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IMPACT OF MISSILE ON CONCRETE OR SOIL OBSTACLE

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Abstract: *Missile-Target interaction analysis is usually based on three essential assumptions and simplifications used to analyze this problem. In this paper the problem of interaction analysis is applied to impact of large body (an airplane, vehicle or a rocket) or small body (concrete fragments) of cylindrical shape as a rule, on concrete obstacle or on soil ground (soils, hard rocks, layered bedrock). In this sense, the paper focuses on impacts of flying body on building structure or on soil in its vicinity. A moving body or its parts may hit various types of structures, and missiles may also enter inside areas of objects through light structures. The impact theory was used to solve the residual mass and velocity of impacting missile, kind of target failure and missile penetration in obstacle. This methodology is based on kinetic energy transfer of the hitting object to the building structure. In this sense, contact areas of the building structure and of the moving object usually need to be specified, based on simplifications of the impact surface of its solid parts.*

Keywords: Missile, Obstacle, Impact, Concrete, Soil.

1. Introduction

In general, upon impact of a moving object on a massive slab-type obstacle the impact surface gradually changes (increases or decreases) as the hitting object is compacted or hits and penetrates the obstacle. When an object hits walls or the ceiling of various structures of an obstacle, parts of the falling object are apparently cut off (for example, wings of airplanes, mudguards and rear-view mirrors of vehicles, etc.). Upon such an impact, total kinetic energy of the falling object is partially consumed for deformation or also for crushing or breaking off of a part of the obstacle. However, the missile still continues to enter the structure at a reduced speed, which is equivalent to energy loss of the whole object upon its impact on a building structure of this type (DOE-STD, 1996). If the object falls on steel beam structures, both the object and its wrecks are slowed down upon impact on load-bearing sections of the structures, which are then deformed or damaged, and the remaining parts continue to further enter the structure at a reduced speed. Similarly, upon impact on concrete walls and boards (or those made of other materials, such as masonry or the ground), engines of vehicles are usually blown off and enter the structure.

Immediately after the impact, the impact is resisted by the structure mass, which corresponds to the area of the impact (collision); this assumption is very conservative and leads to higher velocities of motion of the wrecks upon impact on the structure. The assumption that rather double mass of the impact area resists the impact is apparently closer to reality in flat, large-sized structures.

2. Impact Theory Application

Normal shock of two bodies, an airplane or its wrecks against a building structure, is adapted for nuclear power industry by a DOE (1996) regulation in the U.S. and IAEA (2003) standard, and apparently this regulation can also be applied to other structures. The shock solution methods correspond to procedures commonly used in next publications focused on structure dynamics.

Based on energy comparison, the impact energy E_a transferred to the obstacle is:

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$$E_a = \frac{1}{2} M_e V_t^2 \ \text{if} \ \frac{m}{M_e} \le e \ \text{or} \ E_a = \frac{1}{2} M_e V_t^2 + \frac{1}{2} m V_m^2 \ \text{if} \ \frac{m}{M_e} > e \tag{1}$$

velocities after impact:

$$V_m = \frac{V_0 \left[\frac{m}{M_e} - e \right]}{1 + \frac{m}{M_e}} \ \text{and} \ V_t = \frac{m / M_e}{1 + (\mathrm{m/M_e})} [V_0 (1 + \mathrm{e})] \tag{2}$$

where m is effective (inertial) mass of missile (inertial mass); M_e is effective (inertial) mass of obstacle; V_0 is normal component of missile velocity before impact; V_m is missile velocity after impact and factor of restitution is:

$$e = \frac{V_t - V_e}{V_e} \tag{3}$$

According to the modified NDRC empiric formula (Bangash, 1993, Durchstanzen, 2002) the perforation thickness of reinforced concrete slab caused by a flying solid object is:

$$t_p = \left(\frac{U}{V} \right)^{0.25} \left(\frac{M V^2}{D f_c'} \right)^{0.5} \tag{4}$$

where U is the reference velocity 200 ft/s; V is the missile impact velocity [ft/s]; $M = W / g$ is the missile mass determined based on its gravity W [lb] and gravitational acceleration g = 32.2 ft/s^2; D is missile effective diameter [ft] and f_c' is the limit pressure strength of the concrete [lb/ft^2].

Shear stress needed to penetrate the reinforced concrete slab is approximately: $4\sqrt{f_c'}$ [psi], or potentially up to $10\sqrt{f_c'}$ [psi]. Using the formula to determine the perforation thickness, the penetration thickness for a missile is equal approximately to 50% of the thickness. On the contrary, if the purpose of using the formula above is to prevent perforation, a slab thickness higher than or equal to 1.2 t_p should be used.

For dynamic analysis of interaction of both bodies is possible to use FEM procedure. Example of this solution see (Makovička, 1994) but the truth of the directly dynamic solution and/or energetic method is comparable, especially if the mechanical characteristic of the soil or the form of disturbed missile (by passage through barrier) is determined only very roughly.

3. Fall of Missile on Hard Surface of the Ground

Hard surface is understood either as solidified ground surface, e.g. a road, or hard rock or semi-rock ground. Assuming that the time course of the impact force F_d acting on a solid obstacle, and the time duration of its action $\tau_{ef} = \tau_+ = \Delta t$ are known. Let us assume an impulse $F_d \times \Delta t$ acting approximately on the impact area A; however, considering pliability of various grounds, it is more suitable to consider the area A as a double impact area. Thus for example, for a solid missile (airplane) and its impact at the speed 450 m/s: impact force Fd = 300 MN; time of duration Δt = 0.031 s and impact area $A = 2 \times 16.8$ m^2.

Substituting the elasticity modulus E of the bedrock with the deformation modulus E_{def} = 8500 MPa (rock class R2 based on ČSN 73 1101) per height of the cover over the hard bedrock or over a massive concrete structure ($h \approx 1.0$ m), the result provides general stiffness of the soil (rock) column:

$$k_{soil} = \mathrm{E} \times \mathrm{A} / \mathrm{h} = 8\,500 \times 2 \times 16.8 / 1.0 = 285\,600 \ \mathrm{MN/m} \tag{5}$$

The airplane will thus sink into the ground at the value:

$$y = F / k_{soil} = 300 / 285\,600 = 0.001 \ \mathrm{m} \tag{6}$$

Apparently, the hard bedrock is able to resist an airplane fall, and the sinking depth is virtually negligible.

Considering clay-sandy soil, the deformation modulus is E_{def} = 20 MPa and the result stiffness and penetration are as follows: k_{soil} = 672 MN/m and y = 0.446 m. Thus upon impacting on the ground at this velocity, the missile is virtually crashed (compacted) without exerting any rather significant influence on the structure of the ground obstacle. In this case, let us estimate the sinking (penetration) rate from kinetic energy of the impact of the airplane on the clay and sandy ground surface:

$$E_k = \tfrac{1}{2}\, m v_r^2 = 0.5\ (12 \times 450^2) = 1\ 215\ 000\ \mathrm{tm^2/s^2} \qquad (7)$$

And let this energy be consumed only for sinking of the missile into the ground without any considerable damage of the missile, thus:

$$k_{soil} = \mathrm{E} \times A / h = 20 \times 2 \times 16.8 / 1.0 = 672\ \mathrm{MN/m} \text{ and } E_k = F_d\, x_p \qquad (8)$$

Substituting F_d with the design force for an impact on a solid obstacle F_d = 300 MN, the depth of penetration is as follows: $x_p = E_k / F_d$ = 1 215 000 / 300 000 = 4.05 m. Taking into account the initial assumptions (in particular, no damage to the missile), the determined penetration depth is markedly increased. The probable penetration value will be significantly lower considering compaction of the missile; let us estimate it as half the value (see a similar assumption in (Durchstanzen von Triebwerken, 2002)). Apparently, even thus recalculated penetration depth x_p will be lower taking into account various losses, but it may also be slightly higher (the fall may not follow the normal line; the missile may hit the ground with an edge, wing, etc.), thus approximately in the range from 0.5 m to 3.5 m. Thus upon hitting a pliable ground, the airplane sinks into the ground given that load capacity of the bedrock at the airplane sinking place is exceeded. This sinking will also cause the stress to distribute to the sides, away from the place of impact.

4. Example

The theory above was used for an impact of chosen airplanes on reinforced concrete wall. Results of the calculated parameters are presented in the following Tab. 1.

Tab. 1: Missile impact on RC transversal wall in thickness 900 m.

Airplane (missile)			Airliner		Airliner		small plane		Fighter	
Missile part			unit		engine		unit		unit	
Missile mass	m	[t]	43.6		7.96		3.27		7.96	
Angle of incidence	α	[deg]	30		60		50		60	
Incidence velocity	V	[m/s]	81.3		312		104		312	
Missile diameter	D	[m]	3.75		4.62		3.00		4.62	
Impact area	A	[m^2]	103.8		16.8		11.9		16.8	
Effective mass of obstacle	M_e	[t]	269	538	18.4	36.8	30.8	61.6	43.5	87.0
Missile and obstacle velocity after impact	V_m, V_t	[m/s]	11.3	6.1	8.6	4.6	10.0	5.2	48.3	26.2
Mass of missile after impact	M	[t]	39.2		2.45		2.94		7.96	
Obstacle velocity after impact	V_t	[m/s]	11.3	6.1	8.6	4.6	10.0	5.2	48.3	26.2
Thickness of obstacle	t	[m]	0.90		0.90		0.90		0.90	
Pressure strength of obstacle material	f_c'	[MPa]	10.5		10.5		10.5		10.5	
Perforation depth	t_p	[m]	1.26		0.76		0.46		1.33	

The effect of mass of obstacle is considered in two variants (single and double multiple). This shows that for the big airplane and for fighter the thickness of obstacle is not sufficient. The same may be used for soil barrier; for penetration depth it is possible to use for sandy-clays approximately $f_c^{'} \approx 4$ MPa.

5. Conclusions

Design criteria (DOE, 1996, IAEA 1982 and 2003), used in the world are based particular on the US, Japan and Germany namely experimental investigations. Purpose of these works is development of safety thickness of RC or soil structures on the basis of impact theory and determination of perforation depth into the obstacle. For NPP structures are usually used an airplane and its engine. In our case we used the simplified methods in accordance with international published recommendations and own experiences (Makovička, 1994, 2010 and 2012). The initial kinetic energy of the missile under relatively high speed crash is used for structure solution. Depth of missile penetration into the RC wall or soil layers is function of limit pressure strength of RC or soil materials. The dynamic force of missile, acting on barrier, is then proportion of its kinetic energy and dynamic deflection.

Upon inclined impact of missile and its wrecks on a structure it is assumed that whether or not the structure is broken through depends on the normal component of the part impacting on the surface of the obstacle that is most hazardous for the structure as a rule, and if penetrated, the wrecks together with wrecks of the penetrated building structure continue moving further in the direction of their impact on the structure. However, considering that these phenomena are very fast, the conservative adoption of certain simplifications may be considered.

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