Analysis of behaviour of constructions under impact and explosions: approaches for structural analyses, from material modeling to structural response

Gianfranco De Matteis¹, Ezio Cadoni², Domenico Asprone³

¹ University “G. d’Annunzio” of Chieti-Pescara
² University of Applied Sciences of Southern Switzerland
³ University “Federico II” of Naples
CONTENTS

• New design approaches to urban construction considering blast and impact actions
• Buildings of urban habitat vs. Blast and Impact
• Features of blast and impact
• Dynamic behaviour of materials
• Analysis approach
• Robust” design approach
• Conclusions

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NEW DESIGN APPROACHES TO URBAN CONSTRUCTION 
CONSIDERING BLAST AND IMPACT ACTIONS

Behaviour of constructions under impact and explosions represents a very important issue in modern time

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It has been proved that buildings of urban habitat are quite vulnerable for extreme loads conditions. The most critical aspects can be summarized in the following items:

- **Assessment of loading acting on the structure in case of blast and impact events**, with particular regard to uncertainties related to the load magnitude and duration

- **Definition of suitable structural analysis approach**, taking into account that elements under severe dynamic loads can behave very differently than in case of static load application

- **Mechanical behaviour of the base material**, which can be completely different than in quasi-static conditions
An explosion induces mainly a quick and significant increase of pressure in the medium where it occurs, i.e. air or water. Such overpressure propagates as a wave and is characterized by its speed, duration and intensity. Depending on these parameters, it is possible to evaluate the action provoked on structures in the vicinity.

Blast overpressure in air generated by 1kg of TNT at 2m from the charge
Due to the short duration of blast and impact events, for structural design purpose, blast and impact loadings can be characterized in terms of peak pressure $p_{\text{max}}$ and impulse $i$, the first being the maximum pressure in the pressure history, the latter the integration of positive pressure over time.

For each structural element a $p_{\text{max}}$– $i$ domain curve can be evaluated, reporting the values of impulse and peak pressure able to induce on the structural element a certain damage level. A typical $p_{\text{max}}$ – $i$ relationship is reported in Figure.
FEATURES OF BLAST AND IMPACT

- blast and impact loads are intense and of short duration

G. De Matteis, I. Langone, F.M. Mazzolani

Pressure-Impulse diagram for damage evaluation in load bearing precasted r.c. panel

P. Smith and G. De Matteis

Idealisation of the overpressure vs. time diagram

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FEATURES OF BLAST AND IMPACT

- blast and impact loads are intense and of short duration

P. Smith and A Tyas

Determination of Pressure-time history for internal explosion

M. P. Byfield and S. Paramasivam

Blast wave pressure-time profile due to vehicle borne

Experimental data
Numerical model

Blast load profile for column
FEATURES OF BLAST AND IMPACT

De Matteis et al: Peak pressure in flats due to gas explosions

Interaction of the blast wave with building components

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Blast effects on the Archimede Bridge: interaction of the blast wave with structure

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FEATURES OF BLAST AND IMPACT

Kilic and Smith:

Behaviour of deformable walls for protective structural design

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FEATURES OF BLAST AND IMPACT

- Extreme loads result in large deformations (adsorbing energy through ductility)

C. Seiler

truc impact “TB81”

Impact on guardrails due to vehicle impact

A. M. Gresnigt, A. Karamanos & K. P. Andreadakis

Impact Loading of Pressurized Steel Pipelines

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Under dynamic loading conditions, many construction materials present a different mechanical behavior, with respect to that exhibited in quasi-static regime. Generally, both compressive and tensile strength increase; stiffness can also present higher values whereas failure strains can both increase and decrease.

The dynamic behavior of materials is due to different phenomena, influencing the mechanical properties. To quantify these effects, the strain-rate (measured in $\text{s}^{-1}$) is used as main parameter to describe the dynamic regime.

Several experimental research activities related to dynamic properties of construction materials have been developed. In particular, experimental activities are conducted using different testing procedures. The most used equipments are the Drop-Weight Impact Machine, the Split Hopkinson Pressure Bar (SHPB) and its modifications, and the Hydro-pneumatic machine.
Strain Rate Tests on Pure Aluminium Through A Split Hopkinson Tension Bar

G. De Matteis, G. Brando, F.M. Mazzolani

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Strain Rate Tests on Pure Aluminium Through A Split Hopkinson Tension Bar

G. De Matteis, G. Brando, F.M. Mazzolani

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Tensile dynamic behavior of GFRP subjected to controlled strain rates

D. Asprone, E. Cadoni, A. Prota and G. Manfredi
ANALYSIS APPROACH

• Extreme loads have short duration (structure dependent) and intense (provoking material and structure large deformation)

In order to allow a good structural behaviour avoiding progressive collapse due to the premature loss of a structural components, the structure is specifically designed:

a) by selecting relatively weak ductile structural members connected together by relatively strong joints

b) by allowing the development of global resisting mechanisms, due to alternate load patterns or load resisting mechanisms

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In terms of local mechanisms: **Key element strategy**, which is based on the correct detailing of the vulnerable structural components against the action, is applied;

**De Matteis, Langone, Mazzolani:** blast loads effects on slabs  
**Kilic and Smith:** effectiveness of blast walls  
**Tays:** numerical study on small scale blast walls

In terms of global mechanism: once a local mechanism develops, **alternative load paths strategy** is applied, which is based on the acceptance of the failure of some components, but with the preservation of the whole structure.

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“ROBUST” DESIGN APPROACH

In case of load path strategy, “Robust” design may be achieved by:
Framed structures characterized by full strength rigid connection or by other dissipative sources (bracing, dampers), able to withstand different scenario characterized by some elements loss (based on the structural redundancy)

F. Dinu, D. Dubina

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In case of load path strategy, “Robust” design may be achieved by:

Framed structures characterized by partial strength semirigid beam-to-column joint or pinned joint, able to withstand different scenario characterized by some elements loss

U. Kuhlmann, L. Rölle
“ROBUST” DESIGN APPROACH

In case of load path strategy, “Robust” design may be achieved by:

Framed structures characterized by partial strength semirigid beam-to-column joint or pinned joint, able to withstand different scenario characterized by some elements loss

PLASTIC HINGES PLACED INTO DUCTILE JOINTS developing large tensile (membrane) forces (CATENARY EFFECT)

In this case, a catenary action for redistribution of internal forces within a structural system requires large deformations of the structure. Large deformations demand ductility of the structure and strengthening of the joints in order to achieve that the plastic hinges are placed in the beams is not a necessary condition for activation of catenary action in a frame structure.

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It has been analyzed the behavior of steel and composite building frames further to a column loss, when significant membrane effects developed within the structure, by analytical and experimental methods. The main objective was the evaluation of the influential parameters and the validation of simple analytical procedures for predicting the response of a frame due to column loss.

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CONCLUSIONS

- The interpretation of the real structural response of constructions under impact and explosions represents a very important issue in modern times.

- The main aspects to be considered are:
  - definition of the load accounting for the interaction with the structure;
  - dynamic behaviour of material;
  - Analysis accounting for large deformation of material and structural elements and for possible dynamic load-to-structure interaction.

- The main analysis methods pursue a “Robust” design approach based on “key elements strategy” or “alternative path strategy”.

- Such report has been prepared based on COST C26 WG3 contributions: many other activities exist or should be still developed to cover the large vacuum.
Thank You very much for your kind attention