Coventry University and
The University of Wisconsin Milwaukee Centre for By-products Utilization
Second International Conference on Sustainable Construction Materials and Technologies
June 28 - June 30, 2010, Università Politecnica delle Marche, Ancona, Italy.
Proceedings of Honouree sessions ed. T Naik, F Canpolat, P Claisse, E Ganjian,
ISBN 978-1-4507-1487-7 http://www.claisse.info/Proceedings.htm

Carrying Capacity of Structural Elements of Buildings after Explosions and Impacts

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ABSTRACT

The mode of approximation of dynamic loadings by triangular function is presented with the aim to assess bearing capacity of buildings main structural members at emergency explosions and impacts. For expert estimation of material and human losses at such events the following evaluation criteria are offered:

- material damage to buildings (in % of estimated cost) at different rates of destruction;
- number of injured people in regard to the total number of people being in damaged buildings.

INTRODUCTION

It might be assumed roughly that variation of dynamic loadings at internal explosion of mixed air and gases (AaG) follows the law:

$$P_{\max} \cdot \frac{t}{\theta_1},\ \ 0 \le t \le \theta_1;\ \ P(t) = P_{\max} \cdot \left(1 - \frac{t-\theta_1}{\theta-\theta_1}\right),\ \theta_1 < t \le \theta;\ \ 0, (1\, t > \theta,)$$

Where P_{max} – is the maximum superfluous pressure; Q_1 - time of increase of pressure to P_{max};

Q - total time of dynamic load action

Dynamic loadings can be approximated by triangular function. This allows to give certain estimations upon limiting values of carrying capacity of the basic structural elements of buildings (Table 1).

Table1

NN	Main structural elements of buildings	Design values of permissible loads P_{per}, *kPa*
1.	Hanging precast light weight concrete walls	1,2 … 1,4
2.	Self-bearing brick walls (external and internal): - thickness 120-250 mm - thickness 380-510 mm	 0,8 … 1,2 1,4 … 1,8
3.	Bearing brick walls with thickness 380-510 mm	1,6 … 2,4
4.	Freely supported roof slabs	2,7*… 3,1*
5.	Roof slabs welded to rafter beam	3,6 … 4,0
6.	Cast-in-situ or precast concrete frames	10 кPa and over

Note: Values of loadings denoted by* were determined from the strength conditions of fixing joints for corresponding structures, because carrying capacity of these joints is lower than carrying capacity of the structures

Carrying capacity of structures is defined by the strength of their normal sections in which the maximum bending moments from a special combination of loadings operate. If fixing joints of structures are executed according to project with welding on assembly (for example joints, connecting reinforced-concrete roofing slabs with rafter beams or skeleton columns with beams or wall panels), their design carrying capacity is higher than carrying capacity of the structures. In this case destruction of structures happens on their normal sections.

At free support of roofing structures, for example, roof slabs over rafter beam or beams over brick bearing walls, their carrying capacity is higher than carrying capacity of supporting joints. Taking into account that loadings from the (AaG) explosions are directed from below upwards, i.e. aside, opposite to a direction of action of operational static loadings, so limiting dynamic loadings were defined by a condition of their separation from the supporting surface.

Obtained values of P_{per} are to be considered as the least possible loadings since they were defined using standard strength characteristics of materials. Proceeding from the design values of P_{per} for the basic structural elements, the values of permissible extreme superfluous pressure, at which buildings will undergo this or that degree of destruction, have been obtained:

- At 1 *kPa* $<P_{per.w.}<$ 6 *kPa* buildings undergo weak degree of destruction;
- At 6 *kPa* $<P_{per.av}<$ 9 *kPa* buildings undergo average degree of destruction;
- At 9 *kPa* $<P_{per.s.}<$ 12 *kPa* buildings undergo strong degree of destruction.

Various degrees of destruction of buildings are understood as the following:

<u>Weak degree of destruction:</u>

Destruction of window and doorways interior. Damage in a form of cracks, delamination and spalling of plasters of internal partitions. Cracks over self-bearing brick walls and light weight concrete wall panels.

<u>Average degree of destruction:</u>

Destruction of windows, doors and internal partitions. Damage to separate areas of a soft roof cover in the form of ruptures of waterproof roofing felt. Destruction of separate areas of self-bearing brick walls and separate wall light weight concrete panels. Damage in the form of cracks and residual deflections of bearing brick walls and roofing slabs welded at assembly to rafter beam.

<u>Strong degree of destruction:</u>

Destruction of self-bearing brick walls, light weight concrete wall panels and the big areas of a roofing felt. Damage (residual deformations, cracks, including through cracks, deterioration of a concrete cover, spalling of concrete on supporting areas, etc.) of separate main bearing structures (roofing and flooring slabs, beams, crossbars and skeleton columns) and joints of their connection. Destruction of bearing brick walls and collapse of roofing structures.

At expert estimation of a material damage and human losses it is possible to use data given in Table. 2 and Table. 3.

Table 2.

The material damage put to buildings at various degrees of destruction

Degrees of destruction	Material damage (loss) inflicted to building (in % of estimates)
Weak	5 – 10
Average	10 – 20
Strong	40 – 60
Full	100 – 150

In Table 3 the data characterising a share of injured people from the total number of people, being in buildings subjected to a blast wave, are cited.

By the severity levels of a trauma got by people, they are divided into 3 groups: 1 - the heaviest traumas leading to a fatal outcome (deaths); 2 - heavy traumas and injuries leading to a loss of ability to work and physical inability (1st and 2nd groups); 3 - the traumas of average severity causing temporary disability.

Table. 3.

N N	Degrees of destruction	Number of injured people (in % from the total amount of people being in the building)		
		The heviest traumas	Heavy traumas	Average severity traumas
1.	Weak	-	0,1-0,3	3-7
2.	Average	0,1-0,3	0,5-1,5	5-15
3.	Strong	0,5-1,5	3-7	15-25
4.	Full	5-15	15-25	40-60

Dynamic loading at calculation of buildings stability is replaced by equivalent static loading which is defined according to the formula:

$$P_{eq} = P_{\max} \cdot K_{D,}, \qquad (2)$$

Where P_{max} – is the maximum value of dynamic loading; K_D – is the factor of equal to the maximum value of dynamics function *T (t)*, describing replacement of structures in time (movement of cross-sections).

As follows from the expression (2) for replacement of dynamic loading by equivalent static value it is necessary to define factor of dynamics K_D.

As it is well known the movement of structure in a stage of elastic deformations is described by the equation:

$$\frac{d^2T}{dt^2} + \omega^2 \cdot T = \omega^2 \cdot f(t), \qquad (3)$$

Where ω - is a circular frequency of the structure' own fluctuations; *f (t)* - the function describing time alteration of dimensionless dynamic loading $f(t) = \frac{P(t)}{P}$; *T (t)* – replacement of structure.

The solution of equation (3) at zero entry conditions looks like:

$$T(t) = \omega \cdot \int_0^t f(u) \cdot \sin\omega \cdot (t-u) \cdot du = \omega \cdot (\sin\omega \cdot t \cdot \int_0^t f(u) \cdot \cos\omega \cdot u \cdot du - \\ - \cos\omega \cdot t \cdot \int_0^t f(u) \cdot \sin\omega \cdot u \cdot du). \qquad (4)$$

Numerical integration of expression (4) gives function of structure movement under the influence of force *f (t)* in time. The maximum value of movement function *T (t)* - is the looked for factor of dynamics K_D.

Let's consider the technique of approximate determination of factor of dynamics. With this we use a schematization of time dependence of loading in the form of (1).
The factor of dynamics K_D for loading of the triangular form is determined from the graphical representations resulted on Fig. 1, where θ *and* θ_1 – are the time of action of dynamic loading and time of its increase to the maximum value; ω_b – is the circular frequency of the basic tone of own fluctuations of structures which is defined by the methods of building mechanics. Calculations show, that for the overwhelming majority of real-life structures ω_b $2\geq 0c^{-1}$, i.e. the period of own fluctuations of structures is less than 300мс.

The previous correlations show, that for the determination of factor of dynamics it is necessary to know circular frequency of the basic tone of own fluctuations of structures-ω_b. Frequency of own fluctuations of a structure ω_b should be determined from the formula:

$$\omega_b = \frac{\alpha}{L^2} \cdot \sqrt{\frac{B}{M_s}}, \qquad (5)$$

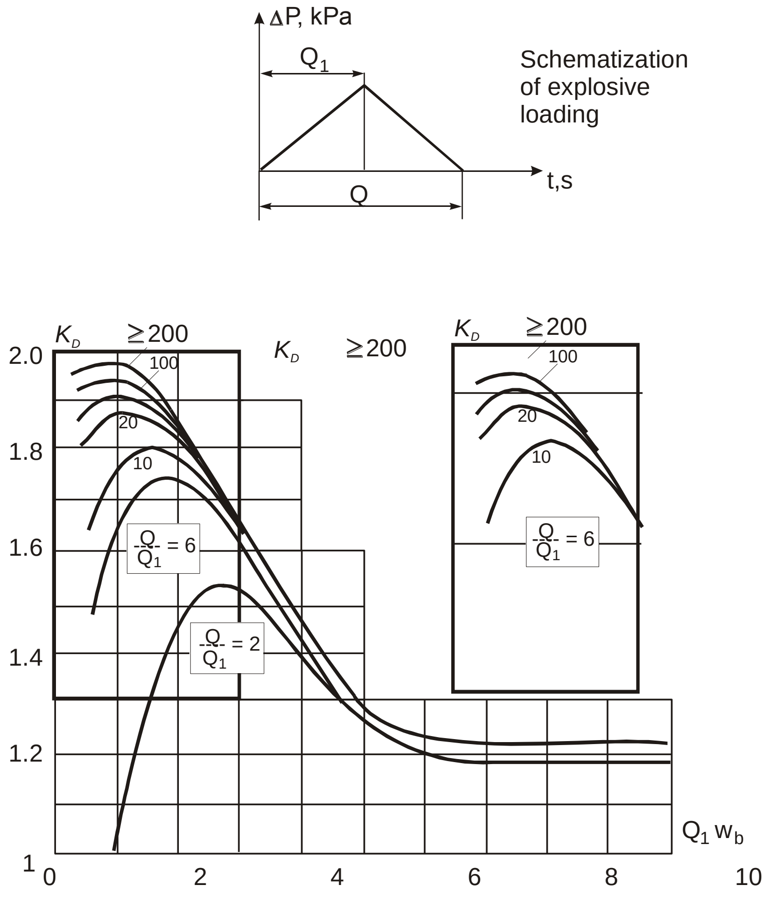
Where L – is the flight of structure; B - flexural rigidity defined for concrete and reinforced-concrete structures using the formula:

$$B = E_{ves} \cdot I, \qquad (6)$$

Where *Eves* – is the initial dynamic module of elasticity of concrete, I - the axial moment of inertia of section, M_s - unit weight of a structure calculated with the formula:

$$M_\kappa = \frac{q}{g}, \qquad (7)$$

Where q – is the unit constant loading from explosion plus dead weight of structure; α- the factor depending on type of structure fixing; g - acceleration of free falling.



,Fig. 1. Diagram for the approximate determination of factor of dynamics K_D

The special group is made by the intensive impact actions accompanying explosions. They can be divided into two categories: the impacts caused by scattering of elements of the equipment and impacts, caused by a collapse of above positioned structures broken in a result of explosion. The first group of impacts usually cause punching and creates holes in structures localizing explosion, creating extreme danger to the people, the second group can cause progressive collapse. The impacts, relating to the first category, in most cases are high-speed and time it takes depends on specific type of equipment and a type of a structure.

The analysis of data testifies that the majority of emergency impacts can be classified as low speed shock actions and by the time it takes as sharp or intermediate sharpness.

To secure buildings and structures against impacts one should proceed from a minimum of total expenses for impact actions prevention, as well as for decrease of intensity of shocks and reinforcement of structures of a building. At possibilities of building damages it is necessary to consider expenses for repair and replacement of relevant structures.

At the analysis of deformation of separate reinforced concrete elements it is necessary to consider local and general action of impact. As a local impact action the primary effect of impact is recognized, causing local damages and destructions in a structure (penetration of spalled fragments into a structure and other minor surface scaling and disruptions) usually ahead of occurrence of considerable general deformations. As a general impact action the secondary effect causing general deformations of structure is recognized (flexure, etc.).

The general system of equations of movement of coimpacting elastic bodies assumes the form **:**

$$[M]\{\ddot{U}\}+[C]\{\dot{U}\}+[K(U)]\{U\}=\{F(t)\}. \qquad (8)$$

After the consideration of results of calculation, conditions of a collapse of above pozitioned structures on underlaying structures are checked. In a moment of interaction of these structures among themselves the resultant contact force develops. Though time of action of contact force is usually very small and is measured in micro-or milliseconds, it develops very quickly and attaines high values.

Let's consider the solution of a problem on coimpact of absolutely firm and elastic bodies:

- When material is considered absolutely elastic and kinetic energy completely converts into potential (absolutely elastic impact);

- And when impact is accepted ideally plastic, i.e. there is no rebound of falling objects from an underlaying slab (absolutely non - elastic impact).

Let's consider coimpact of falling objects with dead weight $[m]=\int\limits_{V^{(e)}}\rho[N]^T[N]dV$

at height of drop h on underlaying structure $[M]=\int\limits_{V}\rho[N]^T[N]\ dV$.

Absolutely elastic impact.

The power approach is the most preferable when only the maximum stress values and dynamic deflections are to be determined and the problem of definition of laws of movement of given system is not considered.

Making power balance of given system at the moment of occurrence of the maximum deflections of all the system structure-basis, we will got:

$$T^u+\Pi^u=T^d+\Pi^d, \qquad (9)$$

Where - $T^u=g\,h\int\limits_{V^{(e)}}\rho[N]^T[N]dV=[m]gh$ -kinetic energy of falling objects;

$\Pi^u=([m]+[M])gU_{max}$ - external forces work at relocation, U_{max}

$\Pi^d=\frac{1}{2}\{u^{(e)}\}^T\left([k_0^{(e)}]+[k_1^{(e)}(u)]+[k_2^{(e)}]\right)\{u^{(e)}\}-\{u^{(e)}\}^T\{f^{(e)}\}=\frac{1}{2}\{u^{(e)}\}^T[k^{(e)}]\{u^{(e)}\}-\{u^{(e)}\}^T\{f^{(e)}\}$, -

Potential energy of deformation of a system,

T^d - Kinetic energy of a system at $U_{\max}$. As at the greatest relocation of a system $\dot{U}_{\max} = 0$, so for the specified moment of time $T^d = 0$.

Considering, that dynamics factor defines how many times the maximum deflection at dynamic loading exceeds the value of deflection arising at static character of applied loading, we will have:

$$\beta = \frac{U_{\max}}{U_{\max,\,cm}} = \left(1 + \frac{[M]}{[m]}\right)\left(1 + \sqrt{1 + \frac{2h}{\left(1 + \frac{[M]}{[m]}\right)^2 U_{\max,\,cm}}}\right). \tag{10}$$

The dynamics factor lies in the range of 14 - 52.

Absolutely non - elastic impact.

If the body with the weight $[m]$ at the moment of impact with another body having the weight $[M]$ possessed the speed v_-^m then the speed of "bonded together" bodies after impact, is defined by the formula obtained from a condition of preservation of quantity of movement:

$$v_+ = \frac{[m]}{[m]+[M]} v_- . \tag{11}$$

Considering further fluctuations of the resulted system arising after impact with one concentrated weight equal to $[M]+[m]$, we will receive expression for dynamics factor:

$$\beta = \frac{U_{\max}}{U_{\max,\,cm}} = \left(1 + \sqrt{1 + \frac{2h}{\left(1 + \frac{[M]}{[m]}\right)^3 U_{\max,\,cm}}}\right). \tag{12}$$

The dynamics factor lies in this case in the range from 2 to 20.

The buildings, structural elements of which can be exposed to emergency impacts of high intensity, should be designed so that to exclude progressing collapse because of possible loss of carrying capacity of the structural element experiencing this influence.

Reinforcement of the linear elements perceiving emergency shock influences, is recommended to be used in the form of woven reinforcing cages.

The cross-section reinforcement of linear elements should be set according to design calculation within all their length; it should be done in the form of the closed ties or transverse bars preventing their opening.

At appointment of longitudinal reinforcement of beams at all other things being equal it is desirable to increase quantity of rebars of smaller diameter; it increases a limiting angle of opening at the expense of change of character of reinforcement bond with concrete.

Conclusions

At selection of cross - section of reinforcement of slabs designed to withstand the action of bending moment, it is expedient to use smaller diameter rebars in combination with the minimum space between them. It improves resistance of structures to local action of impact and boost bond of reinforcement to concrete.

In linear elements as well as in the slabs having both transverse and longitudinal reinforcement on the side to mitigate impact action, it is expedient to increase a thickness of a concrete cover that leads to decrease of contact rigidity and, accordingly, effect of impact.

The all-round estimation of effect of action of emergency loadings on building structures is a subject of concentrated attention and a condition for a choice of optimum solutions to provide appropriate safety of buildings and engineering structures.

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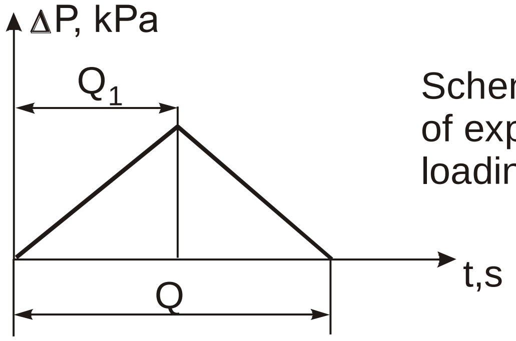

Schematization of explosive loading