The Effect of a Blast Load from Propane Gas Leakage on an RC Structure

A Case Study in Batna, Algeria

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Abstract-The knowledge of the way a gas explosion affects a structure is still in its development. In this study, structural analysis software was used to construct a simplified approach to predict the impact of a Dynamic Blast Load (DBL) from gas leakage. During the explosion process, the overpressure distribution in a room is decomposed to maximum dynamic pressure point (DPPmax), where the explosion damages the most the structure. The simulation of the DBL was compared with the real consequences of gas explosion with the phenomenological data of a case study in Batna, Algeria. The results show that the simulation reproduced by our modeling of the DBL at structural scale is in good agreement with a real explosion. The distribution of stresses and strains over time indicates that the gas explosion inside residential buildings affected the entire surrounding of the area of the blast.

Keywords-Dynamic Blast Load (DBL); maximum Dynamic Pressure Point (DPPmax); propane; gas leakage; RC structure

I. INTRODUCTION

The global demand for natural gas is expected to increase during the next five years [1]. Gas leakage and explosion incidents have often happened inside buildings. 531 gas explosions were reported in China [2] and more than 52 more were observed during 2021 with the most devastating one documented in the city of Batna, Algeria. Many theoretical and experimental studies have been conducted on the damage caused in buildings by dynamic explosive loads [3-5]. Although an explosion from gas propane leakage in a building can only be modeled in the punctual point of pressure, empirical VCE (Vapor Cloud Explosion) models are best suited for such tasks. The TNT equivalent, the TNO multi-energy approach, and the Baker-Strehlow models explain the behavior of an explosion, although they cannot be directly applied to study gas explosion events at structural size. While the structural analysis of a structure damaged by a gas explosion has been understudied, the use of FEM to analyze and calibrate experimental data to fulfill the necessary requirements for the comprehension of the behavior of explosion was successful [6].

Machine learning models for predicting the compressive strength are developed to determine its optimal value [7]. A machine learning model can incorporate more data for its learning process by constant feeding with more parametric simulations that can eventually enhance the compressive strength of concrete that will be considered for the design of RC structure under a dynamic blast load.

Our objective is to study the dynamic characteristics of gas explosions. In order to properly integrate the dynamic blast load at the structural level, we must first understand the dynamic features of gas explosions. The pressure peak is numerically simulated for various proposed models that have been experimentally calibrated. In the meantime, the modeling results are compared with the aftereffects of an actual explosion. Additionally, the structural properties of explosive overpressure (stress, strain, and deformations) are examined. As a case study we will look in an unfortunate incident occurred in a residential building in Batna, Algeria. As shown in Figures 1-2, the ceilings, floor, interior, and exterior walls were blown away. Crack patterns can be seen along with extreme damages to the beams and columns on the floor level from the blast of the explosion, thus confirming the motivation toward an investigation on the effect of the blast over the integrity and stability of an RC structure.

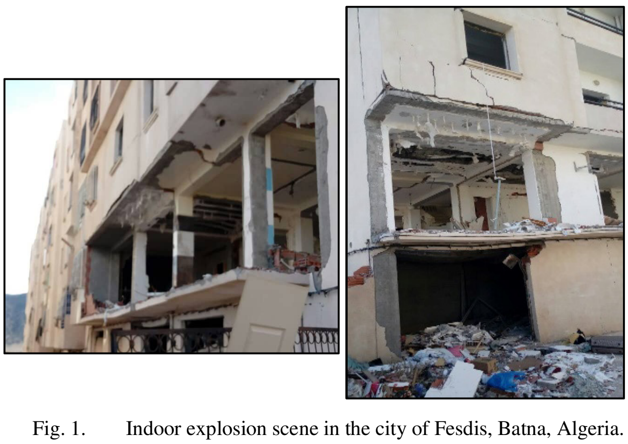

Fig. 1. Indoor explosion scene in the city of Fesdis, Batna, Algeria.

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Fig. 2. The damage of the frame of the RC structural elements.

II. PRESSURE-TIME HISTORY AND PRESSURE MODELS

The estimation of the strength of a blast is a difficult problem which can be overcome depending on the required accuracy and the available resources. Blast loads are extremely complex phenomena characterized by a sadden increase to a maximum peak value of pressure and then decaying to atmospheric pressure [3] in microseconds or even milliseconds. The ambient pressure Po is the reference or zero pressure for the positive and negative pressure values. After the explosion, the blast wave front reaches a target point in time tA and reaches the peak incident pressure Pso which is the maximum positive pressure. Then it promptly decays to the atmospheric pressure Po. Researchers have been in search for models that can calculate the Pso along with other parameters of shock wave for free air burst and surface burst scenarios. In this paper, we will focus on the surface burst models that mimic an indoors explosion.

III. SURFACE BURST MODELS

The latest developed models that can evaluate Pso are summarized in Table I. W=E/Ps$_0$ is the TNT equivalent weight (kg), R is the stand-off distance (m), and Z is the scaled distanced defined [7] below:

$$Z = R/(\mathrm{E/Ps_0})^{1/3} \quad (1)$$

TABLE I. MODELS TO EVALUATE P_{SO}

Model 1	$Pso= 0.6784\ W/R^3 + 0.294\ W^{1/2}/R^{3/2}$	(2)	Newmark and Hansen model
Model 2	$Pso = 1.059\ [R/W^3]^{-2.01}$	(3)	Wu and Hao model
Model 3	$Pso = 1.017\ [R/W^3]^{-1.91}$	(4)	Siddiqui and Ahmad model
Model 4	$Pso = 2.46\ [R/W^3]^{-2.67}$	(5)	Ahmad et al. model
Model 5	$Pso = 1.026\ [R/W^{1/3}]^{-2.67}$	(6)	Iqbal and Ahmad model
Model 6	$P_{so}= 4.34\ W^{-2.84}$	(7)	Badshah model

The results for the same initial conditions are shown in Figures 3-4. The Pso values diverge, which clearly indicates the particularity of each model developed for the specification of its own calibrated experiment. The values of the TNT equivalences as functions of overpressure for propane/oxygen were found in [9] and were calculated using the fitting coefficients shown in Table II.

$$\mathrm{W = J + K\ln Z + L\,(\ln Z)^2 + M(\ln Z)^3} \quad (8)$$

TABLE II. FITTING COEFICIENTS

	J	K	L	M
Propane/Oxygen	0.4580	0.2150	-0.1442	0.0292
Propane	1.2020	1.2464	-0.6410	0.1034

IV. BLASTING DYNAMIC LOAD

An explosion generates an imposed dynamic load on any object in its field. This blasting dynamic load is characterized by a rapidly reaching maximum peak value which then decreases as the blast wave decays. The net effect of the load depends both on the nature of the blast wave and on the geometry and construction of the object [9]. The blast is predicted by:

$$\mathrm{V} = \frac{4}{3}\pi r^3 \quad (9)$$

$$P_s = W\,.\,V\,.\,P_i \quad (10)$$

$$Pi=2.5\ 10^{-6}.S.V_i^2 \quad (11)$$

$$P(t) = 4\ .\ P_s.[e(-t/\sqrt{2})-e(-\sqrt{2}t)] \quad (12)$$

where Vi is the blasting velocity, and S the density of the explosives.

V. DATA USED

TABLE III. PROPANE PARAMETERS

	Propane g/cm^3	Propane Kg/m^3
Blasting velocity V	347	
Explosive density S	0.493	493

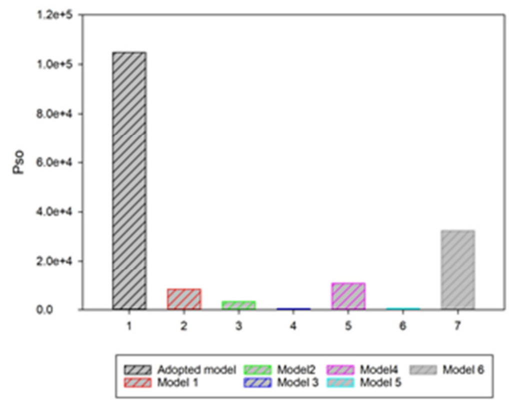


Fig. 3. The peak positive incident pressure (Pso).

As explained above, the results for the peak positive incident pressure (Pso) are very diverse due to the calibration of each model to the chemical components proprieties of the explosion. The blasting velocity and explosion density of propane (Table III) lead us to the inevitability of more exorbitated field experiment.

Authors in [10] experimentally proved that sequences of explosion of the propane air mixture give symmetrical flame propagation. After ignition, the flame speed increased quickly to 2384 m/s. Two milliseconds (0.002s) later the flame reaches the end and stops propagating.

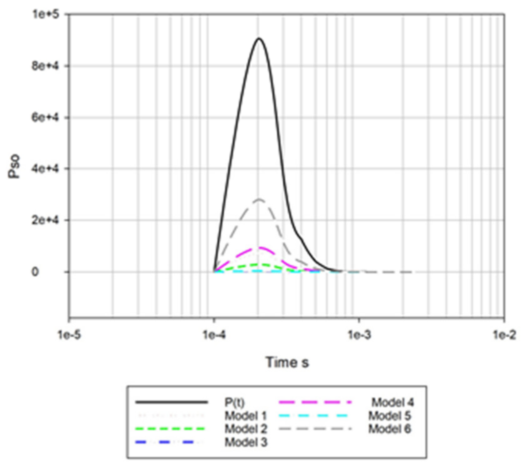


Fig. 4. Dynamic blast load history for a $75m^3$ chamber filled with 90% propane and the model adopted in the current study.

Data from [10] were used and the results were compared with the results of other models. The significance of the right set of experiments to be used to oversee the dynamic blast of propane explosion was clearly shown. Figure 4 indicates the difference in the proportionality of Pso over time.

TABLE IV. PROPANE PARAMETERS USED IN BLAST LOAD CALCULATIONS

Sensor	Peak pressure (kPa)	Sensor	Peak pressure (kPa)
P1	29.76	P2	14.28
P3	15.39	P4	10.98
P5	25.45	P6	12.84
P7	10.85	P8	12.33

Moreover, the setting of pressure sensors shows that the maximum dynamic pressure point DDPmax, as Table IV indicates, is located on the frontal central of the faces of the explosion.

VI. MODELING APPROACH OF DBL

The structural modeling approach of the phenomena is summarized below:

- Designate the explosive material, in our case propane (natural) gas and its flammable characteristics.
- Define the Dynamic Blast Load (DBL) history expression that we are going to use for the assessments.
- Assign the DBL to the corresponding DDP_{max}. In the case of structural walls without openings, the DDP_{ma} will be in the center of the wall, for walls with openings (windows, doors), the DDP_{ma} will be located on the center of each edge of the opening surface.
- Define the DBL force in a structural analysis software (ex. Autodesk Robot structural analysis 2022) as time history analysis as the Figure 5 show.

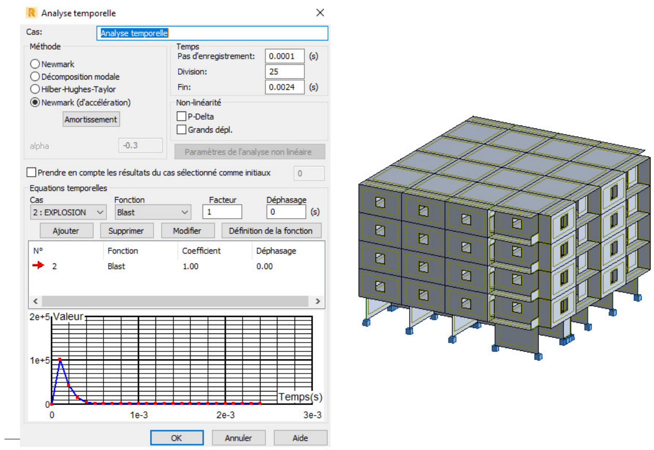


Fig. 5. Location of the DBL force in the structure and time history analysis.

VII. RESULTS AND DISCUSSION

Our approach follows the results of [10] and replicates the propagation wave of the DBL. We can observe that the maximal displacement measured in the damaged structure as shown in Figure 2 is 38cm in a principal beam. On the contrary, our simplified approached with the adopted VCE model, gave 33cm displacement along the position of the punctual point of the peak pressure of the explosion as shown in Figure 6(g).

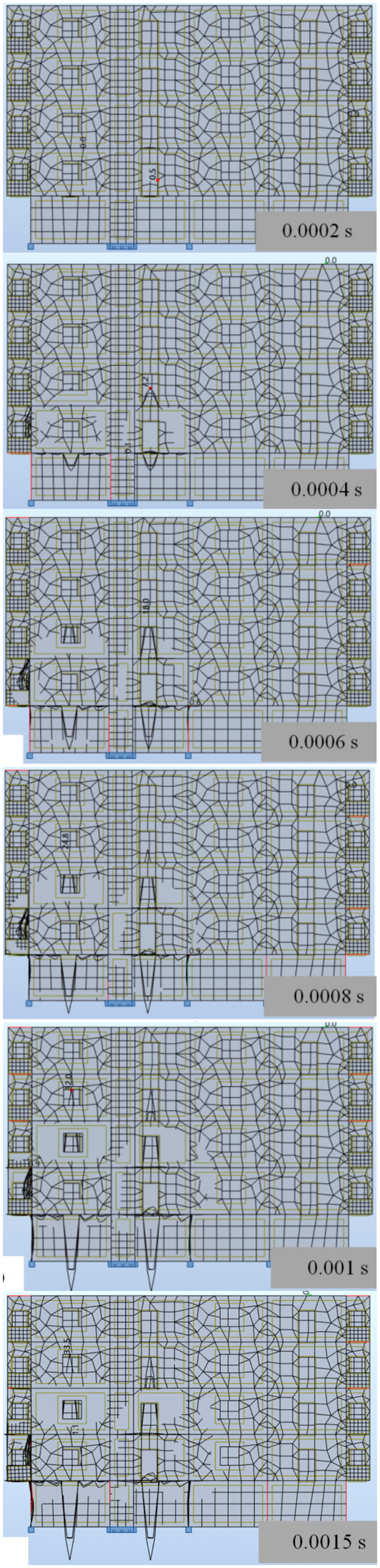
Figures 7-8 indicate that the distribution and arrow orientation of stress show clearly that our model mimics to a certain degree the scale of the actual damage the structure has sustained. As Figure 9 shows, the crack propagation pattern is similar to that of the adopted simplified approach, since the distribution of maximum stress resembles the propagated cracks from the blast.

VIII. CONCLUSIONS

The current study showed that all the considered models are specific to a type of an explosion rather than just a generalization of behavioral phenomena, hence the Pso in all the developed models shows an empirical blast load, either for free air burst or for a surface burst, something that shows a large variation. The current paper is the first milestone toward the implementation of blast load in structural design with a suitable and simplified approach, showing similar results with the case study.

Brick masonry is a principal component in structural construction and infill material in many parts of the world. Therefore, response of clay brick masonry against blast loading will be examined in the future.

(a)
(b)
(c)
(d)
(e)
(f)



(g)

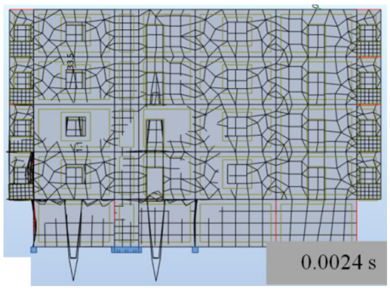


Fig. 6. Nodal and column /beam displacement for each incremental time.

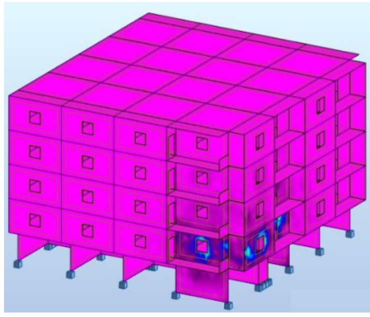


Fig. 7. Distribution of stress at the maximal peak pressure.

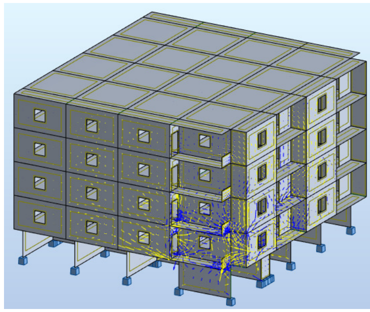


Fig. 8. Arrow orientation of the stress.

Fig. 9. Distibutionof the propagted cracks from the blast.

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