

GUIDE FOR FREE STANDING STEEL STACK CONSTRUCTION



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

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GUIDE FOR FREE STANDING STEEL STACK CONSTRUCTION

THIRD EDITION – SEPTEMBER, 2011



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

**4201 Lafayette Center Drive
Chantilly, VA 20151
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**SHEET METAL AND AIR CONDITIONING CONTRACTORS'
NATIONAL ASSOCIATION, INC.**

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FOREWORD

This Third edition of *Guide for Free Standing Steel Stack Construction* formerly known as *Guide for Steel Stack Construction* – is intended for use by contractors, fabricators, and designers of heating equipment and industrial process facilities.

The Steel Stack Task Force was formed to expand, review, and revise this standard of practices for the selection, fabrication and installation of steel stacks. This document is the result of that effort.

The main changes and additions contained in this edition are:

- A technical review of all the stack selections was completed and a considerable number of improvements made. The vast majority of the changes came in two categories: First, the previous edition contained a number of stacks selected on the basis of resonant vibration where the critical wind speed plus a 20% cushion exceeded 60 MPH, not recognizing that steady state wind conditions are necessary for resonance to be experienced, and steady state wind is not encountered in practice above 60 MPH. Second, the task force established a limit in both stack diameter and material thickness for stacks to be fitted with test platform and access ladder. Therefore, stacks must be 24 inches in diameter or greater and the section to which the platform is to be welded must be a minimum of 10 gage. These two concepts resulted in the vast majority of changes to the stack selection tables.
- All the stack selection tables were expanded to include from one to three larger diameter stacks than the previous edition, up to a new maximum of 120 inches in diameter.
- New requirements for anchoring to Concrete in ACI 318 (Appendix D) resulted in larger bases and anchor bolts than previous editions. Additionally, for some of the larger stacks, this resulted in unusually large anchoring components, forcing consideration of custom designed anchoring systems instead of a standardized schedule.

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TABLE OF CONTENTS

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TABLE OF CONTENTS

FOREWORD	iii
STEEL STACK TASK FORCE	iv
FORMER COMMITTEE MEMBERS AND OTHER CONTRIBUTORS	iv
NOTICE TO USERS OF THIS PUBLICATION	v
TABLE OF CONTENTS	vii

CHAPTER 1	INTRODUCTION	Page
1.1	INTRODUCTION	1.1
1.2	DESIGN LIMITATIONS	1.1
1.3	LOCATION REQUIREMENTS	1.1
CHAPTER 2	FREE STANDING STACK SELECTION	
2.1	DEFINITIONS	2.1
2.2	TERMS	2.1
2.3	SELECTION PROCEDURE	2.1
2.4	TYPES OF MATERIAL	2.2
2.5	STACK DAMPING	2.2
2.6	STACK OPENINGS	2.2
2.7	STACK SELECTION EXAMPLE	2.5
2.8	INTERPOLATING MATERIAL SELECTION TABLES	2.8
CHAPTER 3	STEEL STACK CONSTRUCTION	
3.1	FABRICATION AND INSTALLATION	3.1
3.2	ASSEMBLY AND FITUP	3.1
3.3	WELDING	3.1
3.4	BOLTED CONNECTIONS	3.1
3.5	FIELD ERECTION	3.1
3.6	STACK SAMPLING FACILITIES	3.1
CHAPTER 4	DESIGN CRITERIA	
4.1	FORMULA DERIVATIONS AND PRESENTATIONS	4.1
4.2	LIMITATIONS OF DESIGN	4.1
4.3	DESIGN FOR THICKNESS OF STACK SHELL	4.2
4.4	CALCULATION OF COMBINED STRESSES	4.6
4.5	DESIGN OF STACK STIFFENERS	4.7
4.6	GUIDANCE FOR INTERPOLATION OF THE STACK SELECTION TABLES	4.8
4.7	DESIGN FOR THE REINFORCEMENT OF SHELL OPENINGS	4.8
4.8	DESIGN OF BASE PLATE AND ANCHOR BOLTS	4.9
APPENDIX A	USE OF GUIDE WITH METRICS	
APPENDIX B	BIBLIOGRAPHY	



TABLES

Page

2-1	Stack Height – 20 Feet With Access Ladder and Platform	2.12
2-1	Stack Height – 20 Feet With Access Ladder and Platform (continued)	2.13
2-2	Stack Height – 30 Feet With Access Ladder and Platform	2.14
2-2	Stack Height – 30 Feet With Access Ladder and Platform (continued)	2.15
2-3	Stack Height – 40 Feet With Access Ladder and Platform	2.16
2-3	Stack Height – 40 Feet With Access Ladder and Platform (continued)	2.17
2-4	Stack Height – 50 Feet With Access Ladder and Platform	2.18
2-4	Stack Height – 50 Feet With Access Ladder and Platform (continued)	2.19
2-5	Stack Height – 60 Feet With Access Ladder and Platform	2.20
2-5	Stack Height – 60 Feet With Access Ladder and Platform (continued)	2.21
2-6	Stack Height – 80 Feet With Access Ladder and Platform	2.22
2-6	Stack Height – 80 Feet With Access Ladder and Platform (continued)	2.23
2-7	Stack Height – 100 Feet With Access Ladder and Platform	2.24
2-7	Stack Height – 100 Feet With Access Ladder and Platform (continued)	2.25
2-8	Stack Height – 120 Feet With Access Ladder and Platform	2.26
2-8	Stack Height – 120 Feet With Access Ladder and Platform (continued)	2.27
2-9	Stack Height – 20 Feet Without Access Ladder and Platform	2.30
2-9	Stack Height – 20 Feet Without Access Ladder and Platform (continued)	2.31
2-9	Stack Height – 20 Feet Without Access Ladder and Platform (continued)	2.32
2-10	Stack Height – 30 Feet Without Access Ladder and Platform	2.33
2-10	Stack Height – 30 Feet Without Access Ladder and Platform (continued)	2.34
2-10	Stack Height – 30 Feet Without Access Ladder and Platform (continued)	2.35
2-11	Stack Height – 40 Feet Without Access Ladder and Platform	2.36
2-11	Stack Height – 40 Feet Without Access Ladder and Platform (continued)	2.37
2-11	Stack Height – 40 Feet Without Access Ladder and Platform (continued)	2.38
2-12	Stack Height – 50 Feet Without Access Ladder and Platform	2.39
2-12	Stack Height – 50 Feet Without Access Ladder and Platform (continued)	2.40
2-13	Minimum Flange and Stiffeners Sizes	2.41
2-14	Bolt Size Requirements For Companion Angle Connections	2.43
A-1	Bolt Specifications	A.1

FIGURES

Page

1-1	Stack Discharge and Air Flow Around Stack	1.2
2-1	Typical Free-Standing Steel Stack	2.3
2-2	Typical Stack Base	2.4
2-3	Typical Damping Pad Details At Base of Stack	2.4
2-4	Reinforcement of Stack Opening	2.6
2-5	Typical Access Door Installation	2.7
2-6	Example Stack Base Configuration And Dimensions	2.8
2-7	Gusset Placement	2.9
2-8	Anchor Bolt Placement	2.10
2-9	Base Plate Dimensions	2.10
2-10	Typical Attachment for Companion Angles	2.42
2-11	Typical Attachment for Stiffeners	2.42
3-1	Typical Stack Sampling Facilities (Plan View)	3.3
3-2	Typical Stack Sampling Facilities (Elevation View)	3.4
3-3	Typical Ladder Installation	3.5
4-1	Summation of Moments (Sample 40 ft Stack)	4.4
4-2	Ring Stiffener	4.7
4-3	Base Plate And Anchor Bolt Arrangement	4.9
4-4	Anchor Bolt Ring Elevation	4.10
4-5	Anchor Ring Bearing Diagram	4.11
4-6	Concrete Bearing Plan View	4.11
4-7	Base Plate Dimensions	4.12



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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This publication is devoted exclusively to vertical, uniform diameter, free-standing stacks founded at ground elevation. Tables are provided for stacks of specific 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. When a desired stack, not listed in the tables, is subject to field conditions that may affect the structural integrity of the stack—*i.e.*, higher design wind velocity, increased stack height, etc.—special consideration must be given to the design of the stack to compensate for these conditions.

Generally, the third edition stack weights vary from the weights of the second edition, which did not include the weight of the anchor ring and plates. Some are lighter than the second edition, and most are heavier. This edition's weights are the result of several changes that can add or reduce overall stack weight. The reasons are technically sound and important improvements. Previously a conservative design concept was used which added thickness to the stack from the bottom up such that the critical wind velocity was comfortably in excess of the design wind speed (10 or more mph higher than the design wind speed of 100, 125 and 150 mph). This is unnecessary once the critical wind speed is higher than 72 mph because it takes a steady state wind to achieve stack resonance, not the wind gusts which actually exist once the wind speed approaches 60 mph. Beyond that wind speed, winds at ground level through the 100 foot elevation are turbulent and made up of gusts of various speeds and directions, not steady state. This makes a large design difference for stacks between 42 and 60 in. in diameter. Also the previous scheme of allowable stress based on an older document (ASCE 1975 – Design and Construction of Steel Chimney Liners) was updated resulting in this edition's use of an allowable stress scheme based on the ASME Steel Stack Guide ASME /ANSI STS-1, 2006 edition. In many cases both design stress values coincide, but often the ASME allowable stress value is higher resulting in somewhat lighter stacks. There are also a number of stacks affected by the Task Force decision not to weld platforms and ladders onto stack sections thinner than 10 gage. Many stacks that had top sections in 12 gage have been upgraded to 10 gage and all stacks under 24 in. in diameter were eliminated from having permanent platforms and ladders.

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1.2 DESIGN LIMITATIONS

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

- The stack will be free-standing and founded directly on concrete. If steel nuts are used for leveling (commonly referred to as jacknuts), they will be loosened after shimming the base of the stack.
- The stack will be fabricated of steel with a minimum yield stress of 36 Ksi.
- The stack will have a constant diameter from top to bottom and will be unlined (galvanizing excepted).
- The stack will be anchored on a 4,000-psi or greater concrete foundation, founded directly on the ground.
- The bottom of any breeching or other opening will be at least 5 feet above the ground and its width will not exceed two-thirds the diameter of the stack.
- The inlet temperature of the gases will not exceed 300°F
- The concrete foundation for the stack must extend beyond the anchor bolts a minimum distance equal to 1.3 times the anchor bolt embedment length (l_b) listed in the tables of Chapter 2.

1.3 LOCATION REQUIREMENTS

The location and height of a 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.

Wind flow around stacks creates negative pressure zones and eddies behind the stack in the same manner as air flow around buildings (Figure 1-1). Low stack discharge velocities permit the effluent to be drawn in-



to 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. Increasing stack discharge velocity and temperature will increase flume height and thus effective stack height.

The stack-to-wind-velocity ratio should be 1.5 to 1 or higher so that 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 adequate performance.

The designer is cautioned that the Environmental Pro-

tection 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 stack exhaust into a building's ventilation system. Although the criteria suggested above have been found satisfactory in many cases, the user is directed to Chapter 24, Air Flow Around Buildings, in the 2009 Fundamentals Volume of the ASHRAE Handbook for more extensive treatment of this and other design topics.

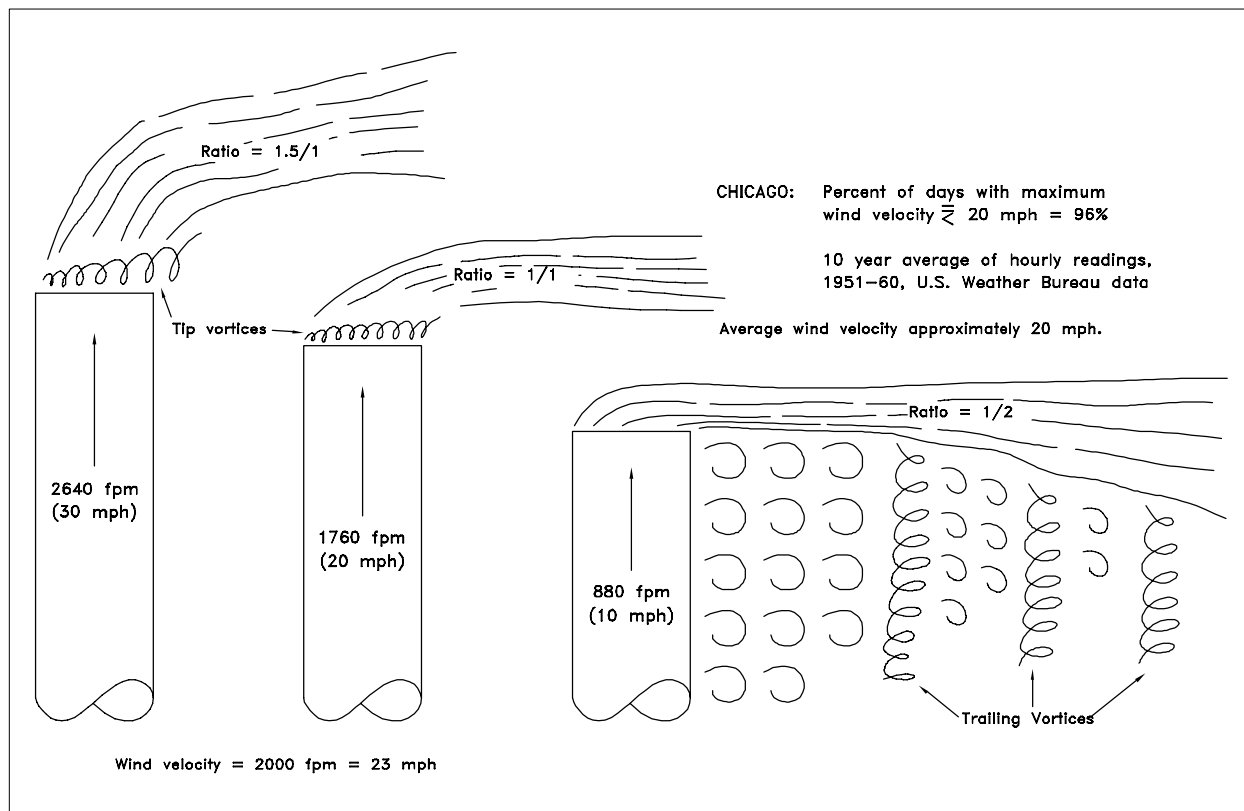


FIGURE 1-1 STACK DISCHARGE AND AIR FLOW AROUND STACK

CHAPTER 2

FREE STANDING STACK SELECTION

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2.1 DEFINITIONS

The following definitions apply to the stack selection tables:

- Material thickness is presented by gage through 10 gage and by plate designation for thickness above 10 gage.
- Where material thicknesses change, the stack section height and material thickness are presented successively with the lowest section listed first.
- Shaded columns indicate dampened stacks.
- Allowable stress is the maximum stress that can be tolerated at the point where maximum stress is developed.
- N designates the total vertical load in Kips for which the foundations should be designed.
- M designates the overturning moment in Kip-ft.
- Anchor bolts are: ANSI F1554, Grade 105.
- n/d designates the number of bolts and the bolt diameter required.
- l_b = embedded anchor bolt length (Figure 2-8).
- $a/b/c$ describe the base plate dimensions. (Figure 2-9).
- 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).

2.2 TERMS

- Critical velocity—the wind velocity that will cause the stack to resonate (vibrate).
- Damping—the act of diminishing 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.
- Vortices—a mass of air having a whirling or circular motion that tends to form a low pressure center.

2.3 SELECTION PROCEDURE

This chapter includes material selection tables for free standing stacks with and without test platforms and ladders. To make the selection possible the required stack diameter, stack height, and design wind velocity must first be established.

Tables 2-1 through 2-8 list stacks with test platforms and access ladders (as illustrated in Figure 2-1) starting at 24 inches in diameter. The tables are organized on the basis of stack height, starting at 20 feet, followed by tables for 30, 40, 50, 60, 80, 100 and 120 feet. Tables 2-1 through 2-8 contains selections for diameters of 24, 28, 32, 36, 42, 48, 54, 60, 72 and 84 inches as applicable, arranged in three sections, corresponding to gust wind velocities of 100, 125, and 150 mph respectively. The 100 and 120 foot tables extend to 96, 108 and 120 in. diameter stacks.

Tables 2-9 through 2-12 list stacks without platforms and ladders starting at 12 inches in diameter. The tables are organized on the basis of stack height, starting at 20 feet, followed by tables for 30, 40, and 50 feet. Tables 2-9 through 2-12 contains selections for diameters of 12, 14, 16, 18, 20, 22, 24, 28, 32, 36, 42, 48, 54, 60, 72, and 84 inches, as applicable, arranged in three sections, corresponding to gust wind velocities of 100, 125, and 150 mph respectively.

In many instances, the stacks are to be constructed in sections of varying material thickness. In these situations, the lowest section is listed first, and the remaining sections listed consecutively thereafter, with the top section (often the lightest section) listed last.

Stack base and anchor bolt specifications are also set forth in the tables. Gussets are required at each bolt location as shown in Figure 2-7. When the number of gussets required exceeds twice the number of anchor bolts, the additional gussets are to be placed equidistant between anchor bolts. Load (N) the total stack weight including appurtenances, and the overturning moment (M) are listed to assist in the design of the stack foundation.

Table 2-13 lists stack stiffener ring sizes and spacing (Stiffener rings are used to prevent stack ovaling resulting from stack resonance with wind eddies) and



companion flange selection requirements for stack sections to be field bolted using companion flanges, rather than field welding. Table 2-14 is the source for number and size of bolts for securing companion flanged stack sections, when not field welded.

NOTE: Not all the tables contain stack base and anchor bolt sizes for every diameter, stack height and wind speed combination, because for some stacks the combination of traditional anchor rings and the requirements of Anchoring to Concrete in ACI 318 (Appendix D) result in unusually large anchoring components, forcing consideration of custom designed alternative anchoring solutions.

2.4 TYPES OF MATERIAL

Hot-rolled carbon steel is the most common material used in steel stack construction. This material is easily fabricated and easily welded. Specifications for the various types of the hot-rolled carbon 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.

Although carbon steels are generally suitable for applications up to 650°F, galvanized steels up to 400°F and stainless steels much higher, the stack selection tables are based on a design limit of 300°F and the strength characteristics of carbon steel. Therefore, a change in type of material or application temperature exceeding 300°F requires professional structural analysis leading perhaps to a new design.

The same caution must be exercised before substituting stainless steel 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 analysis.

Galvanized sheet and plate having a yield strength of 36 ksi or greater, may be used interchangeably with the carbon steel thicknesses listed in the stack selection tables. However, galvanizing only provides some corrosion protection against atmospheric attack, but is not recommended for systems handling corrosives. In those cases, stainless steel alloys highly resistant to corrosion and for use at high temperatures are readily available. Consult steel manufacturers for selection of the material best suited for the application, and submit the stack design to professional analysis.

2.5 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 require stack damping; these instances are indicated by 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 the amplitude of vibration of the stack will not increase interminably, thereby controlling its deflection. Figure 2-2 depicts a typical stack base and Figure 2-3 a common procedure for damping using a ring of preformed material. Damping rings generally vary in thickness up to 2 inches, with 1 inch being the most common.

When damping is required, the contractor can consult with one of several damping ring manufacturers with the stack details (provided in the selection table), and the manufacturer will recommend the selection of the 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.

2.6 STACK OPENINGS

Openings in the stack to accommodate duct connections, access doors or breeching (*see* Figures 2-4 and 2-5) must be adequately reinforced to maintain the structural integrity of the steel stack. The rules for design of this reinforcement are:

- 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.
- One procedure for satisfying this rule is to make the cross-sectional area of the reinforcements at least equal to the cross-section of the material removed for the width of the opening (width of the opening thickness of the shell).
- 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

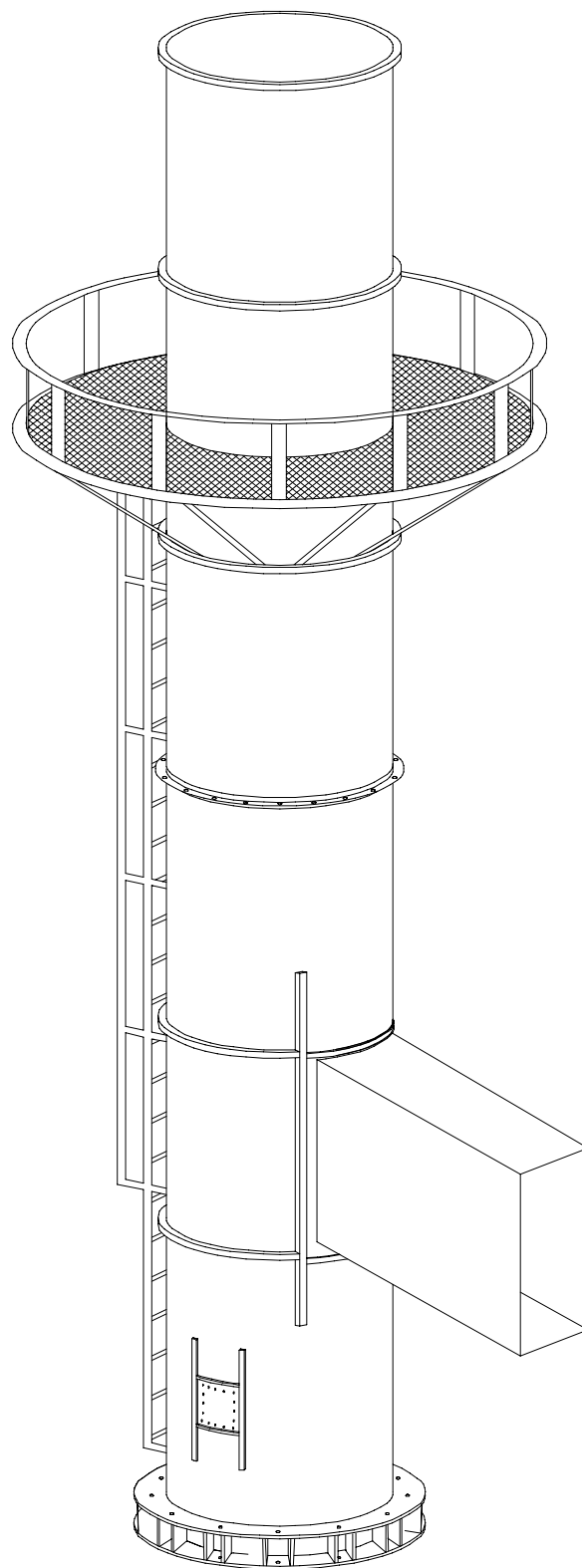


FIGURE 2-1 TYPICAL FREE-STANDING STEEL STACK



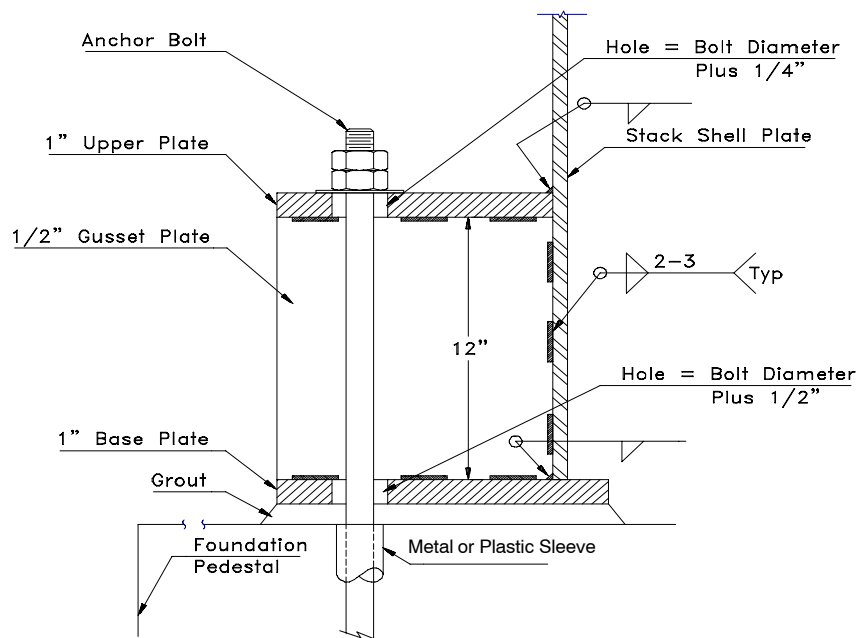


FIGURE 2-2 TYPICAL STACK BASE

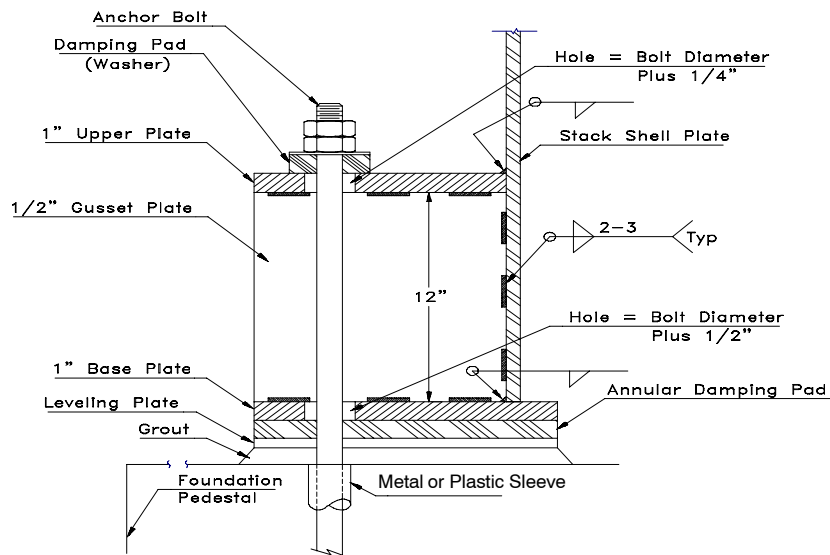


FIGURE 2-3 TYPICAL DAMPING PAD DETAILS AT BASE OF STACK

transfer of the forces which are interrupted by the opening.

- The welds to the stack along both sides of the vertical reinforcements (one reinforcement member on either side of the opening) must be sufficient to transfer the total axial load capacity of the reinforcements along the distance equal to the height of the opening. The welds must be continuous along the full length of the reinforcements. An example of a properly reinforced stack opening is shown in Figure 2-4.
- Under no circumstances shall the opening reinforcement be carried all the way to the foundation without a special design to transfer an axial compressive or tensile stress from the reinforcements to the foundation without disturbing the pattern of stress transfer through the base plate to the concrete (compression) or the anchor bolts to the concrete (tension).
- The maximum width of the opening must not exceed two-thirds the diameter of the stack.

2.7 STACK SELECTION EXAMPLE

Assume a steel stack must be constructed with a diameter of 60 inches and a height of 80 feet. Stack design must be based on a gust wind velocity of 125 miles per hour.

As indicated in Table 2-6, this stack can be constructed entirely of ¼ inch plate.

The base configuration and dimensions are as shown in Figure 2-6. The anchor base requires ten 1-½ inch diameter anchor bolts with an embedment length of 30 inches, and thirty gusset plates uniformly distributed about the anchor bolts, as per the arrangement in Figure 2-7.

Next we turn to Table 2-13 for the selection of ring stiffeners. Angle ring stiffeners of 2½ × 2½ × ¼ in. or bar stiffeners (flat rings) of 4 × ¾ in. on 10-foot centers are required. The arrangement of stiffeners starts with a stiffener at the top of the stack, followed by evenly spaced stiffeners at not more than 10-foot intervals. Additionally, stiffeners are also required at the top and bottom of the stack breeching opening; these are to be coordinated with the stiffeners spaced at 10 foot intervals, not in addition. In other words the spacing between stiffeners may be adjusted throughout the

length of the stack so that all stiffener intervals are reasonably uniform and less than the maximum spacing listed for the stack. The stack may be fabricated in two sections, with a companion flange connection at midpoint. Table 2-13 lists companion flanges of 2½ × 2½ × ¼ angle or 4 × ¾ bar. This flanged joint may substitute for one of the stiffeners, and—since the material thickness for the stack shell is ¼ inch throughout, either the angle or flat rings both exceed the minimum requirement of three-fourths the shell thickness. Bolt requirements for this flange connection are shown in Table 2-14. For a stack designed for a wind velocity of 125 miles per hour, with the flanged joint located 40 feet from the stack top the bolt size listed is ½ inch ASTM A325 or A449. The number of bolts required is equal to half the stack diameter as stated in inches (60 ÷ ½ = 30), that is thirty ½ inch bolts.

When considering an opening in the stack to connect the breeching, the opening must not exceed: $\frac{2}{3} \times D$ in width. For this example:

$$\frac{2}{3} \times 60 \text{ in.} = 40 \text{ inches wide.}$$

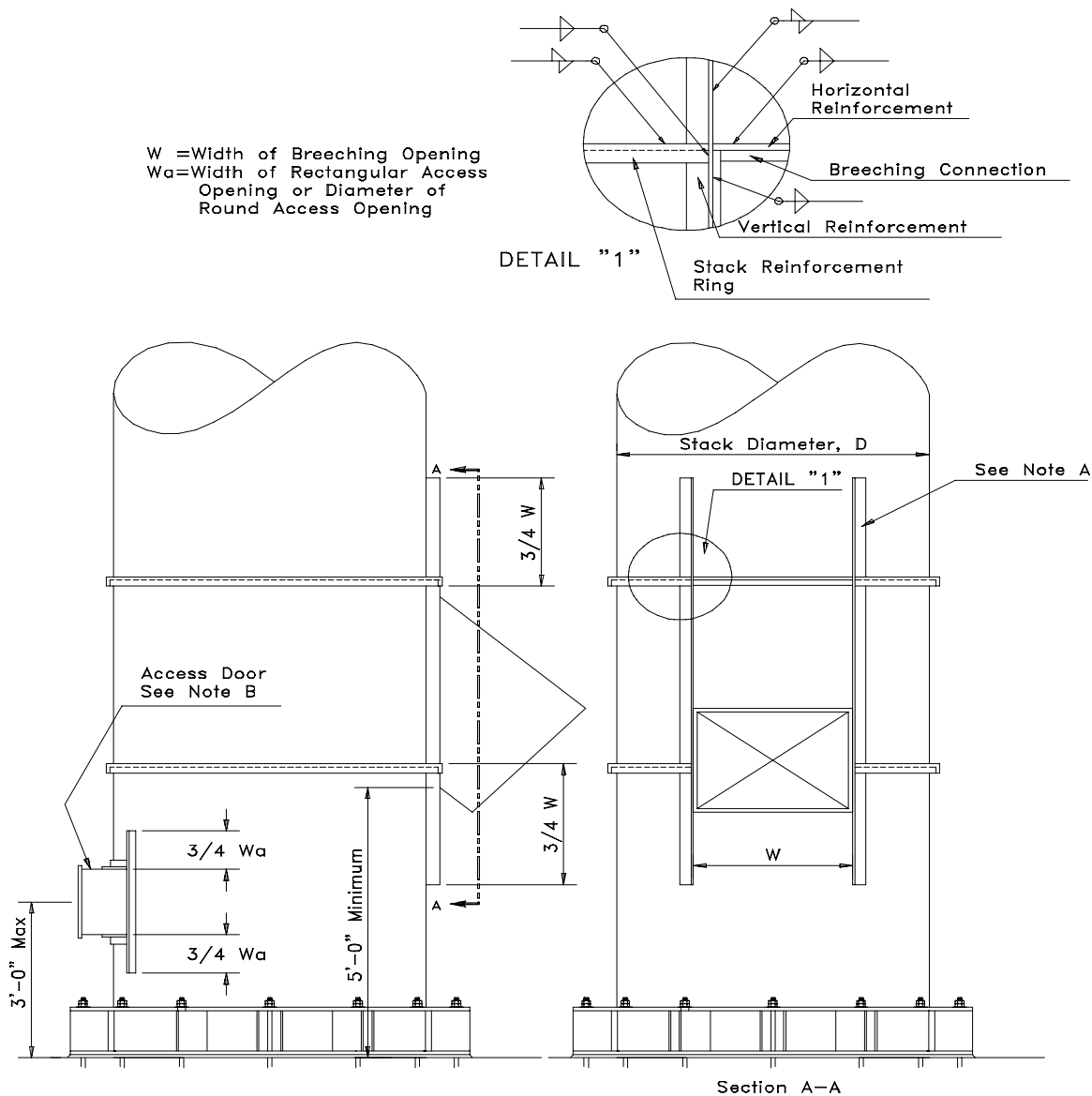
The bottom of the opening must be at least 5 feet from the bottom of the stack (top of the concrete foundation). Assuming a typical stack velocity of 3,000 fpm the opening can reasonably be estimated at 40 inches wide by 64 inches high (Flow area of approximately 18 ft²).

The cross sectional area of the vertical reinforcement members, on either side of the opening, must be calculated. The reinforcement concept requires that these vertical reinforcement members (together) provide a cross-sectional area equal to the horizontal cross-section of the material removed from the stack shell to form the opening.

Therefore, the cross sectional area requirement for the vertical reinforcement members for this example is the equivalent of 40 in. × 0.250 in. (nominal thickness of ¼-inch plate) = 10.0 in.². As there are two vertical reinforcements (one on each side of the opening) each reinforcement must have a minimum 5.0 in.² cross sectional area. The length of each reinforcement is the height of the opening plus 2 × ¾ the width of the opening.

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 satisfy the requirements.





NOTES:

1. THE CROSS-SECTIONAL AREA OF EACH OF THE VERTICAL REINFORCEMENT MEMBERS MUST EQUAL OR EXCEED ONE-HALF OF THE CROSS-SECTION OF STACK MATERIAL REMOVED FOR THE OPENNING. *SEE* SECTION 2.7 STACK SELECTION EXAMPLE.
2. FOR MAXIMUM SIZE OF ACCESS DOORS AND REINFORCEMENT REQUIREMENTS *SEE* FIGURE 2-5

FIGURE 2-4 REINFORCEMENT OF STACK OPENING

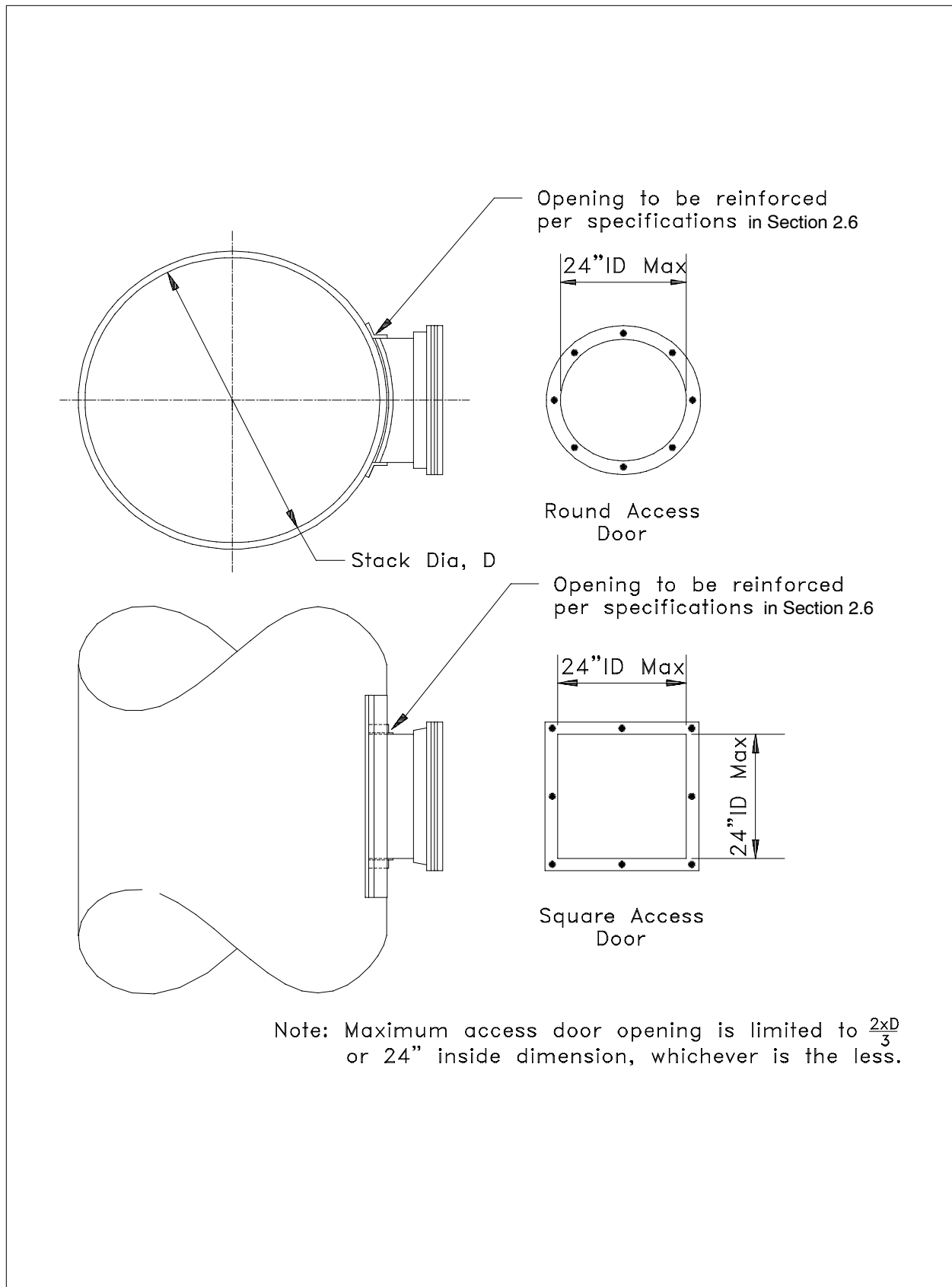


FIGURE 2-5 TYPICAL ACCESS DOOR INSTALLATION



2.8 INTERPOLATING MATERIAL SELECTION TABLES

Usually, interpolation of table values for an intermediate size stack can be safely done if the stack proportions are such that the stack is not threatened by wind resonance. That is frequently evidenced by there being no shaded columns to either side of the desired stack. Shaded columns represent designs controlled by a bending moment resulting from vortex shedding (resonant vibration) in excess of that resulting from wind gusts.

The same cannot be said, however, if the stack proportions are such that the presence of wind resonance is suspected. In this case, the safe thing is to seek engineering assistance and have the desired stack analyzed for resonant vibration. The basic criterion for deciding if resonance may be a problem is the magnitude of the critical velocity. If the critical velocity listed is relatively small (*i.e.*, below 25 mph), one can proceed with interpolation. But, as the critical velocity increases above this value, the risks inherent in the process of interpolating also increase until the critical velocity exceeds 72 mph when it is again safe to attempt interpolating the table data.

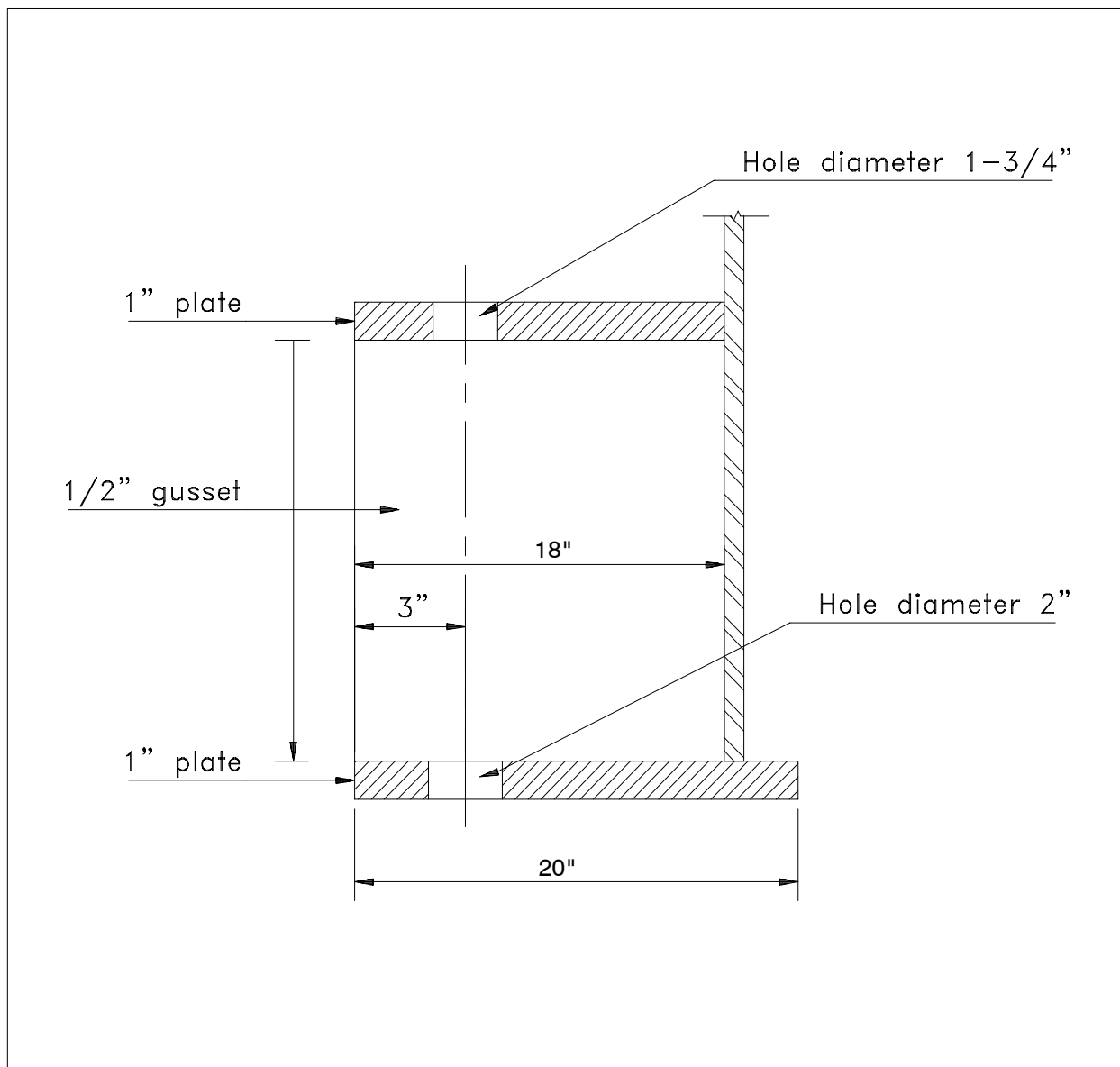


FIGURE 2-6 EXAMPLE STACK BASE CONFIGURATION AND DIMENSIONS

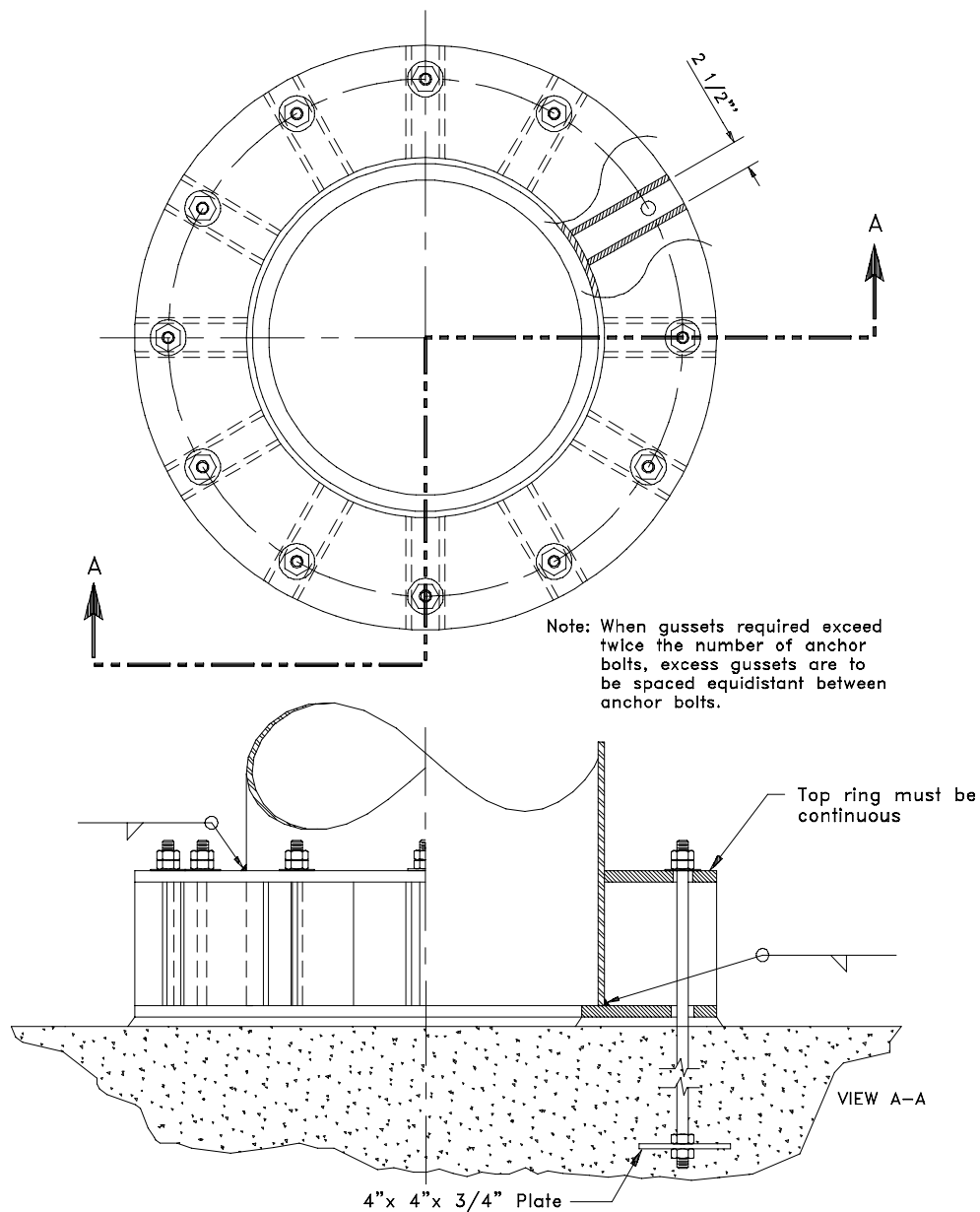


FIGURE 2-7 GUSSET PLACEMENT