculations for the simulation of shock-loaded perforated plates with EUROPLEXUS. JRC Scientific and Technical Research Reports, JRC 112046. European Commission, Luxembourg (2018).
F. Casadei, G. Valsamos, M. Larcher, V. Aune. Implementation of friction in the pinball-based contact-impact model of EUROPLEXUS. JRC Scientific and Technical Research Reports, JRC 112047. European Commission, Luxembourg (2018).
F. Casadei, V. Aune, G. Valsamos, M. Larcher. Contact detection by pseudo-nodal pinballs with mesh adaptivity in EUROPLEXUS. JRC Scientific and Technical Research Reports, JRC 112048. European Commission, Luxembourg (2018).
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F. Casadei, G. Valsamos, M. Larcher, P. Galon, A. Beccantini, F. Daude, V. Aune. Recent developments in the couplings between Cell-Centred Finite Volumes in EUROPLEXUS. JRC Scientific and Technical Research Reports, JRC123807. European Commission, Luxembourg (2021).
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F. Casadei, G. Valsamos, M. Larcher, P. Galon, A. Beccantini, F. Daude, V. Aune, N. Lelong. Implementation of a pipeline-based wall friction model in 2D/3D Cell-Centred Finite Volumes in EUROPLEXUS. JRC Scientific and Technical Research Reports, JRC124068. European Commission, Luxembourg (2021).
F. Casadei, G. Valsamos, M. Larcher, V. Aune. A database of EUROPLEXUS numerical models for the simulation of the NTNU shock tube facility and other test facilities. JRC Scientific and Technical Research Reports, JRC124311. European Commission, Luxembourg (2021).
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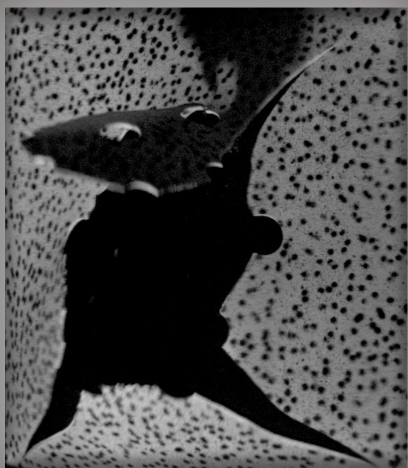

All the experts ...are experts on what was.
There is no expert on what will be.
To become an expert on the future, vision must replace experience.

David Ben-Gurion (1886-1973)