WIND DESIGN GUIDE FOR BALLASTED ROOFING SYSTEMS

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Over the years, designers have taken into account the loads the wind generates on a building. Initially, design enhancements for wind loading were learned through actual field experience, but with the advent of the engineered structure leading to the skyscraper, learning by actual experience was not practical. To aid the designer, sophisticated modeling tests were developed using the wind tunnel to evaluate structural design and surface loading of the building. In addition, full scale mockup testing was developed to evaluate cladding performance under wind and rain loadings to supply additional information before the building was constructed. The data generated by this kind of work has led to the development of building code standards giving minimum guidelines to the designer.

The traditional, fully-adhered roof system has been accounted for in this design development process. Simplified pressure tests were developed to evaluate various roof system constructions for resisting possible uplift forces generated by the wind.

This information, when coupled with the code design standard, gave the designer guidelines on how to construct the roofing system to resist wind loadings for a specific building in a particular location.

In more recent history, the single-ply industry has applied a roof system known as a loose-laid, ballasted roof. In this system, all the components, insulation and waterproofing membrane are laid on the roof deck unattached. The membrane then is covered with 10 to 15 pounds per square foot of ballast, which normally is stone. The first problem the design encounters is that the roof system does not follow the normal code design standards. If the system is tested under the standard uplift test method for roofing, it begins to fail at a pressure of 10 to 15 pounds per square foot. When it is applied to the code design standards, the maximum allowable wind speeds for the roof system are far below any values shown on a wind isotach chart. Yet North American field experience is showing that the 800 million square feet of installed loose-laid, ballasted systems are performing satisfactorily with few exceptions.

This situation has prevented the designer from being able to predict the performance level of the loose-laid roof design applied to a specific building. Up to 1977, this was not a major problem since loose-laid single-ply in the United States was less than 1 percent of the total flat roofing market.

But in 1985, with the loose-laid ballasted single-ply market being approximately 20 percent of the flat roofing market, the designer must have performance justification for the system.

A number of manufacturers in the single-ply industry conducted evaluations using either wind tunnels or full-scale mockups to try to define the performance of the ballasted system. Some of these tests are:

- Kind, R.J. & Wardlaw, R.L., "Design Of Rooftops Against Gravel Blow-Off," National Research Council, NRC No. 15544, Ottawa, Canada.
- Kind, R.J. & Wardlaw, R.L., "Model Studies Of The Wind Resistance Of Two Loose-Laid Roof-Insulation Systems," National Research Council, Report No. LTR-LA-234, Ottawa, Canada.
- Goodwillie, J.M., Jr., "Wind Resistance Of Loose-Laid And Spot-Attached Single-Ply Roofing Membranes," Single Ply Roofing Technology, ASTM STP 790, W.H. Gumpertz, Ed., American Society For Testing And Materials, 1982, Pp. 3-20.
- Phalen, T.E., Jr., "Full-Scale Wind Tests On Conventional Stone And Lightweight Concrete Tapered Ballast Blocks For Loose-Laid Roof Systems," Roofblok Limited Technical Report No. 2, Waltham, 1983.

The most noted work in this area was "Design Of Rooftops Against Gravel Blow-Off," published in 1976 by R. J. Kind and R. L. Wardlaw of the National Research Council of Canada. This work shows the relationship between building height, building shape, parapet height, stone size, wind speed, and how each affects the performance of stone scour on a ballasted roof system.

These various performance parameters then were charted, thereby allowing particular parameters to be picked from the charts and applied to equations that would estimate the wind performance of the roof design.

In 1982, field studies such as "Wind Resistance Of Ballasted Trocal Roofs In Colorado Front Range Area" by Donnel, Cave & Watkins Inc., Consulting Engineers, and Carlisle's "COMPIS," Colorado Multiple Project (Wind) Investigation Study, by Schneider And Associates, Architects, were initiated to study the actual field performance of the ballasted roof systems.

The COMPIS Report (*Figure 1*) was used to verify the wind tunnel work of Kind and Wardlaw and to calibrate it with the actual field data. The field studies showed that the wind tunnel work did indeed predict the trends that occur with the ballasted system in the field, but that the theoretical wind speed values were too conservative.

This field work led to two developments, the first being a computer model to predict ballasted roof system performance, and the second being the issuance in May 1983 of a design guide for ballasted roofing systems, International Conference Of Building Officials (ICBO) Report 3826. This was the first known ballasted roof system design guide in the United States that related wind speed, buildling height, and parapet height to ballasted roof performance. On Sept. 21, 1984, ICBO adopted Report 3826 as their interim design guide for loose-laid, ballasted roofing systems for one year.

Additional field studies were done on more than 100 roofs at building sites ranging from the front range of the Rocky Mountains to Houston area sites that were exposed to Hurricane Alicia *(Figures 2 and 3 summarize some of these studies)*. Information from these additional field studies was used to evaluate the computer model, which continued to prove accurate. In addition, these studies provided information on other items that influence the performance of all roofing systems. These other items included hills, open truck bay doors, the edge termination method for the membrane, and the building ventilation system. One item that did not show up as being influential was deck type, which ranged from accoustical metal decks to poured-in-place concrete decks.

A good portion of the information resulting from these additional field studies had been kept proprietary, as manufacturers used it to obtain various code approvals. This information was made public at the symposium held in Carlisle, Pennsylvania in September 1984. The symposium was attended by individuals representing the following organizations:

Carlisle SynTec Systems
Dow Chemical
Dynamit Nobel
Factory Mutual
Firestone
Goodyear
International Conference of Building Officials
Manville
Midwest Roofing Contractors Association
National Bureau of Standards
National Research Council of Canada
National Roofing Contractors Association
Roofblok
Rubber Manufacturers Association
Single Ply Roof Institute
Syenergy
Underwriter's Laboratories
U.S. Army Corps of Engineers

These activities culminated in the proposed consensus standard for the "Wind Design Guide For Roofing Systems," which is included in this document.

The design guide contains four sections. The first section deals with items that influence all roofing systems. The second and third sections are for fully adhered and mechanically attached roofing systems, and will be inserted at a later date. The ballasted section is the last section of the document. It spells out the specific requirements for ballast, slope, terminations and exposure to be used in determining the design of the ballasted roofing system. Performance requirements for the membranes and the testing procedure for the roof edge termination systems also are included in the document.

In summary, the design guide assists the designer in his thought process by calling attention to items he must consider when designing a roof and by supplying specific application requirements and limitations for ballasted roofing systems. When the document is completed with the additions of the adhered and mechanically attached sections, it will give the designer a single reference document for use when designing a roof system for wind loads.

This design guide currently is being reviewed as a consensus standard for the United States through RMA, SPRI, and ANSI.

WIND DESIGN GUIDE FOR ROOFING SYSTEMS

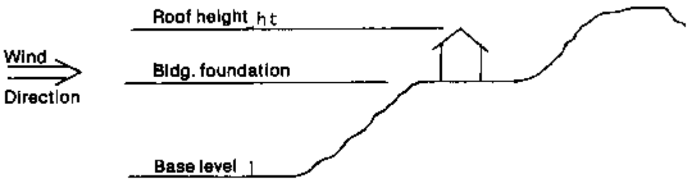
When designing a roof system for a given building, the following design steps are to be taken to address the possible effects of the wind.

A. DESIGN CONSIDERATION AFFECTING ALL ROOF DESIGNS (BUR, FULLY ADHERED, LOOSE-LAID, MECHANICALLY ATTACHED, ETC.)

The items below are to be taken into consideration when designing the roof system.

1. **Unique Topography**

When the building to be roofed is located in a unique topographical region, the topographic effect on the building is to be taken into consideration. For example, if a building is located on a hill, the hill elevation should be added to the roof height.



If the building is located in a valley noted for intensifying winds, the local wind speeds should be used rather than a general Isotach Chart.

2. **Large Openings in a Wall**

If wall openings exist that possibly could be left open during a storm, and if these openings exceed 10 percent of the wall surface, the roof design should be enhanced to handle possible building pressurization due to wind loading through the opening. A warehouse with large truck bay doors on the windward side is an example of a building that may require increased wind uplift resistance. For guidance on the design enhancement, the owner's designated representative or membrane manufacturer should be contacted.

3. **Positive Pressure Ventilation Systems**

Building ventilation systems that generate a positive pressure greater than 0.5 inches of water inside the building need to be factored-in when designing the roof system for uplift loads. This internal pressure, which negates some of the uplift strength of the roof system, must be compensated for by adding it to the wind load requirements of the roof design. For guidance on the design enhancement, the owner's designated representative or membrane manufacturer should be contacted.

4. **Perimeter Attachment**

The perimeter attachment design used to terminate a roofing system must provide a minimum of 75 pounds per lineal foot of holding power. This termination system is to be located at the roof perimeter or at the base of an angle change as shown in Figures 10 and 11. The specific testing procedure for elastomeric EPDM is defined prior to the figures.

B. GENERAL REQUIREMENTS FOR FULLY ADHERED SYSTEMS (BUR, MODIFIED BITUMEN, ELASTOPLASTICS, ETC.)

To be added at a later date.

C. GENERAL REQUIREMENTS FOR MECHANICALLY ATTACHED SYSTEMS

To be added at a later date.

D. GENERAL DESIGN REQUIREMENTS FOR BALLASTED SYSTEMS

This design guide is a minimum standard with the following items taken into consideration when designing all ballasted roofing systems. Enhancements may be used to improve any of the roof systems defined below.

1. Ballast

a. For nominal 1½-inch smooth river bottom stone, used as ballast applied at a minimum rate of 1000 pounds per 100 square feet, ASTM #4, 357, 24, 2 or 1 may be used. For ASTM #2 or 1, additional weight may be required by the membrane manufacturer to meet specific performance requirements. The gradation chart from ASTM D 448 is found in Figure 8.

b. For nominal 2½-inch smooth river bottom stone, ASTM #2 or 1 may be used. The gradation chart from ASTM D 448 is found in Figure 8.

c. Pavers, standard (minimum 15 psf) or approved lightweight (minimum 10 psf) may be substituted for the stone.

d. If crushed stone is used, it must follow the gradation requirements above and an appropriate protection layer is required between the membrane and the stone.

2. Slope

The roof slope is not to exceed 2 inches in 12 inches for the ballasted roof.

3. Roof Structure

The roof design should be examined by the owner or his designated representative to verify that it can support the live and dead loads acting on this roof, including the ballast requirements, without encroaching on the necessary live-load allowances.

4. Gravel Stop

If a gravel stop is used at the building perimeter, its height above the membrane must be a minimum of 2 inches in order to contain the ballast (*Figure 10*).

5. Wind Requirements

There are three key functions that control the designing of a ballasted roof system for wind loads: wind speed, building height and parapet height.

a. The wind speed value should be taken from the organization's Isotach Chart to which the building is being designed: ANSI, Factory Mutual, a Code Group, etc. A Regional Code Agent requiring local wind data to be used would be an exception to this.

b. The building height is the distance from ground level to the roof system surface. A topographical feature may alter this value.

Note: For building heights more than 150 feet and wind speeds more than 120 MPH, special design considerations are required which must be reviewed by the building owner, his designated representative, and the membrane manufacturer.

c. The parapet height is the distance from the roof system surface to the top of the parapet at its lowest height. This minimum parapet height, specified in the attached design tables, is for the corners, the most severe areas of the roof. This minimum parapet height extends from the corner in any direction a distance of not less than 0.4 times the building height. For example, a 50-foot-high building should have the minimum parapet for a distance of 20 feet from the corners.

All other parapets on the building outside of the defined corner area must be at least 30 percent of the height of the corner parapets to a minimum of a two-inch gravel stop. (*Figures 4-8 and 11*).

For example, a 40-foot-high roof using System 1 in a 70 mph wind zone must have a corner parapet at least 6 inches high. The corner is defined as 0.4 times the building height or a zone 16 feet from the corner. Beyond 16 feet the parapet must be at least 30 percent of the height of the corner parapet or a minimum of 2 inches. 30 percent of 6 inches is 1.8 inches. Therefore, the minimum height of two inches must be specified.

The use of artificial parapets at the corners will increase the wind design performance of the roofing system.

These three functions, with any adjustments due to the design consideration section, are to be fitted to Figures 4, 5 and 8, which define the wind performance limits of three ballasted systems. The fit of the three functions to the tables will define which of the three systems is to be used to meet the wind load requirements. The three ballasted systems are described below:

d. System 1

After the membrane is in place, it is to be ballasted with nominal 1½-inch smooth river bottom stone at a minimum rate of 1000 pounds per 100 square feet over the entire roof.

e. System 2

After the membrane is in place, it is to be ballasted as follows:

Corners: At each building corner, nominal 2½-inch smooth river bottom stone is distributed in a square configuration with each side equal to 0.4 times the building height, at a minimum rate of 1,300 pounds per 100 square feet. The minimum length of the side is 8.5 feet (*Figures 6 and 7)*.

Field: In the field of the roof, nominal 1½-inch smooth river bottom stone is to be used at a minimum rate of 1,000 pounds per 100 square feet.

f. System 3

Perimeter: Around the perimeter of the building, a minimum of 8.5-foot-wide section of an I-90 adhered or mechanically attached roof system shall be installed with no ballast placed on the membrane (*Figures 6 and 7)*.

Corners: At each building corner, an I-90 adhered or mechanically attached roof system shall be installed in a square configuration with each side equal to 0.4 times the building height with no ballast placed on the membrane. The minimum length of the side is 8.5 feet (*Figures 6 and 7*).

Field: In the field of the roof, nominal 2½-inch smooth river bottom stone is to be applied at a minimum rate of 1,300 pounds per 100 square feet. There is to be a mechanical termination between the adhered or mechanically attached sections and the loose-laid roof sections. The termination must meet the 75 pounds per lineal foot of holding power as tested in Figure 9.

The type of terrain a building is located in will affect the exposure of that building to the wind. A rough terrain exposure (trees and other buildings) upwind of the bulding will provide more protection from the wind than an open terrain exposure (shoreline or plains). There are two exposures, which follow:

g. Exposure P

Exposure P is for buildings that are located in protected areas such as suburban or small city areas where there are other buildings or trees. These generally give some protection from the wind up to 60 feet in height.

h. Exposure E

Exposure E is for buildings exposed to the wind which can occur in two distinctly different terrains. The first is on open level terrain such as the plains or shoreline which offer little or no protection from the wind. The second is a large city with a concentration of buildings over four stories where the very tall buildings are out of the ground level protection and the lower structures are subject to wind tunneling because of the tall buildings.

6. **Special Considerations for Specific Ballasted Systems**

a. Elastomeric Membranes

When elastomeric membranes are specified in the ballasted system, the membrane must meet the RMA minimum requirements for reinforced and non-reinforced black EPDM or polychloroprene rubber membranes. See Figure 3 for RMA specs IPR-1, IPR-2, and IPR-3.

7. **General Discussion**

In the life of a ballast system, wind scour of the stones can occur. Generally, a scour of 12 square feet or less only would require normal maintenance by moving the stones back into position. Areas of scour greater than 12 square feet should be corrected by increasing the design performance of the roofing system in this area. Remedies such as the use of larger diameter stone or pavers should be considered in those areas where scouring in excess of 12 square feet in diameter is occurring.

ROOF EDGE TERMINATION TEST METHOD FOR ELASTOMERIC MEMBRANES

The method with which the edge of the membrane is terminated (gravel stop, nailer or others) can become very important if the system separates from the roof deck during an extremely high wind. When this happens, the roof system can begin to put a load on the termination. For this reason, the termination should be able to withstand a minimum force of 75 pounds per linear foot when tested in accordance with the following method.

A 6-inch-wide mock-up of the termination system (roof edge and parapet are shown here) should be constructed and mounted on the base of a tensile tester in such a way as to simulate a billowing membrane. Therefore, the membrane should be pulled at an angle of 45° to the theoretical roof deck line (*Figure 9*).

The jaws of the tensile tester are connected to two bars, which have the membrane in between them and bolted together to distribute a uniform load along the 6-inch width of the membrane. The tensile tester runs at a speed of 2 inches per minute until failure occurs. Failure is defined as any event which allows the membrane to come free of the edge termination or termination from its mount.

Location	Ref. No.	Bldg. Ht.	Deck	Para-pet	Type Distress	Actual Wind MPH	Model Speed MPH	Report #3826	Comments
Ft. Collins	1	20'	Concrete	12"	—	110	92	System 2	
	2	NA	Concrete	NA	—	130	NC	?	
	3	30'	Concrete	Low	Scour/Insulation	130	74	System 2	
	4	40'	Concrete	6"/12"	Scour-6"	100	73-6"/77-12"	System 2	
	5	35'	Concrete	12"/ 24'	—	100	79-12"/87-24"	System 2	
	6	25'	Concrete	8"	—	100	82	System 2	
	7	20'	Concrete	6"/12"	Scour	100	84-6"/92-12"	System 2	
	8	13 Story	Metal	High	—	100	NC	Review	
Boulder	1	12'/20'	Metal	0	Scour-20'	100	81-12'/76-20'	*System 2*	*Gravel stop added per ICBO.*
	2	14'/22'	Metal	Low	Puncture	130	86-14'/78-22'	System 2	
	3	12'	NA	High	Scouring	120	NC	System 2	
	4	12'/20'	NA	30"	—	100	152-12'/116-25'	System 2	
	5	25'	Concrete	NA	Scouring	100	NC	System 2	
	6	30'	Metal	NA	Scouring	120	NC	System 2	
	7	23'	Concrete/ Metal	16"	Scouring	97	92	System 2	Rupture at 137
Colorado Springs	1	Single	Metal	Low	Scouring	110	88	System 2	
	2	Single	Metal	Low	Scouring	110	88	System 2	
	3	25"	Concrete	6-36"	Scouring/Insulation	110	80-6"/111-36"	System 2	
	4	2 Story	Metal	0	Scouring	110	76	System 2	
	5	95'	Metal	6"	Rupture	110	54	Review	Under construction
Denver	1	40'	Metal	NA	Scouring	NA	NC	System 2	
	2	15'/25'	Concrete	0	—	100	79-15'/74-25'	System 2	
	3	30'	Concrete	12"	—	100	82	System 2	
	4	11 Story	Concrete	8"	Scouring/Insulation	100	54	Review	
	5	13 Story	NA	NA	—	80	NC	Review	
	6	30'	Metal	18"	Rupture	120	87	System 2	
	7	50 Story	NA	12"	—	80	45	Review	

—No Distress   *ICBO special wind zone   NC: Not calculated

Figure 1   Compis study

Location	Ref. No.	Bldg. Ht.	Deck	Parapet	Type Distress	ICBO Wind Zone MPH	Actual Wind MPH	Model Speed MPH	Report #3826
Illinois	1	70'	Concrete	2"	—	80	69	66	System 2
	2	120'	Concrete	2"	—	80	69	61	Review
Michigan	*1	12'/15'/25'	NA	7"/0"/3"	Metal Flashing-25'/ Scour-15'	80	68	79	System 2*
	2	13'	Steel	1½"/9"/17"/0"	—	80	68	84	System 1
	3	16'/22'/30'	Gypsum	1½"/7"/6"	—	80	68	77	System 2
	4	36'/42'	Concrete	2-40"/1½"	Metal Flashing-36'/ Scour-Insulation-42'	80	68	70	System 2
	5	10'/86'/96'	NA	9"/10"/9"	Termination-Scour-96'	Special Wind	63	64	Review
Minnesota	1	28'	Steel	3"	Scour/G.S. Failed/ Insulation	80	85	75	System 2
	*2	45'	Steel	1"	G.S. Failed	80	61	69	System 2
	*3	32'/36'/62'/96'	Steel	30"/30"/36"/21"	Scouring 96'	80	61	77	Review
	4	13'	Concrete	9"	—	80	61	100	System 1
	5	15'	Steel	5"/15"	—	80	85	88/106	System 1
New Jersey	1	12'/24'/36'	Concrete	3"	—	80	52	72	System 2
	2	100'/108'	Concrete	26"/6"	Rupture-100'/	80	52	58	Review
	3	72'/78'	Concrete	7"/3"	Rupture-72'/ Scour-78'	80	71	67	Review
New York	1	13'/14½'/22'/26'	Gypsum/Steel	1½"	G.S. Failed-13'/22'	70	72	84'-13'/ 77'-22'	System 1
	2	100'/110'	Concrete	1½"/36"/1½"	Rupture	70	72	62	Review
	3	40'/43'/49'	Concrete	2"	Termination/ Rupture-49'	70	72	68	System 2
Texas	*1	35'/33'/20'	Steel	1"/28"/6"	Scour/Insulation-28"	80	60	92-33'	System 1
	2	175'/190'/200'	Concrete/Steel	47"/4"/8"	Scour-4"	80	55	50	Review
	3	30'	Steel	34"	—	80	60	100	System 1

*Michigan #1-ICBO Report would require a gravel stop on 15' roof.
*Minnesota #2-G.S. Failed on fully adhered roof also.
*Minnesota #3-Open hangar door caused failure.
*Texas #1-Open louvers approximately 1000 ft.^{2} of wall space.
—No Distress

Figure 2 Field study

Location	Ref. No.	Bldg. Ht.	Deck	Parapet	Distress	Actual Wind MPH	Model Wind MPH	*ICBO Report	Comments
Baytown	1	18'	Steel	34"	Scour/Insul.	100**	128	System 2	Bur torn off in same complex.
Clute	1	18'	Concrete	1"	—	84	78	System 2	Edging modified for ICBO.
Alvin	1	18'	Steel	0"/0"/24"/24"	—	64	77	System 2	Edging modified for ICBO.
Houston-Downtown	1	90'/100'	Concrete	36"/3"	—	80+	72/63	Review	
	2	220'/238'	Concrete	39"/3"	—	80+	60/57	Review	BUR lost gravel in same area.
Houston-North	1	60'/70'	Steel	33"/4"	Scour/Insul.-60'	80	79/66	System 2/Review	
	2	50'/47'	Concrete	3"/3"	—	80	69	Review	
Houston-East	1	36'	Concrete	36"	Scour/Term/Insul.	84	95	System 2	
	2	23'/29'	Steel	4"/4"	—	84	79/76	System 2	BUR torn off in same complex.
Houston-SE	1	16'/ 16' Garage	Steel	28"/28"	Scour/Insul. Term.-Garage only	84	126/126	System 2	BUR torn off different garage.
	2	20'	Steel	1"	—	84	77	System 2	Edging modification for ICBO.
Houston-South	1	30'	Concrete	37"	—	84	103	System 2	
Houston-SW	1	16'	Steel	1"	Scour	80	80	System 2	Edging modification for ICBO.
Houston-West	1	20'	Steel	22"	—	80	105	System 2	
	2	30'	Steel	20"	Termination	80	89	System 2	
	3	120'	Steel	24"	Scour/Term/Insul.	80	65	Review	
Houston-NW	1	70'/82'	Steel	26"/4"	Scour	80	73/65	System 2/Review	

—No Distress *Wind Zone 90 MPH **Highest recorded winds of Hurricane Alicia

Figure 3 Houston study

FROM 2 INCH HIGH GRAVEL STOP TO 5.9 INCH HIGH PARAPET

	Maximum Wind Speed (mph)					
Bldg.	System 1		System 2		System 3	
Ht. Ft.	Exposure E	Exposure P	Exposure E	Exposure P	Exposure E	Exposure P
0- 15	80	90	100	100	110	120
>15- 30	80	90	100	100	110	120
>30- 45	70	80	90	100	110	120
>45- 60	70	80	90	100	110	120
>60- 75	70	70	90	90	100	100
>75- 90	No	No	90	90	100	100
>90-105	No	No	80	80	90	90
>105-120	No	No	80	80	90	90
>120-135	No	No	80	80	90	90
>135-150	No	No	80	80	90	90

FOR PARAPET HEIGHTS FROM 6.0 TO 11.9 INCHES

	Maximum Wind Speed (mph)					
Bldg.	System 1		System 2		System 3	
Ht. Ft.	Exposure E	Exposure P	Exposure E	Exposure P	Exposure E	Exposure P
0- 15	90	90	100	100	120	120
>15- 30	80	90	100	100	120	120
>30- 45	70	80	100	100	120	120
>45- 60	70	80	90	100	120	120
>60- 75	70	70	90	90	120	120
>75- 90	No	No	90	90	120	120
>90-105	No	No	80	80	120	120
>105-120	No	No	80	80	120	120
>120-135	No	No	80	80	110	110
>135-150	No	No	80	80	100	100

FOR PARAPET HEIGHTS FROM 12.0 TO 17.9 INCHES

	Maximum Wind Speed (mph)					
Bldg.	System 1		System 2		System 3	
Ht. Ft.	Exposure E	Exposure P	Exposure E	Exposure P	Exposure E	Exposure P
0- 15	90	90	100	100	120	120
>15- 30	80	90	100	100	120	120
>30- 45	70	90	100	100	120	120
>45- 60	70	80	90	100	120	120
>60- 75	70	70	90	90	120	120
>75- 90	70	70	90	90	120	120
>90-105	No	No	90	90	120	120
>105-120	No	No	80	80	120	120
>120-135	No	No	80	80	120	120
>135-150	No	No	80	80	110	110

FOR PARAPET HEIGHTS FROM 18.0 TO 23.9 INCHES

	Maximum Wind Speed (mph)					
Bldg.	System 1		System 2		System 3	
Ht. Ft.	Exposure E	Exposure P	Exposure E	Exposure P	Exposure E	Exposure P
0- 15	90	90	100	100	120	120
>15- 30	80	90	100	100	120	120
>30- 45	80	90	100	100	120	120
>45- 60	70	80	100	100	120	120
>60- 75	70	70	90	90	120	120
>75- 90	70	70	90	90	120	120
>90-105	No	No	90	90	120	120
>105-120	No	No	90	90	120	120
>120-135	No	No	80	80	120	120
>135-150	No	No	80	80	120	120

Figure 4 Design tables

FOR PARAPET HEIGHTS FROM 24.0 TO 35.9 INCHES

	Maximum Wind Speed (mph)					
Bldg.	System 1		System 2		System 3	
Ht. Ft.	Exposure E	Exposure P	Exposure E	Exposure P	Exposure E	Exposure P
0- 15	90	90	100	100	120	120
>15- 30	90	90	100	100	120	120
>30- 45	80	90	100	100	120	120
>45- 60	70	90	100	100	120	120
>60- 75	70	70	100	100	120	120
>75- 90	70	70	90	90	120	120
>90-105	70	70	90	90	120	120
>105-120	No	No	90	90	120	120
>120-135	No	No	90	90	120	120
>135-150	No	No	80	80	120	120

FOR PARAPET HEIGHTS FROM 36.0 TO 71.9 INCHES

	Maximum Wind Speed (mph)					
Bldg.	System 1		System 2		System 3	
Ht. Ft.	Exposure E	Exposure P	Exposure E	Exposure P	Exposure E	Exposure P
0- 15	90	90	100	100	120	120
>15- 30	90	90	100	100	120	120
>30- 45	80	90	100	100	120	120
>45- 60	80	90	100	100	120	120
>60- 75	70	70	100	100	120	120
>75- 90	70	70	100	100	120	120
>90-105	70	70	90	90	120	120
>105-120	70	70	90	90	120	120
>120-135	70	70	90	90	120	120
>135-150	No	No	90	90	120	120

FOR PARAPET HEIGHTS FROM 72 TO 96 INCHES

	Maximum Wind Speed (mph)					
Bldg.	System 1		System 2		System 3	
Ht. Ft.	Exposure E	Exposure P	Exposure E	Exposure P	Exposure E	Exposure P
0- 15	90	90	100	100	120	120
>15- 30	90	90	100	100	120	120
>30- 45	80	90	100	100	120	120
>45- 60	80	90	100	100	120	120
>60- 75	80	80	100	100	120	120
>75- 90	80	80	100	100	120	120
>90-105	80	80	100	100	120	120
>105-120	70	70	100	100	120	120
>120-135	70	70	100	100	120	120
>135-150	70	70	90	90	120	120

Exposure P = Suburbs and small cities
Exposure E = Open terrain and large cities

Note: Any building that does not fit the above Design Tables should be treated as a special design consideration which should be reviewed by the architect, building owner and manufacturer.

Figure 5 Design tables

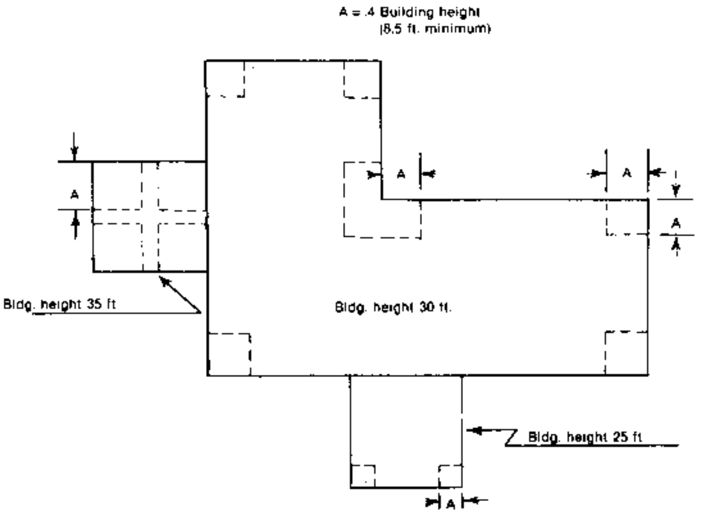


Figure 6 Roof layout, System 2

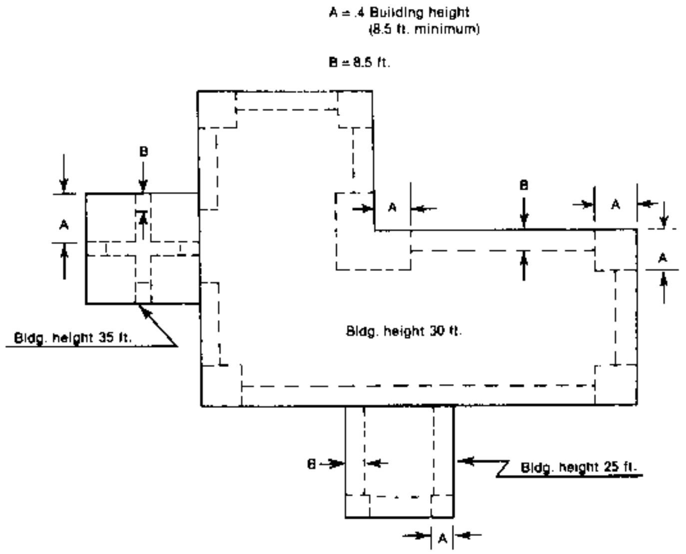
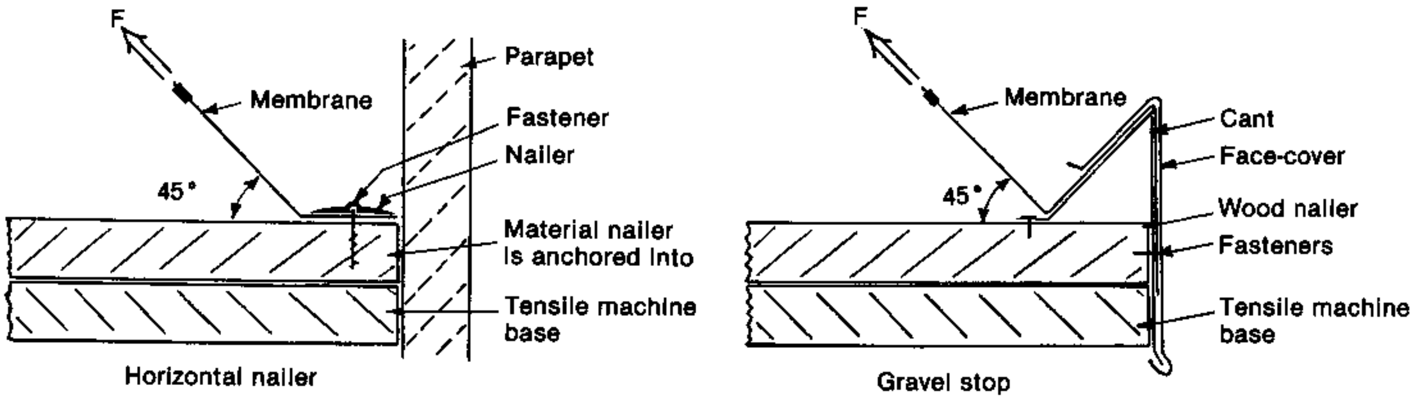


Figure 7 Roof layout, System 3

		Amounts Finer than Each Laboratory Sieve (Square Openings). weight percent														
Size No.	**Nominal Size. Square Openings**	**4-in. (100-mm)**	**3½-in. (90-mm)**	**3-in. (75-mm)**	**2½-in. (63-mm)**	**2-in. (50-mm)**	**1½-in. (37.5 mm)**	**1-in. (25.0-mm)**	**¼-in. (19.0-mm)**	**½-in. (12.5-mm)**	**⅜-in. (9.5-mm)**	**No.4 (4.75-mm)**	**No.8 (2.36-mm)**	**No.16 (1.18-mm)**	**No.50 (300-μm)**	**(150-μm)**
1	3½ to 1½-in. (90 to 37.5-mm)	100	90-100	—	25-60	—	1-15	—	0-5	—	—	—	—	—	—	—
2	2½ to 1½-in. (63 to 37.5-mm)	—	—	100	90-100	35-70	0-15	—	0-5	—	—	—	—	—	—	—
24	2½ to ¾-in. (63 to 19.0-mm)	—	—	100	90-100	—	25-60	—	0-10	0-5	—	—	—	—	—	—
3	2 to 1-in. (50 to 25.0-mm)	—	—	—	100	90-100	35-70	0-15	—	0-5	—	—	—	—	—	—
357	2-in. to No.4 (50 to 4.75-mm)	—	—	—	100	95-100	—	35-70	—	10-30	—	0-5	—	—	—	—
4	1½ to ¾-in. (37.5 to 19.0-mm)	—	—	—	—	100	90-100	20-55	0-15	—	0-5	—	—	—	—	—
467	1½-in. to No.4 (37.5 to 4.75-mm)	—	—	—	—	100	95-100	—	35-70	—	10-30	0-5	—	—	—	—
5	1 to ½-in. (25.0 to 12.5-mm)	—	—	—	—	—	100	90-100	20-55	0-10	0-5	—	—	—	—	—
56	1 to ⅜-in. (25.0 to 9.5-mm)	—	—	—	—	—	100	90-100	40-85	10-40	0-15	0-5	—	—	—	—
57	1-in. to No.4 25.0 to 4.75-mm)	—	—	—	—	—	100	95-100	—	25-60	—	0-10	0-5	—	—	—
6	¾ to ⅜-in. (19.0 to 9.5-mm)	—	—	—	—	—	—	100	90-100	20-55	0-15	0-5	—	—	—	—
67	¾ to No.4 (19.0 to 4.75-mm)	—	—	—	—	—	—	100	90-100	—	20-55	0-10	0-5	—	—	—
68	¾-in. to No.8 (19.0 to 2.36-mm)	—	—	—	—	—	—	100	90-100	—	30-65	5-25	0-10	0-5	—	—
7	½-in. to No.4 (12.5 to 4.75-mm)	—	—	—	—	—	—	—	100	90-100	40-70	0-15	0-5	—	—	—
78	½-in. to No.8 (12.5 to 2.36-mm)	—	—	—	—	—	—	—	100	90-100	40-75	5-25	0-10	0-5	—	—
8	⅜-in. to No.8 (9.5 to 2.36-mm)	—	—	—	—	—	—	—	—	100	85-100	10-30	0-10	0-5	—	—

Figure 8 Standard sizes of coarse aggregate per ASTM D448



Horizontal nailer

Gravel stop

Figure 9

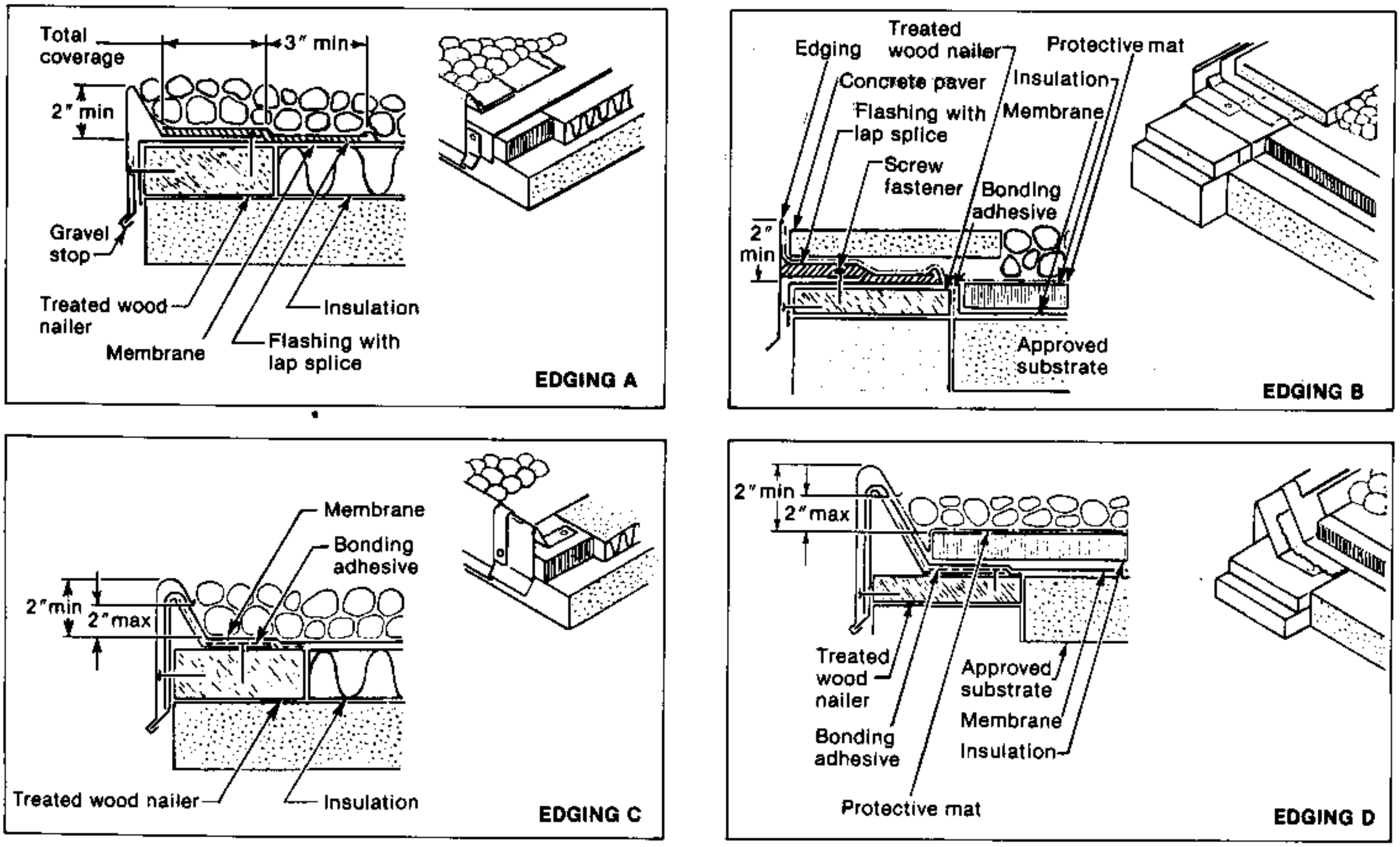


Figure 10 Gravel stop and perimeter attachment

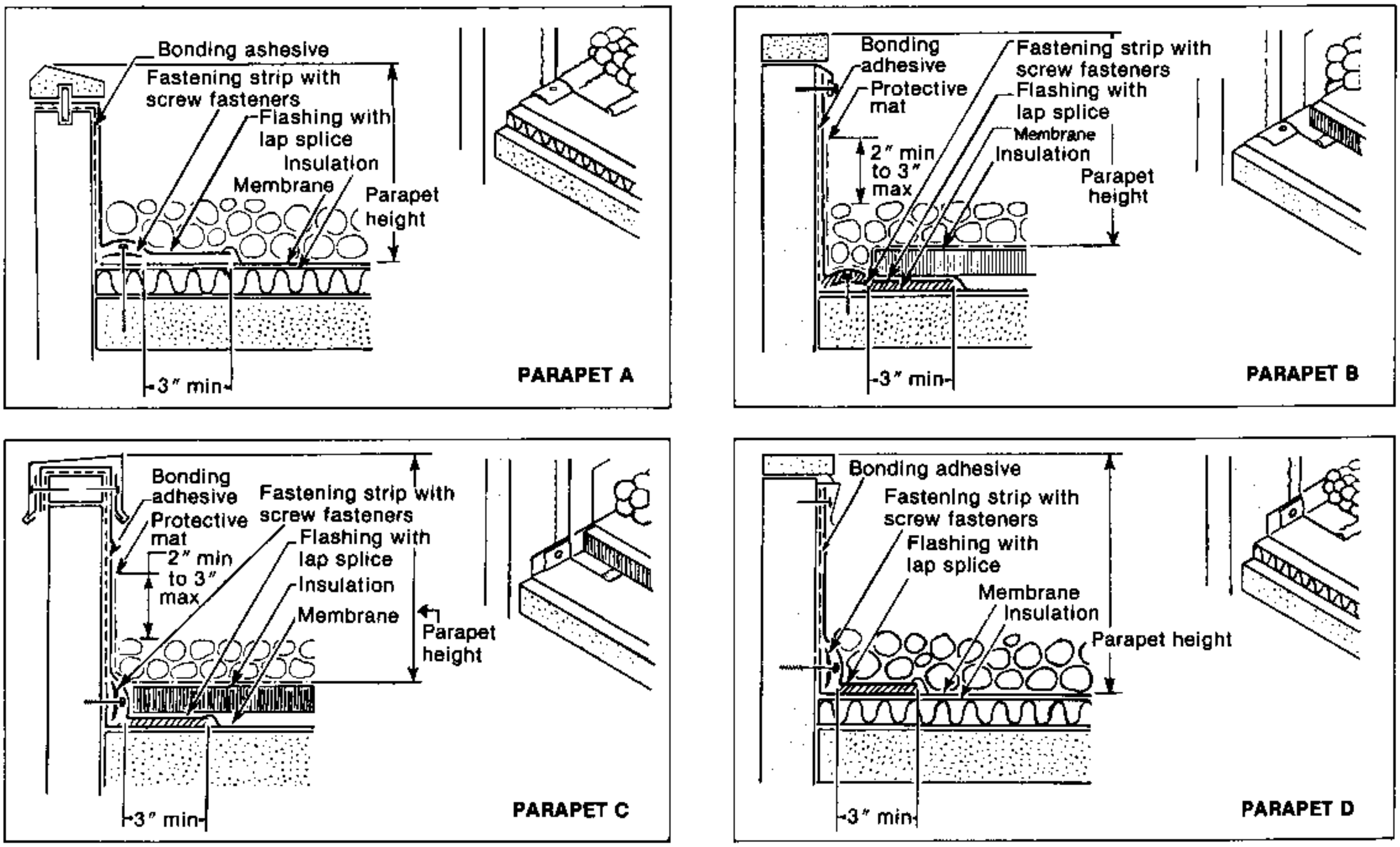


Figure 11 *Parapet and perimeter attachment*