THE BLAST LOADING ON ABOVEGROUND STRUCTURES

by

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SYNOPSIS

The discussion of blast loading on structures is presented here in terms of nuclear blast phenomena and as related to closed, partially closed, open, and cylindrical aboveground structures. To make the complex problem simpler, some assumptions are made regarding the physical conditions of both structures as well as blast waves, which, with a little modification, can be applied to any kind of structure. The various properties of blast waves of a nuclear explosion are given in form of graphs to calculate readily the necessary data required to determine the blast loading on a structure.

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INTRODUCTION

The purpose of this paper is to narrate the facts concerning the effects of nuclear weapons on structures, and to make an objective analysis of those effects in terms of differential loadings on the individual members of structure to resist those effects. The coverage of this report, therefore, is directed to examine the individual structure under the influence of blast loadings and the response of various components of the structure to resist the destructive forces. In this connection, a knowledge and understanding of the mechanical and radiation phenomena are of vital importance, so that it may help those planning to make preparations to deal with the emergencies that may arise from nuclear warfare. In addition, the data thus obtained may be utilized in designing the future structures having increased resistance to damage by blast, shock, and fire, and greater ability to provide shielding against nuclear radiation.

The information given here is within the limitations set by some problems yet to be solved, the basic phenomena and the most recent data concerning the effects associated with explosion of nuclear weapons. This information was collected from various notes and articles issued by various personalities and authorities on the subject, obtained from the observations made following the wartime nuclear bombings in Japan and at the tests carried out at various places in this country, as well as from the experiments with conventional high explosives and mathematical calculations. The tests have provided much important data on weapons' effects on structures, thus leaving us with sufficient scientific knowledge to use to design all our future structures in a way to eliminate those effects or at least minimize such effects to the extent of safely eliminating hazards to life and property.

CHARACTERISTIC OF NUCLEAR EXPLOSION

In order to have a clear picture regarding the effects of the destructive weapons on structures, it is necessary, first, to understand a few phenomena related to the causes of such effects. In this connection, the following terms are defined:

1. Blast and Shock Waves. An explosion, in general, results from very rapid release of a large amount of energy in a short interval of time. This energy release is usually accompanied by increase of temperature, so that the products of an explosion become hot gases. Since these gases are at a very high temperature and pressure, they expand rapidly and thus initiate a pressure wave, called a "shock wave", in the surrounding medium-air, water, or earth. The characteristic of a shock wave is that there is a sudden increase of pressure at the front, with a gradual decrease behind, as shown in Figure 1.[1] A shock wave in air is generally referred to as a "blast wave", because it resembles and is accompanied by a very strong wind. The word "shock" is used, as its effect on a structure is like

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[1] "The Effects of Nuclear Weapons", U.S. Atomic Energy Commission, 1957, p. 74.

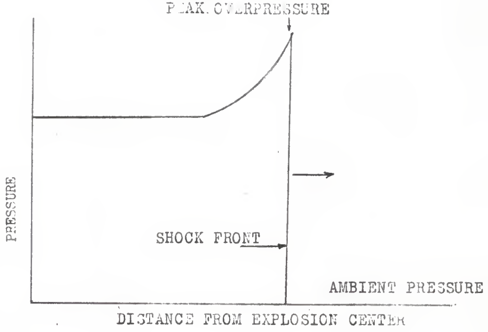

Figure 1. Variation of pressure (in excess of ambient) with distance in shock wave.

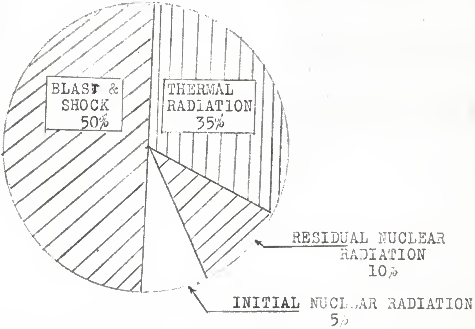

Figure 2. Distribution of energy in a nuclear explosion.

a sudden impact.

2. Thermal Radiation. In case of nuclear blast, first, a fairly large proportion of energy is emitted in the form of light and heat, generally referred to as "thermal radiation". This is capable of causing skin burns and fires at considerable distances. Secondly, the explosion is accompanied by highly-penetrating and harmful invisible rays called "initial nuclear radiation". These rays travel great distances through air and can penetrate a considerable thickness of materials. Finally, the substances remaining after a nuclear explosion are radioactive, emitting similar radiations over an extended period of time, which is known as "residual nuclear radiation". For an ordinary detonation in the atmosphere the energy yield is as shown in Figure 2.[2] Generally, for a protective structure the thermal radiation and nuclear radiation are almost automatically protected against. Nevertheless, the protection against fire potential is also to be considered.

3. Fission and Fusion. These are two methods known to release the energy of a nuclear weapon.

4. Types of Nuclear Explosions. Following are the main types of nuclear explosions:

(a) Air burst and high altitude burst

(b) Under water burst

(c) Underground burst

(d) Surface burst

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[2]Ibid., p. 6.

The height of burst plays an important role in producing the typical effects on structures. Although four types of bursts have been considered as being fairly distinct, there is actually no clear line of demarcation between them.

An air burst magnifies the effects of thermal radiation and low overpressures of about 10 pounds per square inch but eliminates, more or less, the effects of fallout.

A surface burst provides extreme pressures on the surface with a crater, more fallout on large areas, and greater radiation. This surface burst is believed to produce the worst effects on the earth against which the structures are to be reinforced. Hence, it is necessary only to examine the effects of surface bursts in detail.

Underground bursts are only slightly different from surface bursts. The fallout and thermal radiation, in this case, are believed to be reduced to a considerable extent except that the crater, which, in some cases, may be greater than that of surface burst.

5. Fallout. In the case of surface or subsurface burst due to the intense heat, earth, water, debris, and other surrounding materials are fused and vaporized up in the air in form of a cloud known as radioactive cloud. When sufficient cooling has occurred, the earth particles get charged with the radioactive residue of the weapon. As the further cooling takes place due to the subsidence of the explosion, all the charged particles drop back to earth. This effect is referred to as "fallout".

The extent and the nature of the fallout depends upon several factors. The amount of fallout is different with different cases and varies according to the type of burst, the meteorological conditions, the direction of winds, the kind of explosion, etc. It is believed from the various experiments that fallout can cover the area of about few miles upwind, hundreds of miles downwind, and about 100 miles crosswind, with average kind of blast, keeping all other conditions normal. Further, it is observed that these charged particles keep on falling on ground continuously for many hours, starting several hours after the explosion. The size of the falling particles ranges from that of fine sand, i.e., about 100 microns in diameter, to pieces about the size of a marble, i.e., roughly about 1 c.m. in diameter.

6. Fires and Fire Storms. The thermal radiation and the blast wave cause wide-spread fires over a considerable area. Such a raging all-consuming fire develops that the term "fire storm" is used to describe the situation. Experience indicates that the fire storm is likely to occur where the building density is greater than 20 per cent. In such a case, the heat is so intense and the oxygen of the atmosphere so inadequate that any shelter in the area must be completely closed off from the atmosphere, and sufficient oxygen must be provided in the shelter if the occupants are to survive.

7. Energy Yield of a Nuclear Explosion. A nuclear weapon releases an extremely large quantity of energy in a very short interval of time. The quantity of energy released is commonly expressed in terms of energy detonation of the chemical high

explosive, TNT. A small nuclear weapon energy release equivalent to that of 1000 tons of TNT is termed as One Kiloton (KT) weapon. Similarly, a weapon with energy equivalent of 1000 Kilotons of TNT is termed as One Megaton (MT).

PROTECTION AGAINST NUCLEAR WEAPONS

The purpose of protective construction is to increase the probability of survival under nuclear attack. The effects of intense heat, light, thermal radiation, etc., are of such magnitude at close range that protection becomes almost impossible. However, at greater ranges, design becomes manageable, and risks of injury to personnel and damage to structures may be greatly reduced.

From the various tests and experiments with the nuclear weapons in this country and the results obtained from Japan in World War II, it is assumed that our future structures should be such to withstand the following effects of nuclear energy:

1. The initial effects such as the blast, the thermal radiation, and the fires due to the high temperatures, and shock due to the high pressures.

2. Secondary effects covering the major problem of radioactive fallout which may cover thousands of square miles of area. The protection against fallout is somewhat simpler.

The damage from the attack can be greatly reduced if all the future structures are planned to be installed at dispersed areas. In that case the extra cost of construction is also a major problem to be considered.

GENERAL PRINCIPLES FOR DETERMINING THE BLAST-LOADINGS ON STRUCTURES

As in conventional structural engineering, the design of blast resistant structure involves first the selection of proper loading on the structural system which is approximately able to meet the various design conditions. Here, however, for preliminary design procedure, certain simpler analytical processes are described. In general, the process described is for the lowest kind of detonation and in case of multimegaton weapon, it involves proportioning the structural elements of the selected system to offer static resistance equal to or only slightly greater than the peak blast load pressures on the elements.

The most recent data collected by the Defense Department describes the various loading on the structures as follows:

A difference in the air pressure acting on the separate surfaces of a structure produces a force on the structure. The destructive effect of a blast wave, therefore, on the structure is its overpressure on the shock front. The majority of structures will suffer some damage from air blast when the overpressure in the blast wave, i.e., the excess over the atmospheric pressure (14.7 pounds per square inch), is about one-half pound per square inch or more.

In the very early stages, the variation of pressures with distance from the center of source, at a given instant is somewhat as illustrated in Fig. 1. The maximum value, i.e., at the shock front, is called the peak overpressure. As the blast wave travels in the air, the overpressure at the front steadily decreases, and the pressure behind the front falls off in a regular manner. After a short time, the pressure behind the front drops below that of surrounding atmosphere and a so-called "negative phase" forms. This is shown in Fig. 3.[3] In curves marked t_1 through t_5 the pressure in the blast wave has not fallen below the atmospheric, but in curve t_6 it is seen that at some distance behind the shock front the overpressure has a negative value. In this region, the "under pressure" takes place rather than overpressure, producing a partial vacuum, sucking the surrounding air in. From the practical point of view the condition is as shown in Fig. 4.[4] At the time marked 4, the negative pressure takes place.

Although the destructive effects of the blast wave have usually been due to the value of overpressure, there is another quantity of equivalent importance called the dynamic pressure. The dynamic pressure is proportional to the square of the wind velocity and the density of the air behind the shock front. Like peak overpressures, the peak dynamic pressure decreases with increasing distance, and at a given location, it changes with time in a manner like that of overpressure. But the rate of pressure decrease is usually different. This can be seen from Fig. 5.[5]

Some indication of the corresponding values of peak overpressure, peak dynamic pressures, and maximum blast wind velocities

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[3] "The Effects of Nuclear Weapons". U.S. Atomic Commission, 1960, p. 104.

[4] Loc. cit.

[5] Ibid., p. 108.

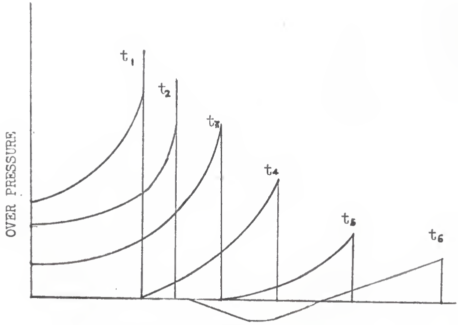

Figure 3. Variation of overpressure with distance at successive times.

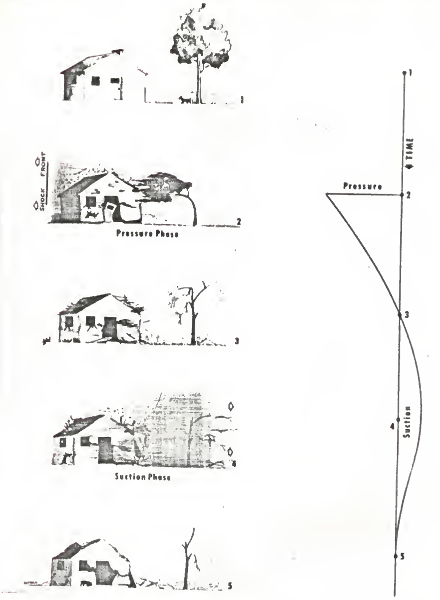

Fig. 4. Variation of pressure with time at a fixed location and effect of blast wave passing over a structure.

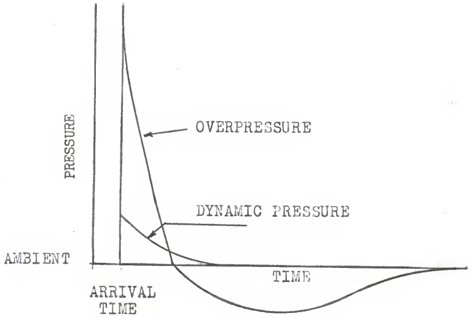

Figure 5. Variation of overpressure and dynamic pressure with time.

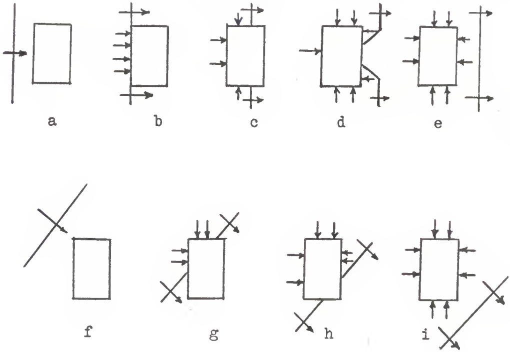

Figure 6. Stages in the Diffraction of a blast wave by a structure without openings.

for an ideal shock front at sea level are given in Table 1.

Table 1. Values of different pressures due to 20 MT surface burst.

Distance in feet	Peak overpressures, P, in psi.	Peak dynamic pressure, q, in psi.	Positive phase duration, t, in sec.	Shock front velocity, U, in fps.
17,000	25	25	5.4	1,800
12,000	50	130	4.6	2,200
9,000	100	220	4.1	2,900
6,700	200	380	3.7	4,000

All these results are obtained from test conducted on 20 MT surface burst. In the case of large powered weapon the values can be obtained by proportioning with help of Scaling Law, which is explained in the end.

From all above discussion, we can now arrive at certain specific effects of nuclear power, for which the loadings are to be computed. It is believed, therefore, that the data on the following characteristics of the nuclear phenomena are necessary:

1. p(t), overpressure versus time
2. po, peak overpressure
3. q(t), dynamic pressure versus time
4. qo, peak dynamic pressure
5. t , duration of positive phase, and
6. U , shock front velocity.

LOADINGS ON ABOVEGROUND STRUCTURES

The behavior of a structure exposed to the blast wave from a nuclear explosion may be considered under two categories: 1. The loading, i.e., forces which result from the action of blast pressure; and 2. the distortion of the structure due to that loading.

The loading on the aboveground structure can, therefore, be divided into two parts: (I) Diffraction loading, which is determined mainly by the peak overpressure in the blast wave, and (II) drag loading, in which dynamic pressure plays the main part. However, all structures are subjected simultaneously to both types of loadings, since the overpressure and dynamic pressures cannot be separated, although for certain structures one may be more important than the other.

Diffraction Loading

When the front of an air blast strikes the face of a building, reflection occurs. As a result, the overpressure builds up rapidly to at least twice that in the incident wave front. As the wave front moves forward, the reflected overpressure on the face drops rapidly to that produced by the blast wave without reflection, plus an added drag force due to the wind (dynamic) pressure. At the same time, the air pressure wave diffracts around the structure, so that the structure is eventually engulfed by the blast, and approximately the same pressure is exerted on the side walls and the roofs. The front wall is, however, still subjected to wind pressure, although the back wall is shielded from it.

The above stages are shown in Fig. 6, marked a, b, c, d, and e, in a simplified form taking a structure without openings. If the structure is at an angle to blast wave, the conditions are shown as in f, g, h, and i.

In case the building has openings, there will be rapid equalization of pressure between inside and outside of the structure. This will tend to reduce the pressure differential while the diffraction is occurring. Large cement concrete buildings, large wall bearing structures, such as apartment houses and wood frame buildings with small window area, respond greatly to the diffraction loading.

Drag Loading

Drag loading or the dynamic pressure on the structure is due to the positive duration of the overpressure caused by the strong winds behind the blast wave front. The drag loading is determined by considering the dynamic pressure and also the shape of the structure. Typical drag type structures are telephone poles, radio-television transmitting towers, electric transmission towers, and truss bridges. For different types and different shapes of the structure, different shape factor (drag coefficient) should be used. It will be less for rounded or streamlined structures than for the irregular shapes.

CONVENTIONALIZED BLAST AND SHOCK LOADING

The development of blast loading presented here is based generally on results obtained by such laboratory and full scale empirical data as were available. Since actual structures are generally complex, the treatment here will be referred to a number of idealized structures of simple shape. The methods presented are for the following relatively simple shapes:

1. Closed box-like structure
2. Partially open box-like structure
3. Open frame structure
4. Cylindrical structures

These methods can be altered somewhat for objects having similar characteristics. The blast wave characteristic which meeds to be known (the method of calculating them is given in the end) and their symbols are summarized in the following table:

Table 2. Blast wave characteristic for determination of loading.

Property	Symbol
Peak overpressure	p
Time variation of overpressure	$p(t)$
Peak dynamic pressure	q
Time variation of dynamic pressure	$q(t)$
Reflected overpressure	p_r
Duration of positive phase	t_+
Blast front (shock) velocity	U

Closed Box-Like Structure

A closed box-like structure is shown in Fig. 7, with length L, height H, and breadth B. In this category will come structures with flat roofs and walls of approximately the same blast resistance as the frame. It is assumed that walls have either no openings or a small number of such openings, up to about 5 per cent of the total area. Further, it is assumed that one face of the structure is perpendicular to the direction of

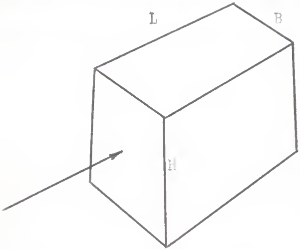

Fig. 7. Representation of closed box-like structure.

the blast wave. The loading diagrams are computed for (a) the front face, (b) the side and top, and (c) the back face.

(a) Average Loading on the Front Face. First the reflected pressure p is determined at time t = 0, when the blast wave first strikes the front face. Next, the time t is calculated at which the stagnation pressure p is first attained. From test results, it is found that

$$t_s = 3S/U$$

where S is equal to H or B/2 whichever is less, taking drag coefficient as unity. The stagnation pressure, therefore, is given by

$$P_s = p(t_s) + q(t_s)$$

where $p(t_s)$ and $q(t_s)$ are overpressure and dynamic pressure at time t_s. The pressure decreases with time so that

$$\text{pressure at time } t = p(t) + q(t)$$

t is the time between t_s and t . In this way a curve for front face can be determined, which is shown in Fig. 8.[6]

(b) Average Loadings on Top and Sides. The sides and top require time L/U to get fully loaded. The average pressure, P_a, at this time, is the sum of the overpressure and the drag loading at distance L/2 from the front face, so that

$$P_a = p(\ L/2U\ ) + C_d\ q(\ L/2U\ )$$

The drag coefficients as suggested by the Defense Department are given in Table No. 3.

Table 3. Drag coefficients for aboveground rectangular structures.

Dynamic pressure	Drag coefficients (side, top, and back)
0-25 psi	-0.4
25-50 psi	-0.3
50-130 psi	-0.2

[6] H. L. Murphy, "Blast Loadings on Structures". ASCE Proceedings, Vol. 84, Part I, November 1958, p. 9.

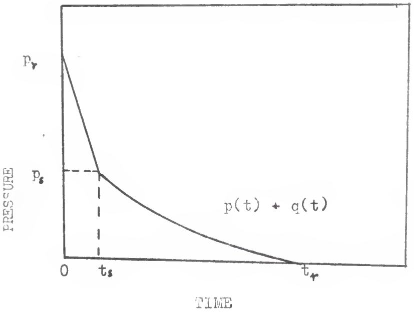

Figure 8. Average front face loading of closed box-like structure.

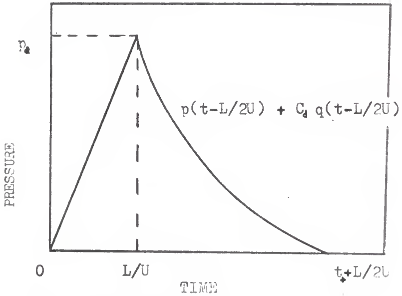

Figure 9. Average side and top loading of a closed box-like structure.

The loading thus increases from zero at $t = 0$ to p_2 at the time L/U, as shown in Fig. 9,[7] after which the pressure at any time t is given by

$$p(t) = p(t - L/2U) + C_d\, q(t-L/2U)$$

where t lies between L/U and $(t_+ + L/2U)$, and overpressure and dynamic pressure is given by

$$(t - L/2U)$$

(c) The Average Loading on Back Face. The back face is effected by shock front at time L/U, but it requires an additional time $4S/U$ for the pressure to build up at the value p_b as shown in Fig. 10,[8] and the pressure at any time t is given by

$$p(t) = p(t - L/U) + C_d\, q(t-L/U)$$

where t lies between $(L + 4S)/U$ and $(t \ + L/U)$ as shown.

(d) Net Horizontal Loading. The net horizontal loading can be obtained by subtracting, graphically, the loadings on front and back faces. The results are shown in Fig. 11.[9] The left figure shows individual loading and right figure shows the difference, which is same shaded area shown as difference in figure shown on right. The net loading is necessary to determine the frame response whereas the walls are effected by the individual loadings on the faces.

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[7]Loc. cit.

[8]Loc. cit.

[9]"The Effects of Nuclear Weapons". U.S. Atomic Commission, 1960, p. 186.

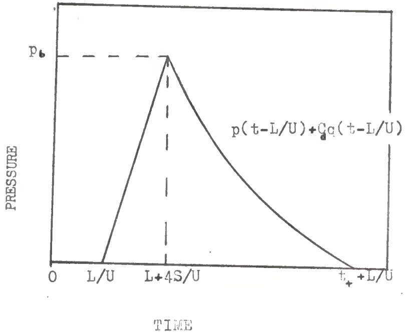

Figure 10. Average back face loading of a closed box-like structure.

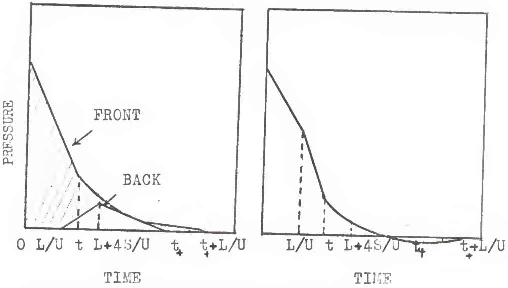

Figure 11. Net Horizontal loading

Partially Open Box-Like Structure

In this type of structure it is assumed that the front and the back have about 30 per cent of opening or window area.

(a) Average Loading on the Front Face. The loading is computed in the same manner as the case of closed box-like shape, except that S is replaced by S' where S' is the average distance from the center of the wall section to one open edge of the wall. The inside of the front face will take time equal to 2L/U to develop the blast wave overpressure value. The dynamic pressures are assumed to be negligible on the interior of the structure. The variation of inside and outside pressures with time are shown in Fig. 12.[10]

For outside

$$P(t) = p(t) + q(t)$$

For inside

$$P(t) = p(t)$$

(b) Average Loading on Sides and Top. Here also, inside pressure requires time = 2L/U to attain the overpressure. Dynamic pressures on interiors are neglected, and wall openings are ignored as their effect is uncertain. The outside pressure at any time is given by

$$P(t) = p(t - L/2U) + C_d\, q(t - L/2U)$$

And for the inside

$$P(t) = p(t - L/2U)$$

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[10]Ibid., p. 187.

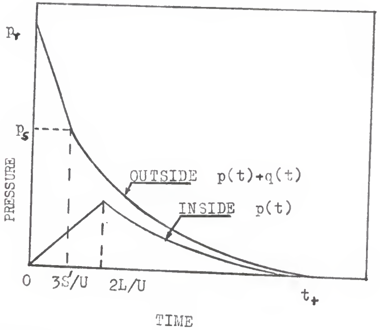

Figure 12. Average front face loading of partially open box-like structure.

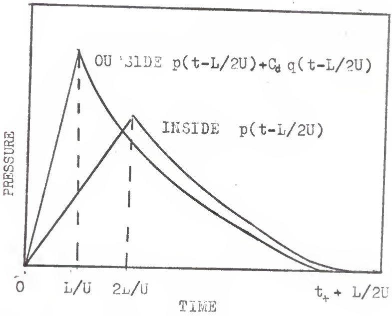

Figure 13. Average side and top loading of partially open box-like structure.

These different variations are shown in Fig. 13.[11]

(c) Average Loading on the Back Face. The outside pressure is same as in the case of closed box-like structure except S' is replaced by S. The inside pressure reflected from inside of the back face reaches same value as the blast overpressure at a time L/U and then decreases as

$$p(t-L/U)$$

The inside and outside pressures, shown in Fig. 14,[12] are given as:

Inside pressure at time t is

$$P(t) = p(t-L/U)$$

And outside is

$$P(t) = p(t-L/U) + C_d\ q\ (t-L/U)$$

For inside the dynamic pressure is considered as negligible.

Open Frame Structure

Under this category are included a truss bridge and steel frame office building, or industrial building with glass walls, with asbestos, light steel or aluminum panels, which quickly becomes open frame structure after the first impact.

As, at present, the behavior of open frame structure is not thoroughly known due to the complications of considering each and every member separately, not much can be said about this.

However, the following recommendations are offered by the

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[11] Ibid., p. 188.
[12] Ibid., p. 189.

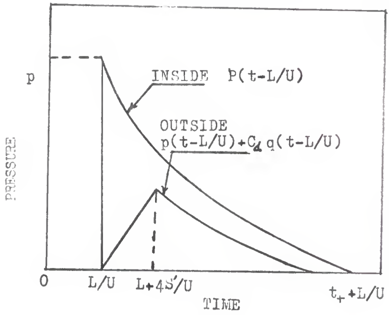

Figure 14. Average back face loading of partially open box-like structure.

U. S. Defense Department to simplify the matter:

1. The load transmitted by glass on frames is considered negligible if the loading is sufficient to fracture the glass.
2. For asbestos, transite, corrugated steel, or aluminum paneling an approximate value of the load transmitted to the frame is an impulse of 0.04 pound-second per square inch.
3. As it is difficult to compute overpressure loading on each individual member, the recommended simplification is to treat the loading as an impulse, the value of which is obtained in the following manner:

The major portion of the loading on an open frame structure is due to the drag (dynamic pressure) loading. The average loading coefficient (drag coefficient) for members, such as I-beams, channels, and angles, is considered to be unity. The force F, on the individual member is given by

$$F\ (\text{member}) = C_d\, q(t)\, A_i$$

where $C_d = 1$ and A_i is the sum of projected areas of all members.

The loading (force) versus time for a frame of length L, having major areas in the planes of the front and rear walls, is shown in Fig. 15.[13] The symbols A_{fw} and A_{bw} represent the areas of the front and back walls, respectively, which transmit loads before failure, and I_{fm} and I_{bm} are the overpressure loading impulses on front and back members, respectively. It is seen that

[13] Ibid., p. 191.

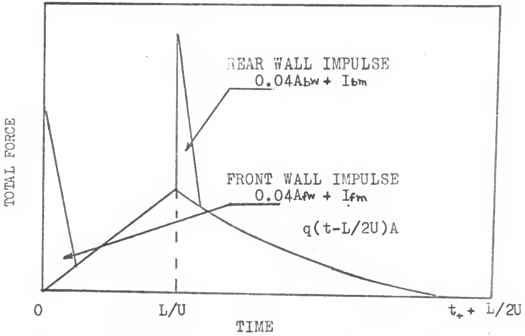

FIGURE 15. Net horizontal loading of an open frame structure.

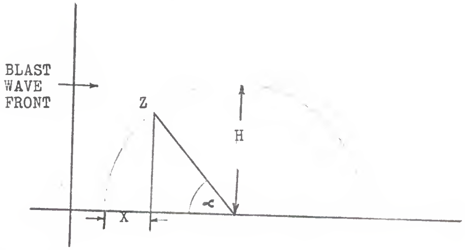

Figure 16. A semicircular arched structure.

the drag force does not attain its full value of $q(L/2U)$ until the time L/U, i.e., when the blast wave reaches the end of the structure.

Cylindrical Structures

The treatment given below and shown in Figures 16[14] and 17, for cylindrical structure, is applicable to the structures having circular cross section, such as telephone poles and smoke stacks, with overpressure limited to the less than 25 pounds per square inch. It can also be applied to arched structures with semi-circular shape or to dome-shaped and spherical structure as rough approximation.

The general situation is given in Fig. 16, where H is the height of arch, and Z is any point on the surface. The angle between horizontal and line joining Z to the center is indicated by α. Further

$$X = H(1 - \cos\alpha)$$

which is the horizontal distance, in the direction of the blast wave, between the bottom of the arch and some arbitrary point Z. A generalized representation of variation of pressure with time at any point Z is shown in Fig. 17. The time required for blast wave front to arrive at point Z is X/U. The overpressure then rises sharply, in the time interval t_1 to the reflected pressure P_1, so that the time t_1 is the rise time. Vortex formation

[14] "Designed Structures to Resist Nuclear Weapons Effects". ASCE Manuals of Engineering Practice, No. 42, p. 49.

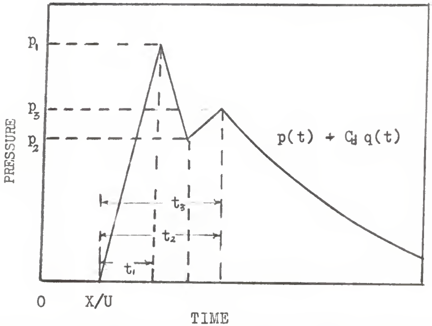

Figure 17. Pressure variation at a point on an arched structure subjected to moving blast wave.

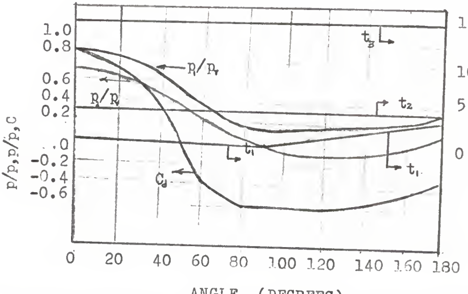

Figure 18. Variation of pressure ratios, drag coefficient, and time intervals for an arched structure.

causes the pressure to drop to p_2, and this is followed by an increase to p_3, the stagnation pressure; subsequently, the pressure, which is equal to $p(t) + C_d\, q(t)$. The values of p_1, p_2, C_d, which are dependent upon value of angle are given in Fig. 18.[15] The rise time t_1 and the time intervals t_2 and t_3 can also be readily determined from the graphs given therein.

STANDARD CURVES AND CALCULATIONS OF BLAST WAVE PROPERTIES

In order to estimate the loading on the structure as discussed previously, it is necessary to have the values of various blast properties, such as peak overpressure, peak dynamic pressure, arrival time, and positive phase duration. In this connection standard "height of burst" curves of various air blast properties, which vary with the distance from ground zero, are presented here. These graphs, prepared by the Defense Department, are based on the combination of theoretical analysis with data obtained from actual nuclear explosions and at various tests, as well as from the laboratory studies. These graphs are prepared on the basis of the results of a one kiloton nuclear explosion, which can be converted for any higher detonation by the help of SCALING LAW.

Scaling Law

According to the cube root law, if D_1 is the distance from an explosion of W_1 kilotons at which a certain overpressure or

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[15] Loc. cit.

dynamic pressure is attained, then for any explosion of W kilotons energy, these same pressures will occur at a distance D given by

$$D/D_1 = (W/W_1)^{1/3}$$

As already stated, the W_1 explosion is conveniently chosen as having an energy yield of 1 kiloton, so that $W_1 = 1$. It follows therefore, that

$$D = D_1 \times W^{1/3}$$

where D_1 refers to the distance from a 1-kiloton explosion. If the distance D is specified, then the value of the explosion energy, W, required to produce a certain effect, e.g., a given peak overpressure, can be calculated. Alternatively, if the energy, W, is specified, the proper distance, D, can be evaluated from the above equation.

Cube root scaling can also be applied to arrival time of the shock front, the positive phase duration, and the impulse, with the understanding that the distances concerned are themselves scaled according to the cube root law. The relationship can be expressed in the form

$$t/t_1 = d/d_1 = (W/W_1)^{1/3} \text{ and}$$
$$I/I_1 = d/d_1 = (W/W_1)^{1/3}$$

where t_1 represents the arrival time or the positive phase duration, and I_1 is the impulse for a reference explosion of energy W_1, and t and I refer to any explosion of energy W; d_1 and d are distances from ground zero. If W_1 is taken as a 1 kiloton, then the various quantities are related as follows:

$$t = t_1 \times W^{1/3} \text{ at a distance } d = d_1 \times W^{1/3}$$

$$I = I_1 \times W^{1/3} \text{ at a distance } d = d_1 \times W^{1/3}$$

Graphs

Following are the various graphs which are proved helpful in calculating blast loadings. An example showing the use of each graph is provided to make the things clear. (These graphs and examples are taken from reference No.

1. The curves shown in Fig. 19,[16] represent the variation of peak overpressure and peak dynamic pressure with distance for a 1 KT surface burst.

Example:

Given: 1 MT surface burst.

Find: The distance to which 2 psi extends.

Solution: From Fig. 19, a peak overpressure of 2 psi occurs at a distance of 2,500 feet for a 1 KT surface burst. Therefore, for a 1 MT surface burst, from equation

$$d/d_1 = (W/W_1)^{1/3}$$

$$d = d_1 \text{ X } W^{1/3} = 2{,}500 \text{ X } (1000)^{1/3}$$

$$= 25{,}000 \text{ feet.}$$

2. The curves shown in Fig. 20,[17] represent the peak overpressure on the ground as a function of distance from ground zero and height of burst for a 1 KT detonation.

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[16] "Effects of Nuclear Weapons". U.S. Atomic Energy Commission, 1960, p. 135.

[17] Ibid., p. 139.

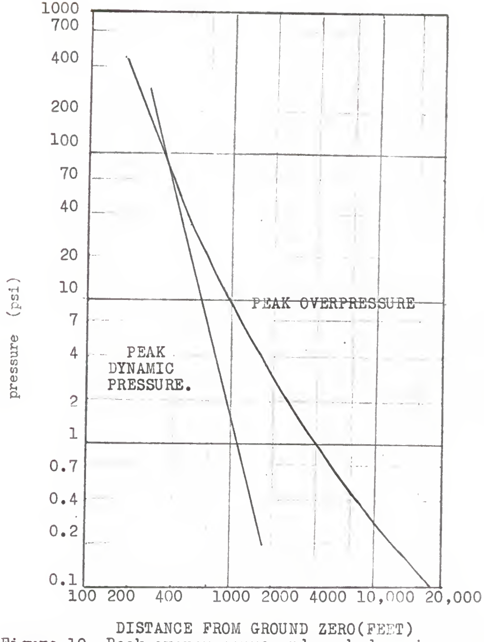

Figure 19. Peak overpressure and peak dynamic pressure for 1-KT surface burst.

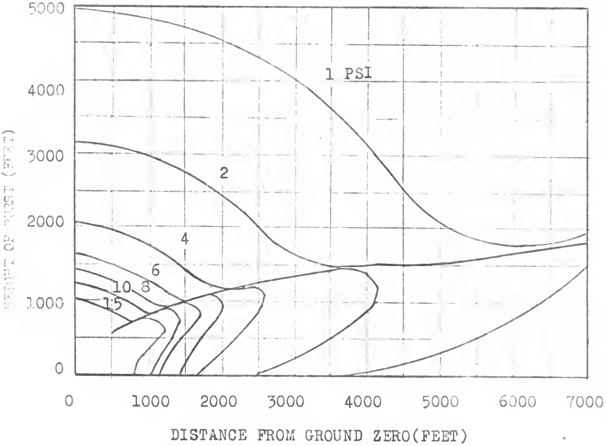

Figure 20. Peak overpressures on the ground for 1-KT burst.

Example:

Given: An 80 KT burst at 2,580 feet.

Find: The distance to which 4 psi extends.

Solution: The height of burst for 1 KT is

$$h_1 = h/W^{1/3} = 2{,}580/(80)^{1/3} = 600 \text{ feet.}$$

From Fig. 20, 4 psi extends to 2,300 feet for a 600-feet burst height for a 1 KT weapon. The corresponding distance for 80 KT is, therefore,

$$d = d_1 W^{1/3} = 2{,}300 \times (80)^{1/3} = 9{,}900 \text{ feet.}$$

3. The curves shown in Fig. 21,[18] represent duration of the positive phase of the overpressure and of the dynamic pressure (in parentheses) on the ground, as the function of distance from ground zero and height of burst for a 1 KT detonation.

Example:

Given: A 160 KT explosion at a height of 3,000 feet.

Find: The positive phase duration on the ground of (a) overpressure, (b) the dynamic pressure at 4,000 feet.

Solution: The required relationships are:

$$d/d_1 = h/h_1 = t/t_1 = W^{1/3}$$

Hence, corresponding height of burst for 1 KT is

$$h_1 = h/W^{1/3} = 3{,}000/(160)^{1/3} = 550 \text{ feet,}$$

and corresponding distance from ground zero is

$$d_1 = d/W^{1/3} = 4{,}000/(160)^{1/3} = 740 \text{ feet.}$$

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[18] Ibid., p. 43.

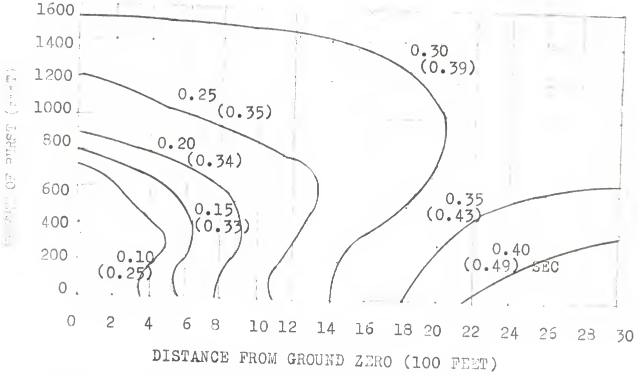

Figure 21. Positive phase duration on the ground of overpressure and dynamic pressure (in parentheses) for 1 KT.

(a) From Fig. 21, the positive phase duration of the overpressure at 740 feet from ground zero and burst height of 550 feet is 0.18 second. Therefore, for 160 KT, the positive phase duration is given as

$$t = t_1 W^{1/3} = 0.18 \text{ X } (160)^{1/3} = 1.0$$

(b) From Fig. 21, the positive phase duration of the dynamic pressure for 1 KT at 740 feet from ground zero and burst height of 550 feet is 0.34 second. The corresponding duration for the dynamic pressure positive phase for 160 KT is

$$t = t_1 W^{1/3} = 0.34 \text{ X } (160)^{1/3} = 1.8 \text{ seconds.}$$

4. The curves shown in Figures 22 and 23[19] give the time of arrival of the blast wave on the ground as a function of distance from ground zero and height of burst for a 1 KT burst.

Example:

Given: 1 MT explosion at a height of 5,000 feet.

Find: The time of arrival of the blast wave at a distance of 10 miles from ground zero.

Solution: The corresponding burst height for 1 KT is

$$h_1 = h/W^{1/3} = 5{,}000/(1{,}000)^{1/3} = 500 \text{ feet.}$$

The corresponding distance from ground zero for 1 KT is

$$d_1 = d/W^{1/3} = (5{,}280 \text{ X } 10)/(1000)^{1/3} = 5{,}280 \text{ feet.}$$

From Fig. 23, at burst height of 500 feet and distance 5,280 feet, the arrival time is 4 seconds. The corresponding arrival time for 1 MT is

$$t = t_1 W^{\frac{1}{3}} = 4.0 \text{ X } (1000)^{1/3} = 40 \text{ seconds.}$$

[19] Ibid., p.145.

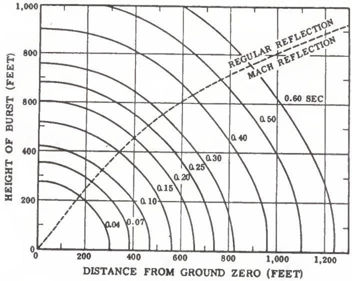

Fig. 22. Arrival times on the ground of blast wave for 1-kiloton burst (early times).

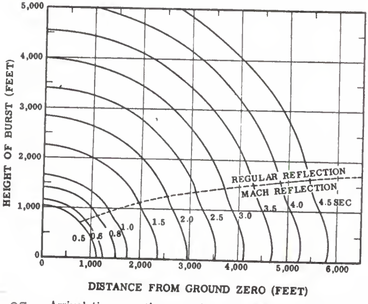

Fig. 23. Arrival times on the ground of blast wave for 1-kiloton burst (late times).

CONCLUSION

In studying and analyzing the effects of nuclear blast on the various structures, one must recognize that the overpressures developed by the size of the device exploded, the distance of the structures from ground zero, and the amount of shielding benefiting the structures will determine the economic feasibility of constructing structures strong enough to offer reasonable protection to the structures from blast effects. Only designing the various members of the structure to withstand the blast wave may not be sufficient, due to the complex variations of atmospheric and other conditions surrounding the structure at the time of the blast. The other side effects which may be of importance to create the protection for structure should also be considered. Following are a few of the important points which can be of greater help and can reduce the cost of construction to great extent:

1. The housing in areas of the country subjected to hurricane winds up to 120 mph. are supposed to resist the blast overpressure of about 0.25 psi. Keeping that in mind, such structures may not require any further overhauling. Test results show that the basements of the houses are very little, if not, effected by the overpressures and dynamic pressures, and, hence, they require very little attention. Similarly, the minor cracks in the bridge piers, in comparison with superstructure damage, show the requirement to give more attention to the superstructure.

2. It was known long before these tests were undertaken that a low wall has greater resistance to lateral pressures than a high

wall of the same material and cross-section, and that a reinforced cement concrete wall is stronger and has more resistance to lateral pressure than a similar unreinforced wall. Also, an axially loaded masonry wall develops greater resistance to lateral loads than an axially unloaded wall. The walls with vertical and horizontal reinforcement have shown their superiority in resisting the destruction.

3. Architectural design has also considerable effect upon the behavior of a dwelling subjected to the nuclear forces. For example, the modern trend towards large windows permits a more rapid equalization of pressure within and outside a building through the blowing out of the window areas; at the same time it could increase the danger to occupants of the houses from flying fragments of glass. In the same way, rounding of the corners of the external walls of buildings or bridges, etc., can reduce the possibilities of developments of cracks to great extent.

4. A flat roof offers much less exposure to wind pressures than a gable roof, and a small projection of the roof over the walls likewise offers less exposure than would be provided by the large overhanging roofs.

5. Tests have shown that the communication poles and transmission towers with more or less rounded shapes, have proved to be very resistant to blast effects. Even at Hiroshima the long brick masonry chimneys of the factories and workshops stood without any apparent damage at the distance of about 360 feet from ground zero. Hence, such structures require only a minor attention.

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THE BLAST LOADING ON ABOVEGROUND STRUCTURES

by

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B. E., M. S. University of Baroda, India, 1958

AN ABSTRACT OF A MASTER'S REPORT

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This report outlines a study of the causes and effects of the nuclear explosions on the aboveground structures. The coverage of this report is specifically directed to obtain the blast loads due to the weapons in the multi-megaton range, to determine the sensitiveness of the various components of the structure to resist the blast overpressure and dynamic pressures, which are believed to cause the major failure of structures. Although this report pertains to the aboveground structures only, it is suggested that with a little modification and with careful study of other references given in the end, the same principles can be applied to the other categories of structures, such as underground and semi-buried.

Since actual structures are generally complex, and their behavior and response to the blast loading depends upon several major and minor characteristics of the explosion, the treatment here is referred to a number of idealized targets of simpler shape. To make the complex problem simpler, some assumptions are made regarding structures, such as:

1. A building is considered as a box-like structure in the shape of a rectangle.

2. It is assumed that one face of the box directly faces the explosion, i.e., the front face is normal to the direction of propagation of the blast wave.

3. Box is rigidly attached to the ground surface and remains motionless when subjected to the loadings.

4. This box-like structure is further considered and analyzed separately as being completely closed, partially closed,

open framed structure, and cylindrical structure.

Each face of the above structure is analyzed separately to show the difference in response of the side walls, the back walls, and the roof, with a view to arrive at the average and the net loadings for which ultimately the structure is to be designed. It should be noted that only the gross characteristics of the development of the loading have been considered here. There are, in actual fact, several cycles of reflected and rarefaction blast waves caused by explosion, travelling across the surfaces before damping down, but these fluctuations, being of minor significance as far as damage to the structure is concerned, are considered neglected.

Further, in order to estimate the necessary data to calculate the loadings on the structure due to the blast waves, a few of the standard "height of burst" curves are given. These graphs, prepared by the Defense Department, are based on the combination of the theoretical analysis with data obtained from actual nuclear explosions and at various tests, as well as from the laboratory studies. The various blast properties can be readily determined with the help of these graphs, which are prepared on the basis of the results of 1 kiloton nuclear explosion and can be converted for any other detonation with the help of so-called SCALLING LAW.