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A COMPARISON OF THE BUILDING PROTECTION FACTOR CODES CAPS-2 AND PF-COMP

(Final Report)

OCD Contract No. DAHC20-67-W-0138
OCD Work Unit 1115D

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A COMPARISON OF THE BUILDING PROTECTION FACTOR CODES CAPS-2 AND PF-COMP

(Final Report)

by

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for

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Office of the Secretary of the Army
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Abstract

The purpose of the study was to determine the relative merits of the computer codes PF-COMP and CAPS-2 for calculating radiation fallout protection factors for shelter areas. These codes were produced for the Office of Civilian Defense (OCD) by the Research Triangle Institute (RTI) and the Architect-Engineering firm of Praeger, Kavanaugh, and Waterbury, respectively.

Protection factors for various detector positions within five building designs of varying complexity were hand calculated using the Engineering Manual method as outlined in the most recent revision. These results were then compared with machine-calculated protection factors using the PF-COMP and CAPS-2 programs. As a result of the comparisons, some program errors were found in PF-COMP. These errors were corrected by the authors of the code and the cases were recalculated.

The PF-COMP code was found to calculate protection factors in the 1-100 range for the five building designs to within ±15% of the hand-calculated values. The protection factors calculated with the CAPS-2 code tended to be high and were within -44 to +90% of the hand-calculated values.

For protection factors above 100, the PF-COMP code gave results that were within -41 to +36% of the hand-calculated values and tended to be conservative. In contrast, CAPS-2 results were generally not conservative, with the percentage error ranging from -10 to +58%. Based on these calculations, along with the relative ease with which the PF-COMP code may be used for multiple-story calculations, the PF-COMP code is deemed the better code and the use of CAPS-2 should be restricted to calculating

structures with low protection factors (about 20 or less) and/or of only limited complexity.

I. Introduction

The Engineering Manual method[4] for calculating building protection factors involves a large number and variety of design-type equations for which much of the shelter configuration-dependent data are available in the form of charts and graphs of limited resolution. The synthesis of a solution to a problem of average complexity is a tedius and oftentimes confusing exercise, and a single calculation for a given problem is of uncertain reliability without some kind of corroboration (which is usually unavailable).

In order to reduce the effort required to analyze structures for shielding effectiveness against fallout radiation and the possibility of error, two computer codes which have the Engineering Manual method as a basis were produced for use by the Office of Civil Defense (OCD). These codes are PF-COMP,[1] produced by the Research Triangle Institute (RTI), and CAPS-2,[2] produced by the Architect-Engineer firm of Praeger, Kavanaugh, and Waterbury. These two computer programs perform the numerical equivalent of the reading of charts and graphs and do the many calculation sequences which would be involved in a hand calculation. The only input required is the configuration data for the shelter.

Use of such computer programs permits detailed evaluations of many structures for a small cost and avoids many of the human errors that would be prevalent in tedious hand calculation. However, the usefulness and reliability of the computer-calculated protection factor depends largely on how accurately the computer code represents the data, equations, and the many matters of judgement which comprise the Engineering Manual method. The purpose of this investigation is to establish how well the computer-calculated protection factors compare with hand-calculated values using the Engineering Manual method for a wide variety of shelter configurations and, on the basis of these comparisons, to achieve an evaluation of the PF-COMP and CAPS-2 programs.

The procedure followed was to specify a set of hypothetical building designs which are representative of the structures that would be encountered in practice, to calculate the protection factors at various locations with both PF-COMP and CAPS-2, and then to compare the results with the hand-calculated values obtained by direct application of the latest version of the Engineering Manual method.[3]

In the following sections the Engineering Manual method and the two computer codes are briefly discussed. The results of the calculations, both by hand and by machine, are compared in graphical and tabular form and conclusions are drawn from these comparisons. In the appendix a sample calculation for one detector is shown in order to demonstrate the tediousness of the calculation and how the Engineering Manual method was applied.

II. The Engineering Manual Method

The equations and basic data which comprise what is commonly referred to as the Engineering Manual method were developed by Eisenhauer[4] with the help of L. N. FitzSimons of the Office of Civil Defense from the basic work by Spencer.[5] The details of the method are given in a number of publications.[3-6]

The fundamental approach to the calculation of a protection factor (the reciprocal of the reduction factor) is to determine the reduction factor associated with the floors above and below the detector as well as the detector floor. To these are added a reduction factor due to the roof and mass thickness between detector and roof, known as the "overhead contribution" to the reduction factor. The floor below analysis considers the ground direct and scattered radiation. The detector floor includes ground direct, scattered, and skyshine, while the floor above takes into account scattered and skyshine contributions.

Equation 1 is a typical equation for calculating the detector floor reduction factor for ground direct, scatter, and skyshine contributions for the case of interior partitions and no mutual shielding:

$$C_g = \Big\{[G_d(\omega,H_d) + G_a(\omega_u) - P_a\, G_a\,(\omega_a)][1 - S_\omega(X_e)]\; B_e(X_e,H) + P_a\; G_a(\omega_a)$$

$$B_e(0,H) + [G_s(\omega_L) + G_s(\omega_u) - P_a\; G_a(\omega_a)]\; S_\omega(X_e)\; E(e)\; B_e(X_e,H)\Big\}$$

$$B_i(X_i)\;, \qquad (1)$$

where

$G_d(\omega_i,H_d)$ = directional response for ground direct contribution to reduction factor based on solid angle, ω_i, and heigh., H_d, above contaminated plane,

$G_s(\omega_i)$ = directional response for wall-scattered ground contribution to reduction factor based on solid angle ω_i,

$G_s(\omega_i)$ = directional response for skyshine ground contribution to reduction factor based on solid angle ω_i,

$S_\omega(X_e)$ = fraction of emergent radiation scattered in exterior wall of mass thickness X_e,

$E(e)$ = shape factor for wall-scattered radiation based on structure eccentricity e,

$B_e(X_e,H)$ = exterior wall barrier reduction factor,

P_a = perimeter ratio of apertures,

$B_i(X_i)$ = interior wall barrier reduction factor for ground contribution based on interior wall mass thickness X_i.

The overhead contribution considers skyshine through the roof, as well as scattered and direct. Methods for handling apertures, limited fields of contamination, effects of interior partitions, and the use of fictitious buildings to determine protection factors for non-rectangular buildings are then developed to complete the basic framework of the method.

III. CAPS-2 and PF-COMP Computer Codes

The computer codes CAPS-2 and PF-COMP were written to facilitate the use of the Engineering Manual method by eliminating the tedious hand calculations.

CAPS-2

The CAPS-2 program was originally developed by the Architectural and Engineering firm of Praeger, Kavanaugh, and Waterbury.[7] Extensive modifications were made by Dirst of the OCD to increase the flexibility of the computations and the input-output routines.[2]

CAPS-2 is written in FORTRAN computer language and is based on the Engineering Manual method with one important exception -- skyshine contribution for the detector floor and the floor above is considered to be affected by mutual shielding buildings. The Engineering Manual method treats this contribution as the same with or without mutual shielding.

The code will handle up to ten detector positions per floor or shelter area. In the analysis of a building, the program logic follows that of a typical engineering manual hand calculation and includes the effects of the roof, exterior walls, apertures, interior partitions, floors, mutual shielding, height above contaminated planes and building geometry.

Certain restrictions are contained in the program, the more important ones being: (a) window sills are at detector level (except for basement), which is 3 ft above detector floor, (b) only two contaminated planes may be considered for each side of a structure, and (c) the exterior wall mass thickness is restricted to only one change between detector floor and adjacent floors. Preparation of the input data is relatively simple but a new set must be prepared for each detector floor. The program allows for a total of four output options depending on the desires of the user. The output is printed in a manner which permits an analysis of those areas in which the effect due to shielding modifications will be most significant.

PF-COMP

The PF-COMP code[1,8] is written in FORTRAN computer language and its use is restricted to the large computers such as the CDC 3600. The program is also based on the Engineering Manual method but it is more comprehensive than CAPS-2. Roof setbacks are included and allowances are made for three contaminated planes, basement areaways, and partial basements. The program allows for different interior and exterior wall mass thicknesses for each floor. In addition, sill levels are not restricted to detector level (3 ft from floor), but only one change is permitted above the second story. Preparation of the input data is more detailed than CAPS-2, but it need be done only once for a building since PF-COMP will calculate a protection factor for the center detector position of each floor in addition to eight other locations for each floor (pre-set by code). The output is essentially the same as CAPS-2.

IV. Building Designs

The descriptions of the five hypothetical buildings (designated as building no.1, building no.2, etc.) and their surroundings are presented only in the detail required for the Engineering Manual hand calculation. Plane and elevation views, dimensional details, construction characteristics, and detector locations are given for each building. In each case considered, the detector was located at the midpoint and 3 ft above the floor.

Building No. 1

Building No. 1 comprises a set of 13 similar buildings (these buildings are designated as 1A, 1B, 1C, ..., 1M) for which only minor design differences exist. The data generated for this case allowed more detailed comparisons to be effected wherein the influence of one portion of the overall calculation could be determined. The plan and elevation views are shown in Fig. 1, and the design specifications are given in Table 1. A protection factor was computed for the center position of the detector in the basement and in the second floor.

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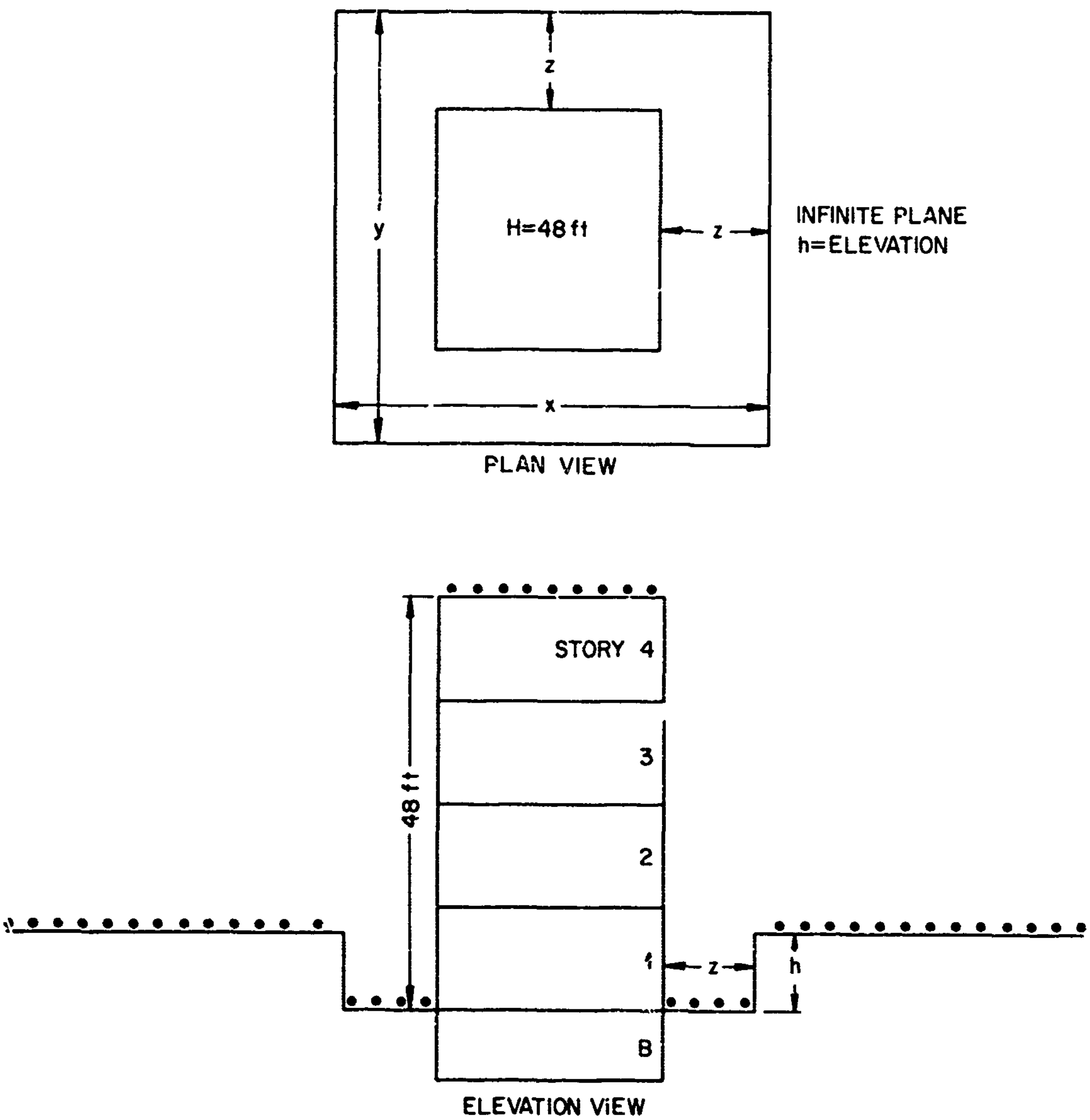

Fig. 1. Building No. 1 Plan and Elevation Views.

Table 1. Specifications for Building No. 1[a]

Building No.	Building Dimensions, ft (x · y)[b]	Width of Apertures per Wall, ft	Percentage Apertures per Wall, ft	Perimeter Ratio	Width of Contaminated Strip, ft (z)[b]	Height of Contaminated Infinite Plane, ft (h)[b]	Mass Thicknesses, psf Ext.Wall	Mass Thicknesses, psf Int.Part.	Mass Thicknesses, psf Floor
1A	100 x 100	60	25	0.6	150	48	60	0	25
1B	100 x 100	60	25	0.6	50	48	60	0	25
1C	100 x 100	60	25	0.6	150	200	60	0	25
1D	100 x 100	60	25	0.6	150	48	40	0	25
1E	100 x 100	60	25	0.6	150	48	60	10	25
1F	100 x 100	60	25	0.6	150	48	60	40	25
1G	100 x 100	60	25	0.6	150	12	60	0	25
1H	100 x 100	60	25	0.6	150	48	60	0	10
1I	100 x 100	96	40	0.96	150	48	60	0	25
1J	150 x 50	90,30	25	0.6	150	48	60	0	25
1K	150 x 50	90,30	25	0.6	150	48	60	10	25
1L	150 x 50	90,30	25	0.6	50	48	60	0	25
1M	150 x 50	90,30	25	0.6	150	48	60	40	25

a. Number of stories, 4 plus basement; height of building, 48 ft; height of basement, 8 ft; sill height, 3 ft; height of aperture, 5 ft; mass thickness of roof, 50 psf.

b. x, y, z, and h are shown in Fig. 1

Building No. 2

The plan and elevation views of building no. 2 are shown in Fig. 2. The shading in the plan view indicates different roof elevations and the numbers in the center of a roof designate the total height of that section above ground level.+ Design specifications are presented in Table 2. A protection factor was computed for the first and fifth floors with the detectors centrally located.

Building No. 3

Building no. 3 is typical of many commercial buildings such as small factories or hospitals. The plan, east-wall elevation, and south-wall elevation views are shown in Fig. 3. Partition layouts for all four floors are shown in Fig. 4. Design specifications are presented in Table 3. Protection factors were computed for the first and fourth floors with the detectors centrally located.

Building No. 4

Building no. 4, together with its surroundings, is typical for a large apartment or office building in a metropolitan area. The plan and elevation views are shown in Fig. 5, and the partition layout for all floors is shown in Fig. 6. The design specifications are given in Table 4. Protection factors are computed for the first and third floors only.

Building No. 5

Building no. 5 could be a part of a hospital or school complex in a suburban area. The structure is not symmetric as was the case for

+This comment applies to all plan views.

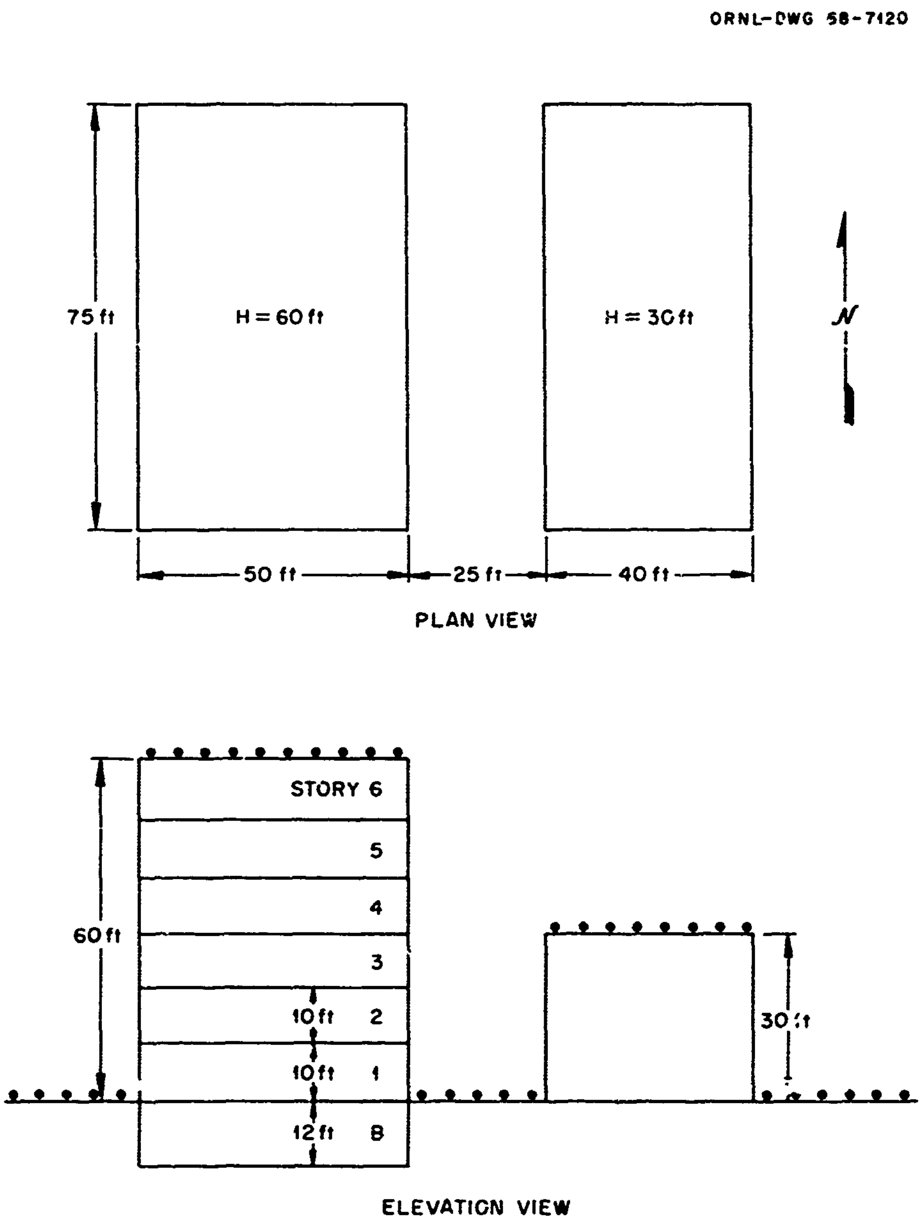

Fig. 2. Building No. 2 Plan and Elevation Views.

Table 2. Specifications for Building No. 2

Dimensional Data:

Total height, 60 ft

Basement height, 12 ft

First floor height, 10 ft

Upper floor height, 10 ft

Aperture heights, 4 ft (bottom to top of aperture)

Sill height, 3 ft

Construction Specifications:

Basement wall mass thickness, 50 pst

First floor wall mass thickness, 50 psf

Upper floor wall mass thickness, 50 psf

Basement floor mass thickness, 35 psf

First floor mass thickness, 40 psf

Upper floor mass thickness, 35 psf

Roof mass thickness, 45 psf

No interior partitions

Apertures:

Basement, 0%

First floor, 30%

Upper floor, 30%

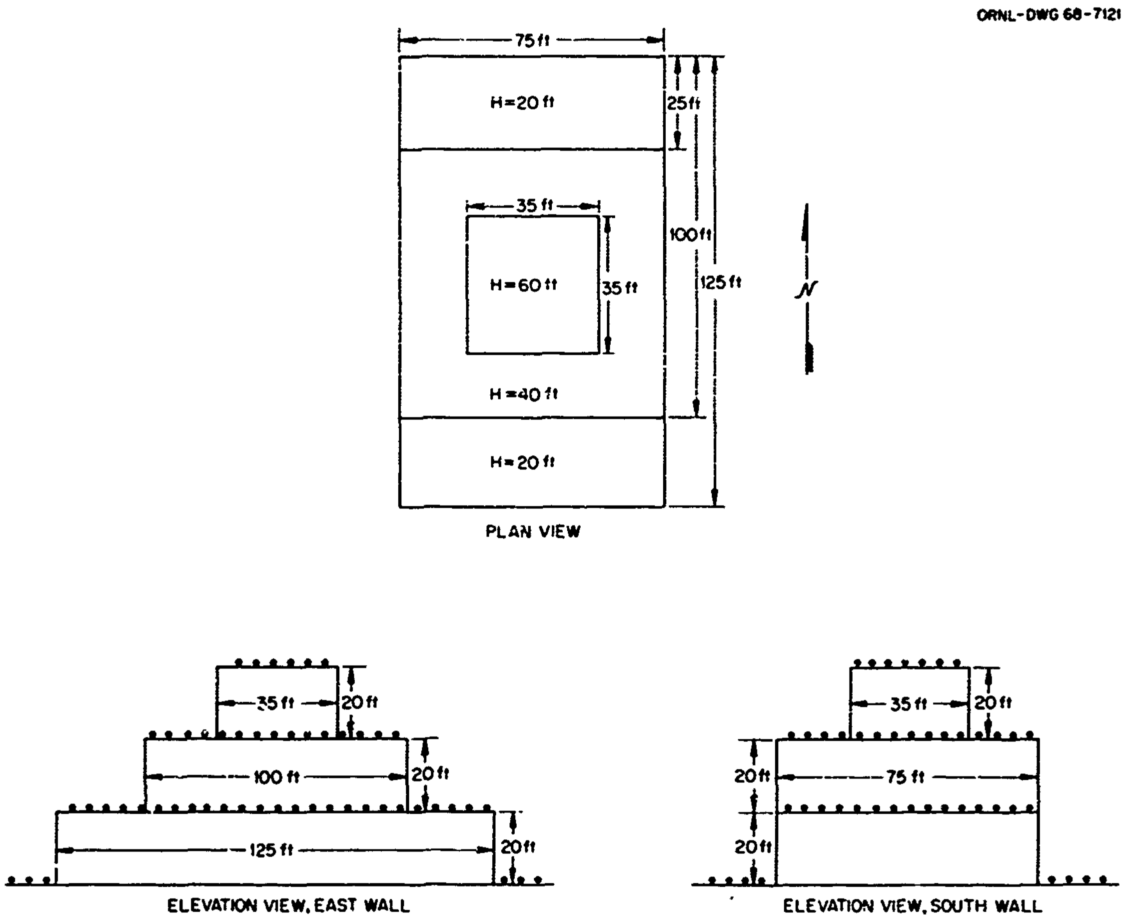

Fig. 3. Building No. 3 Plan and Elevation Views.

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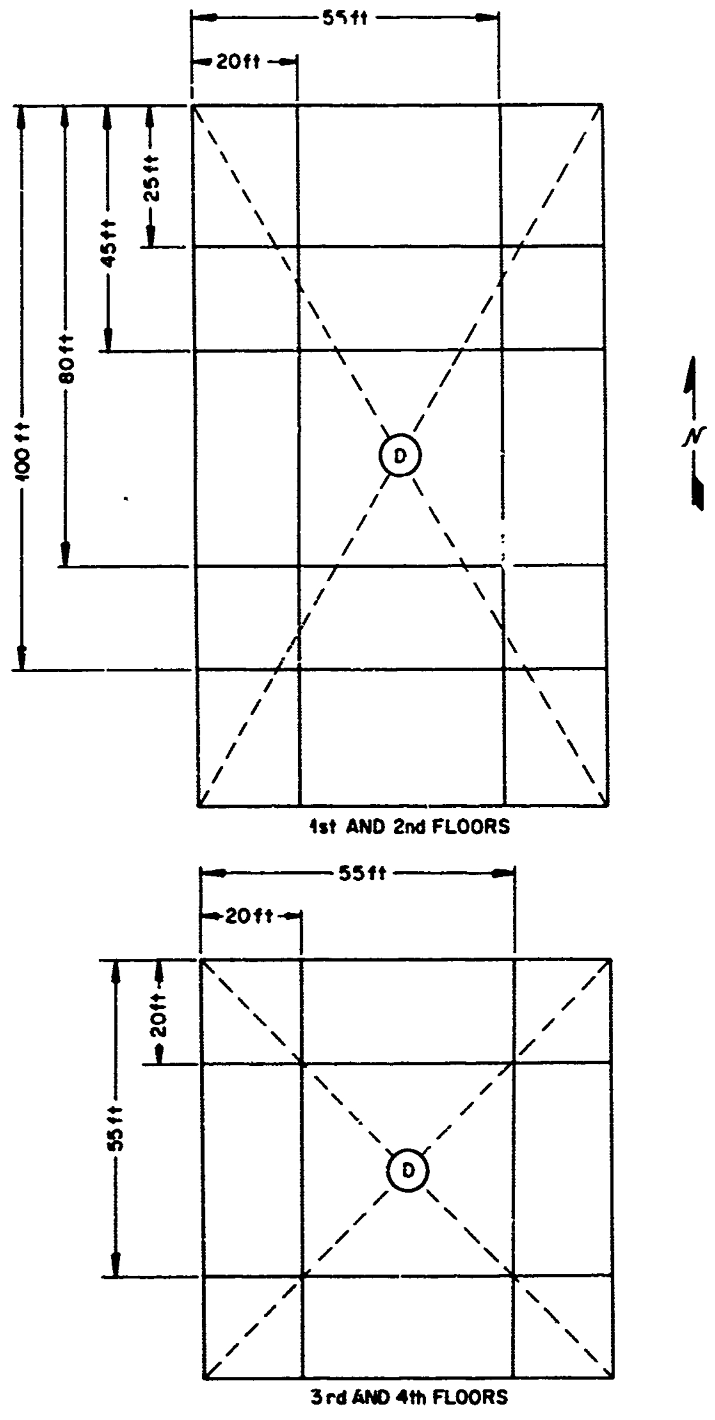

Fig. 4. Partition Layouts c^ Floors 1 to 4 in Building No. 3.

Table 3. Specifications for Building No. 3

Dimensional Data:

Total height, 60 ft
First floor height, 10 ft
Upper floor height, 10 ft
Aperture height, 5 ft (bottom to top of aperture)
Sill height, 3 ft

Construction Specifications:

First floor wall mass thickness, 60 psf
Upper floor wall mass thickness, 60 psf
First floor mass thickness, 30 psf
Upper floor mass thickness, 30 psf
Main roof mass thickness, 40 psf
Setback roof mass thickness, 40 psf
Interior partition mass thickness, 25 psf

No interior partitions on 4th and 5th floors

Apertures:

First floor and second floor:
North and south walls, 35%
East and west walls, 25%

Third and fourth floors:
North and south walls, 35%
East and west walls, 42%

Fifth and sixth floors:
North and south walls, 35%
East and west walls, 35%

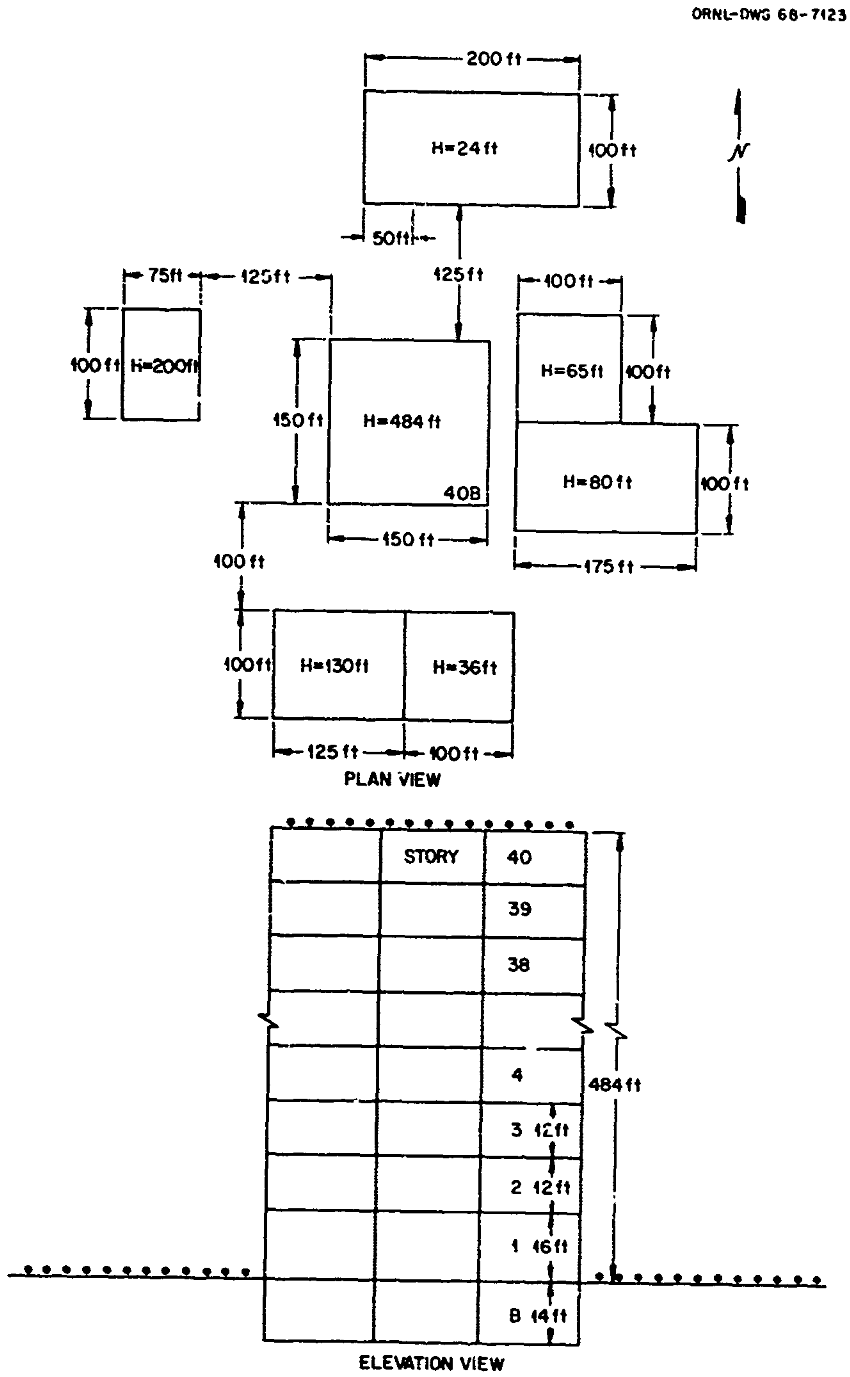

Fig. 5. Building No. 4 Plan and Elevation Views.

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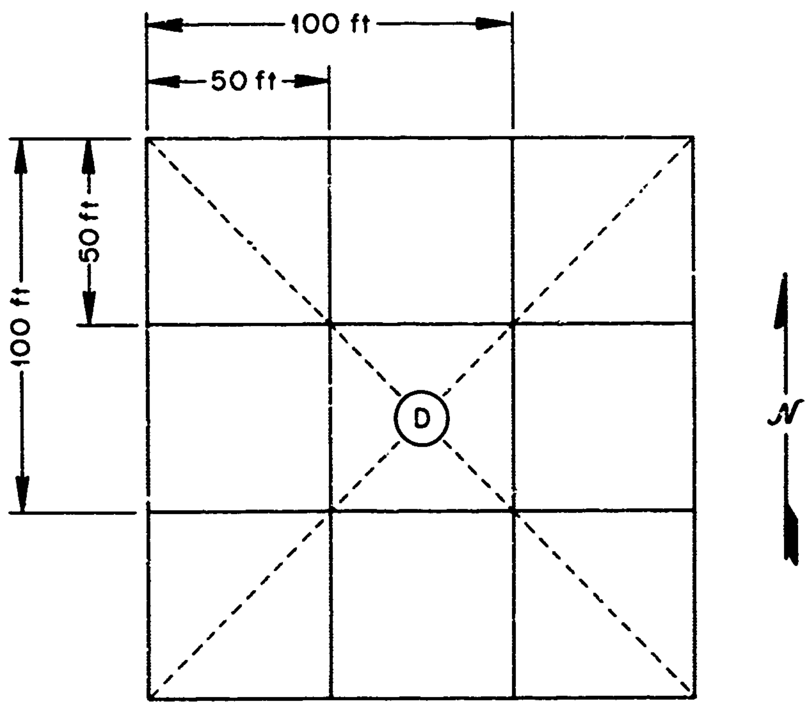

Fig. 6. Partition Layout of All Floors in Building No. 4.

Table 4. Specifications for Building No. 4

Dimensional Data:

Total height of building, 484 ft
Number of stories, 40 with basement
Basement height, 14 ft
First floor height, 16 ft
Upper floor height, 12 ft
Aperture height, 1st floor, 12 ft (bottom to top of aperture)
Upper floor aperture height, 8 ft
Sill height, all floors, 3 ft

Construction Specifications:

Basement wall mass thickness, 75 psf
First floor wall mass thickness, 75 psf
Upper floor wall mass thickness, 75 psf
All interior partition mass thickness, 25 psf
Basement floor mass thickness, 80 psf
First floor mass thickness, 80 psf
Upper floor mass thickness, 35 psf
Roof mass thickness, 70 psf

Apertures:

Basement, 0%
First floor, 60%
Upper floors, 25%

buildings no. 1 through no. 4, and its surroundings include a small lake and two adjacent buildings of comparable size. The plan view of the building and its surroundings is shown in Fig. 7. The north-wall, east-wall, south-wall, and west-wall elevations are shown in Fig. 8, along with the details of an areaway adjacent to building no. 5. Partition layouts for all five floors are shown in Fig. 9. The plan view of the basement is shown in Fig. 10. Design specifications are given in Table 5. Protection factors were calculated for the partial basement, first, and fifth floors.

V. Calculational Procedures and Comparison of Results

Protection factors for the five hypothetical buildings described in the previous section were calculated by hand using equations and data found in TR-20.[5] These calculations were performed with great care and the results should represent the application of the Engineering Manual method to an accuracy within the limitations imposed by reading the charts and the use of good judgement in the areas of uncertainty in application of the method. The aim was to compare computer-calculated protection factors with these "standard" values. In the interpretation of the results, the basic assumption was that any disparities were due to an imperfect representation of the Engineering Manual method by the computer codes.

As an example of the tedious calculations required in applying the Engineering Manual method, the very extensive and complex details of the hand calculation of a protection factor for one detector position in a multiple-story building (building no. 5) with complicated geometry and mutual shielding are given in an appendix to this report.

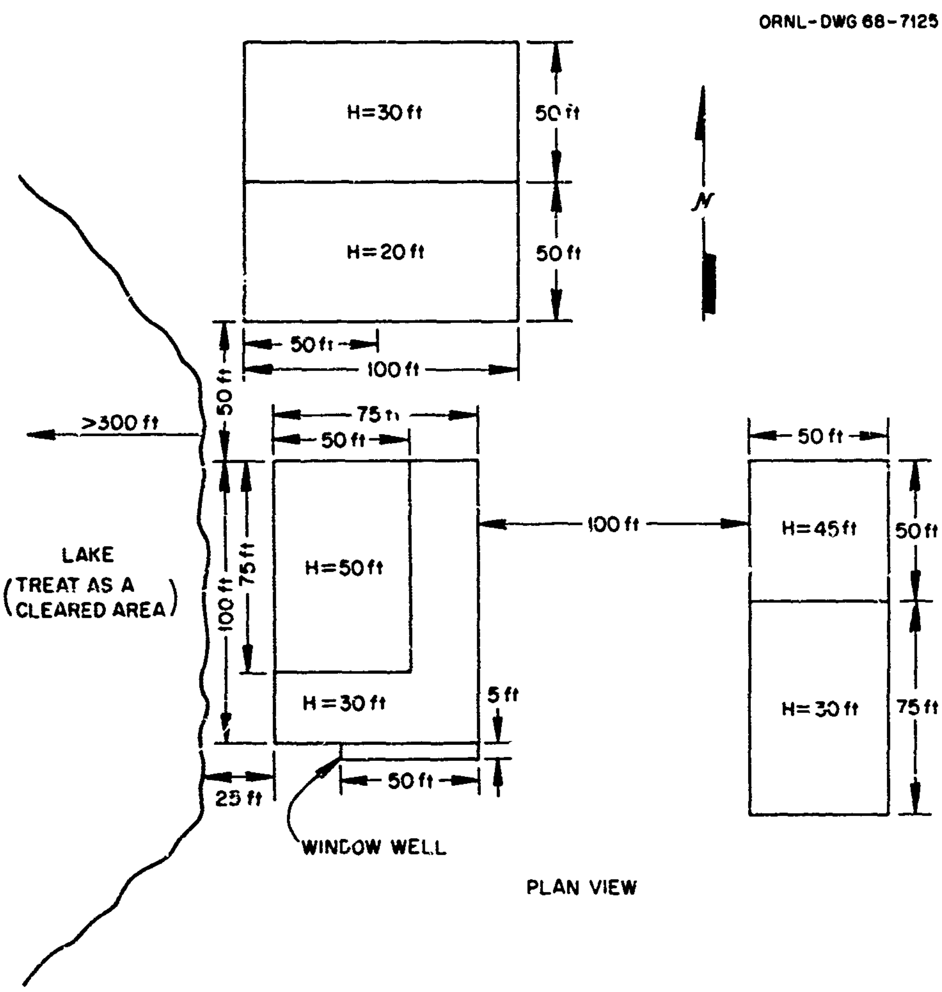

Fig. 7. Building No. 5 Plan View.

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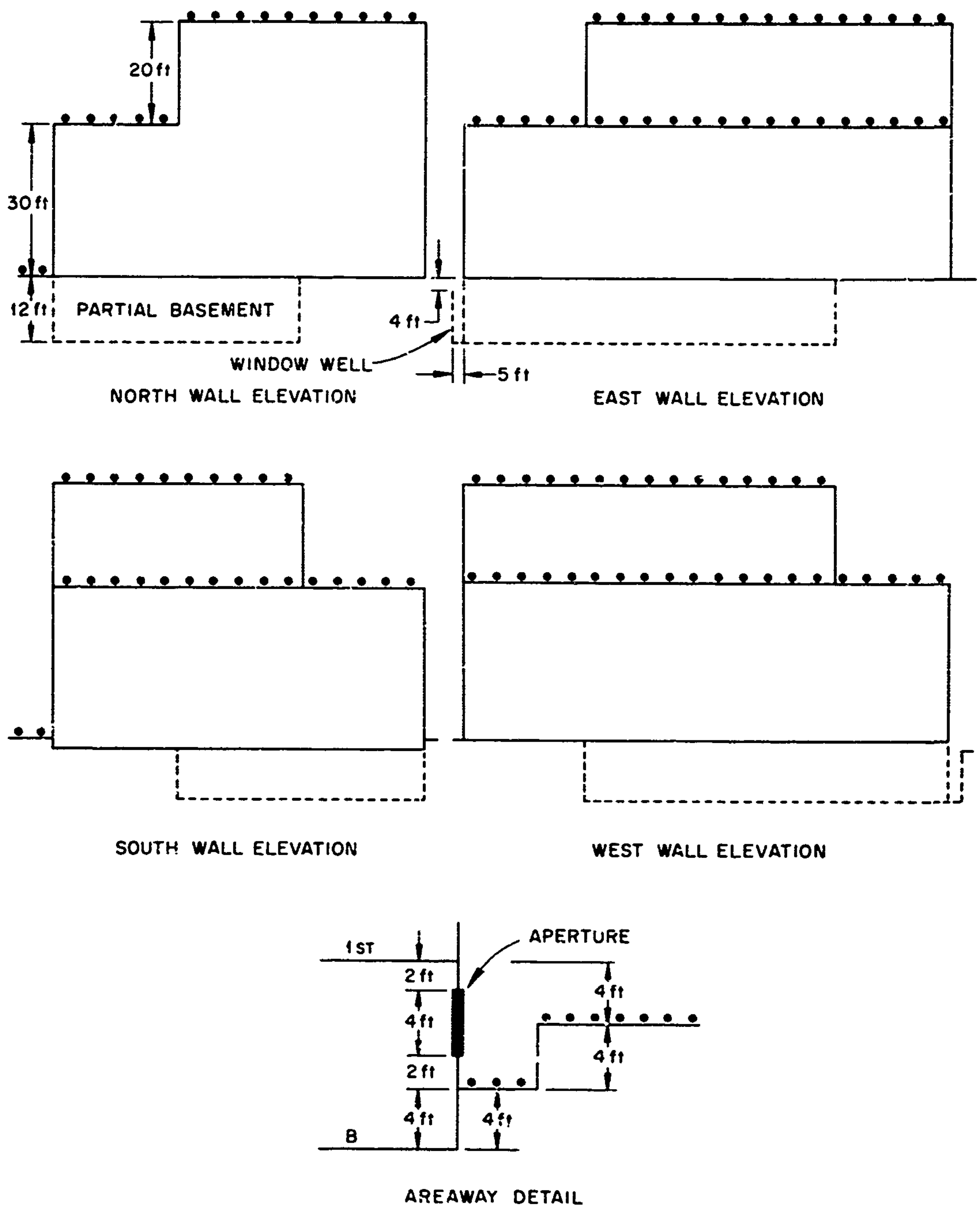

Fig. 8. Building No. 5 Elevation Views and Areaway Detail.

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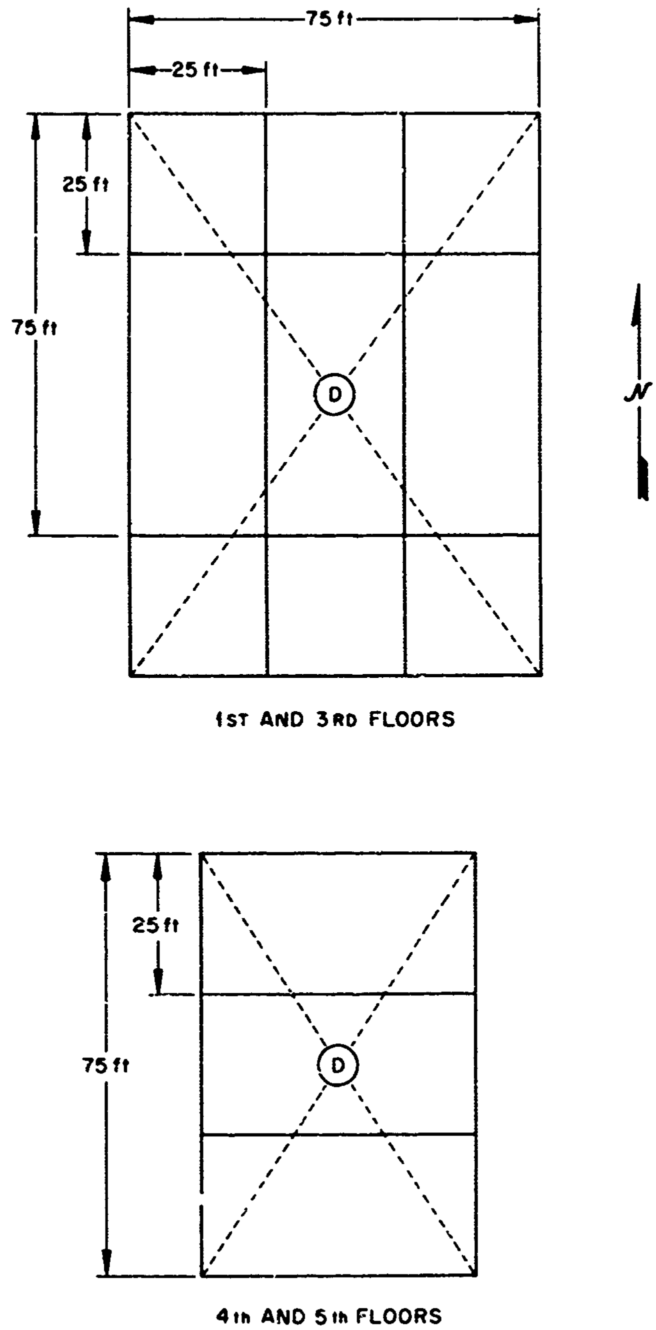

Fig. 9. Partition Layouts of Floors 1 to 5 in Building No. 5.

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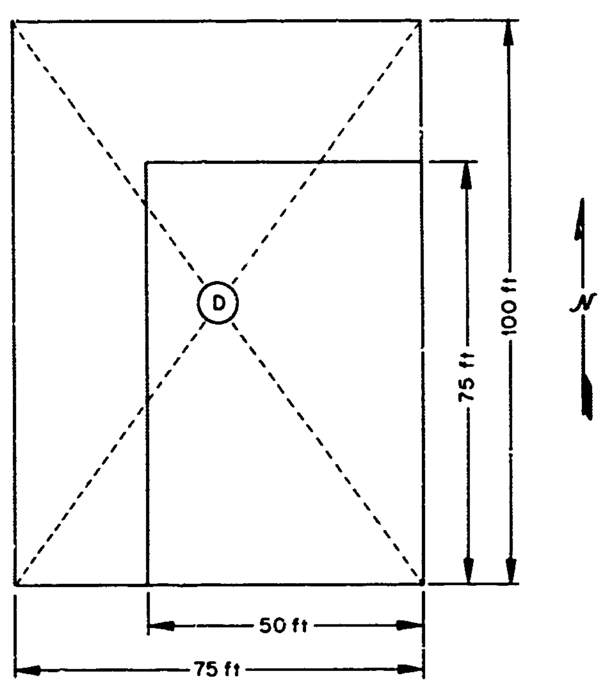

Fig. 10. Basement Plan of Building No. 5.

Table 5. Specifications for Building No. 5

Dimensional Data:

Basement height, 12 ft

First floor height, 10 ft

Upper floor height, 10 ft

Sill heights in basement areaway, 6 ft

Aperture height in basement areaway, 4 ft (bottom to top of aperture)

Upper floor aperture height, 5 ft

Upper floor sill height, 3 ft

Note: On the south wall, the first contaminated plane is 4 ft lower than the other three walls over the entire azimuthal sector seen by the south wall.

Construction Specifications:

Basement wall mass thickness, 60 psf

First floor wall mass thickness:

North wall, 50 psf
East wall, 50 psf
South wall, 50 psf
West wall, 60 psf

Upper floor wall mass thickness (2nd and 3rd floors):

North wall, 50 psf
East wall, 50 psf
South wall, 50 psf
West wall, 60 psf

Upper floor wall mass thickness (4th and 5th floors):

North wall, 45 psf
East wall, 45 psf
South wall, 45 psf
West wall, 45 psf

All interior partition mass thickness, 25 psf

Basement floor mass thickness, 50 psf

First floor mass thickness, 40 psf

Upper floor mass thickness, 35 psf

Upper floor mass thickness (if change), 30 psf

Story of change, 4th

Setback roof mass thickness, 50 psf

Main roof mass thickness, 50 psf

Table 5. (cont.)

Apertures:

Percentage apertures in basement areaway, 20%

Total aperture width of 30 ft in wall of length, 50 ft

Apertures on first floor:

North wall, 25%
East wall, 35%
South wall, 30%
West wall, 40%

Apertures on upper floors (no change):

North wall, 25%
East wall, 35%
South wall, 30%
West wall, 40%

Apertures on upper floors (if change):

North wall, 25%
East wall, 20% (story of change, 4th)
South wall, 15%
West wall, 20%

The PF-COMP and CAPS-2 computer codes were used to calculate protection factors for the same five buildings (as described in the previous section) using exactly the same input data whenever possible. The CAPS-2 computer calculations were run on the IBM 1604 at the Oak Ridge National Laboratory and the PF-COMP calculations were run at the National Civil Defense Computer Facility, Washington, D. C. The operation of both codes seemed routine; however, a detailed comparison of the PF-COMP results with the standard (hand calculated) protection factors suggested that the PF-COMP code was in error. The authors of the code were informed of the discrepancies and they were able to locate and correct the errors, which were in floor-above and floor-below contributions.[8] The complete set of problems was recalculated with the corrected code and better agreement was obtained.

Comparisons of the calculated protection factors are presented in graphical form in Figs. 11 and 12. Fig. 11 is a plot of the protection factors calculated with the PF-COMP code versus the corresponding hand-calculated values. A computer-calculated protection factor would exactly equal the hand-calculated value if the plotted point would lie on the line drawn through the origin at 45°. A point located below the line indicates an underestimate of the protection factor by the computer code with respect to the hand-calculated value; a point above the line indicates an overestimate. Note that the PF-COMP values generally are in good agreement with the hand calculations for buildings having protection factors up to about 100 and generally lie well below the 45° line for larger protection factors.

Fig. 12 is a plot of the protection factors calculated with CAPS-2 versus hand-calculated values. The CAPS-2 data points in general lie above the 45° line, indicating that CAPS-2 generally overestimates the protection factor in comparison with the hand calculations. Note that the CAPS-2 data points form a rather scattered pattern as compared with the PF-COMP calculations shown in Fig. 11.

The protection factors for all detector locations are also presented in Table 6. No attempt was made to estimate error or confidence limits for the individual protection factors because of the nature of the calculations; the percentage deviation shown is relative to the hand calculations.

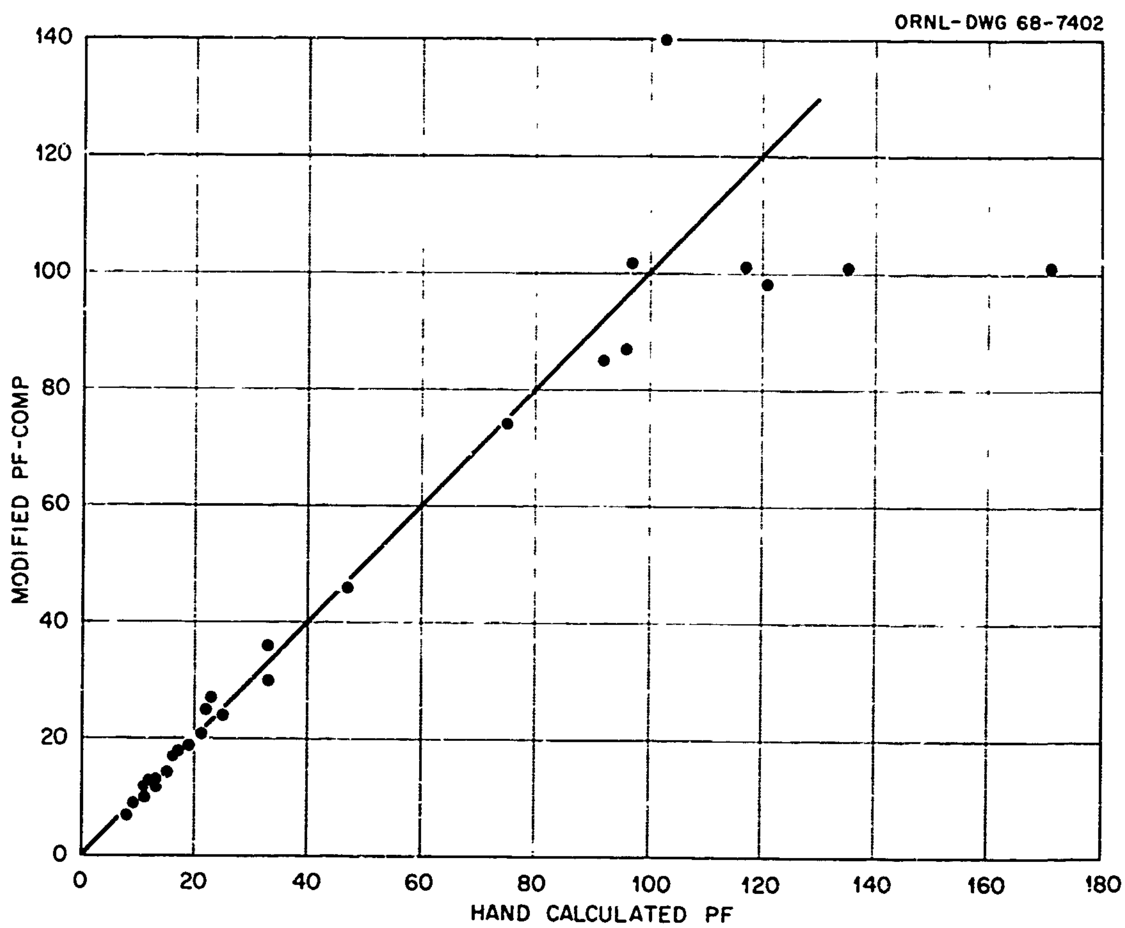

Fig. 11. Comparison of Protection Factors Calculated with the PF-COMP Code and with the Engineering Manual Method.

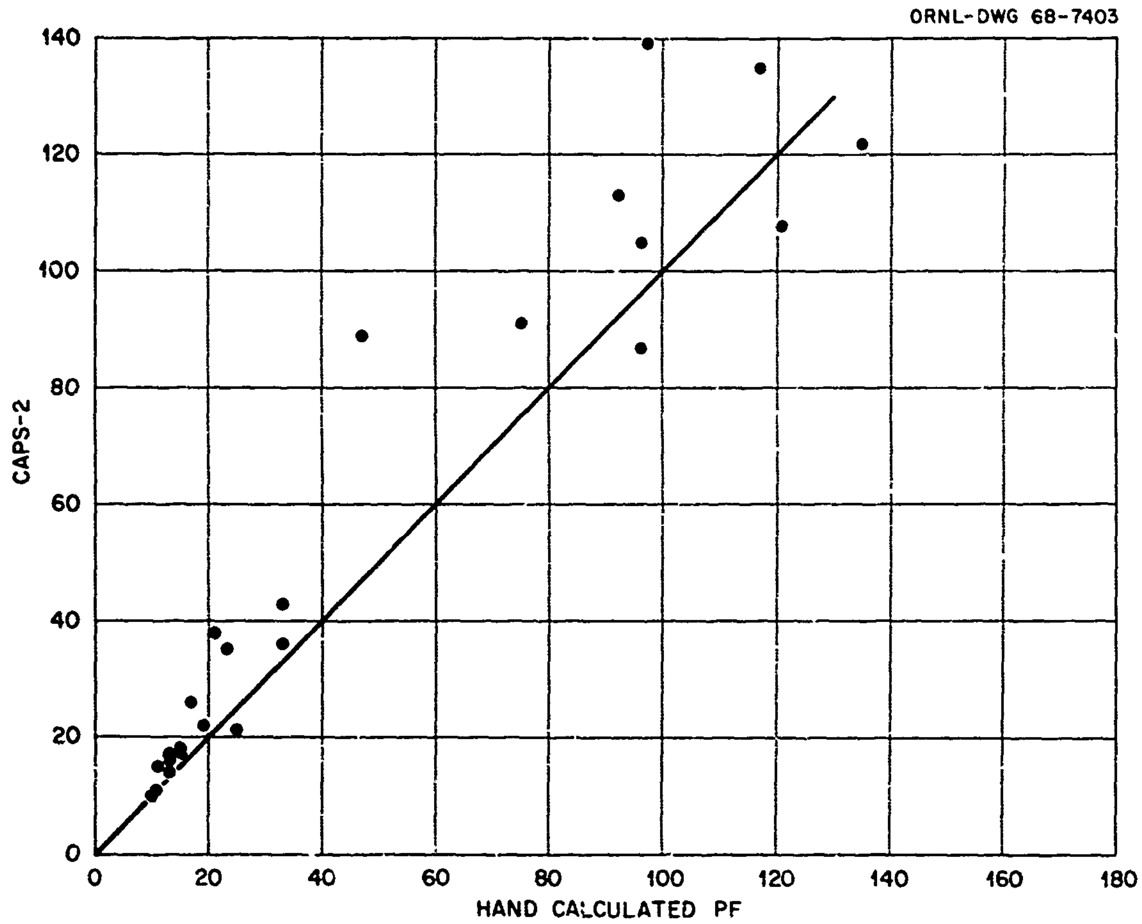

Fig. 12. Comparison of Protection Factors Calculated with the CAPS-2 Code and with the Engineering Manual Method.

Table 6. Protection Factors for Each Detector Location in the Five Building Designs

Building No.	Detector Location	Calculated Protection Factors: PF-COMP	CAPS-2	Hand	Deviation from Hand Calc., %: PF-COMP	CAPS-2
1A	Basement	87	105	96	- 9.4	+ 9.4
1A	2nd floor	14	17	15	- 6.7	+13
1B	Basement	102	139	97	+ 5.2	+41
1B	2nd floor	18	26	17	+ 5.9	+53
1C	Basement	87	-	96	- 9.4	-
1C	2nd floor	14	18	15	- 6.7	+20
1D	Basement	74	91	75	- 1.3	+21
1D	2nd floor	12	14	13	- 7.6	+7.6
1E	Basement	101	135	117	-14	+15
1E	2nd floor	19	22	19	0	+16
1F	Basement	141	243	196	-28	+24
1F	2nd floor	36	43	33	+ 9.1	+30
1G	Basement	87	87	96	- 9.4	- 9.4
1G	3rd floor	11	-	12	- 8.3	-
1H	Basement	30	36	33	- 9.1	+ 9.1
1H	2nd floor	9	10	10	-10	0
1I	Basement	85	113	92	- 8.3	+19
1I	2nd floor	12	16	13	- 9.1	+23
1J	Basement	93	108	121	-19	- 9.9
1J	2nd floor	12	15	11	- 8.3	-36
1K	Basement	101	122	135	-25	- 9.7
1K	2nd floor	13	17	13	0	+31
1L	Basement	294	428	313	- 6.1	+38
1L	2nd floor	21	38	21	0	+81
1M	Basement	101	164	171	-41	- 4.1
1M	2nd floor	17	9	16	+ 6.2	-44
2	1st floor	7	-	8	-12	-
2	5th floor	10	11	11	- 9.1	0

Table 6. (cont.)

Building No.	Detector Location	Calculated Protection Factors			Deviation from Hand Calc., %	
		PF-COMP	CAPS-2	Hand	PF-COMP	CAPS-2
3	1st floor	24	21	25	- 4.0	-16
3	4th floor	25	-	22	+14	0
4	1st floor	46	89	47	- 2.1	+89
4	3rd floor	140	163	103	+36	+58
5	Basement	183	-	115	+45	-
5	1st floor	27	35	23	+17	+52
5	5th floor	9	-	9.5	- 5.3	-

Figs. 13 and 14 are plots of the "floor-above" and "floor-below" contributions as calculated with the original and corrected versions of PF-COMP, respectively, versus the corresponding values calculated by hand. These plots reveal the nature of the errors contained in the original PF-COMP code; the original version of PF-COMP seriously overestimated the reduction factors in most cases for the "floor-above" and "floor-below" contributions. The excellent correlation of the modified PF-COMP results with the hand-calculated ones generally confirms that the errors in the original PF-COMP code have been resolved.

VI. Conclusions and Recommendations

An inspection of Fig. 11 and Table 6 shows that the protection factors < 100 calculated with the PF-COMP code[8] are in good agreement (-12 to +17%) with the hand-calculated values and generally tend to be a little conservative, a desirable characteristic for a calculation of this kind. In contrast, the protection factors calculated with CAPS-2 code[2] tend to be high and do not agree as well with the hand-calculated values (-44 to +90%). The deviations from the hand-calculated values became larger (-41 to +36% for PF-COMP and -10 to +58% for CAPS-2) for protection factors > 100. For this range only PF-COMP should be used since it tends to give conservative values in contrast to CAPS-2.

As a result of this study, along with the relative ease with which PF-COMP may be used for multiple-story calculations, the PF-COMP code is deemed to be the better code and the use of CAPS-2 should be restricted to calculating structures with low protection factors (about 20 or less), and/or of only limited complexity.

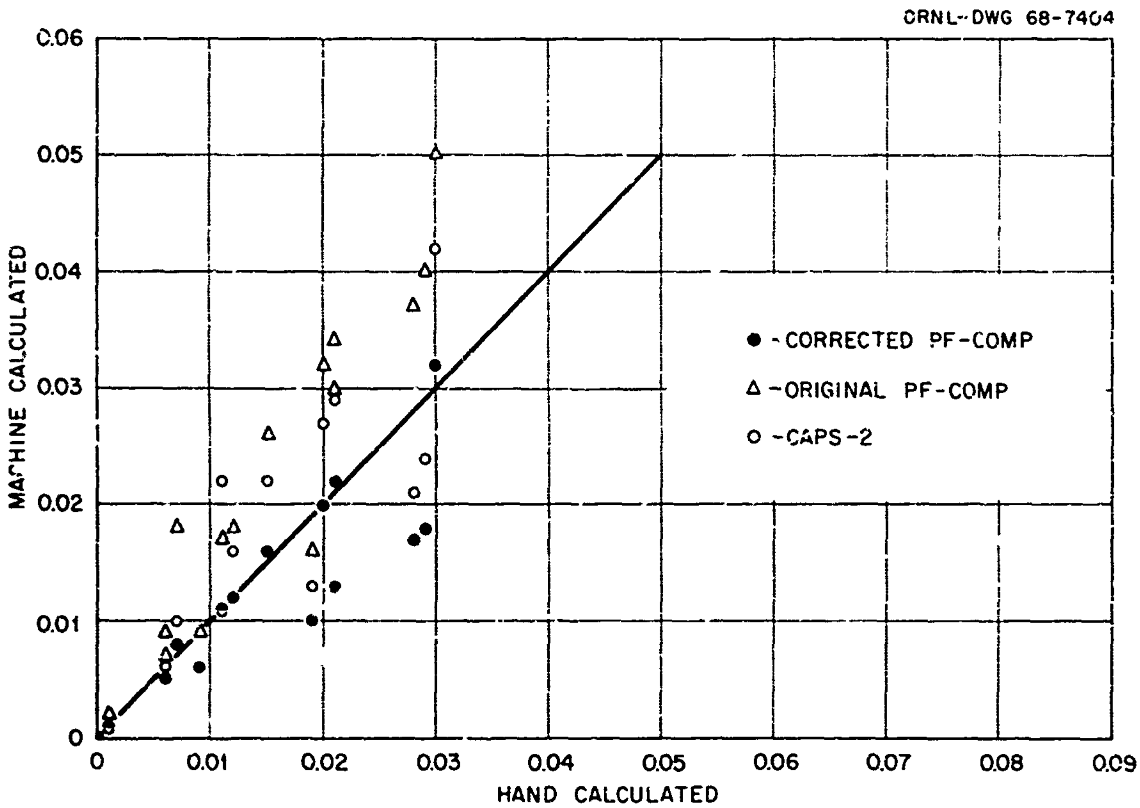

Fig. 13. Comparison of the "Floor-Below" Contributions Calculated with PF-COMP Codes (Original and Revised) and with the Engineering Manual Method.

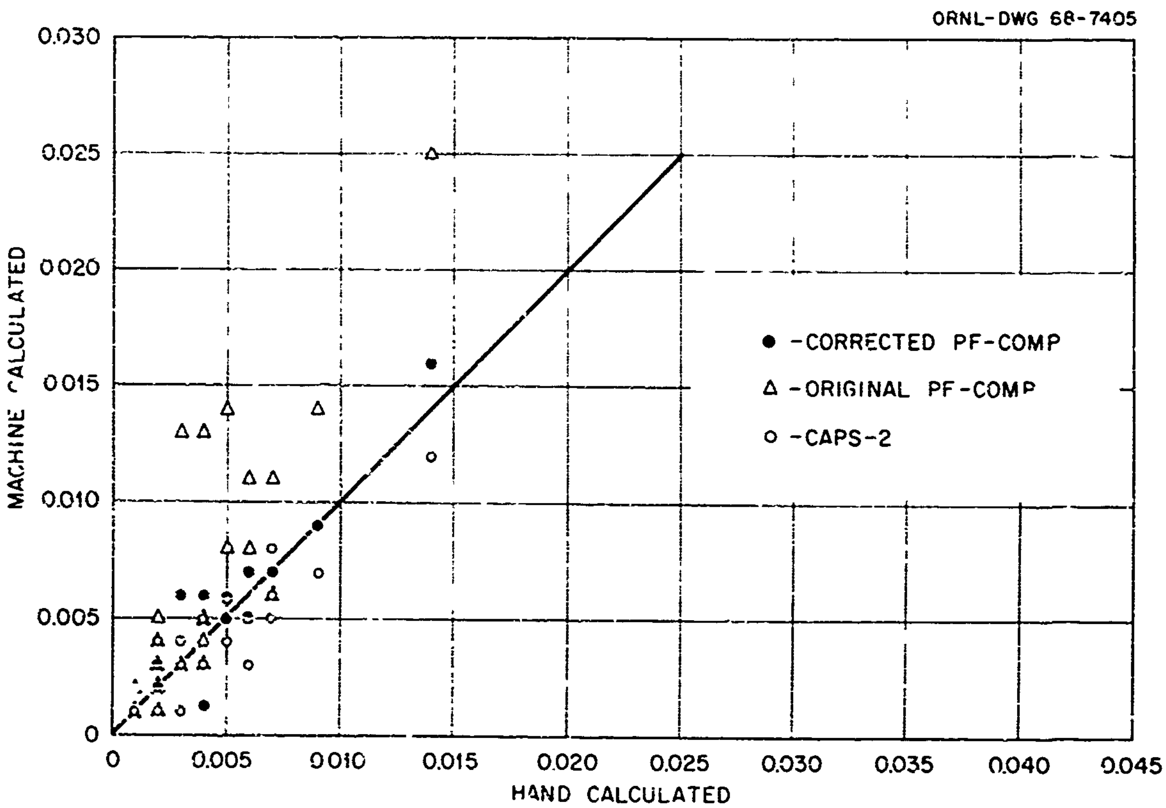

Fig. 14. Comparison of the "Floor-Above" Contributions Calculated with PF-COMP Codes (Original and Revised) and with the Engineering Manual Method.

Acknowledgements

The authors acknowledge the help of Mr. Russ Lyday of the Research Triangle Institute in using PF-COMP and to Mr. John Dirst of the Office of Civil Defense for his assistance in using CAPS-2. Thanks are also extended to H. C. Claiborne of ORNL for his guidance and helpful criticisms and to Mrs. Betty F. Maskewitz and Mrs. Henrietta R. Hendrickson of the Radiation Shielding Information Center for securing the necessary materials and assistance in performing the machine calculations.

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APPENDIX

Sample Calculation for
Building No. 5 First Floor
Detector - Engineering
Manual Method

Table A1. Equations for Calculating Various Contributions to Reduction Factor by Engineering Manual Method+

Eqn. No.	Expressions	Description and Comments
1	$[G_d(\omega_L',H_d) - G_d(\omega_L,H_d)][1 - S_\omega(X_e)\ B_e(X_e,H)\ (1 - A_p)\ B_f(X_f)\ B_i(X_i)$	Solid wall ground direct component; floor below; no mutual shielding.
2	$[G_d(\omega_L',H_d) - G_d(\omega_L,H_d)]\ B_e(0,H)(A_p)\ B_f(X_f)\ B_i(X_i)$	Aperture ground direct component; floor below; no mutual shielding
3	$[G_d(\omega_L',H_d) - G_d(\omega_L'',H_d)][1 - S_\omega(X_e)]\ B_e(X_e,H)(1 - A_p')\ B_f(X_f)\ B_i(X_i)$	Solid wall ground direct component; floor below; mutual shielding; A_p' is % apertures between ω_L'' and ω_L'.
4	$[G_d(\omega_L',H_d) - G_d(\omega_L'',H_d)]\ B_e(0,H)(A_p')\ B_f(X_f)\ B_i(X_i)$	Aperture ground direct component; floor below; mutual shielding.
5	$[G_s(\omega_L') - G_s(\omega_L)]\ S_\omega(X_e)\ E(e)\ B_e(X_e,H)(1 - A_p)\ B_f(X_f)\ B_i(X_i)$	Scatter component for floor below; no mutual shielding
6	$[G_s(\omega_L') - G_s(\omega_L)]\ S_\omega(X_e)\ E(e)\ B_{\omega s}(\omega_s,X_e)(1 - A_p)\ B_f(X_f)\ B_i(X_i)$	Scatter component for floor below; mutual shielding.
7	$G_d(\omega_L,H_d)\ [1 - S_\omega(X_e)]\ B_e(X_e)\ B_i(X_i)$	Ground direct component; detector floor; no mutual shielding.
8	$[G_d(\omega_L,H_d) - G_d(\omega_L'',H_d)][1 - S_\omega(X_e)]\ B_e(X_e)\ B_i(X_i)$	Ground direct component; detector floor; mutual shielding; use only if $\omega_L'' > \omega_L$; if $\omega_L'' \leq \omega$, expression = 0.
9	$[G_s(\omega_L) + G_s(\omega_u) - P_a\ G_s(\omega_a)]\ S_\omega(X_e)\ E(e)\ B_e(X_e,H)\ B_i(X_i)$	Scatter component for detector floor; no mutual shielding.

Table A1. (cont.)

Eqn. No.	Expressions	Description and Comments
10	$[G_s(\omega_L) + G_s(\omega_u) - P_a\ G_s(\omega_a)]\ S_\omega(X_e)\ E(e)\ B_{\omega s}(\omega_s, X_e)\ B_i(X_i)$	Scatter component for detector floor; mutual shielding.
11	$[G_a(\omega_u) - P_a\ G_a(\omega_a)][1 - S_\omega(X_e)]\ B_e(X_e, H)\ B_i(X_i)$	Solid wall skyshine component for detector floor.
12	$P_a\ G_a(\omega_a)\ B_e(O, H)\ B_i(X_i)$	Aperture skyshine component for detector floor.
13	$[G_s(\omega_u') - G_s(\omega_u)]\ S_\omega(X_e)\ E(e)(1 - A_p)\ B_e(X_e, H)\ B_o'(X_o')\ B_i(X_i)$	Scatter component for floor above; no mutual shielding.
14	$[G_s(\omega_u') - G_s(\omega_u)]\ S_\omega(X_e)\ E(e)(1 - A_p)\ B_{\omega s}(\omega_s, X_e)\ B_o'(X_o')\ B_i(X_i)$	Scatter component for floor above; mutual shielding.
15	$[G_a(\omega_u') - G_a(\omega_u)][1 - S_\omega(X_e)]\ B_e(X_e, H)(1 - A_p)\ B_o'(X_o')\ B_i(X_i)$	Solid wall skyshine component for floor above.
16	$[G_a(\omega_u') - G_a(\omega_u)]\ B_e(O, H)(A_p)\ B_o'(X_o')\ B_i(X_i)$	Skyshine aperture component for floor above.

+Since many of the equations used in the engineering method are used repeatedly in the solution to this problem, this table was prepared for ready reference. When these equations are used in the solutions, they are referred to by the number in the table.

Ground Contribution Through North Wall (see Fig. A1)+

Parameters and functions:

	W	L	Z	e	n	ω	$G_d(\omega,3')^a$	$G_s(\omega)^b$	$G_a(\omega)^b$
ω_u'	75	100	17	0.75	0.34	0.66		0.31	0.074
ω_u	75	100	7	0.75	0.14	0.85		0.167	0.045
ω_a	75	100	5	0.75	0.10	0.895		0.122	0.033
ω_L	75	100	3	0.75	0.06	0.936	0.30	0.076	
ω_L''	75	100	1.5	0.75	0.03	0.968	0.175		
$2\omega_s$	100	175	3	0.572	0.034	$\omega_s = 0.956/2 = 0.478$			

a. Chart 6.
b. Chart 5.

$B_e(50,3') = 0.304$ (Chart 2)

$B_e(0,3') = 1.0$ (Chart 2)

$S_\omega(50) = 0.58$ (Chart 7)

$B_o'(35) = 0.126$ (Chart 1)

$B_{\omega s}(0.478,50) = 0.15$ (Chart 9)

$E(0.75) = 1.4$

$A_p = 0.25$

$P_a = 0.506$

$B_i(25) = 0.54$

1. Contribution through shielded sector, $A_{z_1} = 0.147$ (North Wall)

(a) Detector floor (Eqs. 8 + 10 + 11 + 12, Table A1).

+The charts referred to throughout this calculation are the standard charts used in the Engineering Manual Method.

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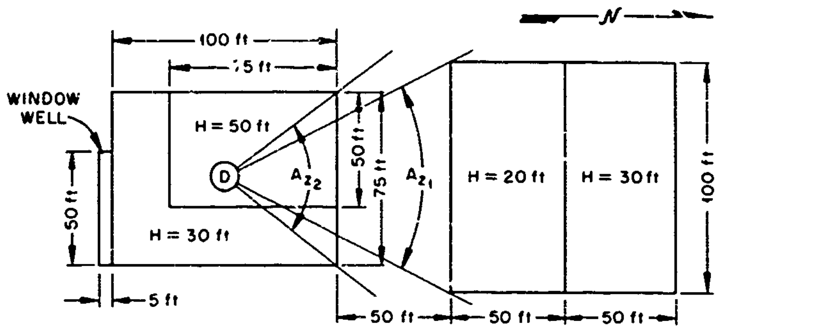
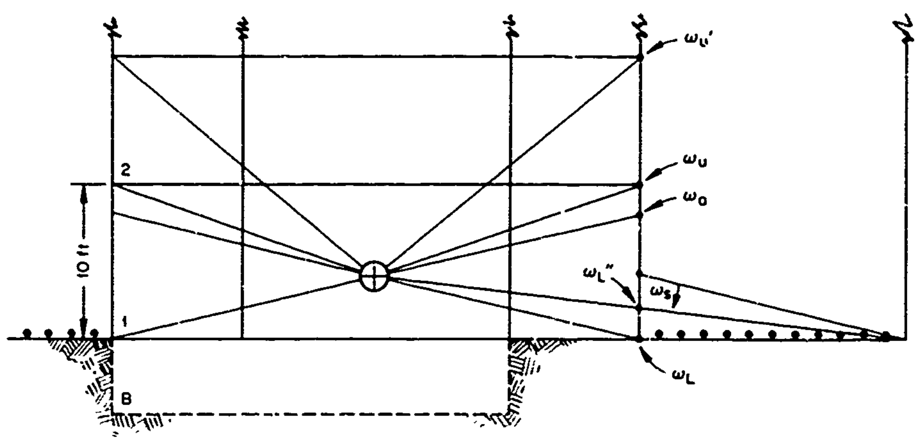


(a)



(b)

Fig. A1. Geometry for Calculating Ground Contribution Through North Wall.

$$C_g = \Big\{(0.30-0.175)(0.415)(0.304) + [0.076+0.167-0.506(0.122)]$$

$$\times\ (0.58)(1.4)(0.15) + [0.045-0.506(0.033)](0.415)(0.304)$$

$$+\ 0.506(0.033)(1.0)\Big\}\ (0.54)(0.145) = 0.00443$$

(b) Floor above (Eqs. 14 + 15 + 16, Table A1)

$$C_g = \Big\{(0.074-0.045)(0.415)(0.304)(0.75) + (0.074-0.045)(0.25)(1.0)$$

$$+\ (0.31-0.167)(0.58)(1.4)(0.15)(0.75)\Big\}\ (0.54)(0.125)(0.1475)$$

$$= 0.00023$$

2. Contribution through unshielded sector, $A_{z_2} - A_{z_1} = 0.0573$

(a) Detector floor (Eqs. 7 + 9 + 11 + 12, Table A1)

$$C_g = \Big\{[0.3+0.045-0.506(0.033)]\ (0.415)(0.304) + 0.506(0.033)(1.0)$$

$$+\ [0.076+0.167-0.506(0.122)](0.58)(1.4)(0.304)\Big\}\ (0.54)(0.0573)$$

$$= 0.00318$$

(b) Floor above (Eqs. 13 + 15 + 16, Table A1)

$$C_g = \Big\{(0.074-0.045)(0.415)(0.304)(0.75) + (0.074-0.045)(1.0)(0.25)$$

$$+\ (0.31-0.167)(0.585)(1.4)(0.304)(0.75)\Big\}\ (0.54)(0.125)(0.0588)$$

$$= 0.00014$$

Total contribution through north wall:

$$0.00463 + 0.00023 + 0.00318 + 0.00014 = 0.00818.$$

Ground Contribution Through East Wall (see Fig. A2)

	W	L	Z	e	n	ω	$G_d(\omega,3')$[a]	$G_s(\omega)$[b]	$G_a(\omega)$[b]
ω_u'	75	100	17	0.75	0.34	0.66		0.31	0.074
ω_u	75	100	7	0.75	0.14	0.85		0.167	0.045
ω_a	75	100	5	0.75	0.10	0.895		0.122	0.033
ω_L	75	100	3	0.75	0.06	0.936	0.30	0.076	
ω_L''	75	100	.818	0.75	0.016	0.983	0.11		
$2\omega_s$	200	300	3	0.667	0.02	ω_s = 0.977/2 = 0.489			

a. Chart 6.
b. Chart 5.

$B_e(50,3') = 0.304$ (Chart 2)

$B_e(0,3') = 1.0$ (Chart 2)

$S_\omega(50) = 0.585$ (Chart 7)

$B_o'(35) = 0.125$ (Chart 1)

$B_{\omega s}(.489,50) = 0.199$ (Chart 9)

$E(.75) = 1.4$ (Chart 8)

$A_p = 0.35$

$P_a = 0.7$

$B_i(25) = 0.54$ (Chart 1)

1. Contribution through shielded sector, $A_{z_1} = 0.135$

(a) Detector floor (Eqs. 8 + 10 + 11 + 12, Table A1)

$$C_g = \Big\{(0.3-0.11)(0.415)(0.304) + [0.076+0.167-0.7(0.122)]\ (0.58) \times (1.4)(0.199) + [0.045-0.7(0.033)]\ (0.415)(0.304) + 0.7(0.033) \times (1.0)\Big\}\ (0.54)(0.135) = 0.00328$$

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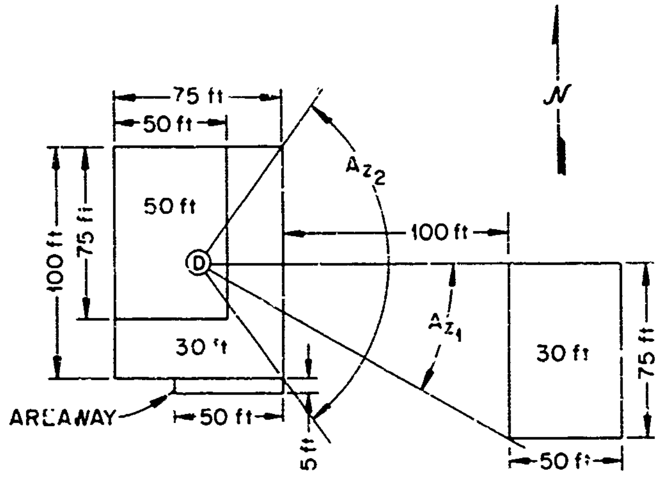
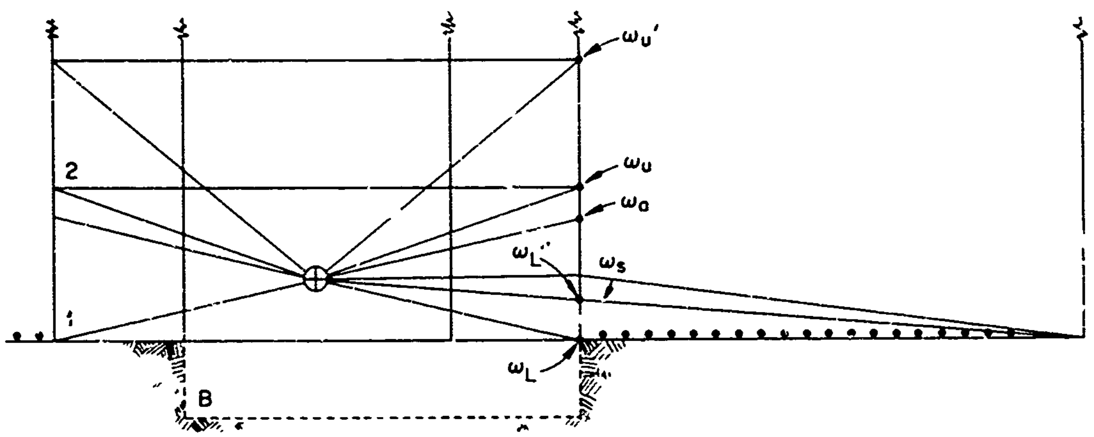


(a)



(b)

Fig. A2. Geometry for Calculating Ground Contribution Through East Wall.

(b) Floor above (Eqs. 14 + 15 + 16, Table A1)

$$C_g = \{(0.074-0.045)(0.415)(0.304)(0.65) + (0.074-0.045)(1.0)(0.35)$$
$$+ (0.31-0.167)(0.585)(1.4)(0.199)(0.65)\} (0.125)(0.54)(0.135)$$
$$= 0.00025$$

2. Contribution through unshielded sector, $A_{z_2} - A_{z_1} = 0.16$

(a) Detector floor (Eqs. 7 + 9 + 11 + 12, Table A1)

$$C_g = \{[0.3+0.045-0.7(0.033)] (0.415)(0.304) + 0.7(0.033)(1.0)$$
$$+ [0.076+0.167-0.7(0.122)] (0.58)(1.4)(0.304)\} (0.54)(0.16)$$
$$= 0.00887$$

(b) Floor above (Eqs. 13 + 15 + 16, Table A1)

$$C_g = \{(0.074-0.045)(0.415)(0.304)(0.65) + (0.074-0.045)(1.0)(0.35)$$
$$+ (0.31-0.167)(0.58)(1.4)(0.304)(0.65)\} (0.125)(0.54)(0.16)$$
$$= 0.00038$$

Total contribution through east wall:

$$0.00548 + 0.00025 + 0.00817 = 0.01498$$

Ground Contribution Through South Wall (see Fig. A3)

Parameters and functions:

	W	L	Z	e	n	ω	$G_d(\omega,7')^b$	$G_s(\omega)^a$	$G_a(\omega)^a$	$G_d(\omega,11')^b$
ω_u'	75	100	17	0.75	0.34	0.66	-	0.31	0.074	
ω_u	75	100	7	0.75	0.14	0.85	-	0.167	0.045	
ω_a	75	100	5	0.75	0.10	0.895	-	0.122	0.033	
ω_L	75	100	3	0.75	0.06	0.936	0.20	0.076	-	
ω_L'	75	100	11	0.75	0.22	0.77		0.245		0.47
ω_L''	75	100	7	0.75	0.14	0.85				0.35
ω_b	75	100	10	0.75	0.20	0.80	0.43	0.215		
$2\omega_s$	10	60	11	0.1667	0.366	$\omega_s = 0.26/2 = 0.13$				
$2\omega_s'$	10	60	7	0.1667	0.233	$\omega_s' = 0.40/2 = 0.20$				

a. Chart 5.
b. Chart 6.

$B_e(60',7') = 0.20$	(Chart 2)
$B_e(50,7') = 0.26$	(Chart 2)
$B_e(0.7') = 0.88$	(Chart 2)
$B_e(60,11') = 0.18$	(Chart 2)
$B_e(0,11') = 0.8$	(Chart 2)
$S_\omega(50) = 0.58$	(Chart 7)
$S_\omega(60) = 0.63$	(Chart 7)
$B_o'(35) = 0.125$	(Chart 1)
$E(.75) = 1.4$	(Chart 8)

$$\left.\begin{matrix} A_p = 0.30 \\ P_a = 0.6 \end{matrix}\right\}\ \text{1st Floor}$$

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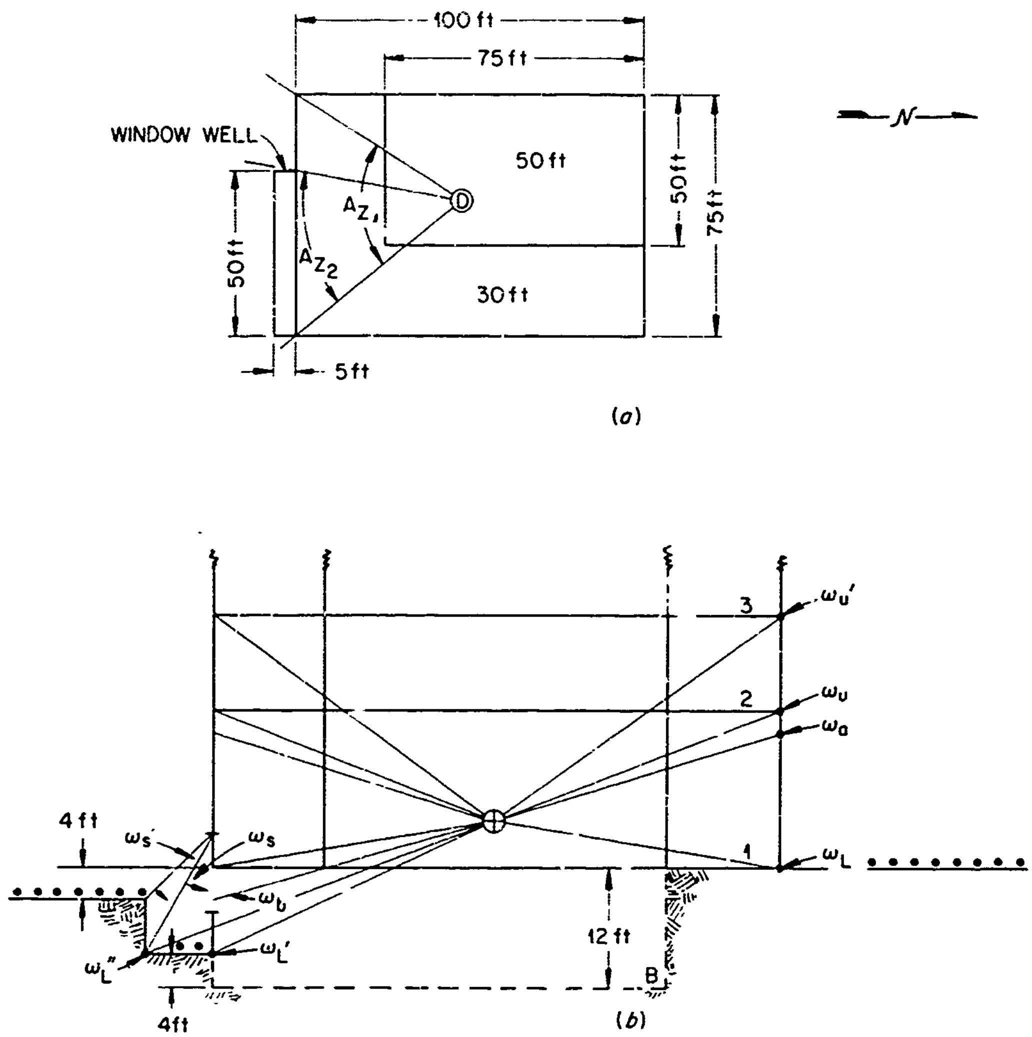

Fig. A3. Geometry for Calculating Ground Contribution Through South Wall.

$A_p = 0.20$, basement

$B_{ws}(0.13,50) = 0.005$ (Chart 9)

$B'_{ws}(0.20,50) = 0.0128$ (Chart 9)

$B_i(25) = 0.546$ (Chart 1)

$B_f(40) = 0.11$ (Chart 1)

1. Contribution through $A_{z_1} = 0.204$

(a) Detector floor (Eqs. 7 + 11 + 9 + 12, Table A1)

$$C_g = \{[0.2+0.045-0.6(0.033)]\ (0.415)(0.26) + 0.6(0.033)(0.88)$$
$$+ [0.076+0.167-0.6(0.122)]\ (0.58)(1.4)(0.26)\}\ (0.546)(0.204)$$
$$= 0.00854$$

(b) Floor above (Eqs. 13 + 15 + 16, Table A1)

$$C_g = \{(0.074-0.045)(0.415)(0.26)(0.7) + (0.074-0.045)(0.88)(0.3)$$
$$+ (0.31-0.167)(0.585)(1.4)(0.26)(0.7)\}\ (0.546)(0.126)(0.204)$$
$$= 0.00043$$

2. Contribution through $A_{z_2} = 0.140$

(a) Areaway sources

(1) Direct

$$C_g = [G_d(\omega_L',11') - G_d(\omega_L'',11')][1 - S_\omega(X_e)]\ B_e(60,11')$$
$$\times\ B_f(X_f)A_{z_2} = (0.47-0.35)(0.37)(0.18)(0.11)(0.140)$$
$$= 0.00012$$

(2) Scatter

$$C_g = [G_s(\omega_L') - G_s(\omega_L)]\ S_\omega(X_e)\ E(e)\ B_{\omega s}(\omega_s, X_e)\ B_f(X_f)\ A_{z_2}$$

$$= [0.245-0.076](0.63)(1.4)(0.005)(0.11)(0.140)$$

$$= 0.000012$$

(b) For infinite field sources

(1) Direct

$$C_g = \Big\{[G_d(\omega_b, 7') - G_d(\omega_L, 7')][1 - S_\omega(X_e)]\ B_e(60, 7')\ B_f(X_f)$$

$$\times\ (1 - A_p) + [G_d(\omega_b, 7') - G_d(\omega_L, 7')]\ B_e(0, 7')\ A_p\Big\}$$

$$\times\ B_f(X_f)\ A_{z_2}$$

$$C_g = \Big\{(0.43-0.20)(0.37)(0.2)(0.7) + (0.43-0.20)(0.88)(0.3)\Big\}$$

$$\times\ (0.126)(0.140) = 0.00112$$

(2) Scatter

$$C_g = [G_s(\omega_b) - G_s(\omega_L)]\ S_\omega(X_e)\ E(e)\ B_{\omega s}'(\omega_s', X_e)\ B_f(X_f')\ A_{z_2}$$

$$= (0.215-0.076)(0.63)(1.4)(0.0128)(0.11)(0.140)$$

$$= 0.000024$$

Total contribution through south wall:

$$0.00854 + 0.00043 + 0.00012 + 0.000012 + 0.00112 + 0.000024 = 0.01024$$

Ground Contribution Through West Wall (see Fig. A4)

Parameters and functions:

	W	L	Z	e	n	ω	$G_d(\omega,3')^a$	$G_s(\omega)^b$	$G_a(\omega)^b$
ω_u'	75	100	17	0.75	0.34	0.66		0.31	0.074
ω_u	75	100	7	0.75	0.14	0.85		0.167	0.045
ω_a	75	100	5	0.75	0.10	0.895		0.122	0.033
ω_L	75	100	3	0.75	0.06	0.936	0.30	0.076	
ω_L''	75	100	1.8	0.75	0.036	0.962	0.195		
$2\omega_s$	50	150	3	0.333	0.04	$\omega_s = 0.92/2 = 0.46$			

a. Chart 6.
b. Chart 5.

$B_e(60,3') = 0.238$ (Chart 2)

$B_e(0,3') = 1.0$ (Chart 2)

$S_\omega(60) = 0.63$ (Chart 7)

$B_o'(35) = 0.125$ (Chart 1)

$B_{\omega s}(0.46,60) = 0.109$ (Chart 9)

$E(0.75) = 1.4$ (Chart 8)

$A_p = 0.40$

$P_a = 0.8$

$B_i(25) = 0.54$ (Chart 1)

$A_{z_1} = 0.295$

1. Detector floor (Eqs. 8 + 10 + 11 + 12, Table A1)

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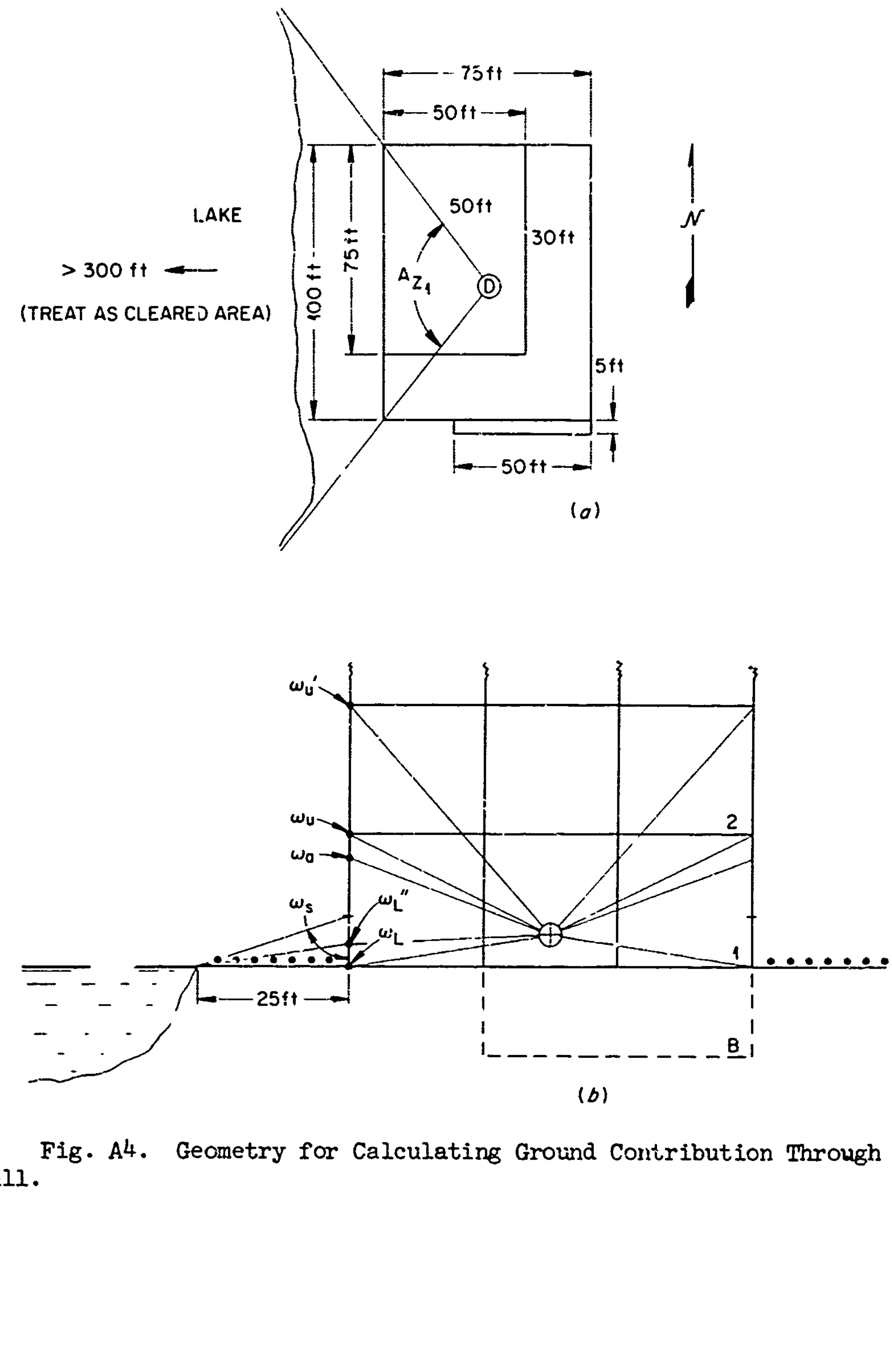

Fig. A4. Geometry for Calculating Ground Contribution Through West Wall.

$$C_g = \{(0.3-0.195)(0.37)(0.238) + [0.076+0.167-0.8(0.122)] (0.63)$$

$$\times (1.4)(0.109) + [0.045-0.8(0.033)] (0.37)(0.238)$$

$$+ 0.8(0.033)(1.0)\} (0.54)(0.295) = 0.00816$$

2. Floor above (Eqs. 14 + 15 + 16, Table A1)

$$C_g = \{(0.074-0.045)(0.37)(0.238)(0.6) + (0.074-0.045)(1.0)(0.4)$$

$$+ (0.31-0.167)(0.63)(1.4)(0.109)(0.6)\} (0.54)(0.295)(0.125)$$

$$= 0.00043$$

Total contribution through west wall:

$$0.00816 + 0.00043 = 0.00859$$

<u>Overhead Contribution</u> (see Fig. A5a)

The overhead contribution consists of that from the 30-ft high setback and the 50-ft high main roof. These contributions may be found by using the fictitious building concept.

The setback contribution, which is the contribution from the shaded area C_{o1} (see Figs. A5b and c) in the actual building, is obtained by subtracting out the contribution of the unshaded area from that obtained for the entire roof of the fictitious building.

$X_o = 120$ psf

$B_i(X_i) = B_i'(25) = 0.43$ (Chart 1)

$\omega_o = \omega\left(\frac{75}{100}, \frac{2(27)}{100}\right) = 0.50$ (Chart 3)

$\omega_o' = \omega\left(\frac{25}{50}, \frac{2(27)}{50}\right) = 0.19$ (Chart 3)

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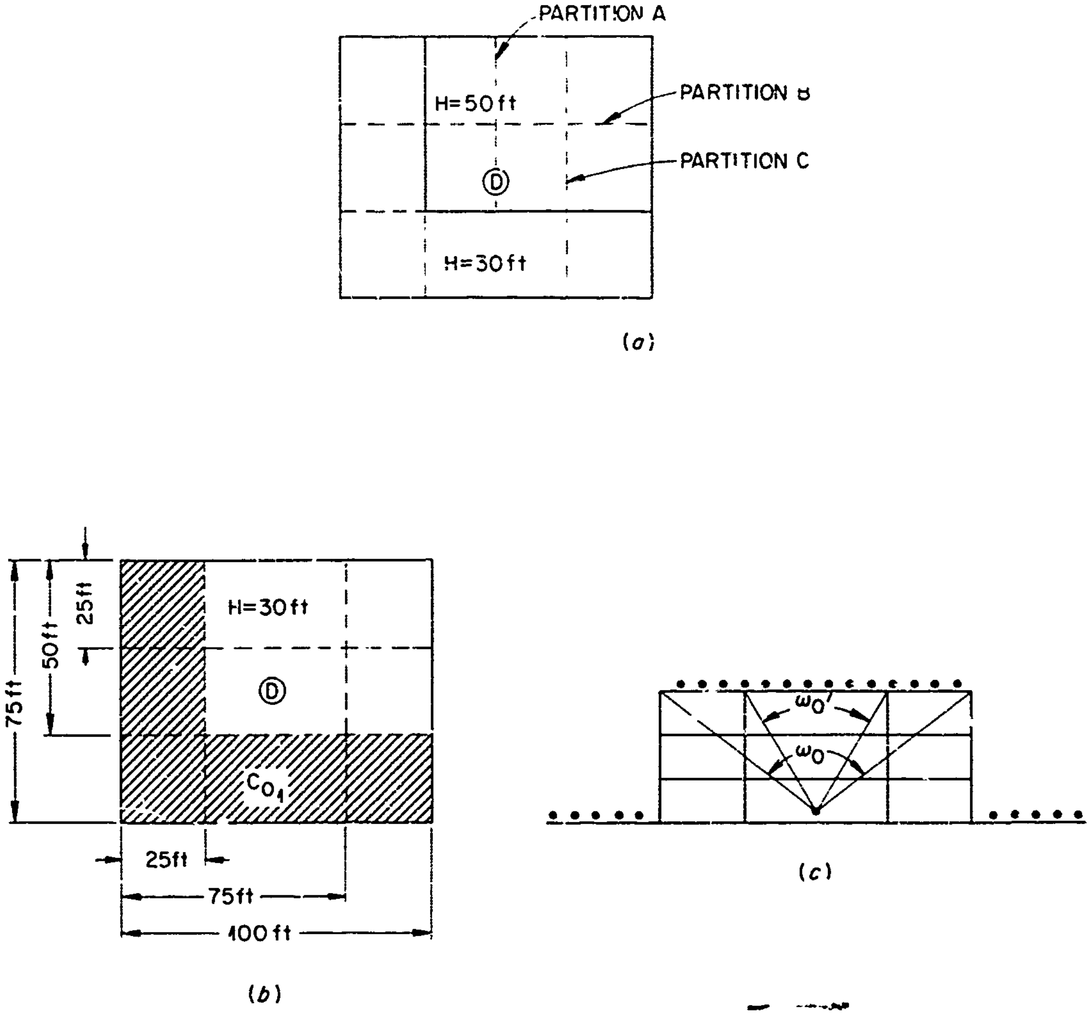

Fig. A5. Geometry for Calculating Overhead Contribution (Setback).

$C_o(\omega_o, 120) = 0.0106$ (Chart 4)

$C_o'(\omega_o', 120) = 0.0058$ (Chart 4)

$$C_{o1} = (0.6)\,[C_o(\omega_o,120) - C_o(\omega_o',120)]\,B_i'(X_i')$$

$$= (0.6)\,[0.0106 - 0.0058]\,(0.43) = 0.00124$$

The contribution from the main roof is more difficult to calculate. Referring to Fig. A5a, partition A lies over the detector and extends from the fourth floor to the roof; hence, it may be neglected. Partition B extends from the first floor to the fourth floor and has a little more effect, but it still is too small to warrant the added complexity of including it. The only partition which affects the main roof contribution significantly is partition C, which shields the contribution from the shaded area C_{o2} (see Figs. A6a and b). This contribution is obtained by subtracting the unshaded area from the total for the fictitious building and proportioning on an area basis:

$X_o = 180$ psf

$B_i'(25) = 0.43$ (Chart 1)

$\omega_o = \omega\left(\frac{75}{100}, \frac{2(41)}{100}\right) = 0.30$ (Chart 3)

$\omega_o' = \omega\left(\frac{50}{75}, \frac{2(47)}{75}\right) = 0.19$ (Chart 3)

$C_o(0.30, 180) = 0.0021$ (Chart 4)

$C_o'(0.19, 180) = 0.0016$ (Chart 4)

$$C_{o2} = (0.0021 - 0.0016)(0.43)\,\frac{(25)(50)}{(75)(25)} = 0.00014$$

The remaining portion from the main roof (see Figs. A6c and d) is straightforward:

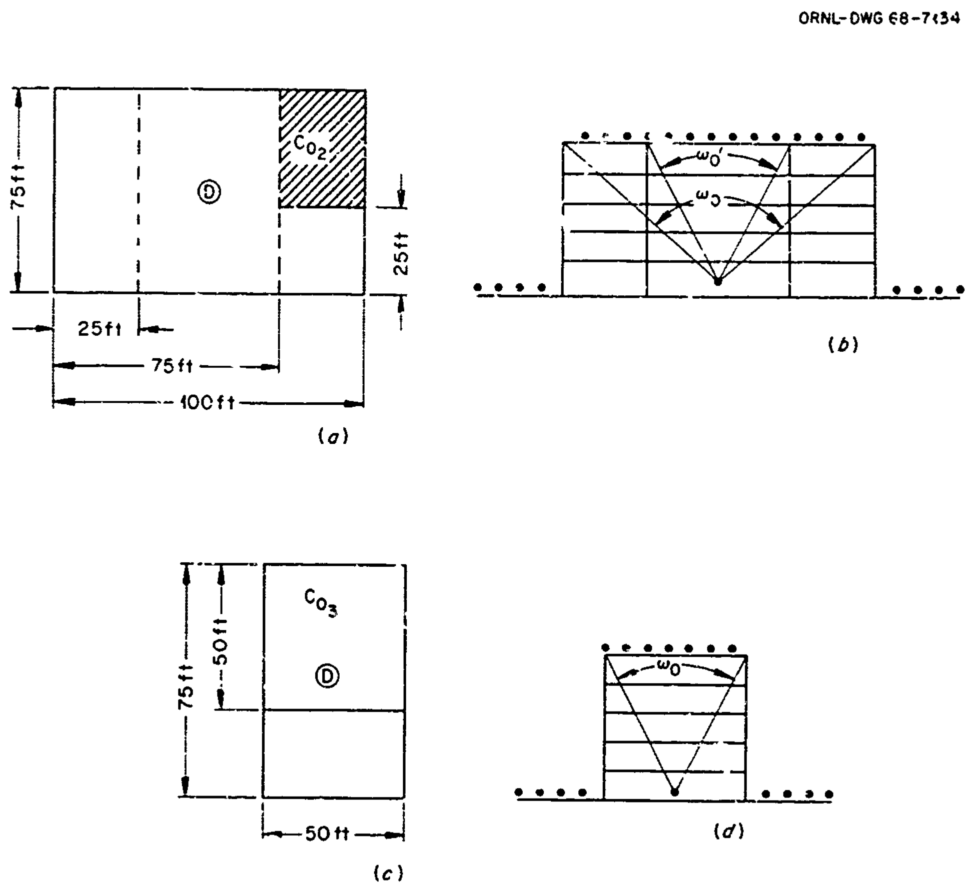

Fig. A6. Geometry for Calculating Overhead Contribution (Main Roof).

$X_o = 180$

$B_i'(X_i') = B_i'(25) = 0.43$ (Chart 1)

$\omega_o = \omega\left(\frac{50}{75}, \frac{2(47)}{75}\right) = 0.19$ (Chart 3)

$C_o(0.19,180) = 0.0016$ (Chart 4)

$$C_{o3} = C_o(0.19,180)\frac{(50)(50)}{(75)(50)} = (0.0016)(0.667) = 0.00106$$

The total overhead contribution to the reduction factor from both the main roof and the setback is:

$$C_o = C_{o1} + C_{o2} + C_{o3} = 0.00124 + 0.00014 + 0.00106 = 0.00244$$

Total Protection Factor for the First Floor

R.F. = North Wall Contribution + East Wall Contribution + South Wall Contribution + West Wall Contribution + Overhead Contribution

= 0.00818 + 0.01498 + 0.01024 + 0.00859 + 0.00244 = 0.0444

or

P.F. = 23

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13. ABSTRACT

The relative merits of two computer codes, PF-COMP and CAPS-2, for calculating radiation fallout protection factors for shelter areas were investigated by comparing the code results with those from hand calculations based on the Engineering Manual method. Five building types were considered. For protection factors in the range of 1 to 100, the PF-COMP code was found to yield values that were within ±15% of the hand-calculated values, while the CAPS-2 code gave results that were within -44 to +90% of the hand-calculated values. For protection factors greater than 100, the PF-COMP code results were within -41 to +36% and the CAPS-2 code results were within -10 to +58% of the hand-calculated values. Based on these calculations, along with the relative ease with which the PF-COMP code may be used for multiple-story buildings, the PF-COMP code is deemed the better code and it is recommended that the CAPS-2 code be restricted to structures with low protection factors (about 20 or less) and/or limited complexity.

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	ROLE	WT	ROLE	WT	ROLE	WT
Engineering Manual Method						
Fallout Shelter Design						
Shielding Code PF-COMP						
Shielding Code CAPS-2						

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