Design Guide for Pile Caps

A Detailed Guide Providing a Comprehensive Overview of Pile Cap Design, Detailing, and Analysis Methodologies Meeting Current Codes and Standards.

First Edition

CRSI Concrete Reinforcing Steel Institute

2015

Founded in 1924, the Concrete Reinforcing Steel Institute (CRSI) is a technical institute and an ANSI-accredited Standards Developing Organization (SDO) that stands as the authoritative resource for information related to steel reinforced concrete construction. Serving the needs of engineers, architects and construction professionals, CRSI offers many industry-trusted technical publications, standards documents, design aids, reference materials and educational opportunities. CRSI Industry members include manufacturers, fabricators, material suppliers and placers of steel reinforcing bars and related products. Our Professional members are involved in the research, design, and construction of steel reinforced concrete. CRSI also has a broad Region Manager network that supports both members and industry professionals and creates awareness among the design/construction community through outreach activities. Together, they form a complete network of industry information and support.

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Foreword

The CRSI Design Handbook, 10th Edition, 2008, was the last comprehensive undertaking completed by CRSI. The *Pile Cap Design Guide* follows the long-established tradition of providing complete, tabulated designs of common reinforced concrete structural members. The tabulated designs are for normally encountered conditions, and are based on the latest applicable code provisions and materials specifications. All of the tabulated designs in this design guide are prepared in accordance with "Building Code Requirements for Structural Concrete (ACI 318-14)." The majority of the notations used in this design guide follows ACI 318-14. In those instances where other notation had to be introduced, symbols are defined or shown on figures.

Since the first CRSI Design Handbook in 1952, users of CRSI publications have been cooperative in suggesting to the Design Aids Committee and CRSI Staff, many improvements, clarifications and additional design short-cuts. This professional assistance is very helpful, and is appreciated. Comments regarding the *Pile Cap Design Guide* are welcome so that future Design Guides can be further improved. Please direct all comments to Mike Mota, Ph.D., P.E., SECB, F.SEI, F.ASCE, F.ACI, CRSI Vice President of Engineering.

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CHAPTER 1
Introduction

1.1 General

The *CRSI Pile Cap Design Guide* has been developed as a standalone publication intended to provide the practicing engineer with a detailed overview of pile cap design, detailing, and analysis methodologies that represent the current state of practice in the industry and meet the latest codes and standards including the *2012 International Building Code* (IBC) and ACI 318-14. The *CRSI Pile Cap Design Guide* is much more than an updated version of Chapter 13 of the *CRSI Design Handbook* (2008). When the *CRSI Design Handbook* (2008) was developed, pile allowable loads exceeding 200 tons were not common. Since that time, 16 inch and 18 inch HP sections with higher allowable loads have been developed and this *guide* has an expanded scope that includes pile allowable loads up to 400 tons. The use of larger and stronger piling (tagged "high load piling" in this guide) necessitates deeper pile caps with larger edge distances. In order to better understand the behavior of deep pile caps, a finite element study was performed and recommendations obtained from that study are presented here and incorporated into new details used for all pile caps utilizing pile allowable loads greater than 200 tons. On a separate note, lateral loads on pile caps are considered for the first time in a CRSI publication in this design guide. A complete design example for detailing a pile cap under combined vertical loading, lateral loading, and overturning is included in this guide. Tabulated designs are also provided for all CRSI considered pile cap configurations and a wide range of vertical loading, lateral loading, and overturning effects.

Although pile caps are an important structure, they are somewhat neglected in handbooks on structural steel design because they are constructed of reinforced concrete or in handbooks on reinforced concrete design in the range where steel piles are commonly used. The complex and often misunderstood load path fundamentals associated with pile caps and the fact that most pile caps are not open to visual inspection under service warrants a conservative design approach. Complete nonlinear finite element modeling of pile caps is not practical in routine design practice and applying geometry specific strut and tie design models for all pile caps can be unconservative when certain modes of failure control the pile cap's response. On the contrary, research performed during the development of this guide suggests that deeper pile caps associated with larger and stronger piling than was considered in the *CRSI Design Handbook* (2008) warrant some new steel details as presented in this guide.

Chapter 2 of this design guide provides an overview of load types considered and how these loads are appropriately combined to design pile caps. Chapter 3 provides an overview of assumptions used to determine the load distribution to piles when caps are subjected to different load cases. Chapter 4 presents pile cap configurations that are considered in the design guide, dimensioning requirements, and the overall recommended layout of steel reinforcement in the pile cap. Chapter 5 and Chapter 6 present pile cap design procedures for vertical and lateral/overturning loads, respectively. Chapter 7 is a special chapter devoted to seismic design of pile caps and Chapter 8 includes practical pile cap design examples including complete manual solutions for vertical and lateral load situations. Chapter 9 presents a description of the tabulated pile cap designs for both vertical loads (based on Chapter 5 methodologies) and combined, vertical, lateral, and overturning actions (based on Chapter 6 methodologies). The design tables are in Section T. The appendices are also replete with practical information. Appendix A presents detailed derivations for several simplified design equations presented in the design guide. Column-to-pile cap and pile-to-pile cap connection details are discussed in Appendix B and C, respectively.

In common with the *CRSI Design Handbook* (2008), this design guide includes simple, easy to use design tables for vertically loaded pile caps. New to this design guide are expanded tables to include piles with larger allowable loads and the inclusion of tabulated designs that also include the effects of lateral loads and overturning. Also new to this publication are downloadable Excel spreadsheets that can be used to design pile caps under different assumptions than those used to generate the tabulated designs presented in Appendix A in this publication.

CHAPTER 2

Loads

2.1 General

The *CRSI Pile Cap Design Guide* has been developed to aid the engineer when designing pile caps that are loaded by columns supported directly at the centroid of the pile cap. To correctly use this guide, all loads must be applied to the pile cap at the column-to-pile cap interface. Technically speaking, these loads may be any combination of gravity loads (i.e., dead, live, or live roof) or environmental loads (i.e., seismic, wind, rain, or snow), but for simplicity all tabulated designs and example problems presented in this guide consider only the effects of dead loads, live loads, wind loads, and seismic loads. Since deep foundations are more commonly used for multistory buildings and since load combinations specified in Chapter 2 of ASCE/SEI 7-10 minimize, at the foundation level, the effect of live roof, snow, and rain loads in combination with floor live loads in multi-story buildings, the exclusion of rain, snow, and live roof loads seems justified. It should be noted, however, that in cases where the designer desires to include the effects of such loads, these additional loads can conservatively be considered as live loads without changing the methodologies presented herein.

Since allowable stress design (ASD) is commonly used by geotechnical engineers and Load and Resistance Factor Design (LRFD) is used almost exclusively by engineers designing reinforced concrete pile caps, both nominal and factored loads are presented throughout this design guide. For example, when considering the overall allowable pile load (ASD) as provided by the geotechnical engineer (i.e., as a result of skin friction and/or end bearing), dead, live, wind, and seismic loads will be presented separately as applied to the pile cap. On the contrary, when designing the reinforced concrete pile cap, only the factored axial force P_u, shear force V_u, and bending moment M_u at the bottom of the column (i.e., column cap interface) will be required for pile cap design. The reader should note that the subscript "u" denotes ultimate and indicates that the load provided has already been factored using the appropriate LRFD Load combination.

Nominal dead loads D are determined in accordance with Section 1606 of the 2012 IBC and Section 3.1 of ASCE/SEI 7-10. Nominal floor live loads L_{floor} are determined in accordance with Section 1607 of the 2012 IBC and Chapter 4 of ASCE/SEI 7-10. Dead and live loads are true nominal loads since they require a load factor greater than 1.0 to reach their ultimate level. Wind loads W are determined in accordance with Section 1609 of the 2012 IBC and Chapters 26 through 31 of ASCE/SEI 7-10. Seismic loads E are determined in accordance with Section 1613 of the 2012 IBC and Chapters 11 and 12 of ASCE/SEI 7-10. Wind and seismic loads, as defined, are not nominal loads since they are already at the ultimate level and utilize a load factor of 1.0 for LRFD when maximizing their load effect.

Deep foundation elements must be designed to resist LRFD and ASD load combinations, as applicable, in accordance with IBC Section 1605.2 and IBC Section 1605.3, respectively. These load combinations can be simplified by considering only the effects of dead, live, wind, and seismic loads as discussed above and presented below.

LRFD Load Combinations (considering only D, L, W, and E):

$1.4D$ (IBC Eq. 16-1)

$1.2D + 1.6L_{floor}$ (IBC Eq. 16-2)

$1.2D + (f_1 L_{floor}$ or $0.5W)$ (IBC Eq. 16-3)

$1.2D + 1.0W + f_1 L_{floor}$ (IBC Eq. 16-4)

$1.2D + 1.0E + f_1 L_{floor}$ (IBC Eq. 16-5)

$0.9D + 1.0W$ (IBC Eq. 16-6)

$0.9D + 1.0E$ (IBC Eq. 16-7)

Note that in the combinations above, f_1 is 1.0 for areas of public assembly, live loads exceeding 100 psf, and parking garages. For all other cases f_1 is taken as 0.5.

Further simplification of the LRFD load combinations above can be made by noting that in the absence of seismic and wind loads, only the load combination $1.2D + 1.6L_{floor}$ need be considered. *In this guide, as consistent with the CRSI Design Handbook (2008), a conservative LRFD load combination* of $1.6(D + L_{floor})$ *will be used for all tabulated designs and worked out problems (note that a strength reduction factor for pile cap shear of* 0.85 *is also used throughout as justified below). Similarly, when considering seismic and wind loads in combination with gravity loads, a conservative LRFD load combination of* $1.2(D + L_{floor}) + 1.0(E$ or $W)$ *will be used for all tabulated designs and worked out problems.*

It should be noted by the reader that the *CRSI Handbook* (2008) pile cap provisions were based on ACI 318-99 and developed utilizing an LRFD load combination of $1.6(D + L_{floor})$ in combination with strength reduction factors for shear and bending of 0.85 and 0.90, respectively. The 1.6 load factor was an assumed reasonable average of the ACI 318-99 load factors 1.4 and 1.7, for dead load and live load, respectively. ACI 318-14 utilizes the load factors 1.2 and 1.6, for dead load and live load, respectively, and strength reduction factors for shear and bending of 0.75 and 0.90, respectively. Hence, an ACI 318-14 reasonable load combination of $1.4(D + L_{floor})$ in combination with a strength reduction factor for shear of 0.75 results in an approximately equivalent factor of safety against shear failure. Further noting that the CRSI considered pile cap configurations usually result in reinforcement ratios at or near minimum ACI 318-14 permitted steel ratios, both codes result in nearly equivalent designs. As such, and in order to maintain an equivalent factor of safety against pile cap failure to that which was used in the development of the *CRSI Handbook* (2008), this design guide, including the tabulated designs, are based on an LRFD load combination of $1.6(D + L_{floor})$ in combination with strength reduction factors for shear and bending of 0.85 and 0.90, respectively. Designers can alter the factor of safety against pile cap failure using the associated design spreadsheets. In a special version of the design spreadsheet, designers can specify load factors applicable to $D + L_{floor}$ to account for project specific situations or to account for load factors associated with vertical load types other than dead and live.

ASD Load Combinations (considering only D, L, W, and E):

$$D \tag{IBC Eq. 16-8}$$

$$D + L_{floor} \tag{IBC Eq. 16-9}$$

$$D + (0.6W \text{ or } 0.7E) \tag{IBC Eq. 16-12}$$

$$D + 0.75(0.6W) + 0.75L_{floor} \tag{IBC Eq. 16-13}$$

$$D + 0.75(0.7E) + 0.75L_{floor} \tag{IBC Eq. 16-14}$$

$$0.6D + 0.6W \tag{IBC Eq. 16-15}$$

$$0.6D + F + 0.7\mathrm{E} + H \tag{IBC Eq. 16-16}$$

Further simplification of the ASD load combinations above can be made by noting that in the absence of seismic and wind loads, only the load combination $D + L_{floor}$ need be considered. *In this guide, as consistent with the CRSI Design Handbook (2008), a conservative ASD load combination of* $D + L_{floor}$ *will be used for all tabulated designs and worked out problems. Similarly, when considering seismic and wind loads in combination with gravity loads, a conservative ASD load combination of* $(D + L_{floor}) + 0.53(E \text{ or } W)$ *will be used for all tabulated designs and worked out problems.*

Special load combinations are provided in ASCE/SEI 7-10 Section 12.4.2.3 for applications when the seismic load is considered:

LRFD Seismic Load Combinations (considering only D, L_{floor}, W, and E):

$$(1.2 + 0.2S_{DS})D + \rho Q_E + L_{floor}$$

$$(0.9 - 0.2S_{DS})D + \rho Q_E$$

$$(1.2 + 0.2S_{DS})D + \Omega_0 Q_E + L_{floor}$$

$$(0.9 - 0.2S_{DS})D + \Omega_0 Q_E$$

In the expressions above, S_{DS} is the design spectral response acceleration parameter at short periods (ASCE/SEI 7-10 Section 11.4.4), ρ is the building's redundancy factor (ASCE/SEI 7-10 Section 12.3.4), Q_E is the horizontal seismic force effect, and Ω_0 is the overstrength factor associated with the lateral force resisting system. The load factor on L_{floor} in the LRFD seismic load combinations is reduced to 0.5 for all occupancies with a design uniform floor live load less than or equal to 100 psf except for garages and public assembly areas.

ASD Seismic Load Combinations (considering only D, L_{floor}, W, and E):

$$(1.0 + 0.14S_{DS})D + 0.7\rho Q_E$$

$$(1.0 + 0.10S_{DS})D + 0.525\rho Q_E + 0.75L_{floor}$$

$$(0.6 - 0.14S_{DS})D + 0.7\rho Q_E$$

$$(1.0 + 0.14S_{DS})D + 0.7\Omega_0 Q_E$$

$$(1.0 + 0.10S_{DS})D + 0.525\Omega_0 Q_E + 0.75L_{floor}$$

$$(0.6 - 0.14S_{DS})D + 0.7\Omega_0 Q_E$$

CHAPTER 3
Pile Cap Behavior

3.1 General

The *CRSI Pile Cap Design Guide* can be used to design and detail pile caps that are loaded by columns supported directly at the centroid of the pile cap. Column axial loads, shear demands, and bending moments can be applied individually or as combined actions. Column loads should be applied to the pile caps as factored loads using load combinations as specified in Chapter 2 of ASCE/SEI 7-10 and discussed in Chapter 2 of this Guide. To best illustrate how pile cap behavior is modeled in this Design Guide, two general load cases should be considered. Load Case I is for pile caps subjected to vertical loading in the absence of lateral load. Load Case II includes column applied axial (vertical load), shear, and moment demands. Chapters 5 and 6 of this Design Guide present pile cap design procedures for pile caps subjected to Load Case I and Load Case II, respectively.

3.2 Load Case I: Vertical Load $D + L_{floor}$

Figure 3.1 shows the special case pile cap loading that consists of only dead load and live load as applied by the supported column (note that in the figure, the load is factored as discussed above and that all piles are identical in size). Load Case I was the only case considered in the previous *CRSI Design Handbook* (2008). For this case and as shown in the figure, the Design Guide assumes that all piles resist an equal portion of the applied vertical load. This may seem counterintuitive and unconservative, but keep in mind that the piles are not rigid vertical supports. In fact, they have a stiffness that is related to (a) the soil t-z or vertical spring stiffness and (b) the axial stiffness of the pile as defined by the AE/L_{pile}, where A is the pile cross-sectional area, E is the pile modulus of elasticity, and L_{pile} is the overall pile length.

During the development of this Design Guide, a finite element study of the global response behavior of pile caps under vertical loading was also conducted and a major conclusion of the associated study was that the assumption that all piles share load equally is appropriate for the pile cap configurations considered in this Design Guide. For example, for the largest pile cap configuration considered in this Design Guide (i.e., 30 piles), an assumed pile cap thickness of 59 inches, and reasonable pile stiffness assumptions (i.e., 40 ft long 10 in square prestressed piles bearing on rock), the two piles closest to the column resist approximately $^{1}/_{27}$ of the overall column demand, the 4 corner piles resist approximately $^{1}/_{33}$ of the overall column demand, and the other 24 piles each resist between $^{1}/_{29}$ and $^{1}/_{31}$ of the overall column demand depending upon how close each pile is to the column centroid in plan. For a truly rigid pile cap supported by piles that are flexible relative to an assumed infinite pile cap stiffness, each pile would resist exactly $^{1}/_{30}$ of the applied vertical loading, irrespective of its location in plan relative to the column centroid. To advance this concept, Table 3.1 presents the approximate demand resisted by the piles mentioned above as a function of pile spring stiffness (k/in.). In the table, P_{center} represents the demand on the two center most piles (per pile) as a fraction of the overall vertical column demand, P_{corner} represents the demand on the four corner piles (per pile) as a fraction of the overall vertical column demand, and P_{other} represents the general range of demands on the other 24 piles as a fraction of the overall vertical column demand.

Table 3.1. Example pile stiffness (assumed 59 inch deep pile cap)

Vertical Pile Stiffness (*k*/in.)	P_{center} (2 piles)	P_{corner} (4 piles)	P_{other} (24 piles)
100	$^{1}/_{30}$	$^{1}/_{30}$	$^{1}/_{30}$
400	$^{1}/_{28}$	$^{1}/_{32}$	$^{1}/_{30.5}$ - $^{1}/_{29.5}$
800	$^{1}/_{27}$	$^{1}/_{33}$	$^{1}/_{31}$ - $^{1}/_{29}$
1,200	$^{1}/_{25}$	$^{1}/_{34}$	$^{1}/_{32}$ - $^{1}/_{28}$
Rigid	$^{1}/_{7}$	$^{1}/_{82}$ (Tension)	$^{1}/_{80}$ - $^{1}/_{10}$

Note that for the example 30 pile configuration considered above with the piles modeled as rigid supports (i.e., roller supports), the piles closest to the column resist the majority of the loading and the corner piles actually go into tension as the corners of the pile cap tend to try to lift upwards. Practically speaking, such behavior does not occur for the caps considered in this Guide. The relative stiffness of the piles as compared to the cap stiffness is such that the assumption of uniform load distribution to the piles is appropriate. However, the reader should verify this assumption in cases where relatively stiff piles are used in combination with relatively thin pile caps, particularly when recommended pile cap detailing procedures presented in Chapter 4 of this Guide are not utilized by the design engineer.

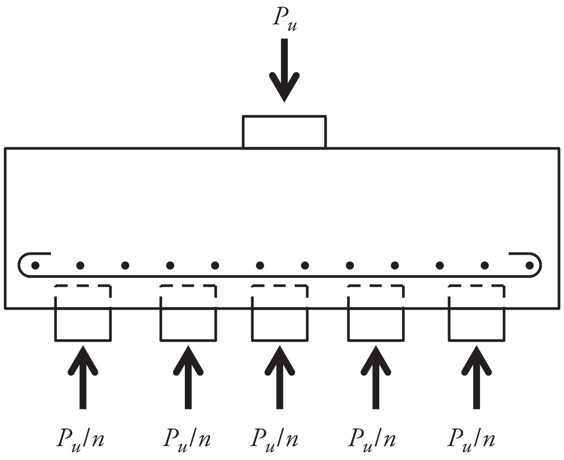

Fig. 3.1. Pile cap with n piles resisting only vertical load.

3.3 Load Case II: Combined Axial, Shear, and Moment Demand

Figure 3.2 shows the more general case, or Load Case II, pile cap loading that consists of combined axial load, shear, and moment as applied by the supported column (note that in the figure, all loads contain the subscript "u" and are factored). Building upon the relatively rigid pile conclusion reached in the Load Case I section above, and in accordance with standard practice, the pile caps in this Guide are modeled as a relatively rigid elements in response to overturning and the top of the piles are modeled as pin connected such that only axial load and shear are transferred from the pile cap to the top of the pile. The piles resist overturning via increased and decreased axial forces depending on their position relative to the pile cap centroid. The shear demand in each pile may be assumed equal in many cases, but the designer should consider other assumptions when pile axial forces result in net tension. Finally, it should be noted that the vertical demand P_u may include significant effects of seismic or wind as caused by overturning making the aforementioned average load factor of 1.6 overly conservative for pile cap design in some cases.

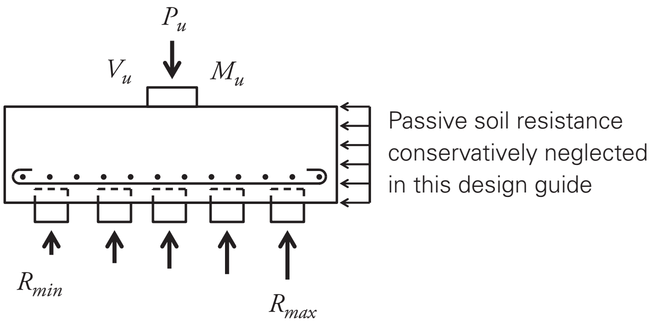

Fig. 3.2 Pile cap resisting column applied axial, shear, and bending moment. Pile head assumed pinned.

CHAPTER 4
Dimensioning and Detailing Pile Caps

4.1 General

In the previous chapter, the pile cap was considered to be a relatively rigid element that distributes vertical and lateral loading and the effects of overturning to the supporting piles. In this and subsequent chapters, adhering to the definition provided in ACI 318 Chapter 13, the pile cap is considered to be a reinforced concrete structural slab supported by piles (see ACI Section R13.2.6.3) which distributes a column's loading to a group of individual piles. The design procedures presented in Chapters 5 and 6 of this guide are based upon the use of a square reinforced concrete column of at least the minimum size indicated or a structural steel column on a square steel base plate such that the section half-way between the column face and the edge of the base plate is at least equivalent to the minimum required column size. Designs based on this assumption are adequate (and conservative) for rectangular columns or steel base plates if the short side or section is at least equal to the minimum tabulated column size as presented in the design tables of this design guide. Columns must be located at the centroid of the pile groups.

Dimensioning and detailing provisions for pile caps as presented herein are based primarily on the 2012 IBC, ACI 318-14, pile cap research results, and some level of engineering judgment. Design procedures used to design pile caps as presented in Chapters 5 and 6 of this guide are based primarily on ACI 318-14. Although hooked bars are used for the tabulated designs presented in this guide, headed bars, which first appeared in the ACI 318-08 Code, are recognized as a viable alternative to hooked bars and may be substituted for hooked bar details when justified and appropriately detailed by the design engineer.

4.2 General Overview of ACI Chapter 15 Provisions as Applied to Pile Caps

ACI 318-14 Chapter 13 provisions are applicable to isolated footings, combined footings, mat foundations, and pile caps. Only those provisions specifically applicable to pile cap foundations are presented in this section. Note that per ACI Section 13.4.2.1 the minimum permitted pile cap effective depth is 12 inches.

ACI 13.2.6.1[1] presents load and reaction requirements for modeling demands on pile caps. As discussed in the previous chapters of this guide, the pile cap itself is to be designed to resist factored loads applied from the supported column and pile support reactions that develop at the supporting pile locations. Note that ACI 13.4.2.2 permits pile reactions to be applied to the pile cap as point loads at the pile centers. It is also required that unfactored loading be used to determine permissible pile capacity (ACI 13.4.1.1).

Since some columns are round and others are square, rectangular, or other regular-polygon shaped, ACI 13.2.7.3 permits an equal area approach for determining critical sections for moment and shear and for determining if appropriate lengths are available for developing reinforcing steel in the footing. In all cases, ACI permits the cross-sectional area of the column to be replaced with an equivalent square cross-sectional area. A similar approach is also used in this guide for the piles. Some piles are round (i.e., round concrete piles, timber piles, and steel pipe piles) while other piles are more or less square shaped (i.e., square concrete piles and HP shapes that include the boundary concrete plug in bearing). Note that research performed on HP shapes used as piles has consistently shown (see for Example AISI, 1982) that so long as some minimum embedment into the pile cap is achieved, the concrete contained in the overall boundary of the HP shape (i.e., d times b_f) adheres to the pile and aids in pile bearing distribution just above the pile.

ACI 13.2.6.4 contains moment provisions for pile caps and considers pile caps, with the exception of the two-pile pile cap, two-way flexural members. The internal bending moment in a pile cap must be calculated across the entire width of the pile cap using a vertical plane or cut. All factored pile reactions on one side of the cut should be used to determine the maximum moment acting on the pile cap. The maximum moment need not be taken directly under the center of the column. ACI 13.2.7 permits the vertical cut to be taken at the face of a concrete column or halfway between the face of a steel column and the edge of the steel base plate.

For pile caps that are rectangular in plan, which encompasses most pile caps considered in this guide, ACI 13.3.3.3 requires that in the long direction, longitudinal reinforcement be distributed at a uniform spacing across the width of the cap. For reinforcing bars spanning the short direction of the cap, a fraction γ_s of the overall required area of steel A_s, or modified area $\gamma_s A_s$, must be provided over the center bandwidth of the pile cap while the remaining portion of the steel $(1 - \gamma_s)A_s$ must be distributed

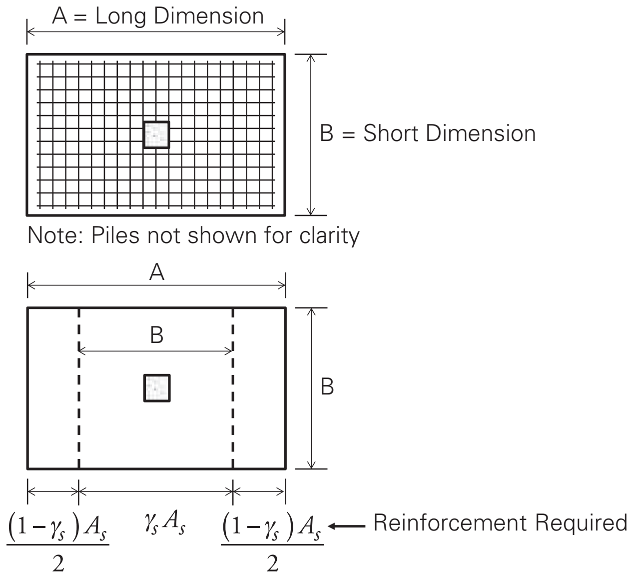

Fig. 4.1 Steel reinforcement requirements for bars running in the short direction of the pile cap per ACI 15.4.4.2.

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[1] *All references in this Design Guide to "Building Code Requirements for Structural Concrete (ACI 318-14)" are given as "ACI" followed by the appropriate Section number.*

on opposite sides of this center ban. Figure 4.1 illustrates the requirements of ACI 13.3.3.3.

The larger decimal percentage of steel required for the band which is centered directly under the column is defined by ACI Equation 13.3.3.3:

$$\gamma_s = \frac{2}{(\beta + 1)}$$

where $\beta = A/B$ or the ratio of the long to short side dimension of the footing.

Rather than having different bands of reinforcement in the short direction, it is preferred to have a uniform distribution of steel in both directions which requires an adjustment in the overall amount of reinforcement required in the short direction.

Note that the reinforcement per unit width for the steel in the center band is $\gamma_s A_s/B$ and the reinforcement per unit width for the steel outside the center band is $(1 - \gamma_s)A_s/(A - B)$.

Letting the adjustment factor for the reinforcement outside the center band be "X" and setting equal the reinforcement per unit width inside and outside the center band:

$$\frac{X(1-\gamma_s)A_s}{(A-B)} = \frac{\gamma_s A_s}{B}$$

Solving for X:

$$X = \frac{(A-B)\gamma_s A_s}{(1-\gamma_s)BA_s} = \frac{(A-B)\gamma_s}{(1-\gamma_s)B}$$

Substitution can then be used:

$$(1-\gamma_s) = 1 - \frac{2}{(\beta+1)} = \frac{B+1-2}{(\beta+1)} = \frac{(\beta-1)}{(\beta+1)}$$

and therefore,

$$X = \frac{(A-B)2}{(\beta+1)}\frac{(\beta+1)}{(\beta-1)}\frac{1}{B} = \frac{2(A-B)}{B(\beta-1)}$$

Using substitution once again:

$$(\beta-1) = \frac{A}{B} - 1 = \frac{(A-B)}{B}$$

and

$$X = \frac{2(A-B)}{B}\frac{B}{(A-B)} = 2$$

Therefore, the reinforcement outside the band must be doubled in order for the reinforcement to be uniform across the width of the footing. Or, stated another way, the requirements of Section 13.3.3.3 of ACI 318-14 results in a concentration of reinforcement inside the band that is double the reinforcement outside the band.

The total amount of reinforcement required in the short direction can then be determined as follows:

$$A_{s,final} = X(1 - \gamma_s)A_s + \gamma_s A_s = 2(1 - \gamma_s)A_s + \gamma_s A_s$$

$$A_{s,final} = 2A_s - 2\gamma_s A_s + \gamma_s A_s = 2A_s - \gamma_s A_s$$

$$A_{s,final} = 2A_s - \frac{2}{(\beta+1)}A_s = \frac{2A_s(\beta+1) - 2A_s}{(\beta+1)}$$

$$A_{s,final} = \frac{2A_s\beta + 2A_s - 2A_s}{(\beta+1)} = \frac{2\beta}{(\beta+1)}A_s$$

In summary, the initial amount of reinforcement required in the short direction, A_S, must be increased by multiplying it by the ratio $2\beta/(\beta + 1)$ so that a uniform arrangement of reinforcement can be used across the entire width of the footing.

ACI 13.4.2.3 contains shear provisions for pile caps. Shear strength determination involves both one-way and two-way shear limit states as presented in ACI Section 13.4. These provisions are quite complex and will be presented in detail in Chapter 5 of this design guide. For concrete columns, the maximum shear demand is taken a specified distance from the face of the column. For steel columns, the maximum shear demand is taken a specified distance from a location halfway between the face of a steel column and the edge of the steel base plate. A similar analysis is required around piles since local one-way and two-way shear failures in the proximity of the piling can occur. These limit states are also discussed in detail in Chapter 5 of this design guide.

ACI Section 13.4.2.5 permits the use of traditional shear analysis and design procedures for pile caps of any thickness and also allows, with certain limitations, the use of strut-and-tie methods (ACI 318 Chapter 23) in special "deep cap" scenarios when the cap thickness measured from the top of the cap to the top of the pile is more than 0.5 times the distance in plan from the centerline of the column to the centerline of the nearest pile. Based on conclusions made using finite element results obtained during the development of this design guide (see Fig. 4.2 for example results) and an examination of design results obtained for typical pile caps using the strut-and-tie method, it was decided that strut-and-tie methods would not be formally presented in this design guide. On the contrary, the finite element results do justify the use of special reinforcing details and a slightly increased edge distance, E, measured from the centerline of the pile to the adjacent concrete pile cap edge when high load piling is used. In this guide, the term "high load pile" refers to any pile with an allowable pile load exceeding 200 tons. The intent of the new high load pile detailing provisions presented in this design guide is to standardize the analysis and design provisions for all pile caps while requiring additional details as justified for pile caps that are deeper than those considered in the previous *CRSI Design Handbook* (2008).

ACI Section 13.4.2.5 provides special provisions for determining which piles should be considered as contributing to the overall shear demand when considering one-way and two-way shear adjacent to the column. However, ACI Commentary R13.4.2.5 refers the reader to the *CRSI Design Handbook* (2008) which contains special provisions and guidance that

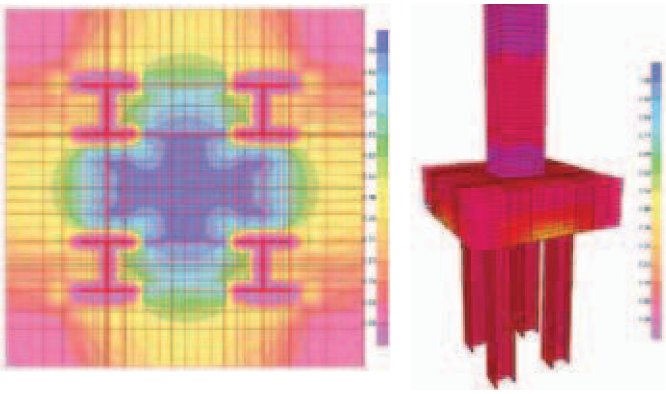


Fig. 4.2 Sample results (stress in ksi) obtained from finite element study – For this example: Four 14 inch HPs, 14 inch square concrete column, E = 27 inches, Load = 400 kips to each pile. Stresses shown are principal tensile stresses.

consider upper limits on the shear strength adjacent to the column face. The same procedures presented in the *CRSI Design Handbook* (2008) are used in this design guide and will be presented in detail in Chapter 5.

Finally ACI Section 13.2.8 requires that all pile caps contain reinforcement in each direction that is fully developed from the location of maximum moment in the pile cap to the termination point (assumed 3 inches short of the pile cap edge) unless a hook or mechanical device is used to provide bar development over a shorter length. Tables 4.1, 4.2 and 4.3 provide development lengths for straight bars, bars with hooks, and headed bars, respectively, for typical values of f'_c used in pile caps.

Table 4.1. Tension development lengths (Class A) for straight bars in pile caps.

Bar Size	f'_c = 3,000 psi	f'_c = 4,000 psi	f'_c = 5,000 psi
#3	12	12	12
#4	13	12	12
#5	17	15	13
#6	20	17	16
#7	29	25	23
#8	33	29	26
#9	41	36	32
#10	51	44	39
#11	61	53	47
#14	83	72	64

Note: Assumes center to center spacing of longitudinal bars exceeds 4 inches plus d_b *per ACI Section 25.4.2.3.*

Table 4.2. Tension development lengths for standard hooks in pile caps.

Bar Size	f'_c = 3,000 psi	f'_c = 4,000 psi	f'_c = 5,000 psi
#3	7	6	6
#4	8	7	7
#5	10	9	8
#6	12	11	10
#7	14	12	11
#8	16	14	12
#9	18	16	14
#10	20	17	16
#11	22	19	17
#14	26	23	21

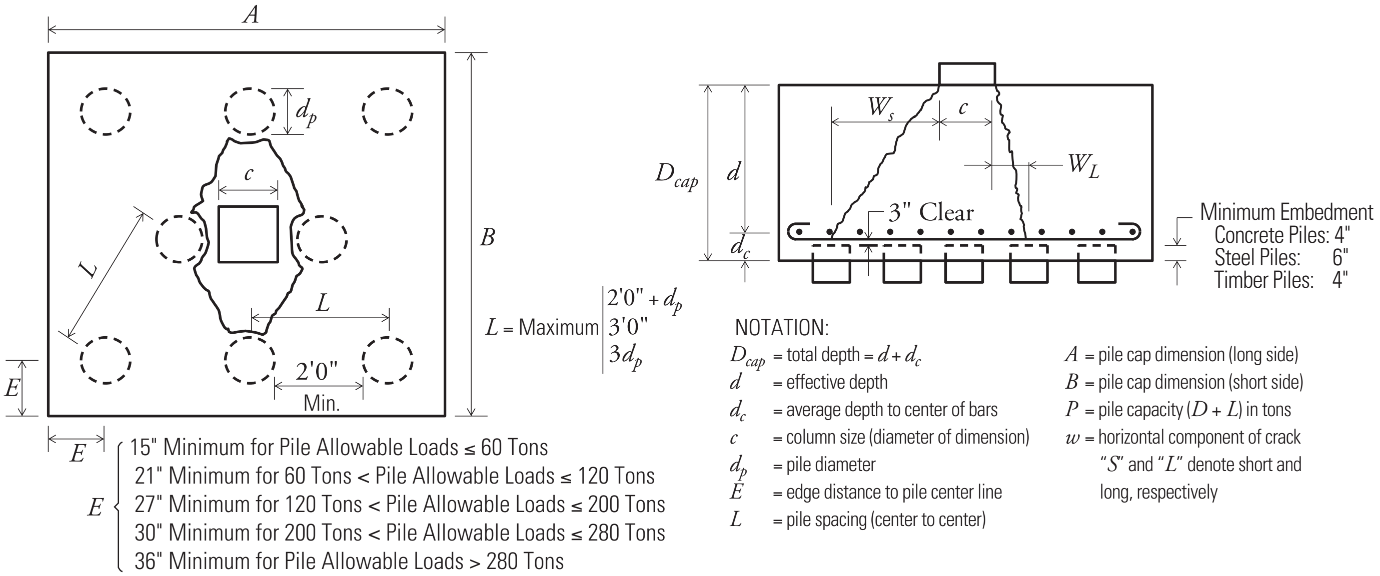
Note: Includes 0.7 reduction factor for cover per ACI Section 25.4.3.2). Note that although ACI does not explicitly permit the reduction for #14 hooked bars, it is believed that its use is justified in conjunction with other conservative assumptions made in the design process. Other options for reducing the required development length include using higher strength steel, providing equivalent steel areas using smaller bars, and using higher strength concrete.

Table 4.3. Tension development lengths for headed bars in pile caps.

Bar Size	f'_c = 3,000 psi	f'_c = 4,000 psi	f'_c = 5,000 psi
#3	7	6	6
#4	9	8	7
#5	11	10	9
#6	13	12	10
#7	16	14	12
#8	18	15	14
#9	20	17	16
#10	23	20	18
#11	25	22	19

Note: Per ACI Section 12.6.1, headed bar sizes larger than #11 are not permitted for development.

Fig. 4.3 defines the general geometry used in this guide for all pile caps.



E
- 15" Minimum for Pile Allowable Loads ≤ 60 Tons
- 21" Minimum for 60 Tons < Pile Allowable Loads ≤ 120 Tons
- 27" Minimum for 120 Tons < Pile Allowable Loads ≤ 200 Tons
- 30" Minimum for 200 Tons < Pile Allowable Loads ≤ 280 Tons
- 36" Minimum for Pile Allowable Loads > 280 Tons

NOTATION:

D_{cap} = total depth = $d + d_c$
d = effective depth
d_c = average depth to center of bars
c = column size (diameter of dimension)
d_p = pile diameter
E = edge distance to pile center line
L = pile spacing (center to center)

A = pile cap dimension (long side)
B = pile cap dimension (short side)
P = pile capacity ($D + L$) in tons
w = horizontal component of crack "S" and "L" denote short and long, respectively

Fig. 4.3 Typical pile cap nomenclature, dimensions, and section details.

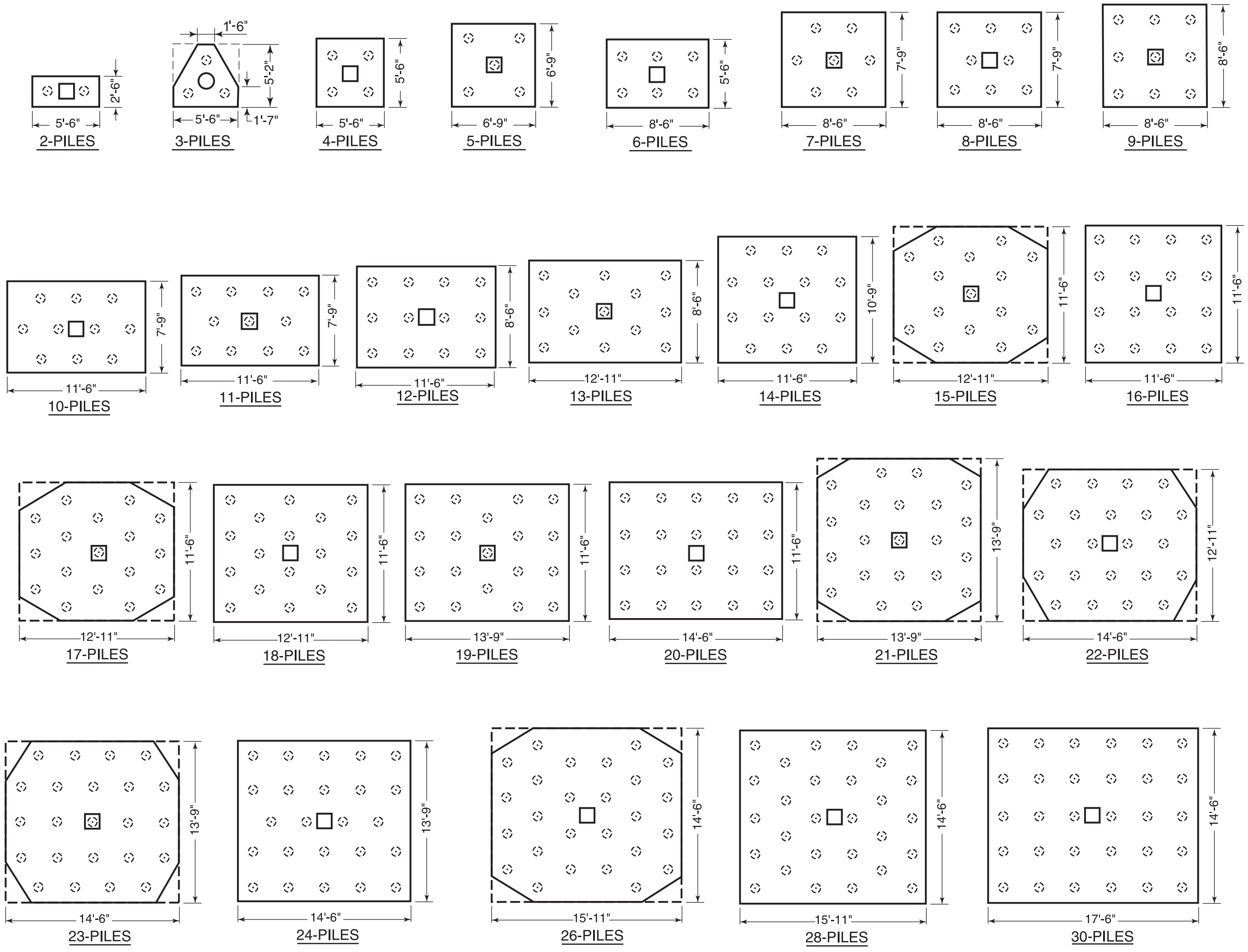


Fig. 4.4 Arrangement of piles and minimum plan dimensions of pile caps.

4.3 Other Pile Cap Requirements and Recommendations as Used in this Design Guide

Concrete Strength: The design procedures presented in this guide are applicable to any value of f'_c. However, it should be noted that 3,000 and 4,000 psi concrete are commonly used for foundation work. Due to space limitations, tabulated designs presented in this design guide are shown for only the two most commonly used concrete compressive strengths, $f'_c = 3{,}000$ and $f'_c = 4{,}000$ psi. Since shear strength controls depth, the savings in concrete and formwork for higher values of f'_c would not ordinarily offset the higher concrete cost and added reinforcing steel required for a lesser depth. If minimum depth is itself an important cost consideration, then a higher strength concrete may be desirable. Such designs could not be adapted from tabulated designs presented in this design guide but may be designed as special cases using the spreadsheets associated with the design guide.

Pile Embedment: A minimum embedment of 6 inches has been established as good practice with structural steel shapes to avoid the use of cover plates for bearing. When precast concrete piles or timber piles are used, a minimum embedment of 4 inches is usually sufficient. Since the design depth is unaffected, tabulated designs presented in this design guide are appropriate for all pile types such that if only 4 inches of embedment is required, 2 inches can be deducted from the tabulated thickness, and the tabulated concrete volume can be reduced accordingly.

Concrete Cover: A concrete cover (measured clear between the top of the pile and the nearest reinforcing bars) is assumed to be 3 inches in this design guide.

Pile Spacing: The minimum recommended pile spacing, measured from center of pile to center of pile, is the largest of three values: (a) three times the pile dimension, (b) one pile dimension plus 2 ft which provides approximately 2 ft clear between adjacent piles, and 3 ft. The three times the pile dimension value will control for larger piles and this value is intended to ensure that the need to consider group effects under axial loading is unlikely (see IBC Section 1810.2.5). Although not directly considered in this design guide, the designer should note that prescriptively, group reduction factors may be applicable to lateral loading when the center-to-center pile spacing is less than 8 pile dimensions. Also, although this design guide is applicable to pile caps supported by auger cast piles, the center-to-center spacing of auger cast piles must not be less than 6 times the pile diameter (IBC Section 1810.4.8).

When utilizing the tabulated designs, note that if a closer pile spacing than the minimum recommended value is used, the tabulated designs for thickness and reinforcing bars are generally conservative. The condition of overlapping critical shear sections for a pair of piles should be investigated and will be presented in detail in Chapter 5 of this guide, but this case should not be critical for the tabulated standard designs as the allowable shear strength v_c will increase if the angle of the potential crack to the vertical, α is less than 45° (see ACI Commentary R13.2.7.2).

Patterns: Patterns for 2-pile to 30-pile pile cap layouts are included in this guide and the associated Excel spreadsheets. See Fig. 4.4 for the appropriate arrangement of piles and minimum plan dimensions used for the different pile caps.

Edge Distance: To prevent vertical edge splitting, the minimum edge distance, E, to the center of piles is 15 inches for pile allowable load $P \leq 60$ tons, 21 inches for 60 tons $< P \leq 120$ tons, 27 inches for 120 tons $< P \leq 200$ tons, 30 inches for 200 tons $< P \leq 280$ tons, and 36 inches for $P > 280$ tons. A minimum clear edge distance, $E' = E - 3$ inches ≥ 9 inches, is required for (hooked or headed) end anchorage. Note that some tabulated designs show dimensions on the line below. These dimensions are for use with "clipped corners" to save concrete as an option. For example, the 3-pile cap shown in Fig. 4.4 would be dimensioned in the tabulated designs as:

Long A	Short B	
5'-6"	5'-2"	(first line)
1'-6"	1'-7"	(second line)

In other words, the "clipped corner" dimensions are the truncated dimensions of the pile cap with the corners removed.

Pile Allowable Load: Pile allowable load is presented in this guide in tons as is usually done in accepted practice. The range considered, 40 tons to 400 tons, covers the usual range for precast concrete, structural steel, and timber piles.

Flexural Reinforcement: All tabulated designs are based on the use of Grade 60 ($f_y = 60{,}000$ psi) reinforcing bars. Areas of required flexural reinforcement can be based on an average effective depth, $d = D_{cap} - d_c$, where D_{cap} = total pile cap depth, and d_c is assumed to be 10 inches for structural steel piles, or 8 inches for concrete and timber piles. The requirements for minimum areas of flexural reinforcement (ACI 9.6.1 and 24.4) are satisfied by the following conservative interpretation, where A_s is the calculated area of reinforcement required for flexure:

(1) if $A_s \geq \eta bd$, use A_s

(2) if $A_s < \eta bd \leq 4/3A_s$, use ηbd

(3) if $0.0018bD_{cap} \leq 4/3A_s < \eta bd$, use $4/3A_s$

(4) if $4/3A_s < 0.0018bD_{cap} \leq \eta bd$, use $0.0018bD_{cap}$

In the expressions above, η is the maximum of (a) $200/f_y = 0.00333$ and (b) $3\sqrt{f'_c}/f_y$

For 2-pile pile caps only, note that with no bending in the short direction, $0.0018bD_{cap}$ should be provided as minimum steel for the short bars. For all other caps and as previously discussed, flexural reinforcement areas in the short direction for rectangular pile caps have been increased in this guide to permit the use of uniform bar spacings which help avoid errors in field placing while still conforming to ACI 13.3.3.3.

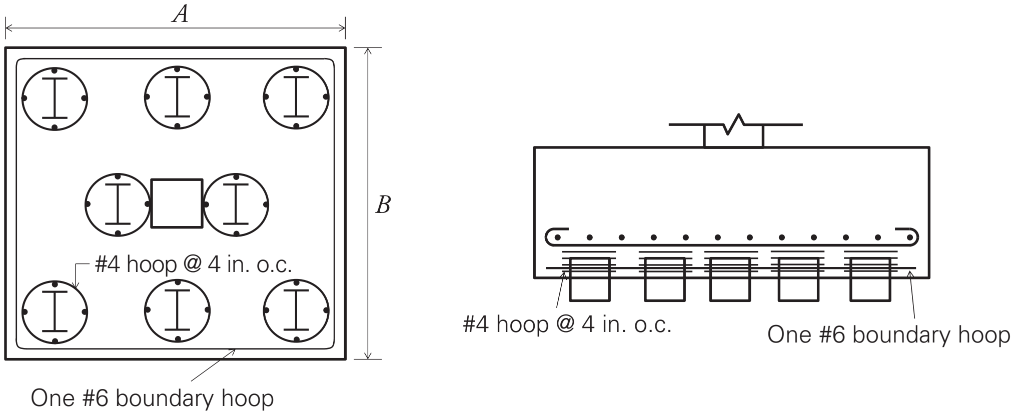


Fig. 4.5 Additional prescriptive steel requirement when high load piles are used.

Anchorage: For pile caps with 2, 3, 4, 5, 6, 7, or 9 piles, all reinforcing bars must be provided with standard end hooks. For pile caps with 8, 10, 11, or 12 piles, only the short reinforcing bars must be provided with end hooks, and should be placed as the lower layer. As an alternative to hooked bars, the bar ends can be headed. For all other caps, pile cap dimensions permit straight reinforcing bars.

Column Size: For the tabulated designs presented in this design guide, the column sizes shown are derived from square column sizes for an assumed bearing stress of 4,000 psi on the gross column area. The tabulated designs are conservative if the column is larger than the minimum column size tabulated.

Special Details for High Load Piling: When piles with an allowable load greater than 200 tons (i.e., high load piles) are used in conjunction with the design procedures presented in this guide, two additional details are required. Fig. 4.5 shows a plan and profile view of a typical pile cap that highlights the special details required for high load piling. Note that the #4 hoops at 4 inches on center should be placed around all piles in the pile cap. The continuous #6 edge bar should be provided around the entire boundary of the pile cap, 3 in. from both the pile cap bottom and pile cap edge.

CHAPTER 5
Pile Cap Design for Gravity Loads

5.1 General

Chapter 4 of this design guide presents a detailed summary of moment, shear, and general detailing provisions for pile caps as mandated by Chapter 13 of ACI 318-14. However, the shear and moment provisions contained in Chapter 13 of ACI 318-14 focus primarily on demand. Nominal bending and shear strength provisions are contained elsewhere in ACI 318-14 and are covered in detail in this chapter. Flexural provisions for pile caps are fairly straightforward, but shear provisions are complicated by pile spacings, pile patterns, and cap thicknesses that can result in deep beam behavior. For example, when a single pile is located in plan directly under a loaded column, it is readily apparent that the pile in question does not cause shear through the pile cap cross section but behaves as a continuation of the loaded column (carrying only its portion of the total column load). Similarly, for relatively thin pile caps with all piles located a distance, from the column face, greater than the overall cap thickness, it is clear that traditional one-way and two-way shear provisions apply to all pile demands without modification. Often times, pile cap geometry is such that some of the piles adjacent to the column are outside the column face (such that they cannot be neglected) yet not an appropriate distance from the column face such that typical ACI provisions may be used. This guide presents special design procedures for these cases by considering one-way and two-way shear at the column face to include the presence of all piles that have centerline locations outside the column face.

5.2 Design Provisions for Flexure

As discussed in Chapter 4 of this guide, ACI 13.2.7.1 permits the vertical cut to be taken at the face of a concrete column or halfway between the face of a steel column and the edge of the steel base plate. To ensure that the designs calculated using the assumptions in this guide are conservative for square reinforced concrete columns of at least the minimum size indicated, rectangular reinforced concrete columns and steel base plates if the short side or section is equal to the minimum tabulated column size presented in the design tables of this guide or designed using the associated software, the critical section used in all calculations is taken at a location halfway between the face of the "representative" square concrete column and the column centroid. Thus, the critical section for bending is located a column dimension "c" divided by four away from the column centerline. This same assumption was utilized in the *CRSI Design Handbook* (2008). Additionally, it should be noted that adverse tolerance effects for pile placement are accounted for in all bending calculations by adding 3 in. to the idealized locations for each pile.

Figure 5.1 shows an example illustration of the methodology used in this chapter to obtain the maximum factored moment at the critical section for bending in the long direction of the pile cap. Note that only three pile centers are located to the right of the critical section shown and assume that pile cap has a total thickness D_{cap} and is constructed using normal weight concrete (i.e., $\gamma_c = 150$ pcf). For this example, since each pile is assumed to have reached its factored demand of $1.6(D + L_{floor})$, the factored total moment at the critical section is found to be:

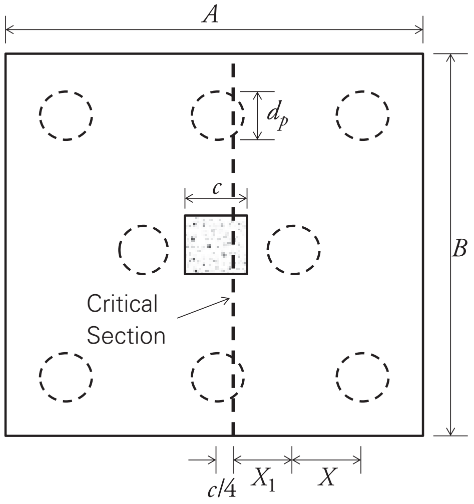


Fig. 5.1 Example geometry used to determine the maximum bending moment in the pile cap about the critical section shown. For this example, note that $c/4 + x_1 = x$ where x is the typical pile spacing.

$$M_u = 1.6(D + L_{floor})[(1\text{ Pile})(x_1 + 3\text{ in.}) + (2\text{ Piles})(x_1 + x + 3\text{ in.})]$$
$$- 1.6(\gamma_c)D_{cap}(A/2 - c/4)(B)(A/2 - c/4)/2$$

In the expression above, the first term is the factored positive moment at the critical section caused by the upward demand of the three piles to the right of the critical section acting on the pile cap. The second term in the expression is the factored negative moment at the critical section caused by the downward weight of the pile cap.

The factored moment acting on a 12 in. strip is then obtained by dividing the total factored moment at the critical section as presented above by the width of the pile cap (B in this example) to obtain M_u/B.

ACI 318-14 requires that the reduced nominal moment strength ϕM_n be greater than or equal to the ultimate factored moment M_u. For flexural members such as pile caps, which are reinforced with tension steel only, the reduced nominal moment strength, is obtained from the following expression:

$$\phi M_n = \phi A_s f_y \left(d - \frac{a}{2}\right)$$

where

$$a = \frac{A_s f_y}{0.85 f_c' ab}$$

For design, the required area of steel needed to satisfy $\phi M_n \geq M_u$ can be obtained from the following expression:

$$A_s = \frac{0.85 f'_c bd}{f_y} - \sqrt{\left(\frac{0.85 f'_c bd}{f_y}\right)^2 - \frac{1.7\, f'_c M_u b}{\phi f_y^2}}$$

The *CRSI Design Handbook* (2008) provides the following approximate solutions to the above expression (assuming $b = 12$ in., $f_y = 60{,}000$ psi, $\phi = 0.9$, and M_u is specified in k-in. per 12 inch strip). These approximate solutions are used in this guide and the associated Excel spreadsheets.

For 3,000 psi concrete:

$$A_s = 0.51d - \sqrt{0.260d^2 - 0.0189M_u}$$

For 4,000 psi concrete:

$$A_s = 0.68d - \sqrt{0.462d^2 - 0.0252M_u}$$

For 5,000 psi concrete:

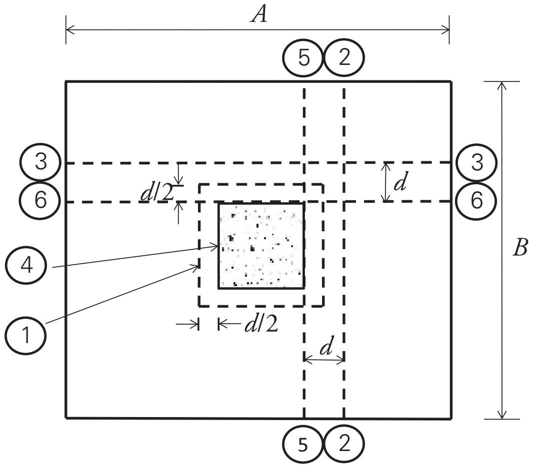
$$A_s = 0.85d - \sqrt{0.723d^2 - 0.0315M_u}$$

Referencing Fig. 4.3, the distance d is taken in this guide to be different for the long bars (spanning the "A" dimension) and the short bars. It is assumed in this guide that the short bars always sit on top of the long bars. As such, the distance "d" for the long bars is found to be the total cap depth D_{cap} minus the pile embedment depth minus the clear cover over the top of the pile (3 in. assumed throughout this guide) minus half the long bar diameter. The distance "d" for the short bars is found to be the d value for the long bars minus the other half the long bar diameter minus half the short bar diameter. For simplicity, most calculations can be based on an average effective depth, $d = D_{cap} - d_c$, where D_{cap} = total pile cap depth, and d_c is assumed to be 10 inches for structural steel piles, or 8 inches for concrete and timber piles (see Fig. 4.3).

Once the required area of steel A_s has been determined for both the short and the long bars, the actual amount of steel to be provided must be determined in accordance with the requirements presented in Chapter 4. Since the depth of the pile cap required is usually established by shear, the flexural reinforcement ratio is usually near or controlled by the minimum ratios required by ACI 9.6.1 and ACI 24.4.1. Once the appropriate area of steel is selected, the chosen bar size must be checked to ensure that the distance from the critical section to the bar termination point provides sufficient length to develop the straight, hooked, or headed bar, as applicable. When performing manual calculations, Tables 4.1, 4.2, and 4.3 may be used to expedite the evaluation.

5.3 Design Provisions for Shear

Due to the variety of conditions resulting from the 26 pile cap patterns presented in Fig. 4.4, a variable number of critical sections for shear must be investigated. Figures 5.2 and 5.3 present all the possible shear limit states considered in this guide. Figure 5.2 presents shear limit states adjacent to (i.e., one-way shear) and around (i.e., two-way shear) the column. In order to determine the demand associated with all 6 limit states identified in the figure (i.e., 1 through 6) the number of piles applying shear to the critical section must first be determined. Piles are considered shear inducing members if their centerline (including an adverse 3 in. tolerance effect) is located on the opposite side of the pile cap critical section relative to the column.



Nomenclature for Critical Shear Sections

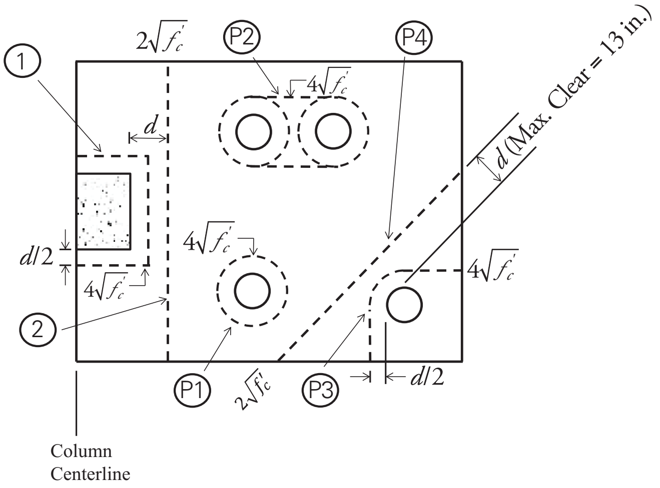
① Two-way at $d/2$ from face of column
② One-way at d from face of column in direction of short width "B"
③ One-way at d from face of column in direction of long width "A"
④ Two-way at face of column
⑤ One-way at face of column in direction of short width "B"
⑥ One-way at face of column in direction of long width "A"

Fig. 5.2 Critical sections and limit state identification tags (i.e., 1 through 6) for traditional one-way and two-way shear analysis (Limit States 1 through 3) and special investigations of deep beam shear (Limit States 4 through 6).

TRADITIONAL ACI 318-14 ONE-WAY AND TWO-WAY SHEAR PROVISIONS AT COLUMN – Limit States 1, 2, and 3

For limit state 1, shear is investigated as prescribed in ACI 318-14 Section 22.6.4 for a "punching" failure about the column at a section located at a distance $d/2$ from the column face ($v_c = 4\sqrt{f'_c}$). A "beam" failure is considered, in limit states 2 and 3, as acting straight across the width of the pile cap in either direction at a section located a distance d from the column face ($v_c = 2\sqrt{f'_c}$). ACI 318-14 Section 8.5.3.1.1 references Section 22.5 in regards to beam shear in the pile cap. Both of these required investigations become at least partially inappropriate as the depth of the footing increases so that the sections at a distance d (or $d/2$) exclude all or part of the pile loads causing shear or even fall outside the footing.

As the previous code-prescribed assumptions become inappropriate, two special investigations for possible shear failure are necessary. The investigation of a column punching failure (see limit state 4 in Fig. 5.2) at the column face is required



Nomenclature for Critical Shear Sections

- (P1) Two-way at $d/2$ from face of pile
- (P2) Two-way at $d/2$ from face of closely spaced pile group
- (P3) Two-way at $d/2$ from face of corner pile
- (P4) One-way at d (or 13 in. clear) from face of corner pile

Fig. 5.3 Critical sections and limit state identification tags (i.e., P1 through P4) for traditional one-way and two-way shear analysis as applicable to individual piles and group piles when spaced close together. Note that Limit States 1 and 2 are also shown here for clarity (see Fig. 5.2).

when the nearest piles cause the failure to occur in a manner approaching "pure shear." Similarly, a beam shear failure (see limit states 5 and 6 in Fig. 5.2) at the column face results in cracking across the width of a footing. Limiting values for v_c under these special conditions, based on research, become very high (Joint ASCE-ACI Committee 426, "The Shear Strength of Reinforced Concrete," Journal of the Structural Division, ASCE, Part I - Beams and Special Members, June 1973 and Part II - Slabs, Aug. 1974).

SPECIAL INVESTIGATION AND DERIVATION – Limit State 4 – Two-Way Shear at Column Face

Limit State 4 is a special case modification of Limit State 1. The shear failure section associated with limit state 1 is technically a pyramidal frustrum with slope angle to the vertical, $\alpha \approx 45^o$, and $w \approx d$. This condition is part of the explicitly ACI 318-14 prescribed investigation. The allowable shear stress on concrete is: $v_c = 4\sqrt{f_c'}$, at a section, which is located at a distance of $d/2$ from the perimeter of the column for all piles outside this section. The shear section perimeter is: $b_o = 4(c + d)$.

Limit State 4 is necessary since when $w < d$, and $45^o > \alpha \geq 0$, the explicit ACI 318-14 provisions presented above do not apply. The condition is an inverted "deep" two-way cantilever slab with concentrated loads (pile loads). Providing horizontal shear-friction reinforcement distributed through $^2/_3$ of the depth as for small one-way corbels is impractical (ACI 318-14 Section 16.5.6). Failure when $\alpha < 45^o$ can occur, but only at increasingly higher values of v_c, approaching a theoretical strength $v_c = 0.5f_c' \approx 32\sqrt{f_c'}$ $at\ \alpha = 0$ ("pure" shear). The "deep" beam formulas in ACI 318-14 Section 9.9 for one-way shear omit limits for cantilever spans and are not applicable to this condition.

Since the various pile arrangements in Fig. 4.4 include variations of distance w from the face of column to the centers of the first piles and w can approach zero, it is most convenient to make this special investigation on the perimeter at the face of the column with the special critical section $b_s = 4c$. This special investigation is made only when $w < d/2$ since the ACI 318-14 prescribed procedure (i.e., limit state 1) can be applied when $w \geq d/2$. It is convenient to convert the ACI 318-14 prescribed v_c from $v_c = 4\sqrt{f_c'}$ acting on the section perimeter at $d/2$, or $b_o = 4(c + d)$, to a new value acting at the perimeter of the column (b_s) as follows:

$$4\left(\sqrt{f_c'}\right)b_o = v_c b_s$$

Solving for v_c,

$$v_c = 4\left(\sqrt{f_c'}\right)\frac{b_o}{b_s} = 4\left(\sqrt{f_c'}\right)\left(\frac{4c+4d}{4c}\right) = 4\left(\sqrt{f_c'}\right)\left(1+\frac{d}{c}\right)$$

For the special investigation then, on a section at the face of the column, when $w = d/2$, the allowable shear stress is $v_c = 4\sqrt{f_c'}(1 + d/c)$ with $b_s = 4c$. A simple conservative linear variation for v_c between the value $v_c = 4\sqrt{f_c'}(1 + d/c)$ at $w = d/2$ and $v_c = 32\sqrt{f_c'}$ at $w = 0$ can be used.

$$v_c = \left(\frac{d}{w}\right)\left(1+\frac{d}{c}\right)\left(2\sqrt{f_c'}\right) \leq 32\sqrt{f_c'}$$

In summary, limit state 4 is applicable when at least one pile is located such that $w < d/2$. For this case, the following expression is used in this guide to determine the reduced nominal shear strength:

$$\phi V_c = \phi v_c(b_s d)$$

SPECIAL INVESTIGATION AND DERIVATION – Limit States 5 and 6 – One-Way Shear at Column Face

Limit States 5 and 6 require a similar special investigation for possible failure in one-way shear as a deep beam. As for the two-way failure mechanism associated with Limit State 4, a one-way shear section is investigated here at the face of the column. In this case, the width of the critical section is unchanged and no correction factor, based upon column size or ratio (d/c), is required. Research reports, including tests for shear with (w/d) as low as 0.5, show shear strengths of approximately 1,200 to 1,300 psi and show an exponential increase in shear strength as (w/d) decreases. These very favorable strengths develop in confined situations (at the face of a support), and the support here (upside down) is the column, the width of which involves a variable (c/A) or (c/B). No test results are available to evaluate the precise effect of the (column width/pile cap width) ratios nor to evaluate the precise upper value for v_c at $w = 0$, at the column. Under

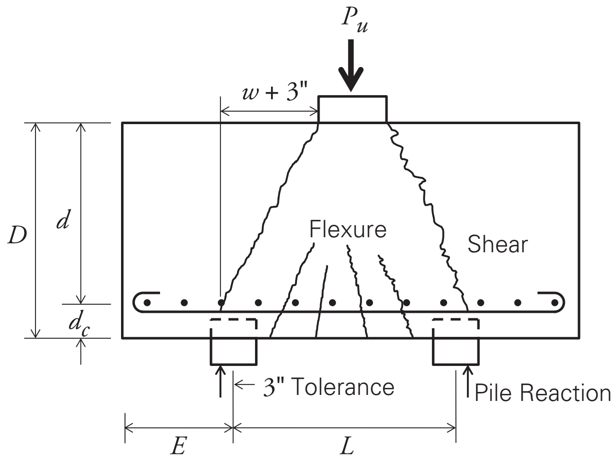


Fig. 5.4 Shear failure model for deep pile cap.

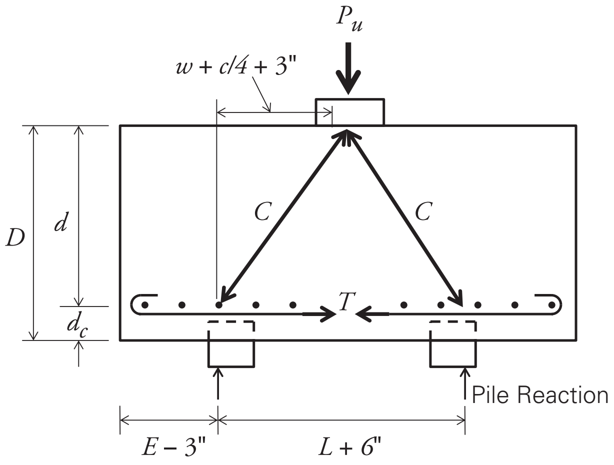


Fig 5.5. Tied-arch model for deep pile cap.

these conditions, no further refinement than an average value for v_c applied across the full footing width is justifiable. A conservative upper limit for the value v_c as w approaches zero is $10\sqrt{f_c'}$ (Rogowsky and MacGregor, "Shear Strength of Deep Reinforced Concrete Continuous Beams," Struct. Eng. Report No. 110, Univ. of Alberta, Nov. 1983). In order to include the effect $M_u/(V_u d)$ for several lines of piles at varying spans, the initial value beginning at $w/d = 1.0$ will be that from ACI 318-14 Equation 22.5.5.1(a), and a simple linear function for the effect of d/w will be used for the transition.

For $w/d \geq 1.0$, the traditional ACI 318-14 one-way shear investigation (i.e., Limit State 2 and Limit State 3) with loads outside the critical section (located at a distance d from the face of the column, b = footing width) is applicable and v_c is determined as follows:

$$v_c = 1.9\sqrt{f_c'} + 2500\rho_w\left(\frac{V_u d}{M_u}\right) \geq 2\sqrt{f_c'}$$

Considering that the area of steel is typically controlled by minimum steel, the above expression can be conservatively simplified by assuming $\rho_w = 0.002$ and $25{,}000\rho_w \approx 0.1\sqrt{f_c'}$.

$$v_c = 1.9\sqrt{f_c'} + 0.1\sqrt{f_c'}\left(\frac{V_u d}{M_u}\right) \geq 2\sqrt{f_c'}$$

For $w/d < 1.0$, $1.0 > M_u/(V_u d) > 0$; $\infty > V_u d/M_u \geq 1.0$

(no limits on M_u and $V_u d$ other than above)

$$v_c = \left(\frac{d}{w}\right)\left[3.5 - 2.5\left(\frac{M_u}{V_u d}\right)\right]\left[1.9\sqrt{f_c'} + 0.1\sqrt{f_c'}\left(\frac{V_u d}{M_u}\right)\right] \leq 10\sqrt{f_c'}$$

The factor

$$\left[3.5 - 2.5\left(\frac{M_u}{V_u d}\right)\right]$$

accounts for increased shear strength associated with deep beams (see, for example, ACI 318-99 Equation 11-29). In summary, Limit States 5 and/or 6 are applicable when at least one pile is located such that $w < d$ in the either the short or long direction of the pile cap. For these cases, referencing the above equation for v_c, and using a general pile cap width b (actually either A or B dimension) the following expression is used in this guide to determine the reduced nominal shear strength:

$$\phi V_c = \phi v_c(bd)$$

SPECIAL INVESTIGATION –
Special Anchorage Requirements for Pile Caps with One Line of Piles Adjacent to a Column

CRSI recommends, and this design guide utilizes, an inclusion of 180° end hooks or heads on all reinforcing bars in pile caps with single lines of piles adjacent to the column. The anchored reinforcement is a prudent precaution against a premature "tied-arch" shear failure mode. See Figs. 5.4 and 5.5. In addition, the maximum bar size should be related to the embedment length available. ACI 318-14 establishes required development lengths for full development of hooks and headed bars and permits a 30 percent reduction in hook development where confining reinforcement and at least $2^1/_2$ inches of concrete cover are present (see Tables 4.2 and 4.3 of this guide). Crossing bars provide a degree of confinement and the compressive reactions of the piles also contribute to confinement.

High load piles, up to the limits set by supporting soil strata, minimize the number of piles required as well as the area of the pile cap for a given column load. An obvious potential economy results in more "deep beam" or "deep slab" pile caps. Theoretical analyses indicating a "tied-arch" mode of failure as depth/span ratios become larger have been confirmed to some extent by model tests and reports of field behavior. When $w << d$ in one-way shear or flexure, and $w << 0.5d$ in two-way shear or flexure, provisions for deep beam reinforcement anchorage are necessary and although not directly applicable, these provisions are discussed in ACI 318-14 Section 9.9.4.5 where design in accordance with ACI 318-14 Chapter 23 (strut-and-tie design) or development f_y for tension reinforcement at the face of the support is required. Conservatively, yet in a manner similar to anchorage development requirements contained in ACI 318-14 Chapter 23, the "tied-arch" model at failure (Fig. 5.5) presented in this guide requires that full development of the hooked bars at the center of the pile support, and this development should include the adverse 3-inch tolerance effect.

TRADITIONAL ACI 318-11 ONE-WAY AND TWO-WAY SHEAR PROVISIONS AT PILES –
Limit States P1, P2, P3, and P4

Shear limit states adjacent to individual piles are presented in Fig. 5.3. For Limit State P1, shear is investigated as prescribed in ACI 318-14 Section 22.6.4 for a "punching" failure about an isolated pile at a section located a distance $d/2$ from the pile face ($v_c = 4\sqrt{f_c'}$). Limit State P2 considers the same failure concept as P1, but for P2 to be applicable, two (or more) adjacent piles must be located close enough to each other that full two-way shear failure mechanisms around adjacent piles overlap or yield a shorter total failure length when combined as shown in Fig. 5.3. To appropriately consider Limit State P2, a "punching" failure about two or more adjacent piles is considered at a section located a distance $d/2$ from each pile face where the controlling mechanism is selected to minimize the overall length of the failure pattern ($v_c = 4\sqrt{f_c'}$). Limit State P3 considers the same failure concept as P1, but for a corner pile, where a shorter overall total failure length is obtained by extending the mechanism to the edge of the pile cap as shown in Fig. 5.3 ($v_c = 4\sqrt{f_c'}$). Finally, Limit State P4 considers a "beam" failure mechanism for a corner pile at a section located a distance $d \le 13$ in. from the pile face ($v_c = 2\sqrt{f_c'}$).

It can be noted that the "single interior pile punching failure" never controlled when creating the tabulated arrangements presented in the design tables. The 3-pile corner failure at 45° in beam (one-way) shear cannot occur with the patterns considered in this guide (see Fig. 4.4). Where "overlaps" exist for pairs of piles, the perimeter is usually incomplete and would not control. The single corner pile limit states do control in some cases.

5.4 Limit State Design Summary for Shear

TWO-WAY SHEAR AT COLUMN –
Limit State 1

Step (1): Based on the geometry shown in Fig. 5.2 and the selected pile configuration, determine the number of piles, $N_{outside}$, that are outside the failure pattern shown. Include the 3 in. adverse tolerance effect.

Step (2): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and reduce the total demand by the portion of the pile cap weight that is outside the critical section. In the expression below, c is the equivalent square column side dimension and d is the effective depth of the pile cap ($d \approx D_{cap} - 10"$ may be assumed). γ_c is the specific weight of concrete (assumed to be normal weight concrete or 150 lb/ft^3 in this guide and associated spreadsheets).

$$V_u = 1.6N_{outside}\left(P_{SERVICE}\right) - 1.6\,\gamma_c ABD_{cap}\frac{AB - \left(c+d\right)^2}{AB}$$

Step (3): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism and geometry shown in Fig. 5.2.

$$\phi V_c = \phi\left(4\sqrt{f_c'}\right)\left(b_o d\right)$$

where

$$b_o = 4(c+d)$$

Step (4): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

ONE-WAY SHEAR AT COLUMN (LONG DIRECTION) –
Limit State 2

Step (1): Based on the geometry shown in Fig. 5.2 and the selected pile configuration, determine the number of piles, $N_{outside}$, that are outside the failure pattern shown. Include the 3 in. adverse tolerance effect.

Step (2): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and reduce the total demand by the portion of the pile cap weight that is outside the critical section. In the expression below, c is the equivalent square column side dimension and d is the effective depth of the pile cap ($d \approx D - 10"$ may be assumed). γ_c is the specific weight of concrete (assumed to be normal weight concrete or 150 lb/ft^3 in this guide and associated spreadsheets).

$$V_u = 1.6N_{outside}\left(P_{SERVICE}\right) - 1.6\,\gamma_c \frac{ABD_{cap}}{2}\,\frac{A/2 - c/2 - d}{A/2}$$

Step (3): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism and geometry shown in Fig. 5.2.

$$\phi V_c = \phi\left(2\sqrt{f_c'}\right)\left(Bd\right)$$

Step (4): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

ONE-WAY SHEAR AT COLUMN (SHORT DIRECTION) –
Limit State 3

Step (1): Based on the geometry shown in Fig. 5.2 and the selected pile configuration, determine the number of piles, $N_{outside}$, that are outside the failure pattern shown. Include the 3 in. adverse tolerance effect.

Step (2): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and reduce the total demand by the portion of the pile cap weight that is outside the critical section. In the expression below, c is the equivalent square column side dimension and d is the effective depth of the pile cap ($d \approx D_{cap} - 10"$ may be assumed). γ_c is the specific weight of concrete (assumed to be normal weight concrete or 150 lb/ft^3 in this guide and associated spreadsheets).

$$V_u = 1.6 N_{outside}\left(P_{SERVICE}\right) - 1.6\,\gamma_c \frac{ABD_{cap}}{2} \frac{B/2\text{-}c/2\text{-}d}{B/2}$$

Step (3): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism and geometry shown in Fig. 5.2.

$$\phi V_c = \phi\left(2\sqrt{f_c'}\right)\left(Ad\right)$$

Step (4): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

TWO-WAY SHEAR AT COLUMN FACE – Limit State 4

Step (1): Based on the geometry shown in Fig. 5.2 and the selected pile configuration, determine the number of piles, $N_{outside}$, that are outside the failure pattern shown. Include the 3 in. adverse tolerance effect.

Step (2): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and reduce the total demand by the portion of the pile cap weight that is outside the critical section. In the expression below, c is the equivalent square column side dimension and d is the effective depth of the pile cap ($d \approx D_{cap} - 10"$ may be assumed). γ_c is the specific weight of concrete (assumed to be normal weight concrete or 150 lb/ft^3 in this guide and associated spreadsheets).

$$V_u = 1.6 N_{outside}\left(P_{SERVICE}\right) - 1.6\gamma_c ABD_{cap} \frac{AB - c^2}{AB}$$

Step (3): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism and geometry shown in Fig. 5.2.

$$v_c = \left(\frac{d}{w}\right)\left(1 + \frac{d}{c}\right)\left(2\sqrt{f_c'}\right) \le 32\sqrt{f_c'}$$

$$\phi V_c = \phi v_c (b_s d)$$

where

$$b_s = 4c$$

and

w is the distance in plan from the face of the column to the centerline of the first pile line (includes additional 3 in. for adverse tolerance effects).

In special cases where w is different in orthogonal directions, step 3 should be performed two times and ϕV_c should be taken as the average value of ϕV_c for the two cases considered.

Step (4): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

ONE-WAY SHEAR AT COLUMN FACE (LONG DIRECTION) – Limit State 5

Step (1): Based on the geometry shown in Fig. 5.2 and the selected pile configuration, determine the number of piles, $N_{outside}$, that are outside the failure pattern shown. Include the 3 in. adverse tolerance effect.

Step (2): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and reduce the total demand by the portion of the pile cap weight that is outside the critical section. In the expression below, c is the equivalent square column side dimension and d is the effective depth of the pile cap ($d \approx D_{cap} - 10"$ may be assumed). γ_c is the specific weight of concrete (assumed to be normal weight concrete or 150 lb/ft^3 in this guide and associated spreadsheets).

$$V_u = 1.6 N_{outside}\left(P_{SERVICE}\right) - 1.6\gamma_c \frac{ABD_{cap}}{2} \frac{A/2 - c/2}{A/2}$$

Step (3): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism and geometry shown in Fig. 5.2. The term $x_{centroid}$ is the perpendicular distance from the critical section to the centroid of the $N_{outside}$ piles.

$$\phi V_c = \phi v_c (bd)$$

where

$$v_c = \left(\frac{d}{w}\right)\left[3.5 - 2.5\left(\frac{M_u}{V_u d}\right)\right]\left[1.9\sqrt{f_c'} + 0.1\sqrt{f_c'}\left(\frac{V_u d}{M_u}\right)\right] \le 10\sqrt{f_c'}$$

$$M_u = 1.6 N_{outside}(P_{SERVICE}) x_{centroid} - 1.6\gamma_c \frac{ABD_{cap}}{2} \frac{A/2 - c/2}{A/2} \frac{\left(A/2 - c/2\right)}{2}$$

and

w is the distance in plan from the face of the column to the centerline of the first pile line in the x or "A" direction (includes additional 3 in. for adverse tolerance effects).

Step (4): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

ONE-WAY SHEAR AT COLUMN FACE (SHORT DIRECTION) – Limit State 6

Step (1): Based on the geometry shown in Fig. 5.2 and the selected pile configuration, determine the number of piles, $N_{outside}$, that are outside the failure pattern shown. Include the 3 in. adverse tolerance effect.

Step (2): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and reduce the total demand by the portion of the pile cap weight that is outside the critical section. In the expression below, c is the equivalent square column side dimension and d is the effective depth of the pile cap ($d \approx D_{cap} - 10"$ may be assumed). γ_c is the specific weight of concrete (assumed to be normal weight concrete or

150 lb/ft^3 in this guide and associated spreadsheets).

$$V_u = 1.6N_{outside}\left(P_{SERVICE}\right) - 1.6\gamma_c \frac{ABD_{cap}}{2}\frac{B/2 - c/2}{B/2}$$

Step (3): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism and geometry shown in Fig. 5.2. The term $y_{centroid}$ is the perpendicular distance from the critical section to the centroid of the $N_{outside}$ piles.

$$\phi V_c = \phi v_c(bd)$$

where

$$v_c = \left(\frac{d}{w}\right)\left[3.5 - 2.5\left(\frac{M_u}{V_u d}\right)\right]\left[1.9\sqrt{f_c^{'}} + 0.1\sqrt{f_c^{'}}\left(\frac{V_u d}{M_u}\right)\right] \le 10\sqrt{f_c^{'}}$$

$$M_u = 1.6N_{outside}(P_{SERVICE})y_{centroid} - 1.6\gamma_c \frac{ABD_{cap}}{2}\frac{B/2 - c/2}{B/2}\frac{(B/2 - c/2)}{2}$$

and

w is the distance in plan from the face of the column to the centerline of the first pile line in the y or "B" direction (includes additional 3 in. for adverse tolerance effects).

Step (4): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

TWO-WAY SHEAR AT PILE – Limit State P1

Step (1): Determine the factored shear, V_u, acting on the critical section (See Fig. 5.3). Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and conservatively neglect any reduction in shear due to the weight of concrete tributary to one pile.

$$V_u = 1.6P_{SERVICE}$$

Step (2): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism and geometry shown in Fig. 5.3. Round or equivalent round piles are assumed in this analysis. d_p is the actual or equivalent pile diameter. d is the effective depth of the pile cap ($d \approx D_{cap} - 10''$ may be assumed).

$$\phi V_c = \phi\left(4\sqrt{f_c^{'}}\right)\left(b_o d\right)$$

where

$$b_o = \pi(d_p + d)$$

Step (3): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

TWO-WAY SHEAR AT TWO ADJACENT PILES – Limit State P2

Step (1): Determine the factored shear, V_u, acting on the critical section (See Fig. 5.3). Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and conservatively neglect any reduction in shear due to the weight of concrete tributary to the two piles considered in this analysis.

$$V_u = 2(1.6P_{SERVICE})$$

Step (2): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism and geometry shown in Fig. 5.3. Round or equivalent round piles are assumed in this analysis. d_p is the actual or equivalent pile diameter. d is the effective depth of the pile cap ($d \approx D_{cap} - 10''$ may be assumed). L is the center to center pile spacing.

$$\phi V_c = \phi\left(4\sqrt{f_c^{'}}\right)\left(b_o d\right)$$

where

$$b_o = \pi(d_p + d) + 2L$$

Step (3): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

TWO-WAY SHEAR AT CORNER PILE – Limit State P3

Step (1): Determine the factored shear, V_u, acting on the critical section (See Fig. 5.3). Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and conservatively neglect any reduction in shear due to the weight of concrete tributary to the corner pile.

$$V_u = 1.6P_{SERVICE}$$

Step (2): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism and geometry shown in Fig. 5.3. Round or equivalent round piles are assumed in this analysis. d_p is the actual or equivalent pile diameter. d is the effective depth of the pile cap ($d \approx D_{cap} - 10''$ may be assumed). E is the center of corner pile to edge of cap dimension in plan.

$$\phi V_c = \phi\left(4\sqrt{f_c^{'}}\right)\left(b_o d\right)$$

where

$$b_o = \frac{\pi\left(d_p + d\right)}{4} + 2E$$

Step (3): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

ONE-WAY SHEAR AT CORNER PILE – Limit State P4

Step (1): Determine the factored shear, V_u, acting on the critical section (See Fig. 5.3). Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and conservatively neglect any reduction in shear due to the weight of concrete tributary to the corner pile.

$$V_u = 1.6P_{SERVICE}$$

Step (2): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism and geometry shown in Fig. 5.3. Round or equivalent round piles are assumed in this analysis. d_p is the actual or equivalent pile diameter. d is the effective depth of the pile cap ($d \approx D_{cap} - 10"$ may be assumed). E is the center of corner pile to edge of cap dimension in plan. The length of the critical section, b, can be found using simple geometry.

$$\phi V_c = \phi\left(2\sqrt{f_c'}\right)(bd)$$

where

$b = 2\left(E\sqrt{2} + d_p/2 + d\right)(d \leq 13\text{ in.}$ in this equation only; no limit on d for ϕVc)

Step (3): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

5.5 Tabulated Pile Cap Designs for Gravity Loads

Tabulated pile cap designs for the 26 pile cap patterns presented in Fig. 4.4 using allowable pile loads ranging from 40 tons to 400 tons in varying increments are presented in the design tables. Two separate spreadsheets are also available to the design engineer from the CRSI website. The first spreadsheet (CRSI-PILECAP (Limited Version B)) was used to generate the tabulated pile cap designs presented here but can also be used to design other pile caps with allowable pile loads that vary from the increments presented in the tables or when pile shapes or types vary. The first spreadsheet also helps the designer customize the solution when a preferred reinforcement arrangement is desired. The second spreadsheet (CRSI-PILECAP (Full Version B)) allows the designer significant freedom to vary from many of the requirements, recommendations, and assumptions presented in this guide. For example, the designer may need to minimize pile cap edge distances when pile caps are adjacent to a property line or use less than the recommend pile spacing in some cases. As such, extra caution should be used by the designer to verify that all final designs meet the *2012 International Building Code* and ACI 318-14. To download either of these spreadsheets, go to the Pile Cap Design Guide download page on the CRSI website at ***www.crsi.org/pilecaps.cfm***.

CHAPTER 6
Pile Cap Design for Lateral Loads

6.1 General

Chapter 6 of this design guide presents a detailed approach commonly used to analyze, design, and detail pile caps to resist the combined effects of concentrated moments (M_x and M_y), shears (V_x and V_y), and axial load (P – tension or compression) applied at the centroid of the pile cap and by the supported column. The procedure assumes a rigid pile cap (relative to the axial stiffness of the piles) and pinned connections between the top of the pile and the pile cap. These assumptions are typical for traditional single-column pile cap applications and justified for the pile cap configurations shown in Fig. 4.4 and the tabulated designs presented in Chapter 5 as discussed in Chapter 3 of this guide. Different assumptions such as fixed pile heads are discussed in Chapter 7.

This chapter begins by presenting pile cap models and analytical properties needed to efficiently determine pile actions (i.e., axial demands) caused by the application of point moments, shears, and axial forces applied at the pile cap-to-column interface. Next, pile cap design provisions are presented as necessary to resist internal shear and bending effects caused by the column provided point actions and the resulting, and varying, axial forces from the piles. It is important to note that once the pile actions are known, the actual pile cap design procedure presented in Chapter 5 for column axial loading is still applicable with only minor modifications necessary. Since it is not practical to consider all combinations of combined axial loading, shear, and biaxial moments on the pile cap configurations presented in Fig. 4.4, random tabulated designs are not presented in this chapter. Instead, the design tables present practical tabulated gravity plus lateral load designs that allow the designer to quickly determine the adequacy of the tabulated gravity only pile cap designs to resist combinations with column applied shear and bending moment in cases (or load combinations) where the full factored axial load (as determined in Chapter 5) is not applied.

6.2 Pile Cap Analysis Models and Properties

A rigid pile cap loaded by the combined effects of concentrated moments (M_x and M_y), shears (V_x and V_y), and axial load (P – tension or compression) applied at the centroid of the pile cap and by the supported column can be analyzed using the principle of superposition. Previously discussed Fig. 3.2 shows the general loading and pile response characteristics for the analytical model (note that in the Fig., all loads contain the subscript "u" and are factored). The piles resist overturning via increased and decreased axial forces depending on their position relative to the pile cap centroid. The shear demand in each pile may be assumed equal in many cases, but the designer should consider other assumptions when pile axial forces result in net tension, particularly when seismic demands are considered.

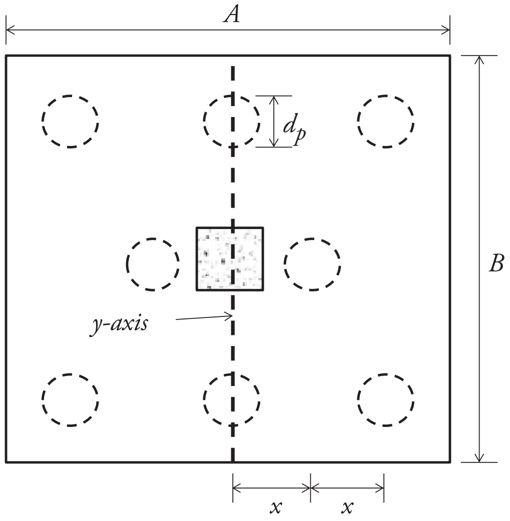


Fig. 6.1 Example geometry used to determine the axial force on individual piles for applied loading P and M_y

Referencing the example pile cap configuration of Fig. 6.1, the axial force on any given pile in the pile group for a column applied axial load P and column applied bending moment M_y, can be determined using the following expression.

$$R = \frac{P}{n} + \frac{M_y X}{I_y}$$

In the above expression, n is the total number of piles, I_y is the moment of inertia of the piles for the pile cap configuration selected, and X is the horizontal distance from the y-axis to the pile in question. For the example in Fig. 6.1, $X = 0$ for the two center piles, $X = x$ for the pile just to the right of the column, $X = -x$ for the pile just to the left of the column, $X = 2x$ for the two piles to the far right, and $X = -2x$ for the two piles to the far left.

Similarly, the axial force on any given pile in the pile group for a column applied axial load P and column applied bending moment M_x, can be determined using the following expression.

$$R = \frac{P}{n} + \frac{M_x Y}{I_x}$$

To aid the designer in determining the axial force demand on each pile as caused by bending moments M_x and M_y, Table 6.1 has been developed to present I_x and I_y for all pile cap configurations presented in Fig. 4.4.

Table 6.1 Pile cap moments of inertia I_x and I_y for pile cap configurations 2 through 30 assuming all piles have an equivalent cross sectional area of $A = 1.0\ \text{ft}^2$.

Number of Piles-Configuration	$I_x(\text{ft}^4)$	$I_y(\text{ft}^4)$
2	NA	$0.5L^2$
3	$0.5L^2$	$0.5L^2$
4	L^2	L^2
5	$2L^2$	$2L^2$
6	$1.5L^2$	$4L^2$
7	$3L^2$	$3L^2$
8	$4.5L^2$	$4.5L^2$
9	$6L^2$	$6L^2$
10	$4.5L^2$	$9L^2$
11	$6L^2$	$12L^2$
12	$8L^2$	$15L^2$
13	$7L^2$	$21L^2$
14	$13.2L^2$	$14L^2$
15	$16L^2$	$18L^2$
16	$20L^2$	$20L^2$
17	$16L^2$	$24L^2$
18	$19L^2$	$28.5L^2$
19	$22L^2$	$33.86L^2$
20	$25L^2$	$40L^2$
21	$29.93L^2$	$34.46L^2$
22	$31.5L^2$	$35L^2$
23	$37.86L^2$	$40L^2$
24	$42.32L^2$	$45L^2$
26	$40L^2$	$60.52L^2$
28	$50L^2$	$67.25L^2$
30	$60L^2$	$87.5L^2$

Table 6.2 Maximum pile forces in edge piles for pile cap configurations 2 through 30 assuming all piles have an equivalent cross sectional area (note $A = 1.0\ \text{ft}^2$ not required since the areas cancel out when solving for the actual pile force).

Number of Piles-Configuration	Maximum Force (*k*) in Edge Pile Caused Moment M_x (k-ft)	Maximum Force (*k*) in Edge Pile Caused Moment M_y (k-ft)
2	NA	$\frac{M_y}{L}$
3	$\frac{1.15M_x}{L}$	$\frac{0.58M_y}{L}$
4	$\frac{0.5M_x}{L}$	$\frac{0.5M_y}{L}$
5	$\frac{0.35M_x}{L}$	$\frac{0.35M_y}{L}$
6	$\frac{0.33M_x}{L}$	$\frac{0.25M_y}{L}$
7	$\frac{0.29M_x}{L}$	$\frac{0.33M_y}{L}$
8	$\frac{0.19M_x}{L}$	$\frac{0.22M_y}{L}$
9	$\frac{0.17M_x}{L}$	$\frac{0.17M_y}{L}$
10	$\frac{0.19M_x}{L}$	$\frac{0.17M_y}{L}$
11	$\frac{0.14M_x}{1L}$	$\frac{0.125M_y}{L}$
12	$\frac{0.13M_x}{L}$	$\frac{0.1M_y}{L}$
13	$\frac{0.14M_x}{L}$	$\frac{0.082M_y}{L}$
14	$\frac{0.10M_x}{L}$	$\frac{0.11M_y}{L}$
15	$\frac{0.094M_x}{L}$	$\frac{0.096M_y}{L}$
16	$\frac{0.075M_x}{L}$	$\frac{0.075M_y}{L}$
17	$\frac{0.094M_x}{L}$	$\frac{0.072M_y}{L}$
18	$\frac{0.079M_x}{L}$	$\frac{0.061M_y}{L}$
19	$\frac{0.068M_x}{L}$	$\frac{0.055M_y}{L}$
20	$\frac{0.06M_x}{L}$	$\frac{0.05M_y}{L}$
21	$\frac{0.062M_x}{L}$	$\frac{0.054M_y}{L}$
22	$\frac{0.055M_x}{L}$	$\frac{0.057M_y}{L}$
23	$\frac{0.049M_x}{L}$	$\frac{0.05M_y}{L}$
24	$\frac{0.044M_x}{L}$	$\frac{0.044M_y}{L}$
26	$\frac{0.05M_x}{2L}$	$\frac{0.037M_y}{L}$
28	$\frac{0.04M_x}{L}$	$\frac{0.033M_y}{L}$
30	$\frac{0.033M_x}{L}$	$\frac{0.029M_y}{L}$

A further simplification can be made by noting that the maximum pile force occurs at the extreme edge of the pile cap such that X and Y are not variables but known as a function of the selected center-to-center pile spacing L. To aid the designer in determining the maximum axial force demand on the critical pile in the pile cap caused by bending moments M_x and M_y, Table 6.2 has been developed.

6.3 Tabulated Pile Cap Designs for Combined Gravity and Lateral Loads

Tabulated pile cap designs for combined gravity and lateral loads for the 26 pile cap patterns presented in Fig. 4.4 using allowable pile loads ranging from 40 tons to 400 tons in varying increments are presented in this design guide. To further aid the designer, a spreadsheet is available. PILEGRP-CRSI has been developed by engineering software designer Alex Tomanovich, PE. PILEGRP-CRSI is specific to this design guide and user input is simplified since the user need only select the appropriate pile cap geometry and pile spacing and define the single column actions to fully analyze the pile cap. To download this spreadsheet, go to the Pile Cap Design Guide download page on the CRSI website at ***www.crsi.org/pilecaps.cfm***.

CHAPTER 7
Seismic Design of Pile Caps

7.1 General

In this chapter, an overview of seismic design provisions applicable to pile caps is presented. Although there are a plethora of seismic provisions applicable to specific pile types and their design details below the bottom face of the pile cap and for the supported column above the top face of the pile cap, only a limited number of seismic provisions actually apply to the pile cap itself.

Provisions applicable to the seismic design of pile caps are included in *2012 IBC* Section 1810.3.11 and ACI 318-14 Section 18.3. A cursory overview of the provisions is presented below.

7.2 Seismic Design of Pile Caps per *2012 IBC* Chapter 18

For Seismic Design Categories C, D, E, and F, the following provisions apply (*2012 IBC* Section 1810.3.11.1):

Provisions Applicable to Concrete Piles:

- All piles must be mechanically anchored to the pile cap (whether or not tension is present); dowels and extended strands are explicitly permitted.
- When dowels are used to anchor the pile, deformed bars with full development lengths in tension or compression (as applicable) must be provided per ACI 318-14 Section 25.4.10.1.
- Alternate details resulting in a ductile behavior are permitted so long as hinging occurs in a confined region. No additional guidance is given here.

Provisions Applicable to Steel Pipe, Tube, and H-Piles:

- When pile tension is a design consideration, anchorage of the pile to the cap must be mechanically detailed (i.e., friction may not be considered)
- For concrete filled pipe piles or tubes designed to resist tension, a minimum reinforcement area equal to 0.01 times the cross sectional area inside the walls of the pipe or tube (i.e., concrete fill area) must be developed into the cap and also extend into a concrete plug at least 2 times the required cap embedment but not less than the tension development length of the reinforcement.

Additional requirements apply to Seismic Design Categories D, E, and F as summarized below (*2012 IBC* Section 1810.3.11.2):

Provisions Applicable to All Piles:

- Must be mechanically anchored to the pile cap (whether or not tension and/or pile fixity is present) and designed to resist the combined effect of axial tension and bending moments, as applicable.
- Regardless of the magnitude and source of the axial tension at the pile/cap interface, anchorage across the interface must develop a minimum of 25 percent of the strength of the pile section in tension.
- When pile tension is a design consideration, pile anchorage across the interface must be designed to resist the least of the following:
  - A. For concrete piles – The nominal tensile strength of the longitudinal reinforcement.
  - B. For steel piles – The nominal tensile strength of the steel pile.
  - C. For all piles – The design skin friction resistance force multiplied by 1.3.
  - D. For all piles – The resulting seismic load effect including Ω_0 using load combinations presented in ASCE/SEI 7-10 Sections 12.4.3 and 12.14.3.2 as applicable.
- When pile fixity is a design consideration, pile anchorage across the interface must be designed to resist the least of the following:
  - E. For all piles – The nominal axial, bending, and shear strength of the pile.
  - F. For all piles – The resulting seismic load effect (i.e., axial, bending, and shear demands) including Ω_0 using load combinations presented in ASCE/SEI 7-10 Sections 12.4.3 and 12.14.3.2 as applicable.
- Where columns are part of the seismic lateral force resisting system (i.e., moment frames), the pile cap flexural strength shall exceed the column flexural strength.

For Seismic Design Categories D, E, and F, *2012 IBC* Section 1810.3.12 requires that grade beams comply with ACI 318-14 Section 18.13.3 unless they are designed to resist the seismic load effect including Ω_0 using load combinations presented in ASCE/SEI 7-10 Sections 12.4.3 and 12.14.3.2 as applicable.

Although grade beams may be used jointly as "seismic ties", *2012 IBC* Section 1810.3.13 requires seismic ties in Seismic Design Categories C, D, E, and F that interconnect pile caps that support columns. When grade beams are not used as ties, slabs on grade or beams within slabs on grade are commonly detailed as the required seismic ties. Either way, seismic ties must be detailed to resist, in tension and in compression, a force equal to the lesser of:

A. The larger pile cap or column factored design gravity load times S_{DS} divided by 10, and
B. 25 percent of the smaller pile or column design gravity load

7.3 Seismic Design of Pile Caps per ACI 318-14 Section 18.13

For Seismic Design Categories D, E, and F, the following provisions apply:

Provisions Applicable to Pile Caps:

- All longitudinal reinforcement in columns resisting seismic effects shall be developed into the pile cap (full tension development). Additionally, if the tension forces are from column base fixity, the developed reinforcement, when hooks are used, shall be turned in towards the center of the column (in plan).

- Where column uplift is a design consideration, longitudinal steel shall be placed in the top of the pile cap as required to resist the demand and shall not be less than minimum longitudinal steel as prescribed in ACI 318-14 Section 9.6.1.
- Where seismic induced pile tension is a design consideration, concrete piles anchored with post installed dowels in grout sleeves at the top of the pile shall be anchored to the pile to develop 125 percent of the yield strength of the bars developed into the pile cap.

Provisions Applicable to Grade Beams:

- Where grade beams are detailed as horizontal seismic ties between pile caps (see previous discussion), continuous longitudinal reinforcement must be provided and developed within or beyond the supported column or anchored in the pile cap when terminating the grade beam.
- Where grade beams are detailed as horizontal seismic ties between pile caps (see previous discussion), the grade beams shall be sized such that the smallest cross-sectional dimension of the grade beam is greater than or equal to the column clear spacing divided by 20. However, grade beam cross-sectional dimensions need not exceed 18 in. Closed ties shall be provided in all grade beams used as seismic ties and the spacing of these ties need not exceed the lesser of one-half the smallest cross-sectional dimension of the grade beam and 12 in.

CHAPTER 8
Design Examples

8.1 General

Chapter 8 of the design guide provides a series of design examples where tabulated design solutions obtained using the design provisions presented in Chapters 5 and 6 of this guide are verified using hand calculations.

The examples were selected in order to help the reader fully understand assumptions associated with the design procedures and to provide adequate applications for the different pile cap configurations such that the user could design other pile cap configurations as necessary. Although complete calculations are provided for each pile cap, the main reasons for the selection of each example problem is summarized below.

Example 1: 16 Pile Cap – This example is a symmetrical cap (i.e., square in plan) with two rows of piles on all 4 sides of the column. The larger pile cap plan dimensions result in straight bars and it is one of the easiest pile configurations to work with calculation wise. Low pile service loads are used in the example.

Example 2: 5 Pile Cap – This example is also a symmetrical cap (i.e., square in plan) but it has only 1 row of piles on each side of the column. The smaller pile cap plan dimensions result in hooked bars and it has a unique pile layout. It is the only cap that utilizes 45 degree angles in the pile plan geometry. Moderate pile service loads are used in the example.

Example 3: 6 Pile Cap – This example is an unsymmetrical cap (i.e., rectangular in plan). It was also chosen since it is also one of the special caps where Limit State 4 calculations require an average width "w" in orthogonal directions.

Example 4: 7 Pile Cap – This example is an unsymmetrical cap. It was chosen since it is one of only two caps that are uniquely detailed for round columns (rather than equivalent square columns).

Example 5: 5 Pile Cap – This example was selected as a comparison design with Example 2 and it utilizes high load piles.

Example 6: 16 Pile Cap – This example was selected as a comparison design with Example 1 but it is designed for combined gravity and lateral loading.

Note that as discussed in Chapter 2, the tabulated designs of Chapter 9, are based on an LRFD load combination of $1.6(D + L_{floor})$ in combination with strength reduction factors for shear and bending of 0.85 and 0.90, respectively. Designers can alter the factor of safety against pile cap failure using the associated design spreadsheets. In a special version of the design spreadsheet, designers can specify load factors applicable to $D + L_{floor}$ to account for project specific situations or to account for load factors associated with vertical load types other than dead and live.

As a final note, due to rounding and conservative assumptions made in the following hand calculation examples (such as average effective depth "d"), some of the limit state checks in the following examples are determined to be no good (i.e., labeled "N.G.") as a result of approximately 1 percent to 5 percent overstress which appears to conflict with the tabulated solutions (where these same designs are shown as acceptable). Since CRSI does not encourage the use of a small degree of permissible overstress, the conclusion in the example problems will typically be to use the more accurate tabulated design solution geometry or make the pile cap a few inches thicker so that the limit state check is then satisfied.

8.2 Design Example #1: 16 Piles

Given Information:

Piles

Pile Service Load = $P_{SERVICE}$ = 40 tons (80 kips)

Pile Diameter = 8 in. Pile Spacing = L = 3 ft.

Pile Cap

$f'_c = 3{,}000$ psi	$f_y = 60{,}000$ psi
Cover = 3 in.	$d_c = 10$ in. (assumed 6 in. pile embedment)
$E = 15$ in.	$D_{cap} = 48$ in. (total cap thickness)
Load Factor = 1.6	$\phi = 0.9$ (bending); 0.85 (shear)

Column

$P_u/A_g = 4{,}000$ psi

Solution:

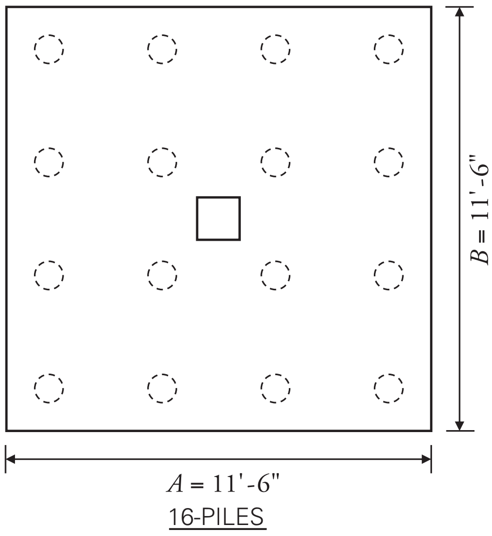


Fig. 8.1 Design example #1.

Column Size Determination

N = number of piles = 16

Net Column Capacity:

$$P_u = 1.6(N)(P_{SERVICE}) - 1.6(A)(B)(D_{cap})\gamma_{concrete}$$

$$P_u = 1.6(16)(80) - 1.6(11.5)(11.5)\left(\frac{48}{12}\right)(0.150) = 1{,}921 \text{ k}$$

Column Size: $c = \sqrt{P_u/4} = \sqrt{1{,}921/4} = 21.91 \text{ in.} (\text{use } 22 \text{ in.})$

Required Flexural Reinforcement

For symmetrical pile cap (i.e., $A = B$ and same pile configuration each direction), only one flexural steel requirement need be calculated since the same amount of steel reinforcement is required in each direction.

$d = D_{cap} - d_c = 48 - 10 = 38$ in.

Summing moments caused by piles to the right of the column about a line $c/4 = 5.5$ in. to the right of the column centroid and reduced by the moment caused by the weight of the pile cap to the right of the line results in the following factored moment M_u (note that piles are assumed to be located 3 in. further away from the column centroid than assumed by the idealized location).

$$\begin{aligned} M_u = {} & 1.6(4 \text{ Piles})(P_{SERVICE})(L/2 - c/4 + 3) \\ & + 1.6(4 \text{ Piles})(P_{SERVICE})(3L/2 - c/4 + 3 \text{ in.}) \\ & - 1.6(A/2 - c/4)(B)(D_{cap})\gamma_{concrete}(A/2 - c/4)/2 \end{aligned}$$

$$\begin{aligned} M_u = {} & 1.6(4)(80)(3/2 - 22/12/4 + 3/12) + 1.6(4)(80)(3(3)/2 \\ & - 22/12/4 + 3/12) - 1.6(11.5/2 - 22/12/4)(11.5)(48/12) \\ & (0.15)(11.5/2 - 22/12/4)/2 = 2{,}704 \text{ k-ft} = 32{,}450 \text{ k-in.} \end{aligned}$$

For a 1 ft strip, M_u can be found by dividing the full moment by B:

$$M_u = (2{,}704 \text{ k-ft})/11.5 \text{ ft} = 235 \text{ k-ft/ft} = 2{,}820 \text{ k-in./ft}$$

The amount of reinforcing steel required to meet the moment demand can be determined as follows:

$$A_s = 0.51d - \sqrt{0.260d^2 - 0.0189M_u}$$

$$A_s = 0.51(38) - \sqrt{0.260(38)^2 - 0.0189(2{,}820)} = 1.43 \text{ in.}^2/\text{ft}$$

Note that formula above is only applicable for 3,000 psi concrete and 60,000 psi reinforcing steel (see Chapter 5 for appropriate equations when using other material properties).

The total steel required for all bars (spanning in the A and the B direction) can be found as:

$$A_s = 1.43(11.5) = 16.33 \text{ in.}^2/\text{ft}$$

Recall that the procedure in this design guide uses the following conservative interpretation to determine if more than the previously determined A_s need be provided:

1. if $A_s \geq hbd$, use A_s
2. if $A_s < \eta bd \leq 4/3A_s$, use ηbd
3. if $0.0018bD_{cap} \leq 4/3A_s < \eta bd$, use $4/3A_s$
4. if $4/3A_s < 0.0018bD_{cap} \leq \eta bd$, use $0.0018bD_{cap}$

In the expressions above, η is the maximum of

A. $200/f_y = 0.00333$ and

B. $\dfrac{3\sqrt{f_c'}}{f_y}$

$$\eta = \text{maximum of } 0.00333 \text{ and } \frac{3\sqrt{3{,}000}}{60{,}000} = 0.00274$$

$$\eta = 0.00333$$

$$\eta bd = 0.00333(11.5{*}12)(38) = 17.5 \text{ in.}^2$$

$$(4/3)A_s = (4/3)(16.33) = 21.8 \text{ in.}^2$$

$$0.0018bD_{cap} = 0.0018(11.5{*}12)(48) = 11.9 \text{ in.}^2$$

Item (2) controls and $A_{s,required} = 17.5 \text{ in.}^2$

Provide 11 #11 bars each way (17.2 in.^{2} – say ok based on average d distance used)

Center to center bar spacing provided is approximately 13.1 in. o.c.

Note that the tabulated 16-pile pile caps do not require hooked bars. Therefore, straight bar development is checked here. For non-epoxy-coated bars $\psi_e = 1.0$. The bars are bottom bars and therefore $\psi_t = 1.0$. For #11 bars, $\psi_s = 1.0$. Assume $K_{tr} = 0$.

c_b is found as the minimum of the nearest cover (3.705 in.) to the center of the developed bar and half the center to center bar spacing (13.1/2 = 6.6 in.).

$c_b = 3.705$ in.

$(c_b + K_{tr})/d_b = (3.705 + 0)/1.41 = 2.63 > 2.5$ N.G., use 2.5 for calculations).

$$l_d = \frac{3}{40}\frac{f_y}{\sqrt{f_c'}}\frac{\psi_t\psi_e\psi_s}{\left(\dfrac{c_b + K_{tr}}{d_b}\right)}d_b = \frac{3}{40}\frac{60{,}000}{\sqrt{3{,}000}}\frac{(1)(1)(1)}{(2.5)}1.41 = 46.3 \text{ in.}$$

The available length is calculated as:

$$l_{available} = \frac{A}{2} - \frac{c}{2} - 3 \text{ in.} = \frac{11.5(12)}{2} - \frac{22}{2} - 3 \text{ in.} = 55 \text{ in.}$$

The #11 bars are acceptable for straight bar development and hooked bars are not required.

Limit State 1 – Traditional ACI Two-Way Shear at $d/2$ from Column Face

Step (1): Based on the geometry shown in Fig. 8.2, determine the number of piles, $N_{outside}$, that are outside the failure pattern shown. Include the 3 in. adverse tolerance effect.

Note that the two-way failure plane is taken at a distance $d/2 = 19$ in. from the face of the column. The distance from the column centroid the failure plane is $c/2 + 19$ in. $= 22/2 + 19 = 30$ in. Note that the distance from the centroid of the column to the nearest pile line is $L/2 + 3$ in. (offset) $= 36/2 + 3 = 21$ in. Since 30 in. is greater than 21 in., all piles adjacent to the column do not provide shear forces to the failure plane (note that 30 in. does not reach the outer piles). Figure 8.2 shows piles contributing to shear in Limit State 1 as shaded. Note that

$b_o = 4(c + d) = 4(60) = 240$ in.

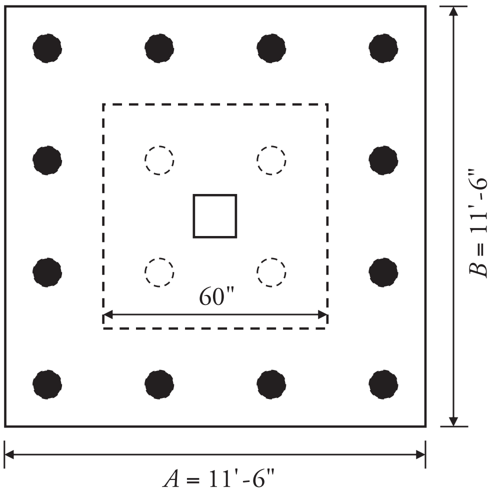


Fig. 8.2

Step (2): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and reduce the total demand by the portion of the pile cap weight that is outside the critical section. In the expression below, c is the equivalent square column side dimension and d is the effective depth of the pile cap. γ_c is the specific weight of concrete (assumed to be normal weight concrete or 150 lb/ft^3 in this guide and associated spreadsheets).

$$V_u = 1.6N_{outside}\left(P_{SERVICE}\right) - 1.6_c ABD_{cap}\frac{AB-(c+d)^2}{AB}$$

$$V_u = 1.6(12\text{ piles})(80\text{ k})$$

$$-1.6(0.150)(11.5)(11.5)\left(\frac{48}{12}\right)\left[\frac{(11.5)(11.5)-\left(\frac{60}{12}\right)^2}{(11.5)(11.5)}\right]$$

$$= 1{,}433\text{ k}$$

Step (3): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism and geometry shown in the Fig. 8.2.

$$\phi V_c = 0.85\left(4\sqrt{f_c'}\right)\left(b_o d\right)$$

$$\phi V_c = 0.85\left(4\sqrt{f_c'}\right)\left(b_o d\right) = 0.85\left(4\sqrt{3{,}000}\right)(240)(38) = 1{,}698{,}000\text{ lb}$$

$$= 1{,}698\text{ k}$$

Step (4): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$\phi V_c = 1{,}698\text{ k} > V_u = 1{,}433\text{ k}$ O.K.

Limit State 2 – Traditional ACI One-Way Shear (through Short Dimension) at *d* from Column Face

Step (1): Based on the geometry shown in Fig. 8.3, determine the number of piles, $N_{outside}$, that are outside the failure pattern shown. Include the 3 in. adverse tolerance effect.

Note that the one-way failure plane is taken at a distance $d = 38$ in. from the face of the column. The distance from the column centroid the failure plane is $c/2 + 38$ in. $= 22/2 + 38 = 49$ in. Note that the distance from the centroid of the column to the nearest pile line is $L/2 + 3$ in. (offset) $= 36/2 + 3 = 21$ in. Since 49 in. is greater than 21 in., piles adjacent to the column do not provide shear forces to the failure plane (note that 49 in. does not reach the outer piles). Fig. 8.3 shows piles contributing to shear in Limit State 2 as shaded. Note that $A = B = 11.5$ ft $= 138$ in.

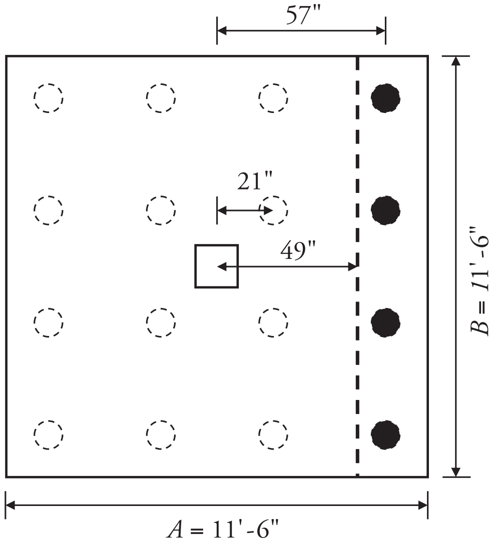


Fig. 8.3

Step (2): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and reduce the total demand by the portion of the pile cap weight that is outside the critical section. In the expression below, c is the equivalent square column side dimension and d is the effective depth of the pile cap. γ_c is the specific weight of concrete (assumed to be normal weight concrete or 150 lb/ft^3 in this guide and associated spreadsheets).

$$V_u = 1.6N_{outside}\left(P_{SERVICE}\right) - 1.6\gamma_c\frac{ABD_{cap}}{2}\frac{A/2-c/2-d}{A/2}$$

$$V_u = 1.6(4\text{ piles})(80\text{ k})$$

$$-1.6(0.150)\frac{(11.5)(11.5)\left(\frac{48}{12}\right)}{2}\frac{\left(\frac{11.5}{2}-\frac{22}{12(2)}-\frac{38}{12}\right)}{11.5/2}$$

$$= 494\text{ k}$$

Step (3): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism and geometry shown in Figure 5.2.

$$\phi V_c = 0.85\left(2\sqrt{f_c'}\right)(Bd)$$

$$\phi V_c = 0.85\left(2\sqrt{f_c'}\right)(Bd) = 0.85\left(2\sqrt{3{,}000}\right)(138)(38)$$

$$= 488{,}000 \text{ lb} = 488 \text{ k}$$

Step (4): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$\phi V_c = 488 \text{ k} < V_u = 494 \text{ k}$ N.G.

At this point, the pile cap thickness should be increased from 48 in. to 49 in. or the designer must make a decision that 1 percent overstress is acceptable. Subsequent calculations are based on the given pile cap thickness of 48 in. Note that the tabulated design tables show that 48 in. is acceptable based on rounding differences and less conservative assumptions.

Limit State 3 – Traditional ACI One-Way Shear (through Long Dimension) at *d* from Column Face

Note that the following calculations are not required since Limit State 2 and Limit State 3 are identical when the pile cap is square in plan.

Step (1): Based on the geometry shown in the figure below, determine the number of piles, $N_{outside}$, that are outside the failure pattern shown. Include the 3 in. adverse tolerance effect.

Note that the one-way failure plane is taken at a distance $d = 38$ in. from the face of the column. The distance from the column centroid the failure plane is $c/2 + 38$ in. $= 22/2 + 38 = 49$ in. Note that the distance from the centroid of the column to the nearest pile line is $L/2 + 3$ in. (offset) $= 36/2 + 3 = 21$ in. Since 49 in. is greater than 21 in., piles adjacent to the column do not provide shear forces to the failure plane (note that 49 in. does not reach the outer piles). Figure 8.4 shows piles contributing to shear in Limit State 2 as shaded. Note that $A = B = 11.5$ ft $= 138$ in.

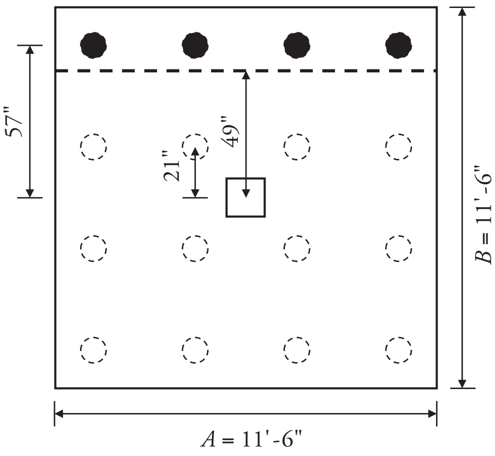


Fig. 8.4

Step (2): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and reduce the total demand by the portion of the pile cap weight that is outside the critical section. In the expression below, c is the equivalent square column side dimension and d is the effective depth of the pile cap. γ_c is the specific weight of concrete (assumed to be normal weight concrete or 150 lb/ft^3 in this guide and associated spreadsheets).

$$V_u = 1.6N_{outside}\left(P_{SERVICE}\right) - 1.6\gamma_c \frac{ABD_{cap}}{2}\,\frac{B/2 - c/2 - d}{B/2}$$

$$V_u = 1.6(4 \text{ piles})(80 \text{ k})$$

$$-1.6(0.150)\frac{(11.5)(11.5)\left(\frac{48}{12}\right)}{2}\,\frac{\left(\frac{11.5}{2} - \frac{22}{12(2)} - \frac{38}{12}\right)}{11.5/2}$$

$$= 494 \text{ k}$$

Step (3): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism and geometry shown in Figure 5.2.

$$\phi V_c = 0.85\left(2\sqrt{f_c'}\right)(Ad)$$

$$\phi V_c = 0.85\left(2\sqrt{f_c'}\right)(Ad) = 0.85\left(2\sqrt{3{,}000}\right)(138)(38)$$

$$= 488{,}000 \text{ lb} = 488 \text{ k}$$

Step (4): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$\phi V_c = 488 \text{ k} < V_u = 494 \text{ k}$ N.G.

At this point, the pile cap thickness should be increased from 48 in. to 49 in. or the designer must make a decision that 1 percent overstress is acceptable. Subsequent calculations are based on the given pile cap thickness of 48 in. Note that the tabulated design tables show that 48 in. is acceptable based on rounding differences and less conservative assumptions.

Limit State 4 – *MODIFIED* ACI Two-Way Shear at Column Face

Step (1): Determine the number of piles, $N_{outside}$, that are outside the failure pattern. Include the 3 in. adverse tolerance effect.

Note that the two-way failure plane is taken at the column face which is a distance $c/2 = 11$ in. from the column centroid. Thus, all piles are located outside the column face and contribute shear at the column face. The distance w taken from the face of the column to the nearest pile center (with offset) is found as $L/2 - c/2 + 3$ in. $= 36/2 - 22/2 + 3 = 10$ in. Note that $b_s = 4c = 4(22) = 88$ in.

Step (2): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and reduce the total demand by the portion of the pile cap weight that is outside the critical section. In the expression below, c is the equivalent square column side dimension and d is the effective depth of the pile cap. γ_c is the specific weight of concrete (assumed to be normal weight concrete or 150 lb/ft^3 in this guide and associated spreadsheets).

$$V_u = 1.6N_{outside}\left(P_{SERVICE}\right) - 1.6\gamma_c ABD_{cap}\frac{AB - c^2}{AB}$$

$$V_u = 1.6(16\text{ piles})(80\text{ k})$$

$$-1.6(0.150)(11.5)(11.5)\left(\frac{48}{12}\right)\left[\frac{(11.5)(11.5)-\left(\frac{22}{12}\right)^2}{(11.5)(11.5)}\right]$$

$$= 1{,}924\text{ k}$$

Step (3): Determine the reduced nominal shear strength, ϕV_c, per Chapter 5.

$$v_c = \left(\frac{d}{w}\right)\left(1+\frac{d}{c}\right)\left(2\sqrt{f_c'}\right) \le 32\sqrt{f_c'}$$

$$v_c = \left(\frac{38}{10}\right)\left(1+\frac{38}{22}\right)\left(2\sqrt{3{,}000}\right) = 1{,}135\text{ psi}$$

$$\le 32\sqrt{f_c'} = 32\sqrt{3{,}000} = 1{,}753\text{ psi}\quad\text{O.K.}$$

$$\phi V_c = 0.85v_c(b_s d)$$

$$\phi Vc = 0.85(1.135)(88)(38) = 3{,}226\text{ k}$$

Step (4): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$$\phi V_c = 3{,}226\text{ k} > V_u = 1{,}924\text{ k}\quad\text{O.K.}$$

Limit State 5 – *MODIFIED* ACI One-Way Shear (through Short Dimension) at Column Face

Step (1): Based on the geometry shown in Fig. 8.5, determine the number of piles, $N_{outside}$, that are outside the failure pattern shown. Include the 3 in. adverse tolerance effect.

Note that the one-way failure plane is taken at the column face which is a distance $c/2 = 11$ in. from the column centroid. Thus, all eight shaded piles shown in Fig. 8.5 contribute shear at the column face. The distance w taken from the face of the column to the nearest pile center (with offset) is found as $L/2 - c/2 + 3$ in. $= 36/2 - 22/2 + 3 = 10$ in.

Step (2): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and reduce the total demand by the portion of the pile cap weight that is outside the critical section. In the expression below, c is the equivalent square column side dimension and d is the effective depth of the pile cap. γ_c is the specific weight of concrete (assumed to be normal weight concrete or 150 lb/ft^3 in this guide and associated spreadsheets).

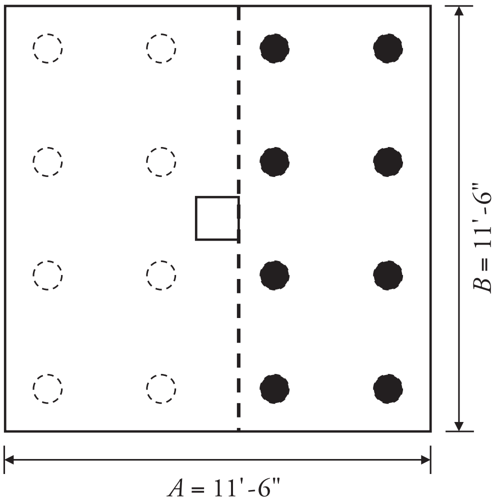


Fig. 8.5

$$V_u = 1.6N_{outside}\left(P_{SERVICE}\right) - 1.6\gamma_c\frac{ABD_{cap}}{2}\frac{A/2 - c/2}{A/2}$$

$$V_u = 1.6(8\text{ piles})(80\text{ k})$$

$$-1.6(0.150)\frac{(11.5)(11.5)\left(\frac{48}{12}\right)}{2}\frac{\left(\frac{11.5}{2}-\frac{22}{12(2)}\right)}{\frac{11.5}{2}}$$

$$= 971\text{ k}$$

Step (3): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism and geometry shown in the figure above. The term $x_{centroid}$ is the perpendicular distance from the critical section to the centroid of the $N_{outside}$ piles. Note that the centroid of the shaded piles is located a distance from the column face equal to $L - c/2 + 3$ in. (offset) $= 36 - 22/2 + 3 = 28$ in.

$$M_u = 1.6N_{outside}\left(P_{SERVICE}\right)x_{centroid} - 1.6\gamma_c\frac{ABD_{cap}}{2}\frac{\left(\frac{A}{2}-\frac{c}{2}\right)}{\frac{A}{2}}\frac{\left(\frac{A}{2}-\frac{c}{2}\right)}{2}$$

$$M_u = 1.6(8\text{ piles})(80\text{ }k)\left(\frac{28}{12}\right)$$

$$-1.6(0.150)\frac{(11.5)(11.5)\left(\frac{48}{12}\right)}{2}\frac{\left(\frac{11.5}{2}-\frac{22}{12(2)}\right)}{\frac{11.5}{2}}\frac{\left(\frac{11.5}{2}-\frac{22}{12(2)}\right)}{2}$$

$$= 2{,}260\text{ k-ft} = 27{,}120\text{ k-in.}$$

$$v_c = \left(\frac{d}{w}\right)\left[3.5-2.5\left(\frac{M_u}{V_u d}\right)\right]\left[1.9\sqrt{f_c'}+0.1\sqrt{f_c'}\left(\frac{V_u d}{M_u}\right)\right] \le 10\sqrt{f_c'}$$

$$v_c = \left(\frac{38}{10}\right)\left[3.5-2.5\left(\frac{27{,}120}{971(38)}\right)\right]$$

$$\left[1.9\sqrt{3{,}000}+0.1\sqrt{3{,}000}\left(\frac{971(38)}{27{,}120}\right)\right]$$

$$= 705\text{ psi} \le 10\sqrt{f_c'} = 10\sqrt{3{,}000} = 548\text{ psi}\quad\text{N.G.}$$

Therefore,
$v_c = 548\text{ psi}$

$\phi V_c = 0.85 v_c(Bd) = 0.85(0.548)(138)(38) = 2{,}440\text{ k}$

Step (4): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$\phi V_c = 2{,}440\text{ k} > V_u = 971\text{ k}$ O.K.

Limit State 6 – *MODIFIED* ACI One-Way Shear (through Long Dimension) at Column Face

Note that the following calculations are not required since Limit State 5 and Limit State 6 are identical when the pile cap is square in plan.

Step (1): Based on the geometry shown in the figure below, determine the number of piles, $N_{outside}$, that are outside the failure pattern shown. Include the 3 in. adverse tolerance effect.

Note that the one-way failure plane is taken at the column face which is a distance $c/2 = 11$ in. from the column centroid. Thus, all eight shaded piles shown in Fig. 8.6 contribute shear at the column face. The distance w taken from the face of the column to the nearest pile center (with offset) is found as $L/2 - c/2 + 3\text{ in.} = 36/2 - 22/2 + 3 = 10\text{ in.}$

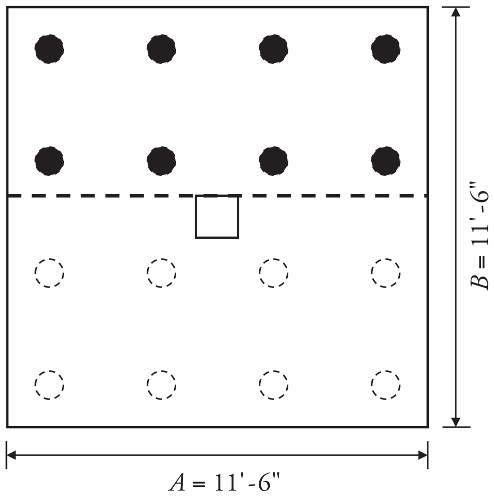


Fig. 8.6

Step (2): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and reduce the total demand by the portion of the pile cap weight that is outside the critical section. In the expression below, c is the equivalent square column side dimension and d is the effective depth of the pile cap. γ_c is the specific weight of concrete (assumed to be normal weight concrete or 150 lb/ft^3 in this guide and associated spreadsheets).

$$V_u = 1.6N_{outside}\left(P_{SERVICE}\right) - 1.6\gamma_c \frac{ABD_{cap}}{2}\frac{B/2 - c/2}{B/2}$$

$$V_u = 1.6(8\text{ piles})(80\text{ k}) - 1.6(0.150)\frac{(11.5)(11.5)\left(\frac{48}{12}\right)}{2}\frac{\left(\frac{11.5}{2}-\frac{22}{12(2)}\right)}{\frac{11.5}{2}}$$

$$= 971\text{ k}$$

Step (3): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism and geometry shown in Fig. 8.6. The term $y_{centroid}$ is the perpendicular distance from the critical section to the centroid of the $N_{outside}$ piles. Note that the centroid of the shaded piles is located a distance from the column face equal to $L - c/2 + 3$ in. (offset) $= 36 - 22/2 + 3 = 28$ in.

$$M_u = 1.6N_{outside}\left(P_{SERVICE}\right)y_{centroid} - 1.6\gamma_c\frac{ABD_{cap}}{2}\frac{\left(\frac{B}{2}-\frac{c}{2}\right)}{\frac{B}{2}}\frac{\left(\frac{B}{2}-\frac{c}{2}\right)}{2}$$

$$M_u = 1.6(8\text{ piles})(80\ k)\left(\frac{28}{12}\right) - 1.6(0.150)\frac{(11.5)(11.5)\left(\frac{48}{12}\right)}{2}\frac{\left(\frac{11.5}{2}-\frac{22}{12(2)}\right)}{\frac{11.5}{2}}\frac{\left(\frac{11.5}{2}-\frac{22}{12(2)}\right)}{2}$$

$$= 2{,}260\text{ k-ft} = 27{,}120\text{ k-in.}$$

$$v_c = \left(\frac{d}{w}\right)\left[3.5 - 2.5\left(\frac{M_u}{V_u d}\right)\right]\left[1.9\sqrt{f_c'} + 0.1\sqrt{f_c'}\left(\frac{V_u d}{M_u}\right)\right] \le 10\sqrt{f_c'}$$

$$v_c = \left(\frac{38}{10}\right)\left[3.5 - 2.5\left(\frac{27{,}120}{971(38)}\right)\right]\left[1.9\sqrt{3{,}000} + 0.1\sqrt{3{,}000}\left(\frac{971(38)}{27{,}120}\right)\right]$$

$$= 705\text{ psi} \le 10\sqrt{f_c'} = 10\sqrt{3{,}000} = 548\text{ psi} \quad \text{N.G.}$$

Therefore,
$v_c = 548\text{ psi}$

$\phi V_c = 0.85 v_c(Ad) = 0.85(0.548)(138)(38) = 2{,}440\text{ k}$

Step (4): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$\phi V_c = 2{,}440\text{ k} > V_u = 971\text{ k}$ O.K.

Limit State P1 – Two-Way Shear at Single Pile

Step (1): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and conservatively neglect any reduction in shear due to the weight of concrete tributary to one pile.

$V_u = 1.6P_{SERVICE} = 1.6(80) = 128\text{ k}$

Step (2): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism. Round or equivalent round piles are assumed in this analysis. d_p is the actual or equivalent pile diameter. d is the effective depth of the pile cap.

$$b_o = \pi(d_p + d) = \pi(8 + 38) = 144.5 \text{ in.}$$

$$\phi V_c = 0.85\left(4\sqrt{f_c'}\right)(b_o d) = 0.85\left(4\sqrt{3{,}000}\right)(144.5)(38)$$

$$= 1{,}022{,}000 \text{ lb} = 1{,}022 \text{ k}$$

Step (3): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$$\phi V_c = 1{,}022 \text{ k} > V_u = 128 \text{ k} \quad \text{O.K.}$$

Limit State P2 – Two-Way Shear at Two Adjacent Piles

Step (1): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and conservatively neglect any reduction in shear due to the weight of concrete tributary to the two piles considered in this analysis.

$$V_u = 2(1.6P_{SERVICE}) = 2(1.6)(80) = 256 \text{ k}$$

Step (2): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism. Round or equivalent round piles are assumed in this analysis. d_p is the actual or equivalent pile diameter. d is the effective depth of the pile cap. L is the center to center pile spacing.

$$b_o = \pi(d_p + d) + 2L = \pi(8 + 38) + 2(36) = 216 \text{ in.}$$

$$\phi V_c = 0.85\left(4\sqrt{f_c'}\right)(b_o d) = 0.85\left(4\sqrt{3{,}000}\right)(216)(38)$$

$$= 1{,}530{,}000 \text{ lb} = 1{,}530 \text{ k}$$

Step (3): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$$\phi V_c = 1{,}530 \text{ k} > V_u = 256 \text{ k} \quad \text{O.K.}$$

Limit State P3 – Two-Way Shear at Corner Pile

Step (1): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and conservatively neglect any reduction in shear due to the weight of concrete tributary to the corner pile.

$$V_u = 1.6P_{SERVICE} = 1.6(80) = 128 \text{ k}$$

Step (2): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism. Round or equivalent round piles are assumed in this analysis. d_p is the actual or equivalent pile diameter. d is the effective depth of the pile cap. E is the center of corner pile to edge of cap dimension in plan.

$$b_o = \frac{\pi\left(d_p + d\right)}{4} + 2E = \frac{\pi(8+38)}{4} + 2(15) = 66.1 \text{ in.}$$

$$\phi V_c = 0.85\left(4\sqrt{f_c'}\right)(b_o d) = 0.85\left(4\sqrt{3{,}000}\right)(66.1)(38)$$

$$= 468{,}000 \text{ lb} = 468 \text{ k}$$

Step (3): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$$\phi V_c = 468 \text{ k} > V_u = 128 \text{ k} \quad \text{O.K.}$$

Limit State P4 – One-Way Shear at Corner Pile

Step (1): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and conservatively neglect any reduction in shear due to the weight of concrete tributary to the corner pile.

$$V_u = 1.6P_{SERVICE} = 1.6(80) = 128 \text{ k}$$

Step (2): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism. Round or equivalent round piles are assumed in this analysis. d_p is the actual or equivalent pile diameter. d is the effective depth of the pile cap. E is the center of corner pile to edge of cap dimension in plan. The length of the critical section, b, can be found using simple geometry.

$$b = 2\left(E\sqrt{2} + d_p/2 + d\right) \quad (d \le 13 \text{ in. in this equation only; no limit on } d \text{ for } \phi V_c)$$

$$b = 2\left(15\sqrt{2} + 8/2 + 13\right) = 76.7 \text{ in.}$$

$$\phi V_c = 0.85\left(2\sqrt{f_c'}\right)(bd) = 0.85\left(2\sqrt{3{,}000}\right)(76.7)(38)$$

$$= 271{,}000 \text{ lb} = 271 \text{ k}$$

Step (3): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$$\phi V_c = 271 \text{ k} > V_u = 128 \text{ k} \quad \text{O.K.}$$

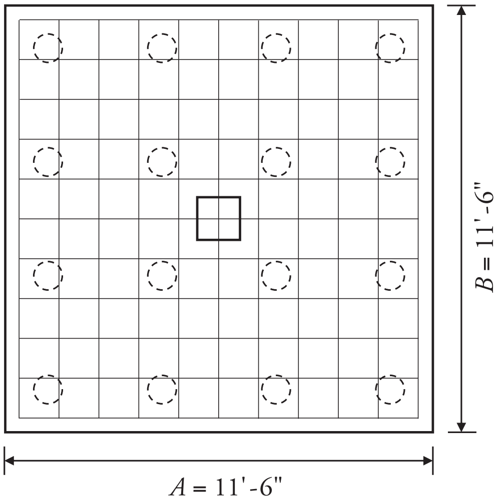


Fig. 8.7 Reinforcement Summary for design example #1: Use 11 #11 bars each way

8.3 Design Example #2: 5 Piles

Given Information:

Piles

Pile Service Load = $P_{SERVICE}$ =100 tons (200 kips)

Pile Diameter = 10 in.   Pile Spacing = L = 3 ft.
Note only cap with 45° pile configuration

Pile Cap

$f'_c = 3{,}000$ psi $f_y = 60{,}000$ psi
Cover = 3 in. d_c = 10 in. (assumed 6 in. pile embedment)
E = 21 in. D_{cap} = 43 in. (total cap thickness)
Load Factor = 1.6 ϕ = 0.9 (bending); 0.85 (shear)

Column

$P_u/A_g = 4{,}000$ psi

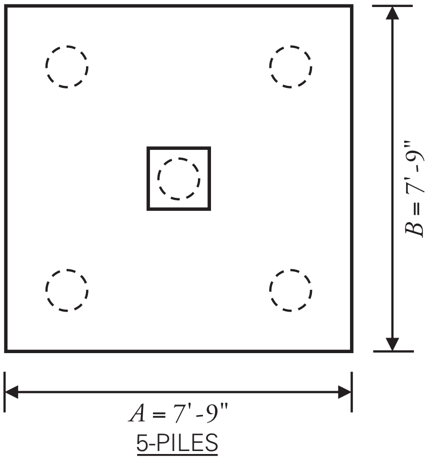


Fig. 8.8 Design example #2.

Solution:

Column Size Determination

N = number of piles = 5

Net Column Capacity:
$P_u = 1.6(N)(P_{SERVICE}) - 1.6(A)(B)(D_{cap})\gamma_{concrete}$

$$P_u = 1.6(5)(200) - 1.6(7.75)(7.75)\left(\frac{43}{12}\right)(0.150) = 1{,}600 \text{ k}$$

Column Size: $c = \sqrt{P_u/4} = \sqrt{1{,}600/4} = 20 \text{ in.} (\text{use } 20 \text{ in.})$

Required Flexural Reinforcement

For symmetrical pile cap (i.e., $A = B$ and same pile configuration each direction), only one flexural steel requirement need be calculated since the same amount of steel reinforcement is required in each direction.

$d = D_{cap} - d_c = 43 - 10 = 33$ in.

Summing moments caused by piles to the right of the column about a line $c/4$ = 5 in. to the right of the column centroid and reduced by the moment caused by the weight of the pile cap to the right of the line results in the following factored moment M_u (note that piles are assumed to be located 3 in. further away from the column centroid than assumed by the idealized location).

$$M_u = 1.6(2 \text{ Piles})(P_{SERVICE})(0.7071L - c/4 + 3 \text{ in.}) - 1.6(A/2 - c/4)(B)(D_{cap})\gamma_{concrete}(A/2 - c/4)/2$$

$$M_u = 1.6(2)(200)[0.7071(3) - 20/12/4 + 3/12] - 1.6(7.75/2 - 20/12/4)(7.75)(43/12)(0.15)(7.75/2 - 20/12/4)/2 = 1{,}211 \text{ k-ft} = 14{,}533 \text{ k-in.}$$

For a 1 ft strip, M_u can be found by dividing the full moment by B:

M_u = (1,211 k-ft)/7.75 ft = 156 k-ft/ft = 1,880 k-in./ft

The amount of reinforcing steel required to meet the moment demand can be determined as follows:

$$A_s = 0.51d - \sqrt{0.260d^2 - 0.0189M_u}$$

$$A_s = 0.51(33) - \sqrt{0.260(33)^2 - 0.0189(1{,}880)} = 1.09 \text{ in.}^2/\text{ft}$$

Note that formula above is only applicable for 3,000 psi concrete and 60,000 psi reinforcing steel (see Chapter 5 for appropriate equations when using other material properties).

The total steel required for all bars (spanning in the A and the B direction) can be found as:

$A_s = 1.09(7.75) = 8.45 \text{ in.}^2/\text{ft}$

Recall that the procedure in this design guide uses the following conservative interpretation to determine if more than the previously determined A_s need be provided:

1. if $A_s \geq \eta bd$, use A_s
2. if $A_s < \eta bd \leq 4/3A_s$, use ηbd
3. if $0.0018bD_{cap} \leq 4/3A_s < \eta bd$, use $4/3A_s$
4. if $4/3A_s < 0.0018bD_{cap} \leq \eta bd$, use $0.0018bD_{cap}$

In the expressions above, η is the maximum of

A. $200/f_y = 0.00333$ and

B. $\dfrac{3\sqrt{f'_c}}{f_y}$

$$\eta = \text{maximum of } 0.00333 \text{ and } \frac{3\sqrt{3{,}000}}{60{,}000} = 0.00274$$

$\eta = 0.00333$

$\eta bd = 0.00333(7.75*12)(33) = 10.22 \text{ in.}^2$

$(4/3)A_s = (4/3)(8.45) = 11.3 \text{ in.}^2$

$0.0018bD_{cap} = 0.0018(7.75*12)(43) = 7.20 \text{ in.}^2$

Item (2) controls and $A_{s,\text{required}} = 10.22 \text{ in.}^2$

Provide 13 #8 bars each way (10.2 in.^{2} O.K. and based on average d distance used)

Note that 5 pile caps require hooked bars in each direction. Therefore, hooked bar development is checked here. For non-epoxy-coated bars $\psi_e = 1.0$.

The length available to develop the longitudinal bar past the last pile is $E' = E - 3$ in. (offset) = 21 − 3 = 18 in.

$$l_{dh} = 0.7(0.02)\frac{\psi_e f_y}{\sqrt{f_c'}} d_b = 0.7(0.02)\frac{(1)60,000}{\sqrt{3,000}}(1$$

$$= 15.3 \text{ in.} < 18 \text{ in.} \quad \text{O.K.}$$

The #8 bars are acceptable for hooked bar development.

Limit State 1 – Traditional ACI Two-Way Shear at *d*/2 from Column Face

Step (1): Based on the geometry in Fig. 8.9, determine the number of piles, $N_{outside}$, that are outside the failure pattern shown. Include the 3 in. adverse tolerance effect.

Note that the two-way failure plane is taken at a distance $d/2 = 16.5$ in. from the face of the column. The distance from the column centroid the failure plane is $c/2 + 16.5$ in. $= 20/2 + 16.5 = 26.5$ in. Note that the distance from the centroid of the column to the nearest pile line is $0.7071L + 3$ in. (offset) $= 0.7071(36) + 3 = 28.5$ in. Since 28.5 in. is greater than 26.5 in., only the center pile directly under the column does not provide shear to the failure plane. Fig. 8.9 shows piles contributing to shear in Limit State 1 as shaded. Note that $b_o = 4(c + d) = 4(53) = 212$ in.

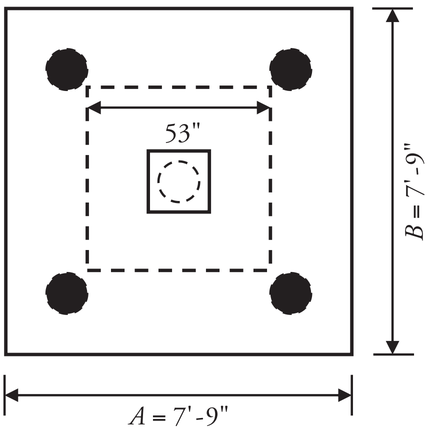


Fig. 8.9

Step (2): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and reduce the total demand by the portion of the pile cap weight that is outside the critical section. In the expression below, c is the equivalent square column side dimension and d is the effective depth of the pile cap. γ_c is the specific weight of concrete (assumed to be normal weight concrete or 150 lb/ft^3 in this guide and associated spreadsheets).

$$V_u = 1.6N_{outside}(P_{SERVICE}) - 1.6\gamma_c ABD_{cap}\frac{AB-(c+d)^2}{AB}$$

$$V_u = 1.6(4 \text{ piles})(200 \text{ k})$$

$$-1.6(0.150)(7.75)(7.75)\left(\frac{43}{12}\right)\left[\frac{(7.75)(7.75)-\left(\frac{53}{12}\right)^2}{(7.75)(7.75)}\right]$$

$$= 1,245 \text{ k}$$

Step (3): Determine the reduced nominal shear strength, ϕVc, for the failure mechanism and geometry shown in the Fig. 8.9.

$$\phi V_c = 0.85\left(4\sqrt{f_c'}\right)(b_o d) = 0.85\left(4\sqrt{3,000}\right)(212)(33)$$

$$= 1,303,000 \text{ lb} = 1,303 \text{ k}$$

Step (4): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$$\phi V_c = 1,303 \text{ k} > V_u = 1,245 \text{ k} \quad \text{O.K.}$$

Limit State 2 – Traditional ACI One-Way Shear (through Short Dimension) at *d* from Column Face

Step (1): Based on the geometry shown in Fig. 8.9, determine the number of piles, $N_{outside}$, that are outside the failure pattern. Include the 3 in. adverse tolerance effect.

Note that the one-way failure plane is taken at a distance $d = 33$ in. from the face of the column. The distance from the column centroid the failure plane is $c/2 + 33$ in. $= 20/2 + 33 = 43$ in. Note that the distance from the centroid of the column to the nearest pile line is $0.7071L + 3$ in. (offset) $= 0.7071(36) + 3 = 28.5$ in. Since 43 in. is greater than 28.5 in., no piles provide shear forces to the failure plane. *Therefore, this limit state is not applicable.*

Limit State 3 – Traditional ACI One-Way Shear (through Long Dimension) at *d* from Column Face

Note that the following calculations are not required since Limit State 2 and Limit State 3 are identical when the pile cap is square in plan.

Step (1): Based on the geometry shown in the Fig. 8.9, determine the number of piles, $N_{outside}$, that are outside the failure pattern. Include the 3 in. adverse tolerance effect.

Note that the one-way failure plane is taken at a distance $d = 33$ in. from the face of the column. The distance from the column centroid the failure plane is $c/2 + 33$ in. $= 20/2 + 33 = 43$ in. Note that the distance from the centroid of the column to the nearest pile line is $0.7071L + 3$ in. (offset) $= 0.7071(36) + 3 = 28.5$ in. Since 43 in. is greater than 28.5 in., no piles provide shear forces to the failure plane. *Therefore, this limit state is not applicable.*

Limit State 4 – *MODIFIED* ACI Two-Way Shear at Column Face

Step (1): Determine the number of piles, $N_{outside}$, that are outside the failure pattern. Include the 3 in. adverse tolerance effect.

Note that the two-way failure plane is taken at the column face which is a distance $c/2 = 10$ in. from the column centroid. Thus, all piles except the pile directly under the column are located outside the column face and contribute shear at the column face. The distance w taken from the face of the column to the nearest pile center (with offset) is found as $0.7071L - c/2 + 3$ in. $= 0.7071(36) - 20/2 + 3 = 18.5$ in. Note that $b_s = 4c = 4(20) = 80$ in.

Step (2): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and reduce the total demand by the portion of the pile cap weight that is outside the critical section. In the expression below, c is the equivalent square column side dimension and d is the effective depth of the pile cap. γ_c is the specific weight of concrete (assumed to be normal weight concrete or 150 lb/ft^3 in this guide and associated spreadsheets).

$$V_u = 1.6N_{outside}\left(P_{SERVICE}\right) - 1.6\gamma_c ABD_{cap}\frac{AB - c^2}{AB}$$

$$V_u = 1.6(4\text{ piles})(200\text{ k})$$

$$-1.6(0.150)(7.75)(7.75)\left(\frac{43}{12}\right)\left[\frac{(7.75)(7.75) - \left(\frac{20}{12}\right)^2}{(7.75)(7.75)}\right]$$

$$= 1{,}231\text{ k}$$

Step (3): Determine the reduced nominal shear strength, ϕV_c, per Chapter 5.

$$v_c = \left(\frac{d}{w}\right)\left(1 + \frac{d}{c}\right)\left(2\sqrt{f_c'}\right) \le 32\sqrt{f_c'}$$

$$v_c = \left(\frac{33}{18.5}\right)\left(1 + \frac{33}{20}\right)\left(2\sqrt{3{,}000}\right) = 517\text{ psi}$$

$$\le 32\sqrt{f_c'} = 32\sqrt{3{,}000} = 1{,}753\text{ psi} \quad \text{O.K.}$$

$$\phi V_c = 0.85 v_c (b_s d)$$

$$\phi V_c = 0.85(0.517)(80)(33) = 1{,}160\text{ k}$$

Step (4): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$$\phi V_c = 1{,}160\text{ k} < V_u = 1{,}231\text{ k} \quad \text{N.G.}$$

At this point, the pile cap thickness should be increased from 43 in. to 45 in. or the designer must make a decision that 5 percent overstress is acceptable. Subsequent calculations are based on the given pile cap thickness of 43 in. Note that the tabulated design tables show that 43 in. is acceptable based on rounding differences and less conservative assumptions.

Limit State 5 – *MODIFIED* ACI One-Way Shear (through Short Dimension) at Column Face

Step (1): Based on the geometry shown in Fig. 8.10, determine the number of piles, $N_{outside}$, that are outside the failure pattern shown. Include the 3 in. adverse tolerance effect.

Note that the one-way failure plane is taken at the column face which is a distance $c/2 = 10$ in. from the column centroid. Thus, the two shaded piles shown in Fig. 8.10 contribute shear at the column face. The distance w taken from the face of the column to the nearest pile center (with offset) is found as $0.7071L - c/2 + 3$ in. $= 0.7071(36) - 20/2 + 3 = 18.5$ in.

Step (2): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and reduce the total demand by the portion of the pile cap weight that is outside the critical section. In the expression below, c is the equivalent square column side dimension and d is the effective depth of the pile cap. γ_c is the specific weight of concrete (assumed to be normal weight concrete or 150 lb/ft^3 in this guide and associated spreadsheets).

$$V_u = 1.6N_{outside}\left(P_{SERVICE}\right) - 1.6\gamma_c\frac{ABD_{cap}}{2}\,\frac{A/2 - c/2}{A/2}$$

$$V_u = 1.6(2\text{ piles})(200\text{ k})$$

$$-1.6(0.150)\frac{(7.75)(7.75)\left(\frac{43}{12}\right)}{2}\,\frac{\left(\frac{7.75}{2} - \frac{20}{12(2)}\right)}{\frac{7.75}{2}} = 620\text{ k}$$

Step (3): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism and geometry shown in Fig. 8.10. The term $x_{centroid}$ is the perpendicular distance from the critical section to the centroid of the $N_{outside}$ piles. Note that the centroid of the shaded piles is located a distance from the column face equal to $0.7071L - c/2 + 3$ in. (offset) $= 0.7071(36) - 20/2 + 3 = 18.5$ in.

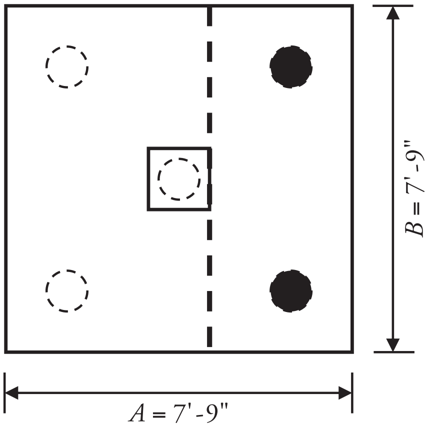


Fig. 8.10

$$M_u = 1.6N_{outside}(P_{SERVICE})x_{centroid} - 1.6\gamma_c\frac{ABD_{cap}}{2}\frac{\left(\frac{A}{2}-\frac{c}{2}\right)}{\frac{A}{2}}\frac{\left(\frac{A}{2}-\frac{c}{2}\right)}{2}$$

$$M_u = 1.6(2\text{ piles})(200\ k)\left(\frac{18.5}{12}\right)$$

$$-1.6(0.150)\frac{(7.75)(7.75)\left(\frac{43}{12}\right)}{2}\frac{\left(\frac{7.75}{2}-\frac{20}{12(2)}\right)}{\frac{7.75}{2}}\frac{\left(\frac{7.75}{2}-\frac{20}{12(2)}\right)}{2}$$

$$= 950\text{ k-ft} = 11{,}470\text{ k-in.}$$

$$v_c = \left(\frac{d}{w}\right)\left[3.5-2.5\left(\frac{M_u}{V_u d}\right)\right]\left[1.9\sqrt{f_c'}+0.1\sqrt{f_c'}\left(\frac{V_u d}{M_u}\right)\right] \le 10\sqrt{f_c'}$$

$$v_c = \left(\frac{33}{18.5}\right)\left[3.5-2.5\left(\frac{11{,}470}{620(33)}\right)\right]$$

$$\left[1.9\sqrt{3{,}000}+0.1\sqrt{3{,}000}\left(\frac{620(33)}{11{,}470}\right)\right]$$

$$= 426\text{ psi} \le 10\sqrt{f_c'} = 10\sqrt{3{,}000} = 548\text{ psi} \qquad \text{O.K.}$$

Therefore,
$v_c = 426$ psi

$\phi V_c = 0.85 v_c(Bd) = 0.85(0.426)(93)(33) = 1{,}111$ k

Step (4): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$\phi V_c = 1{,}111\text{ k} > V_u = 620\text{ k}$ O.K.

Limit State 6 – *MODIFIED* ACI One-Way Shear (through Long Dimension) at Column Face

Note that the following calculations are not required since Limit State 5 and Limit State 6 are identical when the pile cap is square in plan.

Step (1): Based on the geometry shown in Fig. 8.11, determine the number of piles, $N_{outside}$, that are outside the failure pattern shown. Include the 3 in. adverse tolerance effect.

Note that the one-way failure plane is taken at the column face which is a distance $c/2 = 10$ in. from the column centroid. Thus, the two shaded piles shown in Fig. 8.11 contribute shear at the column face. The distance w taken from the face of the column to the nearest pile center (with offset) is found as $0.7071L - c/2 + 3$ in. $= 0.7071(36) - 20/2 + 3 = 18.5$ in.

Step (2): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and reduce the total demand by the portion of the pile cap weight that is outside the critical section. In the expression below, c is the equivalent square column side dimension and d is the effective depth of the pile cap. γ_c is the specific weight of concrete (assumed to be normal weight concrete or 150 lb/ft^3 in this guide and associated spreadsheets).

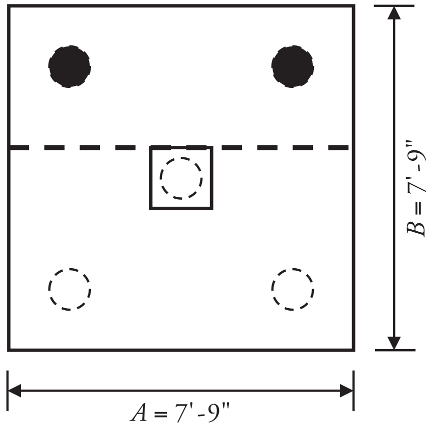


Fig. 8.11

$$V_u = 1.6N_{outside}(P_{SERVICE}) - 1.6\gamma_c\frac{ABD_{cap}}{2}\frac{B/2-c/2}{B/2}$$

$V_u = 1.6(2\text{ piles})(200\text{ k})$

$$-1.6(0.150)\frac{(7.75)(7.75)\left(\frac{43}{12}\right)}{2}\frac{\left(\frac{7.75}{2}-\frac{20}{12(2)}\right)}{\frac{7.75}{2}} = 620\text{ k}$$

Step (3): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism and geometry shown in Fig. 8.11. The term $y_{centroid}$ is the perpendicular distance from the critical section to the centroid of the $N_{outside}$ piles. Note that the centroid of the shaded piles is located a distance from the column face equal to $L - c/2 + 3$ in. (offset) $= 36 - 22/2 + 3 = 28$ in.

$$M_u = 1.6N_{outside}(P_{SERVICE})y_{centroid} - 1.6\gamma_c\frac{ABD_{cap}}{2}\frac{\left(\frac{B}{2}-\frac{c}{2}\right)}{\frac{B}{2}}\frac{\left(\frac{B}{2}-\frac{c}{2}\right)}{2}$$

$$M_u = 1.6(2\text{ piles})(200\ k)\left(\frac{18.5}{12}\right)$$

$$-1.6(0.150)\frac{(7.75)(7.75)\left(\frac{43}{12}\right)}{2}\frac{\left(\frac{7.75}{2}-\frac{20}{12(2)}\right)}{\frac{7.75}{2}}\frac{\left(\frac{7.75}{2}-\frac{20}{12(2)}\right)}{2}$$

$$= 950\text{ k-ft} = 11{,}470\text{ k-in.}$$

$$v_c = \left(\frac{d}{w}\right)\left[3.5-2.5\left(\frac{M_u}{V_u d}\right)\right]\left[1.9\sqrt{f_c'}+0.1\sqrt{f_c'}\left(\frac{V_u d}{M_u}\right)\right] \le 10\sqrt{f_c'}$$

$$v_c = \left(\frac{33}{18.5}\right)\left[3.5-2.5\left(\frac{11{,}470}{620(33)}\right)\right]$$

$$\left[1.9\sqrt{3{,}000}+0.1\sqrt{3{,}000}\left(\frac{620(33)}{11{,}470}\right)\right]$$

$$= 426\text{ psi} \le 10\sqrt{f_c'} = 10\sqrt{3{,}000} = 548\text{ psi} \qquad \text{O.K.}$$

Therefore,

$v_c = 426$ psi

$\phi V_c = 0.85 v_c(Ad) = 0.85(0.426)(93)(33) = 1{,}111$ k

Step (4): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$\phi V_c = 1{,}111 \text{ k} > V_u = 620 \text{ k}$ O.K.

Limit State P1 – Two-Way Shear at Single Pile

Step (1): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and conservatively neglect any reduction in shear due to the weight of concrete tributary to one pile.

$V_u = 1.6P_{SERVICE} = 1.6(200) = 320$ k

Step (2): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism. Round or equivalent round piles are assumed in this analysis. d_p is the actual or equivalent pile diameter. d is the effective depth of the pile cap.

$b_o = \pi(d_p + d) = \pi(10 + 33) = 135$ in.

$$\phi V_c = 0.85\left(4\sqrt{f_c'}\right)\left(b_o d\right) = 0.85\left(4\sqrt{3{,}000}\right)(135)(33)$$

$$= 829{,}600 \text{ lb} = 830 \text{ k}$$

Step (3): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$\phi V_c = 830 \text{ k} > V_u = 320 \text{ k}$ O.K.

Limit State P2 – Two-Way Shear at Two Adjacent Piles

Step (1): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and conservatively neglect any reduction in shear due to the weight of concrete tributary to the two piles considered in this analysis.

$V_u = 2(1.6P_{SERVICE}) = 2(1.6)(200) = 640$ k

Step (2): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism. Round or equivalent round piles are assumed in this analysis. d_p is the actual or equivalent pile diameter. d is the effective depth of the pile cap. L is the center to center pile spacing.

$b_o = \pi(d_p + d) + 2L = \pi(10 + 33) + 2(36) = 207$ in.

$$\phi V_c = 0.85\left(4\sqrt{f_c'}\right)\left(b_o d\right) = 0.85\left(4\sqrt{3{,}000}\right)(207)(33)$$

$$= 1{,}272{,}000 \text{ lb} = 1{,}272 \text{ k}$$

Step (3): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$\phi V_c = 1{,}272 \text{ k} > V_u = 640 \text{ k}$ O.K.

Limit State P3 – Two-Way Shear at Corner Pile

Step (1): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and conservatively neglect any reduction in shear due to the weight of concrete tributary to the corner pile.

$V_u = 1.6P_{SERVICE} = 1.6(200) = 320$ k

Step (2): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism. Round or equivalent round piles are assumed in this analysis. d_p is the actual or equivalent pile diameter. d is the effective depth of the pile cap. E is the center of corner pile to edge of cap dimension in plan.

$$b_o = \frac{\pi\left(d_p + d\right)}{4} + 2E = \frac{\pi(10+33)}{4} + 2(21) = 75.8 \text{ in.}$$

$$\phi V_c = 0.85\left(4\sqrt{f_c'}\right)\left(b_o d\right) = 0.85\left(4\sqrt{3{,}000}\right)(75.8)(33)$$

$$= 466{,}000 \text{ lb} = 466 \text{ k}$$

Step (3): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$\phi V_c = 466 \text{ k} > V_u = 320 \text{ k}$ O.K.

Limit State P4 – One-Way Shear at Corner Pile

Step (1): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and conservatively neglect any reduction in shear due to the weight of concrete tributary to the corner pile.

$V_u = 1.6P_{SERVICE} = 1.6(200) = 320$ k

Step (2): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism. Round or equivalent round piles are assumed in this analysis. d_p is the actual or equivalent pile diameter. d is the effective depth of the pile cap. E is the center of corner pile to edge of cap dimension in plan. The length of the critical section, b, can be found using simple geometry.

$b = 2\left(E\sqrt{2} + d_p/2 + d\right)$ ($d \le 13$ in. in this equation only; no limit on d for ϕV_c)

$$b = 2\left(21\sqrt{2} + 10/2 + 13\right) = 95.4 \text{ in.}$$

$$\phi V_c = 0.85\left(2\sqrt{f_c'}\right)\left(bd\right) = 0.85\left(2\sqrt{3{,}000}\right)(95.4)(33)$$

$$= 293{,}000 \text{ lb} = 293 \text{ k}$$

Step (3): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$\phi V_c = 293 \text{ k} < V_u = 320 \text{ k}$ N.G.

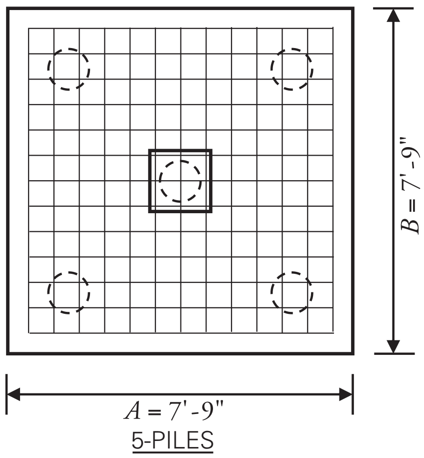


Fig. 8.12 Reinforcement Summary for design example #2: Use 13 #8 bars each way.

Based only on these hand calculations, the pile cap thickness should be increased from 43 in. to 46 in. or the designer could make a decision that 9 percent overstress is acceptable. Subsequent calculations are based on the given pile cap thickness of 43 in. since the tabulated design tables show that 43 in. is acceptable based on rounding differences and less conservative assumptions. In this case, for example, the tabulated values include the reduction in shear due to cap weight outside the critical section.

8.4 Design Example #3: 6 Piles

Given Information:

Piles

Pile Service Load = $P_{SERVICE}$ = 100 tons (200 kips)

Pile Diameter = 10 in. Pile Spacing = L = 3 ft.

Pile Cap

f'_c = 3,000 psi f_y = 60,000 psi

Cover = 3 in. d_c = 10 in. (assumed 6 in. pile embedment)

E = 21 in. D_{cap} = 48 in. (total cap thickness)

Load Factor = 1.6 ϕ = 0.9 (bending); 0.85 (shear)

Column

P_u/A_g = 4,000 psi

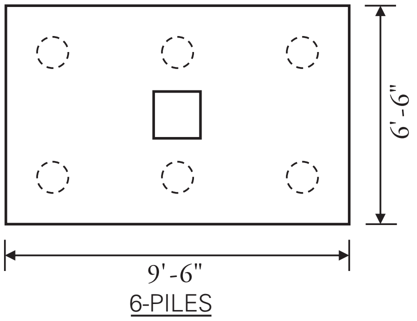


Fig. 8.13 Design example #3.

Solution:

Column Size Determination

N = number of piles = 6

Net Column Capacity:

$$P_u = 1.6(N)(P_{SERVICE}) - 1.6(A)(B)(D_{cap})\gamma_{concrete}$$

$$P_u = 1.6(6)(200) - 1.6(9.5)(6.5)\left(\frac{48}{12}\right)(0.150) = 1{,}860 \text{ k}$$

Column Size: $c = \sqrt{P_u/4} = \sqrt{1{,}860/4} = 21.6 \text{ in.} (\text{use } 22 \text{ in.})$

Required Flexural Reinforcement

$d = D_{cap} - d_c = 48 - 10 = 38$ in.

Short Bars

Summing moments caused by piles above (in plan) the column about a line $c/4 = 5.5$ in. above the column centroid and reduced by the moment caused by the weight of the pile cap above the line results in the following factored moment M_u (note that piles are assumed to be located 3 in. further away from the column centroid than assumed by the idealized location).

$$M_u = 1.6(3 \text{ piles})(P_{SERVICE})(L/2 - c/4 + 3 \text{ in.}) - 1.6(A)(B/2 - c/4)(D_{cap})\gamma_{concrete}(B/2 - c/4)/2$$

$$M_u = 1.6(3)(200)[3/2 - 22/12/4 + 3/12] - 1.6(9.5)(6.5/2 - 22/12/4)(48/12)(0.15)(6.5/2 - 22/12/4)/2 = 1{,}205 \text{ k-ft} = 14{,}450 \text{ k-in.}$$

For a 1 ft strip, M_u can be found by dividing the full moment by A:

$$M_u = (1{,}205 \text{ k-ft})/9.5 \text{ ft} = 127 \text{ k-ft/ft} = 1{,}520 \text{ k-in./ft}$$

The amount of reinforcing steel required to meet the moment demand can be determined as follows:

$$A_s = 0.51d - \sqrt{0.260d^2 - 0.0189M_u}$$

$$A_s = 0.51(38) - \sqrt{0.260(38)^2 - 0.0189(1{,}520)} = 0.76 \text{ in.}^2/\text{ft}$$

Note that formula above is only applicable for 3,000 psi concrete and 60,000 psi reinforcing steel (see Chapter 5 for appropriate equations when using other material properties).

The total steel required for the short bars (spanning in the B direction) can be found as:

$$A_s = 0.76(9.5) = 7.22 \text{ in.}^2/\text{ft}$$

Recall that the procedure in this design guide uses the following conservative interpretation to determine if more than the previously determined A_s need be provided:

1. if $A_s \geq \eta bd$, use A_s
2. if $A_s < \eta bd \leq 4/3A_s$, use ηbd
3. if $0.0018bD_{cap} \leq 4/3A_s < \eta bd$, use $4/3A_s$
4. if $4/3A_s < 0.0018bD_{cap} \leq \eta bd$, use $0.0018bD_{cap}$

In the expressions above, η is the maximum of

A. $200/f_y = 0.00333$ and

B. $\dfrac{3\sqrt{f_c'}}{f_y}$

$$\eta = \text{maximum of } 0.00333 \text{ and } \frac{3\sqrt{3{,}000}}{60{,}000} = 0.00274$$

$\eta = 0.00333$

$\eta bd = 0.00333(9.5*12)(38) = 14.43 \text{ in.}^2$

$(4/3)A_s = (4/3)(7.22) = 9.63 \text{ in.}^2$

$0.0018bD_{cap} = 0.0018(9.5*12)(48) = 9.85 \text{ in.}^2$

Item (4) controls and $A_{s,required} = 9.85 \text{ in.}^2$

Provide 10 #9 bars (10.0 in.^{2} O.K.)

Since cap is not symmetrical, verify that extra short bars are not required per ACI 318-14 Section 13.3.3.3.

$$\beta = \frac{A}{B} = \frac{9.5}{6.5} = 1.46$$

$$\gamma_s = \frac{2}{\beta+1} = \frac{2}{1.46+1} = 0.813$$

$$\begin{aligned} A_{s,required,structural,total} &= A_s\beta\gamma_s = 7.22(1.46)(0.813) \\ &= 8.57\text{in.}^2 < 9.85 \text{ in.}^2 \quad \text{O.K.} \end{aligned}$$

Note that 6 pile caps require hooked bars in each direction. Therefore, hooked bar development is checked here. For non-epoxy-coated bars $\psi_e = 1.0$.

The length available to develop the longitudinal bar past the last pile is $E' = E - 3$ in. (offset) = 21 − 3 = 18 in.

$$\begin{aligned} l_{dh} &= 0.7(0.02)\frac{\psi_e f_y}{\sqrt{f_c'}}d_b = 0.7(0.02)\frac{(1)60{,}000}{\sqrt{3{,}000}}(1.128) \\ &= 17.3 \text{ in.} < 18 \text{ in.} \quad \text{O.K.} \end{aligned}$$

The #9 bars are acceptable for hooked bar development.

Long Bars

Summing moments caused by piles to the right (in plan) of the column about a line $c/4 = 5.5$ in. to the right of the column centroid and reduced by the moment caused by the weight of the pile cap to the right of the line results in the following factored moment M_u (note that piles are assumed to be located 3 in. further away from the column centroid than assumed by the idealized location).

$$M_u = 1.6(2 \text{ Piles})(P_{SERVICE})(L - c/4 + 3 \text{ in.}) - 1.6(A/2 - c/4)(B)(D_{cap})\gamma_{concrete}(A/2 - c/4)/2$$

$$M_u = 1.6(2)(200)[3 - 22/12/4 + 3/12] - 1.6(9.5/2 - 22/12/4)(6.5)(48/12)(0.15)(9.5/2 - 22/12/4)/2 = 1{,}729 \text{ k-ft} = 20{,}750 \text{ k-in.}$$

For a 1 ft strip, M_u can be found by dividing the full moment by B:

$M_u = (1{,}729 \text{ k-ft})/6.5 \text{ ft} = 266 \text{ k-ft/ft} = 3{,}192 \text{ k-in./ft}$

The amount of reinforcing steel required to meet the moment demand can be determined as follows:

$$A_s = 0.51d - \sqrt{0.260d^2 - 0.0189M_u}$$

$$A_s = 0.51(38) - \sqrt{0.260(38)^2 - 0.0189(3{,}192)} = 1.63 \text{ in.}^2/\text{ft}$$

Note that formula above is only applicable for 3,000 psi concrete and 60,000 psi reinforcing steel (see Chapter 5 for appropriate equations when using other material properties).

The total steel required for the long bars (spanning in the A direction) can be found as:

$A_s = 1.63(6.5) = 10.6 \text{ in.}^2/\text{ft}$

Recall that the procedure in this design guide uses the following conservative interpretation to determine if more than the previously determined A_s need be provided:

1. if $A_s \geq \eta bd$, use A_s
2. if $A_s < \eta bd \leq 4/3A_s$, use ηbd
3. if $0.0018bD_{cap} \leq 4/3A_s < \eta bd$, use $4/3A_s$
4. if $4/3A_s < 0.0018bD_{cap} \leq \eta bd$, use $0.0018bD_{cap}$

In the expressions above, η is the maximum of

A. $200/f_y = 0.00333$ and

B. $\dfrac{3\sqrt{f_c'}}{f_y}$

$$\eta = \text{maximum of } 0.00333 \text{ and } \frac{3\sqrt{3{,}000}}{60{,}000} = 0.00274$$

$\eta = 0.00333$

$\eta bd = 0.00333(6.5*12)(38) = 9.88 \text{ in.}^2$

$(4/3)A_s = (4/3)(10.6) = 14.21 \text{ in.}^2$

$0.0018bD_{cap} = 0.0018(6.5*12)(48) = 6.74 \text{ in.}^2$

Item (1) controls and $A_{s,required} = 10.6 \text{ in.}^2$

Provide 13 #8 bars (10.2 in.^{2} N.G., should use 14 #8 bars; note that 13 #8 bars are acceptable per the tabulated design based on less conservative assumptions; subsequent calculations use 13 #8 bars in accordance with the tabulated design)

Note that 6 pile caps require hooked bars in each direction. Therefore, hooked bar development is checked here. For non-epoxy-coated bars $\psi e = 1.0$.

The length available to develop the longitudinal bar past the last pile is $E' = E - 3$ in. (offset) = 21 − 3 = 18 in.

$$\begin{aligned} l_{dh} &= 0.7(0.02)\frac{\psi_e f_y}{\sqrt{f_c'}}d_b = 0.7(0.02)\frac{(1)60{,}000}{\sqrt{3{,}000}}(1) \\ &= 15.3 \text{ in.} < 18 \text{ in.} \quad \text{O.K.} \end{aligned}$$

The #8 bars are acceptable for hooked bar development.

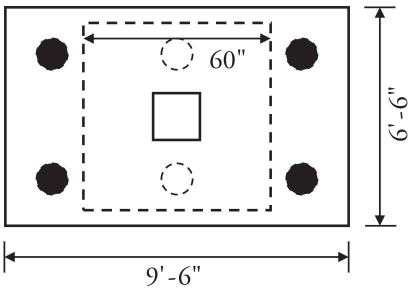


Fig. 8.14

Limit State 1 – Traditional ACI Two-Way Shear at $d/2$ from Column Face

Step (1): Based on the geometry shown in Fig. 8.14, determine the number of piles, $N_{outside}$, that are outside the failure pattern shown. Include the 3 in. adverse tolerance effect.

Note that the two-way failure plane is taken at a distance $d/2 = 19$ in. from the face of the column. The distance from the column centroid the failure plane is $c/2 + 19$ in. $= 22/2 + 19 = 30$ in. Note that the distance from the centroid of the column to the pile line above is $L/2 + 3$ in. (offset) $= 36/2 + 3 = 21$ in. Also, note that the distance from the centroid of the column to the pile lines left and right of the column center is $L + 3$ in. (offset) $= 36 + 3 = 39$ in. Since 30 in. is greater than 21 in. but less than 39 in., only the two piles above and below the column do not provide shear to the failure plane. Figure 8.14 shows piles contributing to shear in Limit State 1 as shaded. Note that $b_o = 4(c + d) = 4(60) = 240$ in.

Step (2): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and reduce the total demand by the portion of the pile cap weight that is outside the critical section. In the expression below, c is the equivalent square column side dimension and d is the effective depth of the pile cap. γ_c is the specific weight of concrete (assumed to be normal weight concrete or 150 lb/ft^3 in this guide and associated spreadsheets).

$$V_u = 1.6N_{outside}\left(P_{SERVICE}\right) - 1.6\gamma_c ABD_{cap}\frac{AB-\left(c+d\right)^2}{AB}$$

$$V_u = 1.6(4\text{ piles})(200\text{k})$$

$$-1.6(0.150)(9.5)(6.5)\left(\frac{48}{12}\right)\left[\frac{(9.5)(6.5)-\left(\frac{60}{12}\right)^2}{(9.5)(6.5)}\right] = 1{,}245\text{ k}$$

Step (3): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism and geometry shown in the Fig. 8.14.

$$\phi V_c = 0.85\left(4\sqrt{f_c'}\right)\left(b_o d\right)$$

$$\phi V_c = 0.85\left(4\sqrt{f_c'}\right)\left(b_o d\right) = 0.85\left(4\sqrt{3{,}000}\right)(240)(38)$$

$$= 1{,}698{,}000\text{ lb} = 1{,}698\text{ k}$$

Step (4): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$\phi V_c = 1{,}698\text{ k} > V_u = 1{,}245\text{ k}$ O.K.

Limit State 2 – Traditional ACI One-Way Shear (through Short Dimension) at d from Column Face

Step (1): Based on the geometry shown in Fig. 8.14, determine the number of piles, $N_{outside}$, that are outside the failure pattern. Include the 3 in. adverse tolerance effect.

Note that the one-way failure plane is taken at a distance $d = 38$ in. from the face of the column. The distance from the column centroid the failure plane is $c/2 + 38$ in. $= 22/2 + 38 = 49$ in. Note that the distance from the centroid of the column to the rightmost pile line is $L + 3$ in. (offset) $= 36 + 3 = 39$ in. Since 49 in. is greater than 39 in., no piles provide shear forces to the failure plane. *Therefore, this limit state is not applicable.*

Limit State 3 – Traditional ACI One-Way Shear (through Long Dimension) at d from Column Face

Step (1): Based on the geometry shown in Fig. 8.14, determine the number of piles, $N_{outside}$, that are outside the failure pattern. Include the 3 in. adverse tolerance effect.

Note that the one-way failure plane is taken at a distance $d = 38$ in. from the face of the column. The distance from the column centroid the failure plane is $c/2 + 38$ in. $= 22/2 + 38 = 49$ in. Note that the distance from the centroid of the column to the upper pile line is $L/2 + 3$ in. (offset) $= 36/2 + 3 = 21$ in. Since 49 in. is greater than 21 in., no piles provide shear forces to the failure plane. *Therefore, this limit state is not applicable.*

Limit State 4 – *MODIFIED* ACI Two-Way Shear at Column Face

Step (1): Determine the number of piles, $N_{outside}$, that are outside the failure pattern. Include the 3 in. adverse tolerance effect.

Note that the two-way failure plane is taken at the column face which is a distance $c/2 = 11$ in. from the column centroid. Thus, all 6 piles are located outside the column face and contribute shear at the column face. The distance w taken from the face of the column to the nearest pile center (with offset) is found as $L/2 - c/2 + 3$ in. $= 36/2 - 22/2 + 3 = 10$ in. In the orthogonal direction, the distance w taken from the face of the column to the nearest pile center (with offset) is found as $L - c/2 + 3$ in. $= 36 - 22/2 + 3 = 28$ in. Note that $b_s = 4c = 4(22) = 88$ in.

Step (2): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and reduce the total demand by the portion of the pile cap weight that is outside the critical section. In the expression below, c is the equivalent square column side dimension and d is the effective depth of the pile cap. γ_c is the specific weight of concrete (assumed to be normal weight concrete or 150 lb/ft^3 in this guide and associated spreadsheets).

$$V_u = 1.6N_{outside}\left(P_{SERVICE}\right) - 1.6\gamma_c\, ABD_{cap}\frac{AB-c^2}{AB}$$

$$V_u = 1.6(6 \text{ piles})(200 \text{ k})$$

$$-1.6(0.150)(9.5)(6.5)\left(\frac{48}{12}\right)\left[\frac{(9.5)(6.5)-\left(\frac{22}{12}\right)^2}{(9.5)(6.5)}\right] = 1{,}864 \text{ k}$$

Step (3): Determine the reduced nominal shear strength, ϕV_c, per Chapter 5.

Based on w for closest pile in any direction:

$$v_c = \left(\frac{d}{w}\right)\left(1+\frac{d}{c}\right)\left(2\sqrt{f_c'}\right) \le 32\sqrt{f_c'}$$

$$v_c = \left(\frac{38}{10}\right)\left(1+\frac{38}{22}\right)\left(2\sqrt{3{,}000}\right) = 1{,}135 \text{ psi}$$

$$\le 32\sqrt{f_c'} = 32\sqrt{3{,}000} = 1{,}753 \text{ psi} \quad \text{O.K.}$$

$$\phi V_c = 0.85 v_c(b_s d)$$

$$\phi V_c = 0.85(1.135)(88)(38) = 3{,}226 \text{ k}$$

Based on w for closest pile in orthogonal direction:

$$v_c = \left(\frac{d}{w}\right)\left(1+\frac{d}{c}\right)\left(2\sqrt{f_c'}\right) \le 32\sqrt{f_c'}$$

$$v_c = \left(\frac{38}{28}\right)\left(1+\frac{38}{22}\right)\left(2\sqrt{3{,}000}\right) = 405 \text{ psi}$$

$$\le 32\sqrt{f_c'} = 32\sqrt{3{,}000} = 1{,}753 \text{ psi} \quad \text{O.K.}$$

$$\phi V_c = 0.85 v_c(b_s d)$$

$$\phi V_c = 0.85(0.405)(88)(38) = 1{,}151 \text{ k}$$

When pile lines are not equidistant from the column center in orthogonal direction, this design guide utilizes the average reduced nominal shear strength, ϕV_c.

$$\phi V_c = 3{,}226 \text{ k (using minimum } w)$$

$$\phi V_c = 1{,}151 \text{ k (using orthogonal } w)$$

Step (4): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$$\frac{V_u}{\phi V_c} = \frac{1{,}864\ k}{3{,}226\ k} = 0.578 \ \text{(minimum)}$$

$$\frac{V_u}{\phi V_c} = \frac{1864\ k}{1{,}151\ k} = 1.62 \ \text{(orthogonal)}$$

$$\frac{V_u}{\phi V_c} = \frac{0.578+1.62}{2} = 1.09 \ \text{(average)}$$

The design procedure presented in this guide assumes that so long as the "average" interaction $V_u/\phi V_c \le 1.0$, Limit State 4 is acceptable. In this example, 1.09 may be considered unacceptably high and a thicker pile cap should be chosen.

Limit State 5 – *MODIFIED* ACI One-Way Shear (through Short Dimension) at Column Face

Step (1): Based on the geometry shown in Fig. 8.15, determine the number of piles, Noutside, that are outside the failure pattern shown. Include the 3 in. adverse tolerance effect.

Note that the one-way failure plane is taken at the column face which is a distance $c/2 = 11$ in. from the column centroid. Thus, the two shaded piles shown in Fig. 8.15 contribute shear at the column face. The distance w taken from the face of the column to the nearest pile center (with offset) is found as $L - c/2 + 3$ in. $= 36 - 22/2 + 3 = 28$ in.

Step (2): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and reduce the total demand by the portion of the pile cap weight that is outside the critical section. In the expression below, c is the equivalent square column side dimension and d is the effective depth of the pile cap. γ_c is the specific weight of concrete (assumed to be normal weight concrete or 150 lb/ft^3 in this guide and associated spreadsheets).

$$V_u = 1.6N_{outside}\left(P_{SERVICE}\right) - 1.6\gamma_c\frac{ABD_{cap}}{2}\frac{A/2-c/2}{A/2}$$

$$V_u = 1.6(2 \text{ piles})(200 \text{ k})$$

$$-1.6(0.150)\frac{(9.5)(6.5)\left(\frac{48}{12}\right)}{2}\frac{\left(\frac{9.5}{2}-\frac{22}{12(2)}\right)}{\frac{9.5}{2}} = 616 \text{ k}$$

Step (3): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism and geometry shown in Fig. 8.15. The term $x_{centroid}$ is the perpendicular distance from the critical section to the centroid of the $N_{outside}$ piles. Note that the centroid of the shaded piles is located a distance from the column face equal to $L - c/2 + 3$ in. (offset) $= 36 - 22/2 + 3 = 28$ in.

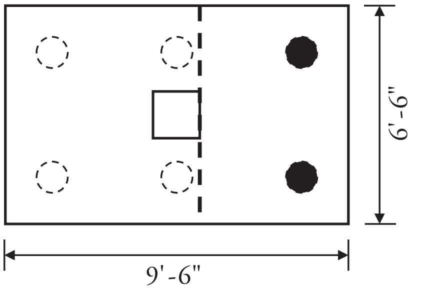


Fig. 8.15

$$M_u = 1.6N_{outside}\left(P_{SERVICE}\right)x_{centroid} - 1.6\gamma_c \frac{ABD_{cap}}{2}\frac{\left(\frac{A}{2}-\frac{c}{2}\right)}{\frac{A}{2}}\frac{\left(\frac{A}{2}-\frac{c}{2}\right)}{2}$$

$$M_u = 1.6(2\text{ piles})(200\ k)\left(\frac{28}{12}\right)$$

$$-1.6(0.150)\frac{(9.5)(6.5)\left(\frac{48}{12}\right)}{2}\frac{\left(\frac{9.5}{2}-\frac{22}{12(2)}\right)}{\frac{9.5}{2}}\frac{\left(\frac{9.5}{2}-\frac{22}{12(2)}\right)}{2}$$

= 1,447 k-ft = 17,370 k-in.

$$v_c = \left(\frac{d}{w}\right)\left[3.5-2.5\left(\frac{M_u}{V_u d}\right)\right]\left[1.9\sqrt{f_c'}+0.1\sqrt{f_c'}\left(\frac{V_u d}{M_u}\right)\right] \le 10\sqrt{f_c'}$$

$$v_c = \left(\frac{38}{28}\right)\left[3.5-2.5\left(\frac{17{,}370}{616(38)}\right)\right]\left[1.9\sqrt{3{,}000}+0.1\sqrt{3{,}000}\left(\frac{616(38)}{17{,}370}\right)\right]$$

$$= 249\text{ psi} \le 10\sqrt{f_c'} = 10\sqrt{3{,}000} = 548\text{ psi} \quad \text{O.K.}$$

Therefore,
$v_c = 249$ psi

$\phi V_c = 0.85 v_c(Bd) = 0.85(0.249)(78)(38) = 627$ k

Step (4): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$\phi V_c = 627\text{ k} > V_u = 616\text{ k}$ O.K.

Limit State 6 – *MODIFIED* ACI One-Way Shear (through Long Dimension) at Column Face

Step (1): Based on the geometry shown in Fig. 8.16, determine the number of piles, $N_{outside}$, that are outside the failure pattern shown. Include the 3 in. adverse tolerance effect.

Note that the one-way failure plane is taken at the column face which is a distance $c/2 = 11$ in. from the column centroid. Thus, the three shaded piles shown in Fig. 8.16 contribute shear at the column face. The distance w taken from the face of the column to the nearest pile center (with offset) is found as
$L/2 - c/2 + 3\text{ in.} = 36/2 - 22/2 + 3 = 10\text{ in.}$

Step (2): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and reduce the total demand by the portion of the pile cap weight that is outside the critical section. In the expression below, c is the equivalent square column side dimension and d is the effective depth of the pile cap. γ_c is the specific weight of concrete (assumed to be normal weight concrete or 150 lb/ft^3 in this guide and associated spreadsheets).

$$V_u = 1.6N_{outside}\left(P_{SERVICE}\right) - 1.6\gamma_c \frac{ABD_{cap}}{2}\frac{B/2 - c/2}{B/2}$$

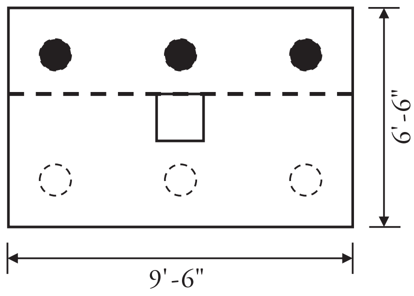


Fig. 8.16

$$V_u = 1.6(3\text{ piles})(200\text{ k})$$

$$-1.6(0.150)\frac{(9.5)(6.5)\left(\frac{48}{12}\right)}{2}\frac{\left(\frac{6.5}{2}-\frac{20}{12(2)}\right)}{\frac{6.5}{2}} = 938\text{ k}$$

Step (3): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism and geometry shown in Fig. 8.16. The term $y_{centroid}$ is the perpendicular distance from the critical section to the centroid of the $N_{outside}$ piles. Note that the centroid of the shaded piles is located a distance from the column face equal to $L/2 - c/2 + 3$ in. (offset) $= 36/2 - 22/2 + 3 = 10$ in.

$$M_u = 1.6N_{outside}\left(P_{SERVICE}\right)y_{centroid} - 1.6\gamma_c \frac{ABD_{cap}}{2}\frac{\left(\frac{B}{2}-\frac{c}{2}\right)}{\frac{B}{2}}\frac{\left(\frac{B}{2}-\frac{c}{2}\right)}{2}$$

$$M_u = 1.6(3\text{ piles})(200\ k)\left(\frac{10}{12}\right)$$

$$-1.6(0.150)\frac{(9.5)(6.5)\left(\frac{48}{12}\right)}{2}\frac{\left(\frac{6.5}{2}-\frac{22}{12(2)}\right)}{\frac{6.5}{2}}\frac{\left(\frac{6.5}{2}-\frac{22}{12(2)}\right)}{2}$$

= 775 k-ft = 9,300 k-in.

$$v_c = \left(\frac{d}{w}\right)\left[3.5-2.5\left(\frac{M_u}{V_u d}\right)\right]\left[1.9\sqrt{f_c'}+0.1\sqrt{f_c'}\left(\frac{V_u d}{M_u}\right)\right] \le 10\sqrt{f_c'}$$

$$v_c = \left(\frac{38}{10}\right)\left[3.5-2.5\left(\frac{9{,}300}{938(38)}\right)\right]\left[1.9\sqrt{3{,}000}+0.1\sqrt{3{,}000}\left(\frac{938(38)}{9{,}300}\right)\right]$$

$$= 1353\text{ psi} \le 10\sqrt{f_c'} = 10\sqrt{3{,}000} = 548\text{ psi} \quad \text{N.G.}$$

Therefore,
$v_c = 548$ psi

$\phi V_c = 0.85 v_c(Ad) = 0.85(0.548)(114)(38) = 2{,}018$ k

Step (4): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$\phi V_c = 2{,}018\text{ k} > V_u = 938\text{ k}$ O.K.

Limit State P1 – Two-Way Shear at Single Pile

Step (1): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and conservatively neglect any reduction in shear due to the weight of concrete tributary to one pile.

$$V_u = 1.6P_{SERVICE} = 1.6(200) = 320 \text{ k}$$

Step (2): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism. Round or equivalent round piles are assumed in this analysis. d_p is the actual or equivalent pile diameter. d is the effective depth of the pile cap.

$$b_o = \pi(d_p + d) = \pi(10 + 38) = 151 \text{ in.}$$

$$\phi V_c = 0.85\left(4\sqrt{f_c'}\right)(b_o d) = 0.85\left(4\sqrt{3{,}000}\right)(151)(38)$$

$$= 1{,}069{,}000 \text{ lb} = 1{,}069 \text{ k}$$

Step (3): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$$\phi V_c = 1{,}069 \text{ k} > V_u = 320 \text{ k} \quad \text{O.K.}$$

Limit State P2 – Two-Way Shear at Two Adjacent Piles

Step (1): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and conservatively neglect any reduction in shear due to the weight of concrete tributary to the two piles considered in this analysis.

$$V_u = 2(1.6P_{SERVICE}) = 2(1.6)(200) = 640 \text{ k}$$

Step (2): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism. Round or equivalent round piles are assumed in this analysis. d_p is the actual or equivalent pile diameter. d is the effective depth of the pile cap. L is the center to center pile spacing.

$$b_o = \pi(d_p + d) + 2L = \pi(10 + 38) + 2(36) = 223 \text{ in.}$$

$$\phi V_c = 0.85\left(4\sqrt{f_c'}\right)(b_o d) = 0.85\left(4\sqrt{3{,}000}\right)(223)(38)$$

$$= 1{,}578{,}000 \text{ lb} = 1{,}578 \text{ k}$$

Step (3): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$$\phi V_c = 1{,}578 \text{ k} > V_u = 640 \text{ k} \quad \text{O.K.}$$

Limit State P3 – Two-Way Shear at Corner Pile

Step (1): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and conservatively neglect any reduction in shear due to the weight of concrete tributary to the corner pile.

$$V_u = 1.6P_{SERVICE} = 1.6(200) = 320 \text{ k}$$

Step (2): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism. Round or equivalent round piles are assumed in this analysis. d_p is the actual or equivalent pile diameter. d is the effective depth of the pile cap. E is the center of corner pile to edge of cap dimension in plan.

$$b_o = \frac{\pi\left(d_p + d\right)}{4} + 2E = \frac{\pi(10+38)}{4} + 2(21) = 79.7 \text{ in.}$$

$$\phi V_c = 0.85\left(4\sqrt{f_c'}\right)(b_o d) = 0.85\left(4\sqrt{3{,}000}\right)(79.7)(38)$$

$$= 564{,}000 \text{ lb} = 564 \text{ k}$$

Step (3): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$$\phi V_c = 564 \text{ k} > V_u = 320 \text{ k} \quad \text{O.K.}$$

Limit State P4 – One-Way Shear at Corner Pile

Step (1): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and conservatively neglect any reduction in shear due to the weight of concrete tributary to the corner pile.

$$V_u = 1.6P_{SERVICE} = 1.6(200) = 320 \text{ k}$$

Step (2): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism. Round or equivalent round piles are assumed in this analysis. d_p is the actual or equivalent pile diameter. d is the effective depth of the pile cap. E is the center of corner pile to edge of cap dimension in plan. The length of the critical section, b, can be found using simple geometry.

$$b = 2\left(E\sqrt{2} + d_p/2 + d\right) \quad (d \le 13 \text{ in. in this equation only; no limit on d for } \phi V_c)$$

$$b = 2\left(21\sqrt{2} + 10/2 + 13\right) = 95.4 \text{ in.}$$

$$\phi V_c = 0.85\left(2\sqrt{f_c'}\right)(bd) = 0.85\left(2\sqrt{3{,}000}\right)(95.4)(38)$$

$$= 338{,}000 \text{ lb} = 338 \text{ k}$$

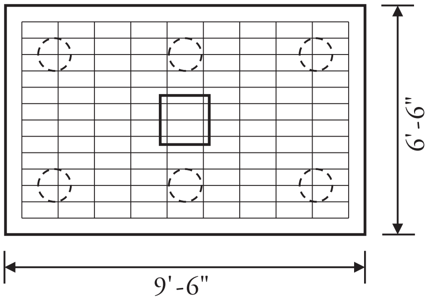


Fig. 8.16 Reinforcement Summary for design example #3: Use 10 #9 bars (short); Use 13 #8 bars (long)

Step (3): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$\phi V_c = 338 \text{ k} > V_u = 320 \text{ k} \quad \text{O.K.}$

8.5 Design Example #4: 7 Piles

Given Information:

Piles

Pile Service Load = $P_{SERVICE}$ = 40 tons (80 kips)

Pile Diameter = 8 in. Pile Spacing = L = 3 ft.

Pile Cap

$f'_c = 3{,}000$ psi $f_y = 60{,}000$ psi

Cover = 3 in. $d_c = 10$ in. (assumed 6 in. pile embedment)

$E = 15$ in. $D_{cap} = 38$ in. (total cap thickness)

Load Factor = 1.6 $\phi = 0.9$ (bending); 0.85 (shear)

Column

$P_u/A_g = 4{,}000$ psi

Note that column is ROUND.

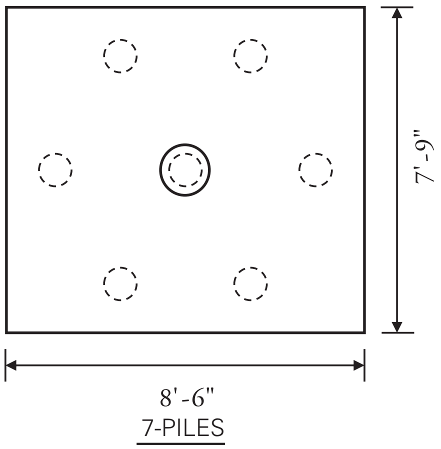


Fig. 8.18 Design example #4.

Solution:

Column Size Determination

N = number of piles = 7

Net Column Capacity:

$P_u = 1.6(N)(P_{SERVICE}) - 1.6(A)(B)(D_{cap})\gamma_{concrete}$

$$P_u = 1.6(7)(80) - 1.6(8.5)(7.75)\left(\frac{38}{12}\right)(0.150) = 846\ k$$

Column Size: $c = \sqrt{P_u/\pi} = \sqrt{846/\pi} = 16.4 \text{ in.} (\text{use } 17 \text{ in.})$

Required Flexural Reinforcement

$d = D_{cap} - d_c = 38 - 10 = 28$ in.

Short Bars

Summing moments caused by piles above (in plan) the column about a line $c/4 = 4.25$ in. above the column centroid and reduced by the moment caused by the weight of the pile cap above the line results in the following factored moment M_u (note that piles are assumed to be located 3 in. further away from the column centroid than assumed by the idealized location).

$$M_u = 1.6(2 \text{ Piles})(P_{SERVICE})(0.866L - c/4 + 3 \text{ in.}) - 1.6(A)(B/2 - c/4)(D_{cap})\gamma_{concrete}(B/2 - c/4)/2$$

$$M_u = 1.6(2)(80)[0.866(3) - 17/12/4 + 3/12] - 1.6(8.5)(7.75/2 - 17/12/4)(38/12)(0.15)(7.75/2 - 17/12/4)/2 = 598 \text{ k-ft} = 7{,}180 \text{ k-in.}$$

For a 1 ft strip, M_u can be found by dividing the full moment by A:

$M_u = (598 \text{ k-ft})/8.5 \text{ ft} = 70.4 \text{ k-ft/ft} = 844 \text{ k-in./ft}$

The amount of reinforcing steel required to meet the moment demand can be determined as follows:

$$A_s = 0.51d - \sqrt{0.260d^2 - 0.0189M_u}$$

$$A_s = 0.51(28) - \sqrt{0.260(28)^2 - 0.0189(844)} = 0.573 \text{ in.}^2/\text{ft}$$

Note that formula above is only applicable for 3,000 psi concrete and 60,000 psi reinforcing steel (see Chapter 5 for appropriate equations when using other material properties).

The total steel required for the short bars (spanning in the B direction) can be found as:

$A_s = 0.573(8.5) = 4.87 \text{ in.}^2/\text{ft}$

Recall that the procedure in this design guide uses the following conservative interpretation to determine if more than the previously determined A_s need be provided:

1. if $A_s \geq \eta bd$, use A_s
2. if $A_s < \eta bd \leq 4/3A_s$, use ηbd
3. if $0.0018\text{b}D_{cap} \leq 4/3A_s < \eta bd$, use $4/3A_s$
4. if $4/3A_s < 0.0018bD_{cap} \leq \eta bd$, use $0.0018bD_{cap}$

In the expressions above, η is the maximum of

A. $200/f_y = 0.00333$ and

B. $\dfrac{3\sqrt{f'_c}}{f_y}$

$$\eta = \text{maximum of } 0.00333 \text{ and } \frac{3\sqrt{3{,}000}}{60{,}000} = 0.00274$$

$\eta = 0.00333$

$\eta bd = 0.00333(8.5*12)(28) = 9.51 \text{ in.}^2$

$(4/3)A_s = (4/3)(4.87) = 6.49 \text{ in.}^2$

$0.0018bD_{cap} = 0.0018(8.5*12)(38) = 6.98 \text{ in.}^2$

Item (4) controls and $A_{s,required} = 6.98 \text{ in.}^2$

Provide 16 #6 bars (7.07 in.^{2} O.K.)

Since cap is not symmetrical, verify that extra short bars are not required per ACI 318-14 Section 13.3.3.3.

$$\beta = \frac{A}{B} = \frac{8.5}{7.75} = 1.10$$

$$\gamma_s = \frac{2}{\beta + 1} = \frac{2}{1.10 + 1} = 0.952$$

$$A_{s,required,structural,total} = A_s \beta \gamma_s = 4.87(1.10)(0.952)$$
$$= 5.10 \text{ in.}^2 < 6.98 \text{ in.}^2 \quad \text{O.K.}$$

Note that 7 pile caps require hooked bars in each direction. Therefore, hooked bar development is checked here. For non-epoxy-coated bars $\psi_e = 1.0$.

The length available to develop the longitudinal bar past the last pile is $E' = E - 3$ in. (offset) = $15 - 3 = 12$ in.

$$l_{dh} = 0.7(0.02)\frac{\psi_e f_y}{\sqrt{f_c'}} d_b = 0.7(0.02)\frac{(1)60{,}000}{\sqrt{3{,}000}}(0.75)$$
$$= 11.5 \text{ in.} < 12 \text{ in.} \quad \text{O.K.}$$

The #6 bars are acceptable for hooked bar development.

Long Bars

Summing moments caused by piles to the right (in plan) of the column about a line $c/4 = 4.25$ in. to the right of the column centroid and reduced by the moment caused by the weight of the pile cap to the right of the line results in the following factored moment M_u (note that piles are assumed to be located 3 in. further away from the column centroid than assumed by the idealized location).

$$M_u = 1.6(2 \text{ Piles})(P_{SERVICE})\left(\frac{L}{2} - \frac{c}{4} + 3 \text{ in.}\right)$$
$$+ 1.6(1 \text{ Piles})(80\ k)\left(L - \frac{c}{4} + 3 \text{ in.}\right) - 1.6(A/2 - c/4)$$
$$(B)(D_{cap})\gamma_{concrete}(A/2 - c/4)/2$$

$$M_u = 1.6(2)(80)[3/2 - 17/12/4 + 3/12] + 1.6(1)(80)$$
$$[3 - 17/12/4 + 3/12] - 1.6(8.5/2 - 17/12/4)(7.75)$$
$$(38/12)(0.15)(8.5/2 - 17/12/4)/2 = 687 \text{ k-ft} = 8{,}240 \text{ k-in.}$$

For a 1 ft strip, M_u can be found by dividing the full moment by B:

$$M_u = (687 \text{ k-ft})/7.75 \text{ ft} = 88.6 \text{ k-ft/ft} = 1{,}064 \text{ k-in./ft}$$

The amount of reinforcing steel required to meet the moment demand can be determined as follows:

$$A_s = 0.51d - \sqrt{0.260d^2 - 0.0189M_u}$$

$$A_s = 0.51(28) - \sqrt{0.260(28)^2 - 0.0189(1{,}064)} = 0.725 \text{ in.}^2 / \text{ft}$$

Note that formula above is only applicable for 3,000 psi concrete and 60,000 psi reinforcing steel (see Chapter 5 for appropriate equations when using other material properties).

The total steel required for the long bars (spanning in the A direction) can be found as:

$$A_s = 0.725(7.75) = 5.62 \text{ in.}^2/\text{ft}$$

Recall that the procedure in this design guide uses the following conservative interpretation to determine if more than the previously determined A_s need be provided:

1. if $A_s \geq \eta bd$, use A_s
2. if $A_s < \eta bd \leq 4/3A_s$, use ηbd
3. if $0.0018bD_{cap} \leq 4/3A_s < \eta bd$, use $4/3A_s$
4. if $4/3A_s < 0.0018bD_{cap} \leq \eta bd$, use $0.0018bD_{cap}$

In the expressions above, η is the maximum of

A. $200/f_y = 0.00333$ and

B. $\dfrac{3\sqrt{f_c'}}{f_y}$

$$\eta = \text{maximum of } 0.00333 \text{ and } \frac{3\sqrt{3{,}000}}{60{,}000} = 0.00274$$

$$\eta = 0.00333$$

$$\eta bd = 0.00333(7.75{*}12)(28) = 8.68 \text{ in.}^2$$

$$(4/3)A_s = (4/3)(5.62) = 7.49 \text{ in.}^2$$

$$0.0018bD_{cap} = 0.0018(7.75{*}12)(38) = 6.36 \text{ in.}^2$$

Item (3) controls and $A_{s,required} = 7.49$ in.^{2}

Provide 16 #6 bars (7.07 in.^{2} N.G., should provide 17 #6 bars; note that tabulated design found acceptable with 16 #6 bars using less conservative assumptions).

Note that 7 pile caps require hooked bars in each direction. Therefore, hooked bar development is checked here. For non-epoxy-coated bars $\psi_e = 1.0$.

The length available to develop the longitudinal bar past the last pile is $E' = E - 3$ in. (offset) = $15 - 3 = 12$ in.

$$l_{dh} = 0.7(0.02)\frac{\psi_e f_y}{\sqrt{f_c'}} d_b = 0.7(0.02)\frac{(1)60{,}000}{\sqrt{3{,}000}}(0.75)$$
$$= 11.5 \text{ in.} < 12 \text{ in.} \quad \text{O.K.}$$

The #6 bars are acceptable for hooked bar development.

Limit State 1 – Traditional ACI Two-Way Shear at $d/2$ from Column Face

Step (1): Based on the geometry shown in Fig. 8.19, determine the number of piles, $N_{outside}$, that are outside the failure pattern shown. Include the 3 in. adverse tolerance effect.

Note that the two-way failure plane is taken at a distance $d/2 = 14$ in. from the face of the column. The distance from the column centroid the failure plane is $c/2 + 14$ in. $= 17/2 + 14 = 22.5$ in. Note that the distance from the centroid of the column to the surrounding pile centers is $L + 3$ in. (offset) $= 36 + 3 = 39$ in. Since 39 in. is greater than 22.5 in., only the pile directly underneath the column does not provide shear to the failure plane. Fig. 8.19 shows piles contributing to shear in Limit State 1 as shaded. Note that $b_o = \pi(c + d) = \pi(45) = 141.4$ in.

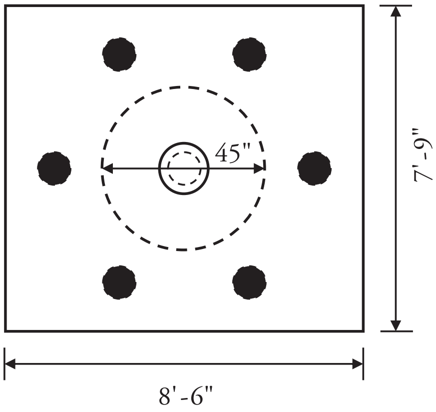


Fig. 8.19

Step (2): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and reduce the total demand by the portion of the pile cap weight that is outside the critical section. In the expression below, c is the column diameter and d is the effective depth of the pile cap. γ_c is the specific weight of concrete (assumed to be normal weight concrete or 150 lb/ft^3 in this guide and associated spreadsheets).

$$V_u = 1.6N_{outside}\left(P_{SERVICE}\right) - 1.6\gamma_c ABD_{cap}\frac{AB-\pi\left(\frac{c+d}{2}\right)^2}{AB}$$

$$V_u = 1.6(6\text{ piles})(80\text{ k})$$

$$-1.6(0.150)(8.6)(7.75)\left(\frac{38}{12}\right)\left[\frac{(8.6)(7.75)-\pi\left(\frac{45}{2(12)}\right)^2}{(8.6)(7.75)}\right]$$

$$= 725\text{ k}$$

Step (3): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism and geometry shown in the Fig. 8.19.

$$\phi V_c = 0.85\left(4\sqrt{f_c'}\right)\left(b_o d\right)$$

$$\phi V_c = 0.85\left(4\sqrt{f_c'}\right)\left(b_o d\right) = 0.85\left(4\sqrt{3{,}000}\right)(141.4)(28)$$

$$= 737{,}000\text{ lb} = 737\text{ k}$$

Step (4): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$\phi V_c = 737\text{ k} > V_u = 725\text{ k}$ O.K.

Limit State 2 – Traditional ACI One-Way Shear (through Short Dimension) at *d* from Column Face

Step (1): Based on the geometry shown in Fig. 8.20, determine the number of piles, $N_{outside}$, that are outside the failure pattern. Include the 3 in. adverse tolerance effect.

Note that the one-way failure plane is taken at a distance $d = 28$ in. from the face of the column. The distance from the column centroid the failure plane is $c/2 + 28$ in. $= 17/2 + 28 = 36.5$ in. Note that the distance from the centroid of the column to the nearest pile line is $L/2 + 3$ in. (offset) $= 36/2 + 3 = 21$ in. Since 36.5 in. is greater than 21 in., the first row of piles to the right of the column do not provide shear forces to the failure plane (note that 36.5 in. does not reach the rightmost pile). Fig.8.20 shows piles contributing to shear in Limit State 2 as shaded.

Step (2): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and reduce the total demand by the portion of the pile cap weight that is outside the critical section. In the expression below, c is the column diameter and d is the effective depth of the pile cap. γ_c is the specific weight of concrete (assumed to be normal weight concrete or 150 lb/ft^3 in this guide and associated spreadsheets).

$$V_u = 1.6N_{outside}\left(P_{SERVICE}\right) - 1.6\gamma_c\frac{ABD_{cap}}{2}\frac{A/2-c/2-d}{A/2}$$

$$V_u = 1.6(1\text{ pile})(80\text{ k})$$

$$-1.6(0.150)\frac{(8.5)(7.75)\left(\frac{38}{12}\right)}{2}\frac{\left(\frac{8.5}{2}-\frac{17}{12(2)}-\frac{38}{12}\right)}{8.5/2} = 126\text{ k}$$

Step (3): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism and geometry shown in Fig. 5.2.

$$\phi V_c = 0.85\left(2\sqrt{f_c'}\right)(Bd)$$

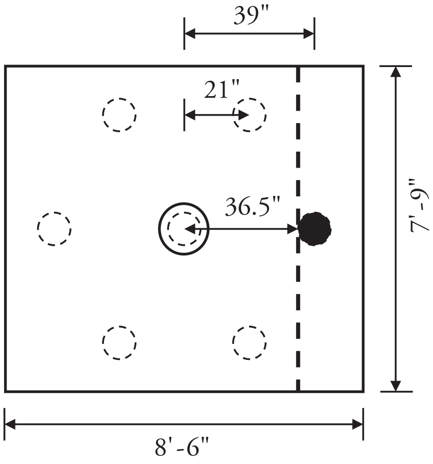


Fig. 8.20

$$\phi V_c = 0.85\left(2\sqrt{f_c'}\right)(Bd) = 0.85\left(2\sqrt{3{,}000}\right)(93)(28)$$

$$= 242{,}000 \text{ lb} = 242 \text{ k}$$

Step (4): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$$\phi V_c = 242 \text{ k} > V_u = 126 \text{ k} \quad \text{O.K.}$$

Limit State 3 – Traditional ACI One-Way Shear (through Long Dimension) at d from Column Face

Note that the following calculations are not required since Limit State 2 and Limit State 3 are identical when the pile cap is square in plan.

Step (1): Based on the geometry shown in the figure above, determine the number of piles, $N_{outside}$, that are outside the failure pattern. Include the 3 in. adverse tolerance effect.

Note that the one-way failure plane is taken at a distance $d = 28$ in. from the face of the column. The distance from the column centroid the failure plane is $c/2 + 28$ in. $= 17/2 + 28 = 36.5$ in. Note that the distance from the centroid of the column to the upper pile line is $0.866L + 3$ in. (offset) $= 0.866(36) + 3 = 34.2$ in. Since 36.5 in. is greater than 34.2 in., no piles provide shear forces to the failure plane. *Therefore, this limit state is not applicable.*

Limit State 4 – *MODIFIED* ACI Two-Way Shear at Column Face

Step (1): Determine the number of piles, $N_{outside}$, that are outside the failure pattern. Include the 3 in. adverse tolerance effect.

Note that the two-way failure plane is taken at the column face which is a distance $c/2 = 11$ in. from the column centroid. Thus, all piles except for the pile directly below the column are located outside the column face and contribute shear at the column face. Recalling the circular failure mechanism (see Limit State 1 – similar), the radial distance w taken from the face of the column to the nearest pile center (with offset) is found as $L - c/2 + 3$ in. $= 36 - 17/2 + 3 = 30.5$ in. Since 30.5 in. is greater than $d = 28$ in. for all piles outside the column face, *this limit state is not applicable.*

Limit State 5 – *MODIFIED* ACI One-Way Shear (through Short Dimension) at Column Face

Step (1): Based on the geometry shown in Fig. 8.21, determine the number of piles, $N_{outside}$, that are outside the failure pattern shown. Include the 3 in. adverse tolerance effect.

Note that the one-way failure plane is taken at the column face which is a distance $c/2 = 8.5$ in. from the column centroid. Thus, the three shaded piles shown in Fig. 8.21 contribute shear at the column face. The distance w taken from the face of the column to the nearest pile center (with offset) is found as $L/2 - c/2 + 3$ in. $= 36/2 - 17/2 + 3 = 12.5$ in.

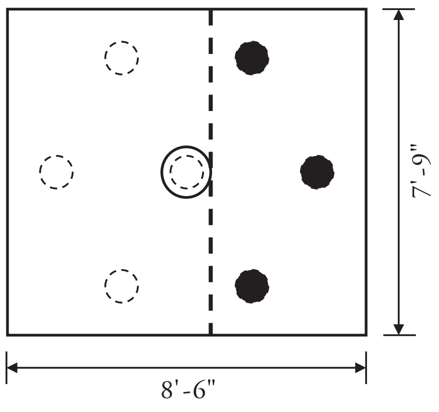


Fig. 8.21

Step (2): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and reduce the total demand by the portion of the pile cap weight that is outside the critical section. In the expression below, c is the column diameter and d is the effective depth of the pile cap. γ_c is the specific weight of concrete (assumed to be normal weight concrete or 150 lb/ft^3 in this guide and associated spreadsheets).

$$V_u = 1.6N_{outside}\left(P_{SERVICE}\right) - 1.6\gamma_c\frac{ABD_{cap}}{2}\frac{A/2 - c/2}{A/2}$$

$$V_u = 1.6(3 \text{ piles})(80 \text{ k})$$

$$-1.6(0.150)\frac{(8.5)(7.75)\left(\frac{38}{12}\right)}{2}\frac{\left(\frac{8.5}{2}-\frac{17}{12(2)}\right)}{\frac{8.5}{2}} = 363 \text{ k}$$

Step (3): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism and geometry shown in the figure above. The term $x_{centroid}$ is the perpendicular distance from the critical section to the centroid of the $N_{outside}$ piles. Note that the centroid of the shaded piles is located a distance from the column face equal to $(2/3)L - c/2 + 3$ in. (offset) $= (2/3)36 - 17/2 + 3 = 18.5$ in.

$$M_u = 1.6N_{outside}\left(P_{SERVICE}\right)x_{centroid} - 1.6\gamma_c\frac{ABD_{cap}}{2}\frac{\left(\frac{A}{2}-\frac{c}{2}\right)}{\frac{A}{2}}\frac{\left(\frac{A}{2}-\frac{c}{2}\right)}{2}$$

$$M_u = 1.6(3 \text{ piles})(80 \text{ k})\left(\frac{18.5}{12}\right)$$

$$-1.6(0.150)\frac{(8.5)(7.75)\left(\frac{38}{12}\right)}{2}\frac{\left(\frac{8.5}{2}-\frac{17}{12(2)}\right)}{\frac{8.5}{2}}\frac{\left(\frac{8.5}{2}-\frac{17}{12(2)}\right)}{2}$$

$$= 555 \text{ k-ft} = 6{,}660 \text{ k-in.}$$

$$v_c = \left(\frac{d}{w}\right)\left[3.5 - 2.5\left(\frac{M_u}{V_u d}\right)\right]\left[1.9\sqrt{f_c'} + 0.1\sqrt{f_c'}\left(\frac{V_u d}{M_u}\right)\right] \le 10\sqrt{f_c'}$$

$$v_c = \left(\frac{28}{12.5}\right)\left[3.5 - 2.5\left(\frac{6{,}660}{363(28)}\right)\right]$$

$$\left[1.9\sqrt{3{,}000} + 0.1\sqrt{3{,}000}\left(\frac{363(28)}{6{,}660}\right)\right]$$

$$= 469 \text{ psi} \le 10\sqrt{f_c'} = 10\sqrt{3{,}000} = 548 \text{ psi} \qquad \text{O.K.}$$

Therefore,
$v_c = 469$ psi

$\phi V_c = 0.85 v_c (Bd) = 0.85(0.469)(93)(28) = 1{,}038$ k

Step (4): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$\phi V_c = 1{,}038 \text{ k} > V_u = 363 \text{ k}$ O.K.

Limit State 6 – *MODIFIED* ACI One-Way Shear (through Long Dimension) at Column Face

Note that the following calculations are not required since Limit State 5 and Limit State 6 are identical when the pile cap is square in plan.

Step (1): Based on the geometry shown in Fig. 8.22, determine the number of piles, $N_{outside}$, that are outside the failure pattern shown. Include the 3 in. adverse tolerance effect.

Note that the one-way failure plane is taken at the column face which is a distance $c/2 = 8.5$ in. from the column centroid. Thus, the two shaded piles shown in Fig. 8.22 contribute shear at the column face. The distance w taken from the face of the column to the nearest pile center (with offset) is found as $0.866L - c/2 + 3 \text{ in.} = 0.866(36) - 17/2 + 3 = 25.7$ in.

Step (2): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and reduce the total demand by the portion of the pile cap weight that is outside the critical section. In the expression below, c is the column diameter and d is the effective depth of the pile cap. γ_c is the specific weight of concrete (assumed to be normal weight concrete or 150 lb/ft^3 in this guide and associated spreadsheets).

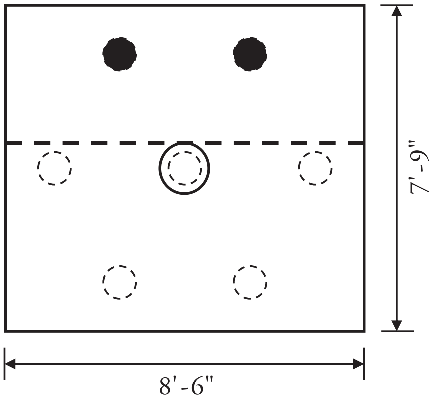


Fig. 8.22

$$V_u = 1.6N_{outside}\left(P_{SERVICE}\right) - 1.6\gamma_c \frac{ABD_{cap}}{2}\frac{B/2 - c/2}{B/2}$$

$V_u = 1.6(2 \text{ piles})(80 \text{ k})$

$$-1.6(0.150)\frac{(8.5)(7.75)\left(\frac{38}{12}\right)}{2}\frac{\left(\frac{7.75}{2} - \frac{17}{12(2)}\right)}{\frac{7.75}{2}} = 236 \text{ k}$$

Step (3): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism and geometry shown in the Fig. 8.22. The term $y_{centroid}$ is the perpendicular distance from the critical section to the centroid of the $N_{outside}$ piles. Note that the centroid of the shaded piles is located a distance from the column face equal to $0.866L - c/2 + 3 \text{ in. (offset)} = 0.866(36) - 17/2 + 3 = 25.7$ in.

$$M_u = 1.6N_{outside}\left(P_{SERVICE}\right)y_{centroid} - 1.6\gamma_c \frac{ABD_{cap}}{2}\frac{\left(\frac{B}{2} - \frac{c}{2}\right)}{\frac{B}{2}}\frac{\left(\frac{B}{2} - \frac{c}{2}\right)}{2}$$

$$M_u = 1.6\left(2 \text{ piles}\right)\left(80\ k\right)\left(\frac{25.7}{12}\right)$$

$$-1.6(0.150)\frac{(8.5)(7.75)\left(\frac{38}{12}\right)}{2}\frac{\left(\frac{7.75}{2} - \frac{17}{12(2)}\right)}{\frac{7.75}{2}}\frac{\left(\frac{7.75}{2} - \frac{17}{12(2)}\right)}{2}$$

$$= 516 \text{ k-ft} = 6{,}190 \text{ k-in.}$$

$$v_c = \left(\frac{d}{w}\right)\left[3.5 - 2.5\left(\frac{M_u}{V_u d}\right)\right]\left[1.9\sqrt{f_c'} + 0.1\sqrt{f_c'}\left(\frac{V_u d}{M_u}\right)\right] \le 10\sqrt{f_c'}$$

$$v_c = \left(\frac{28}{25.7}\right)\left[3.5 - 2.5\left(\frac{6{,}190}{236(28)}\right)\right]$$

$$\left[1.9\sqrt{3{,}000} + 0.1\sqrt{3{,}000}\left(\frac{236(28)}{6{,}190}\right)\right]$$

$$= 139 \text{ psi} \le 10\sqrt{f_c'} = 10\sqrt{3{,}000} = 548 \text{ psi} \qquad \text{O.K.}$$

Therefore,
$v_c = 139$ psi

$\phi V_c = 0.85 v_c (Ad) = 0.85(0.139)(102)(28) = 337$ k

Step (4): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$\phi V_c = 337 \text{ k} > V_u = 236 \text{ k}$ O.K.

Limit State P1 – Two-Way Shear at Single Pile

Step (1): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and conservatively neglect any reduction in shear due to the weight of concrete tributary to one pile.

$$V_u = 1.6P_{SERVICE} = 1.6(80) = 128 \text{ k}$$

Step (2): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism. Round or equivalent round piles are assumed in this analysis. d_p is the actual or equivalent pile diameter. d is the effective depth of the pile cap.

$$b_o = \pi(d_p + d) = \pi(8 + 28) = 113 \text{ in.}$$

$$\phi V_c = 0.85\left(4\sqrt{f_c'}\right)(b_o d) = 0.85\left(4\sqrt{3{,}000}\right)(113)(28)$$

$$= 589{,}000 \text{ lb} = 589 \text{ k}$$

Step (3): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$$\phi V_c = 589 \text{ k} > V_u = 128 \text{ k} \quad \text{O.K.}$$

Limit State P2 – Two-Way Shear at Two Adjacent Piles

Step (1): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and conservatively neglect any reduction in shear due to the weight of concrete tributary to the two piles considered in this analysis.

$$V_u = 2(1.6P_{SERVICE}) = 2(1.6)(80) = 256 \text{ k}$$

Step (2): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism. Round or equivalent round piles are assumed in this analysis. d_p is the actual or equivalent pile diameter. d is the effective depth of the pile cap. L is the center to center pile spacing.

$$b_o = \pi(d_p + d) + 2L = \pi(8 + 28) + 2(36) = 185 \text{ in.}$$

$$\phi V_c = 0.85\left(4\sqrt{f_c'}\right)(b_o d) = 0.85\left(4\sqrt{3{,}000}\right)(185)(28)$$

$$= 956{,}000 \text{ lb} = 965 \text{ k}$$

Step (3): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$$\phi V_c = 965 \text{ k} > V_u = 256 \text{ k} \quad \text{O.K.}$$

Limit State P3 – Two-Way Shear at Corner Pile

This limit state is not applicable since there are no corner piles.

Limit State P4 – One-Way Shear at Corner Pile

This limit state is not applicable since there are no corner piles.

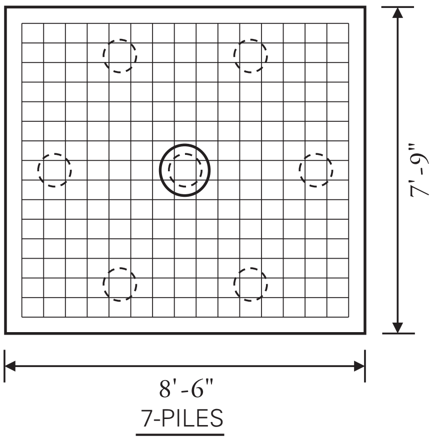


Fig. 8.24 Reinforcement Summary for design example #4: Use 16 #6 bars each way.

8.6 Design Example #5: 5 Piles (HIGH LOAD PILING)

Given Information:

Piles

Pile Service Load = $P_{SERVICE}$ = 400 tons (800 kips)

Pile Diameter = 20 in. Pile Spacing = L = 5 ft.

Note only cap with 45° pile configuration

Pile Cap

$f_c' = 3{,}000$ psi	$f_y = 60{,}000$ psi
Cover = 3 in.	$d_c = 10$ in. (assumed 6 in. pile embedment)
$E = 36$ in.	$D_{cap} = 69$ in. (total cap thickness)
Load Factor = 1.6	$\phi = 0.9$ (bending); 0.85 (shear)

Column

$P_u/A_g = 4{,}000$ psi

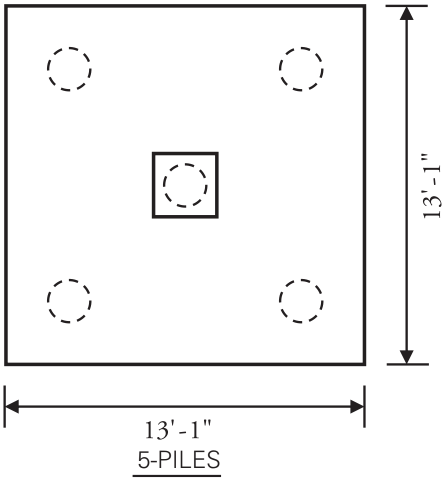


Fig. 8.24 Design example #5.

Solution:

Column Size Determination

N = number of piles = 5

Net Column Capacity:

$$P_u = 1.6(N)(P_{SERVICE}) - 1.6(A)(B)(D)\gamma_{concrete}$$

$$P_u = 1.6(5)(800) - 1.6(13.08)(13.08)\left(\frac{69}{12}\right)(0.150) = 6{,}164 \text{ k}$$

Column Size: $c = \sqrt{P_u/4} = \sqrt{6{,}164/4} = 39.3 \text{ in.} (\text{use } 40 \text{ in.})$

Required Flexural Reinforcement

For symmetrical pile cap (i.e., $A = B$ and same pile configuration each direction), only one flexural steel requirement need be calculated since the same in each direction.

$d = D_{cap} - d_c = 69 - 10 = 59$ in.

Summing moments caused by piles to the right of the column about a line $c/4 = 10$ in. to the right of the column centroid and reduced by the moment caused by the weight of the pile cap to the right of the line results in the following factored moment M_u (note that piles are assumed to be located 3 in. further away from the column centroid than assumed by the idealized location).

$$\begin{aligned} M_u = {} & 1.6(2 \text{ Piles})(P_{SERVICE})(0.7071L - c/4 + 3 \text{ in.}) \\ & - 1.6(A/2 - c/4)(B)(D_{cap})\gamma_{concrete}(A/2 - c/4)/2 \end{aligned}$$

$$\begin{aligned} M_u = {} & 1.6(2)(800)[0.7071(5) - 40/12/4 + 3/12] \\ & - 1.6(13.08/2 - 40/12/4)(13.08)(69/12)(0.15) \\ & (13.08/2 - 40/12/4)/2 = 7{,}264 \text{ k-ft} = 87{,}160 \text{ k-in.} \end{aligned}$$

For a 1 ft strip, M_u can be found by dividing the full moment by B:

$M_u = (7{,}264 \text{ k-ft})/13.08 \text{ ft} = 555 \text{ k-ft/ft} = 6{,}660 \text{ k-in./ft}$

The amount of reinforcing steel required to meet the moment demand can be determined as follows:

$$A_s = 0.51d - \sqrt{0.260d^2 - 0.0189M_u}$$

$$A_s = 0.51(59) - \sqrt{0.260(59)^2 - 0.0189(6{,}660)} = 2.18 \text{ in.}^2/\text{ft}$$

Note that formula above is only applicable for 3,000 psi concrete and 60,000 psi reinforcing steel (see Chapter 5 for appropriate equations when using other material properties).

The total steel required for all bars (spanning in the A and the B direction) can be found as:

$A_s = 2.18(13.08) = 28.5 \text{ in.}^2/\text{ft}$

Recall that the procedure in this design guide uses the following conservative interpretation to determine if more than the previously determined A_s need be provided:

1. if $A_s \geq \eta bd$, use A_s
2. if $A_s < \eta bd \leq 4/3A_s$, use ηbd
3. if $0.0018bD_{cap} \leq 4/3A_s < \eta bd$, use $4/3A_s$
4. if $4/3A_s < 0.0018bD_{cap} \leq \eta bd$, use $0.0018bD_{cap}$

In the expressions above, η is the maximum of

A. $200/f_y = 0.00333$ and

B. $\dfrac{3\sqrt{f_c'}}{f_y}$

η = maximum of 0.00333 and $\dfrac{3\sqrt{3{,}000}}{60{,}000} = 0.00274$

$\eta = 0.00333$

$\eta bd = 0.00333(13.08*12)(59) = 30.87 \text{ in.}^2$

$(4/3)A_s = (4/3)(28.5) = 38 \text{ in.}^2$

$0.0018bD_{cap} = 0.0018(13.08*12)(69) = 19.49 \text{ in.}^2$

Item (2) controls and $A_{s,required} = 30.87 \text{ in.}^2$

Provide 14 #14 bars each way (31.5 in.^2 O.K.)

Note that 5-pile pile caps require hooked bars in each direction. Therefore, hooked bar development is checked here. For non-epoxy-coated bars $\psi_e = 1.0$.

The length available to develop the longitudinal bar past the last pile is $E' = E - 3$ in. (offset) $= 36 - 3 = 33$ in.

$$l_{dh} = 0.7(0.02)\frac{\psi_e f_y}{\sqrt{f_c'}} d_b = 0.7(0.02)\frac{(1)60{,}000}{\sqrt{3{,}000}}(1.693)$$

$$= 25.96 \text{ in.} < 33 \text{ in.} \quad \text{O.K.}$$

The #14 bars are acceptable for hooked bar development.

Limit State 1 – Traditional ACI Two-Way Shear at $d/2$ from Column Face

Step (1): Based on the geometry shown in Fig. 8.25, determine the number of piles, $N_{outside}$, that are outside the failure pattern shown. Include the 3 in. adverse tolerance effect.

Note that the two-way failure plane is taken at a distance $d/2 = 29.5$ in. from the face of the column. The distance from the column centroid the failure plane is $c/2 + 29.5$ in. $= 40/2 + 29.5$

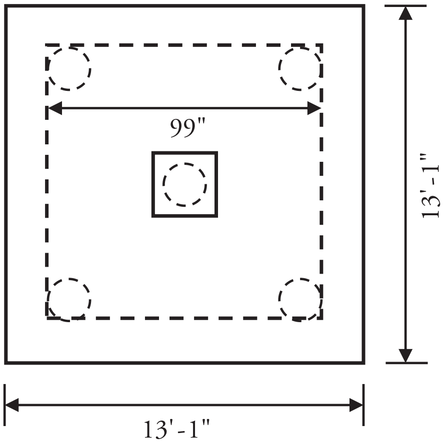


Fig. 8.25

$= 49.5$ in. Note that the distance from the centroid of the column to the nearest pile line is $0.7071L + 3$ in. (offset) $= 0.7071(60) + 3 = 45.4$ in. Since 49.5 in. is greater than 45.4 in., all piles are inside the failure plane and no piles provide shear to the failure plane. The Fig. 8.25 shows that no piles contribute to shear in Limit State 1. Note that $b_o = 4(c + d) = 4(99) = 212$ in. *Therefore, this limit state is not applicable.*

Limit State 2 – Traditional ACI One-Way Shear (through Short Dimension) at d from Column Face

Step (1): Based on the geometry shown in Fig. 8.25, determine the number of piles, $N_{outside}$, that are outside the failure pattern. Include the 3 in. adverse tolerance effect.

Note that the one-way failure plane is taken at a distance $d = 59$ in. from the face of the column. The distance from the column centroid the failure plane is $c/2 + 59$ in. $= 40/2 + 59 = 79$ in. Note that the distance from the centroid of the column to the nearest pile line is $0.7071L + 3$ in. (offset) $= 0.7071(60) + 3 = 45.4$ in. Since 79 in. is greater than 45.4 in., no piles provide shear forces to the failure plane. *Therefore, this limit state is not applicable.*

Limit State 3 – Traditional ACI One-Way Shear (through Long Dimension) at d from Column Face

Step (1): Based on the geometry shown in Fig. 8.25, determine the number of piles, $N_{outside}$, that are outside the failure pattern. Include the 3 in. adverse tolerance effect.

Note that the one-way failure plane is taken at a distance $d = 59$ in. from the face of the column. The distance from the column centroid the failure plane is $c/2 + 59$ in. $= 40/2 + 59 = 79$ in. Note that the distance from the centroid of the column to the nearest pile line is $0.7071L + 3$ in. (offset) $= 0.7071(60) + 3 = 45.4$ in. Since 79 in. is greater than 45.4 in., no piles provide shear forces to the failure plane. *Therefore, this limit state is not applicable.*

Limit State 4 – *MODIFIED* ACI Two-Way Shear at Column Face

Step (1): Determine the number of piles, $N_{outside}$, that are outside the failure pattern. Include the 3 in. adverse tolerance effect.

Note that the two-way failure plane is taken at the column face which is a distance $c/2 = 20$ in. from the column centroid. Thus, all piles except the pile directly under the column are located outside the column face and contribute shear at the column face. The distance w taken from the face of the column to the nearest pile center (with offset) is found as $0.7071L - c/2 + 3$ in. $= 0.7071(60) - 20/2 + 3 = 25.4$ in. Note that $b_s = 4c = 4(40) = 160$ in.

Step (2): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and reduce the total demand by the portion of the pile cap weight that is outside the critical section. In the expression below, c is the equivalent square column side dimension and d is the effective depth of the pile cap. γ_c is the specific weight of concrete (assumed to be normal weight concrete or 150 lb/ft^3 in this guide and associated spreadsheets).

$$V_u = 1.6N_{outside}\left(P_{SERVICE}\right) - 1.6\gamma_c ABD_{cap}\frac{AB - c^2}{AB}$$

$$V_u = 1.6(4\text{ piles})(800\text{ k})$$

$$-1.6(0.150)(13.08)(13.08)\left(\frac{69}{12}\right)\left[\frac{(13.08)(13.08) - \left(\frac{40}{12}\right)^2}{(13.08)(13.08)}\right]$$

$$= 4{,}900\text{ k}$$

Step (3): Determine the reduced nominal shear strength, ϕV_c, per Chapter 5.

$$v_c = \left(\frac{d}{w}\right)\left(1 + \frac{d}{c}\right)\left(2\sqrt{f_c'}\right) \le 32\sqrt{f_c'}$$

$$v_c = \left(\frac{59}{25.4}\right)\left(1 + \frac{59}{40}\right)\left(2\sqrt{3{,}000}\right) = 630\text{ psi}$$

$$\le 32\sqrt{f_c'} = 32\sqrt{3{,}000} = 1{,}753\text{ psi} \quad \text{O.K.}$$

$$\phi V_c = 0.85v_c(b_s d)$$

$$\phi V_c = 0.85(0.630)(160)(59) = 5{,}055\text{ k}$$

Step (4): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$$\phi V_c = 5{,}055\text{ k} > V_u = 4{,}900\text{ k} \quad \text{O.K.}$$

Limit State 5 – *MODIFIED* ACI One-Way Shear (through Short Dimension) at Column Face

Step (1): Based on the geometry shown in Fig. 8.26, determine the number of piles, $N_{outside}$, that are outside the failure pattern shown. Include the 3 in. adverse tolerance effect.

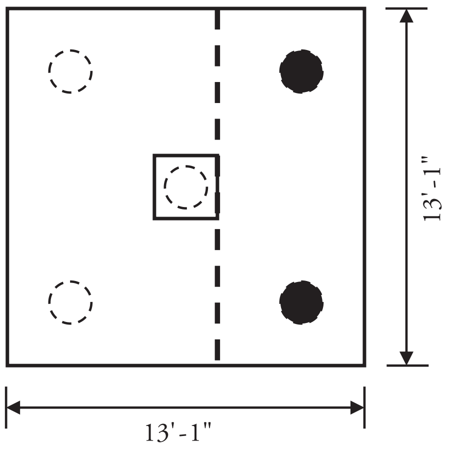


Fig. 8.26

Note that the one-way failure plane is taken at the column face which is a distance $c/2 = 20$ in. from the column centroid. Thus, the two shaded piles shown in Fig. 8.26 contribute shear at the column face. The distance w taken from the face of the column to the nearest pile center (with offset) is found as $0.7071L - c/2 + 3$ in. $= 0.7071(60) - 40/2 + 3 = 25.4$ in.

Step (2): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and reduce the total demand by the portion of the pile cap weight that is outside the critical section. In the expression below, c is the equivalent square column side dimension and d is the effective depth of the pile cap. γ_c is the specific weight of concrete (assumed to be normal weight concrete or 150 lb/ft^3 in this guide and associated spreadsheets).

$$V_u = 1.6N_{outside}\left(P_{SERVICE}\right) - 1.6\gamma_c \frac{ABD_{cap}}{2}\,\frac{A/2 - c/2}{A/2}$$

$$V_u = 1.6(2\text{ piles})(800\text{ k}) - 1.6(0.150)\frac{(13.08)(13.08)\left(\frac{69}{12}\right)}{2}\,\frac{\left(\frac{13.08}{2} - \frac{40}{12(2)}\right)}{\frac{13.08}{2}}$$

$$= 2{,}472\text{ k}$$

Step (3): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism and geometry shown in the Fig. 8.26. The term $x_{centroid}$ is the perpendicular distance from the critical section to the centroid of the $N_{outside}$ piles. Note that the centroid of the shaded piles is located a distance from the column face equal to $0.7071L - c/2 + 3$ in. (offset) $= 0.7071(60) - 40/2 + 3 = 25.4$ in.

$$M_u = 1.6N_{outside}\left(P_{SERVICE}\right)x_{centroid} - 1.6\gamma_c \frac{ABD_{cap}}{2}\,\frac{\left(\frac{A}{2} - \frac{c}{2}\right)}{\frac{A}{2}}\,\frac{\left(\frac{A}{2} - \frac{c}{2}\right)}{2}$$

$$M_u = 1.6(2\text{ piles})(800\ k)\left(\frac{25.4}{12}\right) - 1.6(0.150)$$

$$\frac{(13.08)(13.08)\left(\frac{69}{12}\right)}{2}\,\frac{\left(\frac{13.08}{2} - \frac{40}{12(2)}\right)}{\frac{13.08}{2}}\,\frac{\left(\frac{13.08}{2} - \frac{40}{12(2)}\right)}{2}$$

$$= 5{,}204\text{ k-ft} = 62{,}500\text{ k-in.}$$

$$v_c = \left(\frac{d}{w}\right)\left[3.5 - 2.5\left(\frac{M_u}{V_u d}\right)\right]\left[1.9\sqrt{f_c'} + 0.1\sqrt{f_c'}\left(\frac{V_u d}{M_u}\right)\right] \le 10\sqrt{f_c'}$$

$$v_c = \left(\frac{59}{25.4}\right)\left[3.5 - 2.5\left(\frac{62{,}500}{2{,}472(59)}\right)\right]$$

$$\left[1.9\sqrt{3{,}000} + 0.1\sqrt{3{,}000}\left(\frac{2{,}472(59)}{62{,}500}\right)\right]$$

$$= 659\text{ psi} > 10\sqrt{f_c'} = 10\sqrt{3{,}000} = 548\text{ psi} \qquad \text{N.G.}$$

Therefore,

$v_c = 548$ psi

$\phi V_c = 0.85 v_c(Bd) = 0.85(0.548)(157)(59) = 4{,}300$ k

Step (4): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$\phi V_c = 4{,}300\text{ k} > V_u = 2{,}472\text{ k}$ O.K.

Limit State 6 – *MODIFIED* ACI One-Way Shear (through Long Dimension) at Column Face

Step (1): Based on the geometry shown in Fig. 8.27, determine the number of piles, $N_{outside}$, that are outside the failure pattern shown. Include the 3 in. adverse tolerance effect.

Note that the one-way failure plane is taken at the column face which is a distance $c/2 = 20$ in. from the column centroid. Thus, the two shaded piles shown below contribute shear at the column face. The distance w taken from the face of the column to the nearest pile center (with offset) is found as $0.7071L - c/2 + 3$ in. $= 0.7071(60) - 40/2 + 3 = 25.4$ in.

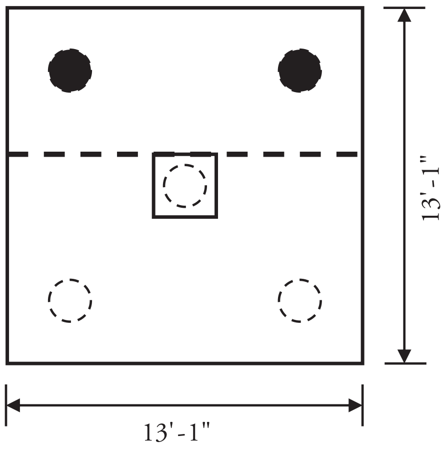


Fig. 8.27

Step (2): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and reduce the total demand by the portion of the pile cap weight that is outside the critical section. In the expression below, c is the equivalent square column side dimension and d is the effective depth of the pile cap. γ_c is the specific weight of concrete (assumed to be normal weight concrete or 150 lb/ft^3 in this guide and associated spreadsheets).

$$V_u = 1.6N_{outside}\left(P_{SERVICE}\right) - 1.6\gamma_c \frac{ABD_{cap}}{2}\,\frac{B/2 - c/2}{B/2}$$

$$V_u = 1.6(2\text{ piles})(800\text{ k})$$

$$-1.6(0.150)\frac{(13.08)(13.08)\left(\frac{69}{12}\right)}{2}\frac{\left(\frac{13.08}{2}-\frac{40}{12(2)}\right)}{\frac{13.08}{2}}$$

$$= 2{,}472\text{ k}$$

Step (3): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism and geometry shown in Fig. 8.27. The term $x_{centroid}$ is the perpendicular distance from the critical section to the centroid of the $N_{outside}$ piles. Note that the centroid of the shaded piles is located a distance from the column face equal to $0.7071L - c/2 + 3$ in. (offset) $= 0.7071(60) - 40/2 + 3 = 25.4$ in.

$$M_u = 1.6N_{outside}(P_{SERVICE})y_{centroid} - 1.6\gamma_c\frac{ABD_{cap}}{2}\frac{\left(\frac{B}{2}-\frac{c}{2}\right)}{\frac{B}{2}}\frac{\left(\frac{B}{2}-\frac{c}{2}\right)}{2}$$

$$M_u = 1.6(2\text{ piles})(800\text{ k})\left(\frac{25.4}{12}\right) - 1.6(0.150)$$

$$\frac{(13.08)(13.08)\left(\frac{69}{12}\right)}{2}\frac{\left(\frac{13.08}{2}-\frac{40}{12(2)}\right)}{\frac{13.08}{2}}\frac{\left(\frac{13.08}{2}-\frac{40}{12(2)}\right)}{2}$$

$$= 5{,}204\text{ k-ft} = 62{,}500\text{ k-in.}$$

$$v_c = \left(\frac{d}{w}\right)\left[3.5 - 2.5\left(\frac{M_u}{V_u d}\right)\right]\left[1.9\sqrt{f_c'} + 0.1\sqrt{f_c'}\left(\frac{V_u d}{M_u}\right)\right] \le 10\sqrt{f_c'}$$

$$v_c = \left(\frac{59}{25.4}\right)\left[3.5 - 2.5\left(\frac{62{,}500}{2{,}472(59)}\right)\right]$$

$$\left[1.9\sqrt{3{,}000} + 0.1\sqrt{3{,}000}\left(\frac{2{,}472(59)}{62{,}500}\right)\right]$$

$$= 659\text{ psi} > 10\sqrt{f_c'} = 10\sqrt{3{,}000} = 548\text{ psi} \quad \text{N.G.}$$

Therefore,
$v_c = 548$ psi

$$\phi V_c = 0.85v_c(Bd) = 0.85(0.548)(157)(59) = 4{,}300\text{ k}$$

Step (4): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$$\phi V_c = 4{,}300\text{ k} > V_u = 2{,}472\text{ k} \quad \text{O.K.}$$

Limit State P1 – Two-Way Shear at Single Pile

Step (1): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and conservatively neglect any reduction in shear due to the weight of concrete tributary to one pile.

$$V_u = 1.6P_{SERVICE} = 1.6(800) = 1{,}280\text{ k}$$

Step (2): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism. Round or equivalent round piles are assumed in this analysis. d_p is the actual or equivalent pile diameter. d is the effective depth of the pile cap.

$$b_o = \pi(d_p + d) = \pi(20 + 59) = 248\text{ in.}$$

$$\phi V_c = 0.85\left(4\sqrt{f_c'}\right)(b_o d) = 0.85\left(4\sqrt{3{,}000}\right)(248)(59)$$

$$= 2{,}725{,}000\text{ lb} = 2{,}725\text{ k}$$

Step (3): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$$\phi V_c = 2{,}725\text{ k} > V_u = 1{,}280\text{ k} \quad \text{O.K.}$$

Limit State P2 – Two-Way Shear at Two Adjacent Piles

Step (1): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and conservatively neglect any reduction in shear due to the weight of concrete tributary to the two piles considered in this analysis.

$$V_u = 2(1.6P_{SERVICE}) = 2(1.6)(800) = 2{,}560\text{ k}$$

Step (2): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism. Round or equivalent round piles are assumed in this analysis. d_p is the actual or equivalent pile diameter. d is the effective depth of the pile cap. L is the center to center pile spacing.

$$b_o = \pi(d_p + d) + 2L = \pi(20 + 59) + 2(60) = 368\text{ in.}$$

$$\phi V_c = 0.85\left(4\sqrt{f_c'}\right)(b_o d) = 0.85\left(4\sqrt{3{,}000}\right)(368)(59)$$

$$= 4{,}043{,}000\text{ lb} = 4{,}043\text{ k}$$

Step (3): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$$\phi V_c = 4{,}043\text{ k} > V_u = 2{,}560\text{ k} \quad \text{O.K.}$$

Limit State P3 – Two-Way Shear at Corner Pile

Step (1): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and conservatively neglect any reduction in shear due to the weight of concrete tributary to the corner pile.

$$V_u = 1.6P_{SERVICE} = 1.6(800) = 1{,}280\text{ k}$$

Step (2): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism. Round or equivalent round piles are assumed in this analysis. d_p is the actual or equivalent pile diameter. d is the effective depth of the pile cap. E is the center of corner pile to edge of cap dimension in plan.

$$b_o = \frac{\pi\left(d_p + d\right)}{4} + 2E = \frac{\pi(20+59)}{4} + 2(36) = 134 \text{ in.}$$

$$\phi V_c = 0.85\left(4\sqrt{f_c'}\right)\left(b_o d\right) = 0.85\left(4\sqrt{3{,}000}\right)(134)(59)$$

$$= 1{,}472{,}000 \text{ lb} = 1{,}472 \text{ k}$$

Step (3): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$\phi V_c = 1{,}472 \text{ k} > V_u = 1{,}280 \text{ k}$ O.K.

Limit State P4 – One-Way Shear at Corner Pile

Step (1): Determine the factored shear, V_u, acting on the critical section. Use the ASD allowable pile load $P_{SERVICE}$ to determine the total demand caused by the piling and conservatively neglect any reduction in shear due to the weight of concrete tributary to the corner pile.

$V_u = 1.6P_{SERVICE} = 1.6(800) = 1{,}280 \text{ k}$

Step (2): Determine the reduced nominal shear strength, ϕV_c, for the failure mechanism. Round or equivalent round piles are assumed in this analysis. d_p is the actual or equivalent pile diameter. d is the effective depth of the pile cap. E is the center of corner pile to edge of cap dimension in plan. The length of the critical section, b, can be found using simple geometry.

$b = 2\left(E\sqrt{2} + d_p/2 + d\right)$ ($d \le 13$ in. in this equation only; no limit on d for ϕV_c)

$$b = 2\left(36\sqrt{2} + 20/2 + 13\right) = 147.8 \text{ in.}$$

$$\phi V_c = 0.85\left(2\sqrt{f_c'}\right)(bd) = 0.85\left(2\sqrt{3{,}000}\right)(147.8)(59)$$

$$= 812{,}000 \text{ lb} = 812 \text{ k}$$

Step (3): Determine if the reduced nominal shear strength ϕV_c is greater than the factored demand V_u. If not, the pile cap thickness must be increased until this limit state is satisfied.

$\phi V_c = 812 \text{ k} < V_u = 1{,}280 \text{ k}$ N.G.

At this point, it appears that the pile cap thickness should be increased substantially, yet this exact design is listed in the tabulated designs. CRSI Limit State P4 is very restrictive and overly conservative for thicker pile caps and may not be entirely applicable in some cases. The spreadsheet associated with this design guide conservatively applies the limit state to all caps with corner piles but assumes the one way shear strength is limited to $2\sqrt{f_c'}$ which is very conservative when the critical distance from the cap is limited to 13 in. As a result, the design guide review committee has reviewed the results for the tabulated designs and believes that increasing the one way shear strength to $3\sqrt{f_c'}$ is still conservative for the configurations considered in the tabulated designs. The purpose of this example was to warn the designer that limit state P4 controls in several cases for high load piling, particularly near the allowable pile demand of 400 tons.

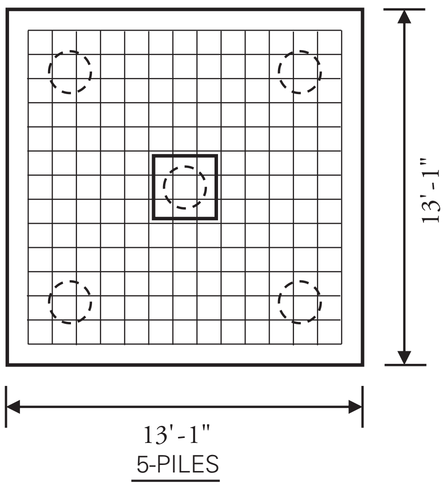


Fig. 8.28 Reinforcement Summary for design example 5: Use 14 #14 bars each way.

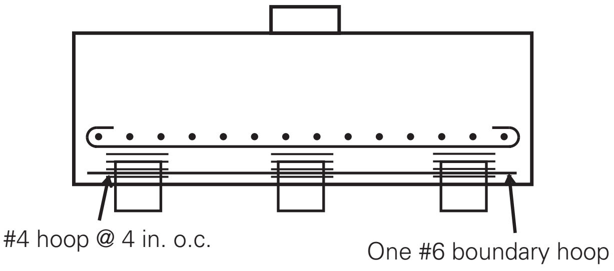


Fig. 8.29 Special steel required for high load piles.

8.7 Design Example #6: 16 Piles – Axial Plus Lateral Demand

Given Information:

Piles

Pile Service Load = $P_{SERVICE}$ = 40 tons (80 kips)

Pile Diameter = 8 in. Pile Spacing = L = 3 ft.

Pile Cap

$f_c' = 3{,}000$ psi $f_y = 60{,}000$ psi

Cover = 3 in. $d_c = 10$ in. (assumed 6 in. pile embedment)

$E = 15$ in. $D_{cap} = 48$ in. (total cap thickness)

Column

$P_u/A_g = 4{,}000$ psi

$P_u = 1{,}921$ k [see Example #1; based on $1.6(D + L_{floor})$]

Required:

Assume the pile cap has been designed for a vertical only demand as defined in Design Example #1. The resulting pile cap, as defined above, must be checked for combined vertical and lateral demand using factored load combinations. If the factored load combination with vertical and lateral (wind or seismic) demand included results in 40% of P_u based on $1.6(D + L_{floor})$ being utilized, determine the maximum available resistance to a factored moment M_{uy}.

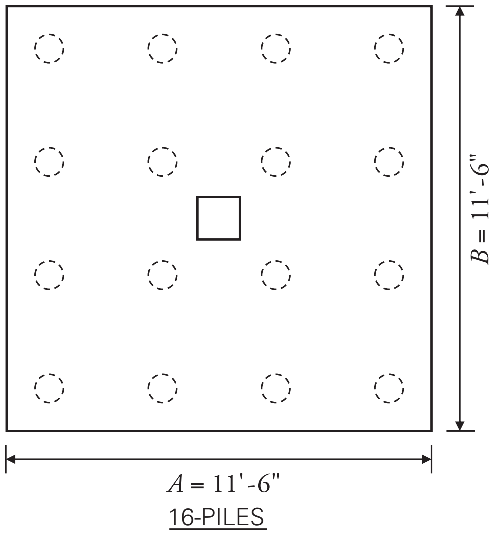


Fig. 8.30 Design example #6.

Solution:

Vertical Only

Load Combinations Considered:

LRFD: $1.6(D + L_{floor})$

ASD: $1.0(D + L_{floor})$

N = number of piles = 16

Determine the ASD axial load on the column at 40% of P_u (given demand)

$$P_{D+L} = \frac{1{,}921}{1.6}(0.40) = 480 \text{ k}$$

Determine the ASD axial load on all piles at 40% of P_u (given demand)

$$P_{D+L} = (80 \text{ k})(0.40) = 32 \text{ k}$$

$$\text{Cap Weight} = \gamma_c ABD_{cap} = 0.150(11.5)(11.5)(48/12) = 79.35 \text{ k}$$

Vertical Plus Lateral Load

Load Combinations Considered:

LRFD: $1.2(D + L_{floor}) + 1.0(E \text{ or } W)$

ASD: $1.0(D + L_{floor}) + 0.53(E \text{ or } W)$

Determine new column P_u for LRFD: $1.2(D + L_{floor}) + 1.0(E \text{ or } W)$

$$P_u = 1.2(16)(32) - 1.2(79.35) = 519 \text{ k}$$

With 40% of the ASD pile allowable demand already utilized, only 80 − 32 = 48 k are available to resist bending. Determine the ASD allowable moment M_y.

$$\text{Max demand in edge pile} = \frac{0.075M_y}{L}$$

$$48 = \frac{0.075M_{uy}}{3}$$

$$M_y = 1{,}920 \text{ k-ft}$$

Noting that this demand is based on an ASD factor of 0.53 for E or W, the LRFD factored moment M_{uy} accompanying P_u is found as:

$$M_{uy} = \frac{1{,}920 \ k\text{-ft}}{0.53} = 3{,}623 \ k\text{-ft}$$

Conclusion: Considering the LRFD load combination $1.2(D + L_{floor}) + 1.0(E \text{ or } W)$, the cap defined in this example is capable of resisting a factored demands $P_u = 519$ k and $M_{uy} = 3{,}623$ k-ft, simultaneously.

Note that the edge pile on the opposite side of the cap may be subjected to tensile forces under this load application. In such cases, positive anchorage for the factored tensile force resisted by the pile must be provided at the pile to pile cap interface. Likewise, in cases where the pile cap is required to resist negative bending moments, a top mat of reinforcement should be detailed to resist the tensile stresses in the upper part of the cap.

CHAPTER 9
Tabulated Designs

9.1 General

In Section T, tabulated designs are presented for gravity loads (see Chapter 5) and then for gravity loads combined with lateral loads (see Chapter 6). The following paragraphs explain the methodology used.

9.2 Tabulated Pile Cap Designs for Gravity Loads

Tabulated pile cap designs for the 26 pile cap patterns presented in Fig. 4.4 using allowable pile loads ranging from 40 tons to 400 tons in varying increments are presented first in this chapter. Conservatively, the tabulated designs are provided for steel piles. If precast concrete piles or wood piles are to be used, a minimum embedment of 4 inches is usually sufficient. The tabulated design is still applicable since the design depth is unaffected by the pile type and the final design can be obtained by simply deducting 2 inches from tabulated thickness Dcap, and reducing the tabulated concrete volume appropriately. The design requirements and recommendations presented elsewhere in this guide are followed for all tabulated designs.

9.3 Tabulated Pile Cap Designs for Combined Gravity and Lateral Loads

The Tables section concludes by presenting tabulated pile cap designs for the 26 pile cap configurations presented in Fig. 4.4 using allowable pile loads ranging from 40 tons to 400 tons in varying increments and combined gravity and lateral loading. To generate the tabulated designs, the tabulated designs of Chapter 5 were used as the baseline designs for the vertical only load combination $1.6(D + L_{floor})$. The user should note that in the combined gravity and lateral load tables, the column data under the headings "Piles", "Columns", and "Pile Cap" contain the same information as contained in the gravity load only tables. The other columns in the tables present the remaining capacities of the pile caps (i.e., M_{ux} and M_{uy}) when the same caps have a reduced axial load demand. The values for M_{ux} and M_{uy} have been determined using the LRFD load combination $1.2(D + L_{floor}) + 1.0(E \; or \; W)$ and the ASD load combination $1.0(D + L_{floor}) + 0.53(E \; or \; W)$, as appropriate. The governing limit state for all designs presented in the gravity plus lateral load tabulated designs is edge pile failure under allowable load (i.e., ASD design considering geotechnical failure of the resisting soil).

CHAPTER 10
Selected References

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Notations

a = depth of equivalent rectangular stress block

A = long dimension of pile cap (in plan)

A = pile cross-sectional area (gross) *(derivation/illustration only)*

$A_{s,final}$ = The total amount of reinforcement required in the short direction

A_g = gross cross-sectional area of the column

b = pile cap width (A or B depending on direction considered)

b_f = width of steel flange *(derivation/illustration only)*

b_o = perimeter of critical section for shear in pile cap

b_s = column perimeter

B = short dimension of pile cap *(in plan)*

c = column size *(diameter of dimension)*

c_b = the minimum of the nearest cover to the center of the developed bar and half the center to center bar spacing

d = effective depth of pile cap

d = depth of steel shape *(derivation/illustration only)*

D = dead load

d_b = nominal diameter of reinforcing bar

d_c = average depth to center of bars *(considers both short and long bars)*

d_p = pile diameter or dimension

D_{cap} = total depth of pile cap

E = pile edge distance measured from the centerline of the pile to the adjacent concrete pile cap edge

E = seismic load

E = pile modulus of elasticity *(derivation/illustration only)*

E' = modified edge distance to include tolerance effect (i.e., $E - 3$ inches)

f = strength reduction factor

f_1 = live load factor used in LRFD load combinations *(see Chapter 2)*

f'_c = specified compressive strength of concrete

f_y = specified yield strength of reinforcement

I_x = the x-axis moment of inertia of the piles for the pile cap configuration selected *(derivation/illustration only)*

I_y = the y-axis moment of inertia of the piles for the pile cap configuration selected *(derivation/illustration only)*

K_{tr} = transverse reinforcement index
L = pile spacing *(center to center)*
$l_{available}$ = length available for bar development
l_d = tension development length for straight bars
l_{dh} = tension development length for bars with standard hooks
L_{floor} = floor live load
L_{pile} = overall pile length *(derivation/illustration only)*
M_u = factored moment at section
M_x = concentrated moment at base of the column about the y-axis *(derivation/illustration only)*
M_y = concentrated moment at base of the column about the x-axis *(derivation/illustration only)*
M_{ux} = factored moment at section about y-axis
M_{uy} = factored moment at section about x-axis
n = number of piles resisting vertical loads *(derivation/illustration only)*
n = total number of piles *(derivation/illustration only)*
N = total number of piles
$N_{outside}$ = number of piles that are outside the failure pattern indicated
P = $P_{SERVICE}$ = ASD or allowable pile demand $(D + L)$
P = axial load at the base of the column *(derivation/illustration only)*
P_u = factored axial force
P_{center} = demand on the two center most piles (per pile) as a fraction of the overall vertical column demand *(derivation/illustration only)*
P_{corner} = demand on the four corner piles (per pile) as a fraction of the overall vertical column demand *(derivation/illustration only)*
P_{other} = demand on the other 24 piles as a fraction of the overall vertical column demand *(derivation/illustration only)*
Q_E = horizontal seismic force effect
R = axial force pile reaction *(derivation/illustration only)*
R_{max} = maximum pile reaction *(derivation/illustration only)*
R_{min} = minimum pile reaction *(with overturning) (derivation/illustration only)*
S_{DS} = design spectral response acceleration parameter at short periods
v_c = allowable pile shear strength
V_u = factored shear force at section
V_x = concentrated shear at base of the column in the x direction *(derivation/illustration only)*
V_y = concentrated shear at base of the column in the y direction *(derivation/illustration only)*

w = horizontal component of crack (subscripts "S" and "L" denote short and long dimensions when nearest piles lines are not equidistant from column face)

W = wind load

x = 0.5 times pile spacing *(derivation/illustration only)*

x_1 = distance from critical section for moment to first line of piles in x direction *(derivation/illustration only)*

$x_{centroid}$ = perpendicular distance from the critical section to the centroid of the Noutside piles *(in the x-direction) (derivation/illustration only)*

X = adjustment factor for the reinforcement outside the center band

X = horizontal distance from the y-axis to the pile in question *(derivation/illustration only)*

$y_{centroid}$ = perpendicular distance from the critical section to the centroid of the Noutside piles (in the y-direction) *(derivation/illustration only)*

Y = horizontal distance from the x-axis to the pile in question *(derivation/illustration only)*

α = angle of the potential shear crack to the vertical

β = A/B or the ratio of the long to short side dimension of the pile cap

η = the maximum of (a) $200/f_y = 0.00333$ and (b) $3\sqrt{f_c'}/f_y$ *(note: stresses in psi)*

γ_c = specific weight of concrete

γ_s = the fraction of the overall required area of steel As that must be provided over the center bandwidth of the pile cap

ρ = seismic redundancy factor (see Chapter 2)

ρ_w = ratio of steel area A_s to the product of the pile cap width b and the effective depth d

ϕM_n = reduced nominal moment strength at section

Ω_0 = seismic overstrength factor

ψ_e = reinforcement coating factor

ψ_t = reinforcement location factor

ψ_s = reinforcement size factor

f'_c = 3,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 8 in. spaced at 3' - 0"

GRAVITY LOADS ONLY
40-TON STEEL PILES

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 15 in.

PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	246	10	5-6	2-6	34	1.4	8H#5	2.37	7H#7	4.04	0.057	0.956	N/A
3	370	11	5-6 1-6	5-2 1-7	31	2	4H#6	1.78	3-WAYS	3-WAYS	0.057	0.775	0.952
4	493	12	5-6	5-6	31	2.9	11H#6	4.76	11H#6	4.76	0.105	0.762	0.965
5	608	13	6-9	6-9	35	4.9	14H#6	6.31	14H#6	6.31	0.159	0.859	0.688
6	726	14	8-6	5-6	44	6.3	14H#6	6.31	18H#6	8.08	0.184	0.968	0.399
7	845	17	8-6	7-9	38	7.7	16H#6	7.25	16H#6	6.98	0.215	0.707	0.985
8	972	16	8-6	7-9	39	7.9	21H#6	9.08	22H#6	9.77	0.289	0.967	0.748
9	1089	17	8-6	8-6	43	9.6	22H#6	9.77	22H#6	9.77	0.308	0.909	0.795
10	1206	18	11-6	7-9	41	11.3	8#10	10.2	23H#6	10.18	0.338	0.621	0.852
11	1331	19	11-6	7-9	43	11.8	12#9	12.06	25H#6	11.15	0.386	0.813	0.954
12	1442	19	11-6	8-6	48	14.5	10#10	13.04	27H#6	11.92	0.426	0.997	0.881
13	1549	20	12-11	8-6	52	17.6	14#9	14.43	18#8	14.51	0.488	0.923	0.747
14	1690	21	11-6	10-9	41	15.6	12#10	15.08	16#9	16.41	0.563	0.883	0.994
15	1790	22	12-11 5-11	11-6 7-6	48	19.9	14#10	17.65	19#9	19.2	0.729	0.673	0.993
16	1921	22	11-6	11-6	48	19.6	18#9	17.68	18#9	17.68	0.673	0.985	0.844
17	2038	23	12-11 5-11	11-6 7-6	51	21.2	15#10	19.03	18#9	17.65	0.737	0.787	0.992
18	2152	24	12-11	11-6	51	23.4	15#10	19.03	20#9	20	0.775	0.903	0.97
19	2261	24	13-9	11-6	54	26.4	16#10	20.41	21#9	20.88	0.849	0.835	0.973
20	2376	25	14-6	11-6	55	28.3	13#11	20.84	22#9	22.63	0.895	0.944	0.92
21	2492	25	13-9 11-1	13-9 3-5	56	30.2	19#10	24.8	19#10	24.8	1.083	0.764	0.988
22	2632	26	14-6 10-6	12-11 5-11	53	28.3	14#11	22.37	19#10	24.33	1.028	0.961	0.975
23	2728	27	14-6 10-6	13-9 6-9	58	33.2	17#11	26.56	21#10	26.86	1.231	0.711	0.987
24	2852	27	14-6	13-9	55	33.8	16#11	24.91	20#10	25.49	1.165	0.813	0.986
26	3080	28	15-11 8-11	14-6 10-6	57	38.1	18#11	28.74	19#11	29.21	1.444	0.633	0.995
28	3307	29	15-11	14-6	60	42.7	19#11	29.17	20#11	31.12	1.522	0.716	0.881
30	3540	30	17-6	14-6	59	46.2	22#11	34.82	21#11	33.52	1.775	0.741	0.979

* Concrete columns - side dimension of square column. Structural steel columns - b or t plus 0.5 times the sum of overhangs to edges of base plate. For 3-pile and 7-pile caps, diameter of round column.

** See detail layouts for clipped corner pile cap arrangements. Concrete quatities based on clipped corners.

(1) "H" - use hooked or headed bars

(2) Total reinforcing steel weight - long plus short bars. For 3-pile cap, total of all 3 bands.

$f_c' = 3{,}000$ psi							**GRAVITY LOADS ONLY**							Minimum cover = 3 in.
$f_y = 60$ ksi							**50-TON STEEL PILES**							$d_c = 10$ in.
Minimum Pile Diameter = 8 in. spaced at 3' - 0"														Edge $E = 15$ in.
PILES	**COLUMN**		**PILE CAP**				**REINFORCING BARS**					**SHEAR**		
Number of Piles	**Max. Load P_u (net)**	**Min. Size ***	**Long A ****	**Short B ****	**D**	**Concrete ****	**Long A Bars (1)**	**$A_{minimum}$ A Bars**	**Short B Bars (1)**	**$A_{minimum}$ B Bars**	**Steel Weight (2)**	**$V_u/\phi V_n$ Beam One-Way**	**$V_u/\phi V_n$ Slab Two-Way**	
per cap	**(kips)**	**(in.)**	**(ft - in.)**	**(ft - in.)**	**(in.)**	**(c.y.)**	**No.-Size**	**(in²)**	**No.-Size**	**(in²)**	**(tons)**	**Ratio**	**Ratio**	
2	309	10	5-6	2-6	39	1.7	8H#5	2.46	8H#7	4.63	0.061	0.853	N/A	
3	466	13	5-6	5-2	33	2.2	7H#5	1.99	3-WAYS	3-WAYS	0.068	0.627	0.972	
			1-6	1-7										
4	619	13	5-6	5-6	34	3.2	12H#6	5.42	12H#6	5.42	0.114	0.598	0.946	
5	767	14	6-9	6-9	36	5.1	16H#6	7.19	16H#6	7.19	0.182	0.874	0.794	
6	917	16	8-6	5-6	45	6.5	17H#6	7.67	19H#6	8.26	0.21	0.968	0.462	
7	1064	19	8-6	7-9	42	8.5	18H#6	7.82	17H#6	7.71	0.236	0.491	0.96	
8	1225	18	8-6	7-9	41	8.3	22H#6	9.8	24H#6	10.5	0.309	0.839	0.813	
9	1376	19	8-6	8-6	44	9.8	26H#6	11.58	26H#6	11.58	0.364	0.911	0.919	
10	1525	20	11-6	7-9	42	11.6	10#10	12.42	24H#6	10.72	0.391	0.579	0.985	
11	1676	21	11-6	7-9	47	12.9	13#9	13.35	28H#6	12.27	0.424	0.923	0.962	
12	1808	22	11-6	8-6	57	17.2	16#9	16.13	32H#6	14.16	0.523	0.409	0.632	
13	1952	23	12-11	8-6	58	19.7	13#10	16.44	20#8	16.18	0.561	0.995	0.474	
14	2128	24	11-6	10-9	45	17.2	16#9	16.41	18#9	17.65	0.613	0.999	0.982	
15	2257	24	12-11	11-6	53	22	16#10	19.95	21#9	21.16	0.82	0.637	0.993	
			5-11	7-6										
16	2414	25	11-6	11-6	55	22.4	21#9	20.9	21#9	20.9	0.785	0.422	0.772	
17	2577	26	12-11	11-6	53	22	16#10	19.95	21#9	20.83	0.82	0.985	0.82	
			5-11	7-6										
18	2707	27	12-11	11-6	58	26.6	17#10	22.25	21#9	20.87	0.847	0.983	0.788	
19	2859	27	13-9	11-6	57	27.8	18#10	22.41	24#9	24.16	0.962	0.992	0.812	
20	3003	28	14-6	11-6	59	30.4	15#11	23.65	25#9	25.61	1.025	0.946	0.972	
21	3150	29	13-9	13-9	60	32.4	21#10	27	21#10	27	1.197	0.916	0.599	
			11-1	3-5										
22	3318	29	14-6	12-11	58	31	16#11	24.95	21#10	27.23	1.156	0.95	0.99	
			10-6	5-11										
23	3450	30	14-6	13-9	62	35.5	18#11	28.76	23#10	29.55	1.325	0.871	0.958	
			10-6	6-9										
24	3608	31	14-6	13-9	58	35.7	18#11	27.52	22#10	28.32	1.297	0.966	0.842	
26	3886	32	15-11	14-6	63	42.2	20#11	31.38	21#11	32.57	1.6	0.767	0.986	
			8-11	10-6										
28	4189	33	15-11	14-6	63	44.9	21#11	33.61	26#10	33.08	1.643	0.858	0.97	
30	4470	34	17-6	14-6	65	50.9	24#11	38.33	29#10	37.77	1.957	0.844	0.982	

* Concrete columns - side dimension of square column. Structural steel columns - b or t plus 0.5 times the sum of overhangs to edges of base plate. For 3-pile and 7-pile caps, diameter of round column.

** See detail layouts for clipped corner pile cap arrangements. Concrete quatities based on clipped corners.

(1) "H" - use hooked or headed bars

(2) Total reinforcing steel weight - long plus short bars. For 3-pile cap, total of all 3 bands.

f'_c = 3,000 psi

f_y = 60 ksi

Minimum Pile Diameter = 8 in. spaced at 3' - 0"

GRAVITY LOADS ONLY

60-TON STEEL PILES

Minimum cover = 3 in.

d_c = 10 in.

Edge E = 15 in.

PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	372	10	5-6	2-6	43	1.8	6H#6	2.61	9H#7	5.11	0.067	0.829	N/A
3	561	14	5-6	5-2	35	2.3	5H#6	2.18	3-WAYS	3-WAYS	0.071	0.549	0.994
			1-6	1-7									
4	746	14	5-6	5-6	36	3.4	13H#6	5.86	13H#6	5.86	0.124	0.539	0.974
5	927	16	6-9	6-9	36	5.1	16H#6	7.19	16H#6	7.19	0.182	0.937	0.915
6	1109	17	8-6	5-6	46	6.6	18H#6	8.06	19H#6	8.45	0.217	1	0.523
7	1284	21	8-6	7-9	45	9.1	19H#6	8.45	19H#6	8.26	0.256	0.408	0.966
8	1481	20	8-6	7-9	41	8.3	22H#6	9.8	24H#6	10.64	0.309	0.915	0.945
9	1661	21	8-6	8-6	46	10.3	28H#6	12.45	28H#6	12.45	0.393	0.816	0.975
10	1834	22	11-6	7-9	48	13.2	12#9	12.29	27H#6	11.92	0.398	0.531	0.945
11	2019	23	11-6	7-9	52	14.3	14#9	13.92	29H#6	12.92	0.449	0.997	0.914
12	2194	24	11-6	8-6	56	16.9	16#9	15.79	31H#6	13.91	0.516	0.507	0.771
13	2357	25	12-11	8-6	63	21.3	14#10	18.14	22#8	17.58	0.609	0.445	0.471
14	2564	26	11-6	10-9	50	19.1	17#9	17.39	18#9	18.14	0.632	0.75	0.929
15	2740	27	12-11	11-6	52	21.6	15#10	19.49	21#9	21.27	0.793	0.796	0.841
			5-11	7-6									
16	2929	28	11-6	11-6	54	22	21#9	21.04	21#9	21.04	0.785	0.523	0.932
17	3097	28	12-11	11-6	62	25.7	19#10	24.09	20#9	20.2	0.882	0.382	0.584
			5-11	7-6									
18	3274	29	12-11	11-6	61	28	19#10	23.63	23#9	23.39	0.938	0.432	0.59
19	3439	30	13-9	11-6	66	32.2	20#10	25.93	23#9	23.62	1	0.403	0.603
20	3616	31	14-6	11-6	67	34.5	17#11	26.36	25#9	25.7	1.1	0.997	0.679
21	3804	31	13-9	13-9	65	35.1	23#10	29.75	23#10	29.75	1.311	0.388	0.608
			11-1	3-5									
22	4016	32	14-6	12-11	60	32.1	17#11	26.83	22#10	28.39	1.22	0.528	0.83
			10-6	5-11									
23	4178	33	14-6	13-9	64	36.6	23#10	29.9	24#10	30.8	1.377	0.782	0.952
			10-6	6-9									
24	4352	33	14-6	13-9	64	39.4	23#10	29.9	24#10	30.8	1.377	0.874	0.824
26	4697	35	15-11	14-6	68	45.5	22#11	34.03	27#10	35.1	1.714	0.899	0.998
			8-11	10-6									
28	5062	36	15-11	14-6	68	48.4	23#11	36.46	28#10	36.26	1.785	0.957	0.983
30	5399	37	17-6	14-6	71	55.6	26#11	41.03	33#10	41.97	2.168	0.893	0.975

* Concrete columns - side dimension of square column. Structural steel columns - b or t plus 0.5 times the sum of overhangs to edges of base plate. For 3-pile and 7-pile caps, diameter of round column.

** See detail layouts for clipped corner pile cap arrangements. Concrete quatities based on clipped corners.

(1) "H" - use hooked or headed bars

(2) Total reinforcing steel weight - long plus short bars. For 3-pile cap, total of all 3 bands.

f'_c = 3,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 10 in. spaced at 3' - 0"

GRAVITY LOADS ONLY
80-TON STEEL PILES

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 21 in.

PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	494	12	6-6	3-6	38	2.7	4H#9	3.98	9H#7	5.34	0.108	0.96	N/A
3	743	16	6-6	6-2	39	3.8	3H#9	2.41	3-WAYS	3-WAYS	0.13	0.477	0.985
			2-1	2-3									
4	991	16	6-6	6-6	39	5.1	10H#8	7.41	10H#8	7.41	0.209	0.474	0.915
5	1233	18	7-9	7-9	39	7.2	9H#9	9.13	9H#9	9.13	0.298	0.681	0.974
6	1479	20	9-6	6-6	46	8.8	12H#8	9.49	12H#8	9.44	0.299	0.983	0.657
7	1708	24	9-6	8-9	50	12.8	12H#8	9.45	10H#9	10.26	0.356	0.376	0.985
8	1968	23	9-6	8-9	48	12.3	13H#9	13.24	14H#9	14.18	0.51	0.506	0.967
9	2210	24	9-6	9-6	52	14.5	15H#9	14.88	15H#9	14.88	0.586	0.529	0.962
10	2448	25	12-6	8-9	51	17.2	12#10	14.82	14H#9	13.77	0.566	0.583	0.976
11	2695	26	12-6	8-9	55	18.6	13#10	16.92	19H#8	15.46	0.591	0.559	0.666
12	2939	28	12-6	9-6	56	20.5	20#9	19.64	17H#9	17.46	0.74	0.607	0.974
13	3166	29	13-11	9-6	61	24.9	16#10	20.93	23#8	18.34	0.738	0.508	0.493
14	3422	30	12-6	11-9	55	24.9	17#10	21.32	22#9	22.08	0.86	0.55	0.971
15	3670	31	13-11	12-6	54	26.1	18#10	23.47	20#10	25.31	1.036	0.937	0.99
			6-2	8-1									
16	3911	32	12-6	12-6	59	28.5	19#10	24.68	19#10	24.68	0.981	0.577	0.995
17	4166	33	13-11	12-6	59	28.6	21#10	26.44	21#10	26.77	1.148	0.503	0.812
			6-2	8-1									
18	4402	34	13-11	12-6	59	31.7	23#10	29.3	27#9	26.81	1.215	0.517	0.796
19	4631	35	14-9	12-6	63	35.9	20#11	30.85	30#9	30.7	1.369	0.528	0.837
20	4856	35	15-6	12-6	68	40.7	20#11	31.09	32#9	32.75	1.45	0.49	0.847
21	5122	36	14-9	14-9	63	39	25#10	32.46	25#10	32.46	1.533	0.505	0.822
			11-9	3-7									
22	5385	37	15-6	13-11	62	38	21#11	33.5	27#10	34.14	1.616	0.638	0.988
			11-1	6-2									
23	5608	38	15-6	14-9	66	43.1	21#11	33.69	27#10	34.22	1.665	0.95	0.977
			11-1	7-0									
24	5842	39	15-6	14-9	66	46.6	23#11	36.48	29#10	37.24	1.806	0.529	0.978

* Concrete columns - side dimension of square column. Structural steel columns - b or t plus 0.5 times the sum of overhangs to edges of base plate. For 3-pile and 7-pile caps, diameter of round column.

** See detail layouts for clipped corner pile cap arrangements. Concrete quatities based on clipped corners.

(1) "H" - use hooked or headed bars

(2) Total reinforcing steel weight - long plus short bars. For 3-pile cap, total of all 3 bands.

f'_c = 3,000 psi f_y = 60 ksi Minimum Pile Diameter = 10 in. spaced at 3' - 0"							**GRAVITY LOADS ONLY** **100-TON STEEL PILES**						Minimum cover = 3 in. d_c = 10 in. Edge E = 21 in.
PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	621	13	6-6	3-6	41	2.9	6H#8	4.41	10H#7	5.76	0.116	0.991	N/A
3	933	18	6-6	6-2	42	4.1	6H#9	2.67	3-WAYS	3-WAYS	0.13	0.542	0.923
			2-1	2-3									
4	1246	18	6-6	6-6	40	5.2	8H#9	7.91	8H#9	7.91	0.231	0.576	0.931
5	1548	20	7-9	7-9	43	8	13H#8	10.39	13H#8	10.39	0.315	0.532	0.956
6	1860	22	9-6	6-6	48	9.1	13H#8	10.41	10H#9	9.85	0.333	0.946	0.994
7	2148	27	9-6	8-9	55	14.1	13H#8	10.39	11H#9	11.29	0.389	0.421	0.981
8	2476	25	9-6	8-9	50	12.8	14H#9	14.15	15H#9	14.94	0.548	0.508	0.967
9	2778	27	9-6	9-6	56	15.6	17H#9	16.74	17H#9	16.74	0.665	0.459	1
10	3088	28	12-6	8-9	51	17.2	18#9	18.46	16H#9	15.67	0.66	0.727	0.973
11	3404	30	12-6	8-9	53	17.9	17#10	22.02	20H#9	19.89	0.804	0.739	0.788
12	3702	31	12-6	9-6	58	21.3	18#10	23.34	21H#9	20.71	0.875	0.732	0.695
13	4001	32	13-11	9-6	60	24.5	21#10	26.89	23#8	18.63	0.883	0.583	0.595
14	4303	33	12-6	11-9	60	27.2	19#10	23.67	24#9	24.58	0.95	0.622	0.997
15	4614	34	13-11	12-6	59	28.6	20#10	25.98	27#9	27.76	1.128	0.57	0.803
			6-2	8-1									
16	4916	36	12-6	12-6	65	31.3	27#9	27.72	27#9	27.72	1.102	0.646	0.996
17	5254	37	13-11	12-6	59	28.6	26#10	32.84	27#9	27.05	1.301	0.634	0.98
			6-2	8-1									
18	5558	38	13-11	12-6	58	31.1	29#10	37.45	31#9	31.45	1.47	0.666	0.994
19	5844	39	14-9	12-6	64	36.4	29#10	37.63	31#9	31.66	1.522	0.654	0.984
20	6132	40	15-6	12-6	69	41.3	24#11	37.93	35#9	35.98	1.67	0.607	0.99

* Concrete columns - side dimension of square column. Structural steel columns - b or t plus 0.5 times the sum of overhangs to edges of base plate. For 3-pile and 7-pile caps, diameter of round column.

** See detail layouts for clipped corner pile cap arrangements. Concrete quatities based on clipped corners.

(1) "H" - use hooked or headed bars

(2) Total reinforcing steel weight - long plus short bars. For 3-pile cap, total of all 3 bands.

f'_c = 3,000 psi | **GRAVITY LOADS ONLY** | Minimum cover = 3 in.

f_y = 60 ksi | **120-TON STEEL PILES** | d_c = 10 in.

Minimum Pile Diameter = 12 in. spaced at 3' - 0" | Edge E = 21 in.

PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	747	14	6-6	3-6	45	3.2	6H#8	4.69	11H#7	6.32	0.121	0.971	N/A
3	1124	19	6-6 2-2	6-2 2-3	43	4.2	3H#9	3.09	3-WAYS	3-WAYS	0.13	0.633	0.972
4	1502	20	6-6	6-6	40	5.2	8H#9	7.93	8H#9	7.93	0.231	0.693	0.987
5	1865	22	7-9	7-9	45	8.3	11H#9	10.99	11H#9	10.99	0.365	0.495	0.997
6	2242	24	9-6	6-6	50	9.5	12H#9	11.8	11H#9	10.81	0.394	0.891	0.954
7	2588	29	9-6	8-9	60	15.4	11H#9	11.34	12H#9	12.31	0.434	0.456	0.501
8	2987	28	9-6	8-9	51	13.1	18H#8	14.53	15H#9	15.37	0.534	0.559	0.941
9	3347	29	9-6	9-6	60	16.7	18H#9	18.25	18H#9	18.25	0.704	0.419	0.989
10	3726	31	12-6	8-9	52	17.6	17#10	21.45	18H#9	18.08	0.768	0.726	0.976
11	4112	33	12-6	8-9	51	17.2	22#10	27.78	22H#9	21.83	0.97	0.936	0.987
12	4477	34	12-6	9-6	55	20.2	29#9	29.88	22H#9	22.39	1.022	0.944	0.843
13	4838	35	13-11	9-6	58	23.7	26#10	33.92	29#8	22.9	1.099	0.73	0.743
14	5185	37	12-6	11-9	65	29.5	26#9	26.05	27#9	27.15	1.047	0.682	0.988
15	5581	38	13-11 6-2	12-6 8-1	57	27.6	25#10	32.27	34#9	34.25	1.415	0.718	0.991
16	5922	39	12-6	12-6	71	34.2	30#9	30.72	30#9	30.72	1.224	0.702	0.987

* Concrete columns - side dimension of square column. Structural steel columns - b or t plus 0.5 times the sum of overhangs to edges of base plate. For 3-pile and 7-pile caps, diameter of round column.

** See detail layouts for clipped corner pile cap arrangements. Concrete quatities based on clipped corners.

(1) "H" - use hooked or headed bars

(2) Total reinforcing steel weight - long plus short bars. For 3-pile cap, total of all 3 bands.

f'_c = 3,000 psi **GRAVITY LOADS ONLY** **Minimum cover = 3 in.**
f_y = 60 ksi **140-TON STEEL PILES** **d_c = 10 in.**
Minimum Pile Diameter = 12 in. spaced at 3' - 0" **Edge E = 27 in.**

PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	867	15	7- 6	4- 6	42	4.4	4H#11	5.83	11H#7	6.80	0.186	0.975	N/A
3	1305	21	7- 6	7- 2	44	5.9	3H#10	3.32	3-WAYS	3-WAYS	0.19	0.619	0.934
			2- 8	2-11									
4	1745	21	7- 6	7- 6	41	7.1	6H#11	9.39	6H#11	9.82	0.324	0.676	0.986
5	2169	24	8- 9	8- 9	46	10.9	8H#11	12.7	8H#11	13.33	0.485	0.494	0.98
6	2607	26	10- 6	7- 6	51	12.4	11H#10	13.13	8H#11	12.27	0.52	0.775	0.947
7	3019	32	10- 6	9- 9	57	18	8H#11	12.86	10H#10	13.82	0.54	0.508	0.585
8	3479	30	10- 6	9- 9	51	16.1	13H#10	16.13	11H#11	17.45	0.722	0.584	0.987
9	3897	32	10- 6	10- 6	61	20.8	13H#11	20.41	13H#11	20.61	0.909	0.432	0.989
10	4335	33	13- 6	9- 9	55	22.3	18#10	22.67	12H#11	19.74	0.899	0.708	0.99
11	4785	35	13- 6	9- 9	54	21.9	23#10	29.27	15H#11	23.66	1.138	0.911	0.77
12	5220	37	13- 6	10- 6	55	24.1	26#10	34.01	16H#11	26.2	1.287	0.995	0.94
13	5645	38	14-11	10- 6	57	27.6	31#10	39.88	26#9	26.11	1.404	0.787	0.862
14	6031	39	13- 6	12- 9	70	37.2	24#10	30.79	31#9	32.5	1.317	0.673	0.98

* Concrete columns - side dimension of square column. Structural steel columns - b or t plus 0.5 times the sum of overhangs to edges of base plate. For 3-pile and 7-pile caps, diameter of round column.

** See detail layouts for clipped corner pile cap arrangements. Concrete quatities based on clipped corners.

(1) "H" - use hooked or headed bars

(2) Total reinforcing steel weight - long plus short bars. For 3-pile cap, total of all 3 bands.

f'_c = 3,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 15 in. spaced at 3' - 9"

GRAVITY LOADS ONLY
160-TON STEEL PILES

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 27 in.

PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	988	16	8-3	4-6	48	5.5	6H#10	6.91	14H#7	8.55	0.232	0.99	N/A
3	1486	22	8-3	7-9	49	7.7	3H#11	4.23	3-WAYS	3-WAYS	0.261	0.559	0.986
			2-9	2-11									
4	1985	23	8-3	8-3	46	9.7	8H#11	12	8H#11	12	0.464	0.603	0.978
5	2461	25	9-10	9-10	51	15.2	13H#10	16.27	13H#10	16.27	0.681	0.51	0.982
6	2959	28	12-0	8-3	57	17.4	13H#10	16.45	12H#10	14.97	0.674	0.918	0.985
7	3407	33	12-0	11-0	67	27.3	10H#11	15.92	11H#11	17.37	0.789	0.419	0.984
8	3937	32	12-0	11-0	60	24.4	14H#11	22.13	15H#11	23.46	1.09	0.48	0.972
9	4409	34	12-0	12-0	69	30.7	16H#11	25.37	16H#11	25.37	1.247	0.412	0.974
10	4912	36	15-9	11-0	60	32.1	19#11	29.47	16H#11	24.88	1.351	0.747	0.967
11	5413	37	15-9	11-0	63	33.7	22#11	35.07	20H#11	31.52	1.617	0.759	0.823
12	5886	39	15-9	12-0	68	39.7	24#11	37.78	21H#11	33.42	1.79	0.764	0.728

f'_c = 3,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 15 in. spaced at 3' - 9"

GRAVITY LOADS ONLY
180-TON STEEL PILES

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 27 in.

PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	1114	17	8-3	4-6	51	5.8	6H#10	7.28	15H#7	9.09	0.237	0.974	N/A
3	1677	24	8-3	7-9	50	7.8	3H#11	4.56	3-WAYS	3-WAYS	0.261	0.615	0.953
			2-9	2-11									
4	2240	24	8-3	8-3	47	9.9	8H#11	12.31	8H#11	12.31	0.464	0.661	0.974
5	2777	27	9-10	9-10	53	15.8	11H#11	17.03	11H#11	17.03	0.731	0.471	0.976
6	3339	29	12-0	8-3	59	18	14H#10	17.73	10H#11	16	0.722	0.878	0.959
7	3844	35	12-0	11-0	71	28.9	11H#11	16.87	12H#11	18.4	0.864	0.442	0.975
8	4449	34	12-0	11-0	60	24.4	14H#11	22.13	15H#11	23.46	1.09	0.543	0.954
9	4979	36	12-0	12-0	71	31.6	18H#11	27.39	18H#11	27.39	1.403	0.404	0.986
10	5548	38	15-9	11-0	61	32.6	21#11	32.39	17H#11	27.2	1.468	0.826	0.979

* Concrete columns - side dimension of square column. Structural steel columns - b or t plus 0.5 times the sum of overhangs to edges of base plate. For 3-pile and 7-pile caps, diameter of round column.

** See detail layouts for clipped corner pile cap arrangements. Concrete quatities based on clipped corners.

(1) "H" - use hooked or headed bars

(2) Total reinforcing steel weight - long plus short bars. For 3-pile cap, total of all 3 bands.

f'_c = 3,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 15 in. spaced at 3' - 9"

GRAVITY LOADS ONLY
200-TON STEEL PILES

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 27 in.

PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	1239	18	8-3	4-6	54	6.2	6H#10	7.46	16H#7	9.62	0.243	0.989	N/A
3	1868	25	8-3	7-9	51	8	4H#10	4.89	3-WAYS	3-WAYS	0.273	0.668	0.951
			2-9	2-11									
4	2494	25	8-3	8-3	48	10.1	8H#11	12.64	8H#11	12.64	0.464	0.717	0.959
5	3095	28	9-10	9-10	54	16.1	11H#11	17.42	11H#11	17.42	0.731	0.513	0.987
6	3723	31	12-0	8-3	59	18	15H#10	19.63	11H#11	17.38	0.782	0.909	0.991
7	4295	37	12-0	11-0	70	28.5	14H#10	17.98	14H#10	18.14	0.833	0.502	0.547
8	4961	36	12-0	11-0	60	24.4	14H#11	22.35	16H#11	25.28	1.126	0.606	0.977
9	5552	38	12-0	12-0	72	32	19H#11	29.22	19H#11	29.22	1.481	0.444	0.998
10	6178	40	15-9	11-0	64	34.2	21#11	33.6	18H#11	28.13	1.504	0.745	0.978

f'_c = 3,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 18 in. spaced at 4' - 6"

GRAVITY LOADS ONLY
240-TON STEEL PILES
Note: Special Detailing Required for High Load Piling

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 30 in.

PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	1480	20	9-6	5-0	58	8.5	7H#11	9.66	12H#9	11.90	0.387	0.995	N/A
3	2227	27	9-6	8-12	57	11.7	4H#11	6.15	3-WAYS	3-WAYS	0.388	0.605	0.965
			3-0	3-3									
4	2976	28	9-6	9-6	53	14.8	11H#11	16.45	11H#11	16.45	0.711	0.657	0.976
5	3683	31	11-5	11-5	60	24.1	10H#14	22.9	10H#14	22.9	1.179	0.488	0.985
6	4429	34	14-0	9-6	67	27.5	11H#14	24.22	14H#11	21.62	1.21	0.917	0.96
7	5092	41	14-0	12-10	79	43.8	10H#14	22.43	15H#11	23.89	1.306	0.444	0.997
8	5888	39	14-0	12-10	71	39.4	14H#14	31.39	15H#14	33.3	1.93	0.504	0.868
9	6590	41	14-0	14-0	82	49.6	16H#14	36.94	16H#14	36.94	2.203	0.406	0.985
10	7347	43	18-6	12-10	70	51.3	28#11	43.75	16H#14	36.7	2.369	0.796	0.98

* Concrete columns - side dimension of square column. Structural steel columns - b or t plus 0.5 times the sum of overhangs to edges of base plate. For 3-pile and 7-pile caps, diameter of round column.

** See detail layouts for clipped corner pile cap arrangements. Concrete quatities based on clipped corners.

(1) "H" - use hooked or headed bars

(2) Total reinforcing steel weight - long plus short bars. For 3-pile cap, total of all 3 bands.

f'_c = 3,000 psi

f_y = 60 ksi

Minimum Pile Diameter = 18 in. spaced at 4' - 6"

GRAVITY LOADS ONLY

280-TON STEEL PILES

Note: Special Detailing Required for High Load Piling

Minimum cover = 3 in.

d_c = 10 in.

Edge E = 30 in.

PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	1730	21	9-6	5-0	65	9.5	7H#11	9.84	14H#9	13.34	0.405	0.993	N/A
3	2610	29	9-6 3-0	8-12 3-3	58	11.9	5H#11	6.91	3-WAYS	3-WAYS	0.582	0.693	0.992
4	3486	30	9-6	9-6	54	15	8H#14	17.78	8H#14	17.78	0.826	0.752	0.982
5	4318	33	11-5	11-5	62	24.9	15H#11	23.88	15H#11	23.88	1.122	0.522	0.99
6	5195	37	14-0	9-6	68	27.9	12H#14	27.65	11H#14	24.14	1.394	0.928	0.976
7	5980	44	14-0	12-10	81	44.9	11H#14	25.02	11H#14	24.49	1.466	0.507	0.538
8	6916	42	14-0	12-10	70	38.8	14H#14	31.01	16H#14	35.11	1.994	0.603	0.957
9	7734	44	14-0	14-0	84	50.8	18H#14	40.6	18H#14	40.6	2.479	0.443	0.998
10	8613	47	18-6	12-10	73	53.5	30#11	47.98	18H#14	39.98	2.593	0.763	0.998

f'_c = 3,000 psi

f_y = 60 ksi

Minimum Pile Diameter = 20 in. spaced at 5' - 0"

GRAVITY LOADS ONLY

320-TON STEEL PILES

Note: Special Detailing Required for High Load Piling

Minimum cover = 3 in.

d_c = 10 in.

Edge E = 36 in.

PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	1964	23	11-0	6-0	63	12.8	8H#11	12.77	15H#9	14.97	0.520	0.98	N/A
3	2958	31	11-0 3-6	10-5 3-10	63	17.5	4H#14	7.82	3-WAYS	3-WAYS	0.861	0.616	0.951
4	3955	32	11-0	11-0	58	21.7	14H#11	21.25	14H#11	21.25	1.017	0.676	0.982
5	4890	35	13-1	13-1	67	35.4	13H#14	29.91	13H#14	29.91	1.699	0.47	0.973
6	5887	39	16-0	11-0	73	39.7	14H#14	31.96	18H#11	27.98	1.724	0.915	0.998
7	6745	47	16-0	14-8	90	65.2	13H#14	28.51	14H#14	31.1	1.994	0.444	0.495
8	7840	45	16-0	14-8	75	54.3	17H#14	38.22	18H#14	40.62	2.586	0.551	0.976
9	8750	47	16-0	16-0	91	71.9	21H#14	47.55	21H#14	47.55	3.213	0.4	0.979
10	9765	50	21-0	14-8	77	73.2	25#14	56.92	21H#14	47.51	3.46	0.825	0.996

* Concrete columns - side dimension of square column. Structural steel columns - b or t plus 0.5 times the sum of overhangs to edges of base plate. For 3-pile and 7-pile caps, diameter of round column.

** See detail layouts for clipped corner pile cap arrangements. Concrete quatities based on clipped corners.

(1) "H" - use hooked or headed bars

(2) Total reinforcing steel weight - long plus short bars. For 3-pile cap, total of all 3 bands.

f'_c = 3,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 20 in. spaced at 5' - 0"

GRAVITY LOADS ONLY
360-TON STEEL PILES
Note: Special Detailing Required for High Load Piling

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 36 in.

PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	2212	24	11-0	6-0	69	14.1	8H#11	12.77	17H#9	16.39	0.540	0.986	N/A
3	3341	33	11-0 3-6	10-5 3-10	64	17.7	4H#14	8.52	3-WAYS	3-WAYS	0.688	0.682	0.954
4	4465	34	11-0	11-0	59	22	10H#14	22.11	10H#14	22.11	1.148	0.748	0.965
5	5527	38	13-1	13-1	68	35.9	19H#11	30.51	19H#11	30.51	1.59	0.523	0.964
6	6648	41	16-0	11-0	75	40.7	15H#14	34.76	13H#14	30.04	1.893	0.889	0.979
7	7655	50	16-0	14-8	87	63	14H#14	32.03	19H#11	30.35	1.946	0.524	0.562
8	8864	48	16-0	14-8	75	54.3	18H#14	40.08	20H#14	45.36	2.805	0.624	0.999
9	9891	50	16-0	16-0	93	73.5	23H#14	51.79	23H#14	51.79	3.519	0.442	0.977
10	11014	53	21-0	14-8	82	78	26#14	58.77	22H#14	48.89	3.61	0.747	0.982

f'_c = 3,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 20 in. spaced at 5' - 0"

GRAVITY LOADS ONLY
400-TON STEEL PILES
Note: Special Detailing Required for High Load Piling

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 36 in.

PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	2461	25	11-0	6-0	75	15.3	8H#11	12.75	18H#9	17.82	0.561	0.991	N/A
3	3725	35	11-0 3-6	10-5 3-10	64	17.7	7H#11	9.34	3-WAYS	3-WAYS	0.653	0.759	0.991
4	4977	36	11-0	11-0	59	22	11H#14	24.25	11H#14	24.25	1.262	0.833	0.984
5	6163	40	13-1	13-1	69	36.5	14H#14	30.96	14H#14	30.96	1.83	0.573	0.97
6	7416	44	16-0	11-0	75	40.7	17H#14	38.45	14H#14	32.46	2.104	0.911	0.997
7	8565	53	16-0	14-8	84	60.8	16H#14	36.6	16H#14	35.03	2.366	0.61	0.628
8	9883	50	16-0	14-8	76	55	19H#14	43.65	22H#14	49.37	3.024	0.686	0.999
9	11038	53	16-0	16-0	94	74.3	24H#14	53.86	24H#14	53.86	3.672	0.488	0.993
10	12301	56	21-0	14-8	81	77	29#14	66.18	24H#14	54.66	3.988	0.847	0.827

* Concrete columns - side dimension of square column. Structural steel columns - b or t plus 0.5 times the sum of overhangs to edges of base plate. For 3-pile and 7-pile caps, diameter of round column.

** See detail layouts for clipped corner pile cap arrangements. Concrete quatities based on clipped corners.

(1) "H" - use hooked or headed bars

(2) Total reinforcing steel weight - long plus short bars. For 3-pile cap, total of all 3 bands.

f'_c = 4,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 8 in. spaced at 3' - 0"

GRAVITY LOADS ONLY
40-TON STEEL PILES

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 15 in.

PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	246	10	5-6	2-6	33	1.4	4H#7	2.36	7H#7	3.92	0.058	0.914	N/A
3	371	11	5-6 1-6	5-2 1-7	30	2	3H#7	1.75	3-WAYS	3-WAYS	0.061	0.817	0.894
4	494	12	5-6	5-6	29	2.7	8H#7	4.55	8H#7	4.55	0.109	0.92	0.984
5	609	13	6-9	6-9	34	4.8	11H#7	6.43	11H#7	6.43	0.178	0.879	0.638
6	727	14	8-6	5-6	43	6.2	11H#7	6.48	13H#7	7.89	0.197	0.96	0.364
7	848	17	8-6	7-9	36	7.3	13H#7	7.81	12H#7	7.05	0.238	0.83	0.964
8	973	16	8-6	7-9	38	7.7	15H#7	8.85	16H#7	9.41	0.294	0.962	0.687
9	1091	17	8-6	8-6	42	9.4	17H#7	10.1	17H#7	10.1	0.336	0.902	0.725
10	1206	18	11-6	7-9	41	11.3	8#10	10.09	17H#7	10.18	0.344	0.544	0.738
11	1336	19	11-6	7-9	40	11	13#9	13.23	20H#7	12.33	0.425	0.77	0.966
12	1451	20	11-6	8-6	43	13	11#10	14.33	21H#7	12.89	0.468	0.985	0.806
13	1552	20	12-11	8-6	51	17.3	9#11	14.04	14#9	14.23	0.487	0.913	0.674
14	1695	21	11-6	10-9	39	14.9	13#10	16.05	14#10	17.56	0.616	0.817	0.986
15	1798	22	12-11 5-11	11-6 7-6	45	18.7	13#10	16.27	14#10	17.62	0.679	0.825	0.986
16	1936	23	11-6	11-6	42	17.1	16#10	20.15	16#10	20.15	0.757	0.993	0.953
17	2046	23	12-11 5-11	11-6 7-6	48	19.9	11#11	17.67	15#10	19.09	0.718	0.791	0.975
18	2158	24	12-11	11-6	49	22.5	12#11	18.87	15#10	19.61	0.751	0.894	0.913
19	2273	24	13-9	11-6	50	24.4	17#10	21.11	17#10	21.5	0.887	0.902	0.987
20	2379	25	14-6	11-6	54	27.8	16#10	20.91	18#10	23.01	0.908	0.917	0.827
21	2506	26	13-9 11-0	13-9 3-5	52	28.1	15#11	23.26	15#11	23.26	1.056	0.72	0.982
22	2635	26	14-6 10-6	12-11 5-11	52	27.8	14#11	21.85	15#11	23.71	1.015	0.86	0.982
23	2743	27	14-6 10-6	13-9 6-9	54	30.9	16#11	24.36	16#11	24.87	1.158	0.654	0.988
24	2864	27	14-6	13-9	52	32	16#11	25.27	17#11	26.19	1.193	0.791	0.958
26	3098	28	15-11 8-11	14-6 10-6	53	35.5	20#11	31.4	17#11	26.67	1.451	0.817	0.999
28	3316	29	15-11	14-6	58	41.3	19#11	29.7	19#11	29.85	1.485	0.648	0.978
30	3540	30	17-6	14-6	59	46.2	15#14	34.48	21#11	33.32	1.756	0.648	0.848

* Concrete columns - side dimension of square column. Structural steel columns - b or t plus 0.5 times the sum of overhangs to edges of base plate. For 3-pile and 7-pile caps, diameter of round column.

** See detail layouts for clipped corner pile cap arrangements. Concrete quatities based on clipped corners.

(1) "H" - use hooked or headed bars

(2) Total reinforcing steel weight - long plus short bars. For 3-pile cap, total of all 3 bands.

f'_c = 4,000 psi

f_y = 60 ksi

Minimum Pile Diameter = 8 in. spaced at 3' - 0"

GRAVITY LOADS ONLY

50-TON STEEL PILES

Minimum cover = 3 in.

d_c = 10 in.

Edge E = 15 in.

PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	310	10	5-6	2-6	35	1.5	6H#6	2.56	7H#7	4.16	0.061	0.969	N/A
3	466	13	5-6	5-2	31	2	3H#7	1.83	3-WAYS	3-WAYS	0.061	0.747	0.976
			1-6	1-7									
4	620	13	5-6	5-6	32	3	11H#6	4.98	11H#6	4.98	0.105	0.679	0.945
5	768	14	6-9	6-9	35	4.9	16H#6	6.92	16H#6	6.92	0.182	0.883	0.734
6	918	16	8-6	5-6	44	6.3	13H#7	7.6	18H#6	8.08	0.214	0.949	0.42
7	1068	19	8-6	7-9	39	7.9	14H#7	8.65	13H#7	7.83	0.257	0.593	0.977
8	1225	18	8-6	7-9	41	8.3	16H#7	9.78	17H#7	10.43	0.313	0.735	0.704
9	1377	19	8-6	8-6	43	9.6	19H#7	11.41	19H#7	11.41	0.375	0.894	0.836
10	1528	20	11-6	7-9	40	11	13#9	13.13	19H#7	11.41	0.416	0.657	0.948
11	1681	21	11-6	7-9	44	12.1	15#9	14.48	22H#7	13.4	0.481	0.866	0.957
12	1816	22	11-6	8-6	53	16	15#9	14.77	22H#7	13.17	0.498	0.978	0.635
13	1968	23	12-11	8-6	51	17.3	13#10	16.63	18#8	14.23	0.54	0.999	0.814
14	2136	24	11-6	10-9	42	16	14#10	17.95	15#10	19.46	0.662	0.939	0.983
15	2265	24	12-11	11-6	50	20.8	12#11	18.54	16#10	20.13	0.774	0.579	0.969
			5-11	7-6									
16	2422	25	11-6	11-6	52	21.2	15#10	19.49	15#10	19.49	0.71	0.988	0.75
17	2580	26	12-11	11-6	52	21.6	13#11	19.8	17#10	21.16	0.831	0.872	0.999
			5-11	7-6									
18	2725	27	12-11	11-6	52	23.8	14#11	21.81	17#10	21.16	0.864	0.969	0.85
19	2875	27	13-9	11-6	52	25.4	16#11	25.16	18#10	22.53	0.989	0.95	0.846
20	3016	28	14-6	11-6	55	28.3	16#11	25.72	20#10	25.49	1.068	0.89	0.969
21	3160	29	13-9	13-9	57	30.8	17#11	26.01	17#11	26.01	1.197	0.84	0.992
			11-0	3-5									
22	3332	29	14-6	12-11	54	28.9	16#11	25.58	17#11	26.32	1.156	0.871	0.989
			10-6	5-11									
23	3461	30	14-6	13-9	59	33.8	17#11	27.11	18#11	27.77	1.266	0.786	0.973
			10-6	6-9									
24	3616	31	14-6	13-9	56	34.5	18#11	28.55	19#11	29.46	1.338	0.875	0.992
26	3904	32	15-11	14-6	59	39.5	22#11	33.88	19#11	30.49	1.608	0.693	0.972
			8-11	10-6									
28	4212	33	15-11	14-6	58	41.3	24#11	37.13	21#11	32.98	1.764	0.812	0.988
30	4495	34	17-6	14-6	60	47	19#14	42.3	24#11	37.68	2.128	0.801	0.995

* Concrete columns - side dimension of square column. Structural steel columns - b or t plus 0.5 times the sum of overhangs to edges of base plate. For 3-pile and 7-pile caps, diameter of round column.

** See detail layouts for clipped corner pile cap arrangements. Concrete quatities based on clipped corners.

(1) "H" - use hooked or headed bars

(2) Total reinforcing steel weight - long plus short bars. For 3-pile cap, total of all 3 bands.

f'_c = 4,000 psi **GRAVITY LOADS ONLY** Minimum cover = 3 in.

f_y = 60 ksi **60-TON STEEL PILES** d_c = 10 in.

Minimum Pile Diameter = 8 in. spaced at 3' - 0" Edge E = 15 in.

PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	373	10	5-6	2-6	40	1.7	5H#7	2.86	8H#7	4.75	0.070	0.841	N/A
3	562	14	5-6 1-6	5-2 1-7	33	2.2	5H#6	2.01	3-WAYS	3-WAYS	0.071	0.625	0.986
4	747	14	5-6	5-6	34	3.2	9H#7	5.4	9H#7	5.4	0.123	0.594	0.962
5	928	16	6-9	6-9	35	4.9	12H#7	7.03	12H#7	7.03	0.194	0.937	0.844
6	1109	17	8-6	5-6	45	6.5	13H#7	7.82	14H#7	8.26	0.224	0.973	0.475
7	1288	21	8-6	7-9	42	8.5	15H#7	9.26	14H#7	8.41	0.276	0.462	0.968
8	1483	20	8-6	7-9	40	8.1	16H#7	9.74	18H#7	10.98	0.322	0.893	0.863
9	1665	21	8-6	8-6	43	9.6	19H#7	11.41	19H#7	11.41	0.375	0.977	0.973
10	1845	22	11-6	7-9	42	11.6	15#9	14.7	21H#7	12.69	0.472	0.531	0.994
11	2028	23	11-6	7-9	47	12.9	16#9	15.82	24H#7	14.57	0.518	0.966	0.974
12	2194	24	11-6	8-6	56	16.9	16#9	15.79	23H#7	13.91	0.526	0.439	0.667
13	2362	25	12-11	8-6	61	20.7	11#11	17.44	21#8	17.02	0.587	0.992	0.435
14	2571	26	11-6	10-9	47	17.9	18#9	18.32	20#9	19.6	0.685	0.998	0.913
15	2740	27	12-11 5-11	11-6 7-6	52	21.6	15#10	19.49	17#10	21.23	0.803	0.696	0.728
16	2929	28	11-6	11-6	54	22	16#10	20.92	16#10	20.92	0.757	0.453	0.807
17	3107	28	12-11 5-11	11-6 7-6	58	24.1	14#11	22.22	17#10	22.03	0.864	0.998	0.699
18	3277	29	12-11	11-6	60	27.5	15#11	23.14	19#10	23.85	0.944	0.999	0.528
19	3458	30	13-9	11-6	60	29.3	16#11	24.86	21#10	26.73	1.06	0.988	0.63
20	3643	31	14-6	11-6	59	30.4	18#11	28.11	22#10	27.81	1.19	0.99	0.754
21	3829	31	13-9 11-0	13-9 3-5	58	31.3	18#11	27.64	18#11	27.64	1.267	0.998	0.66
22	4016	32	14-6 10-6	12-11 5-11	60	32.1	17#11	26.54	22#10	28.39	1.22	0.462	0.719
23	4189	33	14-6 10-6	13-9 6-9	61	34.9	18#11	28.29	18#11	28.93	1.303	0.942	0.96
24	4372	34	14-6	13-9	59	36.3	20#11	31.93	21#11	32.86	1.483	0.994	0.827
26	4714	35	15-11 8-11	14-6 10-6	64	42.8	23#11	36.45	21#11	33.67	1.723	0.807	0.972
28	5085	36	15-11	14-6	63	44.9	25#11	39.86	22#11	35.31	1.842	0.899	0.987
30	5425	37	17-6	14-6	66	51.7	20#14	44.75	25#11	39.76	2.23	0.876	0.972

* Concrete columns - side dimension of square column. Structural steel columns - b or t plus 0.5 times the sum of overhangs to edges of base plate. For 3-pile and 7-pile caps, diameter of round column.

** See detail layouts for clipped corner pile cap arrangements. Concrete quatities based on clipped corners.

(1) "H" - use hooked or headed bars

(2) Total reinforcing steel weight - long plus short bars. For 3-pile cap, total of all 3 bands.

f'_c = 4,000 psi | **GRAVITY LOADS ONLY** | Minimum cover = 3 in.

f_y = 60 ksi | **80-TON STEEL PILES** | d_c = 10 in.

Minimum Pile Diameter = 10 in. spaced at 3' - 0" | Edge E = 21 in.

PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	495	12	6-6	3-6	36	2.5	3H#10	3.7	9H#7	5.05	0.106	0.967	N/A
3	744	16	6-6	6-2	37	3.6	3H#9	2.58	3-WAYS	3-WAYS	0.13	0.444	0.959
			2-1	2-3									
4	992	16	6-6	6-6	37	4.8	7H#9	7.13	7H#9	7.13	0.202	0.441	0.959
5	1235	18	7-9	7-9	37	6.9	7H#10	8.68	7H#10	8.68	0.304	0.742	0.947
6	1480	20	9-6	6-6	45	8.6	9H#9	9.21	9H#9	9.23	0.306	0.952	0.596
7	1713	24	9-6	8-9	47	12.1	8H#10	10.25	10H#9	9.64	0.386	0.353	0.969
8	1978	23	9-6	8-9	42	10.8	12H#9	11.85	11H#10	13.42	0.497	0.737	0.98
9	2217	24	9-6	9-6	48	13.4	15H#9	14.61	15H#9	14.61	0.586	0.628	0.981
10	2455	25	12-6	8-9	48	16.2	10#11	15.98	11H#10	13.84	0.581	0.541	0.956
11	2700	26	12-6	8-9	53	17.9	11#11	17.62	13H#10	16.27	0.661	0.998	0.651
12	2943	28	12-6	9-6	54	19.8	16#10	20.42	14H#10	18.31	0.77	0.55	0.907
13	3166	29	13-11	9-6	61	24.9	13#11	20.72	18#9	18.34	0.739	0.447	0.427
14	3434	30	12-6	11-9	51	23.1	17#10	21.33	18#10	22.65	0.875	0.776	0.977
15	3683	31	13-11	12-6	50	24.2	17#11	25.83	22#10	27.99	1.174	0.854	0.998
			6-2	8-1									
16	3924	32	12-6	12-6	55	26.5	21#10	26.52	21#10	26.52	1.084	0.546	0.988
17	4166	33	13-11	12-6	59	28.6	17#11	26.19	21#10	26.69	1.148	0.435	0.703
			6-2	8-1									
18	4402	34	13-11	12-6	59	31.7	19#11	28.98	21#10	26.69	1.219	0.448	0.689
19	4631	35	14-9	12-6	63	35.9	19#11	30.48	24#10	30.65	1.339	0.457	0.725
20	4856	35	15-6	12-6	68	40.7	20#11	30.75	25#10	32.56	1.442	0.424	0.733
21	5122	36	14-9	14-9	63	39	21#11	32.24	21#11	32.24	1.59	0.437	0.712
			11-9	3-7									
22	5401	37	15-6	13-11	58	35.6	23#11	36.18	24#11	37.03	1.772	0.573	0.972
			11-1	6-2									
23	5621	38	15-6	14-9	63	41.1	23#11	35.43	23#11	36.09	1.787	0.81	0.978
			11-1	7-0									
24	5865	39	15-6	14-9	61	43	25#11	40.02	26#11	41.02	1.98	0.984	0.984

* Concrete columns - side dimension of square column. Structural steel columns - b or t plus 0.5 times the sum of overhangs to edges of base plate. For 3-pile and 7-pile caps, diameter of round column.

** See detail layouts for clipped corner pile cap arrangements. Concrete quatities based on clipped corners.

(1) "H" - use hooked or headed bars

(2) Total reinforcing steel weight - long plus short bars. For 3-pile cap, total of all 3 bands.

f'_c = 4,000 psi | **GRAVITY LOADS ONLY** | Minimum cover = 3 in.

f_y = 60 ksi | **100-TON STEEL PILES** | d_c = 10 in.

Minimum Pile Diameter = 10 in. spaced at 3' - 0" | Edge E = 21 in.

PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	622	13	6-6	3-6	39	2.7	4H#9	4.12	10H#7	5.48	0.109	0.979	N/A
3	934	18	6-6	6-2	40	3.9	3H#9	2.84	3-WAYS	3-WAYS	0.13	0.501	0.949
			2-1	2-3									
4	1247	18	6-6	6-6	38	5	6H#10	7.39	6H#10	7.39	0.228	0.535	0.967
5	1551	20	7-9	7-9	40	7.4	10H#9	9.5	10H#9	9.5	0.331	0.612	0.966
6	1863	22	9-6	6-6	46	8.8	11H#9	10.93	8H#10	10.32	0.367	0.984	0.993
7	2155	27	9-6	8-9	51	13.1	9H#10	11.24	8H#10	10.47	0.42	0.401	0.988
8	2480	25	9-6	8-9	48	12.3	11H#10	13.45	11H#10	14.1	0.542	0.516	0.958
9	2784	27	9-6	9-6	53	14.8	13H#10	16.48	13H#10	16.48	0.662	0.488	0.966
10	3088	28	12-6	8-9	51	17.2	14#10	18.24	12H#10	15.66	0.648	0.638	0.843
11	3404	30	12-6	8-9	53	17.9	17#10	21.68	16H#10	19.78	0.82	0.64	0.683
12	3704	31	12-6	9-6	57	20.9	19#10	23.57	17H#10	21.08	0.923	0.648	0.987
13	4001	32	13-11	9-6	60	24.5	17#11	26.53	19#9	18.62	0.897	0.515	0.515
14	4315	33	12-6	11-9	56	25.4	18#10	23.34	19#10	24.57	0.925	0.587	0.987
15	4614	34	13-11	12-6	59	28.6	20#10	25.69	22#10	27.51	1.145	0.493	0.695
			6-2	8-1									
16	4929	36	12-6	12-6	61	29.4	22#10	28.31	22#10	28.31	1.136	0.605	0.973
17	5261	37	13-11	12-6	57	27.6	22#11	33.96	22#10	28.18	1.352	0.575	0.906
			6-2	8-1									
18	5561	38	13-11	12-6	57	30.6	24#11	37.77	25#10	31.98	1.501	0.589	0.89
19	5855	39	14-9	12-6	61	34.7	25#11	39.59	26#10	33.56	1.618	0.601	0.933
20	6144	40	15-6	12-6	66	39.5	25#11	39.67	27#10	34.19	1.693	0.555	0.932

* Concrete columns - side dimension of square column. Structural steel columns - b or t plus 0.5 times the sum of overhangs to edges of base plate. For 3-pile and 7-pile caps, diameter of round column.

** See detail layouts for clipped corner pile cap arrangements. Concrete quatities based on clipped corners.

(1) "H" - use hooked or headed bars

(2) Total reinforcing steel weight - long plus short bars. For 3-pile cap, total of all 3 bands.

f'_c = 4,000 psi

f_y = 60 ksi

Minimum Pile Diameter = 12 in. spaced at 3' - 0"

GRAVITY LOADS ONLY

120-TON STEEL PILES

Minimum cover = 3 in.

d_c = 10 in.

Edge E = 21 in.

PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	748	14	6-6	3-6	42	2.9	5H#9	4.54	10H#7	5.90	0.127	0.981	N/A
3	1126	19	6-6 2-2	6-2 2-3	41	4	3H#10	3.27	3-WAYS	3-WAYS	0.171	0.584	0.993
4	1503	20	6-6	6-6	39	5.1	8H#9	8.19	8H#9	8.19	0.231	0.621	0.934
5	1868	22	7-9	7-9	43	8	8H#10	10.34	8H#10	10.34	0.347	0.512	0.962
6	2244	24	9-6	6-6	48	9.1	10H#10	12.36	9H#10	11.43	0.426	0.91	0.946
7	2596	29	9-6	8-9	55	14.1	12H#9	12.03	9H#10	11.29	0.449	0.44	0.998
8	2988	28	9-6	8-9	50	12.8	11H#10	14.13	12H#10	15.49	0.566	0.496	0.963
9	3353	29	9-6	9-6	57	15.9	14H#10	18	14H#10	18	0.713	0.428	0.981
10	3732	31	12-6	8-9	49	16.5	18#10	22.94	15H#10	19.05	0.822	0.792	0.987
11	4112	33	12-6	8-9	51	17.2	21#10	27.19	17H#10	21.66	0.948	0.811	0.855
12	4477	34	12-6	9-6	55	20.2	23#10	29.37	18H#10	22.3	1.052	0.817	0.73
13	4838	35	13-11	9-6	58	23.7	21#11	33.28	23#9	22.85	1.1	0.632	0.644
14	5199	37	12-6	11-9	60	27.2	16#11	25.09	17#11	26.25	1.018	0.651	0.996
15	5581	38	13-11 6-2	12-6 8-1	57	27.6	20#11	31.85	26#10	33.96	1.384	0.622	0.859
16	5937	39	12-6	12-6	66	31.8	24#10	30.19	24#10	30.19	1.239	0.663	0.98

* Concrete columns - side dimension of square column. Structural steel columns - b or t plus 0.5 times the sum of overhangs to edges of base plate. For 3-pile and 7-pile caps, diameter of round column.

** See detail layouts for clipped corner pile cap arrangements. Concrete quatities based on clipped corners.

(1) "H" - use hooked or headed bars

(2) Total reinforcing steel weight - long plus short bars. For 3-pile cap, total of all 3 bands.

f'_c = 4,000 psi | **GRAVITY LOADS ONLY** | Minimum cover = 3 in.

f_y = 60 ksi | **140-TON STEEL PILES** | d_c = 10 in.

Minimum Pile Diameter = 12 in. spaced at 3' - 0" | Edge E = 27 in.

PILES	COLUMN		PILE CAP					REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	869	15	7-6	4-6	40	4.2	4H#11	5.47	11H#7	6.48	0.182	0.957	N/A
3	1307	21	7-6 2-8	7-2 2-11	42	5.6	3H#10	3.52	3-WAYS	3-WAYS	0.19	0.57	0.949
4	1747	21	7-6	7-6	40	6.9	6H#11	9.09	6H#11	9.09	0.324	0.605	0.931
5	2172	24	8-9	8-9	44	10.4	8H#11	12.03	8H#11	12.03	0.485	0.453	0.986
6	2610	26	10-6	7-6	49	11.9	6H#14	13.79	8H#11	12.6	0.549	0.783	0.935
7	3019	32	10-6	9-9	57	18	8H#11	12.8	10H#10	12.93	0.54	0.44	0.507
8	3483	30	10-6	9-9	49	15.5	7H#14	16.13	8H#14	18.42	0.809	0.532	0.973
9	3901	32	10-6	10-6	59	20.1	9H#14	20.6	9H#14	20.6	0.998	0.39	0.952
10	4345	33	13-6	9-9	51	20.7	16#11	24.86	14H#11	21.13	1.014	0.674	0.993
11	4793	35	13-6	9-9	51	20.7	20#11	31.19	11H#14	24.6	1.269	0.848	0.968
12	5228	37	13-6	10-6	52	22.8	23#11	36.15	12H#14	27.28	1.46	0.925	0.906
13	5645	38	14-11	10-6	57	27.6	25#11	39.06	21#10	26.31	1.409	0.682	0.747
14	6048	39	13-6	12-9	65	34.5	18#11	28.2	19#11	29.1	1.24	0.637	0.975

* Concrete columns - side dimension of square column. Structural steel columns - b or t plus 0.5 times the sum of overhangs to edges of base plate. For 3-pile and 7-pile caps, diameter of round column.

** See detail layouts for clipped corner pile cap arrangements. Concrete quatities based on clipped corners.

(1) "H" - use hooked or headed bars

(2) Total reinforcing steel weight - long plus short bars. For 3-pile cap, total of all 3 bands.

f'_c = 4,000 psi

f_y = 60 ksi

Minimum Pile Diameter = 15 in. spaced at 3' - 9"

GRAVITY LOADS ONLY

160-TON STEEL PILES

Minimum cover = 3 in.

d_c = 10 in.

Edge E = 27 in.

PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	989	16	8-3	4-6	46	5.3	5H#10	6.55	14H#7	8.20	0.205	0.957	N/A
3	1488	22	8-3	7-9	47	7.3	3H#11	4.45	3-WAYS	3-WAYS	0.261	0.511	0.983
			2-9	2-11									
4	1988	23	8-3	8-3	44	9.2	9H#10	11.34	9H#10	11.34	0.41	0.553	0.984
5	2467	25	9-10	9-10	48	14.3	10H#11	15.06	10H#11	15.06	0.664	0.557	0.962
6	2963	28	12-0	8-3	55	16.8	11H#11	17.09	10H#11	15.69	0.719	0.922	0.957
7	3420	33	12-0	11-0	62	25.3	11H#11	17.14	10H#11	16.07	0.792	0.399	0.99
8	3948	32	12-0	11-0	56	22.8	9H#14	20.31	10H#14	22.53	1.125	0.524	0.988
9	4423	34	12-0	12-0	64	28.4	17H#11	26.06	17H#11	26.06	1.325	0.46	0.974
10	4919	36	15-9	11-0	58	31	19#11	30.42	17H#11	25.87	1.387	0.677	0.932
11	5413	37	15-9	11-0	63	33.7	22#11	34.5	14H#14	31.37	1.695	0.657	0.713
12	5886	39	15-9	12-0	68	39.7	24#11	37.23	15H#14	33.27	1.89	0.661	0.631

* Concrete columns - side dimension of square column. Structural steel columns - b or t plus 0.5 times the sum of overhangs to edges of base plate. For 3-pile and 7-pile caps, diameter of round column.

** See detail layouts for clipped corner pile cap arrangements. Concrete quatities based on clipped corners.

(1) "H" - use hooked or headed bars

(2) Total reinforcing steel weight - long plus short bars. For 3-pile cap, total of all 3 bands.

f'_c = 4,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 15 in. spaced at 3' - 9"

GRAVITY LOADS ONLY
180-TON STEEL PILES

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 27 in.

PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	1116	17	8-3	4-6	48	5.5	6H#10	6.91	14H#7	8.55	0.232	0.97	N/A
3	1679	24	8-3	7-9	48	7.5	4H#11	4.78	3-WAYS	3-WAYS	0.261	0.561	0.945
			2-9	2-11									
4	2242	24	8-3	8-3	45	9.5	8H#11	12.36	8H#11	12.36	0.464	0.606	0.976
5	2783	27	9-10	9-10	50	14.9	7H#14	15.79	7H#14	15.79	0.741	0.502	0.971
6	3345	29	12-0	8-3	56	17.1	12H#11	18.81	11H#11	17.1	0.787	0.931	0.982
7	3860	36	12-0	11-0	65	26.5	8H#14	17.8	11H#11	16.85	0.889	0.426	0.989
8	4454	34	12-0	11-0	58	23.6	14H#11	21.25	15H#11	23.75	1.09	0.491	0.992
9	4991	36	12-0	12-0	67	29.8	12H#14	27.43	12H#14	27.43	1.469	0.422	0.986
10	5559	38	15-9	11-0	58	31	22#11	34.15	13H#14	28.98	1.637	0.76	0.963

f'_c = 4,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 15 in. spaced at 3' - 9"

GRAVITY LOADS ONLY
200-TON STEEL PILES

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 27 in.

PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	1242	18	8-3	4-6	50	5.7	5H#11	7.25	15H#7	8.91	0.243	0.979	N/A
3	1870	25	8-3	7-9	49	7.7	4H#11	5.13	3-WAYS	3-WAYS	0.348	0.608	0.939
			2-9	2-11									
4	2497	25	8-3	8-3	46	9.7	6H#14	13.27	6H#14	13.27	0.562	0.656	0.956
5	3099	28	9-10	9-10	52	15.5	11H#11	16.64	11H#11	16.64	0.731	0.471	0.966
6	3727	31	12-0	8-3	57	17.4	9H#14	20.38	12H#11	18.25	0.899	0.902	0.958
7	4297	37	12-0	11-0	69	28.1	8H#14	18.28	14H#10	17.88	0.891	0.442	0.974
8	4966	36	12-0	11-0	58	23.6	10H#14	23.19	12H#14	26.43	1.301	0.547	0.941
9	5561	38	12-0	12-0	69	30.7	18H#11	28.46	18H#11	28.46	1.403	0.405	0.986
10	6195	40	15-9	11-0	59	31.5	23#11	36.95	13H#14	30.08	1.678	0.829	0.987

* Concrete columns - side dimension of square column. Structural steel columns - b or t plus 0.5 times the sum of overhangs to edges of base plate. For 3-pile and 7-pile caps, diameter of round column.

** See detail layouts for clipped corner pile cap arrangements. Concrete quatities based on clipped corners.

(1) "H" - use hooked or headed bars

(2) Total reinforcing steel weight - long plus short bars. For 3-pile cap, total of all 3 bands.

f'_c = 4,000 psi

f_y = 60 ksi

Minimum Pile Diameter = 18 in. spaced at 4' - 6"

GRAVITY LOADS ONLY

240-TON STEEL PILES

Note: Special Detailing Required for High Load Piling

Minimum cover = 3 in.

d_c = 10 in.

Edge E = 30 in.

PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	1483	20	9-6	5-0	55	8.1	4H#14	9.03	12H#9	11.29	0.360	0.977	N/A
3	2231	27	9-6	8-12	54	11.1	6H#10	6.54	3-WAYS	3-WAYS	0.382	0.56	0.996
			3-0	3-3									
4	2979	28	9-6	9-6	51	14.6	11H#11	16.59	11H#11	16.59	0.711	0.597	0.958
5	3694	31	11-5	11-5	56	22.5	14H#11	21.14	14H#11	21.14	1.048	0.542	0.976
6	4437	34	14-0	9-6	64	26.3	11H#14	25.41	10H#14	22.88	1.274	0.949	0.959
7	5110	41	14-0	12-10	74	41	11H#14	24.23	10H#14	22.8	1.401	0.416	0.976
8	5906	39	14-0	12-10	66	36.6	13H#14	28.83	14H#14	32.45	1.796	0.511	0.973
9	6614	41	14-0	14-0	76	46	16H#14	37.05	16H#14	37.05	2.203	0.451	0.982
10	7361	43	18-6	12-10	67	49.1	20#14	45.81	17H#14	38.81	2.472	0.726	0.971

f'_c = 4,000 psi

f_y = 60 ksi

Minimum Pile Diameter = 18 in. spaced at 4' - 6"

GRAVITY LOADS ONLY

280-TON STEEL PILES

Note: Special Detailing Required for High Load Piling

Minimum cover = 3 in.

d_c = 10 in.

Edge E = 30 in.

PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	1735	21	9-6	5-0	59	8.6	7H#11	9.86	13H#9	12.11	0.390	0.99	N/A
3	2613	29	9-6	8-12	56	11.5	5H#11	7.1	3-WAYS	3-WAYS	0.485	0.626	0.961
			3-0	3-3									
4	3490	30	9-6	9-6	52	14.5	12H#11	18.59	12H#11	18.59	0.776	0.683	0.96
5	4323	33	11-5	11-5	60	24.1	10H#14	22.9	10H#14	22.9	1.179	0.473	0.951
6	5203	37	14-0	9-6	65	26.7	13H#14	28.94	11H#14	25.44	1.463	0.954	0.972
7	5988	44	14-0	12-10	79	43.8	16H#11	25.62	11H#14	24.2	1.417	0.452	0.988
8	6923	42	14-0	12-10	68	37.7	14H#14	31.85	16H#14	36.08	1.994	0.541	0.906
9	7750	45	14-0	14-0	80	48.4	17H#14	39.29	17H#14	39.29	2.341	0.409	0.979
10	8637	47	18-6	12-10	68	49.8	23#14	52.03	19H#14	41.78	2.807	0.834	0.985

* Concrete columns - side dimension of square column. Structural steel columns - b or t plus 0.5 times the sum of overhangs to edges of base plate. For 3-pile and 7-pile caps, diameter of round column.

** See detail layouts for clipped corner pile cap arrangements. Concrete quatities based on clipped corners.

(1) "H" - use hooked or headed bars

(2) Total reinforcing steel weight - long plus short bars. For 3-pile cap, total of all 3 bands.

f'_c = 4,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 20 in. spaced at 5' - 0"

GRAVITY LOADS ONLY
320-TON STEEL PILES
Note: Special Detailing Required for High Load Piling

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 36 in.

PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	1970	23	11-0	6-0	59	12	8H#11	11.83	14H#9	14.02	0.507	0.984	N/A
3	2964	31	11-0	10-5	60	16.6	4H#14	8.27	3-WAYS	3-WAYS	0.688	0.566	0.962
			3-6	3-10									
4	3960	32	11-0	11-0	56	20.9	14H#11	21.22	14H#11	21.22	1.017	0.612	0.95
5	4904	36	13-1	13-1	63	33.3	12H#14	27.82	12H#14	27.82	1.568	0.477	0.973
6	5897	39	16-0	11-0	70	38	15H#14	33.34	13H#14	29.43	1.893	0.931	0.984
7	6778	47	16-0	14-8	83	60.1	19H#11	30.39	13H#14	28.68	1.87	0.423	0.994
8	7844	45	16-0	14-8	74	53.6	17H#14	37.64	18H#14	40.93	2.586	0.485	0.986
9	8775	47	16-0	16-0	86	68	21H#14	48.56	21H#14	48.56	3.509	0.408	0.987
10	9790	50	21-0	14-8	73	69.4	26#14	60.16	22H#14	50.57	3.61	0.759	0.966

f'_c = 4,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 20 in. spaced at 5' - 0"

GRAVITY LOADS ONLY
360-TON STEEL PILES
Note: Special Detailing Required for High Load Piling

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 36 in.

PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	2222	24	11-0	6-0	62	12.6	8H#11	12.55	15H#9	14.73	0.517	0.998	N/A
3	3346	33	11-0	10-5	61	16.9	4H#14	9.02	3-WAYS	3-WAYS	0.688	0.626	0.961
			3-6	3-10									
4	4472	34	11-0	11-0	56	20.9	15H#11	23.56	15H#11	23.56	1.089	0.69	0.985
5	5537	38	13-1	13-1	65	34.3	13H#14	28.86	13H#14	28.86	1.699	0.478	0.961
6	6658	41	16-0	11-0	72	39.1	16H#14	36.35	14H#14	31.76	2.119	0.896	0.96
7	7655	50	16-0	14-8	87	63	14H#14	31.86	19H#11	30.21	1.946	0.454	0.487
8	8878	48	16-0	14-8	72	52.1	19H#14	41.78	21H#14	47.55	3.099	0.568	0.978
9	9917	50	16-0	16-0	88	69.5	22H#14	50.02	22H#14	50.02	3.366	0.409	0.998
10	11058	53	21-0	14-8	75	71.3	29#14	65.11	23H#14	53.31	3.916	0.833	1

* Concrete columns - side dimension of square column. Structural steel columns - b or t plus 0.5 times the sum of overhangs to edges of base plate. For 3-pile and 7-pile caps, diameter of round column.

** See detail layouts for clipped corner pile cap arrangements. Concrete quatities based on clipped corners.

(1) "H" - use hooked or headed bars

(2) Total reinforcing steel weight - long plus short bars. For 3-pile cap, total of all 3 bands.

f'_c = 4,000 psi

f_y = 60 ksi

Minimum Pile Diameter = 20 in. spaced at 5' - 0"

GRAVITY LOADS ONLY

400-TON STEEL PILES

Note: Special Detailing Required for High Load Piling

Minimum cover = 3 in.

d_c = 10 in.

Edge E = 36 in.

PILES	COLUMN		PILE CAP				REINFORCING BARS					SHEAR	
Number of Piles	Max. Load P_u (net)	Min. Size *	Long A **	Short B **	D	Concrete **	Long A Bars (1)	$A_{minimum}$ A Bars	Short B Bars (1)	$A_{minimum}$ B Bars	Steel Weight (2)	$V_u/\phi V_n$ Beam One-Way	$V_u/\phi V_n$ Slab Two-Way
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(c.y.)	No.-Size	(in^2)	No.-Size	(in^2)	(tons)	Ratio	Ratio
2	2471	25	11-0	6-0	67	13.6	6H#14	13.72	16H#9	15.92	0.588	0.994	N/A
3	3730	35	11-0	10-5	61	16.9	4H#14	9.12	3-WAYS	3-WAYS	0.688	0.697	0.997
			3-6	3-10									
4	4982	36	11-0	11-0	57	21.3	11H#14	25.28	11H#14	25.28	1.262	0.753	0.95
5	6174	40	13-1	13-1	66	34.9	14H#14	30.66	14H#14	30.66	1.83	0.524	0.964
6	7426	44	16-0	11-0	72	39.1	18H#14	40.16	15H#14	34.31	2.323	0.917	0.977
7	8565	53	16-0	14-8	84	60.8	16H#14	36.37	22H#11	34.76	2.237	0.528	0.544
8	9897	50	16-0	14-8	73	52.9	20H#14	45.42	23H#14	51.67	3.313	0.623	0.976
9	11059	53	16-0	16-0	90	71.1	23H#14	51.12	23H#14	51.12	3.801	0.445	0.979
10	12313	56	21-0	14-8	79	75.1	29#14	67.21	25H#14	56.02	4.059	0.755	0.993

* Concrete columns - side dimension of square column. Structural steel columns - b or t plus 0.5 times the sum of overhangs to edges of base plate. For 3-pile and 7-pile caps, diameter of round column.

** See detail layouts for clipped corner pile cap arrangements. Concrete quatities based on clipped corners.

(1) "H" - use hooked or headed bars

(2) Total reinforcing steel weight - long plus short bars. For 3-pile cap, total of all 3 bands.

f'_c = 3,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 8 in. spaced at 3' - 0"

GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS

40-TON STEEL PILES

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 15 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	246	10	5-6	2-6	34	31	0	69	0	108	0	146	0
3	370	11	5-6	5-2	31	47	314	105	235	162	157	220	78
			1-6	1-7									
4	493	12	5-6	5-6	31	63	725	139	543	216	362	293	181
5	608	13	6-9	6-9	35	72	1025	168	768	264	512	360	256
6	726	14	8-6	5-6	44	84	1087	199	815	314	543	429	272
7	845	17	8-6	7-9	38	96	1255	231	941	365	627	499	314
8	972	16	8-6	7-9	39	115	1882	268	1412	422	941	575	471
9	1089	17	8-6	8-6	43	126	2174	298	1630	471	1087	644	543
10	1206	18	11-6	7-9	41	137	1882	329	1412	521	941	713	471
11	1331	19	11-6	7-9	43	153	2510	365	1882	576	1255	787	627
12	1442	19	11-6	8-6	48	160	2898	390	2174	621	1449	851	725
13	1549	20	12-11	8-6	52	163	2536	413	1902	663	1268	912	634
14	1690	21	11-6	10-9	41	192	3483	461	2612	730	1742	999	871
15	1790	22	12-11	11-6	48	191	3864	479	2898	767	1932	1055	966
			5-11	7-6									
16	1921	22	11-6	11-6	48	212	4830	519	3623	826	2415	1134	1208
17	2038	23	12-11	11-6	51	223	3864	549	2898	876	1932	1202	966
			5-11	7-6									
18	2152	24	12-11	11-6	51	232	4589	577	3442	923	2294	1268	1147
19	2261	24	13-9	11-6	54	237	5313	601	3985	966	2657	1331	1328
20	2376	25	14-6	11-6	55	246	6038	630	4528	1014	3019	1398	1509
21	2492	25	13-9	13-9	56	256	5806	659	4354	1063	2903	1466	1451
			11-1	3-5									
22	2632	26	14-6	12-11	53	284	6588	707	4941	1129	3294	1552	1647
			10-6	5-11									
23	2728	27	14-6	13-9	58	280	7348	721	5511	1163	3674	1604	1837
			10-6	6-9									
24	2852	27	14-6	13-9	55	296	8215	757	6161	1217	4107	1678	2054
26	3080	28	15-11	14-6	57	313	7245	812	5434	1312	3623	1811	1811
			8-11	10-6									
28	3307	29	15-11	14-6	60	330	9057	867	6792	1405	4528	1943	2264
30	3540	30	17-6	14-6	59	351	10868	927	8151	1503	5434	2079	2717

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 3,000 psi — **GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS** — Minimum cover = 3 in.

f_y = 60 ksi — **50-TON STEEL PILES** — d_c = 10 in.

Minimum Pile Diameter = 8 in. spaced at 3' - 0" — Edge E = 15 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	309	10	5-6	2-6	39	40	0	88	0	136	0	184	0
3	466	13	5-6 1-6	5-2 1-7	33	62	392	134	294	206	196	278	98
4	619	13	5-6	5-6	34	80	906	176	679	272	453	368	226
5	767	14	6-9	6-9	36	95	1281	215	961	335	640	455	320
6	917	16	8-6	5-6	45	112	1358	256	1019	400	679	544	340
7	1064	19	8-6	7-9	42	126	1569	294	1176	462	784	630	392
8	1225	18	8-6	7-9	41	151	2353	343	1765	535	1176	727	588
9	1376	19	8-6	8-6	44	168	2717	384	2038	600	1358	816	679
10	1525	20	11-6	7-9	42	184	2353	424	1765	664	1176	904	588
11	1676	21	11-6	7-9	47	201	3137	465	2353	729	1569	993	784
12	1808	22	11-6	8-6	57	204	3623	492	2717	780	1811	1068	906
13	1952	23	12-11	8-6	58	216	3170	528	2377	840	1585	1152	792
14	2128	24	11-6	10-9	45	252	4354	588	3266	924	2177	1260	1089
15	2257	24	12-11 5-11	11-6 7-6	53	253	4830	613	3623	973	2415	1333	1208
16	2414	25	11-6	11-6	55	275	6038	659	4528	1043	3019	1427	1509
17	2577	26	12-11 5-11	11-6 7-6	53	301	4830	709	3623	1117	2415	1525	1208
18	2707	27	12-11	11-6	58	302	5736	734	4302	1166	2868	1598	1434
19	2859	27	13-9	11-6	57	320	6642	776	4981	1232	3321	1688	1660
20	3003	28	14-6	11-6	59	332	7547	812	5660	1292	3774	1772	1887
21	3150	29	13-9 11-1	13-9 3-5	60	347	7257	851	5443	1355	3628	1859	1814
22	3318	29	14-6 10-6	12-11 5-11	58	377	8235	905	6177	1433	4118	1961	2059
23	3450	30	14-6 10-6	13-9 6-9	62	380	9185	932	6889	1484	4593	2036	2296
24	3608	31	14-6	13-9	58	402	10268	978	7701	1554	5134	2130	2567
26	3886	32	15-11 8-11	14-6 10-6	63	419	9057	1043	6792	1667	4528	2291	2264
28	4189	33	15-11	14-6	63	454	11321	1126	8491	1798	5660	2470	2830
30	4470	34	17-6	14-6	65	473	13585	1193	10189	1913	6792	2633	3396

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 3,000 psi | **GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS** | Minimum cover = 3 in.

f_y = 60 ksi | **60-TON STEEL PILES** | d_c = 10 in.

Minimum Pile Diameter = 8 in. spaced at 3' - 0" | Edge E = 15 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	372	10	5-6	2-6	43	49	0	106	0	164	0	221	0
3	561	14	5-6 1-6	5-2 1-7	35	75	471	162	353	248	235	334	118
4	746	14	5-6	5-6	36	99	1087	214	815	329	543	444	272
5	927	16	6-9	6-9	36	119	1537	263	1153	407	768	551	384
6	1109	17	8-6	5-6	46	141	1630	313	1223	486	815	659	408
7	1284	21	8-6	7-9	45	157	1882	358	1412	560	941	761	471
8	1481	20	8-6	7-9	41	189	2824	420	2118	650	1412	880	706
9	1661	21	8-6	8-6	46	209	3260	468	2445	727	1630	987	815
10	1834	22	11-6	7-9	48	224	2824	512	2118	800	1412	1088	706
11	2019	23	11-6	7-9	52	247	3765	564	2824	881	1882	1197	941
12	2194	24	11-6	8-6	56	263	4347	609	3260	954	2174	1300	1087
13	2357	25	12-11	8-6	63	270	3804	645	2853	1019	1902	1393	951
14	2564	26	11-6	10-9	50	310	5225	713	3919	1117	2612	1520	1306
15	2740	27	12-11 5-11	11-6 7-6	52	327	5796	759	4347	1191	2898	1623	1449
16	2929	28	11-6	11-6	54	354	7245	814	5434	1275	3623	1736	1811
17	3097	28	12-11 5-11	11-6 7-6	62	364	5796	854	4347	1344	2898	1833	1449
18	3274	29	12-11	11-6	61	382	6883	900	5162	1419	3442	1937	1721
19	3439	30	13-9	11-6	66	390	7970	938	5977	1485	3985	2032	1992
20	3616	31	14-6	11-6	67	408	9057	984	6792	1560	4528	2136	2264
21	3804	31	13-9 11-1	13-9 3-5	65	434	8708	1039	6531	1643	4354	2248	2177
22	4016	32	14-6 10-6	12-11 5-11	60	478	9882	1111	7412	1745	4941	2378	2471
23	4178	33	14-6 10-6	13-9 6-9	64	484	11022	1146	8267	1809	5511	2471	2756
24	4352	33	14-6	13-9	64	499	12322	1190	9241	1882	6161	2573	3080
26	4697	35	15-11 8-11	14-6 10-6	68	528	10868	1276	8151	2025	5434	2774	2717
28	5062	36	15-11	14-6	68	571	13585	1377	10189	2184	6792	2990	3396
30	5399	37	17-6	14-6	71	593	16302	1457	12226	2321	8151	3185	4075

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 3,000 psi | **GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS** | Minimum cover = 3 in.

f_y = 60 ksi | **80-TON STEEL PILES** | d_c = 10 in.

Minimum Pile Diameter = 10 in. spaced at 3' - 0" | Edge E = 21 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	494	12	6-6	3-6	38	63	0	140	0	217	0	294	0
3	743	16	6-6 2-1	6-2 2-3	39	96	627	212	471	327	314	442	157
4	991	16	6-6	6-6	39	129	1449	282	1087	436	725	590	362
5	1233	18	7-9	7-9	39	157	2049	349	1537	541	1025	733	512
6	1479	20	9-6	6-6	46	188	2174	418	1630	648	1087	879	543
7	1708	24	9-6	8-9	50	206	2510	475	1882	743	1255	1012	627
8	1968	23	9-6	8-9	48	247	3765	554	2824	862	1882	1169	941
9	2210	24	9-6	9-6	52	275	4347	621	3260	966	2174	1312	1087
10	2448	25	12-6	8-9	51	300	3765	684	2824	1068	1882	1452	941
11	2695	26	12-6	8-9	55	332	5020	754	3765	1176	2510	1599	1255
12	2939	28	12-6	9-6	56	361	5796	822	4347	1283	2898	1743	1449
13	3166	29	13-11	9-6	61	378	5072	877	3804	1376	2536	1875	1268
14	3422	30	12-6	11-9	55	416	6967	954	5225	1491	3483	2029	1742
15	3670	31	13-11 6-2	12-6 8-1	54	449	7728	1025	5796	1601	3864	2177	1932
16	3911	32	12-6	12-6	59	476	9660	1090	7245	1704	4830	2319	2415
17	4166	33	13-11 6-2	12-6 8-1	59	513	7728	1166	5796	1819	3864	2472	1932
18	4402	34	13-11	12-6	59	537	9177	1228	6883	1919	4589	2610	2294
19	4631	35	14-9	12-6	63	555	10626	1284	7970	2014	5313	2744	2657
20	4856	35	15-6	12-6	68	570	12075	1338	9057	2106	6038	2874	3019
21	5122	36	14-9 11-9	14-9 3-7	63	616	11611	1422	8708	2229	5806	3035	2903
22	5385	37	15-6 11-1	13-11 6-2	62	660	13177	1504	9882	2349	6588	3194	3294
23	5608	38	15-6 11-1	14-9 7-0	66	673	14696	1556	11022	2440	7348	3323	3674
24	5842	39	15-6	14-9	66	695	16429	1617	12322	2538	8215	3460	4107

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* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D+L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D+L)+0.53(E \text{ or } W)$.

f'_c = 3,000 psi
GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS
Minimum cover = 3 in.

f_y = 60 ksi
100-TON STEEL PILES
d_c = 10 in.

Minimum Pile Diameter = 10 in. spaced at 3' - 0"
Edge E = 21 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	621	13	6-6	3-6	41	82	0	178	0	274	0	370	0
3	933	18	6-6 2-1	6-2 2-3	42	124	784	268	588	412	392	556	196
4	1246	18	6-6	6-6	40	167	1811	359	1358	551	906	743	453
5	1548	20	7-9	7-9	43	201	2562	441	1921	681	1281	921	640
6	1860	22	9-6	6-6	48	243	2717	531	2038	819	1358	1107	679
7	2148	27	9-6	8-9	55	267	3137	603	2353	939	1569	1275	784
8	2476	25	9-6	8-9	50	321	4706	705	3529	1089	2353	1473	1176
9	2778	27	9-6	9-6	56	356	5434	788	4075	1220	2717	1652	1358
10	3088	28	12-6	8-9	51	396	4706	876	3529	1356	2353	1836	1176
11	3404	30	12-6	8-9	53	441	6275	969	4706	1497	3137	2025	1569
12	3702	31	12-6	9-6	58	473	7245	1049	5434	1625	3623	2201	1811
13	4001	32	13-11	9-6	60	505	6340	1129	4755	1753	3170	2377	1585
14	4303	33	12-6	11-9	60	539	8708	1211	6531	1883	4354	2555	2177
15	4614	34	13-11 6-2	12-6 8-1	59	581	9660	1301	7245	2021	4830	2741	2415
16	4916	36	12-6	12-6	65	615	12075	1383	9057	2151	6038	2919	3019
17	5254	37	13-11 6-2	12-6 8-1	59	677	9660	1493	7245	2309	4830	3125	2415
18	5558	38	13-11	12-6	58	712	11472	1577	8604	2441	5736	3305	2868
19	5844	39	14-9	12-6	64	735	13283	1647	9962	2559	6642	3471	3321
20	6132	40	15-6	12-6	69	759	15094	1719	11321	2679	7547	3639	3774

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 3,000 psi | **GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS** | Minimum cover = 3 in.

f_y = 60 ksi | **120-TON STEEL PILES** | d_c = 10 in.

Minimum Pile Diameter = 12 in. spaced at 3' - 0" | Edge E = 21 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	747	14	6-6	3-6	45	99	0	215	0	330	0	445	0
3	1124	19	6-6 2-2	6-2 2-3	43	152	941	325	706	497	471	670	235
4	1502	20	6-6	6-6	40	205	2174	435	1630	666	1087	896	543
5	1865	22	7-9	7-9	45	247	3074	535	2305	823	1537	1111	768
6	2242	24	9-6	6-6	50	299	3260	645	2445	990	1630	1336	815
7	2588	29	9-6	8-9	60	328	3765	731	2824	1135	1882	1538	941
8	2987	28	9-6	8-9	51	397	5647	858	4235	1319	2824	1779	1412
9	3347	29	9-6	9-6	60	437	6521	955	4891	1473	3260	1992	1630
10	3726	31	12-6	8-9	52	491	5647	1067	4235	1643	2824	2219	1412
11	4112	33	12-6	8-9	51	550	7530	1183	5647	1817	3765	2450	1882
12	4477	34	12-6	9-6	55	593	8694	1284	6521	1975	4347	2667	2174
13	4838	35	13-11	9-6	58	633	7608	1382	5706	2131	3804	2880	1902
14	5185	37	12-6	11-9	65	663	10450	1470	7837	2276	5225	3082	2612
15	5581	38	13-11 6-2	12-6 8-1	57	730	11592	1594	8694	2458	5796	3322	2898
16	5922	39	12-6	12-6	71	755	14491	1677	10868	2598	7245	3520	3623

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* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 3,000 psi **GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS** **Minimum cover = 3 in.**

f_y = 60 ksi **140-TON STEEL PILES** **d_c = 10 in.**

Minimum Pile Diameter = 12 in. spaced at 3' - 0" **Edge E = 27 in.**

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	867	15	7-7	4-6	42	113	0	247	0	381	0	516	0
3	1304	21	7-7	7-2	44	172	1129	373	846	575	564	776	282
			2-7	2-11									
4	1743	21	7-7	7-7	42	232	2606	501	1955	770	1303	1038	652
5	2165	24	8-11	8-11	47	280	3686	616	2764	952	1843	1288	921
6	2605	26	10-8	7-7	51	341	3909	744	2932	1147	1955	1551	977
7	3009	31	10-8	9-11	60	375	4514	846	3386	1316	2257	1786	1129
8	3474	30	10-8	9-11	52	455	6771	993	5079	1530	3386	2068	1693
9	3890	32	10-8	10-8	62	498	7819	1103	5864	1708	3909	2313	1955
10	4330	33	13-9	9-11	55	560	6771	1232	5079	1904	3386	2576	1693
11	4780	35	13-9	9-11	54	628	9028	1367	6771	2107	4514	2846	2257
12	5214	37	13-9	10-8	55	685	10425	1491	7819	2298	5213	3104	2606
13	5632	38	15-3	10-8	59	730	9122	1603	6842	2477	4561	3350	2281
14	6021	39	13-9	13-0	70	753	12530	1693	9398	2634	6265	3575	3133

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 3,000 psi

f_y = 60 ksi

Minimum Pile Diameter = 15 in. spaced at 3' - 9"

GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS

160-TON STEEL PILES

Minimum cover = 3 in.

d_c = 10 in.

Edge E = 27 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	988	16	8-3	4-6	48	127	0	280	0	434	0	587	0
3	1486	22	8-3	7-9	49	193	1359	423	1020	654	680	884	340
			2-9	2-11									
4	1985	23	8-3	8-3	46	260	3140	567	2355	874	1570	1182	785
5	2461	25	9-10	9-10	51	310	4440	694	3330	1078	2220	1462	1110
6	2959	28	12-0	8-3	57	376	4709	837	3532	1298	2355	1758	1177
7	3407	33	12-0	11-0	67	405	5438	942	4078	1480	2719	2018	1359
8	3937	32	12-0	11-0	60	495	8157	1110	6118	1724	4078	2338	2039
9	4409	34	12-0	12-0	69	542	9419	1233	7064	1924	4709	2616	2355
10	4912	36	15-9	11-0	60	612	8157	1380	6118	2148	4078	2916	2039
11	5413	37	15-9	11-0	63	681	10876	1525	8157	2370	5438	3215	2719
12	5886	39	15-9	12-0	68	728	12558	1650	9419	2571	6279	3493	3140

f'_c = 3,000 psi

f_y = 60 ksi

Minimum Pile Diameter = 15 in. spaced at 3' - 9"

GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS

180-TON STEEL PILES

Minimum cover = 3 in.

d_c = 10 in.

Edge E = 27 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	1114	17	8-3	4-6	51	144	0	317	0	490	0	663	0
3	1677	24	8-3	7-9	50	221	1529	480	1147	739	765	999	382
			2-9	2-11									
4	2240	24	8-3	8-3	47	298	3532	643	2649	989	1766	1334	883
5	2777	27	9-10	9-10	53	355	4995	787	3746	1219	2498	1651	1249
6	3339	29	12-0	8-3	59	431	5298	949	3974	1467	2649	1986	1325
7	3844	35	12-0	11-0	71	464	6118	1069	4588	1673	3059	2278	1529
8	4449	34	12-0	11-0	60	572	9177	1263	6882	1954	4588	2646	2294
9	4979	36	12-0	12-0	71	624	10596	1401	7947	2179	5298	2957	2649
10	5548	38	15-9	11-0	61	705	9177	1569	6882	2433	4588	3297	2294

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 3,000 psi

GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS

Minimum cover = 3 in.

f_y = 60 ksi

200-TON STEEL PILES

d_c = 10 in.

Minimum Pile Diameter = 15 in. spaced at 3' - 9"

Edge E = 27 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	1239	18	8-3	4-6	54	161	0	353	0	545	0	737	0
3	1868	25	8-3	7-9	51	249	1699	537	1275	825	850	1113	425
			2-9	2-11									
4	2494	25	8-3	8-3	48	335	3925	719	2943	1103	1962	1487	981
5	3095	28	9-10	9-10	54	401	5550	881	4163	1361	2775	1841	1388
6	3723	31	12-0	8-3	59	488	5887	1064	4415	1640	2943	2216	1472
7	4295	37	12-0	11-0	70	533	6797	1205	5098	1877	3399	2549	1699
8	4961	36	12-0	11-0	60	649	10196	1417	7647	2185	5098	2953	2549
9	5552	38	12-0	12-0	72	708	11774	1572	8830	2436	5887	3300	2943
10	6178	40	15-9	11-0	64	793	10196	1754	7647	2714	5098	3674	2549

f'_c = 3,000 psi

GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS

Minimum cover = 3 in.

f_y = 60 ksi

240-TON STEEL PILES

d_c = 10 in.

Minimum Pile Diameter = 18 in. spaced at 4' - 6"

Note: Special Detailing Required for High Load Piling

Edge E = 30 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	1480	20	9-6	5-0	58	188	0	419	0	649	0	880	0
3	2227	27	9-6	8-12	57	288	2824	633	2118	979	1412	1325	706
			3-0	3-3									
4	2976	28	9-6	9-6	53	389	6521	850	4891	1310	3260	1771	1630
5	3683	31	11-5	11-5	60	458	9222	1034	6916	1610	4611	2186	2305
6	4429	34	14-0	9-6	67	557	9781	1248	7336	1939	4891	2631	2445
7	5092	41	14-0	12-10	79	593	11294	1400	8471	2206	5647	3013	2824
8	5888	39	14-0	12-10	71	730	16941	1651	12706	2573	8471	3494	4235
9	6590	41	14-0	14-0	82	795	19562	1832	14672	2869	9781	3906	4891
10	7347	43	18-6	12-10	70	902	16941	2054	12706	3206	8471	4358	4235

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* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 3,000 psi

f_y = 60 ksi

Minimum Pile Diameter = 18 in. spaced at 4' - 6"

GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS

280-TON STEEL PILES

Note: Special Detailing Required for High Load Piling

Minimum cover = 3 in.

d_c = 10 in.

Edge E = 30 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	1730	21	9-6	5-0	65	222	0	491	0	760	0	1029	0
3	2610	29	9-6 3-0	8-12 3-3	58	345	3294	748	2471	1151	1647	1554	824
4	3486	30	9-6	9-6	54	464	7608	1002	5706	1539	3804	2077	1902
5	4318	33	11-5	11-5	62	551	10759	1223	8069	1895	5379	2567	2690
6	5195	37	14-0	9-6	68	671	11411	1477	8558	2283	5706	3090	2853
7	5980	44	14-0	12-10	81	722	13177	1663	9882	2603	6588	3544	3294
8	6916	42	14-0	12-10	70	886	19765	1961	14824	3037	9882	4112	4941
9	7734	44	14-0	14-0	84	962	22823	2172	17117	3381	11411	4591	5706
10	8613	47	18-6	12-10	73	1084	19765	2428	14824	3772	9882	5116	4941

f'_c = 3,000 psi

f_y = 60 ksi

Minimum Pile Diameter = 20 in. spaced at 5' - 0"

GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS

320-TON STEEL PILES

Note: Special Detailing Required for High Load Piling

Minimum cover = 3 in.

d_c = 10 in.

Edge E = 36 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	1964	23	11-0	6-0	63	244	0	551	0	859	0	1166	0
3	2958	31	11-0 3-6	10-5 3-10	63	375	4183	836	3137	1297	2092	1758	1046
4	3955	32	11-0	11-0	58	509	9660	1123	7245	1737	4830	2352	2415
5	4890	35	13-1	13-1	67	596	13662	1364	10246	2132	6831	2900	3415
6	5887	39	16-0	11-0	73	729	14491	1650	10868	2572	7245	3494	3623
7	6745	47	16-0	14-8	90	758	16732	1833	12549	2908	8366	3984	4183
8	7840	45	16-0	14-8	75	965	25098	2194	18824	3422	12549	4651	6275
9	8750	47	16-0	16-0	91	1033	28981	2415	21736	3798	14491	5180	7245
10	9765	50	21-0	14-8	77	1180	25098	2716	18824	4252	12549	5788	6275

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 3,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 20 in. spaced at 5' - 0"

GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS

360-TON STEEL PILES

Note: Special Detailing Required for High Load Piling

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 36 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	2212	24	11-0	6-0	69	277	0	622	0	968	0	1313	0
3	3341	33	11-0	10-5	64	432	4706	951	3529	1469	2353	1987	1176
			3-6	3-10									
4	4465	34	11-0	11-0	59	584	10868	1275	8151	1966	5434	2658	2717
5	5527	38	13-1	13-1	68	689	15370	1553	11527	2417	7685	3281	3842
6	6648	41	16-0	11-0	75	839	16302	1876	12226	2912	8151	3949	4075
7	7655	50	16-0	14-8	87	903	18824	2112	14118	3322	9412	4532	4706
8	8864	48	16-0	14-8	75	1118	28236	2501	21177	3883	14118	5266	7059
9	9891	50	16-0	16-0	93	1197	32604	2753	24453	4308	16302	5863	8151
10	11014	53	21-0	14-8	82	1349	28236	3077	21177	4805	14118	6533	7059

f'_c = 3,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 20 in. spaced at 5' - 0"

GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS

400-TON STEEL PILES

Note: Special Detailing Required for High Load Piling

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 36 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	2461	25	11-0	6-0	75	310	0	694	0	1078	0	1462	0
3	3725	35	11-0	10-5	64	490	5229	1066	3922	1642	2614	2218	1307
			3-6	3-10									
4	4977	36	11-0	11-0	59	661	12075	1429	9057	2197	6038	2965	3019
5	6163	40	13-1	13-1	69	782	17077	1742	12808	2702	8539	3662	4269
6	7416	44	16-0	11-0	75	954	18113	2106	13585	3258	9057	4410	4528
7	8565	53	16-0	14-8	84	1048	20915	2392	15686	3736	10458	5080	5229
8	9883	50	16-0	14-8	76	1268	31373	2804	23530	4340	15686	5876	7843
9	11038	53	16-0	16-0	94	1367	36226	3095	27170	4823	18113	6551	9057
10	12301	56	21-0	14-8	81	1546	31373	3466	23530	5386	15686	7306	7843

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 4,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 8 in. spaced at 3' - 0"

GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS
40-TON STEEL PILES

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 15 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	246	10	5-6	2-6	33	31	0	69	0	108	0	146	0
3	371	11	5-6	5-2	30	48	314	105	235	163	157	221	78
			1-6	1-7									
4	494	12	5-6	5-6	29	63	725	140	543	217	362	294	181
5	609	13	6-9	6-9	34	73	1025	169	768	265	512	361	256
6	727	14	8-6	5-6	43	84	1087	200	815	315	543	430	272
7	848	17	8-6	7-9	36	98	1255	233	941	367	627	502	314
8	973	16	8-6	7-9	38	115	1882	269	1412	423	941	576	471
9	1091	17	8-6	8-6	42	127	2174	300	1630	473	1087	645	543
10	1206	18	11-6	7-9	41	137	1882	329	1412	521	941	713	471
11	1336	19	11-6	7-9	40	157	2510	368	1882	580	1255	791	627
12	1451	20	11-6	8-6	43	167	2898	397	2174	627	1449	858	725
13	1552	20	12-11	8-6	51	166	2536	415	1902	665	1268	914	634
14	1695	21	11-6	10-9	39	196	3483	465	2612	734	1742	1002	871
15	1798	22	12-11	11-6	45	197	3864	485	2898	773	1932	1061	966
			5-11	7-6									
16	1936	23	11-6	11-6	42	223	4830	530	3623	838	2415	1145	1208
17	2046	23	12-11	11-6	48	229	3864	555	2898	882	1932	1208	966
			5-11	7-6									
18	2158	24	12-11	11-6	49	236	4589	582	3442	927	2294	1273	1147
19	2273	24	13-9	11-6	50	246	5313	610	3985	975	2657	1340	1328
20	2379	25	14-6	11-6	54	248	6038	632	4528	1016	3019	1400	1509
21	2506	26	13-9	13-9	52	267	5806	670	4354	1073	2903	1476	1451
			11-0	3-5									
22	2635	26	14-6	12-11	52	287	6588	709	4941	1131	3294	1554	1647
			10-6	5-11									
23	2743	27	14-6	13-9	54	291	7348	732	5511	1174	3674	1616	1837
			10-6	6-9									
24	2864	27	14-6	13-9	52	305	8215	766	6161	1226	4107	1687	2054
26	3098	28	15-11	14-6	53	327	7245	826	5434	1325	3623	1824	1811
			8-11	10-6									
28	3316	29	15-11	14-6	58	337	9057	874	6792	1412	4528	1949	2264
30	3540	30	17-6	14-6	59	351	10868	927	8151	1503	5434	2079	2717

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 4,000 psi

f_y = 60 ksi

Minimum Pile Diameter = 8 in. spaced at 3' - 0"

GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS

50-TON STEEL PILES

Minimum cover = 3 in.

d_c = 10 in.

Edge E = 15 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	310	10	5-6	2-6	35	41	0	89	0	137	0	185	0
3	466	13	5-6	5-2	31	62	392	134	294	206	196	278	98
			1-6	1-7									
4	620	13	5-6	5-6	32	81	906	177	679	273	453	369	226
5	768	14	6-9	6-9	35	96	1281	216	961	336	640	456	320
6	918	16	8-6	5-6	44	113	1358	257	1019	401	679	545	340
7	1068	19	8-6	7-9	39	129	1569	297	1176	465	784	633	392
8	1225	18	8-6	7-9	41	151	2353	343	1765	535	1176	727	588
9	1377	19	8-6	8-6	43	169	2717	385	2038	601	1358	817	679
10	1528	20	11-6	7-9	40	186	2353	426	1765	666	1176	906	588
11	1681	21	11-6	7-9	44	205	3137	469	2353	733	1569	997	784
12	1816	22	11-6	8-6	53	210	3623	498	2717	786	1811	1074	906
13	1968	23	12-11	8-6	51	228	3170	540	2377	852	1585	1164	792
14	2136	24	11-6	10-9	42	258	4354	594	3266	930	2177	1266	1089
15	2265	24	12-11	11-6	50	259	4830	619	3623	979	2415	1339	1208
			5-11	7-6									
16	2422	25	11-6	11-6	52	281	6038	665	4528	1049	3019	1433	1509
17	2580	26	12-11	11-6	52	303	4830	711	3623	1119	2415	1527	1208
			5-11	7-6									
18	2725	27	12-11	11-6	52	316	5736	748	4302	1180	2868	1612	1434
19	2875	27	13-9	11-6	52	332	6642	788	4981	1244	3321	1700	1660
20	3016	28	14-6	11-6	55	342	7547	822	5660	1302	3774	1782	1887
21	3160	29	13-9	13-9	57	354	7257	858	5443	1362	3628	1866	1814
			11-0	3-5									
22	3332	29	14-6	12-11	54	387	8235	915	6177	1443	4118	1971	2059
			10-6	5-11									
23	3461	30	14-6	13-9	59	388	9185	940	6889	1492	4593	2044	2296
			10-6	6-9									
24	3616	31	14-6	13-9	56	408	10268	984	7701	1560	5134	2136	2567
26	3904	32	15-11	14-6	59	432	9057	1056	6792	1680	4528	2304	2264
			8-11	10-6									
28	4212	33	15-11	14-6	58	471	11321	1143	8491	1815	5660	2487	2830
30	4495	34	17-6	14-6	60	491	13585	1211	10189	1931	6792	2651	3396

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 4,000 psi

f_y = 60 ksi

Minimum Pile Diameter = 8 in. spaced at 3' - 0"

GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS

60-TON STEEL PILES

Minimum cover = 3 in.

d_c = 10 in.

Edge E = 15 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	373	10	5-6	2-6	40	49	0	107	0	165	0	222	0
3	562	14	5-6 1-6	5-2 1-7	33	76	471	162	353	249	235	335	118
4	747	14	5-6	5-6	34	99	1087	215	815	330	543	445	272
5	928	16	6-9	6-9	35	120	1537	264	1153	408	768	552	384
6	1109	17	8-6	5-6	45	141	1630	313	1223	486	815	659	408
7	1288	21	8-6	7-9	42	160	1882	361	1412	563	941	764	471
8	1483	20	8-6	7-9	40	191	2824	421	2118	651	1412	882	706
9	1665	21	8-6	8-6	43	212	3260	471	2445	730	1630	990	815
10	1845	22	11-6	7-9	42	232	2824	520	2118	808	1412	1096	706
11	2028	23	11-6	7-9	47	254	3765	571	2824	887	1882	1204	941
12	2194	24	11-6	8-6	56	263	4347	609	3260	954	2174	1300	1087
13	2362	25	12-11	8-6	61	274	3804	648	2853	1023	1902	1397	951
14	2571	26	11-6	10-9	47	315	5225	719	3919	1122	2612	1525	1306
15	2740	27	12-11 5-11	11-6 7-6	52	327	5796	759	4347	1191	2898	1623	1449
16	2929	28	11-6	11-6	54	354	7245	814	5434	1275	3623	1736	1811
17	3107	28	12-11 5-11	11-6 7-6	58	372	5796	861	4347	1351	2898	1841	1449
18	3277	29	12-11	11-6	60	384	6883	903	5162	1421	3442	1939	1721
19	3458	30	13-9	11-6	60	405	7970	952	5977	1499	3985	2046	1992
20	3643	31	14-6	11-6	59	428	9057	1004	6792	1580	4528	2156	2264
21	3829	31	13-9 11-0	13-9 3-5	58	453	8708	1057	6531	1662	4354	2267	2177
22	4016	32	14-6 10-6	12-11 5-11	60	478	9882	1111	7412	1745	4941	2378	2471
23	4189	33	14-6 10-6	13-9 6-9	61	492	11022	1155	8267	1817	5511	2479	2756
24	4372	34	14-6	13-9	59	514	12322	1205	9241	1897	6161	2588	3080
26	4714	35	15-11 8-11	14-6 10-6	64	540	10868	1289	8151	2038	5434	2787	2717
28	5085	36	15-11	14-6	63	588	13585	1395	10189	2201	6792	3007	3396
30	5425	37	17-6	14-6	66	613	16302	1477	12226	2341	8151	3205	4075

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 4,000 psi

GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS

Minimum cover = 3 in.

f_y = 60 ksi

80-TON STEEL PILES

d_c = 10 in.

Minimum Pile Diameter = 10 in. spaced at 3' - 0"

Edge E = 21 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	495	12	6-6	3-6	36	64	0	141	0	218	0	294	0
3	744	16	6-6 2-1	6-2 2-3	37	97	627	212	471	328	314	443	157
4	992	16	6-6	6-6	37	130	1449	283	1087	437	725	590	362
5	1235	18	7-9	7-9	37	158	2049	350	1537	542	1025	734	512
6	1480	20	9-6	6-6	45	188	2174	419	1630	649	1087	880	543
7	1713	24	9-6	8-9	47	210	2510	478	1882	747	1255	1016	627
8	1978	23	9-6	8-9	42	255	3765	562	2824	869	1882	1176	941
9	2217	24	9-6	9-6	48	280	4347	626	3260	972	2174	1317	1087
10	2455	25	12-6	8-9	48	305	3765	689	2824	1073	1882	1457	941
11	2700	26	12-6	8-9	53	335	5020	758	3765	1180	2510	1603	1255
12	2943	28	12-6	9-6	54	364	5796	825	4347	1286	2898	1746	1449
13	3166	29	13-11	9-6	61	378	5072	877	3804	1376	2536	1875	1268
14	3434	30	12-6	11-9	51	425	6967	963	5225	1500	3483	2038	1742
15	3683	31	13-11 6-2	12-6 8-1	50	458	7728	1034	5796	1610	3864	2186	1932
16	3924	32	12-6	12-6	55	485	9660	1100	7245	1714	4830	2329	2415
17	4166	33	13-11 6-2	12-6 8-1	59	513	7728	1166	5796	1819	3864	2472	1932
18	4402	34	13-11	12-6	59	537	9177	1228	6883	1919	4589	2610	2294
19	4631	35	14-9	12-6	63	555	10626	1284	7970	2014	5313	2744	2657
20	4856	35	15-6	12-6	68	570	12075	1338	9057	2106	6038	2874	3019
21	5122	36	14-9 11-9	14-9 3-7	63	616	11611	1422	8708	2229	5806	3035	2903
22	5401	37	15-6 11-1	13-11 6-2	58	672	13177	1516	9882	2361	6588	3206	3294
23	5621	38	15-6 11-1	14-9 7-0	63	683	14696	1566	11022	2449	7348	3333	3674
24	5865	39	15-6	14-9	61	712	16429	1634	12322	2556	8215	3477	4107

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E\ or\ W)$.

f'_c = 4,000 psi

f_y = 60 ksi

Minimum Pile Diameter = 10 in. spaced at 3' - 0"

GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS

100-TON STEEL PILES

Minimum cover = 3 in.

d_c = 10 in.

Edge E = 21 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	622	13	6-6	3-6	39	83	0	179	0	275	0	371	0
3	934	18	6-6 2-1	6-2 2-3	40	125	784	269	588	413	392	557	196
4	1247	18	6-6	6-6	38	167	1811	359	1358	551	906	743	453
5	1551	20	7-9	7-9	40	203	2562	443	1921	683	1281	923	640
6	1863	22	9-6	6-6	46	245	2717	533	2038	821	1358	1109	679
7	2155	27	9-6	8-9	51	272	3137	608	2353	944	1569	1280	784
8	2480	25	9-6	8-9	48	324	4706	708	3529	1092	2353	1476	1176
9	2784	27	9-6	9-6	53	360	5434	792	4075	1224	2717	1656	1358
10	3088	28	12-6	8-9	51	396	4706	876	3529	1356	2353	1836	1176
11	3404	30	12-6	8-9	53	441	6275	969	4706	1497	3137	2025	1569
12	3704	31	12-6	9-6	57	474	7245	1050	5434	1626	3623	2202	1811
13	4001	32	13-11	9-6	60	505	6340	1129	4755	1753	3170	2377	1585
14	4315	33	12-6	11-9	56	548	8708	1220	6531	1892	4354	2564	2177
15	4614	34	13-11 6-2	12-6 8-1	59	581	9660	1301	7245	2021	4830	2741	2415
16	4929	36	12-6	12-6	61	625	12075	1393	9057	2161	6038	2929	3019
17	5261	37	13-11 6-2	12-6 8-1	57	682	9660	1498	7245	2314	4830	3130	2415
18	5561	38	13-11	12-6	57	715	11472	1579	8604	2443	5736	3307	2868
19	5855	39	14-9	12-6	61	743	13283	1655	9962	2567	6642	3479	3321
20	6144	40	15-6	12-6	66	768	15094	1728	11321	2688	7547	3648	3774

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* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 4,000 psi | **GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS** | Minimum cover = 3 in.

f_y = 60 ksi | **120-TON STEEL PILES** | d_c = 10 in.

Minimum Pile Diameter = 12 in. spaced at 3' - 0" | Edge E = 21 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	748	14	6-6	3-6	42	100	0	215	0	331	0	446	0
3	1126	19	6-6	6-2	41	153	967	326	726	499	484	672	242
			2-2	2-3									
4	1503	20	6-6	6-6	39	206	2234	436	1675	666	1117	897	558
5	1868	22	7-9	7-9	43	249	3159	537	2369	825	1580	1113	790
6	2244	24	9-6	6-6	48	301	3351	646	2513	992	1675	1337	838
7	2596	29	9-6	8-9	55	334	3869	737	2902	1141	1935	1544	967
8	2988	28	9-6	8-9	50	398	5804	859	4353	1319	2902	1780	1451
9	3353	29	9-6	9-6	57	441	6702	960	5026	1478	3351	1996	1675
10	3732	31	12-6	8-9	49	495	5804	1071	4353	1647	2902	2223	1451
11	4112	33	12-6	8-9	51	550	7739	1183	5804	1817	3869	2450	1935
12	4477	34	12-6	9-6	55	593	8936	1284	6702	1975	4468	2667	2234
13	4838	35	13-11	9-6	58	633	7819	1382	5864	2131	3909	2880	1955
14	5199	37	12-6	11-9	60	674	10740	1480	8055	2286	5370	3093	2685
15	5581	38	13-11	12-6	57	730	11914	1594	8936	2458	5957	3322	2979
			6-2	8-1									
16	5937	39	12-6	12-6	66	766	14893	1688	11170	2610	7447	3531	3723

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* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 4,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 12 in. spaced at 3' - 0"

GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS
140-TON STEEL PILES

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 27 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	869	15	7-6	4-6	40	114	0	249	0	383	0	517	0
3	1307	21	7-6	7-2	42	174	1129	375	846	577	564	779	282
			2-8	2-11									
4	1747	21	7-6	7-6	40	235	2606	504	1955	773	1303	1041	652
5	2172	24	8-9	8-9	44	285	3686	621	2764	957	1843	1293	921
6	2610	26	10-6	7-6	49	345	3909	748	2932	1151	1955	1554	977
7	3019	32	10-6	9-9	57	383	4514	853	3386	1323	2257	1794	1129
8	3483	30	10-6	9-9	49	462	6771	999	5079	1537	3386	2075	1693
9	3901	32	10-6	10-6	59	507	7819	1111	5864	1716	3909	2321	1955
10	4345	33	13-6	9-9	51	571	6771	1243	5079	1915	3386	2587	1693
11	4793	35	13-6	9-9	51	638	9028	1377	6771	2116	4514	2856	2257
12	5228	37	13-6	10-6	52	695	10425	1502	7819	2308	5213	3115	2606
13	5645	38	14-11	10-6	57	739	9122	1613	6842	2487	4561	3360	2281
14	6048	39	13-6	12-9	65	773	12530	1714	9398	2654	6265	3595	3133

f'_c = 4,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 15 in. spaced at 3' - 9"

GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS
160-TON STEEL PILES

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 27 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	989	16	8-3	4-6	46	127	0	281	0	435	0	588	0
3	1488	22	8-3	7-9	47	194	1359	425	1020	655	680	886	340
			2-9	2-11									
4	1988	23	8-3	8-3	44	262	3140	569	2355	877	1570	1184	785
5	2467	25	9-10	9-10	48	314	4440	698	3330	1082	2220	1466	1110
6	2963	28	12-0	8-3	55	379	4709	840	3532	1301	2355	1761	1177
7	3420	33	12-0	11-0	62	415	5438	952	4078	1490	2719	2027	1359
8	3948	32	12-0	11-0	56	503	8157	1118	6118	1732	4078	2347	2039
9	4423	34	12-0	12-0	64	552	9419	1244	7064	1935	4709	2626	2355
10	4919	36	15-9	11-0	58	617	8157	1385	6118	2153	4078	2921	2039
11	5413	37	15-9	11-0	63	681	10876	1525	8157	2370	5438	3215	2719
12	5886	39	15-9	12-0	68	728	12558	1650	9419	2571	6279	3493	3140

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 4,000 psi

f_y = 60 ksi

Minimum Pile Diameter = 15 in. spaced at 3' - 9"

GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS

180-TON STEEL PILES

Minimum cover = 3 in.

d_c = 10 in.

Edge E = 27 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	1116	17	8-3	4-6	48	146	0	319	0	491	0	664	0
3	1679	24	8-3	7-9	48	222	1529	482	1147	741	765	1000	382
			2-9	2-11									
4	2242	24	8-3	8-3	45	299	3532	645	2649	990	1766	1336	883
5	2783	27	9-10	9-10	50	359	4995	791	3746	1223	2498	1655	1249
6	3345	29	12-0	8-3	56	435	5298	954	3974	1472	2649	1990	1325
7	3860	36	12-0	11-0	65	476	6118	1081	4588	1685	3059	2290	1529
8	4454	34	12-0	11-0	58	576	9177	1267	6882	1958	4588	2649	2294
9	4991	36	12-0	12-0	67	633	10596	1410	7947	2188	5298	2966	2649
10	5559	38	15-9	11-0	58	713	9177	1577	6882	2441	4588	3305	2294

f'_c = 4,000 psi

f_y = 60 ksi

Minimum Pile Diameter = 15 in. spaced at 3' - 9"

GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS

200-TON STEEL PILES

Minimum cover = 3 in.

d_c = 10 in.

Edge E = 27 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	1242	18	8-3	4-6	50	164	0	356	0	548	0	740	0
3	1870	25	8-3	7-9	49	251	1699	539	1275	827	850	1115	425
			2-9	2-11									
4	2497	25	8-3	8-3	46	337	3925	721	2943	1105	1962	1489	981
5	3099	28	9-10	9-10	52	404	5550	884	4163	1364	2775	1844	1388
6	3727	31	12-0	8-3	57	491	5887	1067	4415	1643	2943	2219	1472
7	4297	37	12-0	11-0	69	535	6797	1207	5098	1879	3399	2551	1699
8	4966	36	12-0	11-0	58	653	10196	1421	7647	2189	5098	2957	2549
9	5561	38	12-0	12-0	69	715	11774	1579	8830	2443	5887	3307	2943
10	6195	40	15-9	11-0	59	806	10196	1766	7647	2726	5098	3686	2549

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \; or \; W)$.

f'_c = 4,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 18 in. spaced at 4' - 6"

GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS

240-TON STEEL PILES

Note: Special Detailing Required for High Load Piling

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 30 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux}**							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	1483	20	9-6	5-0	55	191	0	421	0	651	0	882	0
3	2231	27	9-6	8-12	54	291	2824	636	2118	982	1412	1328	706
			3-0	3-3									
4	2979	28	9-6	9-6	51	391	6521	852	4891	1313	3260	1773	1630
5	3694	31	11-5	11-5	56	466	9222	1043	6916	1619	4611	2195	2305
6	4437	34	14-0	9-6	64	563	9781	1254	7336	1945	4891	2637	2445
7	5110	41	14-0	12-10	74	607	11294	1413	8471	2220	5647	3026	2824
8	5906	39	14-0	12-10	66	743	16941	1665	12706	2586	8471	3508	4235
9	6614	41	14-0	14-0	76	813	19562	1850	14672	2887	9781	3924	4891
10	7361	43	18-6	12-10	67	913	16941	2065	12706	3217	8471	4369	4235

f'_c = 4,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 18 in. spaced at 4' - 6"

GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS

280-TON STEEL PILES

Note: Special Detailing Required for High Load Piling

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 30 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux}**							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	1735	21	9-6	5-0	59	226	0	495	0	764	0	1032	0
3	2613	29	9-6	8-12	56	347	3294	750	2471	1153	1647	1557	824
			3-0	3-3									
4	3490	30	9-6	9-6	52	467	7608	1005	5706	1542	3804	2080	1902
5	4323	33	11-5	11-5	60	554	10759	1226	8069	1898	5379	2570	2690
6	5203	37	14-0	9-6	65	677	11411	1483	8558	2289	5706	3096	2853
7	5988	44	14-0	12-10	79	728	13177	1669	9882	2609	6588	3550	3294
8	6923	42	14-0	12-10	68	891	19765	1967	14824	3042	9882	4117	4941
9	7750	45	14-0	14-0	80	974	22823	2184	17117	3393	11411	4603	5706
10	8637	47	18-6	12-10	68	1102	19765	2446	14824	3790	9882	5134	4941

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 4,000 psi **GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS** Minimum cover = 3 in.

f_y = 60 ksi **320-TON STEEL PILES** d_c = 10 in.

Minimum Pile Diameter = 20 in. spaced at 5' - 0" *Note: Special Detailing Required for High Load Piling* Edge E = 36 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	1970	23	11-0	6-0	59	249	0	556	0	863	0	1170	0
3	2964	31	11-0	10-5	60	380	4183	841	3137	1301	2092	1762	1046
			3-6	3-10									
4	3960	32	11-0	11-0	56	512	9660	1127	7245	1741	4830	2356	2415
5	4904	36	13-1	13-1	63	606	13662	1374	10246	2142	6831	2910	3415
6	5897	39	16-0	11-0	70	736	14491	1658	10868	2580	7245	3501	3623
7	6778	47	16-0	14-8	83	783	16732	1858	12549	2933	8366	4008	4183
8	7844	45	16-0	14-8	74	968	25098	2197	18824	3425	12549	4654	6275
9	8775	47	16-0	16-0	86	1052	28981	2434	21736	3816	14491	5199	7245
10	9790	50	21-0	14-8	73	1199	25098	2735	18824	4271	12549	5807	6275

f'_c = 4,000 psi **GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS** Minimum cover = 3 in.

f_y = 60 ksi **360-TON STEEL PILES** d_c = 10 in.

Minimum Pile Diameter = 20 in. spaced at 5' - 0" *Note: Special Detailing Required for High Load Piling* Edge E = 36 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	2222	24	11-0	6-0	62	284	0	630	0	975	0	1321	0
3	3346	33	11-0	10-5	61	436	4706	954	3529	1473	2353	1991	1176
			3-6	3-10									
4	4472	34	11-0	11-0	56	589	10868	1280	8151	1972	5434	2663	2717
5	5537	38	13-1	13-1	65	697	15370	1561	11527	2425	7685	3289	3842
6	6658	41	16-0	11-0	72	846	16302	1883	12226	2920	8151	3957	4075
7	7655	50	16-0	14-8	87	903	18824	2112	14118	3322	9412	4532	4706
8	8878	48	16-0	14-8	72	1129	28236	2511	21177	3894	14118	5276	7059
9	9917	50	16-0	16-0	88	1217	32604	2772	24453	4327	16302	5883	8151
10	11058	53	21-0	14-8	75	1382	28236	3110	21177	4838	14118	6566	7059

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 4,000 psi

f_y = 60 ksi

Minimum Pile Diameter = 20 in. spaced at 5' - 0"

GRAVITY AND LATERAL LOADS, BENDING ABOUT X AXIS

400-TON STEEL PILES

Note: Special Detailing Required for High Load Piling

Minimum cover = 3 in.

d_c = 10 in.

Edge E = 36 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{ux} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{ux}	40% Axial P_u (net)	Available Moment M_{ux}	60% Axial P_u (net)	Available Moment M_{ux}	80% Axial P_u (net)	Available Moment M_{ux}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	2471	25	11-0	6-0	67	317	0	701	0	1085	0	1469	0
3	3730	35	11-0 3-6	10-5 3-10	61	494	5229	1070	3922	1646	2614	2222	1307
4	4982	36	11-0	11-0	57	665	12075	1433	9057	2201	6038	2969	3019
5	6174	40	13-1	13-1	66	790	17077	1751	12808	2711	8539	3671	4269
6	7426	44	16-0	11-0	72	962	18113	2114	13585	3266	9057	4418	4528
7	8565	53	16-0	14-8	84	1048	20915	2392	15686	3736	10458	5080	5229
8	9897	50	16-0	14-8	73	1279	31373	2815	23530	4351	15686	5887	7843
9	11059	53	16-0	16-0	90	1382	36226	3110	27170	4838	18113	6566	9057
10	12313	56	21-0	14-8	79	1555	31373	3475	23530	5395	15686	7315	7843

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 3,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 8 in. spaced at 3' - 0"

GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS
40-TON STEEL PILES

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 15 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	246	10	5-6	2-6	34	31	362	69	272	108	181	146	91
3	370	11	5-6 1-6	5-2 1-7	31	47	627	105	471	162	314	220	157
4	493	12	5-6	5-6	31	63	725	139	543	216	362	293	181
5	608	13	6-9	6-9	35	72	1025	168	768	264	512	360	256
6	726	14	8-6	5-6	44	84	1449	199	1087	314	725	429	362
7	845	17	8-6	7-9	38	96	1087	231	815	365	543	499	272
8	972	16	8-6	7-9	39	115	1630	268	1223	422	815	575	408
9	1089	17	8-6	8-6	43	126	2174	298	1630	471	1087	644	543
10	1206	18	11-6	7-9	41	137	2174	329	1630	521	1087	713	543
11	1331	19	11-6	7-9	43	153	2898	365	2174	576	1449	787	725
12	1442	19	11-6	8-6	48	160	3623	390	2717	621	1811	851	906
13	1549	20	12-11	8-6	52	163	4392	413	3294	663	2196	912	1098
14	1690	21	11-6	10-9	41	192	3381	461	2536	730	1691	999	845
15	1790	22	12-11 5-11	11-6 7-6	48	191	3765	479	2824	767	1882	1055	941
16	1921	22	11-6	11-6	48	212	4830	519	3623	826	2415	1134	1208
17	2038	23	12-11 5-11	11-6 7-6	51	223	5020	549	3765	876	2510	1202	1255
18	2152	24	12-11	11-6	51	232	5961	577	4471	923	2980	1268	1490
19	2261	24	13-9	11-6	54	237	6575	601	4931	966	3287	1331	1644
20	2376	25	14-6	11-6	55	246	7245	630	5434	1014	3623	1398	1811
21	2492	25	13-9 11-1	13-9 3-5	56	256	6771	659	5078	1063	3386	1466	1693
22	2632	26	14-6 10-6	12-11 5-11	53	284	6340	707	4755	1129	3170	1552	1585
23	2728	27	14-6 10-6	13-9 6-9	58	280	7245	721	5434	1163	3623	1604	1811
24	2852	27	14-6	13-9	55	296	8151	757	6113	1217	4075	1678	2038
26	3080	28	15-11 8-11	14-6 10-6	57	313	9817	812	7363	1312	4909	1811	2454
28	3307	29	15-11	14-6	60	330	10912	867	8184	1405	5456	1943	2728
30	3540	30	17-6	14-6	59	351	12679	927	9509	1503	6340	2079	3170

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 3,000 psi **GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS** Minimum cover = 3 in.

f_y = 60 ksi **50-TON STEEL PILES** d_c = 10 in.

Minimum Pile Diameter = 8 in. spaced at 3' - 0" Edge E = 15 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	309	10	5-6	2-6	39	40	453	88	340	136	226	184	113
3	466	13	5-6	5-2	33	62	784	134	588	206	392	278	196
			1-6	1-7									
4	619	13	5-6	5-6	34	80	906	176	679	272	453	368	226
5	767	14	6-9	6-9	36	95	1281	215	961	335	640	455	320
6	917	16	8-6	5-6	45	112	1811	256	1358	400	906	544	453
7	1064	19	8-6	7-9	42	126	1358	294	1019	462	679	630	340
8	1225	18	8-6	7-9	41	151	2038	343	1528	535	1019	727	509
9	1376	19	8-6	8-6	44	168	2717	384	2038	600	1358	816	679
10	1525	20	11-6	7-9	42	184	2717	424	2038	664	1358	904	679
11	1676	21	11-6	7-9	47	201	3623	465	2717	729	1811	993	906
12	1808	22	11-6	8-6	57	204	4528	492	3396	780	2264	1068	1132
13	1952	23	12-11	8-6	58	216	5490	528	4118	840	2745	1152	1373
14	2128	24	11-6	10-9	45	252	4226	588	3170	924	2113	1260	1057
15	2257	24	12-11	11-6	53	253	4706	613	3529	973	2353	1333	1176
			5-11	7-6									
16	2414	25	11-6	11-6	55	275	6038	659	4528	1043	3019	1427	1509
17	2577	26	12-11	11-6	53	301	6275	709	4706	1117	3137	1525	1569
			5-11	7-6									
18	2707	27	12-11	11-6	58	302	7451	734	5588	1166	3726	1598	1863
19	2859	27	13-9	11-6	57	320	8218	776	6164	1232	4109	1688	2055
20	3003	28	14-6	11-6	59	332	9057	812	6792	1292	4528	1772	2264
21	3150	29	13-9	13-9	60	347	8464	851	6348	1355	4232	1859	2116
			11-1	3-5									
22	3318	29	14-6	12-11	58	377	7925	905	5943	1433	3962	1961	1981
			10-6	5-11									
23	3450	30	14-6	13-9	62	380	9057	932	6792	1484	4528	2036	2264
			10-6	6-9									
24	3608	31	14-6	13-9	58	402	10189	978	7642	1554	5094	2130	2547
26	3886	32	15-11	14-6	63	419	12272	1043	9204	1667	6136	2291	3068
			8-11	10-6									
28	4189	33	15-11	14-6	63	454	13639	1126	10230	1798	6820	2470	3410
30	4470	34	17-6	14-6	65	473	15849	1193	11887	1913	7925	2633	3962

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 3,000 psi | **GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS** | **Minimum cover = 3 in.**

f_y = 60 ksi | **60-TON STEEL PILES** | **d_c = 10 in.**

Minimum Pile Diameter = 8 in. spaced at 3' - 0" | **Edge E = 15 in.**

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	372	10	5-6	2-6	43	49	543	106	408	164	272	221	136
3	561	14	5-6 1-6	5-2 1-7	35	75	941	162	706	248	471	334	235
4	746	14	5-6	5-6	36	99	1087	214	815	329	543	444	272
5	927	16	6-9	6-9	36	119	1537	263	1153	407	768	551	384
6	1109	17	8-6	5-6	46	141	2174	313	1630	486	1087	659	543
7	1284	21	8-6	7-9	45	157	1630	358	1223	560	815	761	408
8	1481	20	8-6	7-9	41	189	2445	420	1834	650	1223	880	611
9	1661	21	8-6	8-6	46	209	3260	468	2445	727	1630	987	815
10	1834	22	11-6	7-9	48	224	3260	512	2445	800	1630	1088	815
11	2019	23	11-6	7-9	52	247	4347	564	3260	881	2174	1197	1087
12	2194	24	11-6	8-6	56	263	5434	609	4075	954	2717	1300	1358
13	2357	25	12-11	8-6	63	270	6588	645	4941	1019	3294	1393	1647
14	2564	26	11-6	10-9	50	310	5072	713	3804	1117	2536	1520	1268
15	2740	27	12-11 5-11	11-6 7-6	52	327	5647	759	4235	1191	2824	1623	1412
16	2929	28	11-6	11-6	54	354	7245	814	5434	1275	3623	1736	1811
17	3097	28	12-11 5-11	11-6 7-6	62	364	7530	854	5647	1344	3765	1833	1882
18	3274	29	12-11	11-6	61	382	8941	900	6706	1419	4471	1937	2235
19	3439	30	13-9	11-6	66	390	9862	938	7397	1485	4931	2032	2466
20	3616	31	14-6	11-6	67	408	10868	984	8151	1560	5434	2136	2717
21	3804	31	13-9 11-1	13-9 3-5	65	434	10157	1039	7618	1643	5078	2248	2539
22	4016	32	14-6 10-6	12-11 5-11	60	478	9509	1111	7132	1745	4755	2378	2377
23	4178	33	14-6 10-6	13-9 6-9	64	484	10868	1146	8151	1809	5434	2471	2717
24	4352	33	14-6	13-9	64	499	12226	1190	9170	1882	6113	2573	3057
26	4697	35	15-11 8-11	14-6 10-6	68	528	14726	1276	11045	2025	7363	2774	3682
28	5062	36	15-11	14-6	68	571	16367	1377	12276	2184	8184	2990	4092
30	5399	37	17-6	14-6	71	593	19019	1457	14264	2321	9509	3185	4755

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \textit{ or } W)$.

f'_c = 3,000 psi

GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS

80-TON STEEL PILES

Minimum cover = 3 in.

f_y = 60 ksi

d_c = 10 in.

Minimum Pile Diameter = 10 in. spaced at 3' - 0"

Edge E = 21 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	494	12	6-6	3-6	38	63	725	140	543	217	362	294	181
3	743	16	6-6 2-1	6-2 2-3	39	96	1255	212	941	327	627	442	314
4	991	16	6-6	6-6	39	129	1449	282	1087	436	725	590	362
5	1233	18	7-9	7-9	39	157	2049	349	1537	541	1025	733	512
6	1479	20	9-6	6-6	46	188	2898	418	2174	648	1449	879	725
7	1708	24	9-6	8-9	50	206	2174	475	1630	743	1087	1012	543
8	1968	23	9-6	8-9	48	247	3260	554	2445	862	1630	1169	815
9	2210	24	9-6	9-6	52	275	4347	621	3260	966	2174	1312	1087
10	2448	25	12-6	8-9	51	300	4347	684	3260	1068	2174	1452	1087
11	2695	26	12-6	8-9	55	332	5796	754	4347	1176	2898	1599	1449
12	2939	28	12-6	9-6	56	361	7245	822	5434	1283	3623	1743	1811
13	3166	29	13-11	9-6	61	378	8784	877	6588	1376	4392	1875	2196
14	3422	30	12-6	11-9	55	416	6762	954	5072	1491	3381	2029	1691
15	3670	31	13-11 6-2	12-6 8-1	54	449	7530	1025	5647	1601	3765	2177	1882
16	3911	32	12-6	12-6	59	476	9660	1090	7245	1704	4830	2319	2415
17	4166	33	13-11 6-2	12-6 8-1	59	513	10039	1166	7530	1819	5020	2472	2510
18	4402	34	13-11	12-6	59	537	11922	1228	8941	1919	5961	2610	2980
19	4631	35	14-9	12-6	63	555	13149	1284	9862	2014	6575	2744	3287
20	4856	35	15-6	12-6	68	570	14491	1338	10868	2106	7245	2874	3623
21	5122	36	14-9 11-9	14-9 3-7	63	616	13543	1422	10157	2229	6771	3035	3386
22	5385	37	15-6 11-1	13-11 6-2	62	660	12679	1504	9509	2349	6340	3194	3170
23	5608	38	15-6 11-1	14-9 7-0	66	673	14491	1556	10868	2440	7245	3323	3623
24	5842	39	15-6	14-9	66	695	16302	1617	12226	2538	8151	3460	4075

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 3,000 psi
GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS
Minimum cover = 3 in.
f_y = 60 ksi
100-TON STEEL PILES
d_c = 10 in.
Minimum Pile Diameter = 10 in. spaced at 3' - 0"
Edge E = 21 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	621	13	6-6	3-6	41	82	906	178	679	274	453	370	226
3	933	18	6-6 2-1	6-2 2-3	42	124	1569	268	1176	412	784	556	392
4	1246	18	6-6	6-6	40	167	1811	359	1358	551	906	743	453
5	1548	20	7-9	7-9	43	201	2562	441	1921	681	1281	921	640
6	1860	22	9-6	6-6	48	243	3623	531	2717	819	1811	1107	906
7	2148	27	9-6	8-9	55	267	2717	603	2038	939	1358	1275	679
8	2476	25	9-6	8-9	50	321	4075	705	3057	1089	2038	1473	1019
9	2778	27	9-6	9-6	56	356	5434	788	4075	1220	2717	1652	1358
10	3088	28	12-6	8-9	51	396	5434	876	4075	1356	2717	1836	1358
11	3404	30	12-6	8-9	53	441	7245	969	5434	1497	3623	2025	1811
12	3702	31	12-6	9-6	58	473	9057	1049	6792	1625	4528	2201	2264
13	4001	32	13-11	9-6	60	505	10981	1129	8235	1753	5490	2377	2745
14	4303	33	12-6	11-9	60	539	8453	1211	6340	1883	4226	2555	2113
15	4614	34	13-11 6-2	12-6 8-1	59	581	9412	1301	7059	2021	4706	2741	2353
16	4916	36	12-6	12-6	65	615	12075	1383	9057	2151	6038	2919	3019
17	5254	37	13-11 6-2	12-6 8-1	59	677	12549	1493	9412	2309	6275	3125	3137
18	5558	38	13-11	12-6	58	712	14902	1577	11177	2441	7451	3305	3726
19	5844	39	14-9	12-6	64	735	16437	1647	12328	2559	8218	3471	4109
20	6132	40	15-6	12-6	69	759	18113	1719	13585	2679	9057	3639	4528

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \; or \; W)$.

f'_c = 3,000 psi

GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS

Minimum cover = 3 in.

f_y = 60 ksi

120-TON STEEL PILES

d_c = 10 in.

Minimum Pile Diameter = 12 in. spaced at 3' - 0"

Edge E = 21 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	747	14	6-6	3-6	45	99	1087	215	815	330	543	445	272
3	1124	19	6-6 2-2	6-2 2-3	43	152	1882	325	1412	497	941	670	471
4	1502	20	6-6	6-6	40	205	2174	435	1630	666	1087	896	543
5	1865	22	7-9	7-9	45	247	3074	535	2305	823	1537	1111	768
6	2242	24	9-6	6-6	50	299	4347	645	3260	990	2174	1336	1087
7	2588	29	9-6	8-9	60	328	3260	731	2445	1135	1630	1538	815
8	2987	28	9-6	8-9	51	397	4891	858	3668	1319	2445	1779	1223
9	3347	29	9-6	9-6	60	437	6521	955	4891	1473	3260	1992	1630
10	3726	31	12-6	8-9	52	491	6521	1067	4891	1643	3260	2219	1630
11	4112	33	12-6	8-9	51	550	8694	1183	6521	1817	4347	2450	2174
12	4477	34	12-6	9-6	55	593	10868	1284	8151	1975	5434	2667	2717
13	4838	35	13-11	9-6	58	633	13177	1382	9882	2131	6588	2880	3294
14	5185	37	12-6	11-9	65	663	10143	1470	7608	2276	5072	3082	2536
15	5581	38	13-11 6-2	12-6 8-1	57	730	11294	1594	8471	2458	5647	3322	2824
16	5922	39	12-6	12-6	71	755	14491	1677	10868	2598	7245	3520	3623

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \, or \, W)$.

f'_c = 3,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 12 in. spaced at 3' - 0"

GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS
140-TON STEEL PILES

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 27 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	867	15	7- 6	4- 6	42	113	1303	247	977	381	652	516	326
3	1305	21	7- 6 2- 8	7- 2 2-11	44	172	2257	374	1693	576	1129	777	564
4	1745	21	7- 6	7- 6	41	234	2606	502	1955	771	1303	1040	652
5	2169	24	8- 9	8- 9	46	283	3686	619	2764	955	1843	1291	921
6	2607	26	10- 6	7- 6	51	342	5213	746	3909	1149	2606	1552	1303
7	3019	32	10- 6	9- 9	57	383	3909	853	2932	1323	1955	1794	977
8	3479	30	10- 6	9- 9	51	459	5864	996	4398	1534	2932	2072	1466
9	3897	32	10- 6	10- 6	61	504	7819	1108	5864	1713	3909	2318	1955
10	4335	33	13- 6	9- 9	55	563	7819	1235	5864	1907	3909	2579	1955
11	4785	35	13- 6	9- 9	54	632	10425	1371	7819	2110	5213	2850	2606
12	5220	37	13- 6	10- 6	55	689	13031	1496	9774	2302	6516	3109	3258
13	5645	38	14-11	10- 6	57	739	15800	1613	11850	2487	7900	3360	3950
14	6031	39	13- 6	12- 9	70	760	12163	1701	9122	2642	6081	3582	3041

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E\ or\ W)$.

f'_c = 3,000 psi

f_y = 60 ksi

Minimum Pile Diameter = 15 in. spaced at 3' - 9"

GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS

160-TON STEEL PILES

Minimum cover = 3 in.

d_c = 10 in.

Edge E = 27 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	988	16	8-3	4-6	48	127	1570	280	1177	434	785	587	392
3	1486	22	8-3	7-9	49	193	2719	423	2039	654	1359	884	680
			2-9	2-11									
4	1985	23	8-3	8-3	46	260	3140	567	2355	874	1570	1182	785
5	2461	25	9-10	9-10	51	310	4440	694	3330	1078	2220	1462	1110
6	2959	28	12-0	8-3	57	376	6279	837	4709	1298	3140	1758	1570
7	3407	33	12-0	11-0	67	405	4709	942	3532	1480	2355	2018	1177
8	3937	32	12-0	11-0	60	495	7064	1110	5298	1724	3532	2338	1766
9	4409	34	12-0	12-0	69	542	9419	1233	7064	1924	4709	2616	2355
10	4912	36	15-9	11-0	60	612	9419	1380	7064	2148	4709	2916	2355
11	5413	37	15-9	11-0	63	681	12558	1525	9419	2370	6279	3215	3140
12	5886	39	15-9	12-0	68	728	15698	1650	11774	2571	7849	3493	3925

f'_c = 3,000 psi

f_y = 60 ksi

Minimum Pile Diameter = 15 in. spaced at 3' - 9"

GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS

180-TON STEEL PILES

Minimum cover = 3 in.

d_c = 10 in.

Edge E = 27 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	1114	17	8-3	4-6	51	144	1766	317	1325	490	883	663	442
3	1677	24	8-3	7-9	50	221	3059	480	2294	739	1529	999	765
			2-9	2-11									
4	2240	24	8-3	8-3	47	298	3532	643	2649	989	1766	1334	883
5	2777	27	9-10	9-10	53	355	4995	787	3746	1219	2498	1651	1249
6	3339	29	12-0	8-3	59	431	7064	949	5298	1467	3532	1986	1766
7	3844	35	12-0	11-0	71	464	5298	1069	3974	1673	2649	2278	1325
8	4449	34	12-0	11-0	60	572	7947	1263	5960	1954	3974	2646	1987
9	4979	36	12-0	12-0	71	624	10596	1401	7947	2179	5298	2957	2649
10	5548	38	15-9	11-0	61	705	10596	1569	7947	2433	5298	3297	2649

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 3,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 15 in. spaced at 3' - 9"

GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS
200-TON STEEL PILES

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 27 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	1239	18	8-3	4-6	54	161	1962	353	1472	545	981	737	491
3	1868	25	8-3	7-9	51	249	3399	537	2549	825	1699	1113	850
			2-9	2-11									
4	2494	25	8-3	8-3	48	335	3925	719	2943	1103	1962	1487	981
5	3095	28	9-10	9-10	54	401	5550	881	4163	1361	2775	1841	1388
6	3723	31	12-0	8-3	59	488	7849	1064	5887	1640	3925	2216	1962
7	4295	37	12-0	11-0	70	533	5887	1205	4415	1877	2943	2549	1472
8	4961	36	12-0	11-0	60	649	8830	1417	6623	2185	4415	2953	2208
9	5552	38	12-0	12-0	72	708	11774	1572	8830	2436	5887	3300	2943
10	6178	40	15-9	11-0	64	793	11774	1754	8830	2714	5887	3674	2943

f'_c = 3,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 18 in. spaced at 4' - 6"

GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS
240-TON STEEL PILES
Note: Special Detailing Required for High Load Piling

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 30 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	1480	20	9-6	5-0	58	188	3260	419	2445	649	1630	880	815
3	2227	27	9-6	8-12	57	288	5647	633	4235	979	2824	1325	1412
			3-0	3-3									
4	2976	28	9-6	9-6	53	389	6521	850	4891	1310	3260	1771	1630
5	3683	31	11-5	11-5	60	458	9222	1034	6916	1610	4611	2186	2305
6	4429	34	14-0	9-6	67	557	13042	1248	9781	1939	6521	2631	3260
7	5092	41	14-0	12-10	79	593	9781	1400	7336	2206	4891	3013	2445
8	5888	39	14-0	12-10	71	730	14672	1651	11004	2573	7336	3494	3668
9	6590	41	14-0	14-0	82	795	19562	1832	14672	2869	9781	3906	4891
10	7347	43	18-6	12-10	70	902	19562	2054	14672	3206	9781	4358	4891

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 3,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 18 in. spaced at 4' - 6"

GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS

280-TON STEEL PILES

Note: Special Detailing Required for High Load Piling

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 30 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	1730	21	9-6	5-0	65	222	3804	491	2853	760	1902	1029	951
3	2610	29	9-6 3-0	8-12 3-3	58	345	6588	748	4941	1151	3294	1554	1647
4	3486	30	9-6	9-6	54	464	7608	1002	5706	1539	3804	2077	1902
5	4318	33	11-5	11-5	62	551	10759	1223	8069	1895	5379	2567	2690
6	5195	37	14-0	9-6	68	671	15215	1477	11411	2283	7608	3090	3804
7	5980	44	14-0	12-10	81	722	11411	1663	8558	2603	5706	3544	2853
8	6916	42	14-0	12-10	70	886	17117	1961	12838	3037	8558	4112	4279
9	7734	44	14-0	14-0	84	962	22823	2172	17117	3381	11411	4591	5706
10	8613	47	18-6	12-10	73	1084	22823	2428	17117	3772	11411	5116	5706

f'_c = 3,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 20 in. spaced at 5' - 0"

GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS

320-TON STEEL PILES

Note: Special Detailing Required for High Load Piling

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 36 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	1964	23	11-0	6-0	63	244	4830	551	3623	859	2415	1166	1208
3	2958	31	11-0 3-6	10-5 3-10	63	375	8366	836	6275	1297	4183	1758	2092
4	3955	32	11-0	11-0	58	509	9660	1123	7245	1737	4830	2352	2415
5	4890	35	13-1	13-1	67	596	13662	1364	10246	2132	6831	2900	3415
6	5887	39	16-0	11-0	73	729	19321	1650	14491	2572	9660	3494	4830
7	6745	47	16-0	14-8	90	758	14491	1833	10868	2908	7245	3984	3623
8	7840	45	16-0	14-8	75	965	21736	2194	16302	3422	10868	4651	5434
9	8750	47	16-0	16-0	91	1033	28981	2415	21736	3798	14491	5180	7245
10	9765	50	21-0	14-8	77	1180	28981	2716	21736	4252	14491	5788	7245

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 3,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 20 in. spaced at 5' - 0"

GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS

360-TON STEEL PILES

Note: Special Detailing Required for High Load Piling

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 36 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	2212	24	11-0	6-0	69	277	5434	622	4075	968	2717	1313	1358
3	3341	33	11-0	10-5	64	432	9412	951	7059	1469	4706	1987	2353
			3-6	3-10									
4	4465	34	11-0	11-0	59	584	10868	1275	8151	1966	5434	2658	2717
5	5527	38	13-1	13-1	68	689	15370	1553	11527	2417	7685	3281	3842
6	6648	41	16-0	11-0	75	839	21736	1876	16302	2912	10868	3949	5434
7	7655	50	16-0	14-8	87	903	16302	2112	12226	3322	8151	4532	4075
8	8864	48	16-0	14-8	75	1118	24453	2501	18340	3883	12226	5266	6113
9	9891	50	16-0	16-0	93	1197	32604	2753	24453	4308	16302	5863	8151
10	11014	53	21-0	14-8	82	1349	32604	3077	24453	4805	16302	6533	8151

f'_c = 3,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 20 in. spaced at 5' - 0"

GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS

400-TON STEEL PILES

Note: Special Detailing Required for High Load Piling

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 36 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	2461	25	11-0	6-0	75	310	6038	694	4528	1078	3019	1462	1509
3	3725	35	11-0	10-5	64	490	10458	1066	7843	1642	5229	2218	2614
			3-6	3-10									
4	4977	36	11-0	11-0	59	661	12075	1429	9057	2197	6038	2965	3019
5	6163	40	13-1	13-1	69	782	17077	1742	12808	2702	8539	3662	4269
6	7416	44	16-0	11-0	75	954	24151	2106	18113	3258	12075	4410	6038
7	8565	53	16-0	14-8	84	1048	18113	2392	13585	3736	9057	5080	4528
8	9883	50	16-0	14-8	76	1268	27170	2804	20377	4340	13585	5876	6792
9	11038	53	16-0	16-0	94	1367	36226	3095	27170	4823	18113	6551	9057
10	12301	56	21-0	14-8	81	1546	36226	3466	27170	5386	18113	7306	9057

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \, or \, W)$.

f'_c = 4,000 psi | **GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS** | Minimum cover = 3 in.

f_y = 60 ksi | **40-TON STEEL PILES** | d_c = 10 in.

Minimum Pile Diameter = 8 in. spaced at 3' - 0" | Edge E = 15 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	246	10	5-6	2-6	33	31	362	69	272	108	181	146	91
3	371	11	5-6 1-6	5-2 1-7	30	48	627	105	471	163	314	221	157
4	494	12	5-6	5-6	29	63	725	140	543	217	362	294	181
5	609	13	6-9	6-9	34	73	1025	169	768	265	512	361	256
6	727	14	8-6	5-6	43	84	1449	200	1087	315	725	430	362
7	848	17	8-6	7-9	36	98	1087	233	815	367	543	502	272
8	973	16	8-6	7-9	38	115	1630	269	1223	423	815	576	408
9	1091	17	8-6	8-6	42	127	2174	300	1630	473	1087	645	543
10	1206	18	11-6	7-9	41	137	2174	329	1630	521	1087	713	543
11	1336	19	11-6	7-9	40	157	2898	368	2174	580	1449	791	725
12	1451	20	11-6	8-6	43	167	3623	397	2717	627	1811	858	906
13	1552	20	12-11	8-6	51	166	4392	415	3294	665	2196	914	1098
14	1695	21	11-6	10-9	39	196	3381	465	2536	734	1691	1002	845
15	1798	22	12-11 5-11	11-6 7-6	45	197	3765	485	2824	773	1882	1061	941
16	1936	23	11-6	11-6	42	223	4830	530	3623	838	2415	1145	1208
17	2046	23	12-11 5-11	11-6 7-6	48	229	5020	555	3765	882	2510	1208	1255
18	2158	24	12-11	11-6	49	236	5961	582	4471	927	2980	1273	1490
19	2273	24	13-9	11-6	50	246	6575	610	4931	975	3287	1340	1644
20	2379	25	14-6	11-6	54	248	7245	632	5434	1016	3623	1400	1811
21	2506	26	13-9 11-0	13-9 3-5	52	267	6771	670	5078	1073	3386	1476	1693
22	2635	26	14-6 10-6	12-11 5-11	52	287	6340	709	4755	1131	3170	1554	1585
23	2743	27	14-6 10-6	13-9 6-9	54	291	7245	732	5434	1174	3623	1616	1811
24	2864	27	14-6	13-9	52	305	8151	766	6113	1226	4075	1687	2038
26	3098	28	15-11 8-11	14-6 10-6	53	327	9817	826	7363	1325	4909	1824	2454
28	3316	29	15-11	14-6	58	337	10912	874	8184	1412	5456	1949	2728
30	3540	30	17-6	14-6	59	351	12679	927	9509	1503	6340	2079	3170

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E\ or\ W)$.

f'_c = 4,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 8 in. spaced at 3' - 0"

GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS
50-TON STEEL PILES

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 15 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	310	10	5-6	2-6	35	41	453	89	340	137	226	185	113
3	466	13	5-6	5-2	31	62	784	134	588	206	392	278	196
			1-6	1-7									
4	620	13	5-6	5-6	32	81	906	177	679	273	453	369	226
5	768	14	6-9	6-9	35	96	1281	216	961	336	640	456	320
6	918	16	8-6	5-6	44	113	1811	257	1358	401	906	545	453
7	1068	19	8-6	7-9	39	129	1358	297	1019	465	679	633	340
8	1225	18	8-6	7-9	41	151	2038	343	1528	535	1019	727	509
9	1377	19	8-6	8-6	43	169	2717	385	2038	601	1358	817	679
10	1528	20	11-6	7-9	40	186	2717	426	2038	666	1358	906	679
11	1681	21	11-6	7-9	44	205	3623	469	2717	733	1811	997	906
12	1816	22	11-6	8-6	53	210	4528	498	3396	786	2264	1074	1132
13	1968	23	12-11	8-6	51	228	5490	540	4118	852	2745	1164	1373
14	2136	24	11-6	10-9	42	258	4226	594	3170	930	2113	1266	1057
15	2265	24	12-11	11-6	50	259	4706	619	3529	979	2353	1339	1176
			5-11	7-6									
16	2422	25	11-6	11-6	52	281	6038	665	4528	1049	3019	1433	1509
17	2580	26	12-11	11-6	52	303	6275	711	4706	1119	3137	1527	1569
			5-11	7-6									
18	2725	27	12-11	11-6	52	316	7451	748	5588	1180	3726	1612	1863
19	2875	27	13-9	11-6	52	332	8218	788	6164	1244	4109	1700	2055
20	3016	28	14-6	11-6	55	342	9057	822	6792	1302	4528	1782	2264
21	3160	29	13-9	13-9	57	354	8464	858	6348	1362	4232	1866	2116
			11-0	3-5									
22	3332	29	14-6	12-11	54	387	7925	915	5943	1443	3962	1971	1981
			10-6	5-11									
23	3461	30	14-6	13-9	59	388	9057	940	6792	1492	4528	2044	2264
			10-6	6-9									
24	3616	31	14-6	13-9	56	408	10189	984	7642	1560	5094	2136	2547
26	3904	32	15-11	14-6	59	432	12272	1056	9204	1680	6136	2304	3068
			8-11	10-6									
28	4212	33	15-11	14-6	58	471	13639	1143	10230	1815	6820	2487	3410
30	4495	34	17-6	14-6	60	491	15849	1211	11887	1931	7925	2651	3962

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 4,000 psi

GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS

Minimum cover = 3 in.

f_y = 60 ksi

60-TON STEEL PILES

d_c = 10 in.

Minimum Pile Diameter = 8 in. spaced at 3' - 0"

Edge E = 15 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	373	10	5-6	2-6	40	49	543	107	408	165	272	222	136
3	562	14	5-6 1-6	5-2 1-7	33	76	941	162	706	249	471	335	235
4	747	14	5-6	5-6	34	99	1087	215	815	330	543	445	272
5	928	16	6-9	6-9	35	120	1537	264	1153	408	768	552	384
6	1109	17	8-6	5-6	45	141	2174	313	1630	486	1087	659	543
7	1288	21	8-6	7-9	42	160	1630	361	1223	563	815	764	408
8	1483	20	8-6	7-9	40	191	2445	421	1834	651	1223	882	611
9	1665	21	8-6	8-6	43	212	3260	471	2445	730	1630	990	815
10	1845	22	11-6	7-9	42	232	3260	520	2445	808	1630	1096	815
11	2028	23	11-6	7-9	47	254	4347	571	3260	887	2174	1204	1087
12	2194	24	11-6	8-6	56	263	5434	609	4075	954	2717	1300	1358
13	2362	25	12-11	8-6	61	274	6588	648	4941	1023	3294	1397	1647
14	2571	26	11-6	10-9	47	315	5072	719	3804	1122	2536	1525	1268
15	2740	27	12-11 5-11	11-6 7-6	52	327	5647	759	4235	1191	2824	1623	1412
16	2929	28	11-6	11-6	54	354	7245	814	5434	1275	3623	1736	1811
17	3107	28	12-11 5-11	11-6 7-6	58	372	7530	861	5647	1351	3765	1841	1882
18	3277	29	12-11	11-6	60	384	8941	903	6706	1421	4471	1939	2235
19	3458	30	13-9	11-6	60	405	9862	952	7397	1499	4931	2046	2466
20	3643	31	14-6	11-6	59	428	10868	1004	8151	1580	5434	2156	2717
21	3829	31	13-9 11-0	13-9 3-5	58	453	10157	1057	7618	1662	5078	2267	2539
22	4016	32	14-6 10-6	12-11 5-11	60	478	9509	1111	7132	1745	4755	2378	2377
23	4189	33	14-6 10-6	13-9 6-9	61	492	10868	1155	8151	1817	5434	2479	2717
24	4372	34	14-6	13-9	59	514	12226	1205	9170	1897	6113	2588	3057
26	4714	35	15-11 8-11	14-6 10-6	64	540	14726	1289	11045	2038	7363	2787	3682
28	5085	36	15-11	14-6	63	588	16367	1395	12276	2201	8184	3007	4092
30	5425	37	17-6	14-6	66	613	19019	1477	14264	2341	9509	3205	4755

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E\ or\ W)$.

$f_c' = 4{,}000$ psi			**GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS**										Minimum cover = 3 in.
$f_y = 60$ ksi			**80-TON STEEL PILES**										$d_c = 10$ in.
Minimum Pile Diameter = 10 in. spaced at 3' - 0"													Edge $E = 21$ in.
PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	495	12	6-6	3-6	36	64	725	141	543	218	362	294	181
3	744	16	6-6 2-1	6-2 2-3	37	97	1255	212	941	328	627	443	314
4	992	16	6-6	6-6	37	130	1449	283	1087	437	725	590	362
5	1235	18	7-9	7-9	37	158	2049	350	1537	542	1025	734	512
6	1480	20	9-6	6-6	45	188	2898	419	2174	649	1449	880	725
7	1713	24	9-6	8-9	47	210	2174	478	1630	747	1087	1016	543
8	1978	23	9-6	8-9	42	255	3260	562	2445	869	1630	1176	815
9	2217	24	9-6	9-6	48	280	4347	626	3260	972	2174	1317	1087
10	2455	25	12-6	8-9	48	305	4347	689	3260	1073	2174	1457	1087
11	2700	26	12-6	8-9	53	335	5796	758	4347	1180	2898	1603	1449
12	2943	28	12-6	9-6	54	364	7245	825	5434	1286	3623	1746	1811
13	3166	29	13-11	9-6	61	378	8784	877	6588	1376	4392	1875	2196
14	3434	30	12-6	11-9	51	425	6762	963	5072	1500	3381	2038	1691
15	3683	31	13-11 6-2	12-6 8-1	50	458	7530	1034	5647	1610	3765	2186	1882
16	3924	32	12-6	12-6	55	485	9660	1100	7245	1714	4830	2329	2415
17	4166	33	13-11 6-2	12-6 8-1	59	513	10039	1166	7530	1819	5020	2472	2510
18	4402	34	13-11	12-6	59	537	11922	1228	8941	1919	5961	2610	2980
19	4631	35	14-9	12-6	63	555	13149	1284	9862	2014	6575	2744	3287
20	4856	35	15-6	12-6	68	570	14491	1338	10868	2106	7245	2874	3623
21	5122	36	14-9 11-9	14-9 3-7	63	616	13543	1422	10157	2229	6771	3035	3386
22	5401	37	15-6 11-1	13-11 6-2	58	672	12679	1516	9509	2361	6340	3206	3170
23	5621	38	15-6 11-1	14-9 7-0	63	683	14491	1566	10868	2449	7245	3333	3623
24	5865	39	15-6	14-9	61	712	16302	1634	12226	2556	8151	3477	4075

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 4,000 psi **GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS** Minimum cover = 3 in.

f_y = 60 ksi **100-TON STEEL PILES** d_c = 10 in.

Minimum Pile Diameter = 10 in. spaced at 3' - 0" Edge E = 21 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	622	13	6-6	3-6	39	83	906	179	679	275	453	371	226
3	934	18	6-6	6-2	40	125	1569	269	1176	413	784	557	392
			2-1	2-3									
4	1247	18	6-6	6-6	38	167	1811	359	1358	551	906	743	453
5	1551	20	7-9	7-9	40	203	2562	443	1921	683	1281	923	640
6	1863	22	9-6	6-6	46	245	3623	533	2717	821	1811	1109	906
7	2155	27	9-6	8-9	51	272	2717	608	2038	944	1358	1280	679
8	2480	25	9-6	8-9	48	324	4075	708	3057	1092	2038	1476	1019
9	2784	27	9-6	9-6	53	360	5434	792	4075	1224	2717	1656	1358
10	3088	28	12-6	8-9	51	396	5434	876	4075	1356	2717	1836	1358
11	3404	30	12-6	8-9	53	441	7245	969	5434	1497	3623	2025	1811
12	3704	31	12-6	9-6	57	474	9057	1050	6792	1626	4528	2202	2264
13	4001	32	13-11	9-6	60	505	10981	1129	8235	1753	5490	2377	2745
14	4315	33	12-6	11-9	56	548	8453	1220	6340	1892	4226	2564	2113
15	4614	34	13-11	12-6	59	581	9412	1301	7059	2021	4706	2741	2353
			6-2	8-1									
16	4929	36	12-6	12-6	61	625	12075	1393	9057	2161	6038	2929	3019
17	5261	37	13-11	12-6	57	682	12549	1498	9412	2314	6275	3130	3137
			6-2	8-1									
18	5561	38	13-11	12-6	57	715	14902	1579	11177	2443	7451	3307	3726
19	5855	39	14-9	12-6	61	743	16437	1655	12328	2567	8218	3479	4109
20	6144	40	15-6	12-6	66	768	18113	1728	13585	2688	9057	3648	4528

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 4,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 12 in. spaced at 3' - 0"

GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS
120-TON STEEL PILES

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 21 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	748	14	6-6	3-6	42	100	1117	215	838	331	558	446	279
3	1126	19	6-6	6-2	41	153	1935	326	1451	499	967	672	484
			2-2	2-3									
4	1503	20	6-6	6-6	39	206	2234	436	1675	666	1117	897	558
5	1868	22	7-9	7-9	43	249	3159	537	2369	825	1580	1113	790
6	2244	24	9-6	6-6	48	301	4468	646	3351	992	2234	1337	1117
7	2596	29	9-6	8-9	55	334	3351	737	2513	1141	1675	1544	838
8	2988	28	9-6	8-9	50	398	5026	859	3770	1319	2513	1780	1257
9	3353	29	9-6	9-6	57	441	6702	960	5026	1478	3351	1996	1675
10	3732	31	12-6	8-9	49	495	6702	1071	5026	1647	3351	2223	1675
11	4112	33	12-6	8-9	51	550	8936	1183	6702	1817	4468	2450	2234
12	4477	34	12-6	9-6	55	593	11170	1284	8377	1975	5585	2667	2792
13	4838	35	13-11	9-6	58	633	13543	1382	10157	2131	6771	2880	3386
14	5199	37	12-6	11-9	60	674	10425	1480	7819	2286	5213	3093	2606
15	5581	38	13-11	12-6	57	730	11608	1594	8706	2458	5804	3322	2902
			6-2	8-1									
16	5937	39	12-6	12-6	66	766	14893	1688	11170	2610	7447	3531	3723

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 4,000 psi | **GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS** | Minimum cover = 3 in.

f_y = 60 ksi | **140-TON STEEL PILES** | d_c = 10 in.

Minimum Pile Diameter = 12 in. spaced at 3' - 0" | Edge E = 27 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	869	15	7-6	4-6	40	114	1303	249	977	383	652	517	326
3	1307	21	7-6 2-8	7-2 2-11	42	174	2257	375	1693	577	1129	779	564
4	1747	21	7-6	7-6	40	235	2606	504	1955	773	1303	1041	652
5	2172	24	8-9	8-9	44	285	3686	621	2764	957	1843	1293	921
6	2610	26	10-6	7-6	49	345	5213	748	3909	1151	2606	1554	1303
7	3019	32	10-6	9-9	57	383	3909	853	2932	1323	1955	1794	977
8	3483	30	10-6	9-9	49	462	5864	999	4398	1537	2932	2075	1466
9	3901	32	10-6	10-6	59	507	7819	1111	5864	1716	3909	2321	1955
10	4345	33	13-6	9-9	51	571	7819	1243	5864	1915	3909	2587	1955
11	4793	35	13-6	9-9	51	638	10425	1377	7819	2116	5213	2856	2606
12	5228	37	13-6	10-6	52	695	13031	1502	9774	2308	6516	3115	3258
13	5645	38	14-11	10-6	57	739	15800	1613	11850	2487	7900	3360	3950
14	6048	39	13-6	12-9	65	773	12163	1714	9122	2654	6081	3595	3041

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \, or \, W)$.

f'_c = 4,000 psi

GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS

Minimum cover = 3 in.

f_y = 60 ksi

160-TON STEEL PILES

d_c = 10 in.

Minimum Pile Diameter = 15 in. spaced at 3' - 9"

Edge E = 27 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	989	16	8-3	4-6	46	127	1570	281	1177	435	785	588	392
3	1488	22	8-3	7-9	47	194	2719	425	2039	655	1359	886	680
			2-9	2-11									
4	1988	23	8-3	8-3	44	262	3140	569	2355	877	1570	1184	785
5	2467	25	9-10	9-10	48	314	4440	698	3330	1082	2220	1466	1110
6	2963	28	12-0	8-3	55	379	6279	840	4709	1301	3140	1761	1570
7	3420	33	12-0	11-0	62	415	4709	952	3532	1490	2355	2027	1177
8	3948	32	12-0	11-0	56	503	7064	1118	5298	1732	3532	2347	1766
9	4423	34	12-0	12-0	64	552	9419	1244	7064	1935	4709	2626	2355
10	4919	36	15-9	11-0	58	617	9419	1385	7064	2153	4709	2921	2355
11	5413	37	15-9	11-0	63	681	12558	1525	9419	2370	6279	3215	3140
12	5886	39	15-9	12-0	68	728	15698	1650	11774	2571	7849	3493	3925

f'_c = 4,000 psi

GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS

Minimum cover = 3 in.

f_y = 60 ksi

180-TON STEEL PILES

d_c = 10 in.

Minimum Pile Diameter = 15 in. spaced at 3' - 9"

Edge E = 27 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	1116	17	8-3	4-6	48	146	1766	319	1325	491	883	664	442
3	1679	24	8-3	7-9	48	222	3059	482	2294	741	1529	1000	765
			2-9	2-11									
4	2242	24	8-3	8-3	45	299	3532	645	2649	990	1766	1336	883
5	2783	27	9-10	9-10	50	359	4995	791	3746	1223	2498	1655	1249
6	3345	29	12-0	8-3	56	435	7064	954	5298	1472	3532	1990	1766
7	3860	36	12-0	11-0	65	476	5298	1081	3974	1685	2649	2290	1325
8	4454	34	12-0	11-0	58	576	7947	1267	5960	1958	3974	2649	1987
9	4991	36	12-0	12-0	67	633	10596	1410	7947	2188	5298	2966	2649
10	5559	38	15-9	11-0	58	713	10596	1577	7947	2441	5298	3305	2649

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \; or \; W)$.

f'_c = 4,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 15 in. spaced at 3' - 9"

GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS
200-TON STEEL PILES

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 27 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	1242	18	8-3	4-6	50	164	1962	356	1472	548	981	740	491
3	1870	25	8-3	7-9	49	251	3399	539	2549	827	1699	1115	850
			2-9	2-11									
4	2497	25	8-3	8-3	46	337	3925	721	2943	1105	1962	1489	981
5	3099	28	9-10	9-10	52	404	5550	884	4163	1364	2775	1844	1388
6	3727	31	12-0	8-3	57	491	7849	1067	5887	1643	3925	2219	1962
7	4297	37	12-0	11-0	69	535	5887	1207	4415	1879	2943	2551	1472
8	4966	36	12-0	11-0	58	653	8830	1421	6623	2189	4415	2957	2208
9	5561	38	12-0	12-0	69	715	11774	1579	8830	2443	5887	3307	2943
10	6195	40	15-9	11-0	59	806	11774	1766	8830	2726	5887	3686	2943

f'_c = 4,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 18 in. spaced at 4' - 6"

GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS
240-TON STEEL PILES
Note: Special Detailing Required for High Load Piling

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 30 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	1483	20	9-6	5-0	55	191	3260	421	2445	651	1630	882	815
3	2231	27	9-6	8-12	54	291	5647	636	4235	982	2824	1328	1412
			3-0	3-3									
4	2979	28	9-6	9-6	51	391	6521	852	4891	1313	3260	1773	1630
5	3694	31	11-5	11-5	56	466	9222	1043	6916	1619	4611	2195	2305
6	4437	34	14-0	9-6	64	563	13042	1254	9781	1945	6521	2637	3260
7	5110	41	14-0	12-10	74	607	9781	1413	7336	2220	4891	3026	2445
8	5906	39	14-0	12-10	66	743	14672	1665	11004	2586	7336	3508	3668
9	6614	41	14-0	14-0	76	813	19562	1850	14672	2887	9781	3924	4891
10	7361	43	18-6	12-10	67	913	19562	2065	14672	3217	9781	4369	4891

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 4,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 18 in. spaced at 4' - 6"

GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS

280-TON STEEL PILES

Note: Special Detailing Required for High Load Piling

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 30 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	1735	21	9-6	5-0	59	226	3804	495	2853	764	1902	1032	951
3	2613	29	9-6	8-12	56	347	6588	750	4941	1153	3294	1557	1647
			3-0	3-3									
4	3490	30	9-6	9-6	52	467	7608	1005	5706	1542	3804	2080	1902
5	4323	33	11-5	11-5	60	554	10759	1226	8069	1898	5379	2570	2690
6	5203	37	14-0	9-6	65	677	15215	1483	11411	2289	7608	3096	3804
7	5988	44	14-0	12-10	79	728	11411	1669	8558	2609	5706	3550	2853
8	6923	42	14-0	12-10	68	891	17117	1967	12838	3042	8558	4117	4279
9	7750	45	14-0	14-0	80	974	22823	2184	17117	3393	11411	4603	5706
10	8637	47	18-6	12-10	68	1102	22823	2446	17117	3790	11411	5134	5706

f'_c = 4,000 psi
f_y = 60 ksi
Minimum Pile Diameter = 20 in. spaced at 5' - 0"

GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS

320-TON STEEL PILES

Note: Special Detailing Required for High Load Piling

Minimum cover = 3 in.
d_c = 10 in.
Edge E = 36 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	1970	23	11-0	6-0	59	249	4830	556	3623	863	2415	1170	1208
3	2964	31	11-0	10-5	60	380	8366	841	6275	1301	4183	1762	2092
			3-6	3-10									
4	3960	32	11-0	11-0	56	512	9660	1127	7245	1741	4830	2356	2415
5	4904	36	13-1	13-1	63	606	13662	1374	10246	2142	6831	2910	3415
6	5897	39	16-0	11-0	70	736	19321	1658	14491	2580	9660	3501	4830
7	6778	47	16-0	14-8	83	783	14491	1858	10868	2933	7245	4008	3623
8	7844	45	16-0	14-8	74	968	21736	2197	16302	3425	10868	4654	5434
9	8775	47	16-0	16-0	86	1052	28981	2434	21736	3816	14491	5199	7245
10	9790	50	21-0	14-8	73	1199	28981	2735	21736	4271	14491	5807	7245

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

f'_c = 4,000 psi

f_y = 60 ksi

Minimum Pile Diameter = 20 in. spaced at 5' - 0"

GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS

360-TON STEEL PILES

Note: Special Detailing Required for High Load Piling

Minimum cover = 3 in.

d_c = 10 in.

Edge E = 36 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	2222	24	11-0	6-0	62	284	5434	630	4075	975	2717	1321	1358
3	3346	33	11-0	10-5	61	436	9412	954	7059	1473	4706	1991	2353
			3-6	3-10									
4	4472	34	11-0	11-0	56	589	10868	1280	8151	1972	5434	2663	2717
5	5537	38	13-1	13-1	65	697	15370	1561	11527	2425	7685	3289	3842
6	6658	41	16-0	11-0	72	846	21736	1883	16302	2920	10868	3957	5434
7	7655	50	16-0	14-8	87	903	16302	2112	12226	3322	8151	4532	4075
8	8878	48	16-0	14-8	72	1129	24453	2511	18340	3894	12226	5276	6113
9	9917	50	16-0	16-0	88	1217	32604	2772	24453	4327	16302	5883	8151
10	11058	53	21-0	14-8	75	1382	32604	3110	24453	4838	16302	6566	8151

f'_c = 4,000 psi

f_y = 60 ksi

Minimum Pile Diameter = 20 in. spaced at 5' - 0"

GRAVITY AND LATERAL LOADS, BENDING ABOUT Y AXIS

400-TON STEEL PILES

Note: Special Detailing Required for High Load Piling

Minimum cover = 3 in.

d_c = 10 in.

Edge E = 36 in.

PILES*	COLUMN*		PILE CAP*			FACTORED COLUMN FORCES & ACCEPTABLE FACTORED MOMENT M_{uy} **							
Number of Piles	Max. Load P_u (net)	Min. Size	Long A	Short B	D	20% Axial P_u (net)	Available Moment M_{uy}	40% Axial P_u (net)	Available Moment M_{uy}	60% Axial P_u (net)	Available Moment M_{uy}	80% Axial P_u (net)	Available Moment M_{uy}
per cap	(kips)	(in.)	(ft - in.)	(ft - in.)	(in.)	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft	(kips)	k-ft
2	2471	25	11-0	6-0	67	317	6038	701	4528	1085	3019	1469	1509
3	3730	35	11-0	10-5	61	494	10458	1070	7843	1646	5229	2222	2614
			3-6	3-10									
4	4982	36	11-0	11-0	57	665	12075	1433	9057	2201	6038	2969	3019
5	6174	40	13-1	13-1	66	790	17077	1751	12808	2711	8539	3671	4269
6	7426	44	16-0	11-0	72	962	24151	2114	18113	3266	12075	4418	6038
7	8565	53	16-0	14-8	84	1048	18113	2392	13585	3736	9057	5080	4528
8	9897	50	16-0	14-8	73	1279	27170	2815	20377	4351	13585	5887	6792
9	11059	53	16-0	16-0	90	1382	36226	3110	27170	4838	18113	6566	9057
10	12313	56	21-0	14-8	79	1555	36226	3475	27170	5395	18113	7315	9057

* Piles, column, and pile cap properties are identical to those tabulated in Chapter 5 for axial load alone. Note that column maximum load P_u is based on $1.6(D + L)$.

** Note that combinations of factored column axial load and applied moment are based on $1.0(D + L) + 0.53(E \text{ or } W)$.

Appendix A

Derivations and Proofs

APPENDIX A
Derivations and Proofs

A.1 General

Appendix A has been reserved as a special section and it contains derivations and proofs of equations and table values that may help the reader obtain a better understanding of the theory behind the design provisions utilized in this guide.

A.2 Cap Stiffness Derivations Utilized in Chapter 6

Chapter 6 of this design guide utilizes table values for the pile cap moment of inertia and the maximum demand on critical piles for all 26 pile cap configurations (see Tables 6.1 and 6.2). Derivations of the expressions are presented below. Note that the tabulated expressions use decimal equivalents of the fractions shown below.

Two Pile Cap

Horizontal Pile Spacing $= L$

$$I_y = 2\left(\frac{L}{2}\right)^2 = \frac{L^2}{2}$$

$$\text{Maximum Force in Pile via Bending} = \frac{M_y\left(\frac{L}{2}\right)}{\frac{L^2}{2}} = \frac{M_y}{L}$$

Three Pile Cap

Vertical Pile Spacing $= \dfrac{\sqrt{3}L}{2}$

$$I_x = 2\left(\frac{\sqrt{3}L}{2(3)}\right)^2 + 1\left(\frac{2\sqrt{3}L}{2(3)}\right)^2 = \frac{L^2}{2}$$

$$\text{Maximum Force in Pile via Bending} = \frac{M_x\left(\frac{2}{3}\,\frac{\sqrt{3}L}{2}\right)}{\frac{L^2}{2}} = \frac{2\sqrt{3}M_x}{3L}$$

$$\text{Minimum Force in Pile via Bending} = \frac{M_x\left(\frac{1}{3}\,\frac{\sqrt{3}L}{2}\right)}{\frac{L^2}{2}} = \frac{1\sqrt{3}M_x}{3L}$$

Horizontal Pile Spacing $= L$

$$I_y = 2\left(\frac{L}{2}\right)^2 = \frac{L^2}{2}$$

$$\text{Maximum Force in Pile via Bending} = \frac{M_y\left(\frac{L}{2}\right)}{\frac{L^2}{2}} = \frac{M_y}{L}$$

Four Pile Cap

Vertical Pile Spacing $= L$

$$I_x = 4\left(\frac{L}{2}\right)^2 = L^2$$

$$\text{Maximum Force in Pile via Bending} = \frac{M_x\left(\frac{L}{2}\right)}{L^2} = \frac{M_x}{2L}$$

Horizontal Pile Spacing $= L$

$$I_y = 4\left(\frac{L}{2}\right)^2 = L^2$$

$$\text{Maximum Force in Pile via Bending} = \frac{M_y\left(\frac{L}{2}\right)}{L^2} = \frac{M_y}{2L}$$

Five Pile Cap

Vertical Pile Spacing $= \dfrac{\sqrt{2}L}{2}$

$$I_x = 4\left(\frac{\sqrt{2}L}{2}\right)^2 = 2L^2$$

$$\text{Maximum Force in Pile via Bending} = \frac{M_x\left(\frac{\sqrt{2}L}{2}\right)}{2L^2} = \frac{M_x\sqrt{2}}{4L}$$

Horizontal Pile Spacing $= \dfrac{\sqrt{2}L}{2}$

$$I_y = 4\left(\frac{\sqrt{2}L}{2}\right)^2 = 2L^2$$

$$\text{Maximum Force in Pile via Bending} = \frac{M_y\left(\frac{\sqrt{2}L}{2}\right)}{2L^2} = \frac{M_y\sqrt{2}}{4L}$$

Six Pile Cap

Vertical Pile Spacing $= L$

$$I_x = 6\left(\frac{L}{2}\right)^2 = \frac{3L^2}{2}$$

$$\text{Maximum Force in Pile via Bending} = \frac{M_x\left(\frac{L}{2}\right)}{\frac{3L^2}{2}} = \frac{M_x}{3L}$$

Horizontal Pile Spacing $= L$

$$I_y = 4L^2$$

$$\text{Maximum Force in Pile via Bending} = \frac{M_yL}{4L^2} = \frac{M_y}{4L}$$

Seven Pile Cap

Vertical Pile Spacing $= \dfrac{\sqrt{3}L}{2}$

$$I_x = 4\left(\frac{\sqrt{3}L}{2}\right)^2 = 3L^2$$

Maximum Force in Pile via Bending = $\dfrac{M_x\dfrac{\sqrt{3}L}{2}}{3L^2} = \dfrac{\sqrt{3}M_x}{6L}$

Horizontal Pile Spacing = $\dfrac{L}{2}$

$$I_y = 4\left(\frac{L}{2}\right)^2 + 2L^2 = 3L^2$$

Maximum Force in Pile via Bending = $\dfrac{M_y}{3L}$

Eight Pile Cap

Vertical Pile Spacing = $\dfrac{\sqrt{3}L}{2}$

$$I_x = 6\left(\frac{\sqrt{3}L}{2}\right)^2 = \frac{9L^2}{2}$$

Maximum Force in Pile via Bending = $\dfrac{M_x\dfrac{\sqrt{3}L}{2}}{\dfrac{9L^2}{2}} = \dfrac{\sqrt{3}M_x}{9L}$

Horizontal Pile Spacing = $\dfrac{L}{2}$

$$I_y = 2\left(\frac{L}{2}\right)^2 + 4L^2 = \frac{9L^2}{2}$$

Maximum Force in Pile via Bending = $\dfrac{M_yL}{\dfrac{9L^2}{2}} = \dfrac{2M_y}{9L}$

Nine Pile Cap

Vertical Pile Spacing = L

$I_x = 6L^2$

Maximum Force in Pile via Bending = $\dfrac{M_xL}{6L^2} = \dfrac{M_x}{6L}$

Horizontal Pile Spacing = L

$I_y = 6L^2$

Maximum Force in Pile via Bending = $\dfrac{M_yL}{6L^2} = \dfrac{M_y}{6L}$

Ten Pile Cap

Vertical Pile Spacing = $\dfrac{\sqrt{3}L}{2}$

$$I_x = 6\left(\frac{\sqrt{3}L}{2}\right)^2 = \frac{9L^2}{2}$$

Maximum Force in Pile via Bending = $\dfrac{M_x\dfrac{\sqrt{3}L}{2}}{\dfrac{9L^2}{2}} = \dfrac{\sqrt{3}M_x}{9L}$

Horizontal Pile Spacing = $\dfrac{L}{2}$

$$I_y = 2\left(\frac{L}{2}\right)^2 + 4L^2 + 2\left(\frac{3L}{2}\right)^2 = 9L^2$$

Maximum Force in Pile via Bending = $\dfrac{M_y\dfrac{3L}{2}}{9L^2} = \dfrac{M_y}{6L}$

Eleven Pile Cap

Vertical Pile Spacing = $\dfrac{\sqrt{3}L}{2}$

$$I_x = 8\left(\frac{\sqrt{3}L}{2}\right)^2 = 6L^2$$

Maximum Force in Pile via Bending = $\dfrac{M_x\dfrac{\sqrt{3}L}{2}}{6L^2} = \dfrac{\sqrt{3}M_x}{12L}$

Horizontal Pile Spacing = $\dfrac{L}{2}$

$$I_y = 4\left(\frac{L}{2}\right)^2 + 2L^2 + 4\left(\frac{3L}{2}\right)^2 = 12L^2$$

Maximum Force in Pile via Bending = $\dfrac{M_y\dfrac{3L}{2}}{12L^2} = \dfrac{M_y}{8L}$

Twelve Pile Cap

Vertical Pile Spacing = L

$I_x = 8L^2$

Maximum Force in Pile via Bending = $\dfrac{M_xL}{8L^2} = \dfrac{M_x}{8L}$

Horizontal Pile Spacing = L

$$I_y = 6\left(\frac{L}{2}\right)^2 + 6\left(\frac{3L}{2}\right)^2 = 15L^2$$

Maximum Force in Pile via Bending = $\dfrac{M_y\dfrac{3L}{2}}{15L^2} = \dfrac{M_y}{10L}$

Thirteen Pile Cap

Vertical Pile Spacing = $\dfrac{L}{2}$

$$I_x = 4\left(\frac{L}{2}\right)^2 + 6L^2 = 7L^2$$

Maximum Force in Pile via Bending = $\dfrac{M_xL}{7L^2} = \dfrac{M_x}{7L}$

Horizontal Pile Spacing = $\dfrac{\sqrt{3}L}{2}$

$$I_y = 4\left(\frac{\sqrt{3}L}{2}\right)^2 + 6\left(\sqrt{3}L\right)^2 = 21L^2$$

Maximum Force in Pile via Bending = $\dfrac{M_y\sqrt{3}L}{21L^2} = \dfrac{\sqrt{3}M_y}{21L}$

Fourteen Pile Cap

Vertical Pile Spacing 1 = L

Vertical Pile Spacing 2 = $\dfrac{\sqrt{3}L}{2}$

$$I_x = 8\left(\frac{L}{2}\right)^2 + 6\left(\frac{L}{2}+\frac{\sqrt{3}L}{2}\right)^2 = \left(3\sqrt{3}+8\right)L^2 = 13.2L^2$$

Maximum Force in Pile via Bending =

$$\frac{M_x\left(\frac{L}{2}+\frac{\sqrt{3}L}{2}\right)}{\left(3\sqrt{3}+8\right)L^2} = \frac{M_x\left(5\sqrt{3}-1\right)}{74L} = \frac{0.104M_x}{L}$$

Horizontal Pile Spacing = $\dfrac{L}{2}$

$$I_y = 4\left(\frac{L}{2}\right)^2 + 4L^2 + 4\left(\frac{3L}{2}\right)^2 = 14L^2$$

Maximum Force in Pile via Bending = $\dfrac{M_y\left(\frac{3L}{2}\right)}{14L^2} = \dfrac{3M_y}{28L}$

Fifteen Pile Cap

Vertical Pile Spacing = $\dfrac{L}{2}$

$$I_x = 4\left(\frac{L}{2}\right)^2 + 6L^2 + 4\left(\frac{3L}{2}\right)^2 = 16L^2$$

Maximum Force in Pile via Bending = $\dfrac{M_x\left(\frac{3L}{2}\right)}{16L^2} = \dfrac{3M_x}{32L}$

Horizontal Pile Spacing = $\dfrac{\sqrt{3}L}{2}$

$$I_y = 8\left(\frac{\sqrt{3}L}{2}\right)^2 + 4\left(\sqrt{3}L\right)^2 = 18L^2$$

Maximum Force in Pile via Bending = $\dfrac{M_y\sqrt{3}L}{18L^2} = \dfrac{\sqrt{3}M_y}{18L}$

Sixteen Pile Cap

Vertical Pile Spacing = L

$$I_x = 8\left(\frac{L}{2}\right)^2 + 8\left(\frac{3L}{2}\right)^2 = 20L^2$$

Maximum Force in Pile via Bending = $\dfrac{M_x\left(\frac{3L}{2}\right)}{20L^2} = \dfrac{3M_x}{40L}$

Horizontal Pile Spacing = L

$$I_y = 8\left(\frac{L}{2}\right)^2 + 8\left(\frac{3L}{2}\right)^2 = 20L^2$$

Maximum Force in Pile via Bending = $\dfrac{M_y\left(\frac{3L}{2}\right)}{20L^2} = \dfrac{3M_y}{40L}$

Seventeen Pile Cap

Vertical Pile Spacing = $\dfrac{L}{2}$

$$I_x = 4\left(\frac{L}{2}\right)^2 + 6L^2 + 4\left(\frac{3L}{2}\right)^2 = 16L^2$$

Maximum Force in Pile via Bending = $\dfrac{M_x\left(\frac{3L}{2}\right)}{16L^2} = \dfrac{3M_x}{32L}$

Horizontal Pile Spacing = $\dfrac{\sqrt{3}L}{2}$

$$I_y = 8\left(\frac{\sqrt{3}L}{2}\right)^2 + 6\left(\sqrt{3}L\right)^2 = 24L^2$$

Maximum Force in Pile via Bending = $\dfrac{M_y\sqrt{3}L}{24L^2} = \dfrac{\sqrt{3}M_y}{24L}$

Eighteen Pile Cap

Vertical Pile Spacing = $\dfrac{L}{2}$

$$I_x = 6\left(\frac{L}{2}\right)^2 + 4L^2 + 6\left(\frac{3L}{2}\right)^2 = 19L^2$$

Maximum Force in Pile via Bending = $\dfrac{M_x\left(\frac{3L}{2}\right)}{19L^2} = \dfrac{3M_x}{38L}$

Horizontal Pile Spacing = $\dfrac{\sqrt{3}L}{2}$

$$I_y = 6\left(\frac{\sqrt{3}L}{2}\right)^2 + 8\left(\sqrt{3}L\right)^2 = \frac{57L^2}{2}$$

Maximum Force in Pile via Bending = $\dfrac{M_y\sqrt{3}L}{\frac{57L^2}{2}} = \dfrac{2\sqrt{3}M_y}{57L}$

Nineteen Pile Cap

Vertical Pile Spacing = $\dfrac{L}{2}$

$$I_x = 8\left(\frac{L}{2}\right)^2 + 2L^2 + 8\left(\frac{3L}{2}\right)^2 = 22L^2$$

Maximum Force in Pile via Bending = $\dfrac{M_x\left(\frac{3L}{2}\right)}{22L^2} = \dfrac{3M_x}{44L}$

Horizontal Pile Spacing 1 = $\dfrac{\sqrt{3}L}{2}$

Horizontal Pile Spacing 2 = L

$$I_y = 8\left(\frac{\sqrt{3}L}{2}\right)^2 + 8\left(\frac{\sqrt{3}L}{2}+L\right)^2 = \left(8\sqrt{3}+20\right)L^2 = 33.86L^2$$

Maximum Force in Pile via Bending =

$$\frac{M_y\left(\frac{\sqrt{3}L}{2}+L\right)}{\left(8\sqrt{3}+20\right)L^2}=\frac{M_y\left(\sqrt{3}+4\right)}{104L}=\frac{0.0551M_y}{L}$$

Twenty Pile Cap

Vertical Pile Spacing = L

$$I_x=10\left(\frac{L}{2}\right)^2+10\left(\frac{3L}{2}\right)^2=25L^2$$

Maximum Force in Pile via Bending = $\dfrac{M_x\left(\frac{3L}{2}\right)}{25L^2}=\dfrac{3M_x}{50L}$

Horizontal Pile Spacing = L

$I_y = 8L^2 + 8(2L)2 = 40L^2$

Maximum Force in Pile via Bending = $\dfrac{M_y(2L)}{40L^2}=\dfrac{M_y}{20L}$

Twenty-One Pile Cap

Vertical Pile Spacing 1 = $\dfrac{L}{2}$

Vertical Pile Spacing 2 = $\dfrac{\sqrt{3}L}{2}$

$$I_x=4\left(\frac{L}{2}\right)^2+6L^2+4\left(\frac{3L}{2}\right)^2+4\left(L+\frac{\sqrt{3}L}{2}\right)^2=\left(4\sqrt{3}+23\right)L^2=29.93L^2$$

Maximum Force in Pile via Bending =

$$\frac{M_x\left(L+\frac{\sqrt{3}L}{2}\right)}{\left(4\sqrt{3}+23\right)L^2}=\frac{M_x\left(15\sqrt{3}+34\right)}{962L}=\frac{0.0624M_x}{L}$$

Horizontal Pile Spacing 1 = $\dfrac{L}{2}$

Horizontal Pile Spacing 2 = $\dfrac{\sqrt{3}L}{2}$

$$I_y=4\left(\frac{L}{2}\right)^2+6L^2+8\left(L+\frac{\sqrt{3}L}{2}\right)^2=\left(8\sqrt{3}+21\right)L^2=34.86L^2$$

Maximum Force in Pile via Bending =

$$\frac{M_y\left(L+\frac{\sqrt{3}L}{2}\right)}{\left(8\sqrt{3}+21\right)L^2}=\frac{M_y\left(5\sqrt{3}+18\right)}{498L^2}=\frac{0.0535M_y}{L}$$

Twenty-Two Pile Cap

Vertical Pile Spacing = $\dfrac{\sqrt{3}L}{2}$

$$I_x=10\left(\frac{\sqrt{3}L}{2}\right)^2+8\left(\sqrt{3}L\right)^2=\frac{63L^2}{2}$$

Maximum Force in Pile via Bending = $\dfrac{M_x\left(\sqrt{3}L\right)}{\frac{63L^2}{2}}=\dfrac{2\sqrt{3}M_x}{63L}$

Horizontal Pile Spacing = $\dfrac{L}{2}$

$$I_y=6\left(\frac{L}{2}\right)^2+4L^2+6\left(\frac{3L}{2}\right)^2+4\left(2L\right)^2=35L^2$$

Maximum Force in Pile via Bending = $\dfrac{M_y(2L)}{35L^2}=\dfrac{2M_y}{35L}$

Twenty-Three Pile Cap

Vertical Pile Spacing 1 = L

Vertical Pile Spacing 2 = $\dfrac{\sqrt{3}L}{2}$

$$I_x=10L^2+8\left(L+\frac{\sqrt{3}L}{2}\right)^2=\left(8\sqrt{3}+24\right)L^2=37.86L^2$$

Maximum Force in Pile via Bending =

$$\frac{M_x\left(L+\frac{\sqrt{3}L}{2}\right)}{\left(8\sqrt{3}+24\right)L^2}=\frac{M_x\left(\sqrt{3}+3\right)}{96L}=\frac{0.0493M_x}{L}$$

Horizontal Pile Spacing = $\dfrac{L}{2}$

$$I_y=4\left(\frac{L}{2}\right)^2+6L^2+4\left(\frac{3L}{2}\right)^2+6\left(2L\right)^2=40L^2$$

Maximum Force in Pile via Bending = $\dfrac{M_y(2L)}{40L^2}=\dfrac{M_y}{20L}$

Twenty-Four Pile Cap

Vertical Pile Spacing 1 = $\dfrac{\sqrt{3}L}{2}$

Vertical Pile Spacing 2 = L

$$I_x=10\left(\frac{\sqrt{3}L}{2}\right)^2+10\left(\frac{\sqrt{3}L}{2}+L\right)^2=\left(10\sqrt{3}+25\right)L^2=42.32L^2$$

Maximum Force in Pile via Bending =

$$\frac{M_x\left(\frac{\sqrt{3}L}{2}+L\right)}{\left(10\sqrt{3}+25\right)L^2}=\frac{M_x\left(\sqrt{3}+4\right)}{130L}=\frac{0.0441M_x}{L}$$

Horizontal Pile Spacing = $\dfrac{L}{2}$

$$I_y=2\left(\frac{L}{2}\right)^2+8L^2+2\left(\frac{3L}{2}\right)^2+8\left(2L\right)^2=45L^2$$

Maximum Force in Pile via Bending = $\dfrac{M_y(2L)}{45L^2}=\dfrac{2M_y}{45L}$

Twenty-Six Pile Cap

Vertical Pile Spacing = $\frac{L}{2}$

$$I_x = 8\left(\frac{L}{2}\right)^2 + 4L^2 + 8\left(\frac{3L}{2}\right)^2 + 4(2L)^2 = 40L^2$$

Maximum Force in Pile via Bending = $\frac{M_x(2L)}{40L^2} = \frac{M_x}{20L}$

Horizontal Pile Spacing 1 = L

Horizontal Pile Spacing 2 = $\frac{\sqrt{3}L}{2}$

$$I_y = 8\left(\frac{L}{2}\right)^2 + 10\left(\frac{L}{2} + \frac{\sqrt{3}L}{2}\right)^2 + 8\left(\frac{L}{2} + \sqrt{3}L\right)^2 = \left(13\sqrt{3} + 38\right)L^2 = 60.52L^2$$

Maximum Force in Pile via Bending =

$$\frac{M_y\left(\frac{L}{2} + \sqrt{3}L\right)}{\left(13\sqrt{3} + 38\right)L^2} = \frac{M_y\left(63\sqrt{3} - 40\right)}{1874L} = \frac{0.0369M_y}{L}$$

Twenty-Eight Pile Cap

Vertical Pile Spacing = $\frac{L}{2}$

$$I_x = 4\left(\frac{L}{2}\right)^2 + 8L^2 + 4\left(\frac{3L}{2}\right)^2 + 8(2L)^2 = 50L^2$$

Maximum Force in Pile via Bending = $\frac{M_x(2L)}{50L^2} = \frac{M_x}{25L}$

Horizontal Pile Spacing 1 = L

Horizontal Pile Spacing 2 = $\frac{\sqrt{3}L}{2}$

$$I_y = 10\left(\frac{L}{2}\right)^2 + 8\left(\frac{L}{2} + \frac{\sqrt{3}L}{2}\right)^2 + 10\left(\frac{L}{2} + \sqrt{3}L\right)^2 = \left(14\sqrt{3} + 43\right)L^2 = 67.25L^2$$

Maximum Force in Pile via Bending =

$$\frac{M_y\left(\frac{L}{2} + \sqrt{3}L\right)}{\left(14\sqrt{3} + 43\right)L^2} = \frac{M_y\left(72\sqrt{3} - 41\right)}{2522L} = \frac{0.0332M_y}{L}$$

Thirty Pile Cap

Vertical Pile Spacing = L

$$I_x = 12L^2 + 12(2L)^2 = 60L^2$$

Maximum Force in Pile via Bending = $\frac{M_x(2L)}{60L^2} = \frac{M_x}{30L}$

Horizontal Pile Spacing = L

$$I_y = 10\left(\frac{L}{2}\right)^2 + 10\left(\frac{3L}{2}\right)^2 + 10\left(\frac{5L}{2}\right)^2 = \frac{175L^2}{2}$$

Maximum Force in Pile via Bending = $\frac{M_y\left(\frac{5L}{2}\right)}{\frac{175L^2}{2}} = \frac{5M_y}{175L}$

Appendix B

Column-to-Pile Cap Connections

APPENDIX B
Column-to-Pile Cap Connections

B.1 General

In Appendix B, an overview of column-to-pile cap connections is presented. In general, steel, concrete, and precast columns are all required to meet "transfer of force" provisions contained in ACI 318-14 Section 16.3. Appendix B begins with a summary of these provisions. Next, concrete, steel, and precast column connection load paths are discussed individually with reference to other relevant code provisions and standard practice. Note that sizing column-to-pile cap connections for moment, shear, and axial demands is considered outside the scope of this guide. References, which include some example problems for sizing the connections, are provided in subsequent sections of this appendix.

B.2 General Overview of ACI 318-14 Section 16.3

Chapter 4 of this design guide presents a through overview of ACI 318-14 provisions related to the design and detailing of the actual pile cap itself (i.e., Chapter 13). ACI 318-14 Section 16.3 considers the interface between the supported column and the top of the pile cap and provides all provisions necessary to detail a code compliant load path to transfer shear, moment, and axial load from the base of the column to the pile cap. When compression transfer is desired, column bearing on the concrete pile cap with or without additional mechanical transfer of compression is permitted. Force transfer via reinforcement is required to transfer both tensile forces (from direct tension or from base fixity/moment couple tension component) and shear. In these cases, reinforcement may consist of extending the column reinforcing bars into the pile cap, dowels, anchor bolts, or other mechanical connectors.

Regardless of the column type selected, bearing stress on the top of the pile cap is limited to a lower bound strength of $0.85\phi f'_c$ times the bearing area (e.g., cross sectional area of column or base plate) up to $2(0.85\phi f'_c)$ times the bearing area if the requirements of ACI 318-14 Section 22.8 are satisfied. Note that for the standard designs presented in this guide, the pile cap plan dimensions and thicknesses permit doubling the standard Whitney stress block failure stress as presented in the equation above. Designers should verify that this condition is satisfied when other unique designs are desired. Although not explicitly stated in ACI 318-14 Section 22.8, the designer should note that the commentary to ACI 318-14 Section R16.3.3.4 states that increasing the bearing area in accordance with ACI 318-14 Section 22.8 requires the use of dowels, extended longitudinal reinforcement, or other reinforcement into the pile cap to carry all demands beyond those resisted at the surface of the pile cap (i.e., all forces beyond $0.85\phi f'_c$ times the bearing area). Along these lines, ACI 318-14 Section 16.3.1.2 specifically states that steel crossing the column-to-pile cap interface must be sized to transfer all tension at the interface and compressive forces that exceed the concrete bearing strength of the pile cap at the interface (i.e., without increase per ACI 318-14 Section 22.8). When tension forces caused by bending moments at the base of the column must be resisted, reinforcement crossing the interface must be utilized, and

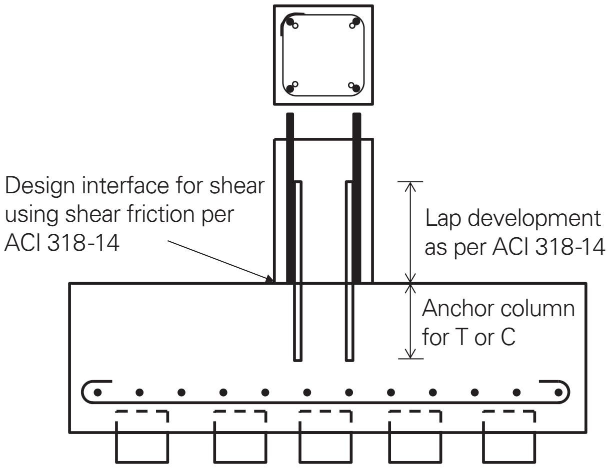


Fig. B.1 *Typical reinforced concrete column-to-pile cap connection detail.*

ACI 318-14 Section 16.3.5.2 mandates that the stringent splice requirements for columns as presented in ACI 318-14 Section 10.7.5.1 are applicable above and below the column-to-pile cap interface. Depending on the column type utilized, shear friction (ACI 318-14 Section 22.9), shear keys, shear lugs, embedded columns, or mechanical devices may be detailed for direct shear transfer across the interface. Different options are discussed in subsequent sections for the different column material types.

B.3 Cast-in-Place Column-to-Pile Cap Connections

ACI 318-14 Section 16.3.5.1 contains provisions applicable to column-to-pile cap connections when the column is constructed using cast-in-place concrete. The reinforcement detailed to cross the column-pile cap interface may consist of extended column longitudinal bars or dowels and the area of reinforcement crossing the interface must not be less than 0.005 times the gross area of the reinforced concrete column. This minimum area of steel is intended to provide some ductility at the column base and to provide some strength and stability during construction and the service life of the structure. Note that ACI does not require all column longitudinal bars to be developed or lapped with matching dowels. However, dowels or extended column longitudinal bars that do cross the interface should be appropriately anchored into the pile cap.

As a general note, ACI 318-14 Section 25.5.1.1 prohibits lapping of #14 and #18 longitudinal bars in columns. However, for pile caps receiving only axial compression from the reinforced concrete column, a special exception exists in ACI 318-14 Section 16.3.5.4 for the interface where #11 and smaller bars may be used as dowels lapping with the #14 and #18 longitudinal bars. The dowel lap splice length (i.e., dowel extension length into the column) is required to be greater than both the compressive development length of the column longitudinal bar and the compression lap splice length of the dowels. Similarly, the dowels must extend into the footing a distance not less than the compression development length of the dowels. A typical reinforced concrete column to pile-cap connection detail is shown in Fig. B.1. As shown in the Fig., longitudinal reinforcement in the column is typically lapped with matching dowels (or less reinforcement depending on demand) as necessary to transfer shear and bending moment at the interface.

Reinforced concrete column-to-pile cap connection design examples can be found in the *CRSI Design Handbook (2008)* and *PCA Notes on ACI 318-14 Building Code (2012).*

B.4 Precast Column-to-Pile Cap Connections

ACI 318-14 Section 16.3.3.6 contains provisions applicable to column-to-pile cap connections when the column is constructed using precast concrete. Anchor bolts must be designed using ACI 318-14 Chapter 17. ACI 318-14 Section 16.2.4.3 requires that the area of steel crossing the interface between the precast column and the pile cap be not less than 200 times the gross cross-sectional area (in^2) of the column divided by the yield strength (psi) of the steel or $200A_g/f_y$. Assuming 36 ksi anchor bolt steel, the area of steel required for the anchor bolts is 0.00555 times the gross cross-sectional area of the column. For comparison, and as discussed in the previous section, cast in place columns require slightly less steel crossing the interface. A typical precast concrete column to pile-cap connection detail is shown in Fig. B.2. As shown in the Fig., longitudinal reinforcement in the column is typically welded to an embed plate which then transfers shear and bending moment through anchor bolts across the interface and into the pile cap.

Precast column-to-pile cap connection design examples can be found in *PCA Notes on ACI 318-14 Building Code (2012).*

B.5 Steel Column-to-Pile Cap Connections

ACI 318-14 Section 16.3 does not contain specific column-to-pile cap connection provisions when the column is constructed using structural steel. Although the steel baseplate design is covered in detail by AISC 360, anchor bolts are typically designed using ACI 318-14 Chapter 17. No minimum total anchor bolt cross sectional area is mandated by ACI 318-14 or AISC 360 beyond that required for strength and based on load path considerations. It should be noted, however, that OSHA does require a minimum of four bolts for steel column base plate connection details. Three typical steel column to pile-cap connection details are shown in Fig.s B.3 through B.5. Fig. B.3 is the most common detail and is applicable to axial load only situations or light shear and bending applications. In this detail shear is transferred via friction or anchor bolt shear and bending moment net tensile demand is transferred through the anchor bolts across the interface and into the pile cap. Since bolt holes in baseplates are commonly oversized and washer welding is not typical, the shear transfer load path is questionable under moderate loading and Fig. B.2 with a specially detailed shear lug provides a more reliable mechanism. In cases where significant moment transfer at the column base is required, Fig. B.3 is commonly detailed. The stiffener plates allow for an economical base plate thickness and reduced bolt prying forces. Shear must still be considered in these applications.

Steel column-to-pile cap connection design examples can be found in *PCA Notes on ACI 318-14 Building Code (2012) and AISC Design Guide 1: Base Plate and Anchor Rod Design (2006).*

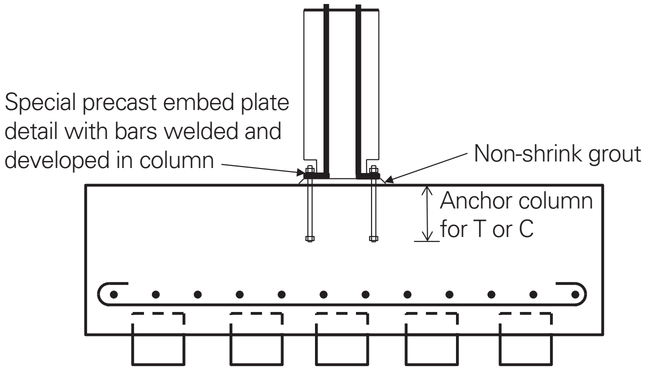


Fig. B.2 Typical precast concrete column-to-pile cap connection detail.

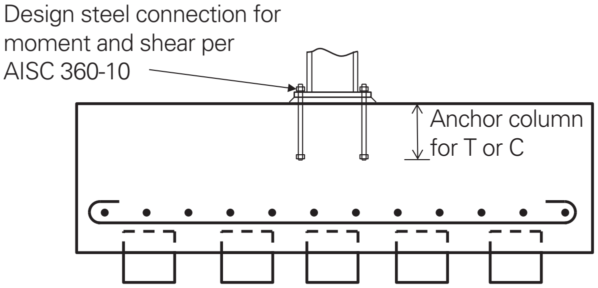


Fig. B.3 Typical steel column-to-pile cap connection detail.

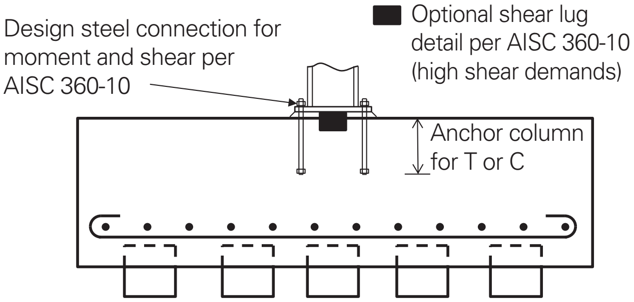


Fig. B.4 Typical steel column-to-pile cap connection detail (high shear demand).

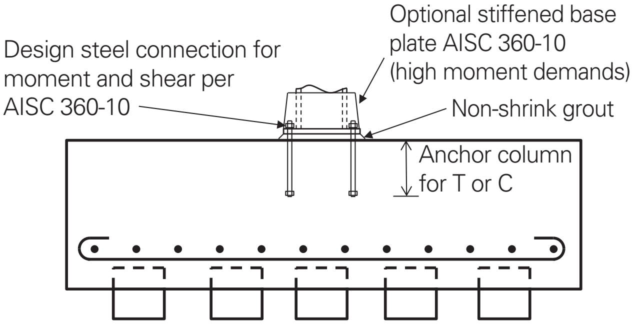


Fig. B.5 Typical steel column-to-pile cap connection detail (high moment demand).

Appendix C

Pile-to-Pile Cap Connections

APPENDIX C
Pile-to-Pile Cap Connections

C.1 General

In Appendix C, an overview of pile-to-pile cap connections is presented. Per ACI 318-14 Section 1.4.6, ACI 318-14 does not govern the design of these connections except for a limited number of provisions for prestressed concrete piles used in structures located in Seismic Design Categories D, E, and F. Special pile and pile cap provisions applicable to these high seismic design categories are summarized separately in Chapter 7 of this design guide. All provisions applicable to pile-to-pile cap connections are included in Chapter 18 of the *2012 IBC*. In general, the *2012 IBC* permits the designer to model the pile head using whatever fixity the designer deems appropriate and justified by the detailing present at the interface. Pin headed piles and fixed headed piles are commonly used but pile heads with partial fixity are detailed on occasion.

This guide focuses on two pile head connection types. Pinned head connections are the common pile head connection detail assumed in all previous chapters of this guide and are made using simple pile embedment with or without longitudinal dowels extending from the pile into the pile cap depending on whether or not pile tension is a design consideration. Although fixed pile heads are not considered in this design guide, they are commonly used when additional pile strength or stiffness is desired and a brief overview of connection details and load path issues is justified.

C.2 Pinned Head Pile-to-Pile Cap Connections

The design procedures presented in Chapters 5 and 6 of this design guide and the tabulated designs in Section T have been developed assuming pinned connections exist at the pile-to-pile cap interface. The common pinned head connection detail is made using minimum pile embedment. *2012 IBC* Section 1810.3.11 requires all piles to be embedded a minimum of 3 inches into the pile-cap and further requires a clear edge distance from the pile surface to the edge of the pile cap of at least 4 inches. These minimum dimensions are exceeded by the recommendations presented earlier in this design guide. Fig. C.1 presents typical pinned head connection details for prestressed, steel and timber piling. Note that when tension is a design consideration, a mechanical device must tie the pile directly to the pile cap.

C.3 Fixed Head Pile-to-Pile Cap Connections

There are many options available to the designer opting to model the pile head as fixed to the pile cap. Some common details are shown in Fig. C.2. The minimum prescriptive dimensions presented in *2012 IBC* Section 1810.3.11 (3 inches embedment into the pile-cap and 4 in. clear edge distance) as discussed in the previous section still apply. The example fully embedded pile shown in Fig. C.2 may require 1.0D to 2.0D embedment into the pile cap to develop the full moment capacity of the pile. See *ASCE/COPRI 61-14 Seismic Design of Piers and Wharfs* (2014) for design procedures associated with various fixed head pile configurations.

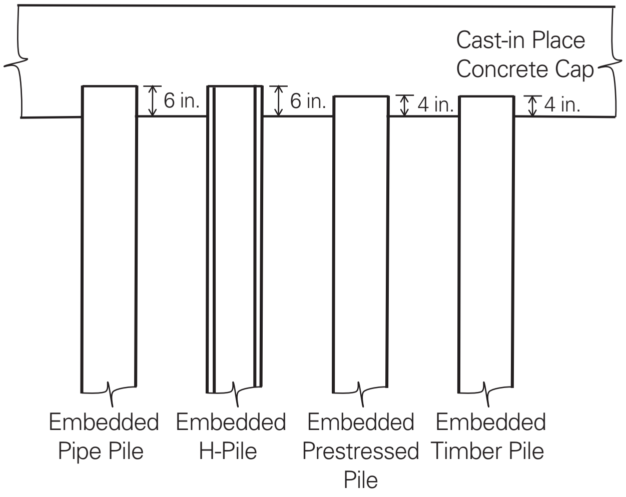


Fig. C.1 Typical pinned pile-to-pile cap connection detail. Mechanical tie detail not required unless pile tension is a design consideration.

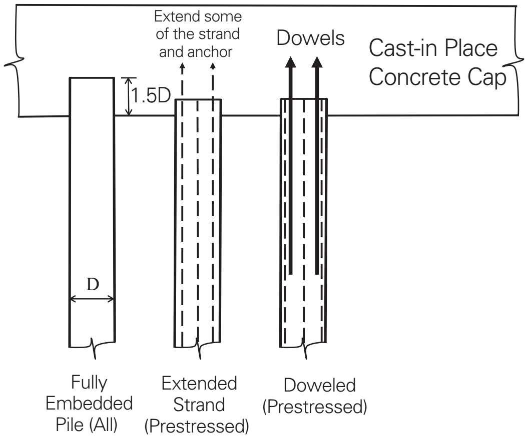
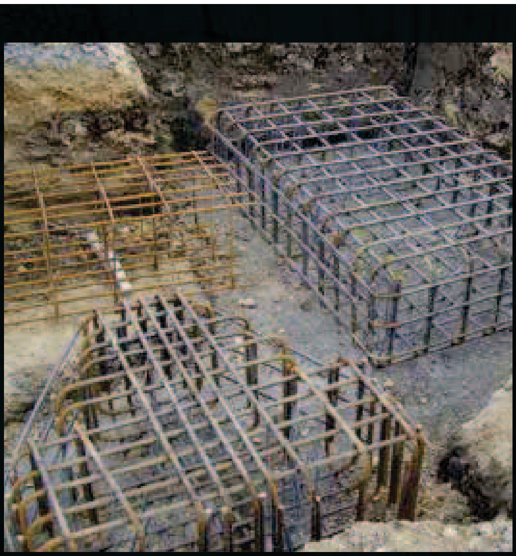


Fig. C.2 Some commonly used fixed pile-to-pile cap connection details.

Notes



Description of Manual

This design guide has been developed to provide the practicing engineer with a detailed overview of pile cap design, detailing, and analysis methodologies that represent the current state of practice in the industry. The guide contains comprehensive technical content and practical design examples utilizing approximately 30 different, yet commonly used, pile cap configurations. Tabulated designs are also provided for all aforementioned pile cap configurations and a wide range of vertical loading, lateral loading, and overturning effects. In order to better understand the behavior of deep pile caps, a finite element study was performed and recommendations obtained from that study are presented here.

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