15th International Conference on
Shock & Impact Loads on Structures
12-13th June 2025, Gothenburg

Conference programme

Conference Venue:

Lindholmen Conference Centre

Google maps, link: **Lindhomspiren 5**

Wednesday, June 11th 2025

	Pre-Conference Event – OpenRadioss Users' Day 2025
	• Lindholmen Conference Centre
16:00	**Conference welcome reception and early registration**
	• Lindholmen Conference Centre

Thursday, June 12th 2025

8:30	**Registration**
	• Coffee

9:00	**Opening session**	**Chairman:**
	• Welcome Remarks by Chairman • Conference opening by Guest of Honour, **Prof. Anders Palmqvist**, Vice President, Chalmers University of Technology • Acknowledgements	**Dr. Joosef Leppänen**
~9:40	**Break**	
	• Morning refreshments	

10:00	**Keynote Session 1**	**Chairman:**
10:00	**Prof. Morteza Haghir Chehreghani,** Chalmers University of Technology *From Data to Predictions and Decisions: An Overview of Machine Learning Models*	**Prof. Anders Ansell**
10:30	**Prof. Sam Rigby,** University of Sheffield *Blast from the past: The importance of prior knowledge in machine learning for blast protection*	
11:00	**Technical Session 1 - Numerical Simulation and Modelling of Impact, Shock and Blast**	**Chairman:**
11:00	**1. Dr. James Wurster,** Viper Applied Science *Fast & Accurate: An accelerated fluid-structure interaction method using Viper::Blast and OpenRadioss* Authors: James Wurster**,** Christopher Stirling, Andrew Nicholson and Peter McDonald	**Prof. Sam Rigby**
11:20	**2. Dr. Leo Laine,** LL Engineering AB *Re-implementation and Characterization of Sjöbo Dry Sand in OpenRadioss: Improving Ground Shock Predictions through Tri-axial and Wave Velocity Testing* Authors: Leo Laine and Ola Pramm Larsen.	
11:40	**3. Andrew Nicholson,** Viper Applied Science, United Kingdom *Blast wave injury risk assessment in complex scenarios using numerical simulation* Authors: María Chiquito, Andrew Nicholson, Lina M. López, Ricardo Castedo, Anastasio P. Santos, Peter McDonald, Chris Stirling, Claudia Rastrojo and Jose I. Yenes.	
12.00	**Lunch**	
	• Restaurant - Lindholmen Conference Centre	

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Afternoon (parallel sessions)

	Lecture hall - Pascal		Lecture hall - Tesla	
13:00	**Technical Session 2 - Dynamic Response of Structural Elements & Design**	**Chairman:**	**Technical Session 3 - Blast or Impact Loading on Structures & Protective Technology**	**Chairman:**
13:00	**1. Prof. Petr Hala,** Fakulta stavebni CVUT v Praze *Response of simply supported laminated glass panels to SEMITEX 1A explosions* Authors: Petr Hála, Paolo Del Linz, Petr Konrád, Přemysl Kheml, Alžběta Měrková	**Dr. Joosef Leppänen**	**1. Yuta Miyahara,** National Defense Academy *Study on Flow Velocity of Boulderly Debris Flow on Impact Load on Flexible Barriers* Authors: Yuta Miyahara, Toshiyuki Horiguchi	**Dr. Michele Godio**
13:20	**2. Dr. Sebastiano Di Mauro,** Politecnico di Milano *Engineering of a foam-filled auxetic absorber for localized impact* Authors: Sebastiano Di Mauro, Alessandro Airoldi, Paolo Astori, Nejc Novak, Serena Graziosi, Raffaele Pugliese and Alessandro Gadola		**2. Thomas, Schubert,** Technische Universität Dresden *Impact experiments on reinforced concrete specimens – investigation of repeatability and scaling* Authors: Thomas Schubert, Petr Máca, Marcus Hering, Georg Fiedler and Birgit Beckmann	
13:40	**3. Viktor Peterson,** KTH Royal Institute of Technology *Strut and tie models for impulse-loaded reinforced concrete beams* Authors: Viktor Peterson, Mikael Hallgren, Anders Ansell		**3. John Abdalnour,** Fortifikationsverket *Drop-weight Impact Test on Reinforced Concrete Beams* Authors: John Abdalnour, Johan Magnusson, and Viktor Peterson	

	Lecture hall - Pascal		Lecture hall - Tesla	
14:00	**Technical Session 4 - Numerical Simulation and Modelling of Impact, Shock and Blast**	**Chairman:**	**Technical Session 5 - Dynamic Soil-Structure Interaction and Ground Shock**	**Chairman:**
14:00	**1. Prof. Toshiyuki Horiguchi,** National Defense Academy *Estimation method of debris flow load using channel flume with movable bed in dam* Authors: Toshiyuki Horiguchi and Kazuki Saito	**Dr. Johan Magnusson**	**1. Dr. Norimitsu Kishi,** School of Engineering *Dynamic response behavior of subway station structure inputting forced displacement at bedrock varying number of CFT central columns* Authors: Norimitsu Kishi, Masato Komuro and Tomoki Kawarai	**Dr. Leo Laine**
14:20	**2. Prof. Tomoki Kawarai,** Muroran Institute of Technology *Elasto-Plastic Impact Response Analysis of Cushion Rubber set RC Beams* Authors: Tomoki Kawarai, Masato Komuro, Norimitsu Kishi and Yasuyoshi Nagai		**2. Dr. Rui Zhao,** Central South University *Stress Wave scattering and Cumulative Damage of Underground Opening Subjected to Dynamic Loading* Authors: Rui Zhao, Ming Tao, Linqi Huang, Tubing Yin, Jiangzhan Chen, Zilong Zhou, and Xibing Lia	
13:40	**3. Prof. Anders Ansell,** KTH Royal Institute of Technology *Modelling of bond-slip for impact-loaded reinforced concrete beams* Authors: Anders Ansell, Marek Pixa, Viktor Peterson, Mikael Hallgren		**3. Arunkumar G,** Larsen & Toubro Construction *Impact of soil-structures interaction on underground shelters with pile foundations and periphery walls under blast loading* Authors: Arunkumar G, Arumugam D, and Dhanasekaran B	
15:00	**Break**		**Break**	
	• Afternoon refreshments			

15:30	**Technical Session 6 - Blast on Civil Structures in Urban Environment**	**Chairman:**
15:30	**1. Prof. Paolo Del Linz,** Singapore Institute of Technology *Optimization of Blast Door Structures* Authors: Sherlene Ng, Paolo Del Linz, Le Shen and Yiaw Heong Ng	**Prof. Mikael Hallgren**
15:50	**2. Prof. Masuhiro Beppu,** National Defense Academy *Numerical simulation on the characteristics of blast pressure acting on a structure* Authors: Masuhiro Beppu, Chien Trinh Minh, Ryo Matsuzawa and Hiroyoshi Ichino	
16:10	**Technical Session 7 - Dynamic Response of Structural Elements & Design**	
16:10	**1. Dr. Gonzalo, S.d. Ulzurrun,** Universidad Politécnica de Madrid *Evaluation of internal forces distribution in RC beams subjected to impact loads* Authors: Gonzalo S.D. de Ulzurrun and Carlos Zanuy	
16:30	**2. Dr. Joosef Leppänen**, Chalmers University of Technology *Response of RC Beams Subjected to Repeated Drop Weight Impact and Static Loading* Authors: Morgan Johansson, Joosef Leppänen, Sebastian Syversen and Christer Trinh	
~16:50	**Adjournment for the day**	
18:10	**Bus leaves to Conference Dinner**	
	• from hotels (tbd)	
18:30	**Conference Dinner - Universium**	
	• Sparkling wine and snacks at “Bridge” • Tour at Universium • Three-course dinner	

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Friday, June 13th 2025

9:00	**Keynote Session 2**	**Chairman:**
9:00 9:30	**Prof. Marek Foglar,** Czech Technical University *Improving blast resistance on concrete structures - an experimental journey* **Prof. Tore Børvik,** Norwegian University of Science and Technology *Ballistic impact on steel plates – revisited*	**Dr. LOK Tat Seng**
10:00	**Break**	
	• Morning refreshments	
10:30	**Technical Session 8 - Numerical Simulation and Modelling of Impact, Shock and Blast**	**Chairman:**
10:30 10:50 11:10 11:30	**1. Prof. Masato Komuro,** Muroran Institute of Technology *Impact response analysis of rockfall protection fence installed on concrete foundation* Authors: Masato Komuro, Tomoki Kawarai, Fumio Yamasawa and Norimitsu Kishi **2. Prof. Niclas Strömberg,** Karlstad University *Development of a Design Optimization Framework for TPMS-based Sandwich Structures under Blast Loading* Authors: Niclas Strömberg **3. Dr. Jonas Rudshaug,** Norwegian Defense Estates Agency *Preliminary study of granite slabs exposed to contact charge* Authors: Jonas Rudshaug, Tormod Grue and Benjamin Stavnar Elveli **4. Viktor Peterson,** KTH Royal Institute of Technology *Effect of intense dynamic loads for reinforced concrete elements* Authors: Viktor Peterson, Mikael Hallgrena, Anders Ansell, Emma Ceberg, Elin Holm, Ellen Kolmodin, Klaudia Kubiak	**Dr. Gonzalo S.D. de Ulzurrun**

12:00	**Lunch**	
	• Restaurant - Lindholmen Conference Centre	
13:00	**Technical Session 9 - Blast or Impact Loading on Structures & Protective Technology**	**Chairman:**
13:00	**1. Prof. Nejc Novak,** University of Maribor *Development, testing and computational simulations of auxetic crash panel* Authors: Nejc Novak, Hasan Al-Rifaie, Alessandro Airoldi, Matej Vesenjak, Zoran Ren	**Prof. Marek Foglar**
13:20	**2. Dr. Johan Magnusson,** Fortifikationsverket *Shear in concrete elements subjected to blast loads* Authors: Johan Magnusson, Mikael Hallgren, Richard Malm and Anders Ansell	
13:40	**3. Dr. Michele Godio,** RISE Research Institutes of Sweden *FEM Meso-scale Modelling of Brick Walls Subjected to Impacts and Blasts: Formulation and Laboratory Test Validation* Authors: Michele Godio, Mathias Flansbjer	
14:00	**4. Taishi Tatsukawa,** National Defense Academy *A study on the classification and evaluation of loads acting on driftwood catchment based on the flow process of driftwood groups* Authors: Taishi Tatsukawa, Toshiyuki Horiguchi, Taro Uchida, Masuhiro Beppu	
14:20	**5. Sherlene Ng,** Singapore Institute of Technology *Investigating Key Parameters for Optimizing Blast Door Performance* Authors: Sherlene Ng, Paolo Del Linz and Le Shen	
14:50	**Break**	
	• Afternoon refreshments	

15:20	**Technical Session 10 - Explosion caused by High Explosives, Gas, BLEVE, Dust and Fertilizers**	**Chairman:**
	1. Fabio Lozano, Chalmers University of Technology *Effect of Partial Confinement on Vapour Cloud Explosions on a Road: A Numerical Study* Authors: Fabio Lozano, Morgan Johansson, Joosef Leppänen, Mario Plos	**Prof. Robert Thomson**
15:40	**Technical Session 11 - Road Vehicle Impacts (Hostile Vehicle Mitigation, Crashworthiness of Road Infrastructure)**	
15:40 16:00	**1. Dr. Damijan Markovic,** European Commission, Joint Research Centre at Ispra *Security Barrier Performance Assessment with Numerical Simulations using Generic Vehicle Models* Authors: Damijan Markovic, Alessandro Scattina and Martin Larcher **2. Er. Dr. LOK Tat Seng,** PHM Technologies Pte Ltd *Cable Fence as an Effective Vehicle Security Barrier* Authors: Tat-Seng LOK, Danny Chin-Teck ONG and Robert STEPHENS	
16:20	**Closing Session**	**Chairman:**
	• The Fortifikationskårens forskningsfond (Fortification corps' research fund) paper Award • The Viper Applied Science paper Award • Open discussion • Closing remarks	**Dr. Joosef Leppänen** **Dr. Leo Laine** **Dr. LOK Tat Seng**
~16:50	Adjourment of Conference	

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FAST & ACCURATE: AN ACCELERATED FLUID-STRUCTURE INTERACTION METHOD USING VIPER::BLAST AND OPENRADIOSS

James Wurster[a], Christopher Stirling[a], Andrew Nicholson[a] and Peter McDonald[a]

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Keywords: Blast, CFD, FEA, FSI, Simulation, Modelling

Abstract

When a blast strikes a structure, how fast does the structure react? Often, the structure's response lags behind the rapid blast, allowing for a simplified, uncoupled simulation. But in scenarios where the structure's reaction is nearly as quick as the blast, such as in large-scale or close-proximity explosions, uncoupled models fall short. Here, a fully coupled fluid-structure interaction (FSI) simulation becomes essential.

FSI simulations are notoriously complex, demanding intensive computational resources for both the fluid and structural domains, especially when these systems interact dynamically. However, the need for fully coupled simulations shouldn't mean sacrificing efficiency or ease of use or accuracy.

In this paper, we introduce VIPER::DEFENCE, a powerful yet user-friendly solution for fast and accurate FSI simulations. By leveraging VIPER::BLAST for fluid dynamics on the GPU and OPENRADIOSS for structural analysis on the CPU, VIPER::DEFENCE optimizes the strengths of each platform to utilise the entire computer. This dual approach enables large, fully coupled simulations to run efficiently (even on a personal laptop!) without compromising accuracy or user experience. Here, we'll specifically discuss the workflow of VIPER::DEFENCE and how it has been optimised for accessibility to the end user. We'll briefly discuss our methodology and provide an overview of our interaction algorithms. Finally, we'll present validation and demonstration cases, illustrating the power of our fast and accurate method that will ultimately democratise FSI modelling!

15th International Conference on
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RE-IMPLEMENTATION AND CHARACTERIZATION OF SJÖBO DRY SAND IN OPENRADIOSS: IMPROVING GROUND SHOCK PREDICTIONS THROUGH TRI-AXIAL AND WAVE VELOCITY TESTING

Leo Laine[a] and Ola Pramm Larsen[b]

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Keywords: Ground shock, Dry Sand, Mechanical Properties of Dry Sand, Compaction Equation of State, Shear Strength Model, Shock Waves in Sand, OpenRadioss

Abstract

This paper presents the re-implementation of a well-established compaction and shear strength model, originally available in AUTODYN and widely cited in the literature, into OpenRadioss, an open-source explicit solver for broad range of applications, including shock and impact simulations. The objective is to enhance ground shock predictions by accurately capturing the compaction behavior and shear strength of dry sand. The study focuses on Sjöbo sand, a well-characterized quartz sand, with mechanical properties determined through triaxial compression tests under isotropic consolidation. A porous equation of state (EOS) was developed based on volumetric compression data, while shear wave and longitudinal wave velocity measurements provided estimates of bulk sound speed and shear modulus over a range of pressures. The in situ dry density of the sand was approximately 1574 kg/m³, with an average water content of 6.57%. The re-implementation ensures consistency with previous AUTODYN models while leveraging OpenRadioss' open-source capabilities for broader accessibility and further development. An improved approach for interpolating the unloading behavior from compaction curves was incorporated, ensuring accurate energy dissipation in high-pressure release scenarios. The implementation is validated through single-element tests and particle velocity impact simulations, providing a benchmark for further studies on granular materials under dynamic loading. As a successor to previous research efforts, this work aims to support the OpenRadioss community by providing a validated dry sand material model, enhancing the simulation of granular materials and facilitating further development in open-source computational mechanics.

BLAST WAVE INJURY RISK ASSESSMENT IN COMPLEX SCENARIOS USING NUMERICAL SIMULATION

María Chiquito[a], **Andrew Nicholson**[b], Lina M. López[a], Ricardo Castedo[a], Anastasio P. Santos[a], Peter McDonald[b], Chris Stirling[b], Claudia Rastrojo[a] and Jose I. Yenes[c]

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Keywords: explosive, numerical modelling, primary injuries, adjusted severity injury index

Abstract

In recent decades, the rise of terrorist actions as a new threat has led to the need to increase safety levels in urban environments. These environments represent a complex scenario for the expansion of the blast wave, which entails an added difficulty when carrying out survivability analyses. Therefore, further research is necessary to better understand the risks of casualties from blast overpressure, particularly from improvised explosive devices (IEDs) and person-borne explosive devices (PBIEDs) detonated inside buildings. To develop a quick blast wave injury risk assessment, numerical simulation appears as a common tool. However, the complexity of the problem means that the level of uncertainty is usually quite high. For this reason, validation of the numerical results by means of experimental tests is of vital importance, but the number of full-scale experiments is very limited. In this research, three tests have been carried out with different IED configurations simulating a PBIED inside a building using vest bombs. The building consisted of a small concrete structure of 6.80 x 5.80 m with a corridor and an inner room. This work focuses on the injury risk assessment inside the building. For this purpose, the Viper Blast CFD solver is employed to accurately model the blast wave propagation and its interaction with the building's facade and structural elements. The assessment is made using Axelsson SP model by means of ASII (Adjusted Severity of Injury Index) together with tertiary blast injury due to whole body translation and impact. The combination of primary and tertiary blast injury results in an overall risk of fatality. The results are validated by comparing the pressure-time histories recorded during the testing with those obtained from numerical simulations at the same locations, demonstrating that such numerical tools can be used with some degree of confidence to perform predictive injury modelling.

15th International Conference on
Shock & Impact Loads on Structures
12-13 June 2025, Gothenburg, Sweden

RESPONSE OF SIMPLY SUPPORTED LAMINATED GLASS PANELS TO SEMTEX 1A EXPLOSIONS

DYNAMIC PERFORMANCE AND RESIDUAL STRENGTH ASSESSMENT

Petr Hála[a], Paolo Del Linz[b], Petr Konrád[a], Přemysl Kheml[a], Alžběta Měrková[a]

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Keywords: multi-layer panels, sacrificial ply design, laminated glass, bending strength, blast

Abstract

Laminated glass is commonly used in structures requiring blast resistance due to its ability to dissipate energy and limit fragmentation. This study examines the performance of two configurations of multi-layer laminated glass panels subjected to Semtex 1A explosions. The panels were designed with a sacrificial ply concept, where one glass layer absorbs energy through fracture, while the remaining layers sustain residual loads. Simply supported panels were tested to simplify boundary conditions and enable numerical and analytical reproduction. The explosive tests measured mid-span deflections, with Semtex 1A chosen for its low soot generation and mass adaptability. Quasi-static three-point bending tests assessed the residual bending strength of blast-damaged panels and compared the bending strength under quasi-static and dynamic conditions for undamaged panels. The findings enhance understanding of the dynamic response and residual strength of laminated glass, contributing to improved designs for blast-resistant structures.

15th International Conference on
Shock & Impact Loads on Structures
12-13 June 2025, Gothenburg, Sweden

ENGINEERING OF A FOAM-FILLED AUXETIC ABSORBER FOR LOCALIZED IMPACT

Sebastiano Di Mauro[a], Alessandro Airoldi[a], Paolo Astori[a], Nejc Novak[b], Serena Graziosi[c], Raffaele Pugliese[d] and Alessandro Gadola[c]

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Keywords: Cellular materials, hexachiral structure, localized impact, drop-weight impact, 3D-printing, thermoplastic polyurethane, numerical modelling, experimental testing, metamodel, optimisation technique

Abstract

In this work the design of an impact energy absorber, based on an auxetic hexachiral frame filled with foam, was developed and was focused on the identification of the geometrical parameters for the fulfilment of the requirements in a pre-defined application scenario. Some of the outcomes of two research in the literature were the starting point of the present work: specifically, the importance of the combination of materials used to build the auxetic structure and the beneficial effects of the interaction between an auxetic frame and foam, which leads to substantial increments of absorbed energy per unit volume and mass. Using materials with high elongation at break, such as an elastomeric material, deserved investigation since it could guarantee the preservation of the auxetic property for the whole duration of the localized impact, as the early breakage of chiral ligaments or chiral nodes, which induce the loss of the auxetic property, could be avoided. All these aspects were considered in the engineering of an absorber concept in a specific crash scenario, represented by the impact between a Vulnerable Road User and the bumper of a vehicle. The regulation EEVC/WG17 EURO Phase2 was taken as a reference in order to perform a realistic study of the energy absorber. Moreover, among different polymeric materials, a thermoplastic polyurethane with micronized waste-tire-rubber was used to build the auxetic frame. It exhibits a large strain at failure and can be 3D-printed to obtain auxetic topologies, and involves the use of recycled material. Dynamic drop-weight impacts were conducted on sample structures and compared with the numerical model. Initial numerical-experimental correlation showed that the FE model had some differences with the experimental results, and this was probably due to the preliminary numerical material model developed and used for the hexachiral frame, but the use of elastomeric material was promising. Despite the differences in its calibration, the FE model was used to build a database and to train two metamodels. Finally, an optimization procedure based on a genetic algorithm was presented. Two optimal solutions of foam-filled hexachiral structure were found, considering the penetration and level of force as targets, and using the geometrical parameters of the auxetic frame as design variables. Results indicated that the optimized auxetic structures were able to absorb the impact energy by mitigating the force on the simplified VRU below the desired level, with a limited penetration.

15th International Conference on
Shock & Impact Loads on Structures
12-13 June 2025, Gothenburg, Sweden

STRUT AND TIE MODELS FOR IMPULSE-LOADED REINFORCED CONCRETE BEAMS

Viktor Peterson[a], Mikael Hallgren[a,b], Anders Ansell[a],

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[b]Tyréns AB, Sweden

Keywords: Strut and tie model, impact-loaded, blast-loaded, reinforced concrete, shear failure

Abstract

Impact loads may arise due to collisions, falling masses, ballistics, or fragments. Such scenarios result in concentrated dynamic forces with durations generally much shorter than the structure's natural period. Explosions may be accidental or antagonistic and result from, e.g. ignition of combustible clouds or explosive charges. The resulting dynamic load is distributed over the structure and is generally relatively short in duration. Both load types fall under the category of impulse-loads. Flexural failure modes are generally desirable for impulse-loaded reinforced concrete elements to safely absorb the work done by the external force. Flexural failures are characterized by wide cracks with significant plastic strain in the reinforcement, resulting in large energy absorption capacities. Shear-type failures are avoided, as these generally are characterized by one significant crack with minor plastic strain in the reinforcement, showing decreased energy absorption capabilities. Thus, models that can predict shear-type failures are needed, such that the beam can be reinforced against them. An agreed-on rational model for shear-type failures for beams without stirrups has yet to be found for static loading cases. Impulse loads add to the complexity of shear-type failures, as inertia- and strain rate effects should also be considered. A simple strut and tie model (STM) was used to predict the dynamic capacity of impulse-loaded beams simulated in the general-purpose finite element package Abaqus FEA. The study utilized material properties validated against previous drop-weight testing in the lab. Concentrated dynamic forces were first applied at an increasing rate on beams with varying shear span-to-depth ratios (moment-to-shear ratios) and compared against the results from the STM. The calculation model and simulation agreed well for the load rates and shear span-to-depth ratios larger than one. Distributed forces were then translated to equivalent concentrated forces using the expression found in the literature for static loads. This expression overestimated the length of the shear span, and a modification for the translation of distributed loads to equivalent concentrated loads based on the load rate is presented.

STUDY ON FLOW VELOCITY OF BOULDERLY DEBRIS FLOW ON IMPACT LOAD ON FLEXIBLE BARRIERS

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Keywords: debris flow, flow velocity, impact load, flexible barrier, buffering effect

Abstract

Debris flow disasters cause severe damage and pose a significant threat to human life in Japan. In particular, the frequency of such disasters caused in small-scale streams has been increasing. Consequently, the need for effective mitigation measures in these environments has become urgent. However, implementing such measures is challenging because small-scale streams are often located near residential areas, leaving limited space for construction. Flexible barriers have been widely adopted as protective structures due to their relatively light weight, ease of installation, and suitability for narrow construction sites. Despite their widespread use, their structural performance under debris flow impact remains unclear. Therefore, this study focuses on debris flow patterns and examines how these patterns influence the impact on flexible barriers. A series of flume experiments was conducted to investigate different debris flow patterns impacting a flexible barrier model. The debris flow models have different debris flow in velocities and depths. Two types of flexible barrier models were tested -one made of steel wires and the other of nylon nets- to evaluate the effect of barrier material stiffness. Additionally, a rigid barrier model was inclined as a reference to quantify the relative buffering capacity of flexible systems. The experimental results indicate that the maximum tensile force in the lower rope of a flexible barrier occurs when the debris flow pressure reaches the middle height of the barrier, while the maximum tensile force in the upper rope occurs when the debris flow reaches the top of the barrier. The tensile force in the rope of steel wire model was larger than that of the nylon net model. In contrast, the impact load acting on both types of flexible barriers showed little difference. Furthermore, the tests demonstrate that flexible barriers can reduce peak impact loads by up to approximately 50% compared to rigid barriers, thereby enhancing energy dissipation under debris flow events. Nonetheless, in some scenarios, the peak impact loads on flexible and rigid barriers were nearly identical. These findings reveal that debris flow velocity significantly affects the impact buffering capability of flexible barriers. As debris flow velocity increases, the effectiveness of flexible barriers to reduce impact loads diminishes, making their performance converge with that of rigid barriers. These insights contribute to a more comprehensive understanding of debris flow protective structure and provide guidance for the design, placement, and implementation of flexible barriers in small-scale streams.

15th International Conference on
Shock & Impact Loads on Structures
12-13 June 2025, Gothenburg, Sweden

IMPACT EXPERIMENTS ON REINFORCED CONCRETE SPECIMENS

INVESTIGATION OF REPEATABILITY AND SCALING

Thomas Schubert[a], Petr Máca[b], Marcus Hering[c], Georg Fiedler[c] and Birgit Beckmann[d]

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Keywords: reinforced concrete, drop-weight impact, scaling, repeatability, digital image correlation

Abstract

Nowadays, the impact resistance of concrete structures has become a prominent concern for critical infrastructure operators, particularly amidst escalating geopolitical tensions. Regulators and design engineers know that reinforced concrete structures can only be developed with high efficiency by considering nonlinear structural and highly nonlinear material behavior. Therefore, specific guidelines on impact design provide instructions for design and analysis of structures required to resist impact loading. These instructions are usually based on published results and evaluated data of impact experiments carried out in laboratories. To widen the knowledge and increase the scientific data the Institute of Concrete Structures (IMB) at TUD Dresden University of Technology (TUD) has carried out many impact experiments on reinforced concrete specimens in recent years. A specially designed drop tower is available for this purpose on the premises of the Otto Mohr Laboratory, TUD.

In the framework of the past research at TUD some important issues, such as influence of rebar arrangement, structural thickness, scalability of specimen and repeatability, with regard to experimental impact testing were investigated. This article presents the drop tower facility and research results of impact experiments on reinforced concrete slabs. First, the scalability of impact experiments will be discussed in conjunction with already known theoretical scaling parameters provided by researchers in the past, e.g. Rüdiger et al. [1]. Scalability of experimental data is of huge importance since protective structures made of reinforced concrete differ usually in size in comparison to experimental specimens. The second important research focus is on repeatably of impact experiments. Since impact experiments are usually time consuming and expensive, a certain impact scenario is mostly carried out only once. It is intended to show the range of deviation of impact tests on some already carried out experiments on reinforced concrete slabs. A possible standard deviation is estimated for the applied test setup.

15th International Conference on
Shock & Impact Loads on Structures
12-13 June 2025, Gothenburg, Sweden

DROP-WEIGHT IMPACT TEST ON REINFORCED CONCRETE BEAMS

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Keywords: Reinforced concrete beams, dynamic loading, shear failure, shear reinforcement configuration, load position, strain rate effect, impact.

Abstract

Reinforced concrete (RC) is commonly used in defence and protective structures such as shelters and barriers. Such protective structures may be subjected to dynamic loads from explosions from conventional weapons. Protective structures are designed for a ductile response, thereby preventing shear-type failures. The results of this paper are based on experiments conducted on 27 reinforced concrete beams, where 18 were tested dynamically and 9 were tested statically at KTH Royal Institute of Technology. A mass was dropped onto the beams in the dynamic tests, while an MTS machine was used to perform the static tests. The load position was varied at different distances from one of the supports. The beams were designed with both compression and tensile reinforcement and three different configurations of shear reinforcement: no stirrups and stirrups with 90 mm and 45 mm spacing, respectively. The tests were instrumented with load cells and accelerometers. The recorded data were analyzed, focusing on three main factors: the effect of load position, shear reinforcement configuration, and dynamic versus static loading effects. The results indicated that compression strut failures occurred when the load was positioned closest to the support, while the failure mode transitioned to flexural shear with the load further from the support. Beams without shear reinforcement exhibited inclined cracks, with a significant shear influence and less contribution from bending. In contrast, beams with higher shear reinforcement content predominantly developed bending cracks with a diminished influence from shear.

15th International Conference on
Shock & Impact Loads on Structures
12-13 June 2025, Gothenburg, Sweden

ESTIMATION METHOD OF DEBRIS FLOW LOAD USING CHANNEL FLUME WITH MOVABLE BED IN DEM

Toshiyuki Horiguchi[a] and Kazuki Saito[b]

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Keywords: *Bouldery debris flow*, impact load, distinct element method, channel flume, movable bed

Abstract

In Japan, the frequency of debris flow disasters has been increasing each year, with large-scale events often triggered by localized torrential rainfall and typhoons. Generally, debris flows can be classified into two categories: bouldery debris flow and mudflow. Bouldery debris flow that is characterized by the concentration of boulders at the front part imparts extremely high impact forces and can cause severe damage to residential areas and other communities. Consequently, the development and implementation of effective measures against these hazards has become an urgent priority. Among the various mitigation measures, steel pipe open Sabo dams that are protective structure for controlling sediment have been constructed. In current design practice, the fluid forces of debris flows acting on the upstream side of the dam are combined with sediment pressure loads extending from the downstream side toward the upstream one. However, recent cases of damage to members and failures at joint sections of steel pipe open Sabo dam have been reported. An analysis of these damaged Sabo dams revealed that the loads acting on the dams can vary locally, influenced by the riverbed morphology and the sediment already trapped. These findings emphasize the need for a more detailed analysis of debris flow loads. Consequently, it is necessary to investigate and clarify the mechanisms underlying load evaluations under conditions resembling a movable bed, where gravel is present from the outset. The study conducted load experiments under a movable bed condition, focusing on the temporal evolution of the load to clarify its characteristics. Furthermore, it performed the distinct element method to reproduce debris flow loads under a condition where a movable bed and pre-deposited gravel were present. The results revealed that pre-deposited gravel significantly influences the maximum load acting on the dam. Large loads occur where the debris flow front collides with each step height of the dam. In addition, the results investigated the underlying mechanisms of impact forces in debris flow loading under detailed experimental data.

ELASTO-PLASTIC IMPACT RESPONSE ANALYSIS OF CUSHION RUBBER SET RC BEAMS

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Keywords: RC beam, cushion rubber, drop-weight impact, FEM, impact response analysis

Abstract

Recently, a cushion rubber was placed on the girder ends of the bridge to mitigate the impact force excited due to the girder colliding with the abutment at earthquake shaking. Even though the intensity of the impact force can be effectively decreased by placing the rubber, the dynamic response characteristics of the rubber placed structures might not have clearly been understood. In addition, since the experimental studies are very costly, it is essential to promote the numerical studies. In this paper, to establish an numerical analysis method to acurately predict the dynamic response characteristics of the rubber placed RC beams under impact loading, 3D elasto-plastic impact response analysis of the RC beams was conducted and the applicability of the method was investigated comparing with the drop-weight impact loading test results. In this study, the time histories of the impact force, the reaction force, and the midspan deflection and also the crack patterns of the side-surface of the beam after the experiment were compared. The results obtained from this study are as follows; 1) dynamic response behavior of the cushion rubber placed RC beams can be appropriately evaluated by using the proposed analysis model and 2) maximum reaction force, maximum and residual deflections may not be significantly decreased by placing the rubber on the impacted area.

15th International Conference on
Shock & Impact Loads on Structures
12-13 June 2025, Gothenburg, Sweden

MODELLING OF BOND-SLIP FOR IMPACT-LOADED REINFORCED CONCRETE BEAMS

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Keywords: Reinforced concrete, Drop-weight impact, Numerical modelling.

Abstract

Reinforced concrete is well-suited for resisting compressive stresses but relies on steel reinforcement to withstand tensile stresses, such as those caused by flexural deformations in beams or slabs. The interaction between concrete and steel, known as bond, facilitates stress transfer and relative displacement, known as bond slip. Concrete structural elements, including beams and slabs, may be subjected to static and dynamic loads. Static loads remain constant over the structure's lifespan, while dynamic loads, such as impacts or collisions, act briefly and intensively. This study investigates the bond-slip behaviour of reinforced concrete under static and dynamic loading through numerical simulations. A calibrated model for static pull-out tests of reinforcing bars was developed, incorporating two simulation approaches: the Cohesive and Connector methods. Both methods were assessed for accuracy, computational efficiency, and ability to capture important results, including deflection and plastic strain over time. Results indicate that both methods yield comparable outcomes but exhibit distinct differences. Compared to previous experimental data, the Cohesive method effectively captures reduced stiffness under static pull-out conditions. However, it underestimates the response once the nonlinear behaviour begins, where the Connector method provides a better match. The Connector method more accurately replicates experimentally observed failure modes for impact loading scenarios and is computationally more efficient. Meanwhile, the Cohesive method better represents deflection trends over time. Notably, lower bond strengths tend to result in bending failures, which are less brittle and offer greater energy absorption than shear failures. The results indicate important modelling considerations and the effect of the bond quality on the resulting failure mode.

15th International Conference on
Shock & Impact Loads on Structures
12-13 June 2025, Gothenburg, Sweden

DYNAMIC RESPONSE BEHAVIOR OF SUBWAY STATION STRUCTURE INPUTTING FORCED DISPLACEMENT AT BEDROCK VARYING NUMBER OF CFT CENTRAL COLUMNS

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Keywords: Hanshin-Awaji earthquake, inland earthquake, subway station, impulse uplift, elasto-plastic response analysis

Abstract

The Daikai Station subway structure in Japan completely collapsed in the great Hanshin-Awaji earthquake that occurred 30 years ago, on January 17, 1995. Since it deformed in an approximately symmetrical manner with respect to the shortened central columns, it might have experienced its catastrophic collapse due to a vertical impulse motion. To investigate the dynamic response behaviour of the structure with the central columns composed of concrete-filled steel tubes (CFTs) that were used to increase the strength of the existing RC columns when the station was reconstructed, a 3D elastoplastic transient response analysis of the station structure was conducted by surcharging an isolated upward pulse-like displacement wave from the bedrock and varying the number of the CFTs for each central column. The results obtained from this study are as follows: on inputting a displacement wave of 5 ms duration and 4 m/s velocity, crushing of the central columns may be effectively prevented by replacing the RC structure with a CFT structure for the central columns; thus the reconstructed station structure, whose central column was strengthened by using three CFTs, should be in a structurally healthy condition when suffering a severe earthquake such as the Great Hanshin-Awaji earthquake.

15th International Conference on
Shock & Impact Loads on Structures
12-13 June 2025, Gothenburg, Sweden

STRESS WAVE SCATTERING AND CUMULATIVE DAMAGE OF UNDERGROUND OPENING SUBJECTED TO DYNAMIC LOADING

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Abstract

In underground mining and geotechnical construction, Excavation Damage Zone (EDZ) and external dynamic disturbances such as blasting, and fault activity are common and cause damage to rock mass. Therefore, understanding the cumulative damage and failure mechanisms of underground openings containing EDZ under dynamic loading, especially in great depth, is crucial. This study used the Continuous Surface Cap Model (CSCM) to model the damage development and failure of stressed rock masses induced by internal excavation unloading and external dynamic loading. This was implemented by combining the implicit-explicit algorithm and the restart technology in the LS-DYNA to account for cumulative damage. The simulation results indicated that the depth of the EDZ increased proportionally with the initial stress, and under external dynamic disturbances, the process zones around the EDZ would fail and form new process zones at the new stable boundary of the Dynamic Damaged Zone (DDZ), which widen the damage extent of the surrounding rock mass and potentially cause multiple dynamically triggered rockbursts.

15th International Conference on
Shock & Impact Loads on Structures
12-13 June 2025, Gothenburg, Sweden

IMPACT OF SOIL-STRUCTURE INTERACTION ON UNDERGROUND SHELTERS WITH PILE FOUNDATIONS AND PERIPHERY WALLS UNDER BLAST LOADING

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Keywords: Blast Impact, Dynamic Analysis, Nonlinear Springs, Piles, Periphery Walls, Underground Buildings, Shelters

Abstract

The rising global threat of war has emphasized the need for underground shelters as vital protection. These shelters have become essential for safeguarding lives in the face of escalating security risks worldwide. In the event of a blast, underground shelters with piles first experience the load on their peripheral walls, supported by the surrounding soil, which then transfers the load to the piles. The optimized pile design can be done by considering the interaction behaviour between the soil and the periphery wall. Dynamic response of the underground building with pile foundation and periphery wall during blast loading condition using the finite element analysis done in ABAQUS CAE software was investigated. The structure is modelled using shell elements, wherein the effects of soil-structure interaction are incorporated by modelling the soil using frequency independent spring dashpot mass model. This study focusses on the effect of soil structure interaction for the above-mentioned building by giving soil conditions with higher and lower stiffness and with blast load of varying duration. The results indicate that, during static conditions the force transfer to the piles is lesser when soil stiffness condition is higher as the periphery wall attracts more force than piles and vice versa. During dynamic conditions, the same behaviour follows with the increased reaction with lesser blast duration and then arrives the static equivalent reaction as the blast duration increases. The findings of the study can be used to optimize the design of pile foundation system along with periphery wall for underground buildings by taking advantage of the surrounding soil.

15th International Conference on
Shock & Impact Loads on Structures
12-13 June 2025, Gothenburg, Sweden

OPTIMISATION OF BLAST DOOR STRUCTURES

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Keywords: OpenRadioss; blast protection; door optimisation; ironmongery

Abstract

Blast protection of structures is an increasing concern worldwide. This issue is particularly relevant in Singapore, where specific legislation mandates that certain structures incorporate built-in protective measures. Blast doors are often critical components of such security strategies, as they must ensure an adequate level of protection while maintaining accessibility to facilities. The objective of this project is to optimize the performance of blast door systems subjected to blast loads from bare charges. These doors typically consist of two metal plate skins connected by steel spacers, often in the form of C-sections or I-beams. However, this design could be improved by incorporating honeycomb cores, which may be fabricated using conventional methods or, in the future, advanced 3D printing techniques. In this study, a finite element analysis (FEA) model was developed using OpenRadioss and validated to evaluate various core designs. Validation was achieved using data from existing literature tests on panels constructed with traditional I-beam spacers, with the model replicating peak deflections. Subsequently, several innovative core configurations were modelled and compared, including square, hexagonal, and re-entrant honeycomb structures. Parametric studies were conducted to assess the influence of honeycomb cell size and wall thickness, while maintaining a consistent panel mass across all designs. The results demonstrated that honeycomb panels outperformed traditional panels with C-section spacers under blast loading, achieving reduced peak and permanent deflections for equivalent panel weights.

15th International Conference on
Shock & Impact Loads on Structures
12-13 June 2025, Gothenburg, Sweden

NUMERICAL SIMULATION ON THE CHARACTERISTICS OF BLAST PRESSURE ACTING ON A STRUCTURE

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Keywords: blast pressure, numerical simulation, blast resistant design

Abstract

This study investigated the blast pressure characteristics acting on a structure by conducting explosion tests and numerical simulations. Prior to the explosion tests, a method for evaluating the blast pressure characteristics proposed by the Unified Facilities Criteria was described and its unpublished concept was discussed. Then, scaled explosion tests for investigating the blast pressure acting on a box-type structure were conducted by using composition C-4 high explosive. Blast pressure characteristics at a front wall, a top roof, and side and rear walls were discussed comparing those estimated by the facility criteria. Numerical simulation was carried out to further investigate the blast pressure characteristics. Numerical results showed good agreement with the test results.

TODYN User's Manual, 2019.

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Shock & Impact Loads on Structures
12-13 June 2025, Gothenburg, Sweden

EVALUATION OF INTERNAL FORCES DISTRIBUTION IN RC BEAMS SUBJECTED TO IMPACT LOADS

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Keywords: reinforced concrete, drop-weight, digital image correlation, impact, shear-span to depth ratio, numerical model

Abstract
The behavior of civil and buildings structures under accidental impulsive loads (impacts or blast) remains a significant research challenge. Impulsive loading leads to resistance and failure modes that differ substantially from those observed under quasi-static loads. Reinforced concrete (RC) structures are very sensible to develop a brittle failure when subjected to impulsive loads. This might be explained by the particularities of the dynamic behavior of structures. In the dynamic range, effects such as the development of inertia forces or the sensibility of failure mechanisms to the strain rate must be considered. In addition, in highly dynamic events, adiabatic conditions are in general prevalent. In the case of the impacts, the load imparted during the shock depends on various factors, such as the kinetic energy of the collision and the interaction between the impacting bodies. This interaction is determined by their stiffness, mass, materials mechanical properties and the non-linear behavior of the contact.

Therefore, evaluating the failure mode of a RC structure under these dynamic conditions might be challenging. One critical aspect of the structural verification under impulsive loads is that the internal forces distribution (shear and bending) is uncertain. In previous contributions, the authors have employed an experimental methodology to assess the time-varying distribution of these forces. This methodology is based on the combined use of digital image correlation (DIC) and a high-speed (HS) camera.

The present study analyzes the time-varying internal forces distribution of RC beams subjected to low-velocity impact loads. The study has an experimental basis and discusses the results with a numerical elastoplastic model. The experimental campaign consists of 12 RC beams with a longitudinal reinforcement ratio of ρ = 1.0%, different quantities of shear reinforcement (ρ_w = 0 and 0.3%) and three shear span-to-depth ratios (a/d), between 2 and 5.3. The aim of the study is to discuss experimental observations with numerical results, focusing on the failure mode and in the sectional forces distribution during the impact event for the different spans of the beams.

15th International Conference on
Shock & Impact Loads on Structures
12-13 June 2025, Gothenburg, Sweden

RESPONSE OF RC BEAMS SUBJECTED TO REPEATED DROP WEIGHT IMPACT AND STATIC LOADING

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Keywords: reinforced concrete, experiments, energy absorption capacity, drop-weight impact, repeated impacts, digital image correlation

Abstract

Reinforced concrete (RC) protective structures, designed to withstand impulsive loading such as blast and impact, may be subjected to both single and repeated loading. To effectively withstand such loads, the protective structure requires a large energy capacity. This has been the focus in several studies. However, research on repeated impulse loading is scarce, and its effect on the structure's dynamic response and total energy absorption are not yet fully understood. Therefore, the aim of this study was to investigate the effect of repeated impulse loading, applied through impact, on the dynamic response and the total energy absorption capacity of RC beams.

Drop weight impact tests of 12 beams were carried out and the residual capacity were tested statically after impact. In addition, six beams were statically tested as references. The beams (2.8 x 0.1 x 0.2 m) were simply supported with a span length of 2.6 m and provided with 2+2 reinforcement bars with a diameter of 6, 8 or 10 mm (reinforcement ratio 0.31-0.87%). The drop weight had a mass of 10, 20 or 40 kg and was released from a height of 5.0 m. The number of impacts varied with the mass of the drop weight: 10 kg, 4-6 drops; 20 kg, 1-2 drops; 40 kg, 1 drop. A high-speed camera (5 000 fps) filmed the beams during the impact tests and digital image correlation (DIC) technique was used to measure deformations and crack propagation.

For the statically loaded reference beams, only bending cracks occurred. However, for impact loaded beams using 20 or 40 kg drop weight, distinctive diagonal shear cracks also formed below the impact zone. For the drop weight of 10 kg, though, such diagonal cracks did not appear until after 2-4 impacts. For a drop weight of 10 kg, the visible damage and plastic deformation obtained was similar for the first 4 impacts after which sudden local concrete failure was obtained. For a drop weight of 20 kg, the difference between the first and second impact was more distinct, but no sudden local failure occurred. It was found that the same impact energy, when obtained due to smaller drop mass but repeated loading, could result in more severe damage compared to that obtained from a single impact from a larger drop mass. This indicates that the effect of several small impulse loads may be more severe than one large load of the same total magnitude.

15th International Conference on
Shock & Impact Loads on Structures
12-13 June 2025, Gothenburg, Sweden

IMPACT RESPONSE ANALYSIS OF ROCKFALL PROTECTION FENCE INSTALLED ON CONCRETE FOUNDATION

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Keywords: rockfall protection fence, dynamic behavior, impact loading, finite element analysis, concrete foundation.

Abstract

In this paper, a 3D elasto-plastic impact response analysis of the rockfall protection fence placed on the concrete foundation blocks was conducted. The applicability of the proposed FE analysis model was investigated comparing with the proto-type impact loading test results. Here, the steel posts of the fence were anchored to the top surface of the concrete foundation with base plate. Findings from this study are as follows: 1) the time histories of the impact force and the tensile forces acting on the wire ropes can be accurately predicted by using the proposed analysis method; and 2) the axial strain distribution of the intermediate post and the local buckling behavior of the steel post near the base can also be better evaluated.

15th International Conference on
Shock & Impact Loads on Structures
12-13 June 2025, Gothenburg, Sweden

DEVELOPMENT OF A DESIGN OPTIMIZATION FRAMEWORK FOR TPMS-BASED SANDWICH STRUCTURES UNDER BLAST LOADING

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Key words: Blast, Triply periodic minimal surfaces, Sandwich structures, Design optimization

Abstract

The demonstrated potential of energy absorption and impact resistance of triply periodic minimal surface (TPMS)-based lattice structures is the motivation of this project. The goal of the project is to develop an efficient framework for finding optimal designs of TPMS-based sandwich structures for blast protection. Optimal grading of the TPMS-based lattice structures is performed by numerical multi-fidelity experiments using Abaqus/Explicit and machine learning supported surrogate models. First, compactly supported radial basis function networks are trained for the low-fidelity data, and then ensembles of surrogate mod-els are generated by minimizing the cross-validation error of the high-fidelity data obtained from the Abaqus/Explicit simulations. The optimization is then performed using these opti-mal ensembles of surrogate models. The blast pressure on the structure is applied using the empirical ConWep model which is implemented in Abaqus/Explicit. During the development of the framework 316L stainless steel is chosen as material for the sandwich structure, which is modelled using J2-plasticity with isotropic Johnson-Cook hardening. The constitutive Johnson-Cook parameters for the hardening are determined using the method of least squares applied to the Cauchy stress and the logarithmic strain. Additionally, a continuum damage model is activated when the logarithmic failure strain is reached. While strain rate and temperature dependencies will be included in future versions of the framework. Furthermore, the lattice structure is modelled using either shell elements with representative thicknesses, or solid el-ements with representative constitutive properties obtained from numerical homogenization. Finally, the optimal result is mapped back to the implicit surface geometry, which in turn is converted to a printable STL-file. The workflow of the framework and optimal designs will be presented at the conference.

15th International Conference on
Shock & Impact Loads on Structures
12-13 June 2025, Gothenburg, Sweden

PRELIMINARY STUDY OF GRANITE SLABS EXPOSED TO CONTACT CHARGE

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Keywords: granite, concrete, contact charge, numerical simulation

Abstract

Norway's hilly landscape facilitates the extensive use of mountains for establishing shelters and other facilities requiring robust protection against military threats. A crucial aspect of ensuring the adequate design of these facilities is a deeper understanding of the rock's material properties under relevant load scenarios. The mountains in Norway comprise various rock types with differing properties. Typically, rocks exhibit high compressive strength and brittle fracture mechanisms, somewhat akin to the behavior of concrete. To ensure accurate material calibration, a variety of validation cases is needed, covering variations in strain rate, pressure, and more. In this study, we aim to supplement the existing validation cases for granite by designing an experimental setup to test granite slabs exposed to contact charge loading. Here, we focus on the preliminary numerical study of the experimental setup. To model the granite slabs, we use a relatively simple concrete model known as the modified Holmquist-Johnson-Cook model (MHJC).

15th International Conference on
Shock & Impact Loads on Structures
12-13 June 2025, Gothenburg, Sweden

EFFECT OF INTENSE DYNAMIC LOADS FOR REINFORCED CONCRETE ELEMENTS

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Keywords: blast load, impulse intensity, reinforced concrete, drop-weight impact

Abstract

Civilian or protective structures may during their lifetime be subjected to intense dynamic loads from explosions, ballistic impacts, fragment impacts or collisions. Under such extreme conditions, the resulting internal forces may differ substantially from those observed during static loading. In particular, large local shear forces can develop early, possibly leading to shear-type failures that differ from the more familiar failures of the flexural-shear type. These shear-dominated responses have been observed in tests with distributed air-blast loads, with abrupt failure near the supports, and during high-velocity impacts where local shear-plug failure at the impact zone occurred. Numerical simulations were carried out in two projects focusing on concentrated and distributed dynamic loads to investigate these local effects. The simulations with concentrated dynamic loads were modelled from previous drop-weight impact tests at KTH. Previous shock-tube tests were used to validate models subjected to distributed air-blast loads. Calibrated models for both load scenarios were then used to study higher loading intensities. Generally, the rate at which the impulse was applied had a major influence on the ultimate failure mode. The dominating shear-type failure transitioned closer to the load point for impact-loaded beams as the intensity of the load increased, and the shear-type failure moved closer to the support for the distributed air-blast load. The effect of the boundary conditions was also studied. The boundary conditions showed a low influence of the local failure mode for intense impact loads, while the influence was higher for air-blast loads.

15th International Conference on
Shock & Impact Loads on Structures
12-13 June 2025, Gothenburg, Sweden

DEVELOPMENT, TESTING AND COMPUTATIONAL SIMULATIONS OF AUXETIC CRASH PANEL

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Keywords: cellular materials, auxetic panel, foam-filled, polyurethane foam, crash absorber, drop test, experimental testing, computational modelling

Abstract

The macro-scale auxetic crash absorbers with inverted honeycomb structures were fabricated by bending and glueing the aluminium sheets. The auxetic panels were fabricated using the relatively cheap and straightforward fabrication method, which was extended by adding the PU foam to obtain foam-filled samples. The samples were tested under compression loading at two different loading velocities using the universal testing machine (quasi-static) and drop tower (dynamic). Detailed quasi-static and dynamic drop tests were compared with a non-linear computational model. The stress-strain relationships, deformation patterns, specific energy absorption, crash force efficiency and Poisson's ratio were comprehensively evaluated. Foam-filled panels revealed higher specific energy absorption and more stable deformation than non-filled panels. The developed computational models successfully describe mechanical and deformation behaviour and can be used for future virtual testing of other configurations. The DIC and the FE models confirmed that the auxetic panel provides the auxetic response up to very large strains. The validated FE models enable the development of new foam-filled auxetic panels with a tailored response, where different geometries, sheet thicknesses, densities and distributions of the foams can be virtually tested before fabrication. This will hopefully lead to the application of modern crash absorption systems on newly built roads or blast protection elements in buildings.

15th International Conference on
Shock & Impact Loads on Structures
12-13 June 2025, Gothenburg, Sweden

SHEAR IN CONCRETE ELEMENTS SUBJECTED TO BLAST LOADS

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Keywords: blast load, concrete element, initial response, flexural shear, direct shear, shear span, support reactions, numerical simulations.

Abstract

Concrete elements subjected to intense dynamic loads have been reported to fail in shear, even if they are designed to fail in a flexural mode under static loads. A flexural response with yielding of the reinforcement is always preferrable over a shear damage response with a limited deformation capacity. This is the case for conditions with static loading and is certainly also the case under dynamic loads such as blast loads. Previous experiments and analyses have provided a greater insight and understanding of shear failures of concrete elements subjected to blast loads. The purpose of this paper is to present the findings of a few selected experimental campaigns and also to discuss the results from the corresponding analyses. The distribution of the deformations, the bending moments and shear are initially significantly different from those in static events and show large variations both in time and space. Analyses of these initial variations provide a better insight into where cracking and failure due to flexure and due to shear may appear. Such analyses are discussed in the paper along with the evolution of shear failures. For static loads, it is well known that the shear slenderness has an influence on shear in concrete elements. Depending on the shear slenderness, different shear failure modes for sufficiently large loads may occur. The issues of the shear slenderness variations throughout a dynamic response are also discussed in the paper.

15th International Conference on
Shock & Impact Loads on Structures
12-13 June 2025, Gothenburg, Sweden

FEM MESO-SCALE MODELLING OF BRICK WALLS SUBJECTED TO IMPACTS AND BLASTS

FORMULATION AND LABORATORY TEST VALIDATION

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Keywords: FEM, Contact, Brick masonry, Drop-weight impact, Blast, DIC

Abstract

Outer walls are a crucial component of the building envelope, providing insulation and structural support. While they are originally designed to support axial loads, these walls can be subjected to extreme loads, like the ones generated by impacts and blasts. Unreinforced brick masonry walls are particularly vulnerable to these actions and pose significant risks when damaged, including flying debris and progressive collapse. Careful engineering judgment is required to evaluate their resistance and design their strengthening in order to address this problem.

A 3D FEM-based meso-scale modelling strategy is developed to simulate the response of masonry walls to blasts and impacts. The models were created in a general-purpose proprietary FEA software package, by making use of material models available in it. Bricks were modelled as nonlinear solid elements, while mortar joints were modelled by contact interfaces with cohesive-damage frictional behaviour. The models were built and verified upon the findings of impact pendulum and quasi-static four-point bending tests, both conducted at RISE Research Institutes of Sweden under various wall configurations. Once validated, the ability of this modelling strategy to conduct blast simulations was demonstrated for one of the tested wall configurations.

This numerical work complements the experimental work previously conducted at RISE to characterize the response of brick masonry walls under impulsive loads. The modelling strategy presented here can assist the analyst evaluate the resistance of brick facades to these loads, allowing for a more precise assessment of urban areas at risk of damage.

15th International Conference on
Shock & Impact Loads on Structures
12-13 June 2025, Gothenburg, Sweden

A STUDY ON THE CLASSIFICATION AND EVALUATION OF LOADS ACTING ON DRIFTWOOD CATCHMENT BASED ON THE FLOW PROCESS OF DRIFTWOOD GROUPS

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Keywords: driftwood groups, debris flow mixed with driftwood, driftwood catchment, impact load

Abstract

In Japan, driftwood-related disasters are increasing annually, and the amount of driftwood reaching downstream areas is increasing. Due to buoyant effects, driftwood is transported by shallow currents, allowing it to easily travel to downstream regions where residential areas and infrastructure are located, resulting in bridge blockages and loss of life. Furthermore, groups of driftwood collide with driftwood catchments such as steel protective barriers causing damage to their crests and side sections. Currently, driftwood catchment countermeasures are being constructed to prevent driftwood from flowing downstream, and large amounts of driftwood are trapped. However, in current designs of driftwood catchment, only the static water pressure load is considered, and the impact loads produced by driftwood groups have not been considered. This study evaluates the impact loads exerted by driftwood groups on driftwood catchment. First, an evaluation of loads with and without the formation of driftwood groups was conducted, demonstrating that driftwood groups can influence impact loads. Subsequently, the experimental results were organized to clarify how changes in the number and length of driftwood affect the acting loads. The time-dependent characteristics of these loads are examined, and their defining features are clarified. In addition, because driftwood catching countermeasures are installed in the downstream area, experiments were conducted to examine the effects on the acting load by changing the gradient and flow rate, and parameters of the downstream environment, and the results were compiled. The results demonstrated that the loads exerted by driftwood groups on driftwood catchment can be divided into three categories (impact zone, transition zone, and deposition zone) based on their temporal progression. Additionally, the maximum impact load depends strongly on the total mass, flow velocity, and deposition *height of the driftwood group. Furthermore, the maximum impact load clearly exceeds the static water pressure load, suggesting the necessity of accounting for dynamic impact forces in the design of driftwood catchment.*

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INVESTIGATING KEY PARAMETERS FOR OPTIMISING BLAST DOOR PERFORMANCE

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Keywords: OpenRadioss; blast protection; door optimisation; ironmongery

Abstract

Blast protection is critical for the safety and security of critical infrastructures, such as data centres and government facilities. One of the key components in blast-resistant structures is the blast door, which serves as a protective barrier against shock waves and debris. Traditionally, blast doors are typically designed with high safety margins, making them excessively heavy and costly due to increased material usage. To address this challenge, this study aims to optimize blast door designs by examining the effects of three key parameters: the number of stiffeners, panel thickness and the presence of ironmongery, on overall structural behaviour. Typically, blast doors are constructed using two steel plates reinforced with stiffeners, such as C-sections or I-beams, to withstand blast loads. To evaluate the structural behaviour of various design configurations under a bare charge blast, finite element analysis (FEA) simulations were conducted using OpenRadioss. Key performance metrics, including central deflection, deflection angle, and internal energy, were analysed to assess the blast performance. The findings from this study provide significant insights into the structural behaviour of blast doors, allowing us to identify an optimal configuration of stiffener count and panel thickness. This optimised configuration minimises material usage and overall weight while still maintaining structural integrity and compliance with safety standards.

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EFFECT OF PARTIAL CONFINEMENT ON VAPOUR CLOUD EXPLOSIONS ON A ROAD: A NUMERICAL STUDY

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Keywords: vapour cloud explosions, traffic environment, computational fluid dynamics, overpressure

Abstract

An accidental release of flammable gas during transport may enable the formation of a premixed cloud of fuel gas and air on the road. In a confined or obstructed environment, combustion of such a gas cloud may result in a powerful vapour cloud explosion (VCE). On an open road, partial confinement or obstruction may occur due to the presence of vehicles. Indeed, the region between the vehicles and the ground, where the flow is largely two-dimensional, is a likely source of strong blast. Fixtures on the road, such as noise barriers, may also enhance the strength of the resulting explosion. While VCEs in industrial settings have been extensively researched, little research work has been devoted to gas explosions in open traffic environments. Therefore, more research efforts in this type of environment are needed to complement the current knowledge. This article presents a numerical investigation of different geometrical parameters that influence the degree of confinement of gas clouds in a traffic environment. Several scenarios consisting of a stoichiometric mixture of propane and air engulfing a group of vehicles were studied. The parameters of interest were the uncertainty in the location of the vehicles, the influence of noise barriers, and the ground clearance. The investigation was conducted using Computational Fluid Dynamics. A considerable influence on the resulting explosion due to the variation of the three studied parameters was observed. Infinitely rigid noise barriers were shown to enhance the explosion strength by up to 30 %. Even barriers that failed at a low overpressure (5 kPa) enabled up to 20 % increase in overpressure. Likewise, varying the location of the vehicles (with regard to an ideal structured configuration) resulted in increased peak overpressure and impulse by approximately 30 % in the critical regions. Finally, in scenarios with a single vehicle, the maximum overpressure was found to decrease as the ground clearance increased. However, in cases with multiple vehicles, the overpressure increased with increasing ground clearance. Overall, the study highlighted the usefulness of Computational Fluid Dynamics methods for evaluating VCEs in traffic-related settings.

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SECURITY BARRIER PERFORMANCE ASSESSMENT WITH NUMERICAL SIMULATIONS USING GENERIC VEHICLE MODELS

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Keywords: vehicle impacts, hostile vehicle mitigation, security barriers, crashworthiness

Abstract

Vehicle security barriers preventing the entry of vehicles into pedestrian zones can effectively mitigate terrorist attacks by vehicle-ramming. The performance of barriers against vehicle impact can be certified through physical tests using real vehicles of given UNECE categories following ISO 22343 (2023). Due to a high cost, the number of performed crash-tests is very limited and cannot cover all impact scenarios of interest for the assessment of a barrier performance.

The use of numerical simulations seems to be the most appropriate way to enhance the physical testing approach, since they are more accurate than simple analytical methods and more cost efficient than experiments. Over the last decades, the automotive industry and associated research communities have developed efficient numerical simulations tools to analyse the vehicle impact, related to the passenger's and vulnerable road users' safety. With some adjustments, these simulations methods and tools can be directly transposed to the analyses of vehicle impacts on security barriers.

The numerical vehicle models used for passengers' safety are far too detailed and too specific than needed for vehicle ramming applications. Namely, in our domain of interest, the objective of the simulation is to assess the performance of a barrier not a passenger safety. In addition, a barrier's performance needs to be assessed for an entire category of vehicles, not for one specific vehicle.

Therefore, for simulating vehicle impacts on security barriers several generic vehicle models have been developed to represent vehicles of a broad range of categories (from 3.5t to 30t trucks). These models are generic in the sense that they do not represent a specific vehicle brand, but are representative of one specific category among those defined by the standard ISO 22343. In addition, they are adjustable through a set of parameters, so that their properties could fit to various vehicle configurations. In particular, the mass of the vehicle, including its distribution, the main vehicle dimensions (length, width, etc.) and mechanical characteristics related to the crash behaviour can be varied.

In this communication, several numerical simulations using the generic vehicle models are presented. Model validation with experimental results and sensitivity analyses of vehicle characteristics and impact configurations are discussed. It is shown that there are several crucial vehicle properties, which can significantly influence the crash behaviour and therefore the load on a security barrier subjected to an impact.

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CABLE FENCE AS AN EFFECTIVE VEHICLE SECURITY BARRIER

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Keywords: Cable Fence System, Design Construction & Testing, Full-Scale Testing, Vehicle Security Barrier, International Test Standard, Compliance

Abstract

This paper considers the design, construction and testing of a cable fence system as a vehicle security barrier (VSB) to resist the impact of a vehicle to comply with existing international test standards. However, the cable fence barrier is not referenced in current standards even though the principles of vehicle intrusion and vehicle penetration are important parameters in risk assessment methodology. The cable fence system differs in configuration from conventional "hard target" designs outlined in existing test standards. In spite of the system being ignored in current VSB test standards, the use of a cable fence system has gained traction due to increasing demand for alternative VSB systems in different threat scenarios, for sustainable and low carbon footprint construction, construction-maintenance-cost pressures in the built environment, security of industrial facilities and in rejuvenation projects where planners prefer the "green" agenda to improve security protection of public spaces.

The authors outline a cable fence barrier, its design, construction and testing to sustain a vehicle impact in accordance with existing international test standards. The system being tested allows project specifiers to select an appropriate standard in their jurisdictions where the current standard may overlap with the most recent test standard for VSB performance. The preliminary design is based on an idealised energy conservation principle to determine vehicle penetration. Acceleration-time history obtained from past tests conducted by the authors on hard RC targets provided appropriate load duration data of the process. This enables estimation of cable force and subsequent vehicle penetration, albeit conservatively. Compliance with two test standards was made possible by using an appropriate vehicle of a certain age. Details of the design, construction and testing are outlined. Video footage of the vehicle impact test showed the efficiency of the designed system.