MATHEMATICAL MODELLING OF RADIOACTIVE DUST RISE DURING COLLAPSE OF "SHELTER" OBJECT BUILDING STRUCTURES

V.G. Batiy, V.P. Mikhailyuk, Yu.I. Rubezhanskiy, V.M. Rudko, A.A. Sizov, D.V. Fedorchenko

Interdisciplinary Scientific and Technical Center "Shelter" of Ukraine's NAS
e-mail: batiy@mntc.org.ua

Model calculations of general dust quantity which is possible to raise during possible crashing of "Shelter" building structures are shown. Mechanism of particle "jump-up" i.e. raising of particles due to dusted surface oscillation is used during calculations. It is shown, that particles with diameter 20 μm are possible to overpass border sublayer and raise over ruins of the "Shelter" building.

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The "Shelter" object's safety level depends to a great extent from the reliability of engineering barriers represented by external bearing and fencing structures, ferroconcrete elements of foundation-basement part, and internal structures of the walls and ceilings. The assessments carried out have shown [1] that during an earthquake of some five numbers in MSK-64 scale, a collapse is possible of "Shelter" object internal structures, which can entail a considerable dust rise of "Shelter" radioactive dust and its release in close vicinity to the Object. On top of that, with 10^{-5} year^{-1} probability, F1, 5 class tornado can arise at the ChNPP industrial site, whose passage over "Shelter" itself can also bring to the collapse of unstable building structures.

Currently there is an opinion that there two basic mechanisms of dust resuspension after falling of building structures on "Shelter" dusty surface: dust blow-off with airflow arising during structures collapse and dust particle "jump-up" associated with dusty surface fluctuations [2-5].

This report covers the particle "jump-up" mechanism, i.e., particle rise appearing due to dusty surface fluctuations.

Let us assume that a solid of $M = 100 \cdot 10^3$ kg is falling on a dusty surface from $H = 10$ m height. Such surface fluctuations arising after transfer to it of falling solid pulse, will lead to dust particle rise.

Let us introduce the main values defining the parameters of falling solid and of material of surface, from which dust rise will occur:

$\rho_{surf} = 2500$ kg/m^3, $l = 54$ m, $s = 24$ m, $h = 0.8$ m,

$E = 0.8\ 10^{11}$ Pa, $\sigma = 0.18$,

where ρ_{surf} – surface material density (concrete density), E – elastic modulus, σ – Poisson factor, l, s, h - length, width and height of plate, correspondingly.

Cyclic frequency of surface fluctuations is define from expression [6]

$$\omega = \pi^2 \sqrt{\frac{D_g}{\rho_{surf} h}} \left(\left(\frac{l}{m} \right)^2 + \left(\frac{s}{n} \right)^2 \right), \tag{1}$$

where m, n = 1, 2, ... are the harmonic numbers along axes x, y, correspondingly, and surface cylindrical hardness D_g totals

$$D_g = \frac{Eh^3}{12(1 - \sigma^2)}. \tag{2}$$

Maximum values of velocity vertical component $v_{\max}$ and acceleration $w_{\max}$ of surface fluctuations make

$$v_{\max} = A\omega, \quad w_{\max} = A\omega^2. \tag{3}$$

Here A is averaged fluctuation amplitude. Dependence of frequency f, vibration amplitude A, velocity vertical component $v_{\max}$ and acceleration $w_{\max}$ of fluctuation harmonic number along axis x is shown in Table 1 (it was assumed that fluctuation harmonic number along axis y $n = 1$).

Table 1. *Dependence of frequency f, vibration amplitude A, velocity vertical component $v_{\max}$ and acceleration $w_{\max}$ of fluctuation harmonic number along axis x*

m	$v_{\max}$, (m/s)	$w_{\max}$, (m/s^2)	f, (s^{-1})
1	8,86	241,42	4,34
2	13,24	539,46	6,48
3	20,55	1298,94	10,06

Dust particle interaction with diverse surfaces is characterized by adhesion force. In [8] experimentally measured values of adhesion force are shown F_{ad} in dependence of diameters of adhered particles. The above dependence can be well approximated with the expression

$$F_{ad} = 1.3 \cdot 10^{-4} \exp\left(\frac{d - 2 \cdot 10^{-5}}{2.1 \cdot 10^{-5}} \right), \tag{4}$$

where d – particles diameter (μm).

Dust particles capable to overcome the laminary sublayer are rising over surface and produce a dust cloud. Laminary sublayer thickness is defined from the ratio [8]

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$$\delta = 33{,}3(\nu_v / v_{\max})^{7/8}(0{,}37x^{4/5}(\nu_v / v_{\max})^{1/5})^{1/8}, \quad (5)$$

where x is the distance from frontier area of surface being blown in (x=10 cm), ν_v is air kinematic viscosity.

In Table 2, dependence of laminary sublayer thickness δ of velocity vertical component $v_{\max}$ is shown.

***Table 2.** Dependence of laminary sublayer thickness δ of velocity vertical component $v_{\max}$*

$v_{\max}$, (m/s)	8,86	13,24	20,55
δ, (mm)	0,15	0,1	0,07

One should note that measured in [7] inherent fluctuation frequency of “Shelter” structures is about 8 … 10 Hz. Considering the data shown in Table 1 and 2, one should take as m = 3.

Equation of particle movement, possessing initial velocity $v(t=0) = v_0 = v_{\max}$ in air medium, has the type

$$m\frac{dv(t)}{dt} = -F_g - F_s, \quad (6)$$

where $m = \rho_{part}\pi d^3/6$ is dust particle mass; ρ_{part} = 6500 kg/m³ is dust particle density; $F_g = mg$ is gravitation interaction force; F_s is forces resisting to particle movement.

Choice of expression for forces depends on movement type, which is defined by Reynolds figure value *Re*. Besides the expression for resistance forces must include adhesion forces F_{ad} [8].

For Reynolds figures *Re* is much more than 1, resistance force equation for medium can be presented as follows

$$F_s = \frac{1}{2}S_A C_D \rho_в v^2. \quad (7)$$

In this formula, S_A is the projection square of dust particle to the plane that is perpendicular to particle velocity ($S_A = \frac{1}{4}\pi d^2$ for spherical particles), C_D is the medium resistance factor [8]

$$C_D = 24(1 + 0.15Re^{0.687})/Re. \quad (8)$$

Equation (6) let us show as follows

$$\frac{dv(t)}{dt} = -\frac{f_1}{m} - \frac{f_2}{m}v^2(t), \quad (9)$$

where $f_1 = mg + F_{ad}$, $f_2 = \frac{1}{2}S_A C_D \rho_в$. Solution of equation (9) looks like as regards

$$v(t) = \frac{a_1}{f_2}\tan\left(\frac{a_1}{m}\left[t - \frac{a_2 m}{a_1}\right]\right). \quad (10)$$

In this formula, the following values are introduced:

$$a_1 = \sqrt{f_1 f_2}, \; a_2 = \arctan\left(\frac{v_{\max} f_2}{\sqrt{f_1 f_2}}\right). \quad (11)$$

The time, during which a particle reaches maximum height, and maximum height of rise, are defined from the ratios

$$t = t_{\max} = \frac{a_2 m}{a_1}, \quad (12)$$

$$h_{\max} = \int_0^t v(t)dt = \frac{m\ln\left(1 + \frac{v_{\max} f_2}{f_1}\right)}{2f_2} - \\ - \frac{m\ln\left(1 + \tan\left(\frac{a_1}{m}\left[t - \frac{a_2 m}{a_1}\right]\right)^2\right)}{2f_2}. \quad (13)$$

Table 3 shows the values of critical diameters d_{cr} of particles (under critical diameter is implied the minimum value of particle diameter, above which the particle is capable to overcome laminary boundary layer and to rise over ruin surface), rise maximum time $t_{\max}$, corresponding to critical diameter, laminary sublayer thickness δ and fluctuation harmonic number m.

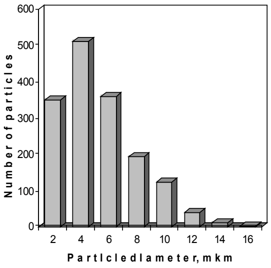
***Table 3.** The values of critical diameters d_{cr} of particles, rise maximum time $t_{\max}$, corresponding to critical diameter, laminary sublayer thickness δ and fluctuation harmonic number m*

m	d_{cr}, (μm)	δ, (mm)	$t_{\max}$, (μs)
1	40	0,15	0,4
2	30	0,1	0,12
3	21	0,07	0,06

Above results testify the facts that over rather short time the particle of $d > 20$ μm diameter is capable to overcome laminary boundary sublayer using “jump-up” mechanism.

One should note, in above “jump-up” mechanism it was not assumed that rising particle would “elementary”, but it deemed that the particle would have a sphere form. In other words, in seen mechanism the conglomerates of bound small particles can rise, whose bonds can later be destroyed in dust cloud. After destruction of those bonds, the newly produced particles will maintain “life time” durability of dust cloud and make its contribution to its activity.

To evaluate total dust amount being risen due to “jump-up” mechanism, let us apply described in [2] experimentally measured distribution of dust particle number in dependence of their diameter (see figure).



Distribution of dust particle numbers vs their diameter

The above [2] experimentally measured distribution of dust particle number $f(d)$ can be satisfactorily approximated by Gaussian function

$$f(d) = 13.76 + 458.12\exp\{-0.056(d - 4.12)^2\}. \quad (14)$$

Let us suppose that all particles, which can overcome laminary sublayer, will rise over surface with producing a dust cloud. The particles of more 300 μm mass are of immediate precipitation; therefore in estimating particle diameter ranges were limited by this value.

Total dust particle mass risen after structure collapse from a single site was defined from the ratio

$$m = \frac{\pi \rho_ч}{2} \int_{d_1}^{d_2} f(d) d^2 \partial d, \quad (15)$$

where d_1, d_2 – range of risen particle diameters, μm. As it was mentioned above, in estimating it was assumed that the range of risen particle diameters is as follows: $d_1 = 20$ μm; $d_2 = 300$ μm.

Obtained value of total dust amount, which can rise from dusty surface when implementing such a scenario of building structures collapse, totals around 1,7 ton.

One should note that a similar approach was used in [4] for quantitative evaluation of mass of dust being risen as a result of SO building structures collapse entailed by an earthquake. The estimates demonstrated in [4] have shown that under such a scenario of collapse the total mass of risen dust will make value of around 3,5 ton.

It was noted in this report that the main mechanism of dust resuspension is the dust blow-off mechanism. Delivered in [4] estimates for "jump-up" mechanism have shown that the diameter of dust particle being risen ≈ 328 μm. One should note that in [4], in contradistinction from this report, medium resistance forces were used for liquid laminary flow, and adhesion forces were not considered.

In the work [9] it was marked that basing on existing data it is complicated enough to quantify total dust mass as a whole for the Object, and there is a lack of information pertaining to dust concentrations in the air and to distribution of dust particle sizes. In this report, some recommendations were worked out for conduct of additional sampling, subsequent measurements of total dust mass and it radioactive components. Implementation of such experimental measurements will need further studying of dust resuspension mechanism.

One should note that described approach was used in analyzing the consequences of probable destruction of "Shelter" Object building structures associated with falling of loads and extremal wind-induced impacts (tornado) in drafting detailed work design for stabilization measures at the "Shelter" object and Conceptual Project of new safe confinement.

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МАТЕМАТИЧЕСКОЕ МОДЕЛИРОВАНИЕ ПОДЪЕМА РАДИОАКТИВНОЙ ПЫЛИ ПРИ ОБРУШЕНИИ СТРОИТЕЛЬНЫХ КОНСТРУКЦИЙ ОБЪЕКТА "УКРЫТИЕ"

В.Г. Батий, В.П. Михайлюк, Ю.И. Рубежанский, В.М. Рудько, А.А. Сизов, Д.В. Федорченко

Проведены модельные расчеты общего количества пыли, которая может подниматься при возможном обрушении внутренних нестабильных конструкций объекта "Укрытие". При расчетах рассматривался механизм "подскока" частиц, т.е. подъем частиц, возникающий из-за колебаний запыленной поверхности. Показано, что частицы пыли диаметром около 20 мкм способны преодолевать ламинарный пограничный подслой и подниматься над развалами объекта "Укрытие".

МАТЕМАТИЧНЕ МОДЕЛЮВАННЯ ПІДЙОМУ РАДІОАКТИВНОГО ПИЛУ ПРИ РУЙНУВАННІ БУДІВЕЛЬНИХ КОНСТРУКЦІЙ ОБ'ЄКТУ "УКРИТТЯ"

В.Г. Батій, В.П. Михайлюк, Ю.І Рубежанський, В.М. Рудько, А.О. Сізов, Д.В. Федорченко

Проведено модельні розрахунки загальної кількості пилу, який може підніматися при можливому руйнуванні внутрішніх нестабільних конструкцій об’єкту “Укриття”. При розрахунках розглядався механізм “підскоку” частинок, тобто підйом частинок, який виникає внаслідок коливань запиленої поверхні. Показано, що частинки пилу діаметром близько 20 мкм здатні долати ламінарний прикордонний підшар і підніматися над розвалами об'єкту “Укриття”.