ABSTRACT

POISEL, MATTHEW JOHN. Development of Draft Provisions for a Concrete Formwork Design Specification. (Under the direction of Dr. David W. Johnston.)

Formwork must be capable of handling all forces imposed on it due to the weight and pressure of the concrete as well as any other loads imposed by personnel, materials, equipment, or environmental loads. Currently there are no mandatory language standards for the design of concrete formwork which may be referenced as required provisions. There is a need for a formwork design standard in mandatory language that can be referenced by safety regulations and project specifications to ensure the safe design of formwork for construction of concrete structures. A review of existing standards and guides was performed to determine existing provisions related to formwork. This review identified wind loads and load combinations as areas requiring clarification in their application to formwork. Additional wind provisions specific to formwork structures were developed. Draft provisions to address the conflicts in load combinations between standards were developed. Current non-mandatory guide provisions for determining the concrete lateral pressure were reformatted to permit their use in a design specification. A design method and corresponding provisions for the bracing of formwork to mass anchors was developed for incorporation into the draft formwork design standard. A draft framework was developed to aid in the continued development of a formwork design specification.

Development of Draft Provisions for a Concrete Formwork Design Specification

by
Matthew John Poisel

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Civil Engineering

Raleigh, North Carolina

2011

APPROVED BY:

Dr. Michael L. Leming

Dr. Min Liu

Dr. David W. Johnston
Chair of Advisory Committee

DEDICATION

This thesis is dedicated to all of those who have pushed me to continue to grow as a student and a person. To all of my teachers and professors who have guided me through my education. To all of my coworkers and supervisors who have provided me with experience and training. And most importantly, to my Mother and Father, who have supported me through this entire process and taught me the value of education and the importance of hard work.

BIOGRAPHY

Matthew J. Poisel was born in Raleigh, North Carolina in 1986. He grew up in Cary, a suburb of Raleigh, and graduated from Cary High School in 2004. In august of 2004, he enrolled in engineering at North Carolina State University, where he received Bachelor of Science degrees in Civil Engineering and Construction Engineering and Management.

While earning his Bachelor degrees, he participated in the student chapter of the American Society of Civil Engineers. He served as a team member on the ASCE Concrete Canoe Competition his junior and senior years. During the fall of 2008, he completed and passed the Fundamentals of Engineering exam. During his freshman and sophomore years, he completed a Co-Op program with Northrop Grumman Newport News naval shipyard. In the summer of 2008, he interned with United Forming Inc. at the UNC Physical Science Building project in Chapel Hill, NC. In the spring and summer of 2009, he interned with POLYCON Construction Group, LLC. in Raleigh, NC.

In August of 2009, he enrolled in the Construction Engineering and Management graduate program in the Department of Civil, Construction, and Environmental Engineering and North Carolina State University. Given the opportunity to expand his knowledge in construction engineering, he became engaged in a research project with Dr. David W. Johnston involving a design specification for concrete formwork. This research resulted in this thesis presented here.

ACKNOWLEDGEMENTS

I would like to acknowledge my family, especially my parents, Boyd and Charlene, and my sister, Shannon. You have pushed me farther than I ever thought possible and have supported me the entire way. Thank you for your help, your understanding, your love, and when necessary, a push in the right direction. I love you all very much.

To my committee, Dr. David Johnston, Dr. Michael Leming, and Dr. Min Liu, thank you for the time and effort you have devoted to making this thesis possible. I would like to especially thank Dr. Johnston for guiding me through this process and his patience and assistance with my copious questions.

I would also like to thank the faculty of the Department of Civil, Construction, and Environmental Engineering at North Carolina State University. Many of you have supported my efforts in both my undergraduate and graduate career. I can never repay the value of the knowledge and experiences you have provided over the years, but I hope to carry it forward to the next generation of engineers.

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1. INTRODUCTION

1.1 <u>Background</u>

Concrete is one of the most common construction materials in use in the world. One of the major benefits of concrete is its ability to conform to any shape that can be imagined, provided a form is designed to shape it. Formwork is used to support and control the shape of fresh concrete. The complex shapes that can be produced using concrete result in complex formwork. The formwork must be capable of handling all of the loads imposed on it through the weight and pressure of the concrete as well as any other loads imposed by personnel, materials, equipment, or environmental loads. It must also support the concrete structure until the concrete has gained enough strength to support itself and all imposed loads.

The endless variations and complexities of formwork that may be required make it difficult to develop a standard method of formwork construction. While the majority of concrete forming may be considered routine; quite often there are shapes, structures, or situations that are difficult to predict with a design standard. Even with the simplest of structures, the available formwork materials and industry systems make it difficult to specify a universal method for each case. Of primary importance when drafting any standard for concrete is not only to ensure the safe construction of concrete structures, but also not to limit, with stringent, prescriptive standards, the flexibility that concrete allows.

There are certain criteria that all formwork must meet to ensure the safety of construction workers and the general public. It is in this area that a design specification is needed. To ensure that all formwork is built adequately and safely, the designer must be aware of these design issues and the criteria for a functional and safe design.

1.2 Problem Statement

Currently there are no mandatory language standards for the design of concrete formwork which formwork designers may reference as required provisions. Several guides exist for formwork, but their language prevents their use as a mandatory standard. There is a need for a formwork design standard in mandatory language that can be referenced by safety regulations and project specifications to ensure the safe construction of concrete structures.

The failure of concrete formwork is a significant cause of injury on construction sites. Particularly with multi-story concrete construction, the failure of formwork can be catastrophic. Several major incidents, such as the collapse at Bailey's Crossroads in Virginia in 1972 [1] and a cooling tower collapse at Willow Island, West Virginia in 1978 [2], have shown that failure of concrete formwork can lead to progressive collapse situations, which leave workers with little opportunity to escape from danger. Several existing standards and guides try to address the problems that have occurred with concrete formwork in the past, but there is no comprehensive, mandatory standard in the United States. A design specification that addresses the specific issues of formwork is needed to clarify problems faced by designers.

1.3 Research Objectives

The following research objectives have been identified:

1. Identify codes and design standards which contain provisions relevant to the design of concrete formwork.
2. Identify guides for formwork that contain best practices in formwork construction.
3. Review current provisions and identify areas of formwork design not covered.
4. Develop a framework for a design specification on concrete formwork so that others may input provisions relevant to formwork.
5. Develop a draft of selected provisions for concrete formwork as examples of possible content.
6. Present a draft of the framework and provisions to ACI Committee 347 for review and comment.
7. Make revised draft available to ACI Committee 347 for their continued development of a new design specification for concrete formwork

2. REVIEW OF LITERATURE RELATING TO STANDARDS

2.1 Introduction

In order to develop a design standard for concrete formwork, the requirements for a design standard must first be known. A review of literature relating to standards was performed concurrently with the literature review of documents pertaining to formwork. Several of the documents referenced have undergone changes during the process of this study. An effort has been made to have the draft provisions recommended herein conform to the most current information available.

2.2 The United States Standards Strategy

The United States Standards Strategy (USSS) [3] is a document published by the American National Standards Institute (ANSI) to outline the principles and vision of standards in the US and global economy. The USSS "consists of a set of strategic initiatives having broad applicability that will be applied according to their relevance and importance to particular sectors." The second of the twelve initiatives of the USSS is to "continue to address the environment, health, and safety in the development of voluntary consensus standards". This strategy set forth by ANSI is that standards be developed on a sector basis, with individual sectors of the economy developing standards for their operations. "The sectoral approach allows interested parties to address their own issues and develop working methods that fit the problems at hand, since no single standards system can satisfy all needs."

“Sectors must develop their own plans; the purpose of this strategy is to provide guidance, coherence and inspiration without constraining creativity or effectiveness.” [3]

2.3 The International Code Council

In the construction industry, standards can be broken down into many levels. Most states or municipalities have adopted codes which serve as standards for constructed facilities. These codes in turn reference standards that supplement the code with additional provisions pertaining to specific aspects of construction. One organization that produces model building codes is the International Codes Council (ICC). The reference standards incorporated in the ICC model codes must meet the criteria of the ICC in order to be incorporated into an ICC code. The ICC publishes the ICC Referenced Standards Guide [4] to detail the requirements standards must meet to be considered for incorporation into a code by reference. Building codes are legal requirements for permanent structures.

The temporary nature of formwork makes it inappropriate to incorporate a design specification for formwork into a building code. Instead a design specification for formwork could be incorporated by reference into a construction safety regulation or project specification. While the proposed document is not intended to be referenced in a code, the language of the document must meet the same requirements as a referenced standard in order to be enforceable in safety regulations or project specifications.

2.4 The American Concrete Institute

The primary industry organization focusing on cast-in-place concrete in the U.S. is the American Concrete Institute (ACI). This organization currently publishes many of the design standards relating to cast-in-place concrete, as well as guides to formwork design and construction. ACI develops these documents through technical committees. The types of documents produced and the process of developing documents by committees is established in the ACI Technical Committee Manual [5].

The ACI Technical Committee Manual (TCM) has undergone several major revisions recently, which will be discussed in detail in Chapter 4. The 2009 TCM [6] provided requirements for non-mandatory language committee reports and for mandatory language requirements for building codes and construction specifications. The 2010 ACI Technical Committee Manual [5] includes changes to the ACI document classification system provided for mandatory language design specifications. A draft of the 2011 ACI Technical Committee Manual [7] is in the final stages of review and will soon be published. The 2011 draft of the ACI Technical Committee Manual eliminates the references to the ACI Style Manual [8] and the ACI Specifications Manual [9] and instead incorporates them into the TCM document as chapters. An additional chapter has been drafted to provide format requirements for ACI design standards. The evolution of the ACI document classification system is further discussed in Chapter 4 of this thesis.

3. REVIEW OF LITERATURE RELATING TO FORMWORK

3.1 Introduction

The primary industry organization dealing with formwork for concrete is ACI. The ACI guide documents ACI 347, "Guide to Concrete Formwork" [10] and ACI special publication SP-4, "Formwork for Concrete" [11] provide recommendations to design and construction personnel for formwork. These documents also reference other standards, such as SEI/ASCE 7 "Minimum Design Loads for Buildings and Other Structures" [12] and SEI/ASCE 37 "Design Loads on Structures During Construction" [13] which contain provisions relevant to formwork design. In addition to the documents published by ACI, all construction activities are subject to the requirements of the Occupational Safety and Health Administration (OSHA) Safety and Health Regulations for Construction [14].

3.2 ACI 347

ACI 347 "Guide to Formwork for Concrete" is a guide document produced and updated regularly by ACI Committee 347, with the latest published revision being ACI 347-04 [10]. It contains concise recommendations for the design and construction of formwork systems. Several important areas covered in this document include: vertical loads placed on formwork, concrete lateral pressures, lateral loads on formwork due to eccentricity of shores and wind loading, and safety factors to be applied to components specific to formwork systems.

ACI 347-04 provides many useful recommendations that a safety regulation or project specification may wish to reference or require; however, this is not possible due to the non-mandatory language of the document. On the first page of ACI 347-04, it states: "Reference to this document shall not be made in contract documents. If items found in this document are desired by the Architect/Engineer to be a part of the contract documents, they shall be restated in mandatory language for incorporation by the Architect/Engineer." This document was never intended to be a mandatory language document, but instead a useful guide.

ACI Committee 347 has provided equations for estimating the concrete lateral pressure on formwork since 1963 [15] and is referenced by many other publications as a guide for formwork pressures. These pressure equations are revised as new information becomes available. In ACI 347-04 the equivalent hydrostatic pressure of the fluid concrete is the general case and additional equations are provided to estimate the concrete lateral pressure when certain conditions apply. These conditions are related to the concrete mixtures and concrete placement operations and the equations provide a reduced concrete lateral pressure when the conditions are met. However, some difficulty has been noted in interpreting the provisions in practice and improved presentation of the methods is needed. These pressure equations are discussed in detail in Chapter 5 of this thesis. For estimating the lateral pressure for concrete mixtures with newly introduced admixtures which affect the slump or set characteristics, such as self-consolidating concrete, ACI 347-04 recommends that the equivalent hydrostatic head be used until form pressures are measured by testing for that specific mixture. ACI 347-04 also provides warning for certain concrete placement operations and concrete mixtures where the concrete pressure may exceed the equivalent hydrostatic head.

ACI 347-04 references several published mandatory standards which include pertinent information related to formwork design, including SEI/ASCE 7 “Minimum Design Loads for Buildings and Other Structures” and SEI/ASCE 37 “Design Loads on Structures During Construction”, generally referred to as ASCE 7 and ASCE 37 respectively. No specific version of ASCE 7 or ASCE 37 is referenced in ACI 347-04, but the most current versions published at the time were ASCE 7-95 [12] and ASCE 37-02 [13].

ACI 347-04 recommends that wind loads be determined in accordance with ASCE 7 with adjustment for shorter recurrence intervals as provided in ASCE 37. ACI 347-04 also provides minimum wind loads for wall forms and elevated slab forms. Minimum loads were provided in the first publication of ACI 347 in 1963 [15] and were increased to the present values in 1978 [16]. ACI 347-04 does not provide commentary on these recommendations and the SP-4 section on wind loads does not provide information on how these minimum loads were established.

ACI 347-04 provides minimum live load values for elevated slab formwork for construction personnel and certain concrete placing equipment. A minimum live load value is provided to cover the use of motorized carts to transport concrete to the area of placement. Also provided are minimum design values for the combined dead and live loads on elevated slab formwork.

ACI 347-04 provides minimum safety factors for specific formwork accessories, such as form ties, form anchors, and form hangers. The safety factors are stated as a ratio of the ultimate strength of the accessory to the unfactored load combination that is applied to the accessory. These minimum safety factors are directly applicable to Allowable Strength Design (ASD) methods, which use unfactored loads in load combinations. However, definition of these safety factors for Load and Resistance Factor Design (LRFD) methods is not provided. Development of safety factors for ASD and LRFD is discussed in Chapter 7.

Although reference is made to ASCE 37 by ACI 347-04 for wind loads, ACI 347-04 does not reference ASCE 37 for load factors or load combinations to be used in designing formwork. The only mention of load combinations in ACI 347-04 is in Section 2.2.1, Vertical Loads, and Section 2.2.3, Horizontal Loads. Section 2.2.1 states: “Vertical loads consist of dead and live loads.” Section 2.2.3 states: “Braces and shores should be designed to resist all horizontal loads such as wind, cable tensions, inclined supports, dumping of concrete, and starting and stopping of equipment.” Except as implied for ASD, these two statements do not provide a clear picture of how a formwork designer should combine loads imposed on formwork.

3.3 <u>ACI SP-4</u>

ACI SP-4 “Formwork for Concrete” is a manual authored by M. K. Hurd under guidance of ACI Committee 347 and is considered by many to be the “Green Bible” for the formwork industry. The seventh edition was published in 2005 [11] and represents the most resent evolution of this manual first published in 1963 [17]. ACI SP-4 provides in-depth coverage of the essential aspects of formwork system and design.

ACI SP-4 references ACI 347 when providing equations for concrete lateral pressures. ACI SP-4 explains how each factor affects the concrete lateral pressure and provides a brief history of the development of the equations. The concrete lateral pressure equations in the 2005 edition of ACI SP-4 are based on the recommendations of ACI 347-04. ACI SP-4 is updated as updates to ACI 347 are made; however it lags behind the revision of ACI 347 by a few years.

Designers who have followed ACI SP-4s recommendations have had success in designing safe, reliable formwork systems. However, since it is a non-mandatory language document, its recommendations may not be referenced in safety regulations or contract specifications as an enforceable requirement.

3.4 ASCE 7

ASCE 7 “Minimum Design Loads for Buildings and Other Structures” is primarily referenced by building codes for loads on the final, permanent structure. For the design of permanent structures, ASCE 7 provides basic load combinations which reflect the typical loading conditions of a permanent structure. These basic load combinations are provided for both LRFD and ASD design methods. The basic load combinations have changed through the past three editions of ASCE 7, ASCE 7-95 [12], ASCE 7-05 [18], and ASCE 7-10 [19]. ASCE 7-05 made changes to the ASCE 7-95 load combinations to increase the load factor on wind forces, as well as increase the live load factor in certain combinations. ASCE 7-10 made changes to ASCE 7-05 load combinations by decreasing the load factor for wind loads in the basic combinations while increasing the wind load itself. A detailed discussion of the changes in wind load factors is included in Chapter 7.

ASCE 7 contains information on wind velocities for regions in the United States, which are used to determine the wind loads on a structure. It also contains several methods for determining the wind pressure on different structure shapes. Most of these methods relate to general building shapes and not specific members; however, there a few methods that can be applied to formwork systems.

The analysis method for wind in ASCE 7-10 has been changed significantly from previous editions. In the 1995 edition of ASCE 7, the wind speed was based on the maximum wind three-second gust speed at 33 feet above ground in Exposure C and associated with an annual probability of 0.02 of being equaled or exceeded for a 50-year mean recurrence interval [12]. This maximum wind speed was used to calculate a wind force on a structure, and in turn this force was multiplied by a load factor of 1.3 in LRFD combinations and 1.0 in ASD combinations. ASCE 7-05 uses the same analysis method and provides the same basic wind speeds, but with slight differences in contour line locations and an increased the wind load factor to 1.6 in LRFD combinations, while maintaining the 1.0 in ASD combinations.

ASCE 7-10 has changed the analysis method for wind loads. When using LRFD, instead of multiplying the wind force by a load factor of 1.6, the load factor is now 1.0 in the same load combinations. When using ASD, the load factor has changed from 1.0 to 0.6 in the same load combinations. An excerpt from the commentary of ASCE 7-10, shown in Figure 3.1, provides the reasoning behind the change in methodology in ASCE 7-10. To provide an equivalent factor of safety for wind, ASCE 7-10 removes the Importance Factor for wind and instead accounts for the buildings importance by establishing different wind contour maps for different Importance levels; each with a different return period. To accommodate the change in the LRFD load factor for wind from 1.6 to 1.0, the return period of the wind speed has been increased from 50 years to 700 years for Category II structures. This increase in the return period results in higher basic wind speeds, 115 miles-per-hour instead of 90 miles-per-hour, and thus greater wind forces. To still allow the use of ASD, ASCE 7-10 now includes a load factor of 0.6 instead of 1.0 on wind loads in ASD load combinations.

Section 6.5.10 of ASCE 7-05 can be used to determine the velocity pressure due to wind speed for structures other than buildings, with adjustment factors to account for several variables. These adjustment factors to the velocity pressure account for wind directionality, exposure categories, surface roughness, importance of the structure, topographical effects, gust effects, and the height of the structure above ground level. This velocity pressure is then used in the appropriate analysis methods to determine the design wind force on a specific structure.

C26.5.1 Basic Wind Speed

This 2010 edition of ASCE 7 departs from prior editions by providing wind maps that are directly applicable for determining pressures for strength design approaches. Rather than using a single map with importance factors and a load factor for each building risk category, in this edition there are different maps for different categories of building occupancies. The updated maps are based on a new and more complete analysis of hurricane characteristics (Vickery et al. 2008a, 2008b and 2009) performed over the past 10 years.

The decision to move to multiple-strength design maps in conjunction with a wind load factor of 1.0 instead of using a single map used with an importance and a load factor of 1.6 relied on several factors important to an accurate wind specification:

i. A strength design wind speed map brings the wind loading approach in line with that used for seismic loads in that they both essentially eliminate the use of a load factor for strength design.
ii. Multiple maps remove inconsistencies in the use of importance factors that actually should vary with location and between hurricane-prone and nonhurricane-prone regions for Risk Category I structures and acknowledge that the demarcation between hurricane and nonhurricane winds change with the recurrence interval.
iii. The new maps establish uniformity in the return period for the design-basis winds, and they more clearly convey that information.
iv. The new maps, by providing the design wind speed directly, more clearly inform owners and their consultants about the storm intensities for which designs are performed.

Figure 3.1 – Commentary on Basic Wind Speed from ASCE 7-10 [19]

ASCE 7-05 provides analysis methods for different types and shapes of permanent structures to determine the wind force. While many of the analysis methods do not relate to formwork, two methods can be applied to typical formwork structures. The wind force analysis method described in ASCE 7-05 section 6.5.14, “Design Wind Loads on Solid Freestanding Walls and Solid Signs” can be directly applied to most wall forms in concrete construction. The equation and adjustment factors provided give a design force at a specific location along a wall.

ASCE 7-05 section 6.5.15, “Design Wind Loads on Other Structures”, provides an equation for determining the wind force on shapes of structures by using a shape factor “C_f”. This shape factor is provided in ASCE 7-05 for several types of common permanent structures; such as solid square or round structures, lattice frameworks, open signs, and trussed towers. These structure shapes are often used in formwork systems and the shape factors provided in ASCE 7-05 can be applied to that component of the formwork system. However, since ASCE 7-05 is based on wind speeds corresponding to very long return periods, it does not apply well to temporary structures that have very short periods of exposure.

3.5 ASCE 37

ASCE 37-02 “Design Loads on Structures During Construction” [13] is intended as the primary document for design loads on temporary structures, such as falsework and formwork. Figure 3.2 provides the definitions of the load types shown in ASCE 37-02. This document is intended to be compatible with ASCE 7-95 load factors and load combinations, but with additional load factors applicable to temporary loads seen in construction.

2.1 Loads Specified

Structures within the scope of this standard shall resist the effects of the following loads and combinations thereof:

Final loads–see Section 3
D–dead load
L–live load

Construction loads–see Section 4
Weight of temporary structures
C_D–construction dead load

Material loads
C_{FML}–fixed material load
C_{VML}–variable material load

Construction procedure loads
C_P–personnel and equipment loads
C_H–horizontal construction loads
C_F–erection and fitting forces
C_R–equipment reactions
C_C–lateral pressure of concrete

Lateral earth pressures–see Section 5
C_{EH}–lateral earth pressures

Environmental loads–see Section 6
W–wind
T–thermal loads
S–snow loads
E–earthquake
R–rain
I–ice

The specified loads are nominal loads that are intended to be suitable for use in either conventional allowable stress design (ASD) or load and resistance factor design (LRFD), provided that appropriate load factors and combinations are used.

Figure 3.2 – Load types defined in ASCE 37-02 [13]

Included in ASCE 37-02 are load combinations for both LRFD and ASD methods. Load factors for LRFD combinations and arbitrary point-in-time (APT) factors for both

LRFD and ASD load combinations are provided for temporary structures in construction. These factors can be utilized in the design of formwork systems to ensure adequate strength.

ASCE 37-02 provides a general formula for combining all applicable loads multiplied by their respective load factors as shown in Figure 3.3. Figure 3.4 shows the load factors listed in ASCE 37-02. It also provides basic load combinations for LRFD and ASD design methods similar to ASCE 7-95, but including additional construction loads. These basic load combinations are shown in Figure 3.5 for LRFD and in Figure 3.6 for ASD.

2.2.1 Additive Combinations

When the effects of different loads are of the same sense, and when structures are subjected to more than one variable load, sufficient load combinations shall be evaluated as follows. The total design load for each combination shall be the sum of the factored dead and/or material loads present, the variable load(s) at their maximum values, and the other uncorrelated loads at their arbitrary point-in-time (APT) values. Correlated variable loads, such as vertical and horizontal construction loads, shall be taken to have their maximum values occurring simultaneously. The generalized form of the load combinations (U) can be written as:

Combined Design Load =
Dead and/or Material Loads
+ Loads at their Maximum Values
+ Loads at their APT Reduced Values.

$$U = \sum_k c_{D,k} D_{n,k} + \sum_i c_{\max,} Q_{n,i} + \sum_j c_{APTj} Q_{n,j} \qquad (2\text{-}1)$$

where c_D = dead load factor, $c_{\max}$ = load factor for the maximum value of variable load, c_{APT} = load factor for the APT value of variable load, D_n = nominal dead or construction material load, Q_n = nominal variable load, k = all dead and construction material loads, i = all loads occurring at maximum value, and j = all relevant simultaneously occurring variable loads at APT values.

Figure 3.3 – Generalized Load Combination Equation from ASCE 37-02 [13]

2.2.2 Load Factors

Minimum load factors for use with strength design are as follows:

Load	Load factor (c_{max})	Arbitrary point-in -time load factor (c_{APT})
D	0.9 (when counteracting wind or seismic loads)	–
	1.4 (when combined with only construction and material loads)	–
	1.2 (for all other combinations)	
L	1.6	0.5
C_D	0.9 (when counteracting wind or seismic loads)	–
	1.4 (when combined with only construction and material loads)	–
	1.2 (for all other combinations)	–
C_{FML}	1.2	–
C_{VML}	1.4	*by analysis*
C_P	1.6	0.5
C_C	1.3 (full head)	–
	1.5 (otherwise)	–
C_{EH}	1.6	–
C_H	1.6	0.5
C_F	2.0	*by analysis*
C_R	2.0 (unrated)	0
	1.6 (rated)	0
W	1.3	0.5
T	1.4	–
S	1.6	0.5
E	1.0	–
R	1.6	–
I	1.6	–

Basic combinations are presented in Section 2.2.3.

Figure 3.4 – Load factors for specific load types listed in ASCE 37-02 [13]

2.2.3 Basic Combinations

Except where applicable codes and standards specify otherwise, structures and their components shall be designed so that their strength exceeds the effects of factored loads in the following combinations:

$$1.4D + 1.4C_D + 1.2C_{FML} + 1.4C_{VML} \quad (2\text{-}2)$$

$$1.2D + 1.2\,C_D + 1.2C_{FML} + 1.4C_{VML} + 1.6C_P + 1.6C_H + 0.5L \quad (2\text{-}3)$$

$$1.2D + 1.2\,C_D + 1.2C_{FML} + 1.3W + 1.4C_{VML} + 0.5C_P + 0.5L \quad (2\text{-}4)$$

$$1.2D + 1.2\,C_D + 1.2C_{FML} + 1.0E + 1.4C_{VML} + 0.5C_P + 0.5L \quad (2\text{-}5)$$

$$0.9D + 0.9\,C_D + (1.3W \text{ or } 1.0E) \quad (2\text{-}6)$$

where *D* is the dead load in place at the stage of construction being considered; *L* is the live load, which may be less than or greater than the final live load; and *W* is the wind load computed using the design velocity reduction per Section 6.2.1.

The most unfavorable effects from both wind and earthquake loads shall be considered, where appropriate, but they need not be assumed to act simultaneously. Similarly, C_H need not be assumed to act simultaneously with wind or seismic loads. Lateral earth pressure, environmental loads, and other construction loads shall be considered if applicable; they are listed in Section 2.2.2. Consideration of these other loads will require the use of load combinations in addition to the basic combinations listed above.

Figure 3.5 – LRFD Basic Load Combinations (from ASCE 37-02) [13]

2.3.1 Additive Combinations

When using load values provided in this standard for ASD, sufficient additive load combinations shall be considered to obtain the maximum design load effects for members and systems.

The following basic combinations shall be investigated as a minimum:

$$D + C_D + C_{FML} + C_{VML} \quad (2\text{-}7)$$

$$D + C_D + C_{FML} + C_{VML} + C_P + C_H + L \quad (2\text{-}8)$$

$$D + C_D + C_{FML} + C_{VML} + W + C_P + L \quad (2\text{-}9)$$

$$D + C_D + C_{FML} + C_{VML} + 0.7E + C_P + L \quad (2\text{-}10)$$

$$D + C_D + (W \text{ or } 0.7E) \quad (2\text{-}11)$$

where *D* is the dead load in place at the stage of construction being considered; *L* is the live load, which may be less than or greater than the final live load; and *W* is the wind load computed using the design velocity factor where appropriate per Section 6.2.1.

The most unfavorable effects from both wind and earthquake loads shall be considered where appropriate, but they need not be considered simultaneously. Similarly, C_H need not be assumed to act simultaneously with wind or seismic loads. Other construction loads that shall be considered if applicable are defined in Section 2.1.

Figure 3.6 – ASD Basic Load Combinations (from ASCE 37-02) [13]

ASCE 37-02 provides a special load factor called an Arbitrary Point-in-Time (APT) value. This APT value is used to reflect that while one transient load may be at its maximum value, other transient loads are unlikely to be at their maximum at the same time.. LRFD load factors and APT values used in both ASD and LRFD load combinations are provided for many types of loads that are seen in construction. The concept of using APT load factors is provided in the commentary of ASCE 37-02, Section C2.2.1:

> "The concept of using maximum and APT loads and corresponding load factors is consistent with ASCE 7-95. Here, in addition to the dead load, which is assumed to be permanent, one or more of the variable loads occurring simultaneously assume APT values (i.e., those values measured at any instant of time). This is consistent with the way loads actually combine in situations in which strength limit states are approached."
> [13]

ASCE 37-02 restates in mandatory language the recommendations of ACI 347R-94 [20] relating to concrete lateral pressure. ASCE 37-02 provides equations for determining concrete lateral pressures, which the commentary states "The lateral pressure formulas are adopted from ACI (ACI 1994; Hurd 1995)", with ACI 1994 referring to ACI 347R-94 [20] and with Hurd 1995 being the 6^{th} edition of ACI SP-4 [21]. Both ACI documents referenced by ASCE-37-02 have been revised since the edition listed and the recommended equations have changed. As a result, the ASCE 37-02 equations do not provide adjustment factors for concrete chemistry and unit weight factors as found in ACI 347-04. The factors listed in ACI 347-04, but not accounted for in SEI/ASCE 37-02, provide a better estimate of concrete lateral pressure and therefore a more accurate formwork design. By stating the concrete lateral pressure provisions in mandatory language, these provisions can be referenced in contract specifications as a requirement for design. However, revisions to ASCE standards are published less often than ACI standards and often do not reference the most current ACI standards or include ACI's current recommendations, which is problematic.

ASCE 37-02 references ASCE 7-95 for wind analysis methods. However, ASCE 37-02 provides reduction factors that can be applied to the basic wind speeds of ASCE 7-95 to account for the short exposure duration of temporary works. ASCE 37-02 further allows designers to ignore the effects of hurricane winds on coastal regions, provided that the temporary structure is either removed or additionally braced in the event a hurricane is predicted to strike. It also provides for the consideration of shielding of wind load on repetitive members, like those commonly used in the shoring of concrete formwork.

ASCE 37 is in the process of being revised. At this point, there have been no indications of how the revised ASCE 37 will address the changes in the wind analysis method in ASCE 7-10. The next publication of ASCE 37 will need to be reviewed before incorporation by reference into the proposed design specification for formwork.

3.6 OSHA Safety and Health Regulations for Construction

The formwork designer must ensure that the design is in compliance with the Occupational Safety and Health Administration (OSHA) Safety and Health Regulations for Construction Subpart Q on Concrete and Masonry Construction Section 1926.703(a) [14]. This regulation states "Formwork shall be designed, fabricated, erected, supported, braced, and maintained so that it will be capable of supporting without failure all vertical and lateral loads that may reasonably be anticipated to be applied to the formwork". While Subpart Q does not specify any of these loads, it does provide in Subpart Q Appendix A non-mandatory references containing information helpful in complying with the requirements. Among these listed references are ACI 347-78 [16] and ACI SP-4. A specific edition of ACI SP-4 is not referenced in OSHA; however, the most current edition is ACI SP-4, 7th edition [11].

OSHA Safety and Health Regulations for Construction Subpart L "Scaffolds" also includes requirements that relate to formwork. The distinction of a structure being classified as either formwork or scaffolding determines what the design requirements are for the system. The primary requirement that impacts formwork design is found in §1926.451(a)(1), "Except as provided in paragraphs (a)(2), (a)(3), (a)(4), (a)(5) and (g) of this section, each scaffold and scaffold component shall be capable of supporting, without failure, its own weight and at least 4 times the maximum intended load applied or transmitted to it" [14]. The OSHA definition of a scaffold is found in §1926.450(b): "Scaffold means any temporary elevated platform (supported or suspended) and its supporting structure (including points of anchorage), used for supporting employees or materials or both" [14]. Some work platforms are attached to and supported directly by the formwork system. OSHA refers to these types of work platforms as form scaffolds and provides the following definition in §1926.450(b): "Form scaffold means a supported scaffold consisting of a platform supported by brackets attached to formwork" [14]. These work platforms are considered scaffolding and the different live load requirements pertaining to scaffolding must be considered in the design of the formwork. OSHA also provides a definition of a large area scaffold in §1926.450(b):

“Large area scaffold means a pole scaffold, tube and coupler scaffold, systems scaffold, or fabricated frame scaffold erected over substantially the entire work area. For example: a scaffold erected over the entire floor area of a room.”

The classification of an elevated surface as formwork or a scaffold has a large impact on the design of the elevated surface. The load combinations which that elevated surface must be designed for change significantly. A detailed discussion of the OSHA requirements and their impact on concrete formwork is found in Chapter 7 of this thesis.

3.7 Shapiro & Shapiro

The first edition of “Cranes and Derricks” by Howard I. Shapiro (1980) [22] is mentioned in the commentary section C6.2.2 of ASCE 37-02 as a source of guidance on shielding effects of wind on open structures [13]. The fourth edition by Shapiro & Shapiro [23], released in 2011, also provides guidance on wind shielding. A detailed method is provided for determining the shielding of repetitive members based on the shape and spacing of the members. It also provides additional shape factors for wind loads on structural members which are not provided in ASCE 7-05. This analysis method and the additional shape factors are repeated in the draft provisions for the proposed design specification and shown in Chapter 6 of this thesis.

3.8 British Standard BS5975-2008

In reviewing standards for formwork, several standards from other countries were identified. One standard in particular that provides provisions related to formwork in the U.S. was British standard BS5975-2008 CORR: 2009 “Code of practice for temporary works procedures and the permissible stress design of falsework” [24]. This standard provides an analysis method consistent with ASCE 7-05 with a shape factor that is applicable to the typical arrangement for forming an elevated slab. The provisions of BS5975 provide a basis for some draft provisions in the proposed formwork design specification and are discussed in Chapter 6 of this thesis.

3.9 Other Source Documents

Several other source documents are referenced in this thesis for specific information or as examples of design methods. The specific section used from each of these documents is sufficiently small to not merit their discussion in this Chapter. The pertinent information from each of these documents is provided in Chapters 5 through 8.

4. DOCUMENT FRAMEWORK

4.1 Introduction

The framework of this draft specification is intended to provide a starting point for ACI Committee 347 to continue its efforts on developing a design specification for formwork. The framework for the draft design specification depends on the classification of the proposed document within ACI publications. Also, the format of the design specification is required to comply with the requirements of ACI. These requirements are discussed in this chapter.

4.2 Classification of Proposed Document

ACI Committee 347 requested approval from the ACI Technical Activities Committee (TAC) on November 11, 2009 to begin work to develop a mandatory language document for concrete formwork. ACI Committee 347 requested that the document be titled as a “design specification” rather than “code requirements” as would be required by the ACI classification systems that existed at that time. An excerpt from the request letter is included below:

> ACI 347 notes that the present ACI document type for design requirements is a “code requirements” document. The committee believes it would be desirable for TAC to consider an alternate name under the same style, in particular a “design specification.” ACI Committee 347 believes that design requirements for formwork would most likely be cited by regulations, construction specifications and agreements other than building codes. The term “design specification” is used for many other design standards outside of ACI and would appear to be a better term in this application. [25]

TAC approved the request to develop a formwork design standard in March 2010. Also, in response to the request, TAC revised the policies which define the classification of documents published by ACI. The 2009 ACI Technical Committee Manual [6] had separated documents published by ACI into two broad categories; "mandatory language documents requiring standardization" and "nonmandatory language documents not requiring standardization". Under the mandatory language category, documents could be classified into many types, but the two that were most relevant to the proposed document were as follows.

> ***Code Requirements***
> ACI codes provide minimum requirements for concrete or masonry structures to safeguard the public safety, health, and general welfare.
>
> If the code is written in a manner that it could be adopted in a more general code or by a regulatory agency, the phrase "code requirements" should be used in the title.
>
> ***Reference specifications***
> Reference specifications are written to be referenced as part of a contract between an owner and a builder and must be worded in explicit, mandatory language subject to only one possible interpretation.
>
> ACI reference specifications must conform to the requirements of the ACI Specification Manual.
>
> [6]

The ACI Specification Manual [9] states "this ACI specification manual provides requirements and recommendations for preparing ACI construction specifications. ACI construction specifications shall be prepared as either ACI Reference Specifications or ACI Guide Specifications". ACI specifications are only intended to be documents that could be part of a construction contract. ACI guide specifications are guides on how to write particular construction project specifications. Thus, neither is an appropriate classification for a design specification.

Under the 2009 ACI TCM system of classifying published documents, the proposed formwork document would appear to best fit under the classification of "code requirements" since it is a design document. However, the formwork design standard is not intended to be a building code provision since it does not cover elements of design for permanent structures or buildings. ACI codes are not in themselves a legal requirement for design or construction, but may become so by being incorporated by reference in a local or state building code or by inclusion in the contract specifications for a construction project.

Several other professional and industry organizations also produce mandatory language design documents and classify them as design specifications. These design specifications are developed by their respective organization and then made available to the public for review and comment like ACI standards. They then can be incorporated by reference in model building codes or project specifications. Examples of such documents are the "Specification for Structural Steel Buildings" [26] published by the American Institute of Steel Construction and the "National Design Specification for Wood Construction" [27] published by the American Forest and Paper Association. Thus, there are examples of design standards that are not titled as "code" documents. If this draft document were classified and title as "code requirements" under the previous ACI document classification system, there would be a potential to generate confusion as to the intent of the document. It was recommended that the document be titled a formwork design specification to avoid this confusion.

In 2010, the ACI Technical Committee Manual was revised to incorporate the new mandatory language document classification of “design specification” [5]. The draft of the 2011 ACI Technical Committee Manual [7] continues to include this new document classification. While still separating ACI documents into mandatory language and nonmandatory documents, the new system now divides mandatory language documents into subdivisions of “design standards” and “construction standards”. The classifications of “code requirements” as well as the new classification of “design specification” fall under the “design standards” subdivision. The classification of “design specification” is provided in sub-paragraph 4.1.1.4 of the Draft 2011 Technical Committee Manual.

> ***4.1.1.4 Design Specifications***
> A design specification provides minimum requirements for concrete or masonry structures within its scope to safeguard the public safety, health, and general welfare. It is written to be referenced in legal documents by entities other than building officials. Design specifications follow the code requirements format.
> [7]

With the intent of the proposed document being a mandatory reference for the safe design of formwork, it now falls under the ACI classification of “design specification”. This classification serves the purpose of aiding the formwork designer while maintaining the mandatory language requirement so that it may be incorporated by reference into project specifications or safety regulations. If incorporated into project specifications or into federal or state safety regulations, the provisions of this design specification would then be enforceable by contract or law.

4.3 <u>Language of Proposed Document</u>

While the proposed design specification is not intended to be referenced by a building code, the writing requirements of a referenced standard for a code still apply. For all standards referenced in ICC model codes, the ICC publishes the ICC Referenced Standards Guide [4]. This guide goes into detail on the language to be used in a standard.

> The need for mandatory language in referenced standards should be obvious in this context because a standard is intended to be utilized for regulatory purposes. As a result, the standard must be presented so that the application and intent is clear to all readers. The use of recommendations, advisory comments, and permissive, non-mandatory terms fails to provide sufficient specific direction to all users. A potential result is non-uniform interpretation or misapplication of the provisions. In particular terms such as 'may', 'should' and 'can' are particularly significant in disrupting consistency of use as they create undefined conditional statements and can confuse the application of regulations
>
> [4]

The draft of the 2011 ACI Technical Committee Manual covers much of the same information as the ICC Referenced Standards Guide. It details the word use for provisions of standards. Regarding the language and verb use in provisions of standards, it states:

> 5.2 – Language
>
> 5.2.1 Verb usage
> Codes use only mandatory verbs, such as "Shall be" or "is". Permissive verbs, such as "may" are never used. The verb in provisions that directs or permits a future action is usually "shall be". The verbs in provisions that define a concept are in present tense, usually "is" and "are". The mandatory mature of code language should be described in Chapter 1".
>
> [4]

The language of provisions for standards is intended to be thorough, yet as concise as possible. Often, provisions can benefit from having an explanation of the provision provided.

The ICC Reverenced Standards Guide addresses the need of additional information on provisions in the statement:

> This is not intended to mean that informational or explanatory materials cannot be developed to aid the reader in the use of the referenced standard. However, such material must be limited to a location within the document that is clearly identified as not being a mandatory part of the standard.
>
> [4]

To provide this additional information on provisions, ACI documents may include commentary for certain provisions. The ACI requirements for commentary are specified in the draft of the 2011 ACI Technical Committee Manual:

> **5.1.6** ***Commentary to the code***
>
> Commentary may provide:
> (a) Basis for the code provision including pertinent references;
> (b) Cross-reference to related material in other standards or in other code sections;
> (c) References to address situations outside the stated limits of a provisions; and
> (d) Discussion highlighting new code provisions.
>
> Commentary should not:
> (a) Repeat code provision;
> (b) Provide general design education; or
> (c) Provide design aids or examples.
>
> Commentary must not:
> (a) Provide exceptions to the code provision;
> (b) Contain additional code requirements; or
> (c) Use mandatory language.
>
> [7]

The proposed design specification is intended to conform to the requirements of the draft of the 2011 ACI Technical Committee Manual. To distinguish between the mandatory provisions and the commentary, ACI design standards use a two-column format. The left column contains the mandatory provision, while the right column contains the commentary to that provision. The mandatory provisions are numbered using the ACI style and use Arial font. The commentary is numbered to match the provision it applies to except that its number is proceeded by an R. The commentary is written in Times New Roman font. An example of this format from ACI 318-08 “Building Code Requirements for Structural Concrete and Commentary” [28] is shown in Figure 4.1.

The draft provisions provided in Chapter 5 through Chapter 8 are a compilation of provisions found in multiple standards as well as best practices reworded into mandatory language. The provisions do not represent the entirety of draft provisions for any section. Rather, the provisions provided in these chapters outline information found from other sources and the changes required for use in a design specification. For the current working draft of the proposed design specification, see Appendix A.

6.1 – Design of formwork	R6.1 – Design of formwork
6.1.1 – Forms shall result in a final structure that conforms to shapes, lines, and dimensions of the members as required by the design drawings and specifications. **6.1.2** – Forms shall be substantial and sufficiently tight to prevent leakage of mortar. **6.1.3** – Forms shall be properly braced or tied together to maintain position and shape. **6.1.4** – Forms and their supports shall be designed so as not to damage previously placed structure. **6.1.5** – Design of formwork shall include consideration of the following factors: (a) Rate and method of placing concrete; (b) Construction loads, including vertical, horizontal, and impact loads; (c) Special form requirements for construction of shells, folded plates, domes, architectural concrete, or similar types of elements. **6.1.6** – Forms for prestressed concrete members shall be designed and constructed to permit movement of the member without damage during application of prestressing force.	Only minimum performance requirements for formwork, necessary to provide for public health and safety, are prescribed in Chapter 6. Formwork for concrete, including proper design construction and removal, demands sound judgment and planning to achieve adequate forms that are both economical and safe. Detailed information on formwork for concrete is given in: **"Guide to Formwork for Concrete,"** reported by Committee 346. (This provides recommendations for design, construction, and materials for formwork, forms for special structures, and formwork for special methods of construction. Directed primarily to contractors, the suggested criteria will aid in preparing project specifications for the contractors.) ***Formwork for Concrete***, reported by ACI Committee 347. (This is a how-to-do-it handbook for contractors, engineers, and architects following the guidelines established in ACI 347. Planning, building, and using formwork are discussed, including tables, diagrams, and formulas for form design loads.)

Figure 4.1 – Example Language and Format from ACI 318-08 [28]

4.4 Format of Draft Provisions for Design Specification

The draft provisions are formatted to meet the Draft 2011 ACI Technical Committee Manual's [7] requirements of chapter 5 "Format and Language for Codes" and chapter 9 "ACI Technical Writing Style". The left column is the mandatory provision of the design specification, while the right column contains commentary on the provision. Text in italics is information included to provide background and to identify issues the ACI Committee 347 must address before completing the design standard. The draft provisions of the following chapters are provided in the U.S. inch-pound units only. The final design specification will be published in two versions, one with U.S. inch-pound units of measure and the other with the International Standards metric units of measure. The draft document in Appendix A contains both units of measure and will be separated upon final development approval of the draft by ACI Committee 347. The following detailed provisions will be considered in this thesis:

- concrete lateral pressures
- wind loads on formwork
- load combinations and load factors
- anchorage of form braces.

5. DRAFT PROVISIONS FOR CONCRETE LATERAL PRESSURE

5.1 <u>Introduction</u>

The best available information for estimating concrete pressure based on U.S. materials is found ACI 347-04. The concrete lateral pressure equations are updated as new information becomes available and is evaluated by ACI Committee 347. The ACI 347-04 equations for concrete lateral pressure include adjustments for different cement types, admixtures, temperature, unit weights of concrete, rate of placement, height of placement, and shape of structure being placed.

5.2 <u>ACI 347-04 Recommendations</u>

ACI 347-04 recommends that unless certain conditions are met, formwork should be designed for the full hydrostatic pressure based on the unit weight of the concrete mixture. It allows the formwork designer to use a lower concrete pressure value if certain conditions are met. These conditions include limitations on slump, placement height, depth of internal vibration, and the use of admixtures. The provisions containing the concrete lateral pressure equations are found in sub-section 2.2.2 of ACI 347-04 are shown in Figure 5.1.

ACI 347-04 presents the recommendations for the lateral concrete pressures in paragraph form. This requires careful reading by the user of the document to ensure that they use the appropriate equation for each specific design case. There is a current movement in ACI code requirements to change from a paragraph-based format for provisions to a tabular and equation-based format. Responding to this trend, the recommendations were reformatted as a part of this effort, as shown in Figure 5.2. One table replaces approximately two paragraphs of complex wording. This is done in an effort to make the standard easier and faster to read. The designer can match the conditions of the specific design case to the requirements of the standard much faster with the tabular and equation-based format.

2.2.2 *Lateral pressure of concrete*—Unless the conditions of Section 2.2.2.1 or 2.2.2.2 are met, formwork should be designed for the lateral pressure of the newly placed concrete given in Eq. (2.1a) or (2.1b). Minimum values given for other pressure formulas do not apply to Eq. (2.1a) and (2.1b).

$$p = wh \text{ (lb/ft}^2\text{)} \quad (2.1a)$$

$$p = \rho g h \text{ (kPa)} \quad (2.1b)$$

where

p = lateral pressure, lb/ft^2 (kPa);
w = unit weight of concrete, lb/ft^3;
ρ = density of concrete, kg/m^3;
g = gravitational constant, 9.81 N/kg; and
h = depth of fluid or plastic concrete from top of placement to point of consideration in form, ft (m).

The set characteristics of a mixture should be understood, and using the rate of placement, the level of fluid concrete can be determined. For columns or other forms that can be filled rapidly before stiffening of the concrete takes place, h should be taken as the full height of the form or the distance between horizontal construction joints when more than one placement of concrete is to be made. When working with mixtures using newly introduced admixtures that increase set time or increase slump characteristics, such as self-consolidating concrete, Eq. (2.1a) [(2.1b)] should be used until the effect on formwork pressure is understood by measurement.

2.2.2.1 *Inch-pound version*—For concrete having a slump of 7 in. or less and placed with normal internal vibration to a depth of 4 ft or less, formwork can be designed for a lateral pressure as follows, where p_{max} = maximum lateral pressure, lb/ft^2; R = rate of placement, ft/h; T = temperature of concrete during placing, °F; C_w = unit weight coefficient per Table 2.1; and C_c = chemistry coefficient per Table 2.2.[2.1]

For columns:

$$p_{max} = C_w C_c[150 + 9000R/T] \quad (2.2)$$

with a minimum of $600C_w$ lb/ft^2, but in no case greater than wh.

For walls with a rate of placement of less than 7 ft/h and a placement height not exceeding 14 ft

$$p_{max} = C_w C_c[150 + 9000R/T] \quad (2.3)$$

with a minimum of $600C_w$ lb/ft^2, but in no case greater than wh.

For walls with a placement rate less than 7 ft/h where placement height exceeds 14 ft, and for all walls with a placement rate of 7 to 15 ft/h

$$p_{max} = C_w C_c[150 + 43{,}400/T + 2800R/T] \quad (2.4)$$

with a minimum of $600C_w$ lb/ft^2, but in no case greater than wh.

Figure 5.1 –Concrete Lateral Pressure Recommendations from ACI 347-04 [10]

7.2.2 – Lateral Pressure of Concrete
7.2.2.1 – *Lateral pressure of concrete equations*

The lateral pressure of concrete, $\mathbf{p_{max}}$ (lbs/ft^2), shall be determined in accordance with the appropriate equation listed in Table 7.2.2.1a.

When working with mixtures using newly introduced admixtures that increase set time or increase slump characteristics, such as Self-Consolidating Concrete, Equation 7.2.2.1a shall be used until the effect on formwork pressure is understood by testing.

Table 7.2.2.1a – Applicable concrete lateral pressure equations

Slump*	Internal vibration depth	Element	Rate of placement	Pressure Equation
> 7 in	Any	Any	Any	7.2.2.1a
≤ 7 in	> 4 ft	Any	Any	7.2.2.1a
≤ 7 in	≤ 4 ft	Column†	Any	7.2.2.1b
		Wall‡ ≤ 14 ft tall	< 7 ft/hr	7.2.2.1b
		Wall‡ > 14 ft tall	< 7 ft/hr	7.2.2.1c
		Wall‡	7 to 15 ft/hr	7.2.2.1c
			> 15 ft/hr	7.2.2.1a

* Slump for determination of lateral pressure shall be measured after the addition of all admixtures

† Columns are defined as vertical elements with no plan dimension exceeding 6.5 ft.

‡ Walls are defined as vertical elements with at least one plan dimension exceeding 6.5 ft.

$$\mathbf{p_{max} = wh} \qquad (7.2.2.1a)$$

Where:
w = unit weight of concrete (lbs/ft^3)
h = height of concrete placement (ft)

$$\mathbf{p_{max} = C_W C_C[150 + 9000R/T]} \qquad (7.2.2.1b)$$

with a minimum of $\mathbf{600C_w}$ lb/ft^2, but in no case greater than **wh**

$$\mathbf{p_{max} = C_W C_C[150 + 43{,}000/T + 2800R/T]} \qquad (7.2.2.1c)$$

with a minimum of $\mathbf{600C_w}$ lb/ft^2, but in no case greater than **wh**

Where:
$\mathbf{C_W}$ = Unit Weight Coefficient from Table 7.2.2.1b
$\mathbf{C_C}$ = Chemistry Coefficient from Table 7.2.2.1c
R = Rate of placement (ft/hr)
T = Temperature of concrete (°F)

R7.2.2.1 The set characteristics of a mixture should be understood, and using the rate of placement, the level of fluid concrete can be determined. For columns or other forms that can be filled rapidly before stiffening of the concrete takes place, **h** should be taken as the full height of the form of the distance between horizontal construction joints when more than one placement of concrete is to be made.

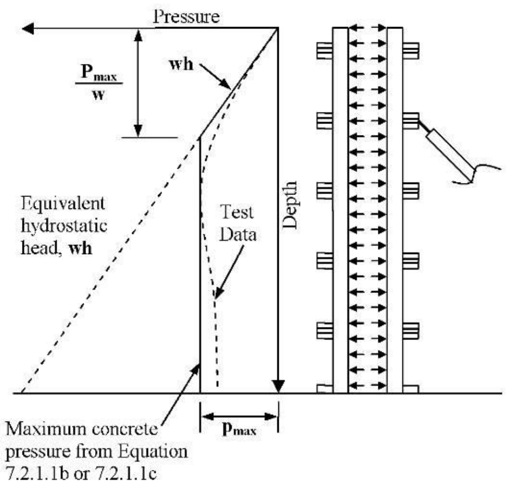


Figure R7.2.2.1a – Concrete Lateral Pressure on Column and Wall Formwork

Equations 7.2.2.1a, 7.2.2.1b, and 7.2.2.1c along with Table 7.2.2.1b and 7.2.2.1c are from Reference 7.1.

Figure 5.2 – Draft Provisions for Concrete Lateral Pressure

The table defining the Chemistry Coefficient in ACI 347-04 has been reformatted to reduce the number of words needed to convey the information and also to clarify the conditions. ACI 347-04 contains the conditions for each chemistry coefficient in sentence form, as shown in Table 5.1. Two of the conditions for the chemistry coefficient state “Other types or blends”, which can be incorrectly interpreted to exclude the already mentioned types of Type I, Type II, and Type III. Also, the proportions of fly ash for each requirement are not clearly worded. It is difficult to tell if the two conditions are for less than 40% fly ash or exactly 40% fly ash. To clarify these conditions, the chemistry coefficient table was reformatted and is shown in the draft Table 7.2.1.1c in Figure 5.4.

Table 5.1 - Chemistry Coefficient Table from ACI 347-04 [10]

Cement type or blend	C_c
Types I, II, and III without retarders*	1.0
Types I, II, and III with a retarder	1.2
Other types or blends containing less than 70% slag or 40% fly ash without retarders*	1.2
Other types or blends containing less than 70% slag or 40% fly ash with a retarder*	1.4
Blends containing more than 70% slag or 40% fly ash	1.4

*Retarders include any admixture, such as a retarder, retarding water reducer, retarding midrange water-reducing admixture, or high-range water-reducing admixture (superplasticizer), that delays setting of concrete.

Table 5.2 – Draft Provision for Concrete Chemistry Coefficient

Cement type	Slag	Fly Ash	Retarders*	C_C
I, II, or III	None	None	None	1.0
			Included	1.2
Any	< 70%	< 40%	None	1.2
			Included	1.4
	≥ 70%	≥ 40%	None	1.4
			Included	1.5

* Retarders include any admixture, such as a retarder, retarding water reducer, retarding midrange water-reducing admixture, or high-range water-reducing admixture (superplasticizer), that delays setting of concrete.

Recommendations of ACI 347-04 are written in non-mandatory language requiring either rewording of the provision or placement in the commentary of the design specification. An example of a recommendation requiring rewording can be found in Subsection 2.2.2.4 of ACI 347-04 shown in Figure 5.3. The reworded draft of the provision can be seen in Figure 5.4.

2.2.2.4—Caution is necessary and additional allowance for pressure should be considered when using external vibration or concrete made with shrinkage compensating or expansive cements. Pressures in excess of the equivalent hydrostatic head can occur.

Figure 5.3 – Cautionary Statement on External Vibration from ACI 347-04 [10]

7.2.2.4 – *Externally vibrated concrete*

When concrete is consolidated by external vibration, the formwork designer shall consider the additional effect of external vibration on form pressure.

R7.2.2.4- Caution is necessary and additional allowance for pressure should be considered when using external vibration. Pressures in excess of the equivalent hydrostatic head can occur.

7.2.2.5 – *Shrinkage compensating or expansive cements*

When concrete mixtures contain shrinkage compensating or expansive cements, the formwork designer shall consider the additional effect of expansion on form pressure.

R7.2.2.5 – Caution is necessary and additional allowance for pressure should be considered when using concrete mixtures made with shrinkage compensating or expansive cements. Pressures in excess of the equivalent hydrostatic head can occur.

Figure 5.4 – Draft Provision for Concrete Consolidated by External Vibration

6. WIND LOADS ON FORMWORK

6.1 Introduction

Wind loads on temporary structures pose a complex problem due to the varying nature of wind and the interaction with different structures. ACI 347-04 recommends that wall forms be designed for wind in accordance with ASCE 7 and using adjustment factors for shorter durations from ASCE 37. ASCE 7 and ASCE 37 contain provisions for wind loads on permanent and temporary structures respectively. Many factors must be considered in determining the wind load on a temporary structure including wind speeds, surrounding terrain, the shape of the structure, and effects of shielding. Many of the ASCE provisions focus on the structure as a whole rather than individual components. Development of clear guidelines for the application of these two documents to the design of formwork is needed.

6.2 ASCE 7 Wind Design Method

ASCE 7-95 and 7-05 use the same design method for wind loads, only with variations of the input variables into the design equations. A design method usable for determining wind load on formwork is outlined here.

First, the basic wind speed for the location is determined from a map of maximum wind speeds. The wind speeds are based on an anticipated design life, and therefore exposure period, of 50 years. This basic wind speed is used to determine the velocity pressure, q_z, for the object. The equation for velocity pressure is:

$$q_z = 0.00256 K_z K_{zt} K_d V^2 I \qquad \text{(Eqn. 6.1)}$$

where:

q_z	=	velocity pressure (lbs/ft^2);
K_z	=	velocity pressure exposure coefficient;
K_{zt}	=	topography factor;
K_d	=	wind directionality factor;
V	=	wind velocity (mph); and
I	=	importance factor.

The factors K_{zt} and K_d are used to account for topography effects of the surroundings and directionality effects of the structure. The velocity pressure exposure coefficient, K_z, is a factor that adjusts the wind pressure to account for the height of the object and the exposure category. The importance factor, I, is used to reduce or amplify the wind pressure depending on the risk to human life should the structure fail.

Second, the force, F, for a specific object shape is determined. For the shapes used in formwork, the appropriate equation is:

$$F = q_z G C_f A_f, \qquad \text{(Eqn. 6.2)}$$

where:

F	=	wind force on object;
q_z	=	velocity pressure;
G	=	gust effect factor;
C_f	=	force coefficient; and
A_f	=	projected area normal to wind.

The gust effect factor, G, accounts for the dynamic response of the structure. For formwork, the structure is assumed rigid and therefore G is 0.75 per ASCE 7-05. The force coefficient, C_f, is used to adjust the velocity pressure to account for wind flow around the object shape. For large, square objects, such as signs or wall forms, this factor typically ranges from 1.0 to 3.0. The resulting force, F, is typically applied at the center of area of the structural shape; however, for some shapes, such as signs and freestanding walls, a different location for this force is specified in ASCE 7-05 due to variation in pressure with height.

For temporary structures, the exposure period is considerably less than 50 years. To account for this, ASCE 37 adjusts the basic wind speeds, as discussed in the following section. Also, ASCE 7 does not permit the design for wind to consider shielding, the logic being that the conditions that result in shielding cannot be predicted for a 50 year period. However, ASCE 37 does permit shielding to be considered, but a design method for shielding is not provided. A shielding design method is discussed later in this chapter.

6.3 Wind Speeds

ASCE 37-02 references ASCE 7-95 for basic wind speeds and provides factors for reducing the ASCE 7-95 basic wind speed to a design wind speed for shorter exposure durations typically seen in temporary works, such as formwork. These reduction factors to the basic wind speed can be seen in Figure 6.1.

6.2.1 Design Velocity

The design wind speed shall be taken as the following factor multiplied by the basic wind speed in ASCE 7-95:

Construction Period	Factor
less than 6 weeks	0.75
6 weeks to 1 year	0.8
1 to 2 years	0.85
2 to 5 years	0.9

Figure 6.1 – Basic Wind Speed Reduction Factors from ASCE 37-02 [13]

Since the pressure is a function of V^2, the 0.75 factor, for example, reduces the pressure to 0.75^2 or 0.56 of the normal pressure. ASCE 7-05 contains some improved methods that can be applied to formwork that were not available in ASCE 7-95. There were only minor changes in the wind speed maps from the 1995 to 2005 editions. Thus, it appears the ASCE 7-05 can be used in combination with ASCE 37-02 without undermining the intent of ASCE 37-02. However, the increased wind speeds of ASCE 7-10 are not compatible with ASCE 37-02 and will be discussed in further detail in section 7.4 of this thesis. An explicit statement could supersede the provision of ASCE 37-02 and allow the formwork designer to use ASCE 7-05 provisions. To accomplish this, the draft design specification for formwork requires in sub-section 7.3.1.1 that the basic wind speed and force calculation methods be taken from ASCE 7-05. After determining the basic wind speed, sub-section 7.3.1.3 of the draft states that reduction factors for shorter durations are applied per ASCE 37-02. These provisions are shown in Figure 6.2.

7.3.1.1 – *Basic Wind Speed*

The basic wind speed shall be determined in accordance with ASCE 7-05 for a Risk Category II structure.

R7.3.1.1 – The Importance Factor, **I**, for temporary structures in construction is 1.0 for all environmental loads per ASCE 37-02. This corresponds to a Risk Category II structure in the ASCE 7-05 classification system.

ASCE 37-02 references ASCE 7-95 for wind speeds; however, ASCE 7-05 represents the most recent revision of ASCE 7 to which ASCE 37-02 reduction factors are applicable. At the time of this draft, ASCE 37 has not been updated to reflect the changes made in ASCE 7-10.

ASCE 7-10 recognizes that applying a blanket factor to wind loads does not reflect the actual variability throughout the US. ASCE 7-10 removes the Importance Factor for wind and instead accounts for the buildings importance by establishing different wind contour maps for different Importance levels, each with a different return period. Also, the wind load factor of 1.6 is removed by increasing the return period of the wind speeds as well. A detailed explanation of this change can be found in the commentary of ASCE 7-10, starting on page 508.

The ASCE 37-02 wind speed reductions and ASCE 37-02 load factors are not applicable to the ASCE 7-10 wind speeds. Until a revision of ASCE 37 has been published to reflect the design practice changes of ASCE 7-10, ASCE 7-05 will be the source of provisions for wind load on temporary structures.

ASCE 7-05 includes several relevant changes versus ASCE 7-95:

- *The wind speed contour lines have been revised; however the speeds have not.*
- *It increased the load factor on wind from 1.3 to 1.6 for permanent structures.*
- *It contains a more detailed approach for wind loads on wall and Solid Signs.*

Since ASCE 37-02 reduces the wind speeds to 90 mph in hurricane regions, the changes in the wind speed contours only apply in the event of an announced hurricane. Also, since ASCE 37-02 provides its own set of load factors for wind loads on temporary structures, the changes in ASCE 7's load factors do not apply. The only significant change is the analysis method for wall and solid signs, which is applicable to wall formwork.

7.3.1.2 – *Hurricane Prone Regions*

Wind velocities for hurricane-prone regions shall comply with the requirements of ASCE 37-02 Sub-section 6.2.1.1 *Construction Period*.

R7.3.1.2 - ACSE 37-02 sub-section 6.2.1.1, *Construction Period*, allows for the reduction of the Basic Wind Speed to a speed of 90 mph in regions along the Gulf Coast and Eastern Seaboard subject to hurricanes. This reduced Basic Wind Speed corresponds to the Basic Wind Speed for the majority of the interior of the US as shown in referenced standard ASCE 7-95.

7.3.1.3 – *Design Velocity*

The basic wind speed from sub-sections 7.3.1.1 and 7.3.1.2 shall be adjusted by multiplying the basic wind speed by the appropriate reduction factor found in ASCE 37-02 Section 6.2.1 to determine the design wind velocity on a formwork system.

R7.3.1.3 - ASCE 37-02 provides reduction factors to adjust the Basic Wind Speed for temporary work to account for the short exposure durations of temporary structures.

Figure 6.2 – Draft Provisions for Determination of Wind Speed

6.4 Reduction of Wind Speeds to Exclude Predictable Extreme Values

In many coastal areas of the U.S., hurricane winds govern wind speeds for permanent structures. However, hurricanes are random events whose occurrence is predictable on a time scale relevant to temporary structures. Hurricanes are spotted and tracked weeks in advance and warning of their impact on the U.S. is provided days in advance. This allows adequate time to either provide additional bracing or to remove the temporary structure. In addition to providing wind speed reduction factors, ASCE 37-02 allows designers of temporary structures to exclude hurricane winds as shown in Figure 6.3. The basic wind speed is reduced to 90 mile per hour in regions of the country subject to hurricane winds if the structure is either removed or additional bracing is provided before onset of the hurricane. By not requiring design to hurricane wind speeds, except when hurricane impact is imminent, this reduces the maximum wind force that a temporary structure must be designed to resist, increasing the economy of temporary structures.

It can be argued that even the 90 mile per hour basic wind speed that is the design speed for the majority of the U.S. is also excessive for formwork. The Council for Masonry Wall Bracing publishes a standard for designing the bracing of masonry walls titled "Standard Practice for Bracing Masonry Walls Under Construction" [29]. This standard addresses the issue of wind loads on work-in-progress and provides a rational for safe design and construction. It does not require the masonry contractor to design the masonry structure for the full wind speed of ASCE 7 or the applicable reduced wind speed of ASCE 37-02. Instead it specifies working wind speeds and requires evacuation of the work area should wind levels exceed working wind speeds. With modern weather prediction capabilities, often warnings of high wind speeds are provided in advance of their occurrence, allowing for additional bracing to be prepared for formwork systems. Furthermore, these wind speeds occur during major storms in which a construction site would typically be evacuated and unoccupied, posing very little risk of injury to personnel.

6.2.1.1 Construction Period. The construction period shall be taken as the time interval from first erection to structural completion of each independent structural system, including installation of cladding.

For construction periods less than 6 weeks, factors of less than 0.75 shall be permitted if justified by a statistical analysis of local wind data for the season during which the subject construction conditions will exist.

For construction between November 1 and July 31 (outside of the hurricane season), the unfactored basic wind speed of 90 mph (40 m/s) shall be permitted for structures near the Gulf Coast and Eastern Seaboard where ASCE 7-95–specified basic wind speed exceeds 90 mph (40 m/s) (3-second gust).

Between August 1 and October 31, basic wind speed of 90 mph (40 m/s) shall be permitted provided additional bracing is prepared in advance and applied in time before the onset of an announced hurricane.

C6.2.1.1 Construction Period. The dates selected to represent the hurricane season are not intended to include all times when hurricanes are possible. The dates are intended to include the period when the most severe hurricanes are probable.

Figure 6.3 – Reduction of Wind Speed in Hurricane Regions from ASCE 37-02 [13]

Certain construction situations can pose risk to the public even when the site is evacuated during storm conditions; examples being formwork construction in urban areas and high-rise construction next to roadways. In these situations, it is reasonable to design the formwork system to the full requirements of ASCE 37-02. While it would be economical for formwork designers to be allowed to design to a lower wind speed in certain situations, there are other factors to consider. To allow for the ready adoption of this document and to avoid interfering with other standards, it is recommended that this design specification should not attempt to reduce the wind speed below those required in ASCE 37.

6.5 <u>Shielding of Wind</u>

Shielding is the situation where the wind pressure on an element is less because it is protected by a windward object. ASCE 7-05 does not allow for consideration of shielding when determining the wind force on a permanent structure because the windward object may be removed in the long life of the structure. ASCE 37-02 does allow for the consideration of shielding on temporary structures. The provisions for shielding do not provide a rigorous methodology, but applies a reduction on repetitive members regardless of their shape or spacing and allows a reduction when protected by surroundings.

For temporary structures like formwork, the condition of the shielding structure by surroundings can be predicted readily for the life of the system. The California Department of Transportation Falsework Manual [30] provides a method of determining the shielding by an obstruction. This method is proposed as the basis for provisions for shielding by other objects in the formwork design specification, as shown in Figure 6.4.

7.3.3.2 – *Shielding by Other Structures*

Formwork shielding shall be permitted for a portion of formwork contained within a shielding zone of an existing structure or obstruction. The zone of shielding shall be the projected face reduced by a rate 1 inward for 2 downwind of the obstruction as shown in Figure 7.3.3.2. This zone of shielding applies to both vertical and horizontal shielding.

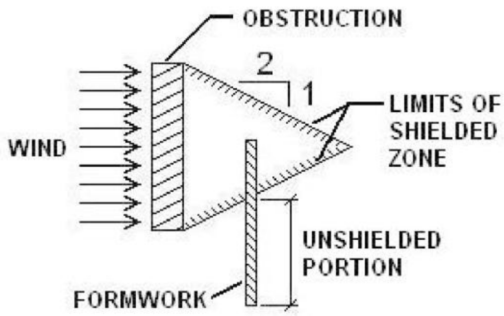


Fig. 7.3.3.2 – Wind shielding by obstruction

R7.3.3.2 - An existing structure or obstruction is any free-standing structure that will remain in place for the duration of the formwork system and can withstand the wind loads imposed on it. This can include recently completed concrete work that has gained sufficient strength to withstand wind loads. It can also include excavations or soil mounds that obstruct wind flow from a specific direction. Any mobile structure, such as equipment, should not be used as shielding.

This method is used by Cal. DOT Falsework Manual as well as British Standard BS5975. Figure 7.3.3.2 is based on Figure 3-6 in Cal. DOT Falsework Manual, 1992.

Figure 6.4 – Draft Provisions for Shielding of Formwork by Obstruction

Shapiro and Shapiro provide a more detailed analysis method for determining the shielding on repetitive members. The detailed analysis in Shapiro and Shapiro is used as the basis for the draft provisions on shielding of repetitive members. This method requires the calculation of a shielding coefficient, η_m, that that modifies the force coefficient for the windward member. The shielding coefficient is a function of the shape of the member and the spacing between members. The figure for determining this shielding coefficient provided in Shapiro and Shapiro was reproduced from the 1970 standard “Rules for the Design of Hoisting Appliances” by the Fédération Européene de la Manutention. The methodology proposed for the formwork design specification is presented in Figure 6.5.

7.3.3.3 – *Wind Shielding on Repetitive Members*

The effective area, $\mathbf{A_f}$, for repetitive members shall be the projected area of an individual member for which the specific cumulative shielding coefficient, $\boldsymbol{\eta_m}$, is determined.

When different sizes, types, spacing, or rows of repetitive members are used; a force coefficient ($\mathbf{C_f}$), $\boldsymbol{\eta_m}$, and $\mathbf{A_f}$ shall be determined for each scenario.

$\mathbf{C_f}$ for repetitive members subject to shielding due to alignment shall be:

$$\mathbf{C_f = \eta_m C_{fi}} \qquad (7.3.3.3a)$$

Where: $\boldsymbol{\eta_m}$ = cumulative shielding coefficient from Equation 7.3.3.3b

$\mathbf{C_{fi}}$ = force coefficient from ASCE 7-05 for an individual member or from Section 7.3.4

$$\boldsymbol{\eta_m = 1 + \eta^1 + \eta^2 + \eta^3 + \eta^4 + \ldots + \eta^{(m-1)} \leq (1 - \eta)^{(m-1)}} \qquad (7.3.3.3b)$$

Where: $\boldsymbol{\eta}$ = shielding coefficient from Figure 7.3.3.3

$\mathbf{m}$ = number of identical, equidistant objects

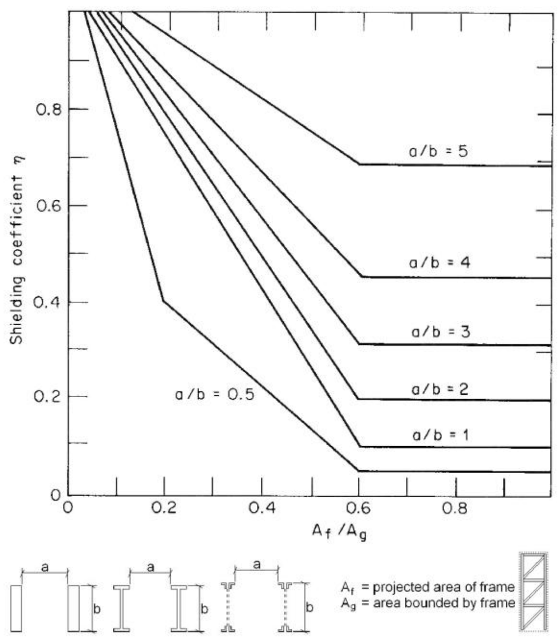


Fig. 7.3.3.3 – Shielding coefficient for repetitive members (reprinted from Cranes & Derricks, 4th edition, Shapiro)

R7.3.3.3 - The shielding coefficient, $\boldsymbol{\eta_m}$, is applied to the force coefficient, $\mathbf{C_f}$, for an individual member in a series of repetitive members. ASCE 7-05 provides $\mathbf{C_f}$ values for latticed or trussed towers. When latticed or trussed towers are used in series and shielding is considered, then $\boldsymbol{\eta_m}$ is applied to the $\mathbf{C_f}$ value for one instance of the tower. For generic shapes, Cranes and Derricks, 4th Edition by Shapiro & Shapiro (2011) is a source of shape factors, $\mathbf{C_s}$, which can be used as force coefficients, $\mathbf{C_f}$.

Equation 7.3.3.3a is used to combine the equation from Cranes and Derricks 4th edition by Shapiro & Shapiro (2011) with ASCE 7-05 Equation 6-28 by providing a new force coefficient, $\mathbf{C_f}$*, that combines the individual member force coefficient,* $\mathbf{C_{fi}}$*, and the cumulative shielding coefficient,* $\boldsymbol{\eta_m}$

Equation 7.3.3.3b and Figure 7.3.3.4 are from Cranes and Derricks 4th edition by Shapiro & Shapiro (2011). Figure 7.3.3.3 is provided in Shapiro and Shapiro and was reproduced from the 1970 standard "Rules for the Design of Hoisting Appliances" by the Fédération Européene de la Manutention.

Figure 6.5 – Draft Provisions for Shielding Coefficient for Repetitive Members

6.6 <u>Detailed Analysis Methods for Wind Loads</u>

ASCE 7-05 provides detailed methods of analysis for wind loads on certain shapes of completed structures. One specific analysis method that is readily applicable to formwork is ACSE 7-05 Section 6.5.14, Design Wind Loads on Solid Freestanding Walls and Solid Signs. This analysis method provides force coefficients for various configurations of freestanding walls similar to wall formwork. Figure 6.6 shows the provisions from ASCE 7-05 for freestanding walls, using force coefficients from ASCE 7-05 Figure 6-20, which is shown in Figure 6.7 of this thesis.

6.5.14 Design Wind Loads on Solid Freestanding Walls and Solid Signs. The design wind force for solid freestanding walls and solid signs shall be determined by the following formula:

$$F = q_h G C_f A_s \text{ (lb) (N)} \qquad (6\text{-}27)$$

where

q_h = the velocity pressure evaluated at height h (defined in Fig. 6-20) using exposure defined in Section 6.5.6.4.1
G = gust-effect factor from Section 6.5.8
C_f = net force coefficient from Fig. 6-20
A_s = the gross area of the solid freestanding wall or solid sign, in ft^2 (m^2)

6.5.15 Design Wind Loads on Other Structures. The design wind force for other structures shall be determined by the following equation:

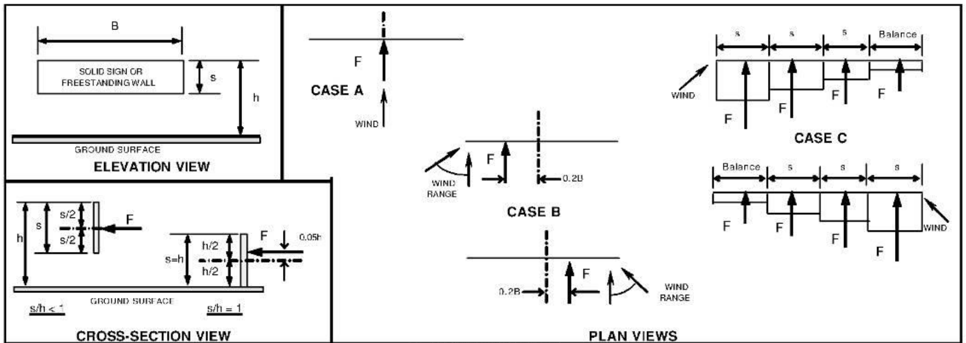
$$F = q_Z G C_f A_f \text{ (lb) (N)} \qquad (6\text{-}28)$$

where

q_z = velocity pressure evaluated at height z of the centroid of area A_f using exposure defined in Section 6.5.6.3
G = gust-effect factor from Section 6.5.8
C_f = force coefficients from Figs. 6-21 through 6-23
A_f = projected area normal to the wind except where C_f is specified for the actual surface area, ft^2 (m^2)

Figure 6.6 – Detailed Analysis Methods from ASCE 7-05 [18]

Other Structures – Method 2		All Heights
Figure 6-20	Force Coefficients, C_f	**Solid Freestanding Walls & Solid Signs**



C_f, CASE A & CASE B

Clearance Ratio, s/h	Aspect Ratio, B/s											
	≤ 0.05	0.1	0.2	0.5	1	2	4	5	10	20	30	≥ 45
1	1.80	1.70	1.65	1.55	1.45	1.40	1.35	1.35	1.30	1.30	1.30	1.30
0.9	1.85	1.75	1.70	1.60	1.55	1.50	1.45	1.45	1.40	1.40	1.40	1.40
0.7	1.90	1.85	1.75	1.70	1.65	1.60	1.60	1.55	1.55	1.55	1.55	1.55
0.5	1.95	1.85	1.80	1.75	1.75	1.70	1.70	1.70	1.70	1.70	1.70	1.75
0.3	1.95	1.90	1.85	1.80	1.80	1.80	1.80	1.80	1.80	1.85	1.85	1.85
0.2	1.95	1.90	1.85	1.80	1.80	1.80	1.80	1.80	1.85	1.90	1.90	1.95
≤0.16	1.95	1.90	1.85	1.85	1.80	1.80	1.85	1.85	1.85	1.90	1.90	1.95

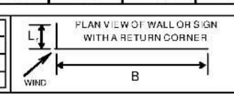
C_f, CASE C

Region (horizontal distance from windward edge)	Aspect Ratio, B/s								
	2	3	4	5	6	7	8	9	10
0 to s	2.25	2.60	2.90	3.10*	3.30*	3.40*	3.55*	3.65*	3.75*
s to 2s	1.50	1.70	1.90	2.00	2.15	2.25	2.30	2.35	2.45
2s to 3s		1.15	1.30	1.45	1.55	1.65	1.70	1.75	1.85
3s to 10s			1.10	1.05	1.05	1.05	1.05	1.00	0.95

Region (horizontal distance from windward edge)	Aspect Ratio, B/s	
	13	≥ 45
0 to s	4.00*	4.30*
s to 2s	2.60	2.55
2s to 3s	2.00	1.95
3s to 4s	1.50	1.85
4s to 5s	1.35	1.85
5s to 10s	0.90	1.10
>10s	0.55	0.55

*Values shall be multiplied by the following reduction factor when a return corner is present:

L_r/s	Reduction Factor
0.3	0.90
1.0	0.75
≥ 2	0.60



Notes:
1. The term "signs" in notes below also applies to "freestanding walls".

2. Signs with openings comprising less than 30% of the gross area are classified as solid signs. Force coefficients for solid signs with openings shall be permitted to be multiplied by the reduction factor $(1 - (1 - \varepsilon)^{1.5})$.

3. To allow for both normal and oblique wind directions, the following cases shall be considered:
   For s/h < 1:
   CASE A: resultant force acts normal to the face of the sign through the geometric center.
   CASE B: resultant force acts normal to the face of the sign at a distance from the geometric center toward the windward edge equal to 0.2 times the average width of the sign.
   For B/s ≥ 2, CASE C must also be considered:
   CASE C: resultant forces act normal to the face of the sign through the geometric centers of each region.
   For s/h = 1:
   The same cases as above except that the vertical locations of the resultant forces occur at a distance above the geometric center equal to 0.05 times the average height of the sign.

4. For CASE C where s/h > 0.8, force coefficients shall be multiplied by the reduction factor (1.8 - s/h).

5. Linear interpolation is permitted for values of s/h, B/s and L_r/s other than shown.

6. Notation:
   B: horizontal dimension of sign, in feet (meters);
   h: height of the sign, in feet (meters);
   s: vertical dimension of the sign, in feet (meters);
   ε: ratio of solid area to gross area;
   L_r: horizontal dimension of return corner, in feet (meters)

Figure 6.7 –ASCE 7-05 Force Coefficients for Solid Freestanding Walls and Solid Signs [18]

Section 6.5.15 of ASCE 7-05 provides a method for other structures or for components of structures as shown in Figure 6.6 of this thesis. This analysis method is very similar to the method for freestanding walls; the only difference being the location of the resulting force and the force coefficients used. Figures 6-21 through 6-23 of ASCE 7-05 provide force coefficients for selected structure components; including trussed towers, lattice frameworks, and chimney-like structures. Trussed towers are often used as shoring for tall elevated structures, while tall column forms may be considered chimney-like structures. However, ASCE 7-05 does not provide a comprehensive list of force coefficients for structure component shapes.

British Standard BS 5975:2008 uses a similar analysis method as ASCE 7-05 and provides force coefficients for typical configurations of elevated slab formwork. These force coefficients and related provisions, shown in Figure 6.8, are reproduced in the draft design specification. Shapiro and Shapiro [23] provide force coefficients for individual structural members which may be used in the ASCE 7 methods. Force coefficients for common structural shapes as provided in Shapiro and Shapiro are incorporated in the proposed specification (Figure 6.9).

7.3.4.6 – *Wind Loads on Elevated Slab Formwork*

C_f of elevated slab formwork shall be determined from Table 7.3.4.6. This force coefficient applies to the slab formwork only and acts through the mid height of the slab formwork. A separate analysis shall be performed for the shoring system supporting the slab formwork.

Table 7.3.4.6 –C_f for elevated slab formwork

Arrangement Case	C_f
Case 1 (Figure 7.3.3.6a)	2.0
Case 2 (Figure 7.3.3.6b)	2.2

A_f of the windward face of elevated slab formwork shall be:

A_f = d x length of formwork considered (7.3.4.6)

Where: **d** = depth of windward face depending on applicable case shown in Figures 7.3.4.6a and 7.3.4.6b

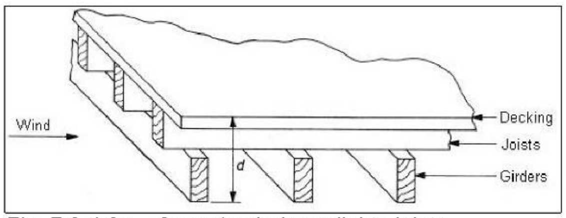


Fig. 7.3.4.6a – Case 1: wind parallel to joists

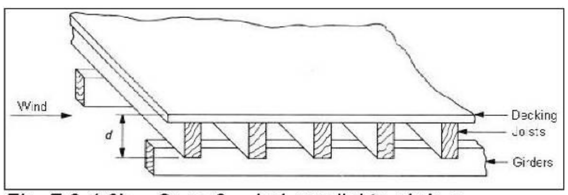


Fig. 7.3.4.6b – Case 2: wind parallel to girders

Wind force is only considered to act on one windward face of elevated slab formwork and is not cumulative on all secondary members of elevated slab formwork. No shielding coefficient shall be applied to joists or girders.

British Standard BS 5975:2008, section 17.5.1.14.2 provides a simplified method of allowing for shielding of repetitive members of elevated slab formwork systems. This method multiplies the projected area of the formwork by a factor depending on the orientation of the supporting members.

Figure 6.8 – Draft Provisions for Force Coefficients for Elevated Slab Formwork (from BS 5975:2008) [24]

7.3.4.7 – *Force Coefficients for Selected Shapes*

Table 7.3.4.7 is from Cranes and Derricks 4th edition by Shapiro & Shapiro (2011)

Table 7.3.4.7 provides $\mathbf{C_f}$ for selected structural shapes.

Table 7.3.4.7 – Force coefficients for selected members

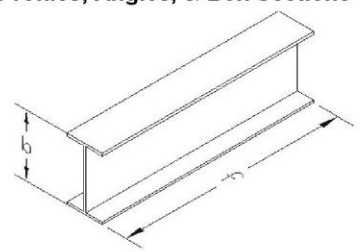
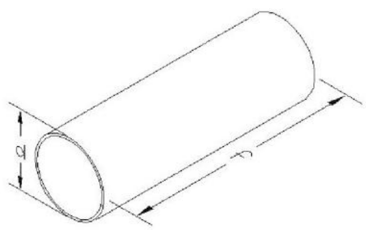
Profiles, Angles, & Box Sections	**f / b**	**C_f**
	50	1.9
	40	1.7
	30	1.65
	20	1.60
	10	1.35
	5	1.30
Tubes	d x V < 50 ft^2/s	
	f/d	**C_f**
	50	1.10
	40	1.00
	30	0.95
	20	0.90
	10	0.80
	5	0.75
	d x V ≥ 50 ft^2/s	
	f/d	**C_f**
	50	0.80
	40	0.75
	30	0.70
	20	0.70
Where: d = diameter (ft)	10	0.65
V = wind velocity (ft/s)	5	0.60

Figure 6.9 – Draft Provisions of Force Coefficients for Common Structural Shapes (from Shapiro & Shapiro) [23]

6.7 Wind Loads for Generic Formwork Cases

In an effort to aid formwork designers, generic wind forces have been determined for common formwork systems that meet certain limiting criteria. For a specific formwork shape that meets certain criteria, these generic wind forces replace the detailed analysis required. The criteria on which this generic case is developed must be stated in the mandatory section of the design standard to provide enforceable limitations of its use in practice. Figure 6.10 shows the provision for the generic case of a simple wall form. A detailed derivation of this force can be found in Appendix B. Figure 6.11 shows the provision for the generic case of an elevated slab form. A detailed derivation of this force can be found in Appendix C.

7.3.4.5a – *Generic Wind Force for Walls*

Equation 7.3.4.5a may be applied to determine the wind load on wall forms provided the following conditions are met:

a. Basic wind speed from Section 7.3.1 is ≤ 90 mph
b. Formwork height not to exceed 20 feet from ground level
c. Formwork duration is less than 6 weeks
d. Formwork is not placed at the top of a hill or in an accelerated wind region
e. Formwork length does not exceed 3 times the height

$\mathbf{F_{wall} = 15h}$ (7.3.4.5a)

Where:

$\mathbf{F_{wall}}$ = wind force along wall form (lbs/ft), applied at mid height of wall form
h = height of wall form (ft)

R7.3.4.5a - The generic design force is based ASCE 7-05 Equation 6-27 using on the following factors:

Basic wind speed: 90 mph
< 6 week duration: 0.75 wind speed reduction
Directionality factor, $\mathbf{K_d}$: 0.85
Terrain Factor, $\mathbf{K_{zt}}$: 1.0
Exposure Category: C, Coefficient, $\mathbf{K_z}$, at 20ft: 0.90
Gust Factor, **G**: 0.85 for a rigid structure
Force Coefficient, $\mathbf{C_f}$: 1.80 for a solid sign with aspect ratio of 3

These factors result in a wind pressure of 13.6 psf applied to a wall. The resulting force is 13.6*h and is applied at a point 0.55h from the base of the wall per ASCE 7-05 Figure 6-20. To provide an equivalent resultant force at the center of the wall, the wind pressure is multiplied by 1.1, resulting in a wind pressure of 15.0 psf.

A lower wind force may be used provided it complies with Sub-section 7.3.4.4 or 7.3.4.5

Figure 6.10 – Draft Provisions for Generic Wind Force for Wall Forms

7.3.4.6b – *Generic Wind Force for Elevated Slabs*

A generic wind force of 70 pounds per linear foot of elevated slab form may be applied to determine the wind load on elevated slab forms provided the following conditions are met.

a. Basic wind speed from Section 7.3.1 is ≤ 90 mph
b. Formwork height not to exceed 40 feet from ground level
c. Formwork duration is less than 6 weeks
d. Formwork is not placed at the top of a hill or in an accelerated wind region
e. Depth of the slab formwork (**d**) shall not exceed 2 feet
f. Depth of the slab edge form ($\mathbf{d_1}$) shall not exceed 1 foot

This generic wind force is applied at the top edge of the elevated slab form.

R7.3.465b - The generic design force is based ASCE 7-05 Equation 6-28 using on the following factors:

Basic wind speed: 90 mph
< 6 week duration: 0.75 wind speed reduction
Directionality factor (K_d): 0.85
Terrain Factor (K_{zt}): 1.0
Exposure Category: C, Coefficient (K_z) at 40ft: 1.04
Gust Factor (G): 0.85 for a rigid structure
Force Coefficient (C_f): 2.2 from Table 7.3.4.6
Depth of Slab Formwork: ≤ 2 ft
Depth of Slab Edge Forms: ≤ 1 ft, 2 edge forms, no shielding

A lower wind force may be used provided it complies with Sub-section 7.3.4.4 or 7.3.4.6

NOTE: This is less than ACI's recommended minimum force of 100 pounds per linear foot, should we provide a minimum elevation where wind should be considered over the ACI minimum? Does ACI's force also account for wind load on shoring?

Figure 6.11 – Draft Provisions for Generic Wind Force for Elevated Slab Forms

6.8 ACI 347-04 Minimum Recommendations

ACI 347-04 provides minimum values for horizontal loadings to ensure a minimum level of stability is achieved regardless of the wind exposure. These minimum horizontal loads were first provided in the original publication in 1963 [15]. In the 1978 publication of ACI 347 [16] the minimum wind pressure on wall forms was increased from 10 pounds per square foot to 15 pounds per square foot and this load has been continued to the 2004 edition. The provisions of ACI 347-04 regarding wind loads are shown in Figure 6.12.

2.2.3 *Horizontal loads*—Braces and shores should be designed to resist all horizontal loads such as wind, cable tensions, inclined supports, dumping of concrete, and starting and stopping of equipment. Wind loads on enclosures or other wind breaks attached to the formwork should be considered in addition to these loads.

2.2.3.1—For building construction, the assumed value of horizontal load due to wind, dumping of concrete, inclined placement of concrete, and equipment acting in any direction at each floor line should be not less than 100 lb/linear ft (1.5 kN/m) of floor edge or 2% of total dead load on the form distributed as a uniform load per linear foot (meter) of slab edge, whichever is greater.

2.2.3.2—Wall form bracing should be designed to meet the minimum wind load requirements of the local building code or ANSI/SEI/ASCE-7 with adjustment for shorter recurrence interval as provided in SEI/ASCE 37. For wall forms exposed to the elements, the minimum wind design load should be not less than 15 lb/ft^2 (0.72 kPa). Bracing for wall forms should be designed for a horizontal load of at least 100 lb/linear ft (1.5 kN/m) of wall length, applied at the top.

2.2.3.3—Wall forms of unusual height or exposure should be given special consideration.

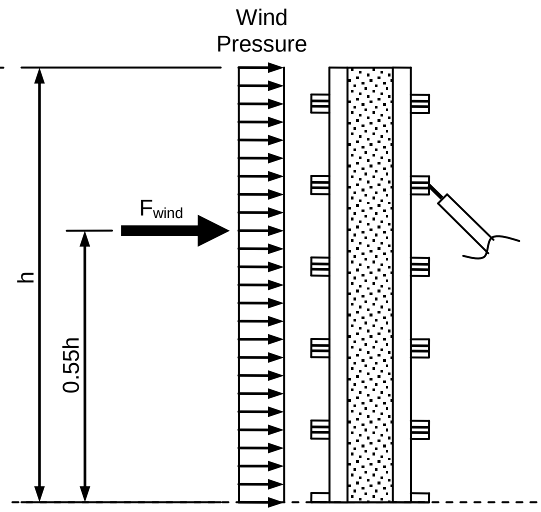
Figure 6.12 – Horizontal Loads Excerpt from ACI 347-04 [10]

British Standard BS5975:2008 recommends a maximum working wind speed of 18 meters per second which is approximately 40 miles per hour [24]. This maximum working wind speed corresponds to the highest wind speed in which formwork construction operations are likely to occur. If this maximum working wind speed of 40 miles per hour is used in the analysis method of ASCE 7-05 for a freestanding wall; the resulting wind pressure is approximately 7 pounds per square foot. The calculation for this wind pressure is shown in Figure 6.13. However, this working wind speed does not correspond to a maximum wind speed if using ASCE 7-05 design methods and the reduction factors from ASCE 37-02. The ACI minimum wind pressure matches the recommended generic wind pressure for walls shown in Appendix B and discussed in section 6.7.

Derivation of Minimum Design Wind Load on Formwork

Using ASCE 7-05 Section 6.5.14 "Design Wind Loads on Solid Freestanding Walls and Solid Signs"

Wall Parameters:
Basic Wind Speed, **V**: 40 mph
Duration: < 6 weeks
Directionality Factor, $\mathbf{K_d}$: 0.85
Terrain Factor, $\mathbf{K_{zt}}$: 1.0
Exposure Category: C
Exposure Coefficient, $\mathbf{K_z}$, at 20 ft: 0.90
Gust Factor, **G**: 0.85 (assumed rigid)
Force Coefficient, $\mathbf{C_f}$: 2.48
(From ASCE 7-05 Fig. 6-20 for a wall with an aspect ratio of 5 long to 1 high)



Importance Factor, **I**, from ASCE 37-02: 1.0

ASCE 7-05 Eq. 6-15: $\mathbf{q_z} = \mathbf{q_h} = 0.00256\mathbf{K_z K_{zt} K_d V^2 I}$

$\mathbf{q_h} = 0.00256(0.90)(1.0)(0.85)(40)^2(1.0) = 3.133 \text{ lb/ft}^2$

ASCE 7-05 Eq. 6-27: $\mathbf{F} = \mathbf{q_h G C_f A_s} = (3.133)(0.85)(2.48)\mathbf{A_s} = 6.61\mathbf{A_s}$
(where F is applied at 0.55**h** per ASCE 7-05 Fig. 6-20)

If wind pressure is applied as a generic pressure, **p**, the resultant force, $\mathbf{F_P}$, would be applied at 0.5**h** instead of 0.55**h**. To provide an equivalent force in the brace, the generic pressure will need to be increased so that the moment generated about the base of the wall form is the same.

Moment due to Wind Force, **F**: $\mathbf{M_F} = 0.55\mathbf{hF}$

Moment due to Generic Pressure, $\mathbf{F_P}$: $\mathbf{M_g} = 0.5\mathbf{hF_P}$ where: $\mathbf{F_P} = \mathbf{pA_s}$

$\mathbf{M_F} = \mathbf{M_g}$ => $0.55\mathbf{hF} = 0.5\mathbf{hF_P}$

substituting in for **F** and $\mathbf{F_P}$: $0.55\mathbf{h}(6.61\mathbf{A_s}) = 0.5\mathbf{h}(\mathbf{pA_s})$ => $\mathbf{p} = 7.27 \text{ lbs/ft}^2$

Figure 6.13 – Derivation of a Work Wind Load on Formwork

While no commentary exists to explain the origin of the minimum loads recommended in ACI 347, they can be derived from knowledge of formwork construction practices. In wall formwork, the 100 pounds per linear foot (Figure 6.12) is an effort to account for overturning loads imposed on formwork by the use of ladders, by construction personnel climbing on the forms, and a wind effect while working or a design wind while not occupied. Ladders typically must be used on forms to gain access to the top of formwork for form inspection and placement operations. Other times, personnel simply climb the framing structure of the formwork system during construction, using positioning harnesses to hold them to the formwork while tying off elsewhere. A formwork system needs to be robust enough to allow for these typical construction activities without failure.

In elevated slab formwork, the 100 pounds per linear foot load is an effort to account for loads imposed by ladders used for access and the starting and stopping of devices used to supply concrete to the slab. Two percent of total dead load applied as a horizontal load is intended to account for erection tolerances of supporting members, including out-of-plumb and eccentricity of members, as well at lateral loads imposed by the moment of concrete placing equipment. A deviation of two inches from plumb in a nine foot shoring member results in a lateral force of approximately two percent of the vertical force on that member as shown in Figure 6.14. This is a noticeable tolerance in the inspection of formwork and results in a reasonable horizontal design force for elevated slab formwork systems. While this deviation from plumb results in the full tolerance, it is unlikely that all shores will be out of plumb in the same direction, therefore the overall lateral effect will less than two percent from shore tolerances alone.

The recommended lateral load of 2 percent of total dead load is particularly important as the eccentricity that results in this load can readily occur in the field. These minimum loads are proposed as requirements in the draft design specification as shown in Figure 6.15.

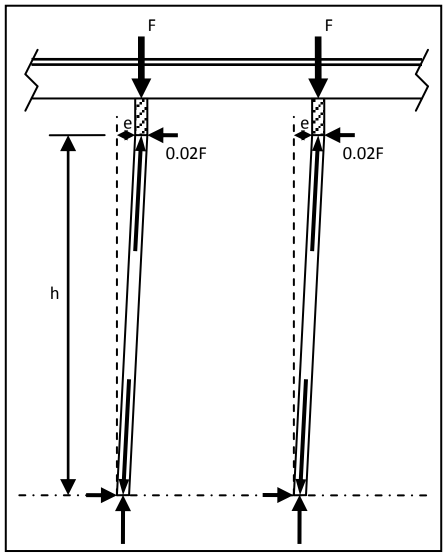


Figure 6.14 – Deviation from Plum of Shores and Resulting Forces

7.2.1 – Minimum Horizontal Loads

7.2.1.1 – Minimum horizontal loads for wall forms

Bracing for wall forms shall be designed for a horizontal load of at least 100 lb/linear ft applied at the top of the wall form.

7.2.1.2 – Minimum horizontal loads for elevated slab forms

The minimum horizontal load for elevated slab forms shall be the greater of:

(a) 100 lb/linear ft applied at the top of the form
(b) 2% of the total dead load on the form distributed as a uniform load per linear foot of slab edge applied at the top edge of the form

This minimum horizontal load shall be applied in two perpendicular directions on the elevated slab form.

Figure 6.15 - Draft Provisions for Minimum Lateral Loads

6.9 Alternative Rational Analysis of Wind Loads

A provision is included to allow a formwork designer to use another method of analysis for wind forces provided it is published in recognized literature. This design specification will need to define recognized literature to make this provision enforceable. Figure 6.16 shows this draft provision.

7.3.4.4 – *Rational Analysis* In lieu of the procedure defined in Sub-Section 7.3.3, determination of the wind load on a formwork system by a rational analysis defined in recognized literature is permitted.	*Similar to ASCE 7-05 paragraph 6.5.8.3 Rational Analysis, though the ASCE section refers only to the gust effect factor.* *Recognized literature needs to be defined for this statement to be enforceable.*

Figure 6.16 – Draft Provisions for Alternative Rational Analysis for Wind Force

7. LOAD COMBINATIONS AND LOAD FACTORS

7.1 Introduction

When designing structures, it is important that the designer provide a factor of safety for the structure. The definition of a factor of safety is the resistance capacity divided by the applied load. Factors of safety are used to account for inaccuracies in theory, material property variances, variations in loading, and durability of the structure. For many structural components, this factor of safety ranges from 1.5 to 3.0 depending on the loading condition and failure mode. In order to understand the impacts of load combinations and load factors on formwork, knowledge of both the Allowable Strength Design method and the Load and Resistance Factor Design method is required.

7.2 LRFD and ASD Design Methods

An early method directly related to a factor of safety is the Allowable Strength Design method (ASD), also referred to as the Allowable Stress Design method. A newer method is the Load and Resistance Factor Design method (LRFD). Both are used in the design of permanent structures. Using the ASD method, the strength of the supporting structural element or resistance to applied loads is reduced by a safety factor. The loads are imposed at their actual values, except that certain ASD load combinations may reduce the extreme value of a transient load type when applied in conjunction with another transient load. The load combinations for extreme values of transient loads are developed to reflect anticipated loading conditions.

The LRFD method involves the use of load factors applied to nominal loads based on the uncertainty associated with each load type. The analysis method used for permanent structures has been in transition from ASD to LRFD. In temporary structures, the analysis method is often determined by the material used for the structure. The industry specifications for various materials are typically written to accommodate both ASD and LRFD design methods; however one design method is typically favored over the other. Historically, formwork has primarily been designed using ASD.

7.3 Application of ASCE 37-02 to Formwork

ASCE 37-02 provides load combinations and load factors which can be used in formwork design for both LRFD and ASD design methods. Load factors are provided for LRFD load combinations and arbitrary point-in-time values are provided for both LRFD and ASD load combinations.

ASCE 37-02 provides two different load factors for lateral concrete pressure. A load factor of 1.3 is applied if full equivalent hydrostatic head is used, but 1.5 is applied for lesser concrete lateral pressures. The commentary of ASCE 37-02 gives the reasoning. “A lower load factor is specified for conditions of full fluid head when designing for lateral pressure of concrete because this condition suggests less uncertainty than partial (unknown) fluid head” [13]. The reduced uncertainty of the loading allows the designer to use a lower load factor knowing that the full liquid head load cannot be exceeded.

7.4 Impacts of ASCE 7-10 on ASCE 37-02 Load Factors

The changes in load factors for wind from different editions of ASCE 7 and ASCE 37 are shown in Table 7.1. ASCE 37-02 has not been updated to reflect the load factor changes in ASCE 7-05 or ASCE 7-10. The LRFD load factor of 1.3 is often still used in temporary works designed in accordance with ASCE 37-02. The changes in basic wind speed from ASCE 7-05 to ASCE 7-10 do not allow for the application of ASCE 37-02 load factors to wind combinations using ASCE 7-10 wind force analysis methods. Using the increased non-hurricane basic wind speeds of ASCE 7-10 in combination with the wind speed adjustment factors and load factors provided in ASCE 37-02 would result in an overly-conservative design.

A revision of ASCE 37 consistent with ASCE 7-10 is needed. For now, the proposed formwork design specification should reference ASCE 37-02 for load factors, APT values, and LRFD and ASD basic load combinations, which are compatible with the wind load methods of ASCE 7-05. It is recommended that ACI Committee 347 continue to monitor the revision of ASCE 37 at this time.

Table 7.1 - LRFD and ASD Wind Load Factors

Standard	**LRFD Load Factor**	**ASD Load Factor**	**Basic Wind Speed** (Category II, non-hurricane)
ASCE 37-02 [13]	1.3	1.0	90 mph*
ASCE 7-95 [12]	1.3	1.0	90 mph
ASCE 7-05 [18]	1.6	1.0	90 mph
ASCE 7-10 [19]	1.0	0.6	115 mph
* ASCE 37-02 references ASCE 7-95 for basic wind speeds			

7.5 Impacts of OSHA Regulations on Formwork Design

As discussed in Chapter 3, OSHA regulations require that scaffold systems be designed to withstand four times the intended live load in addition to the dead weight of the scaffold. As shown in Figure 3.6, the ASCE 37-02 LRFD load factors for formwork are 1.6 for live load and 1.2 for dead load. To comply with OSHA regulations, scaffold systems must be designed to different live load requirements than formwork systems. For the design of a formwork system, this means that work platforms provided for form construction or for concrete placement operations are subject to load factors of 4.0 for live load and 1.0 for dead load. This results in an additional load combination for both ASD and LRFD that must be considered by the designer. Figure 7.1 shows an excerpt from the commentary of ASCE 37-02 that addresses this issue. The draft of the formwork specification provides this load combination (Figure 7.4) as a mandatory requirement for surfaces classified as scaffolding. Also included is a statement to distinguish between scaffolding and formwork.

> OSHA (1977) requires that "scaffolds shall be capable of supporting, without failure, their own weight and at least four times the maximum intended load." ANSI (1989) has a similar requirement. To satisfy the OSHA criterion, the load factor for personnel and equipment load, C_P, fixed material load, C_{FML}, and variable material load, C_{VML}, should be 4.0 and the load factor for construction dead load, C_D, should be 1.0. Also, capacity reduction factors (f factors) used with these load factors should be 1.0. The OSHA requirement may change in the future.

Figure 7.1 - Commentary to ASCE 37-02 related to Scaffolding Design [13]

6.2.2 – *Required strength of work platforms*

Where a structure's primary purpose is to support personnel instead of concrete, it shall be considered scaffolding and subject to the OSHA standards of 26CFR1926, Subpart L and subject to a factor of safety of 4.0 for live loads.

The required strength for scaffolding, $\mathbf{U_S}$, for LRFD design methods shall be determined from Equation 6.2.2.

$$\mathbf{U_S = C_D + 4.0(C_P + C_{FML} + C_{VML})} \qquad (6.2.2)$$

Where:
$\mathbf{C_D}$ = construction dead load
$\mathbf{C_P}$ = construction personnel load
$\mathbf{C_{FML}}$ = construction fixed material load
$\mathbf{C_{VML}}$ = construction variable material load

NOTE: *There are two interpretations of OSHA requirements and their impact on formwork. These two interpretations are included below.*

Interpretation #1 – Load factor is increased, all structures resisting this load must be designed accordingly

Equation 6.2.2 applies to the entire supporting structure.

Interpretation #2 – Factor of Safety of 4.0 applies only to load path specifically for scaffolding. When this load path is combined with non-scaffolding loads, ASCE 37 load combinations are used in lieu of Equation 6.2.2.

Equation 6.2.2 applies to the supporting structure only when the structure does not resist concrete loads. From the point at which the structure supports both personnel and concrete loads, ASCE 37 combinations shall be used.

R6.2.2 - OSHA standard 26CFR1926, Subpart L (Scaffolding) mandates a factor of safety of 4.0 for scaffolding.
OSHA standard 26CFR1926, Subpart Q (Concrete and Masonry Construction) does not provide a minimum factor of safety for shoring or reshoring.

ANSI definitions:
Scaffolding is a temporary elevated or suspended work unit and its supporting structure used for supporting worker(s) or materials, or both.

SSFI provides this explanation:
The primary function of the system determines its classification. If the surface is part of the formwork, it is not scaffolding in spite of the fact that people are standing on that deck.

ASCE 37-02 commentary C2.2.2 states: "To satisfy the OSHA criterion, the load factor for personnel and equipment load, C_P, fixed material load, C_{FML}, and variable material load, C_{VML}, should be 4.0 and the load factor for construction dead load, C_D, should be 1.0. Also, capacity reduction factors (f factors) used with these load factors should be 1.0. The OSHA requirement may change in the future"
Since the OSHA loading is versus failure, it is an LRFD combination.

Commentary to Interpretation #1 :

An example of a load path combination would be a scaffold used on top of a large elevated slab formwork. The scaffold would be subject to a 4:1 Factor of Safety, as well as the elevated slab formwork supporting the scaffold.

Another example of a load path combination would be a walkway bracket attached to a wall form. The planking, walkway bracket and connection to the form would require a 4:1 Factor of Safety. The wall form would also be required to support 4 times the live load applied to the scaffold that is attached to the form.

Commentary to Interpretation #2:

An example of a load path combination would be a scaffold walkway beam also supporting a concrete load. The 4:1 Factor of Safety should only apply to the decking supporting the walkway and the formwork Safety Factor should apply the support beam.

Another example of a load path combination would be a walkway bracket attached to a wall form. The planking, walkway bracket and connection to the form would require a 4:1 Factor of Safety, whereas the load path beyond that point would revert to the appropriate concrete forming Factor of Safety.

Figure 7.2 - Draft Provisions of Scaffolding Requirements

In a technical bulletin published by the Scaffolding, Shoring & Forming Institute (SSFI) shoring is defined as "The vertical supporting members in a formwork system" [31]. To clarify the difference, the following statement is provided: "The primary function of the system determines its classification. In other words, if the deck is part of the formwork, it is not scaffolding in spite of the fact that people are standing on that deck." [31]. This document provides a warning for temporary work platforms that are used to support workers during the erection process of formwork; "A shoring tower that is being used to temporarily support plank for erectors who are constructing a shoring system is a scaffold platform and must comply with the scaffold standards" [31]. According to the statements in the SSFI technical bulletin, if the surface is intended to support concrete at any time, it is classified as formwork and not subject to OSHA scaffolding load combinations. To provide this distinction, the draft provision for the design specification provides the statement: "where a structure's primary purpose is to support personnel instead of concrete, it shall be considered scaffolding and subject to OSHA standards".

During the development of the draft formwork specification, there have been two interpretations of the application of the OSHA scaffold load case to formwork systems. These interpretations deal primarily with work platforms attached to the side of a wall form. This work platform is classified as a scaffold, and therefore must be designed to meet the requirements of scaffolding, but the issue arises when determining load that the scaffolding system imparts on the wall formwork. One interpretation is that the scaffold imparts a load that is the dead load plus four time the live load, thereby requiring that the scaffold be designed to resist the scaffold load combination all the way to the ground. The other interpretation is that the work platform and its associated support brackets must be designed to the scaffold load combination, along with the connections to the formwork. However, the formwork supporting these connections is not required to resist the scaffold load combination containing four times the live load. If the latter interpretation is used, the loads supported by the formwork would be determined from ASCE 37-02, with no amplification of live load in ASD and a load factor of 1.6 in LRFD. A clarification on these two interpretations needs to be decided by ACI Committee 347.

7.6 <u>Incorporation of ASCI 347-04 Minimum Safety Factors into ASD and LRFD</u>

ACI 347-04 provides minimum strength factors for structural components that are specific to formwork. These components are referred to as formwork accessories include form ties, form anchors, and form hangers. The definition of these components can be found in the ACI Concrete Terminology guide [32].

> **tie, form —** a mechanical connection in tension used to prevent concrete forms from spreading due to the fluid pressure of fresh concrete.
> **anchor, form —** device used to secure formwork to previously placed concrete of adequate strength; the device is normally embedded in the concrete during placement.
> **hanger, form —** device used to support formwork from a structural framework; the dead load of forms, mass of concrete, and construction and impact loads must be supported

The minimum safety factors provided for formwork accessories are shown in Table 7.2. Safety factors are based on the ultimate strength of the accessory when new, as noted in the table. There is no clarification on what qualifies as the ultimate strength. In steel, the ultimate strength is the strength at the ultimate stress. For tensile forces, this ultimate stress is the point at which the steel ruptures. This indicates that the safety factors are intended to be applied to the breaking strength of the form tie.

Table 7.2 – Minimum Safety Factors for Formwork Accessories (from ACI 347-04) [10]

Accessory	Safety factor	Type of construction
Form tie	2.0	All applications
Form anchor	2.0	Formwork supporting form weight and concrete pressures only
	3.0	Formwork supporting weight of forms, concrete, construction live loads, and impact
Form hangers	2.0	All applications
Anchoring inserts used as form ties	2.0	Precast-concrete panels when used as formwork

*Safety factors are based on the ultimate strength of the accessory when new.

These safety factors can be used in the ASD method in the same manner as the safety factors provided in the AISC 360-05 [26] as shown in Figure 7.3. The safety factors (Ω) are used to reduce the nominal strength of a structural component to an allowable strength. This same methodology can be used with safety factors provided in ACI 347-04 to reduce the ultimate breaking strength of the form tie to an allowable strength. However, the safety factors of ACI 347-04 are not directly applicable to LRFD methods for determining the design strength.

3. Design for Strength Using Load and Resistance Factor Design (LRFD)

Design according to the provisions for *Load and Resistance Factor Design* (LRFD) satisfies the requirements of this Specification when the *design strength* of each *structural component* equals or exceeds the *required strength* determined on the basis of the *LRFD load combinations*. All provisions of this Specification, except for those in Section B3.4, shall apply.

Design shall be performed in accordance with Equation B3-1:

$$R_u \leq \phi R_n \tag{B3-1}$$

where

R_u = required strength (LRFD)
R_n = *nominal strength*, specified in Chapters B through K
ϕ = *resistance factor*, specified in Chapters B through K
ϕR_n = design strength

4. Design for Strength Using Allowable Strength Design (ASD)

Design according to the provisions for *Allowable Strength Design* (ASD) satisfies the requirements of this Specification when the *allowable strength* of each *structural component* equals or exceeds the *required strength* determined on the basis of the *ASD load combinations*. All provisions of this Specification, except those of Section B3.3, shall apply.

Design shall be performed in accordance with Equation B3-2:

$$R_a \leq R_n / \Omega \tag{B3-2}$$

where

R_a = required strength (ASD)
R_n = *nominal strength*, specified in Chapters B through K
Ω = safety factor, specified in Chapters B through K
R_n/Ω = allowable strength

Figure 7.3- Design Requirements for LRFD and ASD Methods (from AISC 360-05) [26]

Table 7.3 provides a summary of the resistance factors, Φ, and safety factors, Ω, provided in the AISC 360-05. In the draft formwork specification, the provisions of AISC found in B3.3 and B3.4 are reproduced to explain the use of resistance factors and safety factors provided for specific formwork accessories or components. Figure 7.4 shows the draft of these provisions.

Table 7.3 – Summary of Resistance and Safety Factors from AISC 360-05 [26]

Failure Mode	LRFD Resistance Factors (Φ)	ASD Safety Factors (Ω)	Nominal Strength (R_n) Based On:	AISC 360-05 [26] Section
Tension Yielding	$\Phi = 0.90$	$\Omega = 1.67$	Yield	D2
Tension Rupture	$\Phi = 0.75$	$\Omega = 2.0$	Ultimate	D2
Shear Yielding	$\Phi = 1.0$	$\Omega = 1.5$	0.6 x Yield	J4.2
Shear Rupture	$\Phi = 0.75$	$\Omega = 2.0$	0.6 x Ultimate	J4.2
Compression	$\Phi = 0.90$	$\Omega = 1.67$	Yield*	E1
Flexural	$\Phi = 0.90$	$\Omega = 1.67$	Yield†	F1

* Factor is applied to *nominal compressive strength*, P_n, which is based on the yield stress of the steel

† Factor is applied to *nominal flexural strength*, P_n, which is based on the yield stress of the steel

6.3 – Design Strength

6.3.1 – The design strength, $\mathbf{R_d}$, of a material or structural component shall be determined in accordance with an applicable consensus standard.

R6.3.1 - Many material standards provide design strengths for LRFD and allowable strengths for ASD design methods. When these design strengths are calculated from an applicable design standard, no additional resistance factor or safety factor need be applied. Design standards for common materials used in formwork construction are provided in Appendix A.

ACI 347-04 Table 4.1 needs to be reproduced in Appendix A of the draft standard.

6.3.2 - Methods for determining the design strength, $\mathbf{R_d}$, for certain structural components specific to formwork are included in this Standard. When these methods are used, the design strengths shall be determined from Equation 6.1.2a or 6.1.2b

For LRFD design methods:

$$\mathbf{R_d = \Phi R_n} \qquad (6.1.2a)$$

Where:

$\mathbf{\Phi}$ = resistance factor provided for specific component

$\mathbf{R_n}$ = nominal strength provided for specific component

For ASD design methods:

$$\mathbf{R_d = R_n/\Omega} \qquad (6.1.2b)$$

Where:

$\mathbf{\Omega}$ = safety factor provided for specific component

$\mathbf{R_n}$ = nominal strength provided for specific component

R6.1.2 –

Resistance factors, $\mathbf{\Phi}$, for form ties, form anchors, and form hangers are provided in Chapter ##.

Resistance factors, $\mathbf{\Phi}$, and nominal strengths, $\mathbf{R_n}$, for mass anchors are provided in Chapter 21.

Safety factors, $\mathbf{\Omega}$, for form ties, form anchors, and form hangers are provided in Chapter ##.

Safety factors, $\mathbf{\Omega}$, and nominal strengths, $\mathbf{R_n}$, for mass anchors are provided in Chapter 21.

Figure 7.4 – Draft Provisions for the use of Resistance and Safety Factors in LRFD and ASD Design

While ACI 347-04 provides safety factors for use in ASD, it does not provide any guidance for LRFD. AISC faced a similar issue when revising AISC 360 to include both ASD safety factors and LRFD resistance factors. The commentary of the AISC 360-05 explains the process used to develop the ASD safety factors base on the resistance factors for LRFD. Commentary section B3.3 states: “LRFD provisions are based on: (1) probabilistic models of loads and resistance; (2) a calibration of LRFD provisions to the 1978 edition of the ASD Specification for selected members; and (3) the evaluation of the resulting provisions by judgment and past experience aided by comparative design office studies of representative structures.” [26]. “The Committee on Specifications set the point at which LRFD is calibrated to ASD at L/D = 3.0 for braced compact beams in flexure and tension members in yield” [26], where L and D refer to the live load and dead load respectively. This calibration process is mathematically demonstrated for a basic load combination, as shown in Figure 7.4. An interesting note is that AISC LRFD resistance factors were calibrated to previous ASD specifications, yet the current ASD safety factors are calibrated to the current LRFD resistance factors. The advantage of the calibration method provided in the commentary of AISC 360-05 is that the calibration process can work both from ASD to LRFD or from LRFD to ASD, provided a ratio of the dead to live loads is given.

In developing appropriate values of Ω for use in this Specification, the aim was to assure similar levels of safety and reliability for the two methods. A straight forward approach for relating the resistance factor and the safety factor was developed. As already mentioned, the original LRFD Specification was calibrated to the 1978 *ASD Specification* at a live load to dead load ratio of 3. Thus, by equating the designs for the two methods at a ratio of live-to-dead load of 3, the relationship between ϕ and Ω can be determined. Using the live plus dead load combinations, with $L = 3D$, yields

$$\text{For LRFD}: \quad \phi R_n = 1.2D + 1.6L = 1.2D + 1.6 \times 3D = 6D \qquad \text{(C-B3-3)}$$

$$R_n = \frac{6D}{\phi}$$

$$\text{For ASD}: \quad \frac{R_n}{\Omega} = D + L = D + 3D = 4D \qquad \text{(C-B3-4)}$$

$$R_n = 4D\Omega$$

Equating R_n from the LRFD and ASD formulations and solving for Ω yields

$$\Omega = \frac{6D}{\phi} \times \frac{1}{4D} = \frac{1.5}{\phi} \qquad \text{(C-B3-5)}$$

A similar approach was used to obtain the majority of values of Ω throughout the Specification.

Figure 7.5 – Calibration of LRFD Resistance Factors to ASD Safety Factors (from AISC 360-05) [26]

Using this same calibration method for formwork, the LRFD resistance factors for structural components can be derived. However, the load combination used will need to reflect the controlling combination for each structural component. Also, the ratio of dead to live load will need to be adjusted to reflect the loading conditions of the specific formwork component.

Form ties are typically used to hold a two-sided wall form together and to resist the concrete lateral pressure on the formwork, as shown in Figure 7.6. The applicable load combination for form ties used in this manner only contains the concrete pressure. Using ASCE 37-02 load combinations and load factors, the applicable LRFD and ASD load combinations are identified for form ties and shown in Figure 7.7. Figure 7.7 also shows the calibration process for the LRFD resistance factor for form ties using the AISC 360-05 calibration method shown in Figure 7.5.

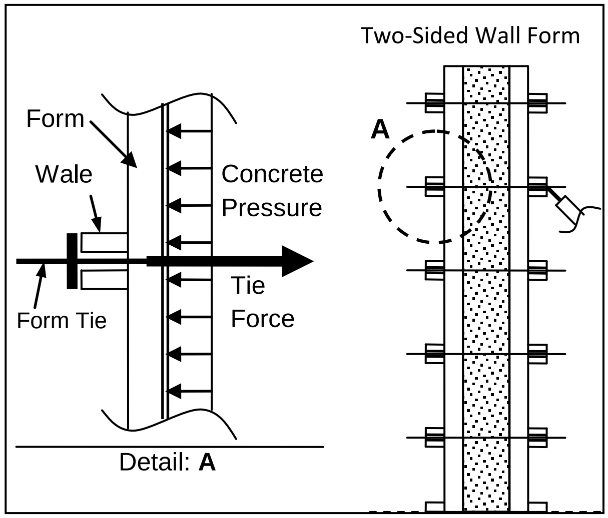


Figure 7.6 – Typical Statics of Form Ties in Two-Sided Wall Forms

Form Ties

LRFD	**ASD**
Using ASCE 37-02 LRFD Load Combinations and Load Factors:	Using ASCE 37-02 Load Combinations:
$R_u = 1.2D + 1.5C_c$	$R_a = D + C_c$
Using AISC 360-05 definition of required resistance:	Using AISC 360-05 definition of allowable resistance:
$R_u \leq \Phi R_n$	$R_a \leq R_n/\Omega$
Substituting for R_u gives:	Substituting for R_a gives:
$\Phi R_n \geq 1.2D + 1.5C_c$	$\Phi R_n \geq D + C_c$

From Statics: No dead load supported by Form Ties, only concrete pressures (C_c)

Therefore:

$\Phi R_n \geq \cancel{1.2D} + 1.5C_c$	$R_n/\Omega \geq \cancel{D} + C_c$

From ACI 347-04: $\Omega = 2.0$, and substituting for C_c gives:

$$\Phi R_n = 1.5(R_n/2.0)$$

Removing R_n gives: $\boxed{\Phi = 0.75}$

Figure 7.7 – Calibration of LRFD Resistance Factor (Φ) to ASD Safety Factor (Ω) for Form Ties

The resulting LRFD resistance factor for form ties is 0.75. This matches the AISC 360-05 resistance factor for a steel member failing in either tension rupture or shear rupture shown in Table 7.3. Rupture strength is based on the ultimate strength of the steel used in the component. When ACI 347-04 provides safety factors for ultimate strength, it does not specify if this ultimate strength is based on the ultimate rupture strength in tension or shear. Form anchors can be subject to both tension and shear forces and it can be assumed that the safety factor of 2.0 or 3.0 is intended for both tension and shear resistance.

The derivation of the LRFD resistance factor for form ties also applies to two other accessories mentioned in Table 2.3 of ACI 347-04; anchoring inserts used as form ties and for form anchors supporting form weight and concrete pressure only. Therefore, the LRFD resistance factor for these two accessories should be 0.75 as well.

The derivation of the LRFD resistance factor for the remaining two accessories, form hangers and form anchors subject to construction live loads, is more difficult to derive. The load combination for these two accessories includes the dead weight of the formwork, the construction live load, and the concrete pressure. Without knowing the ratio of the applied loads, determining the load resistance factor using this method is not possible. ACI Committee 347 will need to discuss the applicable load combinations and determine the typical ratios of the applied loads to complete this derivation on a similar basis.

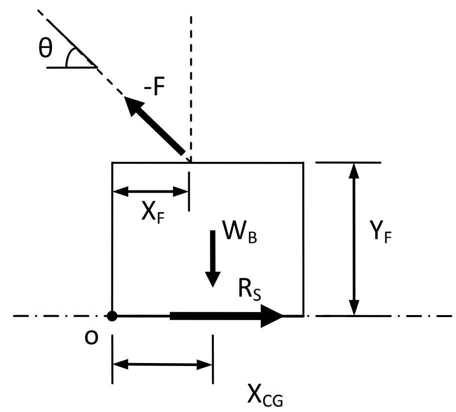
8. MASS ANCHORS

8.1 Introduction

Formwork on grade or close to ground level is often braced to previously cast concrete foundations or slabs. When not available, various temporary anchorages may be used. The correct design of these anchorages is essential to ensure that the formwork is stable and will not collapse. One method is the use of mass anchors, placed on the surrounding surface or cast into shallow excavations as temporary shallow footings.

8.2 Mass Anchors on the Surface

For mass anchors placed on the surrounding surface, the capacity of the mass anchor to resist brace forces is dependent on three failure modes: uplift, overturning failure, or sliding failure. While bearing failure is theoretically possible, typical mass anchors have a sufficient base area to distribute vertical loads over an area well below the allowable bearing stress levels of soils. The free-body diagram for mass anchors is shown in Figure 8.1. The draft of the provisions for the design of mass anchors on the surface can be seen in Appendix A, Section 21.2.1.2. Due to the length of the draft provisions for the design method, the have not been reproduced here.



Where:

F = force on mass anchor from the maximum LRFD or ASD load combination
θ = angle between applied force and horizontal surface supporting mass anchor
X_F = horizontal distance between applied force and overturning point
W_B = weight of mass anchor
X_{CG} = horizontal distance between the center of gravity of the mass anchor and the overturning point
Y_F = vertical distance from applied force to overturning point
o = overturning point

Figure 8.1 – Statics of a Mass Anchor on the Ground Surface

A summation of moments about a tipping point is used to determine the overturning resistance of a mass anchor on the surface. When designing for overturning forces the location of overturning point, **o**, changes depending on the direction of force applied as a result of wind direction reversals. The draft provisions for the design standard illustrate the tipping point for applied loads of both tension and compression.

For determining the sliding resistance, equivalent coefficients of friction are provided and multiplied by the normal force. For mass anchors supported by concrete, friction factors based on ACI 318-08 [28] friction factors for shear friction are provided for different surface roughness finishes of concrete. For soils, the equivalent friction factors are provided and are based on NAVFAC Design Manual 7.2, “Foundations and Earth Structures” [33].

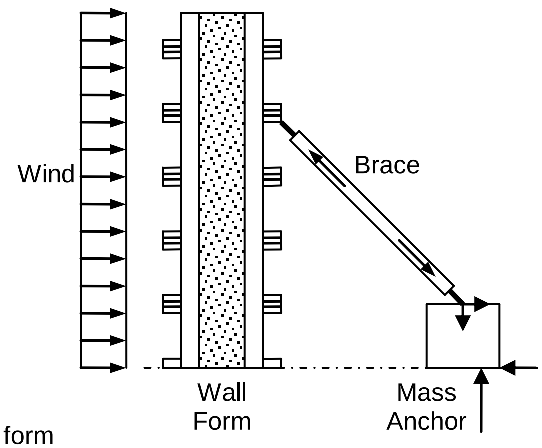
The draft provisions for the formwork design specification are provided to give the formwork designer a method to design brace anchorages using mass anchors. LRFD resistance factors and ASD safety factors are provided to provide a factor of safety on the design of mass anchors. These factors are determined in accordance with ASCE 37-02 section 2.3.3, as seen in Figure 8.2. ASCE 37-02 requires that the allowable or factored resistance for overturning or sliding be two-thirds of the nominal resistance. This corresponds to a safety factor in ASD of 1.5. To calibrate the safety factor for ASD to LRFD load combinations, a method similar to that used for form ties was used. The load combination for this calibration process is for a wall form subject to the maximum wind force, with a LRFD load factor of 1.3. Though the brace may also resist force caused by live loads, construction material loads, or concrete pressures, all of these forces are multiplied by a load factor greater than 1.3 in LRFD combinations. By calibrating the LRFD load factor to the lowest load factor, it provides a higher factor of safety when higher load factors are used for other loads. This calibration can be seen in Figure 8.3.

2.3.3 *Overturning and Sliding*

Buildings and other structures shall be designed so that the overturning moment caused by lateral forces (wind or flood) acting singly or in combination does not exceed two thirds of the dead load stabilizing moment unless the building or structure is anchored to resist the excess moment. The base shear caused by lateral forces (wind or flood) shall not exceed two thirds of the total resisting force caused by friction and adhesion unless the building or structure is anchored to resist the excess sliding force.

Figure 8.2 – Overturning and Sliding Provision from ASCE 37-02 [13]

Calibration of LRFD Resistance Factor to ASD Safety Factor for Mass Anchors



ASD Load Combination from ASCE 37-02:

$D + C_D + C_{FML} + C_{VML} + W + C_P + L$

LRFD Load Combination from ASCE 37-02:

$1.2D + 1.2C_D + 1.2C_{FML} + 1.4C_{VML} + 1.3W + 1.6C_P + 1.6L$

Assumptions:

- Dead load of brace is negligible
- No Construction Dead Load, supported by wall form
- No Fixed Material Load, materials are not to be stored on formwork

Worst Condition: Wind only; no Variable Material Load, Construction Personnel Load, or Live Load

ASD: $\cancel{D} + \cancel{C_D} + \cancel{C_{FML}} + \cancel{C_{VML}} + W + \cancel{C_P} + \cancel{L} \quad \Rightarrow \quad W$

LRFD: $\cancel{1.2D} + \cancel{1.2C_D} + \cancel{1.2C_{FML}} + \cancel{1.4C_{VML}} + 1.3W + \cancel{1.6C_P} + \cancel{1.6L} \quad \Rightarrow \quad 1.3W$

From ASCE 37-02 Section 2.3.3 “Overturning and Sliding”: $R_a = (2/3)R_n$

$R_a = R_n/\Omega \quad \& \quad R_a = R_n/1.5 \quad$ Therefore: $\Omega = 1.5$

ASD Strength Criteria:

$R_n/\Omega = W \quad \Rightarrow \quad R_n/1.5 = W$

LRFD Strength Criteria:

$\Phi R_n = 1.3W$ substituting for W => $\Phi R_n = 1.3(R_n/1.5)$

removing R_n => $\Phi = 1.3/1.5 = 0.8667$

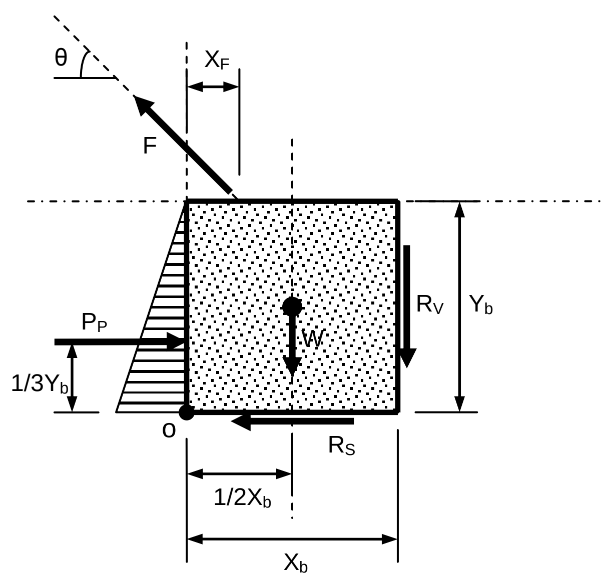
LRFD Resistance Factor: $\boxed{\Phi = 0.86}$

Figure 8.3 – Calibration of LRFD Resistance Factors to ASD Safety Factors for Mass Anchors

8.3 In-Ground Mass Anchors

To increase a mass anchor's resistance against overturning and sliding, they may be constructed by excavating a hole and placing a shallow footing of concrete. This shallow concrete footing becomes the mass anchor in the ground. A mass anchor in ground has the same failure modes as a mass anchor on the surface, those being overturning and sliding. However, the resistance to these failure modes is increased by the presence of passive earth pressure on the sides of the mass anchor and vertical friction of the mass anchor against the surrounding soil. The draft of the provisions for the design of cast-in-ground mass anchors can be seen in Appendix A, Section 21.2.1.4. Due to the length of the draft provisions for the design method, they have not been reproduced here.

In the design method for cast-in-ground mass anchors, the resistance is determined by a summation of moments about a tipping point, similar to the design of mass anchors on the surface. However, additional forces are present in the free-body diagram for a cast-in-ground mass anchor. The free-body diagram for a cast-in-ground member subject to a tension force can be seen in Figure 8.4. For a cast-in-ground mass anchor subject to a compression force, the direction of the applied force is reversed from that in Figure 8.4 and the overturning point is the opposite lower corner.



Where:

P_P = passive earth pressure
R_V = vertical resistance from active earth pressure
W = weight of mass anchor
F = force on mass anchor from the maximum LRFD or ASD load combination
θ = angle between applied force and supporting surface of mass anchor
Y_b = height of mass anchor
X_b = horizontal width of mass anchor
X_F = horizontal distance between applied force and overturning point, **o**

Figure 8.4 - Free Body Diagram of a Cast-in-Ground Mass Anchor Subject to Tension Forces

The draft provision for passive earth pressure is based on the design of anchor beams in granular and cohesive soils, found in “Principles of Foundation Engineering” by Braja Das [34]. This provision can be seen in Section 21.2.1.3.3 of the draft design standard in Appendix A. The draft provision for vertical resistance from active earth pressure is the integral of the active earth pressure applied to the face of the mass anchor multiplied by the equivalent coefficient of friction provided for mass anchors on the surface. This provision can be seen in Section 21.2.1.3.4 of the draft design standard in Appendix A. A complete derivation of the vertical resistance from active earth pressure can be found in Appendix D.

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

The following conclusions are based on the research conducted in this study.

1. A draft framework was established to aid in the development of a formwork design specification consistent with the ACI document classification of design specification.
2. A review of several existing standards identified wind loads and load combinations used for formwork as areas requiring clarification by a design standard.
4. Concrete pressures were identified as a design aspect appropriate for inclusion into a design specification produced by ACI Committee 347. Draft provisions were developed to help accomplish this.
5. Wind loads were analyzed considering the relationships between ASCE 7, ASCE 37, and ACI 347 for application to formwork in design specifications.
6. Conflicts among load factors and load combinations in various documents were identified and draft provisions were developed to address these conflicts.
7. A calibration process for developing LRFD resistance factors based on ASD safety factors has been identified and demonstrated for form ties and mass anchors.
8. A concise design method for mass anchors was developed due to the absence of a design method for mass anchors in existing standards.
9. The draft formwork design specification has been presented to ACI Committee 347 for comment and continued development.

9.2 Recommendations

Several recommendations for future research as well as actions for ACI Committee 347 were identified during this study.

1. ACI Committee 347 should continue to monitor the ongoing revision of ASCE 37 and how it coordinates with ASCE 7-10.
2. LRFD resistance factors for form anchors and form hangers consistent with ASD safety factors should be developed.
4. ACI Committee 347 should continue the development of the formwork design specification and complete the standardization process for this design specification.

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APPENDIX

Appendix A – Draft of Design Specifications for Formwork

The following document is the working draft of the design specification for formwork developed in during this research and simultaneously under review by some members of ACI Committee 347. Several committee members have provided input through comments or draft provisions for inclusion into this design specification. The provisions provided externally are not included in the scope of this thesis.

Statements in italics are comments or questions indicating issues that need further evaluation. Many of these comments are intended to provide further information on the development of the provision and will either be removed or incorporated into the commentary of the final document.

With this document being a working draft, the formatting of provisions is not necessarily in the final format required by ACI. A preliminary review of provisions provided by others has been performed to assist in placing the provisions into the appropriate chapters. Where the comments provided by committee members have concerned this thesis, an attempt has been made to address the recommendations and comments in the development of the draft provisions provided in this document. All provisions of this proposed design specification must be reviewed by ACI Committee 347 and be balloted by the ACI standardization process prior to finalization.

DRAFT 2011-03-16

Design Specification and Commentary for Formwork for Concrete (ACI 347.X-XX)

REPORTED BY ACI COMMITTEE 347

ACI Committee 347
Formwork for Concrete

Chair Secretary

Draft Notes: This draft includes both English and SI units but will eventually be separated into two independent documents upon publication. This draft also contains some notes in italics from the Draft ACI Codes Writing Guide which will eventually be deleted.

PREFACE

Keywords: anchors; architectural concrete; concrete; construction; form ties; forms; formwork; quality control; reshoring; shoring; slipforms; specifications; tolerances.

standard adoption date,
verbiage for metric version,
disclaimer statement, and
copyright information

TABLE OF CONTENTS

ACI design specification with commentary documents hereinafter called "Design Specification" are published in a side-by-side two column format, with Design Specification provisions placed in left column and the commentary text aligned in the right column. To further distinguish the Design Specification and the commentary, the font of the Design Specification is Arial, the same type face in which this column is set.

This paragraph is set in Times Roman, and all portions of the text exclusive to the commentary are published in this type face. Commentary section numbers are preceded by an "R" to further distinguish them from the Design Specification provision numbers.

Marginal Marking (Vertical lines in the margin) indicates a change from the previous edition of the Design Specification. Strictly editorial revisions are not identified with marginal marking.

INTRODUCTION

CHAPTER 1 – GENERAL REQUIREMENTS *The section and subsection numbers correspond to the Chapter number. Use two-column format, the left column for the Design Specification and the right column for the commentary)*		
1.1—Scope This design specification provides minimum requirements for design and construction of formwork for cast-in-place concrete. *This should be a short statement, similar to the title of the design specification, which describes the specific topic addressed. Within this area, some specific inclusions and exclusions are listed in subsections below.*		These temporary structures should be designed to rigorous standards similar to those required of permanent structures. The design calculations, drawings, etc. should be performed with the same rigor as for any other Engineering work. The Design and Design Calculations should be performed to conform to Accepted Engineering Practice including Engineering Mechanics, Determinate and Indeterminate structural analysis and Materials Science. It should be capable of withstanding Engineering Peer Review. If and when deviation from Accepted Engineering Practice is deemed necessary by the designer, then the alternate design should carefully detail such method and should include the appropriate theoretical and experimental results to justify such method. Rules of thumb and approximate methods inconsistent with Accepted Engineering Practice should not to be used in work that is issued "For Construction". *The mandatory language in this section is practically identical to the analysis wording in ASCE 7-05, Section 1.3.4 and ASCE 37-02 Section 1.3.6. The purpose of the statement is to make the analysis process common among all designers so that engineering principles are followed as opposed to simplified procedures that can materially affect the result in an adverse manner. There are shortcuts employed in our industry today that are based on economics and competitive pressure, not sound engineering judgment. Working Stress Design uses Safety Factors applied against some type of yield stress, test result, etc. These Safety Factors have absolutely no meaning if the calculated working load is made by some arbitrary means, such as tributary area, unless there is a sound, defensible reason for that usage. Simply because it worked last time is not a guarantee that it will work in the current situation. The Formwork Engineering "playing field" needs to be leveled so that those who play by the rules are not penalized in the market place by those who do not. Does not each formwork structure we design deserve an appropriate amount of analysis by the designer?*
1.1.1 Specific Inclusions This design specification is limited to the design and construction of formwork for cast-in-place concrete. *This subsection allows the committee to state or clarify any specific inclusions related to the scope of the design specification. This can include such topics as materials, geometries, structure types, or loads.*		

.		
1.1.1.1 The following items are specifically included in the scope of this standard: • Elevated formwork for concrete placements whose volume exceeds 5 cubic feet • Formwork for concrete whose vertical height above grade or above grade footings exceeds 4 feet		*New section; will need commentary.* *Volumes and heights are arbitrarily chosen for committee discussion*
1.1.2 Specific Exclusions *This subsection allows the committee to state or clarify any specific inclusions related to the scope of the design specification. This can include such topics as materials, geometries, structure types, or loads.*		
1.1.2.1 The following items are excluded from the scope of this standard: • Forms for Precast Concrete • Forms for concrete cast on grade whose formed vertical height does not exceed 2 ft. • Forms for concrete walls, piers, and columns cast at grade whose vertical height does not exceed 4 feet and placement volume does not exceed 5 cubic yards		*New section; will need commentary.* *Intended to cover footing, curb and slab-on-grade forms, height arbitrarily chosen.* *Intended to cover short walls at grade, height and volume arbitrarily chosen*
1.1.3 Other Applications *This section allows the committee to indicate if the design specification can apply to other applications, other than those stated in the main scope.*		
1.1.4 Hierarchy of Standards This design specification adopts referenced standards, and these standards form a legal part of this design specification. This design specification governs when these standards contain contradictory information to this design specification. *This subsection clarifies the relationship between design specifications and standards. ACI design specifications commonly adopt referenced standards (e.g., ASTM), and these standards form a legal part of this design specification. ACI design specifications govern when these standards contain requirements conflicting with those of the ACI design specification. ACI design specifications can be adopted as part of a broader-scope regulatory document, and in this case, the ACI design specification/standard forms a legal part of that regulatory document. The regulatory document governs when the ACI design specification contains conflicting requirements.*		AISC Manual for Steel Construction 13th Edition National Design Specification for Wood Construction, 2006 Aluminum Design Manual 2010 AISI Manual Cold Formed Steel Design 2008 ACI Publication SP-4, 7th Edition SEI/ASCE 37-02 Design Loads on Structures During Construction ASCE/SEI 7-05 Minimum Design Loads for Buildings and Other Structures
1.2 Documentation *This section identifies what design and construction items require documentation and for how long.*		

1.3 Quality Assurance / Inspection *This section states QA and construction inspection requirements.*		
1.3.1 — Formwork construction shall be inspected as required by the legally adopted general building code and the governing safety regulations. In the absence of such inspection requirements, formwork construction shall be inspected prior to the placement of concrete by or under the supervision of a licensed design professional in the state of jurisdiction, by a designated competent person, or by a qualified inspector.		*Is a definition of competent person required in this document?* *If not, does it fall back to the OSHA definition?* A designated competent person may be an authorized representative of the design professional responsible for the formwork design. *What is a qualified inspector? How does one become qualified?* Inspectors should be able to demonstrate thorough knowledge of general forming and shoring practice as well as thorough knowledge of the system or systems being used to perform the work. An integral part of this is the capability to read and interpret the shop drawings provided to the project. *Example: CA: "the PE or their authorized representative"* *NY: "All shoring must be inspected" is in code* *Inspected for substantial conformity*
1.3.2 — The inspector shall require substantial compliance with formwork design drawings and specifications. Inspector shall maintain records of inspection as required by project specifications, local Codes, or applicable laws.		Typical inspection records may include information pertaining to the following: • Construction of formwork • Installation and removal of formwork • Installation and removal of shoring and reshoring • Installation, connection, and anchorage of bracing • Deflections at time of placement of concrete • Survey of location and geometry of finished concrete • General progress of work
1.3.3 — Records of inspection shall be preserved until the completion of the project or as required by project specifications, local Codes, or applicable laws.		
1.4 Approval of Alternate Methods or Systems Sponsors of any system of design or construction within the scope of this Design Specification, the adequacy of which has been shown by successful use or by analysis or test, but which does not conform to or is not covered by this Design Specification, shall have the right to present the data on which their design is based to the formwork engineer/contractor for review and approval. The formwork engineer/contractor may investigate the data so submitted, and may require tests and formulate rules governing design and construction of such systems to meet the intent of this Design Specification.		

This section allows the designer to use methods or systems not considered by the design specification. Further, it spells out rules for acceptance of the alternate methods and systems.		
1.5 Alternate Language and Units of Measurement ACI 347.X is also available in an SI [English] units version. *(for now keep both units, separate later)*		

CHAPTER 2 – NOTATION AND DEFINITIONS

For the purpose of this document, the following notation and definitions apply.

2.1 Notation

C_c = chemistry coefficient per Table 2.2.2.1;

C_w = unit weight coefficient per Table 2.1;

g = gravitational constant, 9.81 N/kg;

h = depth of fluid or plastic concrete from top of placement to point of consideration in form, ft (m).

p_{max} = maximum lateral pressure, lb/ft^2(kPa);

R = rate of placement, ft/h_r (m/h_r);

R = reduction in live load, %;

T = temperature of concrete during placing, °F (°C);

p = lateral pressure, lb/ft^2 (kPa);

w = unit weight of concrete, lb/ft^3;

Δ_{max} = calculated deflection due to concrete and slab, in (mm)

Δ_{net} = calculated deflection minus camber, in (mm)]

ρ = density of concrete, kg/m^3;

DESIGN SPECIFICATION		COMMENTARY
2.2 Definitions *This section lists terms and their definitions.*		
backshores—shores placed snugly under a concrete slab or structural member after the original formwork and shores have been removed from a small area at a time, without allowing the slab or member to deflect; thus, the slab or other member does not yet support its own weight or existing construction loads from above.		
centering—specialized temporary support used in the construction of arches, shells, and space structures where the entire temporary support is lowered (struck or decentered) as a unit to avoid introduction of injurious stresses in any part of the structure.		
climbing form (crane-climbing) - a formwork system around the concrete structure is raised with the help of one or more cranes once the hardening concrete achieves a desired strength a form that is raised vertically for succeeding lifts of concrete in a given structure.		Commonly, form height corresponds to one story (9-10 ft), with climbing (and succeeding lifts of concrete) performed one story at a time.
climbing formwork (self-climbing) - formwork around the concrete structure with a supporting system that raises itself with the help of climbing devise with mechanic leverage equipment (ie. electric motor, hydraulics, etc.) anchored in previously cast concrete.		
guided formwork – a formwork system is similar to the self-climbing type above where the climbing process is continuous instead of intermittent, and is usually only interrupted for a very short intervals to fix mounting mechanisms to new anchoring points.		
diagonal bracing—supplementary formwork members designed to resist lateral loads.		

engineer/architect—the engineer, architect, engineering firm, architectural firm, or other agency issuing project plans and specifications for the permanent structure, administering the work under contract documents, or both.		
flying forms—large prefabricated, mechanically handled sections of formwork designed for multiple reuse; frequently including supporting truss, beam, or shoring assemblies completely unitized.		Historically, the term has been applied to floor forming systems. ("tables"); however, it refers also to combined wall-and-floor systems ("tunnels" and "half-tunnels").
form—a temporary structure or mold for the support of concrete while it is setting and gaining sufficient strength to be self-supporting.		
formwork—total system of support for freshly placed concrete, including the mold or sheathing that contacts the concrete and all supporting members, hardware, and necessary bracing.		
formwork ~~engineer~~ designer/contractor—engineer of the formwork system, contractor, or competent person in charge of designated aspects of formwork design and formwork operations.		"Engineer" is a term reserved for Registered Professional Engineers in most state jurisdictions. The formwork designer must be able to demonstrate, by means of training and experience, the level of competence commensurate with the complexity of the formwork design requirements, and to be able to take legal responsibility for that design. *The discussion for the Committee is to determine if we should further determine competency requirements, and how they are to be attained. Certainly a Registered Engineer has the legal authority, both by licensure and Code of Conduct. It is not quite as clear for a competent person. It is crucial that the designer be responsible for the safety and applicability of his or her design to the client, the industry and to the general public.*
ganged forms—large assemblies used for forming vertical surfaces; also called gang forms.		
horizontal lacing—horizontal bracing members attached to shores to reduce their unsupported length, thereby increasing load capacity and stability.		
preshores—added shores placed snugly under selected panels of a deck-forming system before any primary (original) shores are removed. Preshores and the panels they support remain in place until the remainder of the complete bay has been stripped and backshored, a small area at a time.		
reshores—shores placed snugly under a stripped concrete slab or other structural member after the original forms and shores have been removed from a large area, requiring the new slab or structural member to deflect and support its own weight and existing construction loads to be applied before installation of the reshores.		
scaffold—a temporary elevated platform (supported or suspended) and its supporting structure used for supporting workers, tools, and materials; adjustable metal scaffolding can be used for shoring in concrete work, provided its structure has the necessary load-carrying capacity and structural integrity.		
shores—vertical or inclined support members designed to carry the weight of the formwork, concrete, and construction loads above.		

slipform—a form that is pulled or raised in a semi-continuous mode as concrete is placed; may move in a horizontal direction to lay concrete for concrete paving or on slopes and inverts of canals, tunnels, and siphons; or may move vertically to form walls, bins, or silos.		*If only "as concrete is placed" is left, w/o the addition, it may create the false impression that the form's movement is continuous. On the other hand, I think the addition serves to better distinguish slipforms from climbing forms.*
Allowable Stress Design (ASD.) Also known as Working Stress Design. The common design method used in formwork design. By this method, the nominal resistance of the material is divided by a Safety Factor to determine the allowable load.		*I believe that Allowable Stress Design is the most commonly used formwork design for many reasons, not the least of which is that the same formwork components are used in various different applications over time and are used over and over again. This method is implied in the 347 Guide, although, I don't believe, explicitly. I do not believe that LRFD, (Load and Resistance Factor Design) should be included, as Concrete Formwork Specifications seem to never specify any design method. Specifications for permanent structures include both. I would not, however, object to someone who is familiar with designing formwork by LRFD to propose some method of equivalency.*
Stud—In a wall form, the first load gathering member behind the formwork surface (plywood, form boards, etc.) The stud transfers load to wales or formwork ties.		
Wale –In a wall form, the Wale or Waler is the secondary load gathering member after the Stud. It is generally the member that transfers load to the formwork ties.		
Form Ties----The tension members penetrating through both sides of a wall form that ultimately resist the formwork pressure from both sides of the form.		

CHAPTER 3 – NORMATIVE REFERENCES The following normative (i.e. referenced) standards are indispensable for the application and use of this document. For dated reference, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies. Standards referred to in this design specification are listed below with their serial designations, including year of adoption or revision, and are declared to be part of this design specification as if fully set forth herein: *All standards adopted by reference must be in mandatory language and only be included in the design specification portion of the document.*		
American Concrete Institute 117 Specification for Tolerances for Concrete Construction and Materials 301 Specifications for Structural Concrete ~~303.1 Standard Specification for Cast-In-Place Architectural Concrete~~ 318 Building Code Requirements for Reinforced Concrete		*Note: What to reference here is a question to be resolved. We do not want to reference documents that would be citing this document – becomes a circle.* *303.1 is not longer in existence? (Confirmation needed)*
American Forest & Paper Association National Design Specification for Wood Construction, 2005		
American Institute of Steel Construction AISC 360 Specification for Structural Steel Buildings		
American National Standards Institute ANSI/SEI/ASCE-7 Minimum Design Loads for Buildings and Other Structures A48.1 Forms for One-Way Concrete Joist Construction A48.2 Forms for Two-Way Concrete Joist Construction A208.1 Mat-Formed Wood Particle Board		
Aluminum Design Manual The Aluminum Association		*(Confirm Name)*
American Society of Civil Engineers SEI/ASCE-37 Design Loads on Structures During Construction		
APA—The Engineered Wood Association Plywood Design Specification and supplements, 1997		
ASTM International A 446 Standard Specification for Steel Sheet, Zinc-Coated (Galvanized) by the Hot-Dip Process, Structural (Physical) Quality C 532 Standard Specification for Structural Insulating Formboard (Cellulosic Fiber) E 329 Specification for Agencies Engaged in the Testing and/or Inspection of Materials Used in Construction		
SSFI		

CHAPTER 4 – MATERIALS		
4.1 – Strength of materials		
4.1.1 – The unit stress capacity of materials to be used for formwork shall be determined from applicable consensus standards.		Refer to Chapter 3 - Normative References for an applicable consensus standard for a specific material.
4.1.2 – Where no consensus standard exists for a material, data from testing may be used to determine the strength of the material. Refer to Chapter 5 for testing of materials.		
4.1.3 - Concrete compressive strength shall be determined in accordance with Section 5.4 of this Standard.		
4.2 – Inspection for use		
4.2.1 – The designer of formwork shall specify the provisions of 4.2.1.1 through 4.2.1.2		*The requirements listed below are related to the construction process. Careful wording of this section is required.* *Can this be stated as it currently is or will this statement need to be incorporated into each specific provision listed?*
4.2.1.1 – Materials and components used for formwork shall be examined for damage or deterioration before each use.		Specific materials have different inspection requirements. Wood materials should be checked for cracking, splitting, rot, or other signs of decay or damage. Metal components should be checked for straightness, gouging, dents, oxidation (rust), or any other defects. Special attention should be given to any welds of metal components for cracking. SSFI publishes Technical Bulletins that provide for the inspection of metal scaffolding or shoring systems.
4.2.1.2 – Any material not suitable for use in formwork shall be removed from the formwork assembly area and shall be either marked as such or disposed of.		Damaged materials should not be left in the formwork assembly area to prevent their accidental use during formwork assembly. Damaged materials should not be removed to a material storage area but instead disposed of in a proper manner

CHAPTER 5 - Tests		
5.1 – Testing		
5.1.1 - A complete record of all tests shall be retained in accordance with the project specifications, local Codes, or applicable laws. Where no such requirements are specified, records shall be retained until the completion of the project, and made available for inspection during the progress of the Work.		*Similar requirements as 1.3.3 "Records of Inspection"*
5.2 – Tests of Materials		
5.2.2 – Test of materials shall be made in accordance with an applicable consensus standard.		
5.2.3 – Where no such consensus standard exists, testing shall be designed by a licensed professional engineer.		
5.3 – Tests of Systems and Components		
5.3.1 – Formwork systems and components shall be tested prior to use where engineering analysis is incomplete or not practical.		
5.3.1.1 – Tests of systems or components shall be carried out in accordance with an applicable standard and shall include all forms of loading that are to be expected in use.		ANSI/SSFI SC100-5/05 "Standards for Testing and Rating Scaffold Assemblies and Components" (Ref 5.1) provides procedures for testing systems that are similar to many scaffolding systems and components. SSFI SH300-2006 "Standards for Testing and Rating Shoring Equipment" provides procedures for testing most shoring systems and components. Vertical Shoring Support capacities must be reported in __________ literature at a minimum Safety Factor of 2.5:1.
5.3.1.1.a - Where an applicable standard is not available, the testing for a connection shall be designed by a licensed professional engineer.		
5.3.2 - Tests shall be conducted to performance failure. The point at which the system or component experiences performance failure shall be considered the ultimate strength.		
5.3.2.1 – Performance Failure shall be the point at which the applied load cannot continue to increase		*Provide definition here, in commentary, or in Section 2.2 – Definitions?*
5.3.3 – The design strength of connections where ultimate strength is determined by testing shall be reduced by a factor found in Section 6.3		
5.4 – Tests of Concrete When concrete compressive strength is necessary for the performance of formwork systems, the design shall provide the following statements from Sections 5.4.1 to 5.4.2.4 in the contract documents for the formwork design.		
5.4.1 – When necessary for performance of formwork systems, concrete compressive strength shall be determined from test cylinders, field cured the same as the concrete they represent, or alternative method listed in 5.4.2.		*Taken primarily from ACI 301-05*

5.4.1.1 – Cylinders shall be molded in accordance with ASTM C 31/C 31M, and shall be cured in the same conditions for moisture and temperature as used for the concrete they represent.		
5.4.1.2 – Test cylinders in accordance with ASTM C 39/C 39M		
5.4.2 – Alternative methods for determining the compressive strength of concrete may be specified or permitted by the formwork designer to evaluate concrete strength for formwork removal. These methods are found in 5.4.2.1 through 5.4.2.4. Before using methods in 5.4.2.1 through 5.4.2.4, data must be submitted using project materials to demonstrate correlation of measurements on the structure with the compressive strength of laboratory-cured molded cylinders or drilled cores. The designer shall specify that this data be submitted to the Architect/Engineer prior to the use of the methods in 5.4.2.1 through 5.4.2.4		*Wording of this section is important*
5.4.2.1 – Tests of cast-in-place cylinders in accordance with ASTM C 873. This is limited to slabs with concrete depths from 5 to 12 in.		
5.4.2.2 – Penetration resistance in accordance with ASTM C 803/C 803M		
5.4.2.3 – Pullout strength in accordance with ASTM C 900		
5.4.2.4 – Maturity method in accordance with ASTM C 1074		

CHAPTER 6 – Strength and Serviceability		
6.1 – General		
6.1.1 – Structures and structural members shall be designed to have design strengths, $\mathbf{R_d}$, at all sections at least equal to the required strengths, **U**, calculated in accordance with article 6.2. $\mathbf{R_d \geq U}$ (6.1.1) Where: $\mathbf{R_d}$ = design strength from Article 6.3 **U** = required strength from Article 6.2		R6.1.1 -
6.1.2 – Members also shall meet all other requirements of this Standard to ensure adequate performance at service load levels.		
6.2 – Required Strength		
6.2.1 – *Required strength from ASCE 37* The required strength, **U**, shall be determined in accordance with ASCE 37 load combinations. The design of formwork systems and components shall be consistent with either Load and Resistance Factor Design (LRFD) or Allowable Strength Design (ASD) methods.		R6.2.1 – ASCE 37-02, Section 2.2 provides load combinations, load factors, and arbitrary point-in-time (APT) factors for LRFD and ASD design methods.
6.2.2 – *Required strength of work platforms* Where a structure's primary purpose is to support personnel instead of concrete, it shall be considered scaffolding and subject to the OSHA standards of 26CFR1926, Subpart L and subject to a factor of safety of 4.0 for live loads. The required strength for scaffolding, $\mathbf{U_S}$, for LRFD design methods shall be determined from Equation 6.2.2. $\mathbf{U_S = C_D + 4.0(C_P + C_{FML} + C_{VML})}$ (6.2.2) Where: $\mathbf{C_D}$ = construction dead load $\mathbf{C_P}$ = construction personnel load $\mathbf{C_{FML}}$ = construction fixed material load $\mathbf{C_{VML}}$ = construction variable material load NOTE: *There are two interpretations of OSHA requirements and their impact on formwork. These two interpretations are included below.*		R6.2.2 - OSHA standard 26CFR1926, Subpart L (Scaffolding) mandates a factor of safety of 4.0 for scaffolding. OSHA standard 26CFR1926, Subpart Q (Concrete and Masonry Construction) does not provide a minimum factor of safety for shoring or reshoring. ANSI definitions: Scaffolding is a temporary elevated or suspended work unit and its supporting structure used for supporting worker(s) or materials, or both. SSFI provides this explanation: The primary function of the system determines its classification. If the surface is part of the formwork, it is not scaffolding in spite of the fact that people are standing on that deck. ASCE 37-02 commentary C2.2.2 states: "To satisfy the OSHA criterion, the load factor for personnel and equipment load, C_P, fixed material load, C_{FML}, and variable material load, C_{VML}, should be 4.0 and the load factor for construction dead load, C_D, should be 1.0. Also, capacity reduction factors (f factors) used with these load factors should be 1.0. The OSHA requirement may change in the future"

Interpretation #1 – Load factor is increased, all structures resisting this load must be designed accordingly Equation 6.2.2 applies to the entire supporting structure. *Interpretation #2 – Factor of Safety of 4.0 applies only to load path specifically for scaffolding. When this load path is combined with non-scaffolding loads, ASCE 37 load combinations are used in lieu of Equation 6.2.2.* Equation 6.2.2 applies to the supporting structure only when the structure does not resist concrete loads. From the point at which the structure supports both personnel and concrete loads, ASCE 37 combinations shall be used.		*Since the OSHA loading is versus failure, it is an LRFD combination.* *Commentary to Interpretation #1 :* *An example of a load path combination would be a scaffold used on top of a large elevated slab formwork. The scaffold would be subject to a 4:1 Factor of Safety, as well as the elevated slab formwork supporting the scaffold.* *Another example of a load path combination would be a walkway bracket attached to a wall form. The planking, walkway bracket and connection to the form would require a 4:1 Factor of Safety. The wall form would also be required to support 4 times the live load applied to the scaffold that is attached to the form.* *Commentary to Interpretation #2:* *An example of a load path combination would be a scaffold walkway beam also supporting a concrete load. The 4:1 Factor of Safety should only apply to the decking supporting the walkway and the formwork Safety Factor should apply the support beam.* *Another example of a load path combination would be a walkway bracket attached to a wall form. The planking, walkway bracket and connection to the form would require a 4:1 Factor of Safety, whereas the load path beyond that point would revert to the appropriate concrete forming Factor of Safety.*
6.3 – Design Strength		
6.3.1 – The design strength, $\mathbf{R_d}$, of a material or structural component shall be determined in accordance with an applicable consensus standard.		R6.3.1 - Many material standards provide design strengths for LRFD and allowable strengths for ASD design methods. When these design strengths are calculated from an applicable design standard, no additional resistance factor or safety factor need be applied. Design standards for common materials used in formwork construction are provided in Appendix A. *ACI 347-04 Table 4.1 needs to be reproduced in Appendix A of the draft standard.*
6.3.2 - Methods for determining the nominal strength, $\mathbf{R_n}$, for certain structural components specific to formwork are included in this Standard. When these methods are used, the design strengths shall be determined from Equation 6.1.2a or 6.1.2b For LRFD design methods: $\mathbf{R_d = \Phi R_n}$ (6.1.2a) Where: $\mathbf{\Phi}$ = resistance factor provided for specific component $\mathbf{R_n}$ = nominal strength provided for specific component		R6.1.2 – Resistance factors, $\mathbf{\Phi}$, for form ties, form anchors, and form hangers are provided in Chapter ##. Resistance factors, $\mathbf{\Phi}$, and nominal strengths, $\mathbf{R_n}$, for mass anchors are provided in Chapter 21. Safety factors, $\mathbf{\Omega}$, for form ties, form anchors, and form hangers are provided in Chapter ##. Safety factors, $\mathbf{\Omega}$, and nominal strengths, $\mathbf{R_n}$, for mass anchors are provided in Chapter 21.

For ASD design methods:

$\mathbf{R_d = R_n/\Omega}$ (6.1.2b)

Where:
Ω = safety factor provided for specific component
R_n = nominal strength provided for specific component

6.3.3 – *Alternative design strength from published literature*

Methods for determining the nominal strength, R_n, of formwork components from published literature may be used when no applicable consensus standard exists.

This nominal strength shall be used in Equations 6.1.2a or 6.1.2b depending on the design method chosen.

Resistance factors?

The nominal strength of structural components can be determined from published literature when an applicable design standard cannot be identified. Specialty structural components for formwork may not have a design standard published. Where no such material standard exists, determination of nominal strength from published test results may be necessary for formwork accessories.

Should resistance factors from published literature be accepted?

6.3.4 – *Alternative design strength by testing*

Where the strength of formwork material, components, or systems is determined by testing, the nominal strength, R_n, shall be the point at which performance failure occurs.

The design strength, R_d, shall be determined in accordance with Equation 6.1.2a or 6.1.2b depending on the design method used. Resistance factors, Φ, and safety factors, Ω, shall be determined in accordance with Table 6.3.4.

Table 6.3.4 – Resistance and safety factors for material strengths determined by testing

Item Tested	LRFD resistance factor (Φ)	ASD safety factor (Ω)
Connections	0.75	2.0
Members failing in rupture	0.75	2.0
Members failing in yielding	0.9	1.67

R6.3.4 – The LRFD resistance factors and ASD safety factors provided in Table 6.3.4 are based on values in AISC 360-05 for steel members with similar failure modes.

LRFD reduction factors are significantly harder to establish since load factors are applied to each load type. The ratio of one type of load to another impacts the FoS of the overall system.

AISC 360-05 "Specification for Structural Steel Buildings", Commentary B3, 'Design for Strength Using Load and Resistance Factor Design' describes how LRFD strength reduction factors were established and calibrated to existing ASD factors by a ratio of the live and dead loads.

A live to dead load ratio of 3.0 (L/D=3.0) was used for compact beams and tension members in AISC. This ratio would need to be adjusted for concrete formwork to account for the typical ratios of live to dead load.

CHAPTER 7 – DESIGN LOADS AND LOAD COMBINATIONS		
7.1 *Vertical Loads—*		R7.1 Vertical loads consist of dead and live loads. The dead load consists of the weight of formwork plus the weight of the reinforcement and freshly placed concrete. The live load includes the weight of the workers, equipment, material storage, runways, and impact.
7.1.1 Vertical loads assumed for shoring and reshoring design for multistory construction shall include all loads transmitted from the floors above as dictated by the proposed construction schedule. Refer to Section 7.**#**.		
7.1.2 – Dead Load		
7.1.2.1 Formwork shall be designed for its full self weight		Initial formwork design is often designed using a simple allowance for the self weight of the formwork system. Once the formwork system is selected, the dead weight of the system should be compared to the allowance to confirm it falls below the allowance. Typical allowances are: • Wood forms: 10lbs/ft^2 • Steel forms: 25lbs/ft^2
7.1.2.2 Formwork shall be designed for the full weight of all concrete, reinforcement, embedments, and other dead loads imposed on the system.		The weight of concrete and reinforcement is often assumed using a combination of an assumed concrete unit weight and an assumed volume of reinforcing steel. A typical value of 150 lbs/ft^3 is used to account for a concrete unit weight of 140 lbs/ft^3 with 2% reinforcing steel by volume with a steel unit weight of 490 lbs/ft^3. Any allowance used for concrete and reinforcement weight should be checked against actual unit weights of mix designs and weights of reinforcement to be used with the formwork system.
7.1.2.3 – *Vertical Load of Fresh Concrete* The vertical load of fresh concrete shall be considered a variable material load using ASCE 37 load combinations.		R7.1.2.3 – With concrete placement by bucket or pump, the volume of concrete is concentrated at the initial point of placement. With the variability of concrete placement operations having the potential to impart larger loads than calculated by the slab thickness alone, the dead weight of concrete shall be considered a variable material load on formwork.
7.1.3 – Live Load		
7.1.3.1 Formwork shall be designed for a construction live load of not less than 50 lb/ft^2 (2.4 kPa) of horizontal projection. When motorized carts are used, the construction live load shall not be less than 75 lb/ft^2 (3.6 kPa).		*Concern with the 50 lbs live load on formwork, Lower values for larger areas?* *The California Building Code allows a minimum of 20lbs/ft^2.*
7.1.3.2 The design load for combined concrete load, construction live load, and dead load of the formwork shall not be less than 100 lb/ft^2 (4.8 kPa) or 125 lb/ft^2 (6.0 kPa) if motorized carts are used.		

7.1.3.3 A reduction, R in live load may be taken for members with a tributary area exceeding 150ft^2 in accordance with equation 7.1.3.3 R = 0.08*(Tributary Area – 150) (7.1.3.3) R may not exceed 20% for forming and shoring members, and may not exceed 40% for reshoring members.		*The basis of this reduction is found in IBC 1607.9.2, but maximum R values are more conservative than those allowed in IBC.* *IBC is for permanent structures. ASCE 37 only provides reduction for members with contribution areas greater than 400SF.*
7.2 – Horizontal Loads Horizontal loads shall consist of: (a) the minimum horizontal loads (section 7.2.1) (b) the lateral pressure of concrete (section 7.2.2) (c) the lateral pressure due to wind (section 7.3) These lateral loads do not need to be considered simultaneously.		
7.2.1 – Minimum Horizontal Loads		
7.2.1.1 – Minimum horizontal loads for wall forms Bracing for wall forms shall be designed for a horizontal load of at least 100 lb/linear ft applied at the top of the wall form.		*The minimum pressure of 15psf has been placed in 7.3.2.2*
7.2.1.2 – Minimum horizontal loads for elevated slab forms The minimum horizontal load for elevated slab forms shall be the greater of: (a) 100 lb/linear ft applied at the top of the form (b) 2% of the total dead load on the form distributed as a uniform load per linear foot of slab edge applied at the top edge of the form This minimum horizontal load shall be applied in two perpendicular directions on the elevated slab form.		
7.2.2 – Lateral Pressure of Concrete		
7.2.2.1 – *Lateral pressure of concrete equations* The lateral pressure of concrete, $\mathbf{p_{max}}$ (lbs/ft^2), shall be determined in accordance with the appropriate equation listed in Table 7.2.2.1a. When working with mixtures using newly introduced admixtures that increase set time or increase slump characteristics, such as Self-Consolidating Concrete, Equation 7.2.2.1a shall be used until the effect on formwork pressure is understood by testing.		R7.2.2.1 The set characteristics of a mixture should be understood, and using the rate of placement, the level of fluid concrete can be determined. For columns or other forms that can be filled rapidly before stiffening of the concrete takes place, **h** should be taken as the full height of the form of the distance between horizontal construction joints when more than one placement of concrete is to be made.

Table 7.2.2.1a – Applicable concrete lateral pressure equations

Slump*	Internal vibration depth	Element	Rate of placement	Pressure Equation
> 7 in	Any	Any	Any	7.2.2.1a
≤ 7 in	> 4 ft	Any	Any	7.2.2.1a
≤ 7 in	≤ 4 ft	Column†	Any	7.2.2.1b
		Wall‡ ≤ 14 ft tall	< 7 ft/hr	7.2.2.1b
		Wall‡ > 14 ft tall	< 7 ft/hr	7.2.2.1c
		Wall‡	7 to 15 ft/hr	7.2.2.1c
			> 15 ft/hr	7.2.2.1a

* Slump for determination of lateral pressure shall be measured after the addition of all admixtures

† Columns are defined as vertical elements with no plan dimension exceeding 6.5 ft.

‡ Walls are defined as vertical elements with at least one plan dimension exceeding 6.5 ft.

$$\mathbf{p_{max} = wh} \qquad (7.2.2.1a)$$

Where:
w = unit weight of concrete (lbs/ft^3)
h = height of concrete placement (ft)

$$\mathbf{p_{max} = C_W C_C[150 + 9000R/T]} \qquad (7.2.2.1b)$$

with a minimum of **$600C_w$** lb/ft^2, but in no case greater than **wh**

$$\mathbf{p_{max} = C_W C_C[150 + 43,000/T + 2800R/T]} \qquad (7.2.2.1c)$$

with a minimum of **$600C_w$** lb/ft^2, but in no case greater than **wh**

Where:
C_W = Unit Weight Coefficient from Table 7.2.2.1b
C_C = Chemistry Coefficient from Table 7.2.2.1c
R = Rate of placement (ft/hr)
T = Temperature of concrete (°F)

Table 7.2.2.1b – Unit weight coefficient, C_W

Unit weight of concrete (lb/ft^3)	C_W
w < 140	0.5[1+ (w/145)] but not less than 0.80
140 ≤ w ≤ 150	1.0
w > 150	w/145

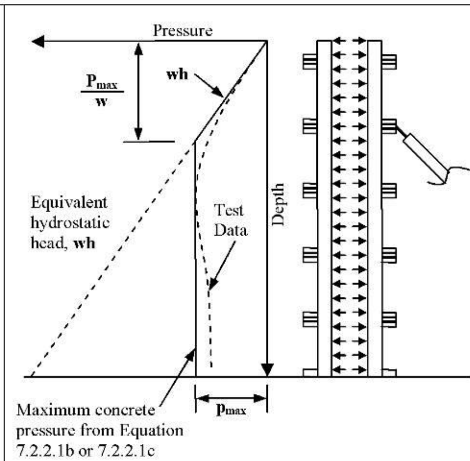


Figure R7.2.2.1a – Concrete Lateral Pressure on Column and Wall Formwork

Equations 7.2.2.1a, 7.2.2.1b, and 7.2.2.1c along with Table 7.2.2.1b and 7.2.2.1c are from Reference 7.1.

Table 7.2.2.1c – Chemistry coefficient, C_C

Cement type	Slag	Fly Ash	Retarders*	C_C
I, II, or III	None	None	None	1.0
			Included	1.2
Any	< 70%	< 40%	None	1.2
			Included	1.4
	≥ 70%	≥ 40%	None	1.4
			Included	1.5

* Retarders include any admixture, such as a retarder, retarding water reducer, retarding midrange water-reducing admixture, or high-range water-reducing admixture (superplasticizer), that delays setting of concrete.

7.2.2.2 – Rational analysis

Alternatively, a method based on appropriate experimental data from tests conforming to published procedures may be used to determine the lateral pressure used for form design.

R7.2.2.2 – A test method based on references 7.2 through 7.10 will provide an acceptable method for determining concrete lateral pressure through testing.

7.2.2.3 – *Concrete pumped into form from base*

If concrete is pumped into the form from the base of the form, the form shall be designed for full hydrostatic head of concrete (Equation 7.2.1.1a) plus a minimum allowance of 25% for pump surge pressure.

R7.2.2.3 – When concrete is placed by pump from the base of the form, pressure can be as high as the face pressure of the pump piston in certain instances.

7.2.2.4 – *Externally vibrated concrete*

When concrete is consolidated by external vibration, the formwork designer shall consider the additional effect of external vibration on form pressure.

R7.2.2.4- Caution is necessary and additional allowance for pressure should be considered when using external vibration. Pressures in excess of the equivalent hydrostatic head can occur.

7.2.2.5 – *Shrinkage compensating or expansive cements*

When concrete mixtures contain shrinkage compensating or expansive cements, the formwork designer shall consider the additional effect of expansion on form pressure.

R7.2.2.5 – Caution is necessary and additional allowance for pressure should be considered when using concrete mixtures made with shrinkage compensating or expansive cements. Pressures in excess of the equivalent hydrostatic head can occur.

7.2.2.6 – *Concrete placed by slipform*

For slipform lateral pressures, refer to Section X.X.X.X

7.3 – Wind		
7.3.1 – Wind Velocity		
7.3.1.1 – *Basic Wind Speed* The basic wind speed shall be determined in accordance with ASCE 7-05 for a Risk Category II structure.		R7.3.1.1 – The Importance Factor, **I**, for temporary structures in construction is 1.0 for all environmental loads per ASCE 37-02. This corresponds to a Risk Category II structure in the ASCE 7-05 classification system. ASCE 37-02 references ASCE 7-95 for wind speeds; however, ASCE 7-05 represents the most recent revision of ASCE 7 to which ASCE 37-02 reduction factors are applicable. At the time of this draft, ASCE 37 has not been updated to reflect the changes made in ASCE 7-10. ASCE 7-10 recognizes that applying a blanket factor to wind loads does not reflect the actual variability throughout the US. ASCE 7-10 removes the Importance Factor for wind and instead accounts for the buildings importance by establishing different wind contour maps for different Importance levels, each with a different return period. Also, the wind load factor of 1.6 is removed by increasing the return period of the wind speeds as well. A detailed explanation of this change can be found in the commentary of ASCE 7-10, starting on page 508. The ASCE 37-02 wind speed reductions and ASCE 37-02 load factors are not applicable to the ASCE 7-10 wind speeds. Until a revision of ASCE 37 has been published to reflect the design practice changes of ASCE 7-10, ASCE 7-05 will be the source of provisions for wind load on temporary structures. *ASCE 7-05 includes several relevant changes versus ASCE 7-95:* • *The wind speed contour lines have been revised; however the speeds have not.* • *It increased the load factor on wind from 1.3 to 1.6 for permanent structures.* • *It contains a more detailed approach for wind loads on walls and Solid Signs.* *Since ASCE 37-02 reduces the wind speeds to 90 mph in hurricane regions, the changes in the wind speed contours only apply in the event of an announced hurricane. Also, since ASCE 37-02 provides its own set of load factors for wind loads on temporary structures, the changes in ASCE 7's load factors do not apply. The only significant change is the analysis method for walls and solid signs, which is applicable to wall formwork.*

7.3.1.2 – *Hurricane Prone Regions* Wind velocities for hurricane-prone regions shall comply with the requirements of ASCE 37-02 Sub-section 6.2.1.1 *Construction Period*.		R7.3.1.2 - ACSE 37-02 sub-section 6.2.1.1, *Construction Period*, allows for the reduction of the Basic Wind Speed to a speed of 90 mph in regions along the Gulf Coast and Eastern Seaboard subject to hurricanes. This reduced Basic Wind Speed corresponds to the Basic Wind Speed for the majority of the interior of the US as shown in referenced standard ASCE 7-95.
7.3.1.3 – *Design Velocity* The basic wind speed from sub-sections 7.3.1.1 and 7.3.1.2 shall be adjusted by multiplying the basic wind speed by the appropriate reduction factor found in ASCE 37-02 Section 6.2.1 to determine the design wind velocity on a formwork system.		R7.3.1.3 - ASCE 37-02 provides reduction factors to adjust the Basic Wind Speed for temporary work to account for the short exposure durations of temporary structures.
7.3.2 – Design Wind Pressure		
7.3.2.1 – Using the wind velocity from Section 7.3.1; the design velocity pressure, $\mathbf{q_z}$, shall be determined in accordance Equation 7.2.3.2.1: $\mathbf{q_z = 0.00256K_zK_{zt}K_dV^2}$ (7.3.2.1) Where: $\mathbf{K_z}$ = velocity pressure exposure coefficient from ASCE 7-05 Section 6.5.6.6 $\mathbf{K_{zt}}$ = topographic factor from ASCE 7-05 Section 6.5.7.2 $\mathbf{K_d}$ = wind directionality factor from ASCE 7-05 Section 6.5.4.4 **V** = basic wind speed from ASCE 7-05 Section 6.5.4.1		R7.3.2.1 – ASCE 7-05 section 6.5.10 *Velocity Pressure* provides an equation for velocity pressure, $\mathbf{q_z}$, appropriate for the design wind pressure on formwork systems. This design wind pressure is used in the calculation of wind forces on structures and components. Equation 7.3.2.1 is equivalent to ASCE 7-05 Equation 6-15 with an Importance Factor, **I**, equal to 1.0 as specified in ASCE 37-02 Section 6.1.
7.3.2.2 – The design wind pressure applied to formwork shall not be less than 15 psf.		R7.3.2.2 - This minimum wind pressure is not intended to be used in combination with force coefficients, but instead applied directly to the formwork surface. *British Standard BS 5975:2008, Section 17.5.1.8 states that formwork should be designed for a working wind pressure corresponding to a maximum working wind speed, typically 18 m/s (40 mph) wind speed with a pressure of 200N/m² (4.2 lbs/ft². This wind pressure is used in conjunction with the force coefficients and shielding coefficients appropriate for each structure type.*
7.3.3 – Shielding from Wind Pressure		
7.3.3.1 – *Shielding of Formwork by Surroundings* Where the formwork is located in an area where it will be shielded from wind by an excavation, existing structure, or other obstruction as defined in 7.3.3.2; the basic wind pressure is allowed to be reduced to the minimum value stated in Sub-section 7.3.2.2 for the shielded portion. The unshielded portion shall be designed for the full wind pressure.		R7.3.3.1 - This minimum pressure provides a minimum level of stability for formwork in shielded areas.

7.3.3.2 – *Shielding by Other Structures*

Formwork shielding shall be permitted for a portion of formwork contained within a shielding zone of an existing structure or obstruction. The zone of shielding shall be the projected face reduced by a rate 1 inward for 2 downwind of the obstruction as shown in Figure 7.3.3.2. This zone of shielding applies to both vertical and horizontal shielding.

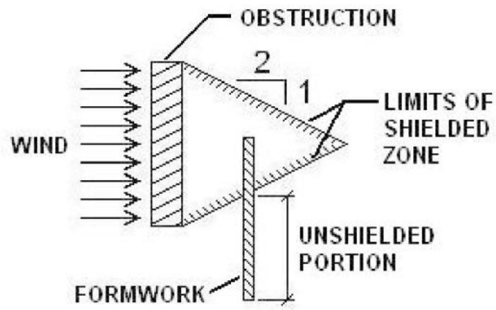


Fig. 7.3.3.2 – Wind shielding by obstruction

R7.3.3.2 - An existing structure or obstruction is any free-standing structure that will remain in place for the duration of the formwork system and can withstand the wind loads imposed on it. This can include recently completed concrete work that has gained sufficient strength to withstand wind loads. It can also include excavations or soil mounds that obstruct wind flow from a specific direction. Any mobile structure, such as equipment, should not be used as shielding.

This method is used by Cal. DOT Falsework Manual as well as British Standard BS5975. Figure 7.3.3.2 is based on Figure 3-6 in Cal. DOT Falsework Manual, 1992.

7.3.3.3 – *Wind Shielding on Repetitive Members*

The effective area, $\mathbf{A_f}$, for repetitive members shall be the projected area of an individual member for which the specific cumulative shielding coefficient, $\boldsymbol{\eta_m}$, is determined.

When different sizes, types, spacing, or rows of repetitive members are used; a force coefficient ($\mathbf{C_f}$), $\boldsymbol{\eta_m}$, and $\mathbf{A_f}$ shall be determined for each scenario.

$\mathbf{C_f}$ for repetitive members subject to shielding due to alignment shall be:

$$\mathbf{C_f = \eta_m C_{fi}} \qquad (7.3.3.3a)$$

Where: $\boldsymbol{\eta_m}$ = cumulative shielding coefficient from Equation 7.3.3.3b

$\mathbf{C_{fi}}$ = force coefficient from ASCE 7-05 for an individual member or from Section 7.3.4

$$\boldsymbol{\eta_m = 1 + \eta^1 + \eta^2 + \eta^3 + \eta^4 + \ldots + \eta^{(m-1)} \leq (1 - \eta)^{(m-1)}} \qquad (7.3.3.3b)$$

Where: $\boldsymbol{\eta}$ = shielding coefficient from Figure 7.3.3.3

m = number of identical, equidistant objects

R7.3.3.3 - The shielding coefficient, $\boldsymbol{\eta_m}$, is applied to the force coefficient, $\mathbf{C_f}$, for an individual member in a series of repetitive members. ASCE 7-05 provides $\mathbf{C_f}$ values for latticed or trussed towers. When latticed or trussed towers are used in series and shielding is considered, then $\boldsymbol{\eta_m}$ is applied to the $\mathbf{C_f}$ value for one instance of the tower. For generic shapes, Cranes and Derricks, 4th Edition by Shapiro & Shapiro (2011) is a source of shape factors, $\mathbf{C_s}$, which can be used as force coefficients, $\mathbf{C_f}$.

Equation 7.3.3.3a is used to combine the equation from Cranes and Derricks 4th edition by Shapiro & Shapiro (2011) with ASCE 7-05 Equation 6-28 by providing a new force coefficient, $\mathbf{C_f}$, *that combines the individual member force coefficient,* $\mathbf{C_{fi}}$, *and the cumulative shielding coefficient,* $\boldsymbol{\eta_m}$

Equation 7.3.3.3b and Figure 7.3.3.4 are from Cranes and Derricks 4th edition by Shapiro & Shapiro (2011). Figure 7.3.3.3 is provided in Shapiro and Shapiro and was reproduced from the 1970 standard "Rules for the Design of Hoisting Appliances" by the Fédération Européene de la Manutention.

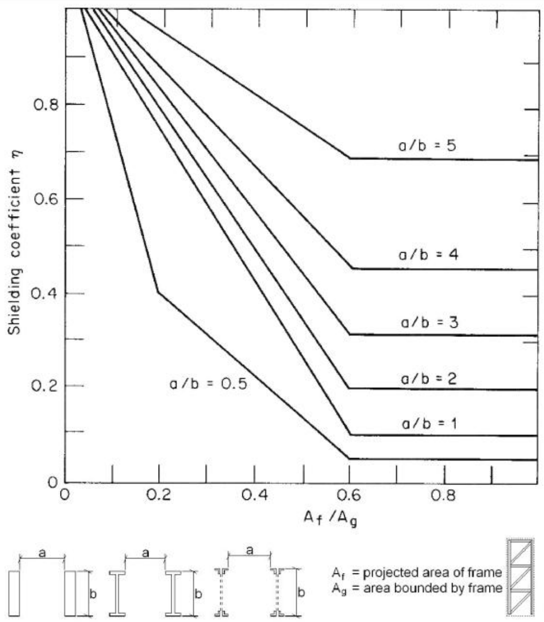


Fig. 7.3.3.3 – Shielding coefficient for repetitive members (reprinted from Cranes & Derricks, 4th edition, Shapiro)

7.3.4 – Design Wind Load

7.3.4.1 - Except as modified in Section 7.3.3, the wind load on formwork systems (F_w) shall be determined using Equation 7.3.4.1.

$$\mathbf{F_w = q_z G C_f A_f} \quad (7.3.4.1)$$

Where:
q_z = design velocity pressure from 7.3.2.1
G = gust-effect factor from Section 7.3.4.2
C_f = force coefficient for formwork component
C_f values for certain structures are provided in ASCE 7-05 Figures 6-20 through 6-23
A_f = projected area normal to the wind

In lieu of the force coefficient, **C_f**, values provided in ASCE 7-05, the additional **C_f** values for typical formwork structural components provided in this chapter are permitted to be used with Equation 7.3.4.1.

R7.3.4.1 - Different formwork systems and components have specific force coefficient, **C_f**, values. The sources for force coefficient values for common systems are provided below.

When special analysis methods are not provided, ASCE 7-05 sub-section 6.5.15 *Design Wind Loads on Other Structures* should be utilized.

Equation 7.3.4.1 is based on ASCE 7-05 Equation 6-28.

ASCE 7-05 Figures 6-20 through 6-23 provide **C_f** values for several structures commonly used in formwork. These include: square or round chimney-like structures, lattice frameworks, and trussed towers.

C_f values for elevated slab formwork systems are provided in Sub-section 7.3.4.6.

C_f values for other common shapes used in formwork design are included in Table 7.3.4.4 or in Cranes and Derricks, 4th Edition by Shapiro and may be utilized in Equation 7.3.4.1

7.3.4.2 - The Gust Effect Factor, **G**, shall be 0.85 for formwork.

R7.3.4.2 – For determination of the gust effect factor, **G**, formwork is assumed to be a rigid structure in ASCE 7-05 Section 6.5.8, resulting in **G** equal to 0.85.

7.3.4.3 – *Combined Wind Loading* Wind load shall be determined in a minimum of two perpendicular directions, one of which being the exposed face with the greatest projected area. For each direction of wind loading, formwork shall be designed to resist the full force of wind load calculated along that direction as well as 50% of the wind load calculated for the perpendicular direction acting simultaneously.		R7.3.4.3 - This is a rewording of ASCE 37-02, sub-section 6.2.2 *Frameworks without Cladding*
7.3.4.4 – *Rational Analysis* In lieu of the procedure defined in Sub-Section 7.3.3, determination of the wind load on a formwork system by a rational analysis defined in recognized literature is permitted.		*Similar to ASCE 7-05 paragraph 6.5.8.3 Rational Analysis, though the ASCE section refers only to the gust effect factor.* *Recognized literature needs to be defined for this statement to be enforceable.*
7.3.4.5 – *Wind Load on Wall Forms* Wind load on wall forms shall be determined in accordance with ASCE 7-05 and using the force coefficients provided therein.		R7.3.4.5 - ASCE 7-05, sub-section 6.5.14 *Design Wind Loads on Solid Freestanding Walls and Solid Signs* provides a design method applicable to formwork for walls.
7.3.4.5a – *Generic Wind Force for Walls* Equation 7.3.4.5a may be applied to determine the wind load on wall forms provided the following conditions are met: a. Basic wind speed from Section 7.3.1 is ≤ 90 mph b. Formwork height not to exceed 20 feet from ground level c. Formwork duration is less than 6 weeks d. Formwork is not placed at the top of a hill or in an accelerated wind region e. Formwork length does not exceed 3 times the height $\mathbf{F_{wall} = 15h}$ (7.3.4.5a) Where: $\mathbf{F_{wall}}$ = wind force along wall form (lbs/ft), applied at mid height of wall form **h** = height of wall form (ft)		R7.3.4.5a - The generic design force is based ASCE 7-05 Equation 6-27 using on the following factors: Basic wind speed: 90 mph < 6 week duration: 0.75 wind speed reduction Directionality factor, $\mathbf{K_d}$: 0.85 Terrain Factor, $\mathbf{K_{zt}}$: 1.0 Exposure Category: C, Coefficient, $\mathbf{K_z}$, at 20ft: 0.90 Gust Factor, **G**: 0.85 for a rigid structure Force Coefficient, $\mathbf{C_f}$: 1.80 for a solid sign with aspect ratio of 3 These factors result in a wind pressure of 13.6 psf applied to a wall. The resulting force is 13.6*h and is applied at a point 0.55h from the base of the wall per ASCE 7-05 Figure 6-20. To provide an equivalent resultant force at the center of the wall, the wind pressure is multiplied by 1.1, resulting in a wind pressure of 15.0 psf. A lower wind force may be used provided it complies with Sub-section 7.3.4.4 or 7.3.4.5
7.3.4.6 – *Wind Loads on Elevated Slab Formwork* $\mathbf{C_f}$ of elevated slab formwork shall be determined from Table 7.3.4.6. This force coefficient applies to the slab formwork only and acts through the mid height of the slab formwork. A separate analysis shall be performed for the shoring system supporting the slab formwork.		*British Standard BS 5975:2008, section 17.5.1.14.2 provides a simplified method for shielding of repetitive members of elevated slab formwork systems. This method multiplies the projected area of the formwork by a factor depending on the orientation of the supporting members.*

Table 7.3.4.6 – C_f for elevated slab formwork

Arrangement Case	C_f
Case 1 (Figure 7.3.3.6a)	2.0
Case 2 (Figure 7.3.3.6b)	2.2

A_f of the windward face of elevated slab formwork shall be:

A_f = d x length of formwork considered (7.3.4.6)

Where: **d** = depth of windward face depending on applicable case shown in Figures 7.3.4.6a and 7.3.4.6b

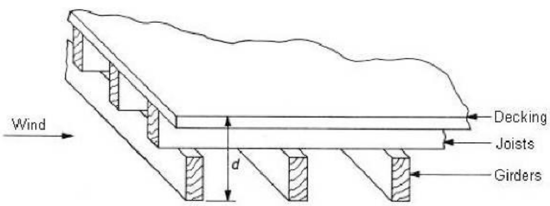


Fig. 7.3.4.6a – Case 1: wind parallel to joists

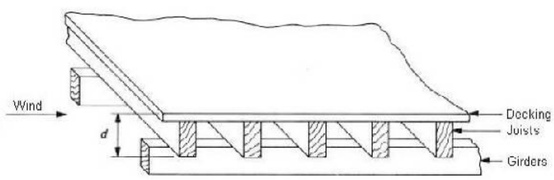


Fig. 7.3.4.6b – Case 2: wind parallel to girders

Wind force is only considered to act on one windward face of elevated slab formwork and is not cumulative on all secondary members of elevated slab formwork. No additional shielding coefficient shall be applied to joists or girders.

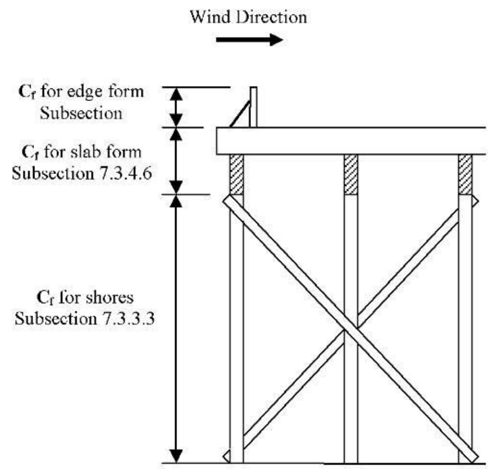


Fig. R7.3.4.6 – Applicable force coefficient provisions for elevated slab formwork

7.3.4.6a – *Wind Force on Slab Edge Forms*

The force coefficients for slab edge forms shall be determined from Table 7.3.4.6a. The definitions of $\mathbf{L_w}$ and $\mathbf{d_1}$ are found in Figure 7.3.4.6a.

Table 7.3.4.6a – C_f for slab edge forms

Edge Form	C_f
Windward Edge Form	**1.8** (1)
Leeward Edge Form	$\mathbf{0.11[(L_w/d_1) - 3]}$ (2) Where: $0.0 \le C_f \le 1.8$

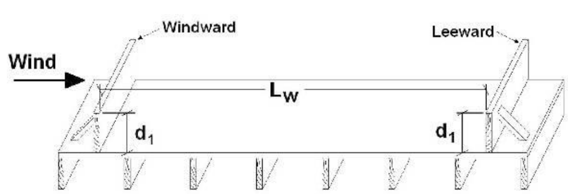


Fig. 7.3.4.6a – Slab Edge Form Dimensions

BS5975:2008 17.5.1.14.3 provides this provision for edge forms. When determining the force coefficient for the leeward form, BS5975:2008 Figure 11 provides a shelter factor. The equation for the shelter factor is $SF = 0.06*[(L_w/d_1) - 3]$ where $0 \le SF \le 1.0$. This shelter factor is then multiplied by the windward force coefficient of 1.8. The force coefficient in Table 7.3.4.6a for the leeward edge form is the equation for the shelter factor multiplied by the force coefficient.

7.3.4.6b – *Generic Wind Force for Elevated Slabs*

A generic wind force of 70 pounds per linear foot of elevated slab form may be applied to determine the wind load on elevated slab forms provided the following conditions are met.

a. Basic wind speed from Section 7.3.1 is ≤ 90 mph
b. Formwork height not to exceed 40 feet from ground level
c. Formwork duration is less than 6 weeks
d. Formwork is not placed at the top of a hill or in an accelerated wind region
e. Depth of the slab formwork, **d**, shall not exceed 2 feet
f. Depth of the slab edge form, $\mathbf{d_1}$, shall not exceed 1 foot

This generic wind force is applied at the top edge of the elevated slab form.

R7.3.465b - The generic design force is based ASCE 7-05 Equation 6-28 using on the following factors:

Basic wind speed: 90 mph
< 6 week duration: 0.75 wind speed reduction
Directionality factor, $\mathbf{K_d}$: 0.85
Terrain Factor, $\mathbf{K_{zt}}$: 1.0
Exposure Category: C, Coefficient, $\mathbf{K_z}$, at 40ft: 1.04
Gust Factor, **G**: 0.85 for a rigid structure
Force Coefficient, $\mathbf{C_f}$: 2.2 from Table 7.3.4.6
Depth of Slab Formwork: ≤ 2 ft
Depth of Slab Edge Forms: ≤ 1 ft, 2 edge forms, no shielding

A lower wind force may be used provided it complies with Sub-section 7.3.4.4 or 7.3.4.6

NOTE: This is less than ACI's recommended minimum force of 100 pounds per linear foot, should we provide a minimum elevation where wind should be considered over the ACI minimum? Does ACI's force also account for wind load on shoring?

7.3.4.7 – *Force Coefficients for Selected Shapes*

Table 7.3.4.7 provides $\mathbf{C_f}$ for selected structural shapes.

Table 7.3.4.7 – Force coefficients for selected members

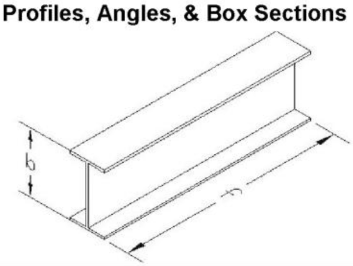
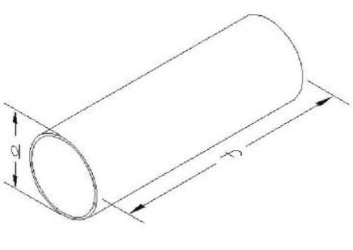
Profiles, Angles, & Box Sections	**f / b**	$\mathbf{C_f}$
	50	1.9
	40	1.7
	30	1.65
	20	1.60
	10	1.35
	5	1.30
Tubes	d x V < 50 ft^2/s	
	f/d	$\mathbf{C_f}$
	50	1.10
	40	1.00
	30	0.95
	20	0.90
	10	0.80
	5	0.75
	d x V ≥ 50 ft^2/s	
	f/d	$\mathbf{C_f}$
	50	0.80
	40	0.75
	30	0.70
	20	0.70
Where: d = diameter (ft)	10	0.65
V = wind velocity (ft/s)	5	0.60

Table 7.3.4.7 is from Cranes and Derricks 4th edition by Shapiro & Shapiro (2011)

Chapter 7 References

7.1 – Barnes, J. M., and Johnston, D. W., "Fresh Concrete Lateral Pressure On Formwork," Construction Research Congress, ASCE , March 19-21, 2003, 8 pp.

7.2 – Gardner, N. J., "Pressure of Concrete Against Formwork," ACI JOURNAL, *Proceedings* V. 77, No. 4, July-Aug. 1980, pp. 279-286; and discussion, *Proceedings* V. 78, No. 3, May-June 1981, pp. 243-246

7.3 – Dunston, P.S, Johnston, D. W., and McCain, P. P., "Formwork Pressures in Tall Walls with Extended Set Concrete," ACI Concrete Inernational, V. 16, No. 11, November 1994, pp. 26-34.

7.4 – Johnston, D. W., Kahn, K. P., and Phillips, J. B., "Formwork Pressures in Tall and Thick Concrete Walls," ASCE Journal of Construction Engineering and Management, V. 115, No. 3, September 1989, pp. 444-461.

7.5 – Gardner, N. J., and Ho, P. T.-J., "Lateral Pressure of Fress Concrete," ACI JOURNAL, *Proceedings* V. 76, No. 7, July 1979, pp. 809-820.

7.6 - Clear, C. A., and Harrison, T. A., 1985, "Concrete Pressure on Formwork," *CIRIA Report* No. 108, Construction Industry Research and Information Association, London, 32 pp.

7.7 - "Pressure of Concrete on Vertical Formwork (Frischbeton auf Lotrechte Schalungen)," DIN 18218, Deutsches Institut für Normung e.V., Berlin, 1980, 4 pp.

7.8 - Gardner, N. J., "Pressure of Concrete on Formwork—A Review," ACI JOURNAL, *Proceedings* V. 82, No. 5, July-Aug. 1985, pp. 744-753.

7.9 - British Cement Association, "Hi-Rib Permanent Formwork Trials," Report and Appendix, RE1.031.01.1 BCA, Slough, UK, Feb. and July 1992, 22 and 9 pp.

7.10 – Johnston, D. W., "Field Measurement of Concrete Lateral Pressure in Formwork," ASCE, Proceedings of the 2010 Construction Research Congress, V. 2, May 2010, pp. 1335-1344

7.11 – Office of Structure Construction, "Falsework Manual," Revision No. 16, 6/92, State of California Department of Transportation, June 1992.

7.12 – Shapiro, L.K. & Shapiro, J.P., "Cranes and Derricks", 4th Edition, McGraw-Hill, New York, NY, 2011.

CHAPTER 8 – ANALYSIS AND DESIGN		
8.1 General Considerations Load effects on formwork structures, and on their respective individual components shall be determined by accepted methods of structural analysis that take into account equilibrium, general stability, geometric compatibility and material properties.		
8.1.1 Loads described in Chapter 7 shall be accounted for as applicable for the member and material type(s) described in Chapter 8.		
8.1.2 Construction live loads shall be considered in strength calculations for all member types.		
8.1.3 Wind loads shall be considered in strength calculations for all member types.		
8.2 Application-Specific Considerations		
8.2.1 Slab Form Members		
8.2.1.1 Slab form members shall be designed to carry the intended loads from section 7.1 and 7.3.		
8.2.1.2 Members with multiple spans and/or cantilevers shall be designed with maximum design load applied to the entire loaded portion. Where member uplift due to uneven loading is a concern, design shall specify construction method to minimize uplift concerns.		
8.2.1.3 Member stability shall be analyzed for all members whose depth-width ratio exceeds 2:1. Where lateral restraint is required to stabilize member, the means of lateral restraint shall be specified as part of the formwork system.		
8.2.2 Gang Form Members		
8.2.2.1 Gang form members shall be designed to carry the intended loads from section 7.2 and 7.3		
8.2.2.2 Members with multiple spans and/or cantilevers shall be designed with uniform load applied to the entire loaded portion.		
8.2.1.3 Member stability shall be analyzed for all members whose depth-width ratio exceeds 2:1. Where lateral restraint is required to stabilize member, the means of restraint shall be specified as part of the formwork system.		
8.2.3 Shores & Reshores		
8.2.3.1 Shore and Reshore members shall be designed to carry the intended loads from section 7.1 and 7.3		
8.2.3.2 Members with rectangular sections shall be independently analyzed in both orientations.		
8.2.3.3 Members shall be designed for a minimum eccentricity of 1/6th the overall dimension in each orientation to account for non-uniform loading and incidental occurrences of out-of-plumb. For the eccentricity to be waived in the design, instructions for construction methods and tolerances shall be specified that eliminate eccentricity in the field.		
8.2.3.4 Effective length for unbraced members in either direction shall be considered equal to the member length. Bracing in either direction reduces the effective length for design, and effective length may be considered the maximum distance between either brace locations and/or end of member. (K_e = 1.0)		

8.2.3.5 In order for a brace to reduce the member's effective length, it must be capable to carry at least 2% of the member's axial load in either direction (tension and compression).		
8.2.3.6 Shores that are built up of multiple members shall either be assigned a capacity based on empirical data in accordance with section 5, or shall be analyzed as built-up columns with appropriate consideration for hinged connection, slippage between members, axial eccentricity, and load transfer through connections.		
8.3 Material-Specific Considerations		
8.3.1 Moisture – Where wood-based forming systems are used, adjustments for moisture shall be applied for any member expected to exceed a moisture content of 16%. Wet-use adjustments shall either be as prescribed in the National Design Specification for Wood Construction or as published by the formwork manufacturer. Moisture adjustments shall apply to Modulus of Elasticity (E), bending strength (F_b), shear strength (F_v), compressive strength (F_c) and bearing strength (F_{cp}).		
8.3.2 Load duration – Where wood-based forming systems are used, adjustments for Duration-of-Load may be applied for forming members whose cumulative exposure to design load does not exceed those durations prescribed in the National Design Specification for Wood Construction. In no case shall load duration adjustment for any member exceed 1.25. Duration-of-Load adjustments shall apply to bending strength (F_b), compressive strength (F_c) and shear strength (F_v).		
8.3.3 Where commodity products are specified (i.e. sawn lumber, steel I-beams), specific grades shall be designated to ensure that product used meets the strength assumed during design.		
8.3.4 Where proprietary products or systems are selected, they shall be of a tested design in accordance with section 5 or based on manufacturer recommendations.		

CHAPTER 9 – DEFLECTION AND CAMBER		
9.1 Deflection		
9.1.1 Specification of deflection shall be included as part of the formwork design. Deflection shall be individually specified and analyzed for each component of the support structure (i.e. sheathing, joist, beam, shore, reshore).		
9.1.2 Deflection of individual formwork components must comply with deflection requirements provided in the contract documents and compatible with ACI-117. In lieu of any other requirement, a simple span maximum deflection of l/240 will be used.		Deflection is typically limited by a ratio of the span in inches to the maximum deflection in inches (i.e. L/360 allows 0.33" of deflection on a 12' span). Deflection is typically further limited by a maximum that is stated in fractions of an inch (i.e. ¼").
9.1.2.1 Camber may be used in accordance with section 9.2 to counter deflection. Where camber is used, deflection shall be determined using equation 9.1.2.1a $\Delta_{net} = \Delta_{max}$ - Camber (eq. 9.1.2.1a) Δ_{max} is the maximum deflection calculated using applicable loads shown in section 7.1. For purposes of determining deflection when camber is used, Δ_{max} is calculated using only concrete pressure and dead load due to forms (no construction live loads).		
9.1.3 Stated deflection ratios apply to spans. For deflection calculations on overhangs, the deflection may be limited to twice the overhang length over the stated ratio (i.e. 2*L/360).		
9.1.4 Stated deflections shall apply only to portions of the formwork that will determine shape of the finished concrete. Portions of the structure to be used as walkways or access need not comply with specified deflections unless specifically stated in the design.		
9.1.5 Deflection calculations need not include construction live loads.		
9.2 Camber		
9.2.1 When camber is used to limit net downward deflection, the following shall be specified:		
9.2.1.1 Method of inducing camber. Commonly used methods of inducing camber in the completed form include: - Camber strips attached to formwork - Manufacture of form members with built-in camber - Jacking/stressing of forms in place to induce camber		
9.2.1.2 Magnitude of camber and allowable tolerance		
9.2.1.3 Frequency and method of determining in-field camber and/or deflection.		
9.2.1.4 Remedial measures to be taken when field-measured camber is found to exceed tolerance. This could include: - restressing of camber bars - addition of camber strips - recalculation of deflection based on existing camber - replacement of forms		

9.2.2 Whenever cambered forms are used to limit net downward deflection, the magnitude of the camber shall be such that $\Delta_{max} \geq$ Camber. This ensures that finished concrete thickness of the completed structure is at least as thick as specified.		
9.2.3 Camber shall be limited to members on either a simple span (supports located at ends of the member), or on a single span with cantilevers occurring at one or both ends. Cambered members shall not be supported at intermediate locations unless specifically designed and detailed for this condition.		
CHAPTER 10 – SHEATHING		
CHAPTER 11 – TIES		
CHAPTER 12 – CONNECTIONS		
12.1 General		
12.2 – Column friction collars		*Add section on design basis for column friction collars*
12.3 – Dowel pin column connections		*Add section on design basis for column dowel bolt/pin connections*
CHAPTER 13 – PERSONNEL PLATFORMS		
13.1 – General		
13.2 – Design loads		
13.2.1 – Live loads		
13.2.2 – Railing Loads		
13.2.3 – Fall protection anchor loads		
13.3 – Loads imparted on forms		
13.4 – Egress requirements		
CHAPTER 14 – FOUNDATION FORMS		
CHAPTER 15 – COLUMN FORMS		
CHAPTER 16 – WALL FORMS		
16.1 – Two-sided wall forms		
16.1.1 – Ties		
16.1.2 – Bracing		
16.2 – One-sided wall forms		
16.2.1 – Bracing		
16.2.2 – Tying to soil/rock		

CHAPTER 17 – ELEVATED FLOOR, SLAB, AND BEAM FORMS		
17.1 – Flat plates of uniform thickness		
17.2 – Slab, beam, and joist systems		
17.3 – Slabs composite with structural steel sections		
17.4 – Slabs on metal decking		
17.5 – Shoring		
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CHAPTER 18 – SHORING AND RESHORING REQUIREMENTS FOR ELEVATED FLOORS		
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18.2 – Stiffness of Floors		
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18.4 – Placement of shores and reshores		
18.5 – Removal of shores and reshores		
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CHAPTER 19 – BEARING OF FORMWORK		
19.1 – Bearing on Soil		
19.2 – Bearing on Mudsills		
19.3 – Bearing on existing structures		
19.4 – Bearing on recently placed concrete		
CHAPTER 20 - ANCHORAGE TO CONCRETE		*See ACI 318 Appendix D*

CHAPTER 21 – GROUND ANCHORS AND DEADMEN

21.1 – Types and applications

21.2 – Design

21.2.1 - Mass Anchors (Dead Men)

21.2.1.1 –*Mass anchor design*

Mass anchors used to anchor bracing shall be designed to resist brace tension and compression forces in accordance with Sections 21.2.1.2 through 21.2.1.6.

21.2.1.2 – *Resistance and safety factors for mass anchors*

For mass anchors, the applicable resistance factor, $\mathbf{\Phi_B}$, or safety factor, $\mathbf{\Omega_B}$, of the mass anchor shall be determined from Table 21.2.1.2

Table 21.2.1.2

LRDF	ASD
$\Phi_B = 0.86$	$\Omega_B = 1.5$

R21.2.1.2 - ASCE 37-02 Section 2.3.3. states: "building and other structures shall be designed so that the overturning moment caused by lateral forces acting singly or in combination does not exceed two thirds of the dead load stabilizing moment." This is the basis for both the ASD safety factor of 1.5.

The LRDF factor is calculated to give an overall resistance of 2/3 by assuming that the controlling case is wind load, with a load factor of 1.3 from ASCE 37-02.

$$\frac{\Phi_B * R_n}{(2/3) * R_n} = \frac{1.3*W}{1.0*W}$$

21.2.1.3 – *Mass anchors placed on the surface*

21.2.1.3.1 – *Strength of mass anchors on the surface*

Mass anchors placed on the surface of the ground or existing structure shall be designed to resist:

(a) Uplift – Paragraph 21.2.1.3.2
(b) Overturning – Paragraph 21.2.1.3.3
(c) Sliding – Paragraph 21.2.1.3.4

The statics of mass anchors placed on the surface of the ground or existing structure is shown in Figures 21.2.1.2.1a and 21.2.1.2.1b.

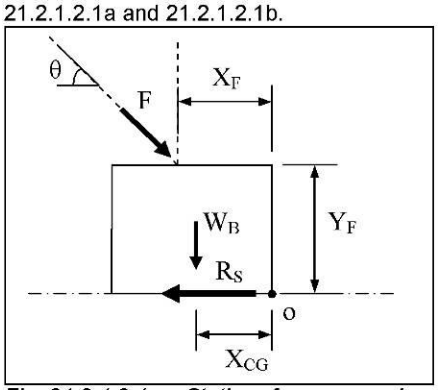


Fig. 21.2.1.3.1a – Statics of a mass anchor subject to a compression force

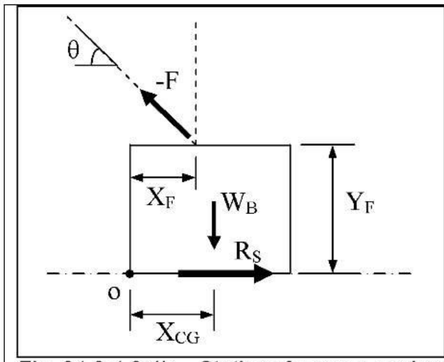
R21.2.1.3.1 - When designing for overturning forces the location of overturning point, **o**, changes depending on the direction of force applied. This is shown in Figures 21.2.1.3.1a and 21.2.1.3.1b by the change in position of the overturning point, **o**, for an applied compression force and tension force.

When designing for sliding forces, the vertical component of the applied force, **Fsin(θ)**, provides additional normal force when the brace is in compression. With the brace is in tension, the applied load, **F**, is negative, therefore the vertical component of the applied force reduces the normal force.

When using an above ground mass anchor as an anchor for a brace, the diagrams of the statics for the mass anchor are shown in the following figures:

(a) Figure 21.2.1.3.1a for compression forces in the brace. **F** is positive for compression forces in the brace
(b) Figure 21.2.1.3.1b for tension forces in the brace. **F** is negative for tension forces in the brace

Bearing failure is possible on exceptionally weak soils. When such soils are present, the bearing capacity of a mass anchor should be checked in accordance with published literature.

 *Fig. 21.2.1.3.1b – Statics of a mass anchor subject to a tension force* Bearing forces can control on exceptionally weak soils. In the presence of exceptionally weak soils, the bearing capacity of the mass anchor shall be evaluated in accordance with published literature.		
21.2.1.3.2 – *Uplift resistance of mass anchors on the surface* For LRFD, mass anchors shall have a factored uplift resistance, $\mathbf{\Phi_B W_B}$**,** greater than the uplift force, $\mathbf{F\sin(\theta)}$, as shown in Equation 21.2.1.3.2a. $\mathbf{\Phi_B W_B \geq F\sin(\theta)}$ (21.2.1.3.2a) Where: $\mathbf{\Phi_B}$ = resistance factor from, Table 21.2.1.2 $\mathbf{W_B}$ = weight of mass anchor **F** = force on mass anchor, from the maximum LRFD load combination force **F** is positive for compression forces, see Figure 21.2.1.3.1a **F** is negative for tension forces, see Figure 21.2.1.3.1b $\boldsymbol{\theta}$ = angle between applied force and horizontal supporting surface of mass anchor For ASD, mass anchors shall have a design strength, $\mathbf{R_O/\Omega}$, greater than the uplift force, $\mathbf{F\sin(\theta)}$, as showing in Equation 21.2.1.2.2b. $\mathbf{W_B/\Omega_B \geq F\sin(\theta)}$ (21.2.1.3.2b) Where: $\mathbf{\Omega_B}$ = safety factor, from Table 21.2.1.3.1 $\mathbf{W_B}$ = weight of mass anchor **F** = force on mass anchor, from the maximum LRFD or ASD load combination **F** is positive for compression forces, see Figure 21.2.1.3.1a **F** is negative for tension forces, see Figure 21.2.1.3.1b $\boldsymbol{\theta}$ = angle between applied force and horizontal supporting surface of mass anchor		

21.2.1.3.3 - *Overturning resistance* For LRFD, mass anchors shall have a factored overturning resistance, $\Phi_B R_O$, greater than the overturning moment, M_O, as shown in Equation 21.2.1.3.3a. $\Phi_B R_O \geq M_O$ (21.2.1.3.3a) Where: Φ_B = resistance factor, from Table 21.2.1.2 R_O = overturning resistance, from Equation 21.2.1.3.3c M_O = overturning moment, from Equation 21.2.1.3.3d For ASD, mass anchors shall have a design strength, R_O/Ω, greater than the overturning moment, M_O, as showing in Equation 21.2.1.3.3b. $R_O/\Omega_B \geq M_O$ (21.2.1.3.3b) Where: Ω_B = safety factor, from Table 21.2.1.2 R_O = overturning resistance, from Equation 21.2.1.3.3c M_O = overturning moment, from Equation 21.2.1.3.3d $R_O = F\sin(\theta)X_F + W_B X_{CG}$ (21.2.1.3.3c) $M_O = \|F\|\cos(\theta)Y_F$ (21.2.1.3.3d) Where: **F** = force on mass anchor from the maximum LRFD or ASD load combination **F** is positive for compression forces, see Figure 21.2.1.3.1a **F** is negative for tension forces, see Figure 21.2.1.3.1b θ = angle between applied force and horizontal supporting surface of mass anchor X_F = horizontal distance between applied force and overturning point , see Figure 21.2.1.3.1a or Figure 21.2.1.3.1b W_B = weight of mass anchor X_{CG} = horizontal distance between the center of gravity of the mass anchor and the overturning point Y_F = vertical distance from applied force to overturning point		
21.2.1.3.4 – *Sliding resistance* For LRFD, mass anchors shall have a factored sliding resistance, $\Phi_B R_O$, greater than the sliding force, F_S, as shown in Equation 21.2.1.3.4a. $\Phi_B R_S \geq F_S$ (21.2.1.3.4a) Where: Φ_B = resistance factor, from Table 21.2.1.2 R_S = sliding resistance, from Equation 21.2.1.3.4c F_S = sliding force, from Equation 21.2.1.3.4e		

For ASD, mass anchors shall have a design strength, $\mathbf{R_S/\Omega}$, greater than the overturning force, $\mathbf{F_S}$, as showing in Equation 21.2.1.3.4b.

$$\mathbf{R_S/\Omega_B \geq F_S} \qquad (21.2.1.3.4b)$$

Where:
$\mathbf{\Omega_B}$ = safety factor from Table 21.2.1.2
$\mathbf{R_S}$ = sliding resistance, from Equation 21.2.1.3.4c
$\mathbf{F_S}$ = sliding force, from Equation 21.2.1.3.4e

$$\mathbf{R_S = \mu_S F_N} \qquad (21.2.1.3.4c)$$

Where:
$\mathbf{\mu_S}$ = friction factor, from Table 21.2.1.3.4
$\mathbf{F_N}$ = Force perpendicular to bearing surface, from Equation 21.2.1.3.4d

Table 21.2.1.3.4 – Friction factors of concrete mass anchors

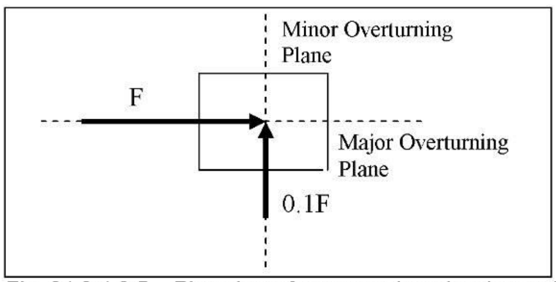
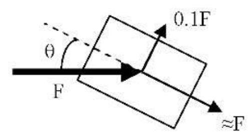
Support Surface of Mass Anchor	Friction Factor (μ_s)
hardened concrete – non roughened surface	0.6
hardened concrete - intentionally roughened surface	1.0
cast against hardened concrete	1.4
gravel, gravel-sand mixtures, coarse sand	0.55 to 0.60
clean fine to medium sand, silty medium to coarse sand, silty or clayey gravel	0.45 to 0.55
clean fine sand, silty or clayey fine to medium sand	0.35 to 0.45
fine sandy silt	0.30 to 0.35
very stiff and hard residual or preconsolidated clay	0.40 to 0.50
medium stiff and stiff clay, silty clay	0.30 to 0.35

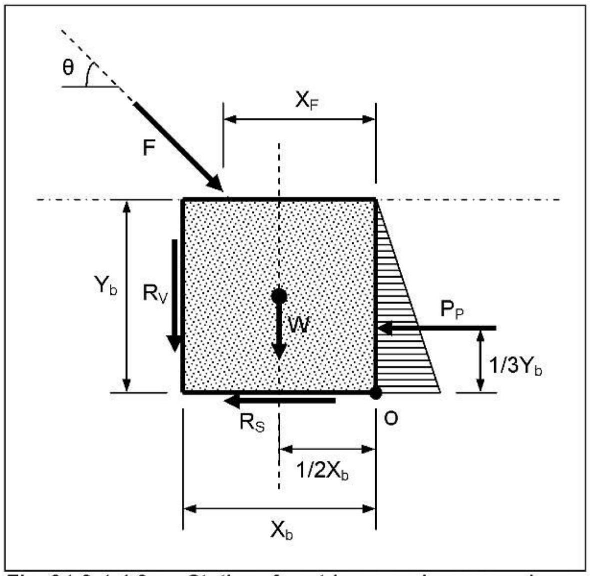
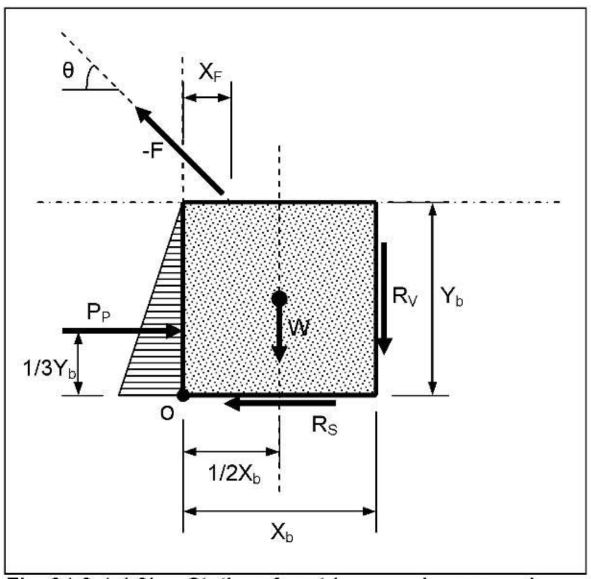
Source for friction factors for concrete against concrete: ACI 318-08, section 11.6.4.3

Source for friction factors for soils: NAVFAC "Foundations and Earth Structures" Design Manual 7.2, Revalidated 1986.

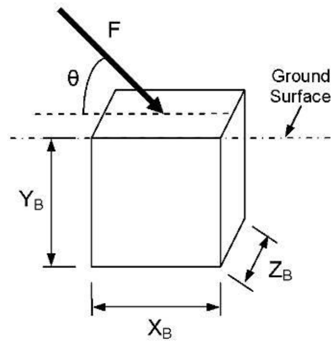
$$\mathbf{F_N = F\sin(\theta)+W_B} \qquad (21.2.1.3.4d)$$

Where:
$\mathbf{F}$ = force from the maximum LRFD or ASD load combination applied on mass anchor
F is positive for compression forces, see Figure 21.2.1.3.1a
F is negative for tension forces, see Figure 21.2.1.3.1b
$\mathbf{W_B}$ = weight of mass anchor

$\mathbf{F_S = \lvert F \rvert cos(\theta)}$ (21.2.1.3.4e) Where: **F** = force on mass anchor from the maximum LRFD or ASD load combination **F** is positive for compression forces, see Figure 21.2.1.3.1a **F** is negative for tension forces, see Figure 21.2.1.3.1b **θ** = angle between applied force and supporting surface of mass anchor		
2.1.2.1.3.5 – *Out-of-Plane Resistance* Mass anchors shall be designed to resist 10% of the applied force for overturning and sliding in the minor overturning plane, Figure 21.2.1.3.5. The resistance shall be calculated in accordance with Paragraphs 21.2.1.3.2, 21.2.1.3.3, and 21.2.1.3.4 using dimensions from the minor overturning plane.  *Fig. 21.2.1.3.5 – Plan view of mass anchor showing major and minor tipping planes for mass anchors.*		*When the out-of-plane force is 10%, it corresponds to a tolerance of 6° out-of-square for the mass anchor. A tolerance of 10° = 18% of F, 15° = 27% of F*  *Fig. R21.2.1.3.5 – Placement tolerance of mass anchors*
21.2.1.4 – *Cast-in-ground mass anchors*		
21.2.1.4.1 – *Strength of cast-in-ground mass anchors* For LRFD, mass anchors shall have a factored overturning resistance, $\mathbf{\Phi_o R_o}$, greater than the overturning moment, $\mathbf{M_o}$, as shown in Equation 21.2.1.4.1a. $\mathbf{\Phi_o R_o \geq M_o}$ (21.2.1.4.1a) Where: $\mathbf{\Phi_o}$ = resistance factor from Table 21.2.1.2 $\mathbf{R_o}$ = nominal overturning resistance, from Eq. 21.2.1.4.2a $\mathbf{M_o}$ = overturning moment, from Eq. 21.2.1.4.2b For ASD, mass anchors shall have a design strength, $\mathbf{R_n/\Omega}$, greater than the overturning force, $\mathbf{F_n}$, as showing in Equation 21.2.1.4.1b. $\mathbf{R_o/\Omega_o \geq M_o}$ (21.2.1.4.1b) Where: $\mathbf{\Omega_o}$ = safety factor from Table 21.2.1.2 $\mathbf{R_o}$ = nominal overturning resistance, from Eq. 21.2.1.4.2a $\mathbf{M_o}$ = overturning moment, from Eq. 21.2.1.4.2b		

21.2.1.4.2 – *Nominal resistance for cast-in-ground mass anchors*  *Fig. 21.2.1.4.2a – Statics of cast-in-ground mass anchors subject to compression forces in attached brace*  *Fig. 21.2.1.4.2b – Statics of cast-in-ground mass anchors subject to tension forces in attached brace*		R21.2.1.4.2 – When designing for overturning forces the location of overturning point, **o**, changes depending on the direction of force applied. This is shown in Figures 21.2.1.4.2a and 21.2.1.4.2b by the change in position of the overturning point, **o**, for an applied compression force and tension force. When designing for overturning forces, the horizontal component of the applied force, **|F|cos(θ)**, always contributes to the overturning of the mass anchor, regardless of the sign of **F**. The vertical component of the applied force, **Fsin(θ)**, subtracts or adds to the overturning force, depending on the sign of **F**. When using a cast-in-ground mass anchor as an anchor for a brace, the diagrams of the statics for the mass anchor are shown in the following figures: (a) Figure 21.2.1.4.2a for compression forces in the brace. **F** is positive for compression forces in the brace (b) Figure 21.2.1.4.2b for tension forces in the brace. **F** is negative for tension forces in the brace

$\mathbf{R_o = P_P(1/3Y_b) + W(1/2X_b) + R_VX_b}$ (21.2.1.4.2a) Where: $\mathbf{P_P}$ = passive earth pressure, from Paragraph 21.2.1.4.3 $\mathbf{Y_b}$ = height of mass anchor, see Fig. 21.2.1.4.2a **W** = weight of mass anchor $\mathbf{X_b}$ = horizontal width of mass anchor, see Fig. 21.2.1.4.2a $\mathbf{R_V}$ = vertical resistance, from Eq. 21.2.1.4.4 $\mathbf{M_o = \|F\|\cos(\theta)Y_b - F\sin(\theta)X_F}$ (21.2.1.4.2b) Where: **F** = force on mass anchor from the maximum LRFD or ASD load combination **F** is positive for compression force in brace, see Fig. 21.2.1.4.2a **F** is negative for compression force in brace, see Fig. 21.2.1.4.2b **θ** = angle between applied force and supporting surface of mass anchor, see Fig. 21.2.1.4.2a $\mathbf{Y_b}$ = height of mass anchor $\mathbf{X_F}$ = horizontal distance between applied force and overturning point, **o** see Fig. 21.2.1.4.2a for compression forces see Fig. 21.2.1.4.2b for tension forces		
21.2.1.4.3 – *Passive earth pressure on cast-in-ground mass anchors* For granular soils, the passive earth pressure, $\mathbf{P_P}$ (lbs), shall be determined from Equation 21.2.1.4.3a. $\mathbf{P_P = [3.3/\tan(\Phi)]\,(Y_b/Z_b)^{0.39}\,(\gamma Z_bY_b^2)}$ (21.2.1.4.3a) Where: **Φ** = shear angle of soil (°) $\mathbf{Y_b}$ = height of mass anchor (ft) $\mathbf{Z_b}$ = width of mass anchor (ft) **γ** = unit weight of soil (lbs/ft^3) For cohesive soils, the passive earth pressure, $\mathbf{P_P}$ (lbs), shall be determined from Equation 21.2.1.4.3b. $\mathbf{P_P = [539 + 114(Y_b/Z_b)](Y_bZ_b)}$ (21.2.1.4.3b) Where: $\mathbf{Y_b}$ = height of mass anchor (ft) $\mathbf{Z_b}$ = width of mass anchor (ft)		R21.2.1.4.3 – Equations 21.2.1.4.3a and 21.2.1.4.3b are based on the analysis of anchor plates in soil from "Principles of Foundation Engineering", 4th edition by Das. *The passive earth pressure is used to determine the ultimate lateral force that is resisted by an anchor placed in soil.* *The basis for Equation 21.2.1.4.3a is the empirical correlation shown in Figure 8.43 of Das for square plates.* *The basis for Equation 21.2.1.4.3b is equation 8.103 from Das. Equation 21.2.1.4.3b assumes that the effective cohesion is 200 lbs/ft^2. For soils with higher cohesion values, this higher cohesion value may be used in Das equation 8.103.*

21.2.1.4.4 – *Vertical resistance on cast-in-ground mass anchors* $$R_V = (1/2)[(1-\sin(\Phi))/(1+\sin(\Phi))](\gamma Yb^2)(Z_b)(\mu_S) \quad (21.2.1.4.4)$$ Where: **Φ** = shear angle of soil (°) Y_b = height of mass anchor (ft) Z_b = width of mass anchor (ft), see Figure 21.2.1.4.4 **γ** = unit weight of soil (lbs/ft³) μ_S = applicable soil coefficient of friction, from Table 21.2.1.3.4  *Fig. 21.2.1.4.4 – Basic dimensions of a cast-in-ground mass anchor*		R21.2.1.4.4 – Equation 21.2.1.4.4 is based on the active earth pressure applied to the face of the mass anchor. Values for shear angle of soil, Φ, and unit weight of soil, γ, for various soil classifications can be found in: NAVFAC Design Manual 7.1, "Soil Mechanics", 1982.
21.2.1.5 - Alternatively, a method based on a detailed analysis from published literature using actual soil conditions from the site may be used to determine the capacity of mass anchors.		
21.2.1.6 - Alternatively, proof loading of a mass anchor to 125% of the design load may be used in lieu of detailed analysis. The proof loading must mimic actual loading conditions as near as possible, including but not limited to: (a) load angle (b) bearing surface (c) connection of brace (d) load reversals		

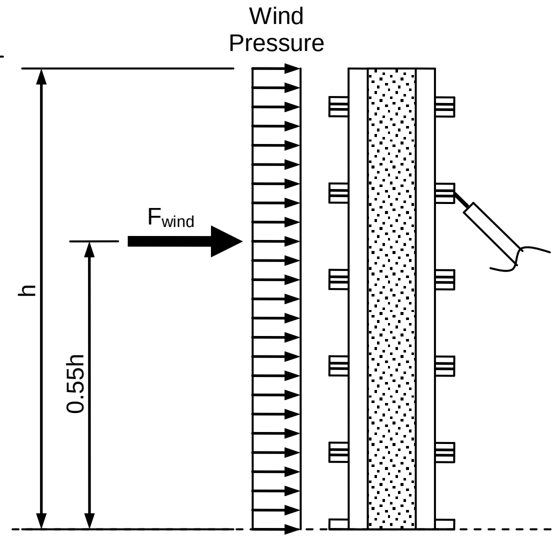
CHAPTER 22 – SLIP FORMS		
CHAPTER 23 – TABLE FORMS		
CHAPTER 24 – CLIMBING FORMS		
24.1 – General Climbing systems consist of vertical wall formwork and a backup system with vertical strongbacks or an anchoring bracket and strongback combined into one unit which can be rolled back to allow for stripping cleaning of the form face before climbing the entire system and is anchored into the previous pour. The system also consists of multiple working platforms to modify, set, plumb or strip the forms and install or removes anchors and ties. After the new wall is cast and achieves a specified strength capable of supporting loads imposed from the climbing formwork, the system is raised up to the next pouring position by either a crane or other mechanical or hydraulic devise and attached to an anchor cast into the pour.		
24.1.1 – Crane climbed Composed of vertical formwork system with an attached backup system and is lifted by crane and climbed up to the next pouring position. Crane climbed forms systems can be move horizontally or vertically to form additional wall pours.		
24.1.2 – Self Climbing Operated hydraulically or mechanically, this system can only climb vertically in the same plan position. Intended to use when crane time is limited and could hamper cycling of the wall forms to meeting the construction schedule.		
24.1.3 – Gliding Vertical crane lifted system that is continually guided by gliding brackets secured to the structure. Especially useful in conditions with large form surfaces susceptible to wind which could present safety concerns to workers.		
24.2 – General considerations Consideration shall be given to the method and cycle time for climbing formwork, crane capacity and availability, slab forming method, material handling and crew size to evaluate which climbing method suits the project schedule.		
24.2.1 – Formwork Various formwork systems are available and can be used along with climbing systems and are design to standard formwork criteria. Consideration must be given the connection of the formwork to the climbing systems to ensure safety.		
24.2.2 – Supporting method Secured to previously cast concrete walls or slabs by an anchoring or gliding type bracket and support from bolts and anchor cones.		

24.3 – Working Platforms These systems are normally designed with a minimum of two or more platforms to facilitate formwork installation or disassembly, operation of climbing equipment, installation of reinforcement, storage of material, or access areas for workers.		
24.3.1 – Material storage Consideration must be given to the types and weigh of material to be stored on specific platforms. These area's must be clearly identified with working loading limits when at rest, marked area's where material can safely placed and the removable of material or allowable loads when climbing.		
24.3.2 – Formwork operation Sufficient access shall be considered for installation or removal of formwork and ties, leveling and height adjustment, plumbing, installation of embedment's and anchors, stripping, setting and cleaning of form faces, application of form release agents, installation or removal of chamfers or reveals, boxouts, pouring concrete, installation or recovery and cycling of anchor or climbing material or other operations necessary to achieve the finish concrete product.		
24.3.3 – Climbing operation Consider access for installation or removal of achors or attachment brackets to secure the climbing system to the structure or assist in the climbing of the system. Lower level platforms may be necessary for the recovery and recycling of reusable anchor parts or climbing material and finishing or patching anchor, tie holes or both.		
24.3.4 – Rebar installation Elevated platforms may be necessary when the installation of rebar, when standard industry practices is a concern for the safety of workers.		
24.4 – Design considerations		
24.4.1 – System weight		
24.4.2 – Live loads – Concrete weight, equipment, port-a-potties, tools		
24.4.3 – Material storage – rebar		
24.4.4 – Impact		
24.4.5 – Wind - also include closing of formwork during storm conditions.		
24.4.6 – Snow		
24,4.7 – Dynamic		
24.4.8 – Safety factors		
24.4.9 – Maximum live loads in anchored position and during climbing		Need to address climbing adjacent units toad railing
24.4.10 – Concrete placing boom		
24.5 – Anchors		
24.5.1 - Safety factors		

24.5.2 – Applied loads		
24.5.3 – Embedment		
24.5.4 – Concrete strength for lifting		
24.5.5 – Concrete strength for anchoring		
24.5.6 – Positioning – level & proper elevation		
24.5.7 – Flat surface – anchors shall not be place in depressions (reveals) architectural features		
24.5.8 – Minimum wall thickness and edge distance		
24.6 – Operator Instructions		
Power supply		
Designated lifting points		
Fall protection		

Appendix B – Calculation of Generic Wind Pressure on Wall Forms

Derivation of Generic Wind Force on Formwork



Using ASCE 7-05 Section 6.5.14 "Design Wind Loads on Solid Freestanding Walls and Solid Signs"

Wall Parameters:
Basic Wind Speed, **V**: 90 mph
Duration: < 6 weeks
Directionality Factor, $\mathbf{K_d}$: 0.85
Terrain Factor, $\mathbf{K_{zt}}$: 1.0
Exposure Category: C
Exposure Coefficient, $\mathbf{K_z}$, at 20 ft: 0.90
Gust Factor, **G**: 0.85 (assumed rigid)
Force Coefficient, $\mathbf{C_f}$: 1.8
(From ASCE 7-05 Fig. 6-20 for a wall with an aspect ratio of 3 long to 1 high)
No shielding

ASCE 37-02 Wind Speed Reduction Factor: 0.75
Importance Factor, **I**, from ASCE 37-02: 1.0

ASCE 7-05 Eq. 6-15: $\mathbf{q_z} = \mathbf{q_h} = 0.00256\mathbf{K_z K_{zt} K_d V^2 I}$

$\mathbf{q_h} = 0.00256(0.85)(1.0)(0.90)[(0.75)(90)]^2(1.0) = 8.92 \text{ lb/ft}^2$

ASCE 7-05 Eq. 6-27: $\mathbf{F} = \mathbf{q_h G C_f A_s} = (8.92)(0.85)(1.8)\mathbf{A_s} = 13.65\mathbf{A_s}$
(where F is applied at 0.55**h** per ASCE 7-05 Fig. 6-20)

If wind pressure is applied as a generic pressure, **p**, the resultant force, $\mathbf{F_P}$, would be applied at 0.5**h** instead of 0.55**h**. To provide an equivalent force in the brace, the generic pressure will need to be increased so that the moment generated about the base of the wall form is the same.

Moment due to Wind Force, **F**: $\mathbf{M_F} = 0.55\mathbf{hF}$

Moment due to Generic Pressure, $\mathbf{F_P}$: $\mathbf{M_g} = 0.5\mathbf{hF_P}$ where: $\mathbf{F_P} = \mathbf{pA_s}$

$\mathbf{M_F} = \mathbf{M_g}$ => $0.55\mathbf{hF} = 0.5\mathbf{hF_P}$

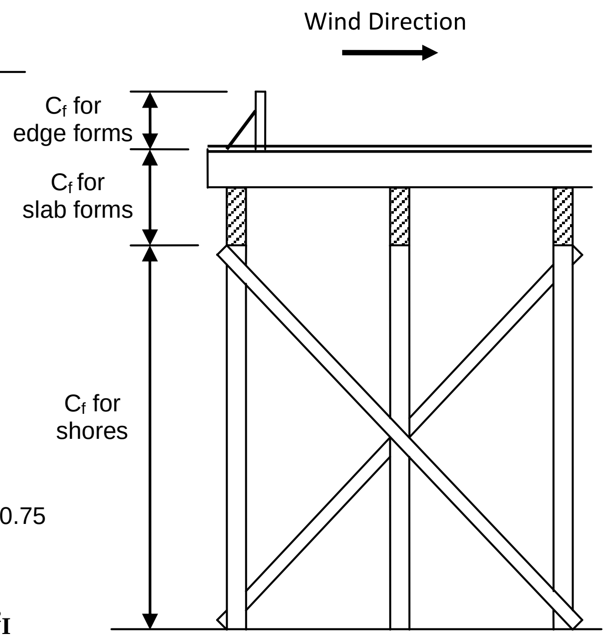
substituting in for **F** and $\mathbf{F_P}$: $0.55\mathbf{h}(13.65\mathbf{A_s}) = 0.5\mathbf{h}(\mathbf{PA_s})$ => $\mathbf{p} = 15.01 \approx 15 \text{ lbs/ft}^2$

The unfactored wind force on wall forms, $\mathbf{F_{wall}}$, is the generic pressure, **p**, multiplied by the height of the wall form, **h**; where $\mathbf{F_{wall}}$ is in pounds per linear foot, applied at the mid height of the wall form.

$\mathbf{F_{wall} = 15h}$

Appendix C – Calculation of Generic Wind Pressure on Elevated Slab Forms

Derivation of Generic Wind Force on Slab Formwork



Using ASCE 7-05 Section 6.5.15 "Design Wind Loads on Other Structures"

Slab Parameters:
Basic Wind Speed, **V**: 90 mph
Duration: < 6 weeks
Directionality Factor, $\mathbf{K_d}$: 0.85
Terrain Factor, $\mathbf{K_{zt}}$: 1.0
Exposure Category: C
Exposure Coefficient, $\mathbf{K_z}$, at 40 ft: 1.04
Gust Factor, **G**: 0.85 (assumed rigid)

Depth of slab formwork: ≤ 2 ft
Height of edge form: ≤ 1 ft

ASCE 37-02 Wind Speed Reduction Factor: 0.75
Importance Factor, **I**, from ASCE 37-02: 1.0

ASCE 7-05 Eq. 6-15: $\mathbf{q_z} = 0.00256\mathbf{K_z K_{zt} K_d V^2 I}$

$\mathbf{q_z} = 0.00256(1.04)(1.0)(0.85)[(0.75)(90)]^2(1.0) = 10.31 \text{ lb/ft}^2$

Slab Formwork

Force Coefficient, $\mathbf{C_f}$: 2.2 (From BS:5975-2008 for wind parallel to joists)

ASCE 7-05 Eq. 6-28: $\mathbf{F} = \mathbf{q_z G C_f A_f} = (10.31)(0.85)(2.2)\mathbf{A_f} = 19.3\mathbf{A_f}$

where: $\mathbf{A_f} = \mathbf{d}$ x length of formwork; $\mathbf{d}$ = 2 ft

therefore: **F** = 19.3(2)(length of formwork) = 38.6 lbs x length of formwork

Edge Forms

Force Coefficient, $\mathbf{C_f}$: 1.8 (From BS:5975-2008 for edge forms with no shielding)

ASCE 7-05 Eq. 6-28: $\mathbf{F} = \mathbf{q_z G C_f A_f} = (10.31)(0.85)(1.8)\mathbf{A_f} = 15.8\mathbf{A_f}$

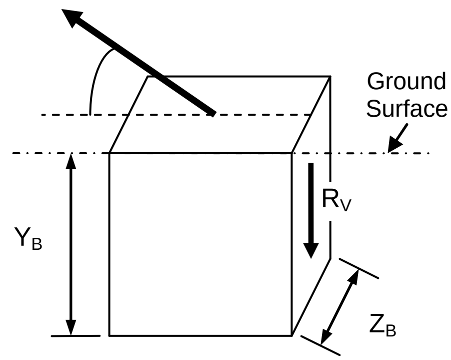
where: $\mathbf{A_f} = \mathbf{d}$ x length of formwork x # of edge forms
d = 1ft
# of edge forms = 2

therefore: **F** = 15.8(1)(2)(length of formwork) = 31.5 lbs x length of formwork

Total force = (38.6 + 31.5) x length of formwork = 70.1 lbs x length of formwork

Appendix D – Derivation of Vertical Resistance Friction for Mass Anchors

Derivation of Vertical Friction Resistance for Mass Anchors



Vertical resistance is a friction force developed by the normal force of the soil on the mass anchor multiplied the applicable friction factor.

The normal force of the soil is the active earth pressure integrated from 0 to $\mathbf{Y_B}$ for the mass anchor.

$$\mathbf{R_V = F_n \mu_S}$$

where:

$\mathbf{R_V}$ = vertical resistance from friction force
$\mathbf{F_n}$ = normal force developed by active earth pressure
$\mathbf{\mu_S}$ = applicable coefficient of friction for soil, from NAVFAC Design Manual 7.2

$$\mathbf{F_n = Z_B \times \int (K_a \sigma_V)} \text{ from 0 to } \mathbf{Y_B}$$

where:

$\mathbf{K_a \sigma_V}$ = active earth pressure

$$\mathbf{K_a} = [1-\sin(\mathbf{\Phi})/\ 1+\sin(\mathbf{\Phi})] \qquad \& \qquad \mathbf{\sigma_V = \gamma_S Y_B}$$

where:

$\mathbf{\Phi}$ = friction angle of soil
$\mathbf{\gamma_S}$ = unit weight of soil (lbs/ft^3)

Substituting:

$$\mathbf{F_n} = \mathbf{Z_B} \times \int[1-\sin(\mathbf{\Phi})/\ 1+\sin(\mathbf{\Phi})](\mathbf{\gamma_S Y_B}) \quad = \quad \mathbf{Z_B} \times (1/2)[1-\sin(\mathbf{\Phi})/\ 1+\sin(\mathbf{\Phi})]\ (\mathbf{\gamma_S Y_B}^2)$$

$$\mathbf{R_V} = (1/2)[1-\sin(\mathbf{\Phi})/\ 1+\sin(\mathbf{\Phi})]\ (\mathbf{\gamma_S Y_B}^2)(\mathbf{Z_B})(\mathbf{\mu_S})$$