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RISK ASSESSMENT OF INDUSTRIAL INFRASTRUCTURES UNDER THE SPECIFIC OUTCOMES INITIATED BY EXPLOSION MATERIALS

Anca-Cristina TATARCAN, Augustin SEMENESCU, Narcis POPA, Madalin ANDREICA, Denisa TUDOR, Dragos Gabriel VASILESCU

Abstract: *The manuscript presents a concise overview of the findings derived from research conducted in the domain of simulating the hazards posed by debris from explosive charges, which are propelled towards workers or industrial targets during tests at explosives testing facilities. In this context, American scientific methodologies have been adopted, notably the FRMS (Fragment Risk Mitigation System) approach, aimed at enhancing the capabilities of specialized software designed for the safety assessment of explosives, such as IMESAFR (e.g., Version 2.0). The improvement process involved the utilization of various probability functions tailored to this specific domain, referred to as Probability Density Functions (PDFs), to effectively represent the graphical and analytical aspects of the phenomenon when debris from explosive charges is ejected.*

Key words: *explosive material, occupational safety and health management, overpressure curve, contour mat, hazard curve, steel frame structure, industrial site safety.*

1. SUMMARY OF THE METHODS USED IN THE MATERIAL'S FORMATION OF FRAGMENTS AFTER INFLAMMABLE FILLERS DETONATE

Discharge of arsenal

Discharge constitutes a physical-chemical mechanism that produces strong forces which cause rocks to break and separate. It is distinguished by a rapid replay speed and the creation of significant amounts of gases at high heat. Many theories were proposed across the world to explain the physical mechanism of detonation, and hydrodynamic theory was one of them. Considering that its explosive propagation method is comparable to that of the pressurized fluid, it was accepted unanimously.

There are three phases in the explosion mechanism: **I.** The thermal breakdown of every layer in the explosive's configuration, up to elevated temperatures, when the chemical feedback proceeds quickly and the dynamic compression technique is imposed without heat reciprocity with the surroundings (adiabatic pressure); **II**. The mechanical compression of every explosive substance molecule moved by a “dynamic pulse”; **III**. The explosive's exothermal breakdown is brought on by “the action of elevated temperatures”.

The formation of pits

A schematic representation of a crater created by an arsenal filler explosion is exposed in figure No. 1. A crater's dimensions are as follows: h1 is the crater's real depth; h is the berm height; D2/D1 is the pit's apparent/actual measurement.

When explosive charges detonate in one of three locations—underground (closed space), on the surface of the earth (air-ground interfacing) or hanging in the air—craters are created. The pit is the result of a blasting, regardless of where the explosive amount was placed.

A powerful decomposition process occurs in his mass when the explosive charge is first initiated, and the ensuing explosion wave travels at a velocity of 2000–8000 m/s. A pressure that can reach 104 MPa develops in the detonation wave front and is transferred through the surroundings as a shock wave that propagates in the same line as the blast ondulation.

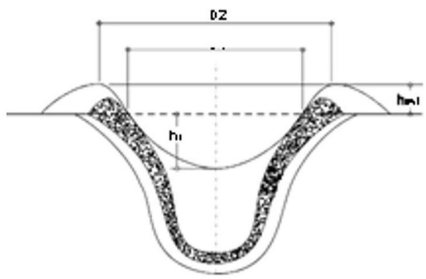

Fig.1. Characterize the scale of a pit.

Three types of pieces are taken into consideration in the material that results from an explosion-type event: primary, secondary, and scrap that comes from the pit that is generated. The body of the detonated explosive is where the majority of the shards are found, followed by the storage room's structure (such as the roof, end walls, side, and rear). Additionally, pieces of the earth or the storage room's foundation structure are produced as remnants in the impact crater formation.

Table 1

Outcomes obtained for the 10 ranks.

Class (Binin n=1,10)	Bin1	Bin2	Bin3	Bin4	Bin5	Bin6	Bin7	Bin8	Bin9	Bin10
Minimum kinetic energy (m-Kg)	100K	30K	10K	3K	1K	300	100	30	10	3
Average kinetic energy(m-Kg)	173K	54K	17K	5K	1,7K	547	173	54	17	5
The maximum kinetic energy (m-Kg)	^{3}300K	100K	30K	10K	3K	1K	300	100	30	10
The average weight of fragments of steel (kg)	1,619,352	675,864	2,875,824	1,206,576	0,512568	0,214553	0,090266	0,038647	0,017191	0,006441
The average weight of concrete fragments (Kg)	3,420,144	142,884	607,824	2,544,696	1,079,568	0,4536	0,190512	0,081648	0,036288	0,013608

Thousands or more separate fragments may be produced in an explosion-type event, each of which may be individually discover by its large scale and sprint, the primary parameters, and, indirectly, by its kinetic vitality. To give a broad summary of the 10 resultant classes (Bin_i, i=1,10).

$$Bin\ n: DAM_N = RM_n + \left(\sum_{i=1}^{n-1}\left(DM_{[i,n]}\right)\right) + \left(\sum_{i=2}^{n-1} B11DM_{[i,n]}\right) \quad (1)$$

where:
DAM – dynamic improvement of the volume of the piece portion RM – the residual piece volume of portions;
DM – the portion volume of piece spreading.

Thus, Bin_1/Bin_{10} represents the portions with the high/ low large scale and level significant/ low of injury and/ or destruction of the anthropoid components. Table 1 explains the outcome for the 10 ranks ($Bin_1 \div Bin_{10}$) matching to level of casualty/ destruction (via kinetic vitality); the expected weights of fragments are determined based on the piece type, with consideration given to the maximal, mean, and minimal probabilities, as well as the median net of each portion.

2. INFORMATION

Description of the primary fragments

The principal pieces come from the detonation of explosives and their packaging, and the number, mass, and maximum throwing range of these fragments determine their design mechanism through modeling. The number of blasting items (N_W) is provided by the relation (2):

$$N_W = \frac{W_1}{\text{NEWQD of one explosive article}} \quad (2)$$

where: W1 – amount of arsenal of the blasting items No.1; NEW – net blasting quantum of a unique item (Table 2); QD – distance reliant on the amount of arsenal.

The principal pieces come from the detonation of explosives and their packaging, and the number, mass, and maximum throwing range of these fragments determine their design mechanism through modelling.(v. Table 3).The amount R_{max} is set at the maximum charge for the extension, whether for one blasting product (RS) or for diversified items (RM), depending on the amount of arsenal deliberate, W1. A significant number of primary fragments are produced regarding an blasting-type event inside a potentially explosive structure (PES) used to collection bursting charge for citizens uses. The quantity and beginning speed of these fragments are determined using the information shown in the tables. No.2 and 3.

Moreover, the PES structure's post-blasting remnants can stop and eliminate the main pieces that came from this incident. Simultaneously, the percentage of the main piece that is blocked by the PES's structural elements (Top, front facade, back facade, and lateral facades) must be ascertained. To ascertain the quantity of primary fragments that could be obstructed by different PES structural elements, the fragments must be categorized based on their corner of projection, specifically: significant angular displacement of potions that impact fragments with angular trajectories originating from the roof and lower sections.

At their turn, the inferior angular pieces split further into horizontal segments displaced in a direction almost horizontal and side impact sections. Additionally, side impact segments have an arching trajectory toward an ES-type arrangement, which is a configuration exposed to explosions; nevertheless, constructed impediments may ultimately block this building's wall. (Figure 2).

The primary portions are split as follows, 25% of the total number of pieces are categorized as high angle segments, 7.5% are classified as side impact parts, and 67.5% are designated as horizontal components. The main pieces are separated into segments that each structure type PES can either contain or obstruct.

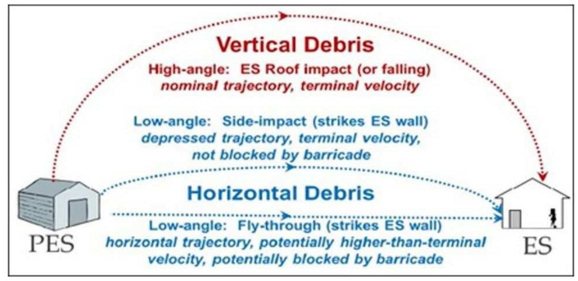

Fig.2. The route trajectories of firstly pieces.

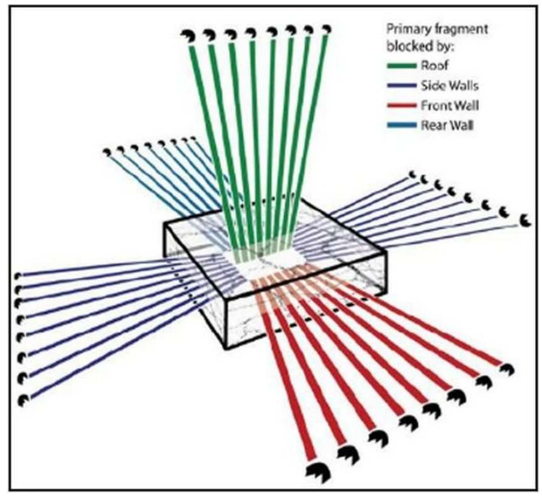

Fig.3. Blocking the firstly particles.

Front facade, lateral facades, and elements of the rear wall structure of type PES have the capacity to block side impact pieces and horizontal portions, while the roof component is thought to have the potential to block high angle fragments (Figure 3).

3. THICKNESS ESTIMATION OF THE PIECES FLOATED

A solid understanding of the primary parameters under evaluation, the impact speed and the projected large scale of the material pieces, is necessary for the estimation of the trajectory followed by the ejected material. This can be accomplished by applying the findings of different research projects in this field. Utilizing differential equations rooted in physical laws would be optimal for deducing the position and velocity upon impact, tailored to individual pieces of ejected material; however, yet, there are no established scientific outcomes for a particular plot related to an explosion type case.

Table 2

Primary fragments resulted.

Explosivecharges	NEW specific for a single type of explosive product (Kg)	Fragments derived from a single product Mass Bin$_n$, n=1÷10									
		1	2	3	4	5	6	7	8	9	10
explosive charges with small fragments	**0,4536**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**5**	**10**
Explosivecharges without primer fragments	**0,4536**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
metallic container with explosive charge	**4.536**	**0**	**0**	**0**	**0**	**0**	**0**	**80**	**4.111**	**796**	**319**
Explosive charge confined inthe metal pipe	**3,901**	**0**	**0**	**0**	**0**	**0**	**0**	**4**	**19**	**44**	**79**

Table 3

The upper limits of action or projection range primary fragments (R_{max}).

Explosive charges	V (m/s)	Rs(m)	RM(m)
Explosive charges with small fragments	**1219,2**	**569,976**	**683,9712**
Explosive charges without primer fragments	**NA**	**NA**	**NA**
Metallic container with explosive charge	**1219,2**	**569,976**	**683,9712**
Explosive charge confined in the metal pipe	**1219,2**	**569,976**	**683,9712**

Nonetheless, the current ranges allocated to every variable can have an impact on Monte Carlo simulations. Additionally, these models need several simulations to be run at the time of analysis, which takes a lot of time and results in a detailed computation that is purely dependent on assumptions.

These models utilize various probability density functions (PDFs) tailored to the explosives field to create a specific graphic-analytical representation. Computerized simulation of test data are employed to derive these PDFs using a specific equation (closed form), enabling the generation of instantaneous results based on the preset density function. Figure 4 provides an illustration of simulated test data.

This PDF forecasts projected portions of the material density practically instantly, acting as a contour map. It can be created with varying degrees of complexity to represent various model types based on the application of probability density actions.

Hence, the Probability Density Functions (PDFs) consist of components related to both aspects (″down-range″ and ″cross-range″). The "down-range" aspect replicates the expansion pattern originating from the blast's epicenter, extending outward in every radial direction.

This crucial factor delineates the regions of material distribution originating from the detonation site of the explosive charge, with the denser concentration extending to a defined distance. As for the "cross-range" facet, also denoted as the azimuthal direction or cross-range, it governs the contour of the model when traversing radially at a set distance from the source. The subsequent sections will meticulously explore the two components of the "PDF modeling technique" widely employed in the "domain of explosives safety".

The prevalent "Probability Density Functions (PDFs)" are characterized by "uniform spreads emanating” from the blast's center, devoid of azimuthal discrepancies.

These distributions encompass diverse debris types, including fragments from the demolished roof or sections of wall structures with differing arc shapes. Such “PDFs serve as effective tools” for “simulating safety scenarios”, as they represent the random or uniform dispersal of debris in all directions surrounding the explosion site.

The first illustration features a Gaussian-style function, akin to a bell-curved distribution, utilized as the "down-range" element without azimuthal alteration. This results in a distribution parameter denoted as bi-variant. (Figure 5).

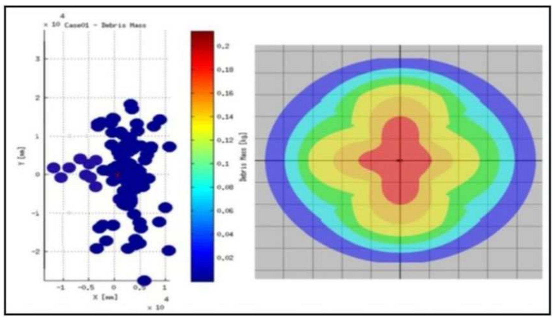

Fig.4. Conversion of the test data into a Probability Density Function (PDF)

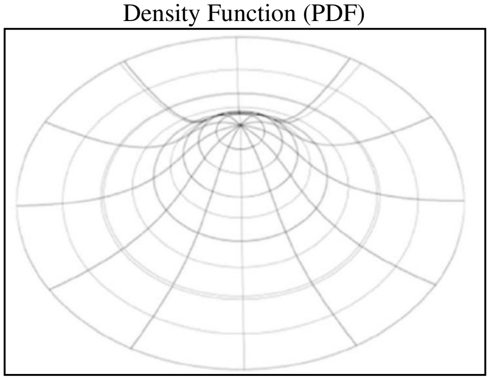

Fig.5. Distribution type Bi-Standard version

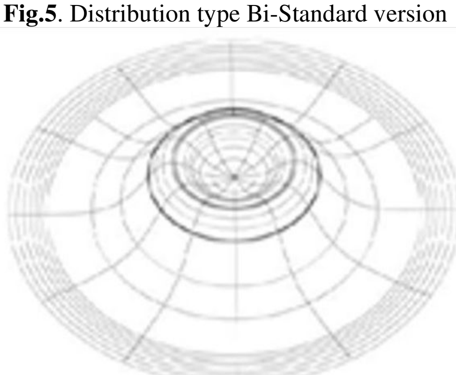

Fig. 6. PDF toroidal without azimuthal variation, type ISURF

The form of the Probability Density Function for the distribution of BVN is determined by:

$$P_i = \frac{1}{2\pi\sigma^2} e^{\left(\frac{-r^2}{2\sigma^2}\right)} \qquad (3)$$

Where P_i - Likelihood of a solitary fragment landing within a designated region;

σ - The standard deviation of the "down-range" distance;

r - Distance from the starting point to the point of interest;

ISURF paradigm

Density function of probabilities When there is little data or information available, BVN is helpful in supporting the basic scenarios. In these scenarios, the detonation of the charging material is thought to increase the risk of projecting material fragments near the blast origin for the production location. Still, there can be circumstances where a large number of the pieces are discarded from their original context. This feature is particularly relevant to primary fragments, explosive charge residues, and secondary fragments originating from wall fragments.

When utilizing the "BVN down-range" model in such scenarios, the challenge with the “Probability Density Function (PDF) “arises from the tendency to excessively predict the “dispersion of fragments near the origin in sporadic quantities”. This enhancement refines the "BVN down-range" model, yielding a toroidal PDF distinguished by its “azimuthal variability” (Figure 6).

Comparative evaluation of the two well-known models to support the projection possibilities of the material pieces that come following the detonation of blasting, specifically with respect to the "BVN down-range" curve and the "PDF toroidal down-range" curve, it's observed that the areas encompassed by both curves are equivalent, indicating an approximate representation of the same total mass of projected fragments.

Additionally, it's observed that the BVN curve model exhibits a conservative behavior within specific intervals compared to the toroidal PDF curve (Figure 7). The newly introduced component of the PDF model, termed "slope (Range)," is determined by the initial ascending function of the newest model, denoted as ISURF (Figure No. 8). The three parameters, a, b, and c, respectively, give the model ISURF its complicated shape.

These parameters can have varying values based on: quantity of the material type that remains after an explosive charge detonates, as well as the kinds of buildings that were utilized in the explosion scenario (ie. the wall or ceiling).

The graphical representation of the exemplary emphasizes the structural elements

- The parameter "a" denotes the proportion between the horizontal coordinate of the peak likelihood (Xpeak) and the maximal horizontal distance of fragment density throw (or "full-throw") (XMT). Its role lies in determining the utmost range.
- The parameter "b" denotes the association between the probability density at the origin (Y0) and the maximal probability density (Ypeak). Its utilization is aimed at determining the ultimate magnitude.
- The parameter "c" is utilized to oversee the arrangement of loops that connect designated points, indicating the ratio of probability contributed by the region beneath the loop.

The incline of the inner and outer surfaces can be ascertained by computing the area beneath the curve, thereby determining the proportion.

ISURFGAD paradigm

This paradigm is used to model uniform directional hazards, including fragments by roofs, the circular indentation phenomenon in explosives storage facilities, as well as explosion situations where fragments are propelled in unpredictable orientations. It is defined by an azimuthal invariant (producing consistent outcomes regardless of direction).

Since it has been noted that the azimuth of the thrown material has a significant impact on the density of the material when centrally positioned loads are present in rectangular buildings (debris tends to "travel along the perpendicular" rather than towards the "edges"), giving rise to a Cloverleaf-like effect (PDF with zero azimuth - lateral range) depicted in Figure 8.

Figure 9 introduces a fresh PDF (ISURFGAD) derived from a lateral range model designed to address this specific effect.

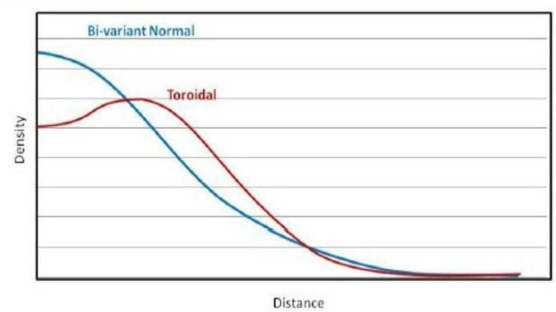

Fig.7. Graph depicting BVN and PDF curves

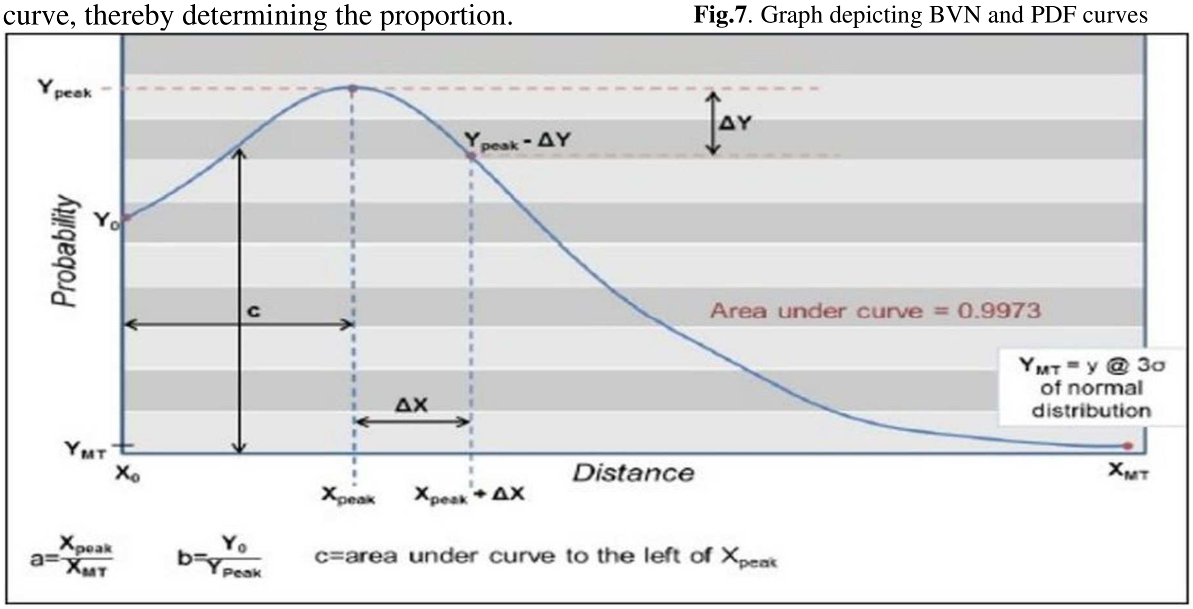

Fig. 8. Graphics of the model *ISURF*

The ISURFGAD PDF derivation is independently conducted for both the functions for "down-range" and lateral radius. It's illustrated for a single dial of 900, showcasing the probability density of material segments distinguished by separate parameters, encompassing the range interval (r) and ejection angle (θ), thus:

$$PDF = f_{(r)} * g_{(\theta)} \tag{4}$$

in which $f_{(r)} = f_1 = A` + B`r + C`r^2 + D`r^3$, out of range $[0, R_{P+}]$;
$f_{(r)} = f_2 = k_1 exp[k_2 * (r - R_{P+})]$, out of range $[R_{P+}, R_{max}]$;
$g_{(\theta)} = [1\backslash(2\pi R_C \sigma_\theta)] exp[-0{,}5(\theta\backslash\sigma_\theta)^2]$.
Where R_{P+} - Maximum probability density value;
R_{max} - The maximal radius of the ejected piece portions;
R_C - The centroid's radius.
The elements of modeling of the components resulting from bursting charge explosion from PES-type structures (used for storing explosive materials) were covered in previous sections. Explosion type events ES (for specific activities) can cause damage to structures exposed to explosive events with serious consequences for personnel health and integrity as well as the local population. To portray the degree of harm inflicted on individuals, a probability equation utilizing the Poisson probability distribution is applied.

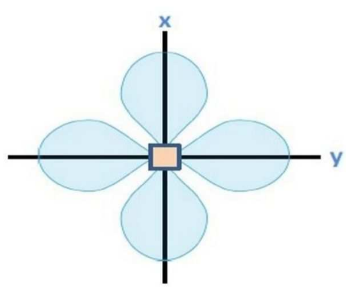

Fig. 9. The Cloverleaf model of material section dispersion

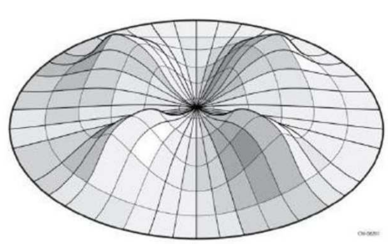

Fig.10. Type ISURFGAD

4. ASSESSMENT OF THE EFFECTS OF MATERIAL FRAGMENTS FOLLOWING EXPLOSIVE CHARGE DETONATION

This equation simulates the interaction between the human body and the ejected fragment (5), respective:

$$P_{impact} = 1 - e^{-EN^*} \tag{5}$$

Where E - This pertains to anthropoid exposure. (0.278 m^2)

N* - refers to the quantity of pieces capable of compromising the structural integrity of anthropoid components.

Based on the projected fragments' kinetic energy, the model estimates the likelihood of mortality zones incurring significant and minor injuries for the purpose of calculating the probability equation (6), respectively:

$$P_{f_{(d)}} = value\ of\ fatility \times p_{impact} \tag{6}$$

The lethality measure is extracted from the graph depicted in Figure No. 11, emphasizing the probability of mortality for a given occurrence Pf|e relative to the kinetic intensity of the propelled pieces. Subsequently, the model computes the cumulative likelihood of mortality stemming from the projected pieces, Pf(d), by aggregating the trajectories of large pieces along with the dispersion of smaller angular variations. The total likelihood of mortality is then determined using the additive principle, applied to events that are not mutually exclusive, as outlined in (7):

$$P_{f_{(d)}} = P_{f_{(d) small\ angle}} + \left(1 - P_{f_{(d) small\ angle}}\right) \times P_{f_{(d) high\ angle}} \tag{7}$$

Where $P_{f(d)}$ - likelihood of fatality resulting from impact with a projected fragment;

$P_{maxi(d)}/P_{mini(d)}$ - The probability of major damage or minor injuries is determined in a manner entirely analogous to that of fatality.

Using a pattern type, the method of hurled fragments is demonstrated to be dangerous. (Figure 12).

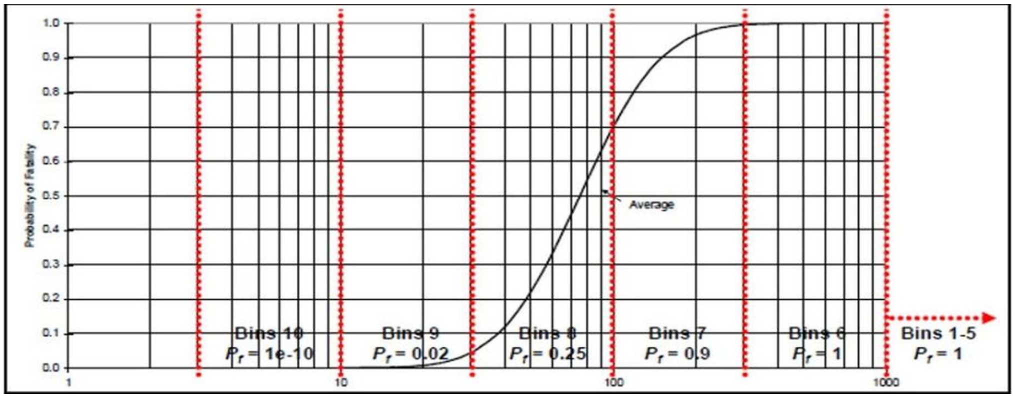

Fig. 11. The probability of the anthropoid component being exposed to kinetic intensity.

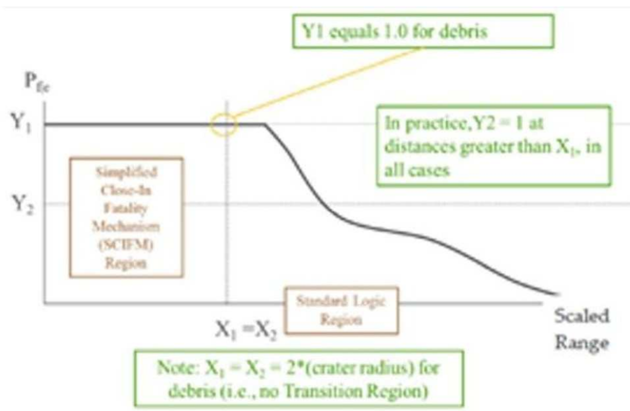

Fig. 12. The SCIFM model for projected items.

5. INSTANCES OF IMPLEMENTING THE MODELS PRESENTED

An instance of a surface Probability Density Function (PDF) showcasing specifications: a/b/c/d = 0.330/0.038/50%/10%, maximum range extension = 0.579 km, and $\sigma = 2x10^2$, is illustrated in the accompanying Figure 13.

The graphical and analytical results stemming from modeling the peril of injury due to projected material fragments resulting from an explosion event can be emphasized.

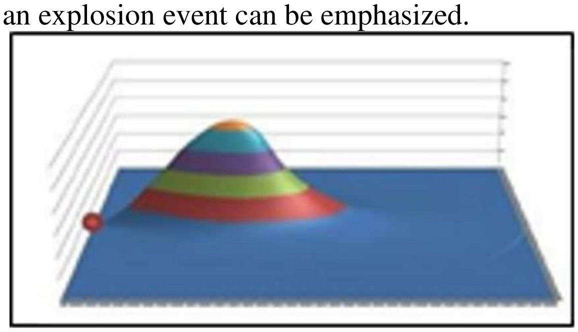

Fig. 13. ISURFGAD PDF

This is accomplished through contour maps delineating the destructive potential unique to the ejected pieces, alongside accompanying diagrams illustrating the kinetic energy of impact from material fragments, as depicted in Figure 14.

Furthermore, analytical graph results showcasing probability values of damage to the anthropoid element delineate distinct zones of interest, including the fatality region (indicating the level of mortality), the region of significant injuries (depicting irreversible damage extent), and the region of minor injuries (highlighting reversible damage extent).

The findings illustrated in Figures 14 would necessitate identifying the following planning zones to determine areas of concern in the event of a blasting resulting from detonation of explosive devices:

1. Region of High Fatality: This pertains to the area where around 50% of the exposed populace faces mortality.

2. Zone of Irreversible Injuries: This encompasses the area characterized by severe physical harm at the somatic and pulmonary levels, grave ailments, as well as first and second-degree burns suffered by the exposed population.

Structures of lesser weight may sustain significant harm, rendering them inoperable. On the other hand, robust buildings could endure minor damage. The focus area, characterized as the radius within which the aftermath of the incident is noticeable, may induce mild, transient illnesses or superficial burns that can be readily treated. Light buildings in the region of concern may sustain modest damage in explosive accidents.

6. CONCLUSIONS

Determining the path configuration of projected material fragments can be accomplished utilizing FRMs. These models employ diverse probability functions dedicated to this domain, such as the ISURFGAD model with azimuthal variation, for graphical and analytical modeling of the phenomenon involving ejected material fragments from explosion events.

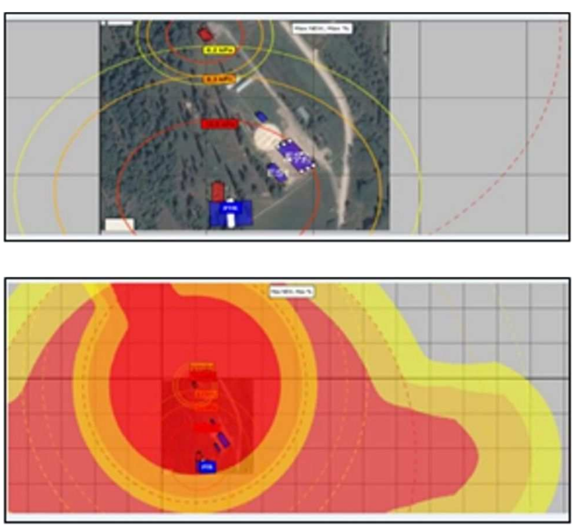

Fig. 14. Contour map illustrating the distribution of an explosives deposit with a capacity of 1220 kg ETNT

Three categories of pieces are taken into account by the paragon for bursting the particles left over after an blast: primary, secondary, and scrap from the crater's generated region.

As a result, the primary sections originate from the frame of exploded explosives, while the secondary fragments originate from the storage room's construction (such as the roof and the front, side, and back walls).

This investigation outlines the technical characteristics of modeling material segments resulting from detonations of explosive devices within potentially hazardous arrangements. These structures encompass PES (utilized for the storage of blasting stuff), which have the capacity to devastate exposed constructions in explosive events, and ES (designed for specialized activities), posing significant health and safety risks to personnel and nearby communities.

The graphical illustrations and histograms displaying probability principles of harm to the anthropoid element (comprising fatalities, severe injuries, and minor injuries) serve to graphically and analytically emphasize the ultimate outcomes of simulating the likelihood of harm stemming from piece projection in an discharge event.

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Evaluarea riscului infrastructurilor industriale sub efectele specifice generate de materialele explozive

Articolul prezintă o imagine de ansamblu concisă a rezultatelor obținute în urma cercetărilor efectuate în domeniul simulării pericolelor reprezentate de resturile de încărcături explozive, care sunt propulsate spre lucrători sau obiective industriale în timpul testelor efectuate în instalațiile de testare a explozibililor. În acest context, au fost adoptate metodologii științifice americane, în special abordarea FRMS (Fragment Risk Mitigation System), menită să îmbunătățească capacitățile software-ului specializat conceput pentru evaluarea siguranței explozivilor, cum ar fi IMESAFR (de exemplu, versiunea 2.0). Acest software a fost obținut ca parte a proiectului NUCLEU-PN 16 43 02 15/2016-2017. Procesul de îmbunătățire a implicat utilizarea diferitelor funcții de probabilitate adaptate acestui domeniu specific, denumite funcții de densitate a probabilității (PDF), pentru a reprezenta în mod eficient aspectele grafice și analitice ale fenomenului atunci când sunt ejectate resturi de la încărcăturile explozive.

Anca-Cristina TATARCAN, PhD. Student**,** National University for Science and Technology POLITEHNICA of Bucharest, 313 Splaiul Independenţei, Bucharest, Romania, anca.tatarcan@stud.fim.upb.ro.

Augustin SEMENESCU, Prof. Habil. Dr., M.Sc., B.Sc. (Engineering, Mathematics, Economics), National University for Science and Technology POLITEHNICA of Bucharest, 313 Splaiul Independenţei, Bucharest, Romania, augustin.semenescu@upb.ro.

Narcis POPA, PhD. Eng., University of Petroșani, 20, University Street, Petroșani, Hunedoara, Romania, narcispopa@upet.ro.

Madalin ANDREICA, PhD. Student., University of Petroșani, 20, University Street, Petroșani, Hunedoara, Romania, madalinandreica@upet.ro.

Denisa TUDOR, Psychologist, University of Petroșani, Petrosani, 20, University Street, Petroșani, Hunedoara, Romania, Is_denisatudor@upet.ro.

Gabriel Dragoş VASILESCU, PhD.Habil.Eng**.,** Researcher I, INSEMEX National Institute for Research and Development in Mine Safety and Protection to Explosion, 32-34, General V. Milea, Petrosani, Hunedoara, Romania, dragos.vasilescu@insemex.ro.