

GUIDE FOR STEEL STACK CONSTRUCTION



**SHEET METAL AND AIR CONDITIONING CONTRACTORS'
NATIONAL ASSOCIATION, INC.**

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SECOND EDITION - JANUARY 1996



**SHEET METAL AND AIR CONDITIONING CONTRACTORS'
NATIONAL ASSOCIATION, INC.**
4201 Lafayette Center Drive
Chantilly, VA 22021

GUIDE FOR STEEL STACK CONSTRUCTION

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by

**SHEET METAL AND AIR CONDITIONING CONTRACTORS'
NATIONAL ASSOCIATION, INC.**

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FOREWORD

At the request of the Industrial Ventilation and Power Industry Committee, Dr. Michael C. Soteriades, who did all the theoretical work for the previous edition, reviewed and updated the material for this new edition.

Although the vast majority of the original material has been reproduced here, some of the major differences with the previous edition are:

- The theoretical basis for the selection tables has been reviewed and expanded to make it more useful and easier to follow.
- The reinforcement criteria for the openings in the stack have been reviewed and clarified, including more detailed illustrations and drawings.
- Consistent with the original recommendation that when available the "undampened" designs have preference over the "dampened" designs, the new edition has eliminated "dampened" solutions when "undampened" designs are also available for the same geometry.
- A new chapter has been added providing conversion factors and guidance for working in the metric (SI) system. In this respect we have deviated from SMACNA's policy of reproducing all numerical data in both the English (I-P) and metric (SI) systems. This is because of the unique circumstance that the design of stacks involves consideration of wind-induced resonant vibration, which makes any deviation from the calculated metal thickness a potential risk. This is true even when going to a greater thickness, which in most other design situations is considered a safe and conservative procedure.
- The new edition has been reformatted per SMACNA's *Manual of Style*, which governs the presentation of all SMACNA publications to create a uniform look and feel.



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TABLE OF CONTENTS

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TABLE OF CONTENTS

Foreword	iii	5.5 ERECTION	5.1
Industrial Ventilation and Power Industry Committee	iv	5.6 STACK SAMPLING FACILITIES	5.2
Notice to Users of this Publication	v		
CHAPTER 1 INTRODUCTION	1.1	CHAPTER 6 DESIGN CRITERIA	6.1
CHAPTER 2 PLANNING STACK LOCATION	2.1	6.1 FORMULA DERIVATIONS AND PRESENTATIONS	6.1
CHAPTER 3 STEEL STACK DESIGN	3.1	6.2 LIMITATIONS OF DESIGN	6.1
3.1 LIMITATIONS OF DESIGN	3.1	6.3 DESIGN FOR THICKNESS OF STACK SHELL	6.2
3.2 SELECTION PROCEDURES	3.1	6.4 DESIGN FOR REINFORCEMENT OF OPENINGS IN SHELL	6.5
3.3 STACK DAMPING	3.1	6.5 DESIGN OF BASE PLATE AND ANCHOR BOLTS	6.5
3.4 STACK OPENINGS	3.5	6.6 DETERMINING ANCHOR BOLT LENGTH	6.10
3.5 TYPES OF MATERIAL	3.5	6.7 DESIGN OF BOLTS FOR COMPANION ANGLE CONNECTIONS	6.11
3.6 DEFINITIONS OF TERMS	3.9	6.8 DESIGN OF STACK STIFFENERS	6.11
CHAPTER 4 STEEL STACK MATERIALS SELECTION	4.1	6.9 EXAMPLE OF INTERPOLATION IN STACK DESIGN	6.13
4.1 DEFINITIONS	4.1		
4.2 USE OF THE TABLES	4.1	APPENDICES	
CHAPTER 5 STEEL STACK CONSTRUCTION	5.1	APPENDIX-1 USE OF GUIDE WITH METRICS	A.1
5.1 FABRICATION AND INSTALLATION	5.1	APPENDIX-2 LIST OF SYMBOLS	A.3
5.2 ASSEMBLY AND FITUP	5.1	APPENDIX-3 BIBLIOGRAPHY	A.5
5.3 WELDING	5.1		
5.4 BOLTED CONNECTIONS	5.1	INDEX	I.1



CHAPTER 1

INTRODUCTION

The industrial sheet metal contractor is often required to provide a steel stack as part of the system for process exhaust ventilation.

This handbook is devoted exclusively to free-standing stacks that are founded at ground elevation and of uniform diameter. The publication provides tables for stacks of fixed height ranging from 20 to 120 feet; specific wind velocities of 100, 125, and 150 miles per hour; and diameters ranging from 12 to 84 inches. The designer is cautioned that where unusual conditions are expected which may affect the structural integrity of the stack—i.e., excessive wind velocity, increased stack height, etc.—special consideration must be given to the design of the stack to compensate for these conditions.

The committee may consider stack design and construction for guyed and intermittently supported stacks in the future.

The Sheet Metal and Air Conditioning Contractors' National Association does not assume any responsibility or liability for the application of the principles and techniques contained in this guide.

The Industrial Ventilation and Power Industry Committee and its predecessor, the Industrial Duct Standards Committee, are indebted to Dr. Michael C. Soteriades of the Catholic University of America for his assistance in developing this guide.



CHAPTER 2

PLANNING STACK LOCATION

The location and height of the stack is greatly influenced by the location, size, and configuration of surrounding buildings and topography.

Air flow over a building creates a positive pressure zone on the upstream side of the building and a negative pressure zone (cavity) on the roof and lee side of the building.

Although contour and cavity zones remain relatively unchanged as the wind velocity changes (only the pressures within these zones change), the contour zone and cavity envelopes can often be erratic in shape due to wind turbulence.

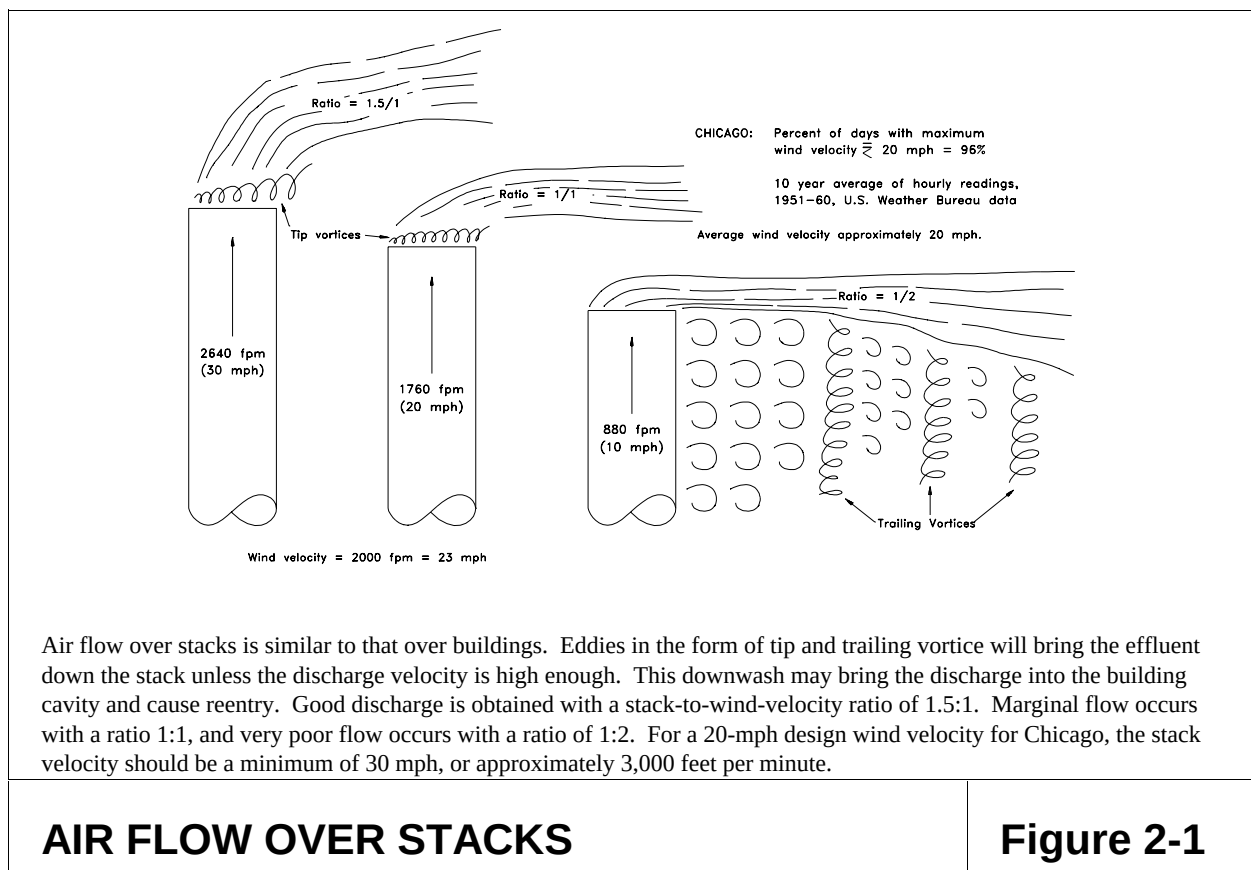
High stack discharge velocity and temperature increase flume height and thus effective stack height.

Wind flow over stacks creates negative zones and eddies behind the stack in the same manner as air flow around buildings. (See Figure 2-1.) Low stack discharge velocities permit the effluent to be drawn into the stack eddy zone and may cause down wash. This reduces the effective stack height and may cause the effluent to enter the building cavity, even though the discharge may be well above this cavity.

The stack-to-wind-velocity ratio should be 1.5 to 1 or higher. Under such conditions, the effluent will break cleanly from the stack, down wash will be eliminated, and the effective stack height will be maximized. In most cases, a stack discharge velocity of 3,000 to 4,000 feet per minute will provide good performance.

The designer is cautioned that the Environmental Protection Agency (EPA) and state and local ordinances may dictate the stack height and location. Federal Aviation Agency (FAA) regulations will often restrict the height and location of stacks. Designers should adhere strictly to the requirements of all codes and other government regulations.

Note: A stack's location, height, and discharge velocity can be critical in preventing the reentry of pollutants into a building's ventilation system, and although the criteria suggested above have been found satisfactory in many cases, the user is directed to Chapter 14, Air Flow Around Buildings, in the 1993 Fundamentals Volume of the *ASHRAE Handbook*, and other design texts listed in Appendix-3, for more extensive treatment of this and other design topics.



CHAPTER 3

STEEL STACK DESIGN

3.1 LIMITATIONS OF DESIGN

This manual is concerned with the design of steel stacks under the following limitations or assumptions:

- The stack will be fabricated of steel with yielding stress in excess of 36 Ksi.
- The bottom of the breeching opening will be at least 5 feet above the ground and its width will not exceed two-thirds the diameter of the stack.
- The stack will have a constant diameter from top to bottom and will be unlined.
- The stack will not be used for flow of corrosive material.
- The temperature of the gases will not exceed 300°F, and the maximum differential temperature along the circumference will not exceed 100°F.
- The stack will be anchored on a 4,000-psi or higher concrete footing founded directly on the ground.
- The stack base will be founded directly on the concrete foundation. If a nut will be used for leveling (commonly referred to as a jacknut), it will be loosened after shimming of the base of the stack.
- No guy wires or other lateral supports will be provided, i.e., the stack will be free-standing. (See Figure 3-1.)
- The concrete base of the stack must extend beyond the fastening bolts a distance at least equal to $1.3 \times \ell_b$.

3.2 SELECTION PROCEDURES

Chapter 4 includes material selection tables for stack diameters of 12, 14, 16, 18, 20, 22, 24, 28, 32, 36, 42, 48, 60, 72, and 84 inches. Stack heights of 20, 30, 40, 50, 60, 80, 100, and 120 feet are listed. For each diameter and height, design criteria are established for wind velocities of 100, 125, and 150 mph.

Separate tables have been provided for stacks with and without test platforms and access ladders. (See Figure 3-2.)

The steel stack selection Tables 4-1 through 4-14 are designed to provide sufficient information for the selection of stack materials and anchor bolt specifications. Load and overturning moment data are also available to assist in the design of the stack foundation.

Table 4-13 provides stack stiffener information and the requirements for companion flange selection.

To use the tables for selecting a steel stack, you first determine the required stack diameter, stack height, and wind velocity for which the stack must be designed.

In many instances, the stacks are to be constructed of varying material thickness. In these situations, the base section is listed first and the remaining sections listed progressively upwards.

The design criteria upon which these tables are based does not permit deviation from the material thickness specified. For instance, the designer should not assume that thicker material will provide more stability or strength. Likewise, it should not be assumed that steel thickness for unlisted diameters can be obtained by interpolation in all cases. The designer should use the standard diameter stack provided by the tables. If this is not possible, engineering expertise should be used to decide whether interpolation is justifiable or not. This should not be automatically assumed as feasible.

Stack base and anchor bolt specifications are also set forth in the tables. Gussets are required at each bolt location as shown in Figure 3-3. When the number of gussets required exceeds twice the number of anchor bolts, the additional gussets are to be placed equidistant between anchor bolts.

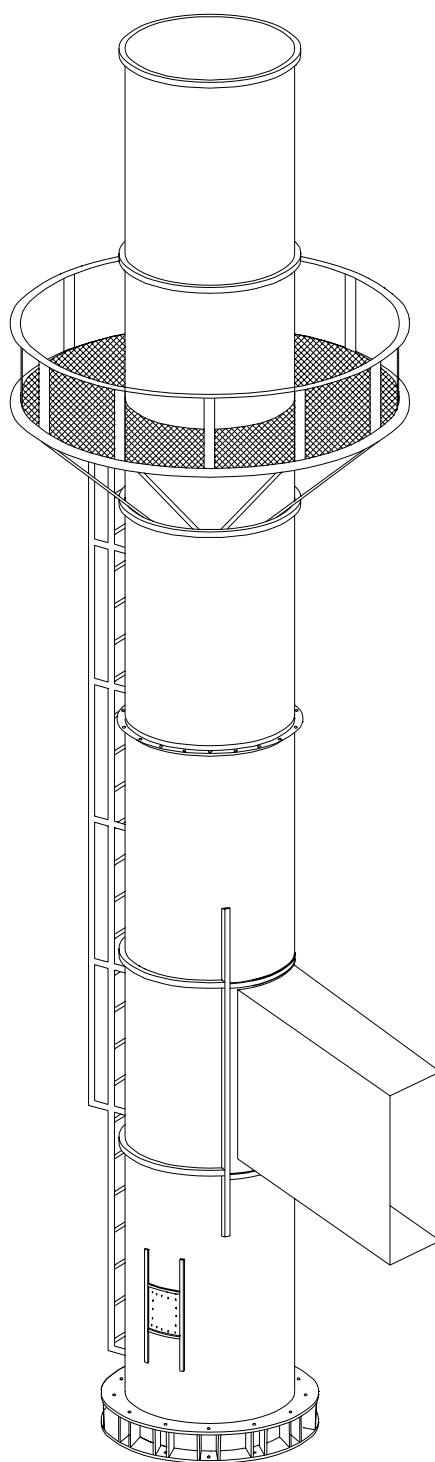
Stiffener rings are required to prevent stack ovaling. Stiffener ring size and spacing can be found in Table 4-13.

When stacks are to be field assembled by the use of matched angle flange connections, the flange size and bolting specification are set forth in Tables 4-13 and 4-14.

3.3 STACK DAMPING

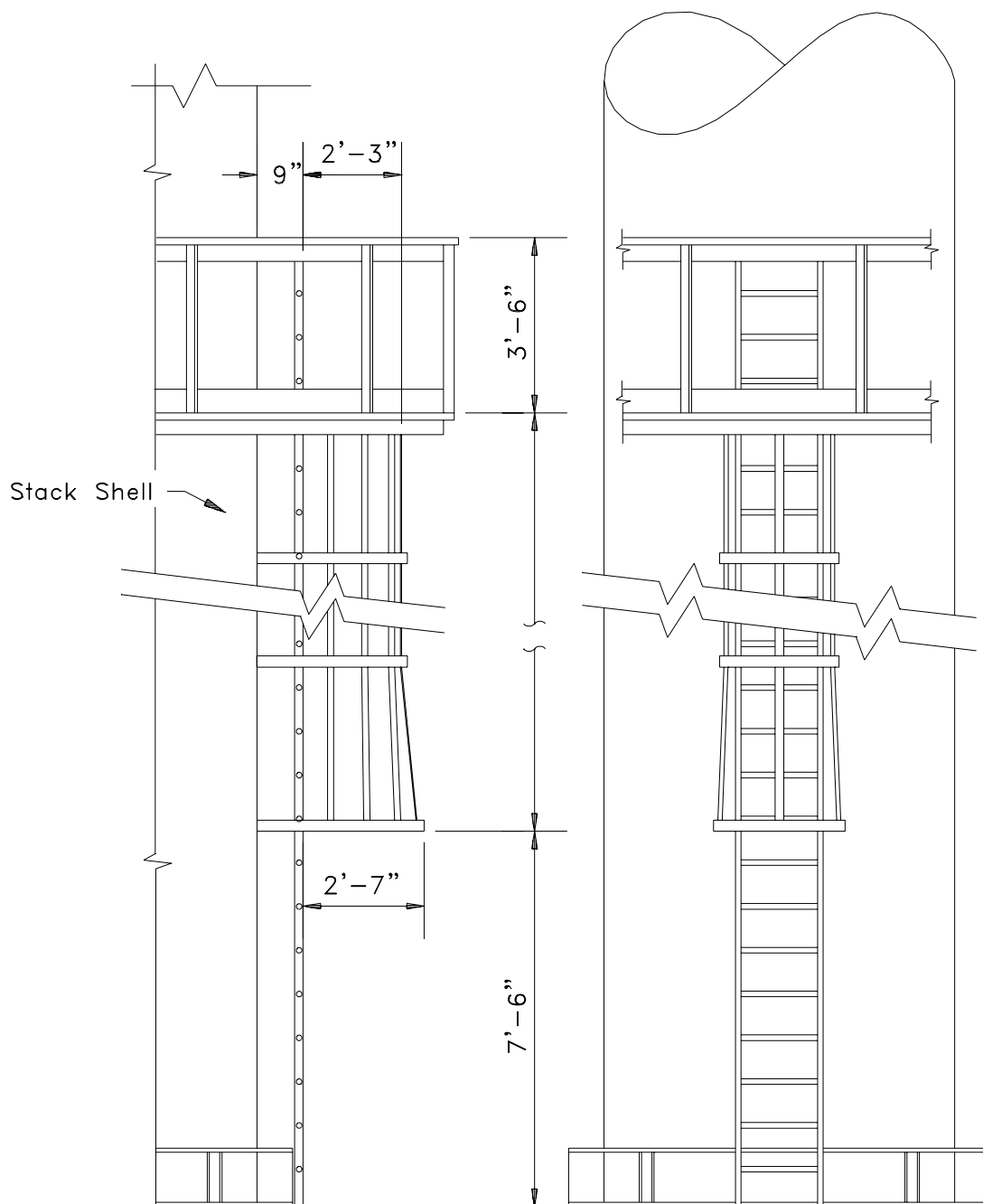
The stack diameter and height determine critical wind speed conditions at which a stack may resonate. Resonant vibration, if uncontrolled, can result in progressively larger displacements of the top of the stack and can ultimately result in structural failure of the stack. In instances where analysis has indicated the possibility of resonant vibration, the selection tables in Chapter 4 require stack damping; these instances are indicated by the shaded columns.

Typically, resonance can be controlled through one of a number of available methods of damping. Damping is a method for absorbing enough of the kinetic energy transferred from the wind to the stack so that



TYPICAL FREE-STANDING STEEL STACK

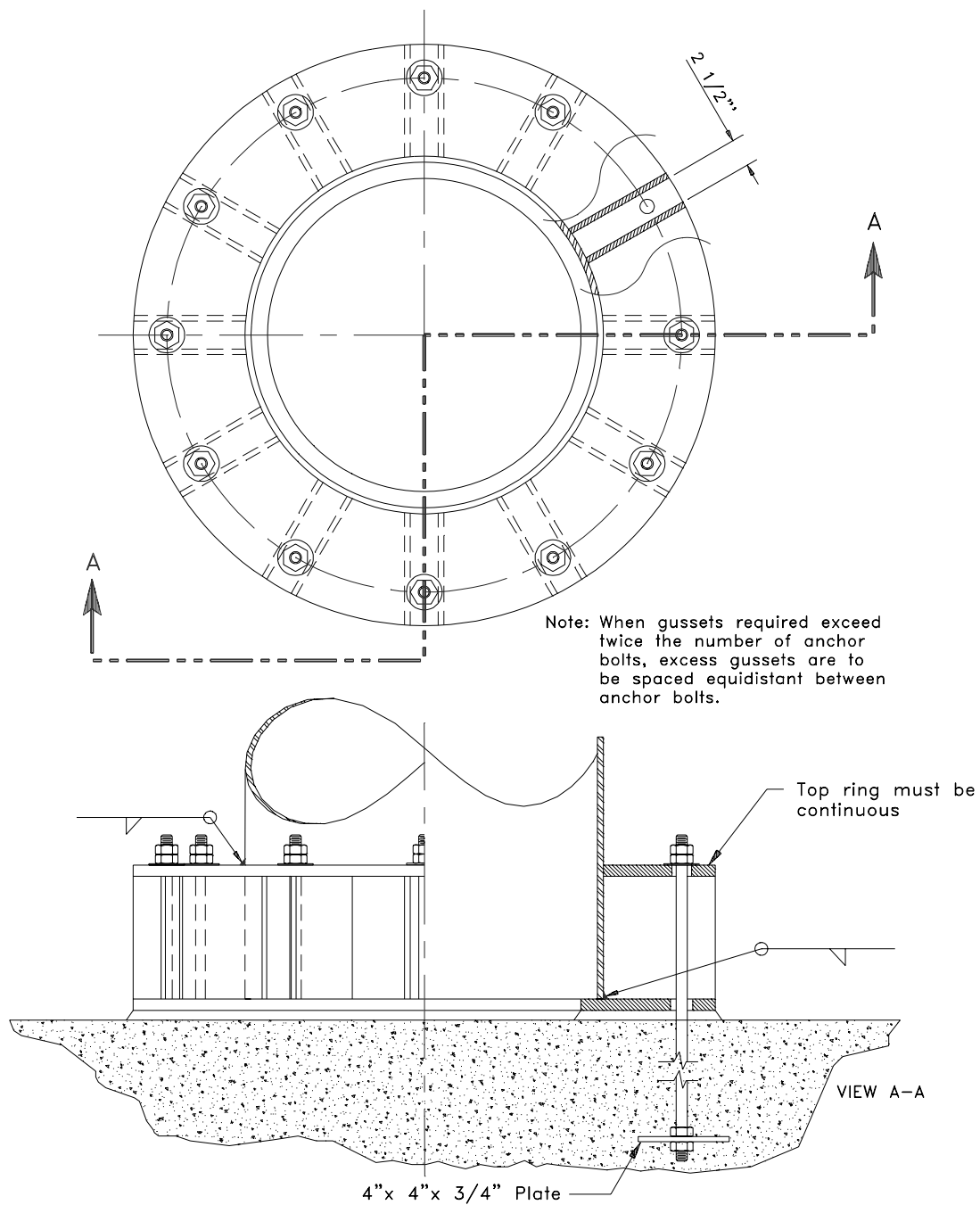
Figure 3-1



TYPICAL LADDER INSTALLATION

Figure 3-2





GUSSET PLACEMENT

Figure 3-3

the amplitude of vibration of the stack will not increase interminably, thereby controlling its deflection. Figure 3-4 depicts a typical stack base and Figure 3-5 a common procedure for damping using a ring of pre-formed fabric. Damping rings vary in thickness from $\frac{5}{8}$ to 2 inches, with 1 inch being the most common.

When damping is required, the contractor can approach one of several damping ring manufacturers with the stack details (provided in the selection table), and the manufacturer will make the selection of the recommended ring, leveling plate, and anchor bolt washers based on their design procedures. They will also provide the contractor with detailed installation instructions, which must be strictly followed to ensure a satisfactory installation.

3.4 STACK OPENINGS

Openings in the stack to accommodate duct connections or breeching (see Figure 3-6) must be adequately reinforced to maintain the structural integrity of the steel stack. The rules for design of this reinforcing are:

- a. The reinforcement must be sufficient to provide a moment of inertia equal to or greater than the moment of inertia of the stack shell with no openings.
- b. A simple procedure for satisfying this rule is to make the cross-section of the reinforcement at least equal to the cross-section of material removed for the opening.
- c. The reinforcement must extend beyond the top and the bottom of the opening for a minimum distance equal to three-quarters the width of the opening to ensure a smooth transfer of forces which may be interrupted by the opening.
- d. The welding of the reinforcement along the length of the stack must be sufficient to transfer stress exhausting the axial load capacity of the reinforcing element at the allowable maximum compressive stress of the shell and, preferably, at a stress of 20 Ksi (i.e., the welding at either end of the reinforcing element should be capable of transferring a force in Kips equal to 20 times the cross-sectional area of the reinforcement expressed in inches square). All this welding capacity must be developed above the elevation of the bottom of the opening. In addition, the reinforcing elements should be continuously welded to the shell along the length of the actual opening. An example of a properly reinforced stack opening is shown in Figure 3-7.
- e. Under no circumstances should the opening reinforcement be carried all the way to the footing

unless a special design has been worked out to transfer an axial compressive or tensile stress from the reinforcement to the foundation directly without disturbing the pattern of stress transfer through the base plate to the concrete (compression) or the anchor bolts to the concrete (tension).

- f. The maximum width of the opening must not exceed two-thirds the diameter of the stack. This rule must not be violated without a detailed engineering analysis.

3.5 TYPES OF MATERIAL

Hot-rolled steel is the most common material used in steel stack construction. Different shapes of structural members are available for reinforcement. This material is easily fabricated and easily welded. It is not recommended for systems handling corrosive aerosols. Specifications for the various types of the hot-rolled steels are: (1) hot-rolled structural steel shapes and plate, ASTM A-36; (2) hot-rolled steel sheet, ASTM A-569, commercial quality; and (3) hot-rolled steel plate, ASTM A-635, commercial quality.

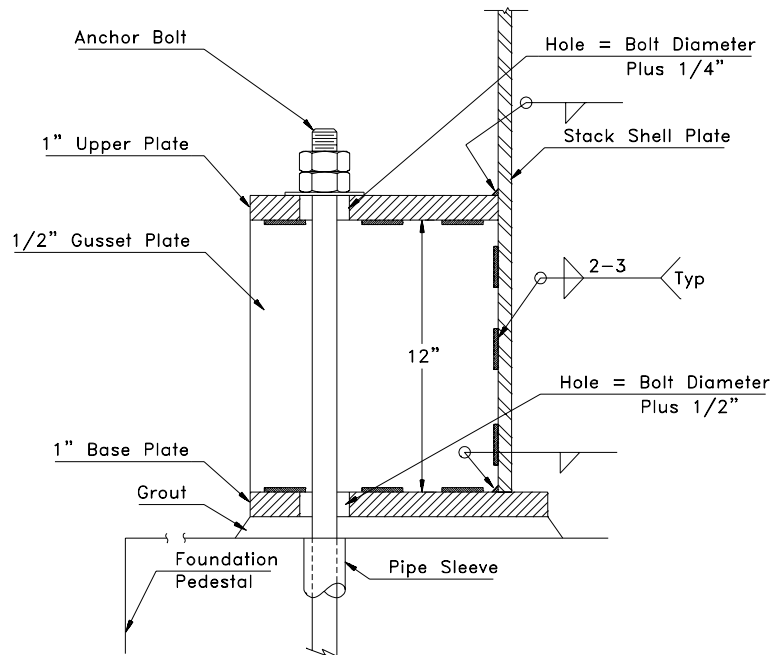
A few words of caution with respect to application temperatures and the selection of steels other than the structural grade hot rolled steel on which the tables of Chapter 4 are based:

Although carbon steels are generally suitable for applications up to 650°F, galvanized steels up to 400°F, and stainless steels much higher, the selection tables in Chapter 4 are based on a design limit of 300°F. Therefore, a change in type of material or application temperatures exceeding 300°F may require careful structural analysis by a competent structural engineer.

The same caution must be exercised before substituting stainless steels for carbon steel because their strength, elasticity, and temperature characteristics vary considerably and the direct substitution of stainless for carbon steel cannot be assumed to be structurally sound without professional review.

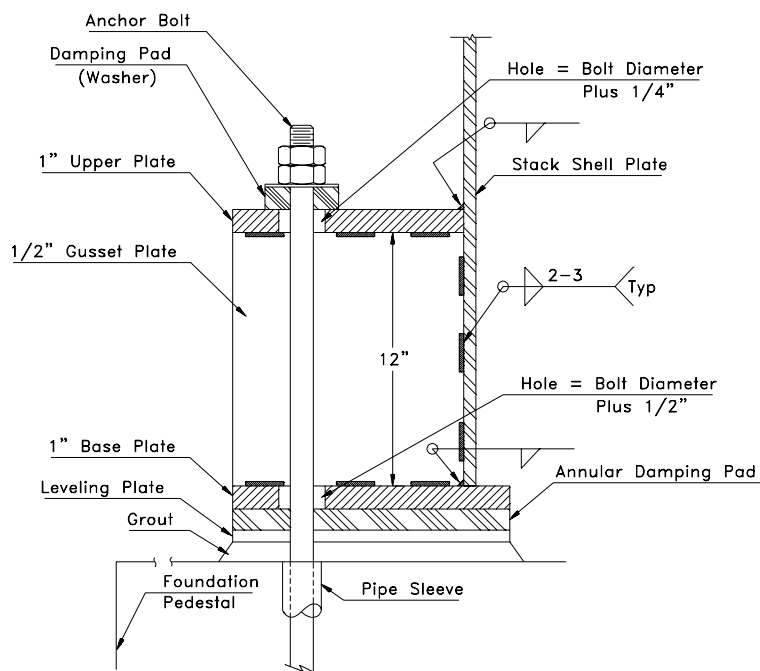
Galvanized sheet and plate may be used for constructing steel stacks. The specification for galvanized steel sheet is ASTM A-924. While galvanized sheet provides protection against atmospheric attack, it is not recommended for systems handling corrosive aerosols.





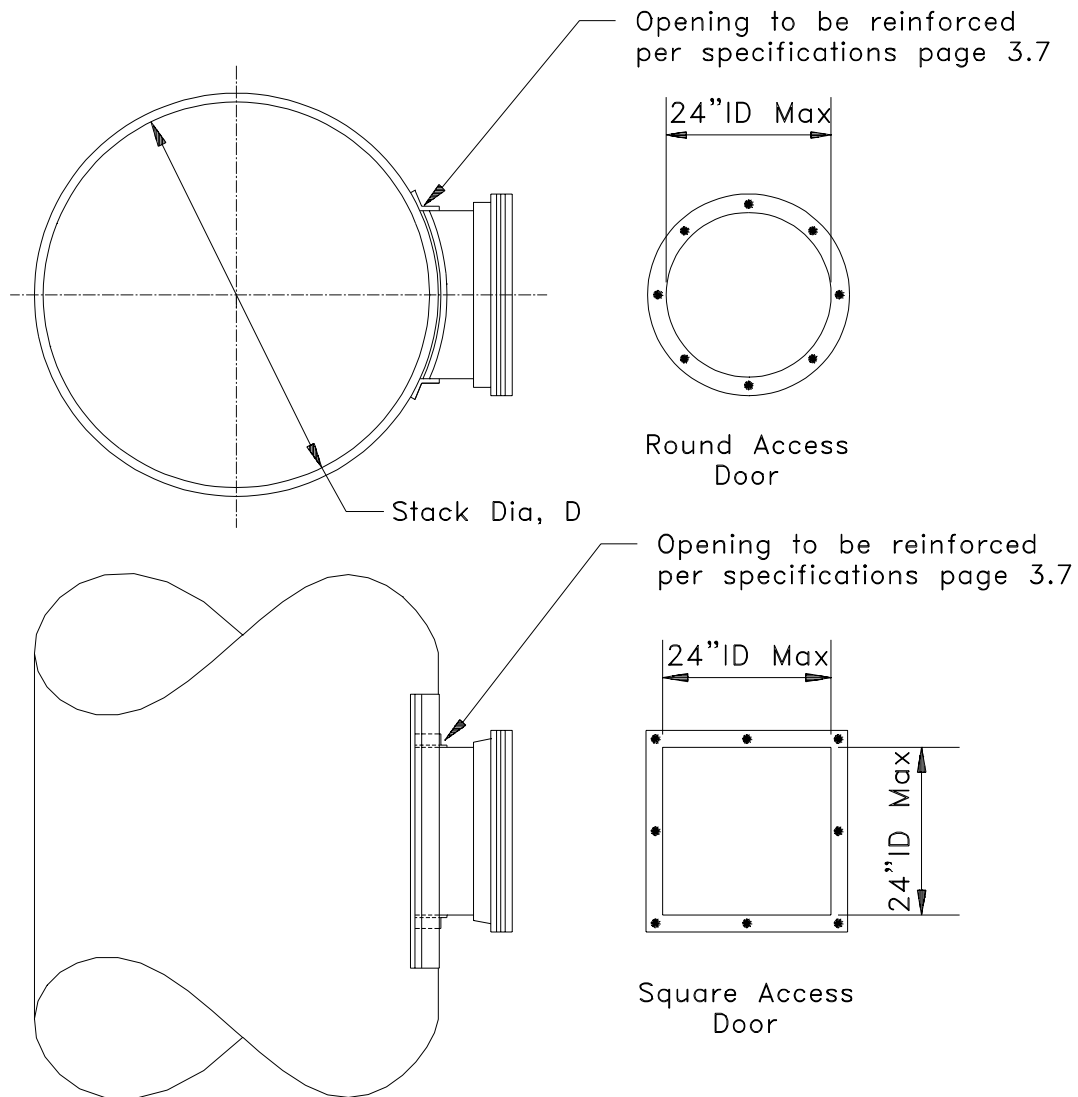
TYPICAL STACK BASE

Figure 3-4



TYPICAL DAMPING PAD DETAILS AT BASE OF STACK

Figure 3-5

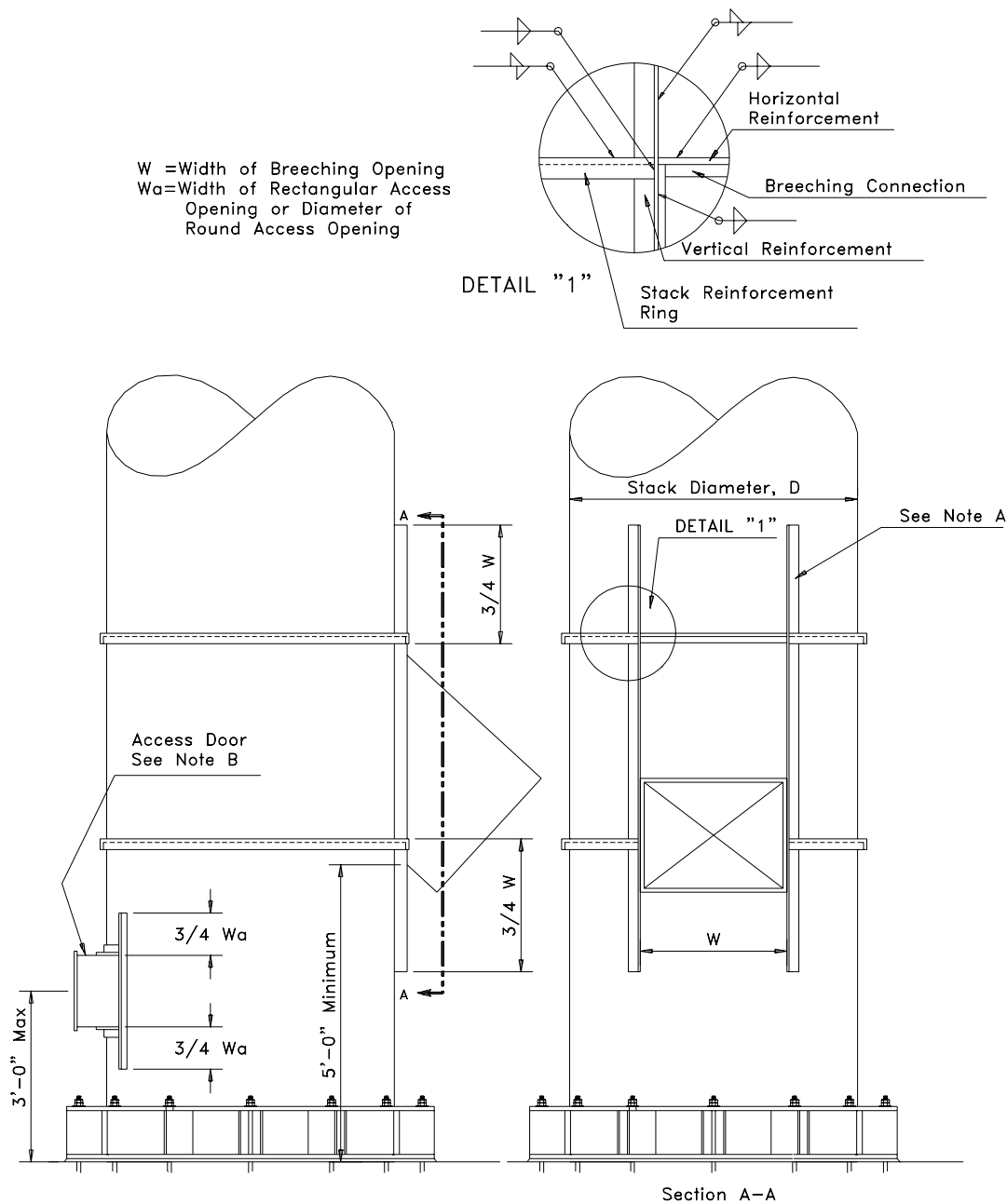


Note: Maximum access door opening is limited to $\frac{2 \times D}{3}$ or 24" inside dimension, whichever is the less.

TYPICAL ACCESS DOOR INSTALLATION

Figure 3-6





- Note A.** The cross-sectional area of both horizontal and vertical reinforcement members must exceed half of the material removed for the stack opening. (See pages 3.7 and 3.11 for detailed requirements and an illustrative example.)
- Note B.** For maximum size of access doors and reinforcement requirements, see Figure 3-6 and pages 3.7 and 3.11.

REINFORCEMENT OF STACK OPENING

Figure 3-7

Stainless steel in sheet, plate, and a limited selection of structural forms can be used to construct steel stacks. Stainless steel alloys highly resistant to corrosion and for use at high temperatures are readily available. Consult the manufacturer for the selection of the material best suited for these applications.

3.6 DEFINITIONS OF TERMS

- Critical velocity-the wind velocity that will cause the stack to resonate (vibrate).
- Damping-the act of progressively diminishing the vibration or oscillation.
- Eddies-currents of air running contrary to the main current; whirlpools.
- Effective stack height-distance from the ground to the top of the stack plus the vertical distance of the discharge plume.
- Founded-set or grounded on something solid.
- Guyed-steadied or reinforced.
- Vortices-a mass of air having a whirling or circular motion that tends to form a cavity or vacuum in the center.

Example:

Assume a steel stack must be constructed with a diameter of 60 inches and a height of 100 feet. Stack design must be based on a wind velocity of 125 miles per hour.

Turn to Chapter 4, Table 4-7. This stack can be constructed of the following material thickness:

20 feet @ ¼-inch plate
 20 feet @ 3/8-inch plate
 20 feet @ ½-inch plate
 20 feet @ 3/8-inch plate
 20 feet @ 5/16-inch plate

Twelve 1½-inch-diameter anchor bolts are required, having an embedded length of 36 inches. A total of 36 gussets will be needed (as shown in the table).

The base configuration and dimensions are as shown in Figure 3-8.

Next we turn to Table 4-13. Stiffeners size 2½ x 2½ x ¼ on 12½-foot centers are required, and we must include a stiffener at the top of the stack. We

will fabricate the stack in two sections, with a matched flange connection at midpoint. Table 4-13 allows companion flanges of 2½ x 2½ x ¼ angle or 2½ x ½ bar. This companion flange may be substituted for one of the stiffeners, and-since the material thickness for the stack shell is ½ inch at midpoint-only the bar flange option meets the minimum requirement of three-fourths the shell thickness. Bolt requirements for this flange connection are shown in Table 4-14. For a stack designed for a wind velocity of 125 miles per hour, with the flange located 50 feet from the stack top, we would, to be conservative, select bolts specified for 60-foot distance from stack top. For a 60-inch-diameter stack, we find that 5/8-inch-diameter bolts are required, and the note tells us that the number of bolts required is equal to half the stack diameter as stated in inches (60 x ½ = 30). Thirty bolts are required.

When considering an opening in the stack to connect the breeching the opening must not exceed $\frac{2xD}{3}$

In this example, $\frac{2 \times 60 \text{ in.}}{3} = 40 \text{ in}$

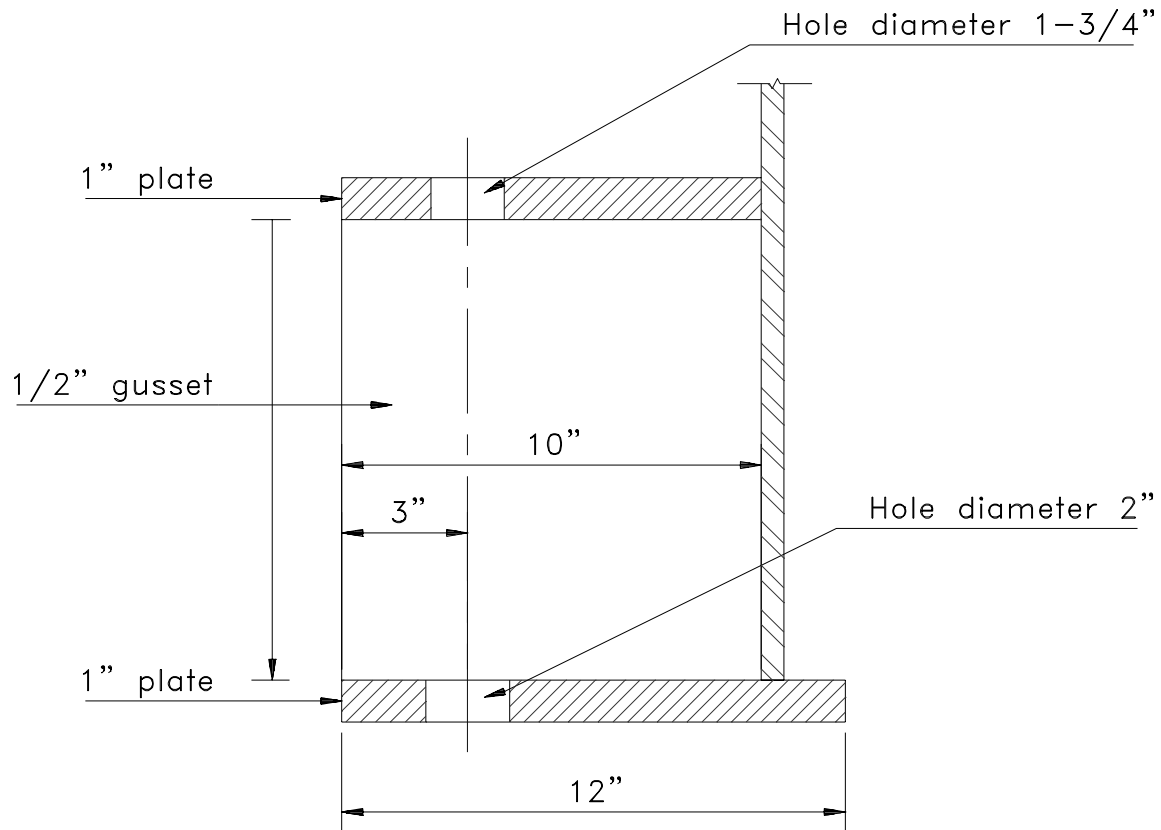
The bottom of the opening must be at least 5 feet from the bottom of the stack (top of the concrete footing). Assume the opening to be 36 inches wide by 64 inches in height.

To select proper reinforcement, both horizontal and vertical reinforcement members must be sized. The reinforcement concept is that the reinforcement members in both the horizontal and vertical directions must provide a cross-sectional area equal to the cross-sectional area of the material removed from the stack shell in the direction perpendicular to the axis being reinforced.

Therefore, the requirement for the vertical reinforcement members for this example (assume two, one on each side of the opening) is the equivalent of 36 in. x 0.740 in. (minimum thickness of ¾-inch plate) = 26.6 in² and for the horizontal reinforcement members, 64 in. x 0.740 in. = 47.4 in.*.

For small stacks, reinforcement requirements can usually be met with standard angle and channel shapes. However, for larger stacks, the designer will need to select combinations of plate and rolled shapes to fully satisfy the requirements.





EXAMPLE STACK BASE CONFIGURATION AND DIMENSIONS

Figure 3-8

CHAPTER 4

STEEL STACK MATERIALS SELECTION

4.1 DEFINITIONS

The following definitions apply to the materials selection tables:

- a. Material thickness is presented by gage through 10 gage and by plate designation for thickness above 10 gage.
- b. Where material thickness varies, the stack section height and material thickness are presented with the lower section listed first and each successive section following.
- c. Shaded columns are for dampened stacks. (See Figure 3-5.)
- d. Allowable stress is the maximum stress that can be tolerated at a point where maximum stress is developed.
- e. N designates the total vertical load (includes accessories when applicable) for which the foundations should be designed.
- f. M designates the overturning moment.
- g. Two types of anchor bolts are specified: ANSI A-325 and ANSI A-307 (ANSI A-325 is preferred).
- h. n/d designates the number of bolts required and the bolt diameter, respectively.

- i. ℓ_b = embedded anchor bolt length. (See Figure 4-1.)
- j. $a/b/c$ describe the base plate dimensions. (See Figure 4-2.)
- k. To ensure maximum anchoring strength, the distance between the anchor-bolt circle and the nearest edge of the concrete foundation should be equal to, or greater than, 1.3 times the embedded anchor bolt length (ℓ_b).

4.2 USE OF THE TABLES

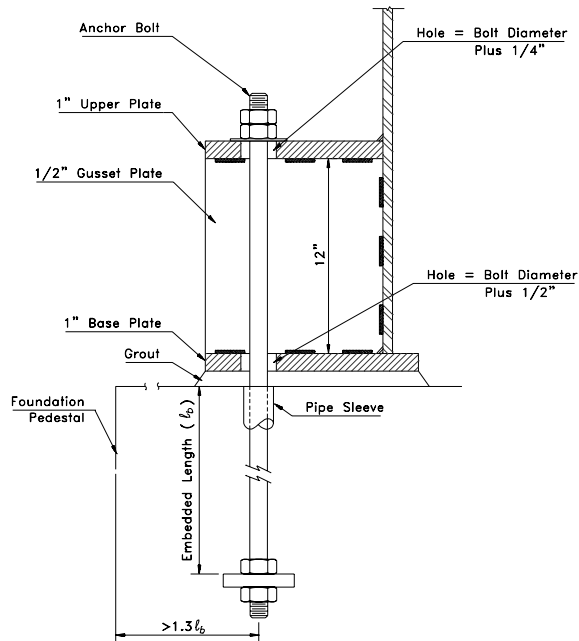
Use of the selection tables is described in Chapter 3, including the example on page 3.9.

When design details for a particular stack diameter and wind velocity have been omitted from the tables (such as on page 4.22), it is because the design requirements for a stable stack were deemed unreasonable, regardless of whether damping is available or not. In such cases, if an alternate stack selection is not possible, the design should be referred to a structural engineer for special engineering.

NOTE: For best results, we recommend that the user review:

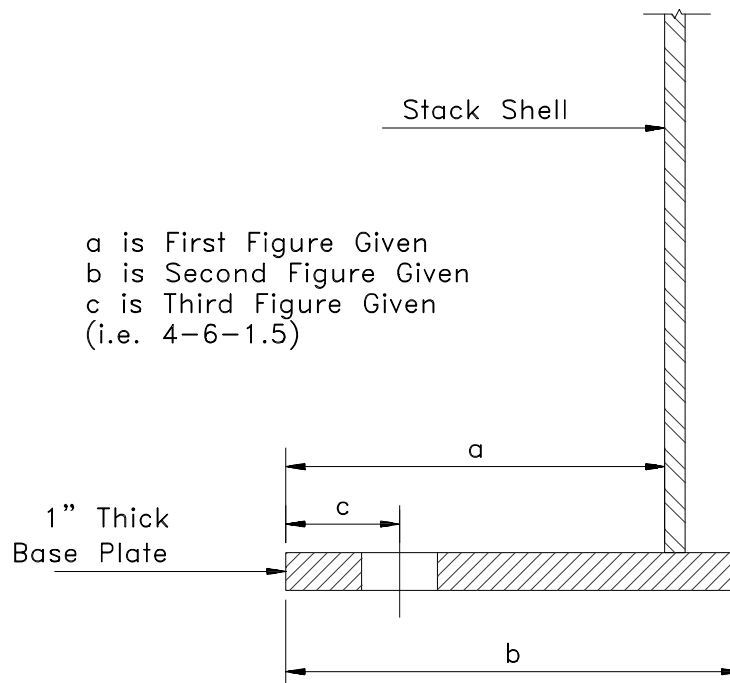
- The definitions above;
- Chapter 3, including the example on page 3.9;
- Figures 4-1 and 4-2; and
- Appendix-2

before selecting a stack from the tables in this chapter.



ANCHOR BOLT PLACEMENT

Figure 4-1



BASE PLATE DIMENSIONS

Figure 4-2