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# Analysis of blast load on a reinforced concrete column in the time domain

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**Abstract.** This paper is concerned with simulation of the blast load on a reinforced concrete column for different design options with the use of the finite element technique in LS-DYNA. Calculations were made with regard to the gravity load. Time-domain analysis was performed for the nonlinear dynamic fracture of the column.

## 1 Introduction

Blast loads may cause damage or destruction of the load bearing or fencing structures in buildings and frameworks, which may result in the death of people inside such buildings. Consequently, over the last few decades studies have been carried out to develop the techniques relevant to examination of the nature of blast loads, the behavior of buildings and frameworks under the blast impact, and the methods to improve the structural resistance to blast effects. Full-scale experiments are expensive, hazardous and labor-intensive in comparison with computational simulation of blast loads based onthe finite element analysis.

## 2 Experiment

The purpose of this paper is simulation and analysis of the stress-strain behaviour of reinforced concrete structures under blast loading, using the finite element technique.

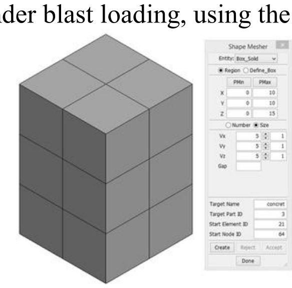

**Fig. 1.**Simulation of the concrete using 8-node finite elements.

The concrete was simulated in LS-PrePost using 8-node finite elements with 24 degrees of freedom (Fig. 1).

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Type 159 material was used to simulate the concrete (CSCM_CONCRETE), Table 1.

**Table 1.**Simulation parameters of the CSCM_CONCRETE material

| Parameters | Value | Unit measure |
|---|---|---|
| Density | 2,400 | kg/m3 |
| ERODE | 1.05 | - |
| Ultimate compressive strength | 14.5 | MPa |

The characteristics of the longitudinal and crosswise reinforcement of the column were simulated using the type 3 material (PLASTIC_KINAMATIC), Table 2.

**Table 2.**Simulation parameters of the PLASTIC_KINAMATIC material

| Parameters | Value | Unit measure |
|---|---|---|
| Density | 7,850 | kg/m3 |
| Young's modulus | 210,000 | MPa |
| Poisson's ratio | 0.3 | - |
| Yield strength | 390 | MPa |
| Plastic strain rate | 0.12 | - |

The design model is a building-shell concrete column reinforced with eight A400 longitudinal bars 18mm in diameter, and A240 binders 10mm in diameter placed at intervals of 250mm. The finite element model of the column is presented in Fig.2.

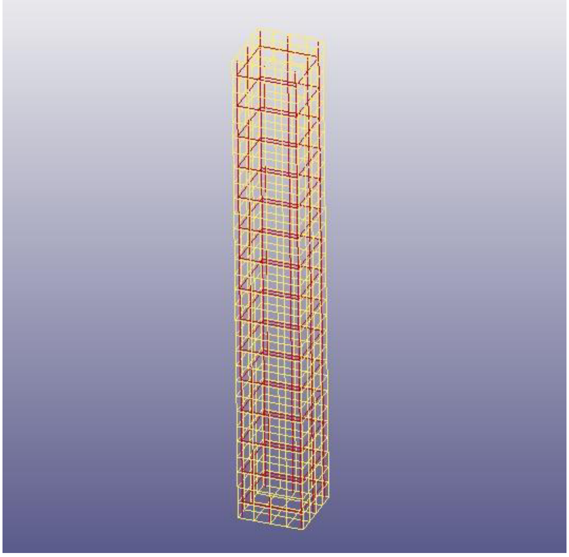

**Fig. 2.**Finite element model of a reinforced concrete column generated in LS-PrePost.

The finite element model was generated in the LS-PrePostpreprocessor and analyzed in LS-DYNA. The concrete and the steel were represented by solid and bar finite elements. The concrete and steel material types were selected for the model with regard to their actual behavior in explosion. The CONSTRAINED_LAGRANGE_IN_SOLIDcommand was used to provide for collaboration of steel and concrete. This commandsets the coupling of the Lagrangian (subordinate) grid of solid elements to the material points at the nodes of the Eulerian (main) grid. The explosion yield of a substanceis shown by the TNT equivalent, the explosive energy of which is equal to that of the particular substance. TNT (trinitrotoluene)was chosen because of its stable characteristics compared with other explosives. The equivalent weight of TNT is calculated by the equation (1), which ties the TNT weight to that of the explosive used:

$$W_{TNT} = W_{exp} \frac{H^d_{exp}}{H^d_{TNT}} , \quad (1)$$

where$W_{TNT}$ is the TNT weight, $W_{exp}$ is the weight of the explosive selected.
Table 3contains a list of widely used explosives and the detonation energy of each of these.

**Table3.**Detonation energy of the most widespread explosives

| **Explosives** | **Detonation energy (MJ/kg)** |
|---|---|
| TNT | 4.1 – 4.55 |
| C4 | 5.86 |
| Hexogen | 5.13 – 6.19 |
| Pentrite | 6.69 |
| Pentolite 50/50 | 5.86 |
| Nitroglycerin | 6.3 |
| Nitromethane | 6.4 |
| Nitrocellulose | 10.6 |
| ANFO (Ammonium nitrate/Fuel oil) | 1.59 |

Table 4 shows the equivalent weights of the most widespread explosives. The equivalent weights can be used to determine the weight of TNT with the shock wave parameters on a par with other explosives of certain weights.

In the LS-DYNA the blast load can be set by any of the three methods:
- empirical method;
- Lagrangian/Eulerian simulation;
- combined use of the empirical method and the Lagrangian/Eulerian simulation.

The empirical method is most suitable for solution of this problem, since it provides the required accuracy and saves time for analysis and simulation. The initial data are the TNT equivalent weight of the explosive, the explosion point coordinates, and the explosion type: surface or air. Lagrangian/Eulerian simulation is the most labor-intensive method that requires creation of a finite-element mesh model of the explosive and of the air environment. The resulting finite-element model leads to a higher-order equation that requires significant resources for solution. However, this method yields more accurate results in comparison with the other techniques. Use of both the empirical method and Lagrangian/Eulerian simulation combines the advantages of both methods: more accurate results than in the case of the empirical method, and a reduced number of elements in the model compared with Lagrangian/Eulerian simulation.

**Table 4.** Equivalent weights of the most widespread explosives

| **Explosives** | **Detonationenergy (MJ/kg)** |
|---|---|
| TNT | 1 |
| C4 | 1.37 |
| Hexogen | 1.1 |
| Pentrite | 1.27 |
| Pentolite 50/50 | 1.42 |
| Nitroglycerin | 1 |
| Nitromethane | 1 |
| Nitrocellulose | 0.5 |
| ANFO (Ammonium nitrate/Fuel oil) | 0.87 |

In this work we used the empirical method for simulation of the blast impact. The blast load was set by the LOAD_BLAST_ENHANCED command, the parameters of which are shown in Table 5.

**Table 5.** Parameters of the LOAD_BLAST_ENHANCED command

| Parameters | Designation in LS-DYNA | Unit measure |
|---|---|---|
| Explosive weight in TNT equivalent | M | kg |
| X coordinate of explosion | XBO | m |
| Y coordinate of explosion | YBO | m |
| Z coordinate of explosion | ZBO | m |
| Detonation time | TOB | ms |

## 3 Results

Blast impact was simulated, equivalent to 10 kg of TNT. The explosion epicenter was at the elevation of 1.2 mfrom the ground surface, and at the distance of 1 m from the column.

Fig. 3 illustrates changing kinetic energy of the model in depending of time.

The compressed elements of the shell contain eccentricities of the applied load. The design model takes into account the column gravity load, in addition to the blast load(Fig. 4).

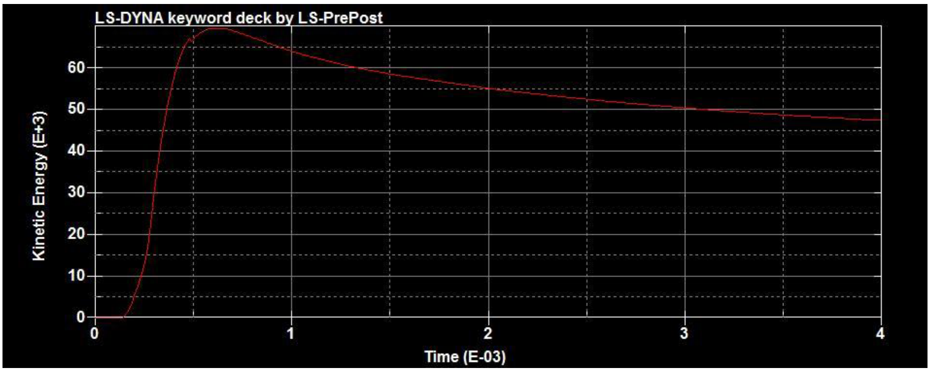


**Fig. 3.**Model kinetic energy - time plot

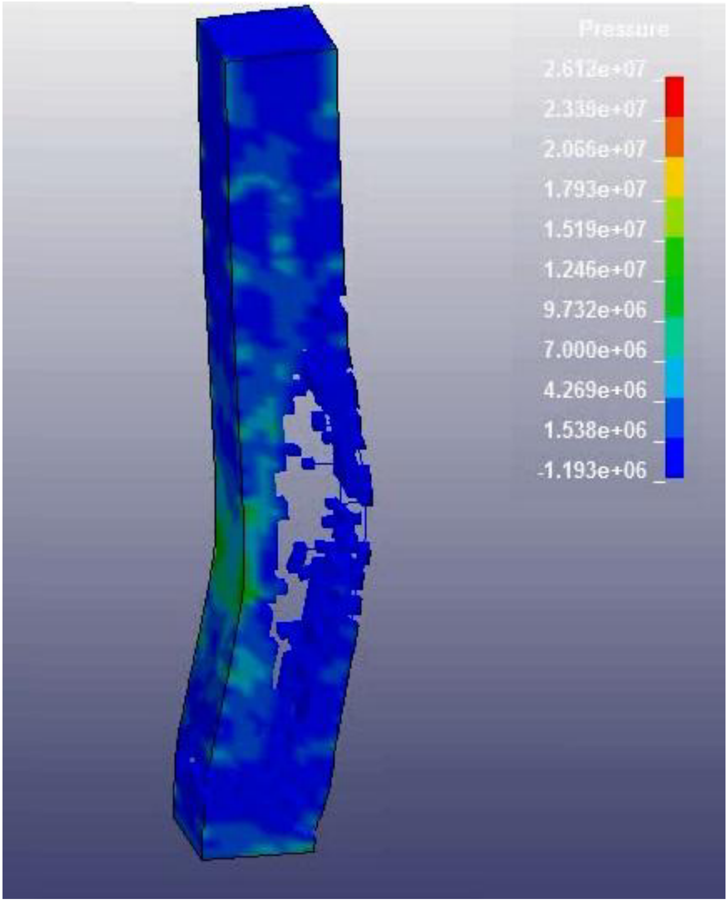


**Fig. 4.**Blast impact on the column at the moment of time t = 0.38 ms

The finite element model is based on the blast load impact. The blast pressure on the column surface was 97 MPa (Fig. 5).

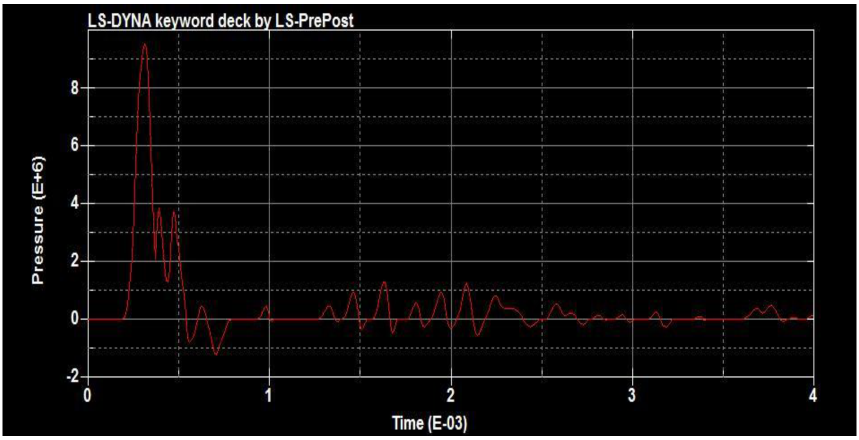


**Fig. 5.**Blast pressure - time plot

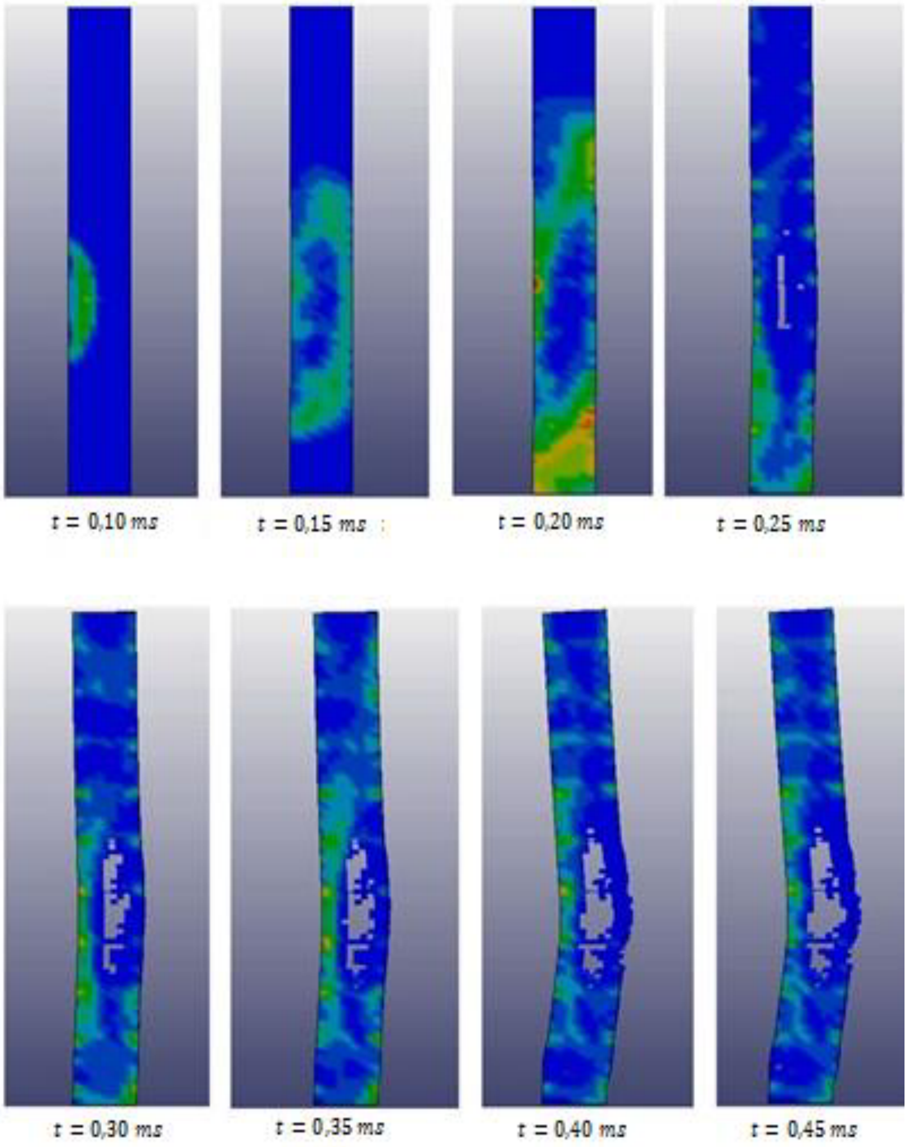


**Fig. 6.**Time-domain fracture of the column

Fig. 6 shows the column fracture process in the time domain under the 10 kg TNT-equivalent blast loading.

A second column model was developed, with a better reinforcement: steel binders with a diameter of 14mm, at 150mm intervals. Fig. 7 shows the column fracture process for the second model.

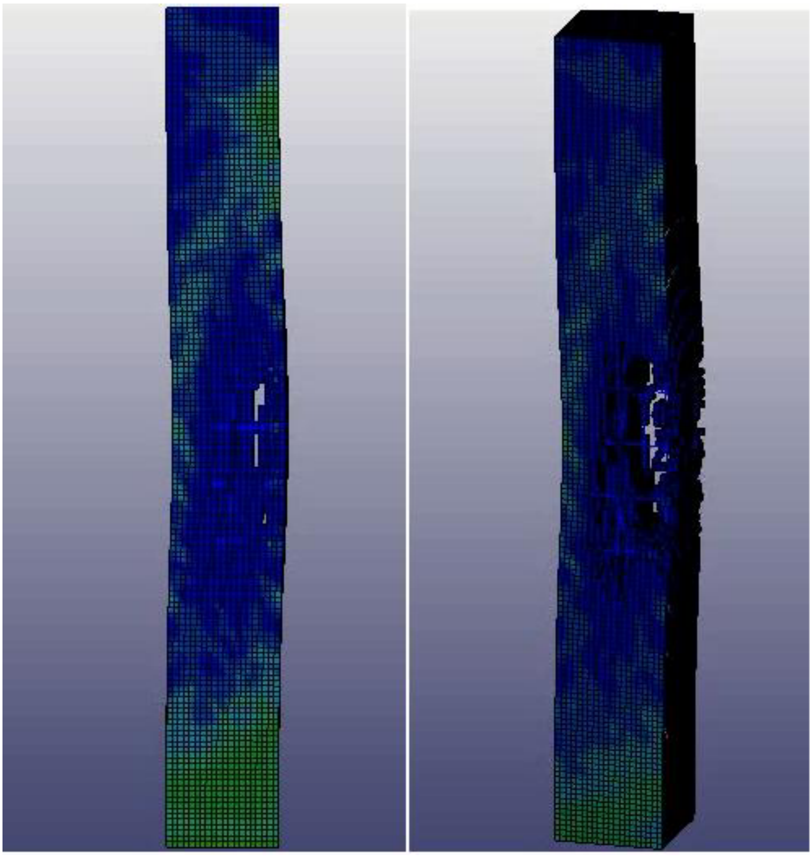

**Fig. 7.**Column fracture process for the second model

# 4 Discussion

In accordance with the types of materials selected, the model elements work during the plastic stage. This causes strain of the solid elements in the design model. When the strain exceeds the strength of the finite elements, the latter fail.Such elements disappear from the finite element model.

Within 0,15 milliseconds (ms) the shock wave spreads throughout the volume of the reinforced concrete column.

# Conclusions

Comparison of the results leads to the conclusion that the steel ratio has a considerable effect on the column resistance to the blast impact. The dynamics of the column fracture demonstrates the work of the crosswise binders with fracture in the load application area.

The structural solution of the second model satisfies the requirements for resistance to accidental impacts. The study of abnormal impacts on a reinforced concrete column makes it possible to issue design recommendations on improvement of the shell reliability. Congested urban areas increase the risk of accidental impact near buildings or in underground parking spaces. Therefore, better reinforcement is needed for the load bearing columns in the ground floor and for the underground part of the shell.

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