LOAD ACTING ON CIVIL DEFENCE WORKS FROM THE COLLAPSE OF THE ABOVE STRUCTURE

*Nguyen Manh Tuan[1]**

Abstract: *Research on special load bearing structures has been carried out widely. Many countries have designated specific design standards for special constructions (civil defense works) [1,2]. The research in Vietnam has many limitations. Vietnam university research are mainly theoretical and result-updated. Experiments were only carried out in the Department of Defense with special Private clairvoyants that used real models. Determining the specific load from structural collapse is one of the research areas that have emerged since the terrorist attacks of the twin towers in the United States in 2001. Beside the high casualties and severe property damages by the immediate special forces on the frames, researchers also consider the effect of the destroyed structures on the basement. This paper presents the initial assumptions about determining the load from the above structural collapse which aims to secure the basements in the event of structural collapse due to the risk of wars and terrorism.*

Keywords: *Special loads; civil defense; overhead structure collapse.*

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1. Introduction

The construction of civil defense system has been addressing concerns to many countries in the world such as Russia, the United States and EU countries [1,2]. The civil defense system is built, utmost, to protect the citizens from nuclear wars that might happen. When those particular situations occur, citizens should be protected from the spread of shock waves, thermal radiations, radioactive radiations from the nuclear blast, as well as chemical and biological weapons. Normally, there are two ways to protect the citizens as existing regulations stipulate:

- Evacuating most of the population first (less than 10 hours with the distance up to 80 km).

- Providing nuclear shelters for the rest of population of the city (15 minutes moving to the shelters, 1 km radius from the evacuation zone to the shelters).

Among these, the special nuclear shelters are Metro subway systems and civil defense structure (temporary shelters) under civil buildings. The design of the above structures is clearly regulated in the SNiP standards of the Russian Federation. According to the standards, in principle, those civil defense structure systems are built under high-rise buildings above the ground functioning similarly to the basements of the buildings. The design is necessary to save construction costs. Besides, during peace time, those shelters can be used as underground garages, stores, commercial centers, etc…

The effect of nuclear weapons leads to the destruction of buildings by the shock waves propagated through the air that results in the collapse of buildings on the ground. While structural design methods for civil defense structures under effects of nuclear explosions have been studied in great details, yet the impacts of the structural collapse of the above ground buildings to the civil defense structures have been under radar. Moreover, there is no technical requirement for such calculations in СП 88.13330.2014. This raises a big question to researchers about this content, as the complexity of the problem has not been determined by a number of uncertainties.

Civil defense structures in NATO nations are an integral part of the national security and defense system built in peacetime and wartime to protect the citizens from weapons of mass destruction and other means of attacks. The construction of civil defense structures addresses interests in the UK, Germany and

[1] Dr, Faculty of Building and Industrial Construction, National University of Civil Engineering.
** Corresponding author. E-mail: tuannm1@nuce.edu.vn.*

some NATO countries. However, corresponding investments in those nations are still limited, between 1% to 4.5% of the total defense expenditures [1].

In the United States, according to some published documents about national security and defense policy, the management of civil defense system is defined as all actions, measures and implements to minimize the consequences of an attack to the United States and to overcome emergency conditions as well as to recover the destroyed or damaged facilities during the attack [1]. According to Edward Teller, the inventor of hydrogen bombs, to create an effective civil defense system to protect against nuclear attacks, it is required to invest not less than 10% of the total military expenditure in several years [1]. The destruction of structures above the ground occurs in case of the largest shock wave force of nuclear explosion in Table 1 appears [3,4]. The data in Table 1 is for some structures with non-earthquake-resistant design. However, the data will be much larger in the design of earthquake resistance.

Table 1. *The load from an explosion affecting the structure*

Structure	Load and degree of destruction (MPa) (The degree of destruction is divided in 4 levels)			
	Entire	Majority	Average	Weak
Multi-story brick building	0.03 - 0.04	0.02 - 0.03	0.012 - 0.02	0.008 - 0.012
Multi-story office building with steel structure	0.115	0.08 - 0.091	0.045 - 0.050	0.01 - 0.015
Multi-story office building with reinforced concrete structure	0.127 - 0.159	0.088 - 0.10	0.051 - 0.064	0.012 - 0.016
Industrial building with reinforced concrete structure	0.06 - 0.10	0.04 - 0.06	0.02 - 0.04	0.01 - 0.02
Industrial building with light steel structure	0.06 - 0.08	0.035 - 0.045	0.02 - 0.035	0.01 - 0.02

According to regulations, protective civil defense structures (PCDS) will be designed to withstand the pressure ΔP when special situations occur [5]. The effect of shock waves of nuclear explosion on ground structures includes the reflective effect of the shock wave from the center of the explosion to the surface of the structures and the effect of actions surrounding the structures. The shock wave passes through the openings of structures on the ground reflecting in the structures. The whole process of transmitting the impact of a nuclear explosion lasts only a few seconds. The surface pressure of waves and the molecules of waves move in a horizontal direction to create a horizontal orbit across the broken structural elements.

The loads applied to the PCDS are generated by the formation of the fall of destructive structures and the formation of the destructive mass on it. The destructive process of the above ground structures is very chaotic. Therefore, the prediction of destructive structure characteristic is nearly impossible. To solve the problem of determining the loads acting on the basement floors of PCDS from the above ground structural collapse, it is necessary to use the actual modeling in order to obtain a theoretical solution.

2. Diagrams of destruction of above ground structures

The processes of the structural destruction is different over time by the dynamic loads with high intensity generated by nuclear weapon tests, building demolitions applying blasting, terrorist attacks.

The diagrams of destructions of the above ground buildings (Table 2) lead to two following cases:

- The impact of the explosion stimulated quickly and strongly which destroy the entire building. Then the debris start to fall to the ground. Then, the kinetic energy of the structural debris when they fall down will turn to the collision energy between the debris and the basement floors with defensive function (Fig. 1d).

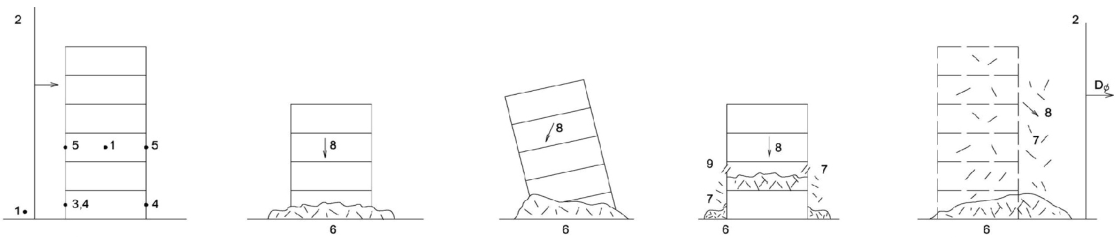

Figure 1. *Structural destruction diagrams affected by the explosion, building in the initial state (a)*

Table 2. *Destructive collapses of above ground structures*

Diagram	Cause of collapses	Impact	Characteristic of the collapse process
b	Symmetrical destruction of the main bearing structural elements at the below floors.	Demolition by blasting, earthquake-resistant buildings, explosion occurs at the below floors of the building.	The slowly falling and destruction of parts of the building in vertical direction. Kinetic energy destroys the structures.
c	Asymmetric destruction of the main bearing structural elements on below floors (structures collapse to one side).	Explosion due to terrorist attacks, due to explosion occurring near the building.	The destruction occurs slowly following the direction of the acting force. Process of falling texture from center of the blast. The debris will spread following the direction of the blast
d	Destruction of the main bearing structural elements on middle floors.	Explosion inside the building at the middle floors due to: fire, earthquake, terrorist attack.	The destroyed structure will fall downward. The kinetic energy will be transformed into the destructive energy of the elements located at the two sides of the destroyed areas. The destructive zone will move downward.
e	Completely destroyed the structure, then the parts of the structure fall down freely.	Affected by nuclear explosion.	Immediate destruction of the entire structure of the building, at the same time all parts will fall down freely vertically.

- The external explosion effect leads to the destruction of main structures (columns, walls), and which then leads to the collapse of the other structural parts of the building. During the collapsing process, there appears the interaction between the structural parts and the debris. The kinetic energy turns to the energy destroying the structure and colliding between the structural debris and the civil defense basement floors. It is expected that the crash time of the case shown in Fig.1c will be greater than that shown in Fig. 1b.

3. Assumptions and the theoretical model

- Accepting that the impact of explosive shock waves leads to instant destruction, and all structural elements along with the connections between them, corresponding to the initial of the simultaneous collapse of all debris (t=0). This assumes the velocity of shock wave propagated through the air is large and the time of destructive wave is very small. At the end of destruction of all structures, the average velocity of debris is near zero.

- The local effects of large debris are ignored because, firstly, their effect is mitigated by the soil layer thickness up to 1m. Secondly, those large debris can fall directly on top of that covering layer with a small falling height. The debris with great falling height will affect directly the debris layer.

- The notion that when collapsed, the loads from the structural collapse is acting uniformly over the floor area of civil defense structure (or a specific floor area). The effects of the floor deformation and the resistance of the air are not taken into consideration. Accepting that at time t=0, the weight of the structure is uniformly distributed over the area and distributed according to the known law of height. In this study, it is accepted that the mass distribution is evenly distributed with height (ρ_0 - the average initial density of the construction mass).

- Therefore, the initial mass density ρ_0 is uniformly distributed. The coordinate system is shown in Fig. 2.d. The falling velocity of the material (collapse) is $u(x, t)$. From the beginning of the collapse, the height of debris layer has risen over time. Assuming that the density of debris is equal and unchanged, the boundary between structural region of density ρ_0 and continuously moves upward with the velocity $D(t)$ is called the boundary of collapse.

- When exposed to the boundary, the particles of collapse texture material will stop immediately (u = 0). As a result, dynamic load occurring is transmitted immediately through the debris layer to the basement floors. The approximation which is demonstrated by the propagation velocity at the debris layer is much larger than the structural collapse speed.

The assumption is that the area of the debris layer is equal to the area of building f.

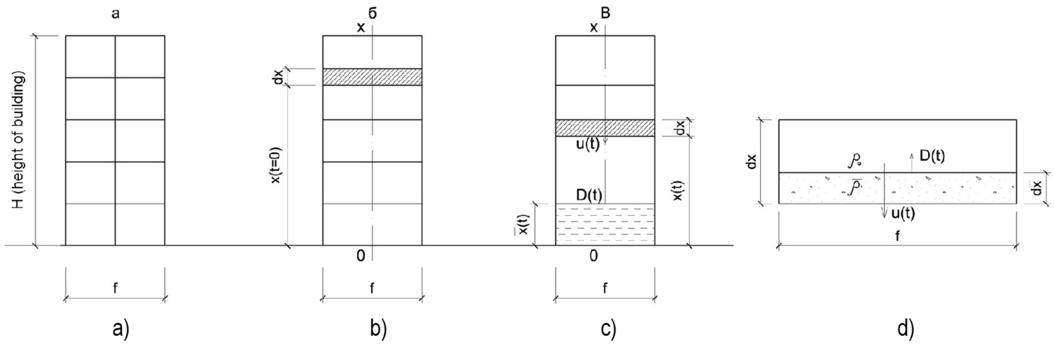

Figure 2. *Building in the initial state (a), the former coordinate system (b), in the collapse process (c) and the considered element (d)*

4. Basic equations

Considering an element dx (Fig. 2b, c) at x-height at time *t*=0 compared to the basement floors, the element *dx* will move to the boundary from the x-height. The initial volume density of the element *dx*, ρ_0, at the boundary will increase to $\overline{\rho}$, and the height *dx* will decrease to $d\overline{x}$ (Fig. 2d). The time of element *dx* passing through the boundary, *dt*, will convert to $d\overline{x}$. To determine the load from the collapse of the above ground structure to the civil defense structure below the ground, we use three conservation laws:

4.1 Condition of preserving element mass dx:

$$dm = \rho_0 \cdot f \cdot dx = \overline{\rho} \cdot f \cdot d\overline{x} \quad (1)$$

$$\frac{\rho_0}{\overline{\rho}} = \frac{d\overline{x}}{dx} \quad (1a)$$

Besides

$$\rho_0 \cdot f \cdot x = \overline{\rho} \cdot f \cdot \overline{x}; \quad \rho_0 \cdot f \cdot H = \overline{\rho} \cdot f \cdot \overline{H}$$

$$\frac{\overline{x}}{x} = \frac{\rho_0}{\overline{\rho}} \quad (1b)$$

$$\frac{\overline{H}}{H} = \frac{\rho_0}{\overline{\rho}} \quad (1c)$$

The time interval, during which the size of the element *dx* becomes equal to $d\overline{x}$, is:

$$dt = \frac{d\overline{x}}{D} = \frac{dx\text{-}d\overline{x}}{u}; \quad \frac{D}{u} = \frac{1}{\frac{\overline{\rho}}{\rho_0} - 1} \quad (2)$$

$$dt = \frac{d\overline{x}}{D} = \frac{dx - d\overline{x}}{u} \Rightarrow \frac{dx}{dt} = u \cdot \frac{1}{1 - \frac{\rho_0}{\overline{\rho}}} \quad (2a)$$

4.2 Equation of the momentum conservation

$$dm \cdot u(t) = f \cdot P(t) \cdot dt \quad (3)$$

$$u \cdot \rho_0 \cdot dx = P(t) \cdot dt \quad (3a)$$

$$P(t) = \rho_0 \cdot u \cdot \frac{dx}{dt} \quad (3b)$$

4.3 Law of conservation of energy

$$\frac{dm \times u^2}{2} = dm \times g \times (x - \overline{x}) \quad (4)$$

where: $(x - \overline{x})$ is the falling height of *dx*

$$u^2 = 2g \times (x - \overline{x}) = 2g \cdot x \cdot \left(1 - \frac{\rho_0}{\overline{\rho}}\right) \quad (4a)$$

We replace in (3b) $\frac{dx}{dt}$ by (2a)

$$P(t)=\frac{\rho_0}{1-\frac{\rho_0}{\overline{\rho}}}\cdot u^2 \tag{3c}$$

Transforming the formula (2a), the integral (time from 0 to *t* and element from 0 to *x*), we get:

The height of the above ground structure over time during collapse:

$$x=\frac{g}{2\left(1-\frac{\rho_0}{\overline{\rho}}\right)}\times t^2 \tag{5}$$

The formula determining the dynamic loads from debris over time:

$$P(t)=\frac{\rho_0\cdot g^2}{1-\frac{\rho_0}{\overline{\rho}}}\cdot t^2,\quad (0<t\le t_H) \tag{6}$$

In which t_H is the complete collapse time of the above ground structure;

Static load due to the mass of the debris on the ground:

$$G(t)=\overline{\rho}\cdot g\cdot\overline{x}=\rho_0\cdot g\cdot x=\frac{1}{2}\cdot\rho_0\cdot g^2\cdot\frac{1}{1-\frac{\rho_0}{\overline{\rho}}}\cdot t^2 \tag{7}$$

- Total dynamic load acting over time:

$$q(t)=P(t)+G(t)=\frac{3}{2}\times\rho_0\times g^2\times\frac{1}{1-\frac{\rho_0}{\overline{\rho}}}\times t^2;\quad (0<t\le t_H)$$
$$q(t)=\rho_0\times g\times H=const;\ (t>t_H) \tag{8}$$

Dynamic load expressing on parameter *x*:

$$P(x)=2\cdot\rho_0\cdot g\cdot x;$$

- Total dynamic load acting on parameters *x*:

$$q(x)=P(x)+G(x)=3\cdot\rho_0\cdot g\cdot x\qquad (0<x\le H) \tag{9}$$

The formula is expressed in unitary form:

$$\tilde{x}=\frac{x}{H};\qquad \tilde{t}=\frac{t}{t_H};\qquad \tilde{q}=\frac{q}{\rho_0\times g\times H}$$

(wavy lines denote dimensionless quantities):

$$\tilde{q}(\tilde{t})=3\cdot\tilde{t}^2;\qquad (0<\tilde{t}\le 1)$$
$$\tilde{q}(\tilde{t})=1.\qquad (\tilde{t}>1) \tag{10}$$

In the formula, ratio $\frac{\rho_0}{\overline{\rho}}$ is described as a basic property that affects the load. This value is defined as volume of debris $\overline{V}$ by volume of the building V_0:

from the formula (1) $\frac{\rho_0}{\overline{\rho}}=\frac{\overline{V}}{V_0}$

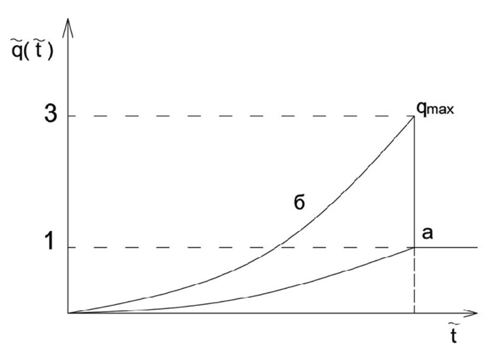

Figure 3. *Dynamic loads from structural collapse on dimensionless form*

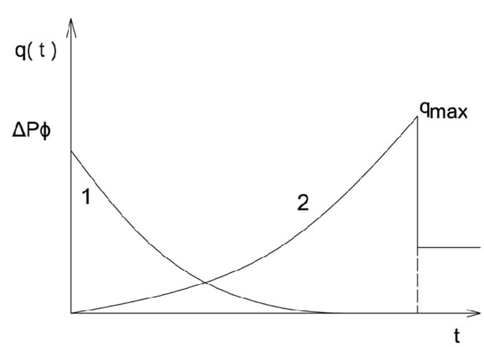

Figure 4. *Explosion load-1, the ground in the Dynamic load from structural collapse-2*

The values of $\frac{\overline{V}}{V_0}$ as researched in [6,7] are shown in Table 3.

Table 3. *Data of one-story industrial building and civil building*

Building type	$\frac{\rho_0}{\rho}=\frac{\overline{V}}{V_0}$; according to	
	[6]	[7]
Industrial building:		
- one-story light type	0,05-0,20	0,14
- one-story medium type		0,16
- one-story heavy type		0,20
- multi-story		0,21
- mixed type		0,22
Residential and Public buildings: - Frameless with walls of brick, light and large blocks	0,35-0,50	0,36
Frame with walls from large panels and stone materials		0,42

5. Numerical examples

In this section, the author will simulate a case where the building was attacked by a nuclear explosion causing a collapse of the above structure. The resulting collapse creates a load on the underground. Examples are to evaluate this load.

5.1 Case 1: Calculate the maximum load on the basement slab of civil defense structure which is located below a high-rise building with the features of the basement below:

- Multi-story reinforced concrete building with load bearing wall panel, span 2 × 12m,

- Building bay: 4 × 6m,

- Building height is 22,5m (5 floors, each is 4,5m high),

- Plan area is 24m × 24m.

Column: 45 columns with unit weight γ = 2,5 (ton/m^3), column's size is 0,4m × 0,5m × 4,5m (b=0.4m, h=0.5m, L=4.5m); As the result, total weight is:

45 × 2.5 × (0.4m × 0.5m × 4.5m) = 101.25 (ton/floor)

Wall, party wall: 12 walls, having the size of 4,1m × 5,5m; the thickness is 0,25m. So, total weight is:

12 × 2,5 × (4.1 × 5.5 × 0.25) = 169.12 (ton)

Slab has the area of 24m × 24m, and 0,4m thick; so that the total weight is:

2.5 × (0.4 × 24m × 24m) = 576 (ton)

The characteristic unit weight of the building is defined as:

$$\rho_0=\frac{M_0}{V_0}=\frac{576+169,25+101,25}{24\times 24\times 4,5}=0,327\left(\frac{ton}{m^3}\right)=327\left(\frac{kG}{m^3}\right)$$

$\frac{\rho_0}{\rho}=0,42;$ (as calculated in Table 3)

Collapse time of the building calculated as formula (5) is:

$$t_H=\sqrt{\frac{2\times H}{g}\left(1-\frac{r_0}{r}\right)}=\sqrt{\frac{2\times 22,5}{9,81}\left(1-0,42\right)}=1,659(s)$$

Maximum load q on basement slab is defined as formula (8), in case $0 < t < t_H$:

$$q_{\max}=\frac{3}{2}\times\rho_0\times g^2\times\frac{1}{\left(1-\frac{\rho_0}{\rho}\right)}\times t_H^2=\frac{3}{2}\times 327\times 9,81^2\times\frac{1}{\left(1-0,42\right)}\times 1,659^2=223.996(Pa)\approx 0,224(MPa)$$

The load of the above structure that affects basement slab (in case $t > t_H$) is defined as:

$$q = \rho_0 \times g \times H = 327 \times 9{,}81 \times 22{,}5 = 72177 (Pa) \approx 0{,}0722 (Mpa)$$

5.2 Case 2: Calculate the maximum floors that can be constructed on a civil defense structure which has features as described below (in case of demolition and collapsing, it is required to have no damage to the basement under it)

Defense basement has load bearing capacity equal to 0,2 Mpa as designed in [5].

In which:

Coefficient of dynamism K_d = 1,2

Coefficient of dynamic reinforcement of stretched reinforcement class AIII – K_{ds} = 1,25.

Dead load on defense basement is q_s:

$$q_s = \frac{\Delta P_f \times K_d}{K_{ds}} = \frac{0{,}2 \times 1{,}2}{1{,}25} = 0{,}192\ (MPa) = 19200\ (Pa)$$

In case of constructing on defense structure, maximum load from building collapse must n=ot over q_s. Consequently, when load increases as collapsing, Coefficient of dynamism is allowed to calculated as 1. As described in formula (9), when $x = H$, maximum height of building is defined as:

$$H_{\max} = \frac{q_s}{3 \times \rho_0 \times g} = \frac{19200}{3 \times 327 \times 9{,}81} = 19{,}95\ (m)$$

The maximum number of stories then is calculated as:

$$n_{\max} = \frac{H_{\max}}{4{,}5} = \frac{19{,}95}{4{,}5} \approx 4{,}4$$

In consequence, in order to achieve safety, the maximum number of stories of building should be 4.

6. Conclusions

The paper discusses the topicality and the necessity of determining the dynamic load acting on the basement floors of a civil defense structure that results in the structural collapse of the above ground building.

The characteristics of the collapse of the above ground structures due to nuclear attacks are considered. Also, the potential impacts of the explosive shock waves and the collapse of the above ground structures simultaneously while affecting the civil defense structures are considered.

In the design of civil defense structures, it is necessary to calculate the effect of structural collapse of the above ground structures. In contrast, when constructing high rise buildings above civil defense structure, it is necessary to assess the maximum number of stories of the building to ensure the security.

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