



U.S. Department of Transportation
Federal Highway Administration

Publication No. FHWA-RC-14-001
February 2014

Implementation Guidance for Using Spread Footings on Soils to Support Highway Bridges



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Technical Report Documentation Page

1. Report No. FHWA-RC-14-001	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Implementation Guidance for Using Spread Footings on Soils to Support Highway Bridges		5. Report Date May 2014	
		6. Performing Organization Code	
7. Author(s) Naser M. Abu-Hejleh, Ph.D., P.E; Daniel Alzamora, P.E.; Khalid Mohamed, P.E, PMP; Thomas Saad, P.E; and Scott Anderson, Ph.D., P.E		8. Performing Organization Report No.	
9. Performing Organization Name and Address FHWA Resource Center (see below for address)		10. Work Unit No. (TRAIS)	
		11. Contract or Grant No.	
12. Sponsoring Agency Name and Address Federal Highway Administration Resource Center 4749 Lincoln Mall Drive, Suite 600 Matteson, IL 60443		13. Type of Report and Period Covered Report	
		14. Sponsoring Agency Code	
15. Supplementary Notes. This report is issued by the FHWA Resource Center as a deployment aid to help highway engineers and agencies recognize the value of spread footings and overcome obstacles to their effective use. This report reinforces and supports the guidance for selection, design, and construction of spread footings provided by the AASHTO and FHWA technical references cited herein.			
16. Abstract. Recent FHWA national surveys revealed that State Departments of Transportation (DOTs) have safely and economically constructed highway bridges supported on spread footings bearing on competent and improved natural soils as well as engineered granular and MSE fills, and that many State DOTs may be missing an opportunity to save time and costs by not doing so more often. The goal of this report is to promote the consideration and use of spread footings on soils when appropriate to support highway bridges. Initially, perceived obstacles in using spread footings are identified. Then, the report presents recommendations to address these obstacles and a guidance to help State DOTs implementing these recommendations that are centered around: 1) deployment of AASHTO and FHWA technical resources; 2) highlighting practices of State DOTs that actively use spread footings, especially for selection of spread footings; 3) a performance review of bridges constructed with spread footings bearing on soils; and 4) LRFD implementation for spread footings. State DOTs' concerns with using spread footings on engineered and MSE fills and with integral abutments are addressed. Consideration of load tests on spread footings, instrumentation programs for bridges with spread footings, and deployment of adequate subsurface investigation and construction programs are recommended. The main concern of State DOTs that do not consider spread footings is excessive settlement of bridges. This report advances a rational procedure for settlement analysis of bridges supported on spread footings bearing on soils. This procedure and the results of the national surveys demonstrate that bridges with spread footings on soil can perform very well with respect to settlement. Development of LRFD design bearing resistances for footings on various types of soils is discussed. Based on the previous recommendations, the report finally provides a technical resource for State DOTs to develop LRFD guidance that would allow selection of spread footings in design when appropriate, and development of accurate and economical design methods for spread footings.			
17. Key Words: Bridge, Spread Footings, Soils, Obstacles, AASHTO, Advantages, FHWA, LRFD, Implementation, Performance, Selection, Design, Specifications, Construction, Settlement, Tolerable Settlement, Improved Soils, Granular Fill, MSE Fill, Integral Abutment, Semi-Integral Abutment, Bearing Resistance, Instrumentation, Load Tests.		18. Distribution Statement No restriction. This document is available to the public from the sponsoring agency.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 83	22. Price

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APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
Mm	millimeters	0.039	inches	In
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm ²	square millimeters	0.0016	square inches	in ²
m ²	square meters	10.764	square feet	ft ²
m ²	square meters	1.195	square yards	yd ²
ha	hectares	2.47	acres	ac
km ²	square kilometers	0.386	square miles	mi ²
VOLUME				
ml	milliliters	0.034	fluid ounces	fl oz
l	liters	0.264	gallons	gal
m ³	cubic meters	35.71	cubic feet	ft ³
m ³	cubic meters	1.307	cubic yards	yd ³
MASS				
G	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
tonnes	tonnes	1.103	tons	tons
TEMPERATURE				
EC	Celsius	1.8 C + 32	Fahrenheit	EF
WEIGHT DENSITY				
kN/m ³	kilonewton / cubic meter	6.36	poundforce / cubic foot	Pcf
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kN	kilonewtons	225	poundforce	lbf
kPa	kilopascals	0.145	poundforce / square inch	psi
kPa	kilopascals	20.9	poundforce / square foot	psf

PREFACE

Recent FHWA national surveys revealed that many State DOTs have safely and economically constructed highway bridges supported on spread footings bearing on competent and improved natural soils as well as engineered granular and MSE fills, and that many State DOTs may be missing an opportunity to save time and money by not actively considering spread footings to support highway bridges. The goal of this report is to promote the consideration and use of spread footings on soils when appropriate (cost-effective) to support highway bridges. Initially, perceived obstacles in using spread footings are identified. Then, the report presents recommendations to address these obstacles and a guidance to help State DOTs implementing these recommendations that are centered around: 1) deployment of AASHTO and FHWA technical resources; 2) highlighting practices of State DOTs that actively use spread footings, especially for selecting spread footings; 3) a performance review of bridges constructed with spread footings bearing on soils; and 4) LRFD implementation for spread footings. State DOTs reported good performance of their bridges constructed on spread footings bearing on soil, with performance similar to bridges supported on deep foundations. The report demonstrates that bridges with spread footings bearing on soil can perform very well with respect to settlement. Based on the previous recommendations, the report finally provides a technical resource for State DOTs to develop LRFD guidance that would allow selection of spread footings in design when appropriate, and development of accurate and economical design methods for spread footings.

Implementation. The materials in this report will be of immediate interest to State DOTs that rarely use spread footings on soils to support highway bridges since it provides recommendations to address their concerns. State DOTs can choose which recommendations to implement based on their specific needs. Concerns of bridge settlement should not limit State DOTs from using spread footings. Implementation of the LRFD platform for spread footings as presented in this report provides an excellent opportunity for State DOTs to change and improve the selection and design practices for spread footings. This report will help both geotechnical and structural engineers understand the advantages of spread footings over deep foundations, understand their respective roles in the selection and design of spread footings, and enhance their understanding of the engineering practices and resources for quality design of spread footings.

This report continues and supplements FHWA efforts published in two recent publications:

- Selection of Spread Footings on Soils to Support Highway Bridge Structures (FHWA, 2010b). The goal of this publication is to promote the use of spread footings on soils to support bridges.
- Implementation of LRFD Geotechnical Design for Bridge Foundations (FHWA, 2010a). The goal of this publication is to assist State DOTs in successfully developing LRFD design guidance for bridge foundations.

The authors wish to thank Jennifer Nicks, Ph.D., from FHWA, for her in-depth and comprehensive review of this report and for providing excellent suggestions to improve it. Also, the authors wish to thank Ben Rivers, P.E.; Justice Maswoswe, Ph.D., P.E.; Barry Siel, P.E., and Silas Nichols, P.E., all from FHWA, for communicating with their contact states and compiling their survey information.

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LIST OF SYMBOLS AND ABBREVIATIONS

New Symbols and Abbreviations Introduced in this Report are listed in Italics

AASHTO	American Association of State Highway and Transportation Officials
ASD	Allowable stress design
B, B'	Footing width, effective width
bpf	Blows per foot
CPT	Cone penetration test
D_f	Depth of footing base below finished grade
D_{f-min}	<i>Minimum embedment depth for spread footing, developed based on depth to competent soil layers (from subsurface investigation program); scour depth for check flood (AASHTO Article 2.6.4.4.1); depths for frost, erosion, and liquefaction; depth to groundwater, seepage, and drainage issues; and slope stability</i>
DMT	Flat plate dilatometer Test
DOSI	Depth of significant influence
DOT	Department of transportation
DSC	Different site conditions
FHWA	Federal Highway Administration
ft	Foot (or feet)
ft ²	Square feet
GRS	Geosynthetic-reinforced soil
IGM	Intermediate geomaterial
in	Inch (or inches)
in ²	Square inch (or inches)
Ksf	Kips per square foot
L, L'	Foundation length, effective length
LRFD	Load and resistance factor design
MSE	Mechanically stabilized earth
N	SPT N-value (uncorrected)
N_{60}	SPT N-value corrected for hammer efficiency
N_{160}	SPT N-value corrected for both overburden and hammer efficiency
NCHRP	National Cooperative of Highway Research Program
NHI	National Highway Institute
$Q_{ser-1}, Q_{ser-2}, Q_{ser-3}, Q_{ser-4}, Q_{ser-5}, \dots, Q_{ser-final}$	<i>The service limit state axial compression loads applied on the spread footings at various stages during and after construction</i>
Q_{str}	<i>The factored axial compression load applied on the spread footings at the strength limit state</i>
$q_{ser-1}, q_{ser-2}, q_{ser-3}, q_{ser-4}, q_{ser-5}, \dots, q_{ser-final}, q_{str}$	<i>The footing factored total bearing stresses that correspond to $Q_{ser-1}, Q_{ser-2}, Q_{ser-3}, Q_{ser-4}, Q_{ser-5}, \dots, Q_{ser-final}$, and Q_{str} loads</i>
$q_{nser-1}, q_{nser-2}, q_{nser-3}, q_{nser-4}, q_{nser-5}, \dots, q_{nser-final}, q_{nstr}$	<i>The footing factored net bearing stresses that correspond to $Q_{ser-1}, Q_{ser-2}, Q_{ser-3}, Q_{ser-4}, Q_{ser-5}, \dots, Q_{ser-final}$, and Q_{str} loads, computed as the factored total bearing stresses minus the factored overburden stresses at footing base level</i>
R_n	Foundation net nominal bearing resistance at the strength limit state
ROW	Right of way

S	Settlement
S_F	<i>Foundation settlement</i>
S_B	<i>Bridge settlement at foundation locations ($S_B \leq S_F$)</i>
S_{BP}	<i>Bridge settlement at foundation locations that impacts bridge performance ($S_B \leq S_{BP}$)</i>
S_{BT}	<i>Bridge tolerable settlement</i>
SCPT	Seismic cone penetration testing
SPT	Standard penetration test
ϕ	Resistance factor for bearing resistance at the strength limit state

CHAPTER 1 OVERVIEW

1.1 BACKGROUND AND PURPOSE

The use of spread footings to support highway bridges has many advantages (FHWA, 2010b, 2006a, 2002a, and 2001):

- Cost savings in design, construction, quality control, and maintenance.
- Accelerated design, construction, and maintenance.
- Simple and flexible design, construction, quality control, and maintenance. For example, when compared to deep foundations, construction quality control is simpler for spread footings because the bearing area and foundation can be visually inspected and improved if needed during construction.
- Spread footings are appropriate for situations where pile driving or drilled shaft installations are not recommended, such as to a) accommodate the presence of aquifers, underground structures such as utilities and obstructions beneath foundations; b) generate less noise, ground vibrations, and movements of nearby structures, including residential and historical buildings; and c) reduce excavation of contaminated soils such as in the case of drilled shafts.
- Construction of spread footings utilizes common materials, and can be constructed with readily available labor, simple and small equipment, and without the need for specialty construction contractors.
- Finally, the use of spread footings alleviates the bump at the end of the bridge problem, creating a safer and smoother transition between the bridge and approach embankment (Briaud et al., 1997; Abu-Hejleh et al., 2006).

In 2007, the FHWA developed and distributed a national survey of State DOT geotechnical practices. Survey results from geotechnical engineers in 44 states indicated that the average distribution of bridge foundation types considered by State DOTs across the United States was approximately 24 percent (%) spread footings (11.5% on soils, 12.5% on rock) and 76% deep foundations (56.5% driven piles and 19.5% drilled shafts). Paikowsky et al. (2010) recently reported similar results. The FHWA national survey identified the states with significant and moderate use of spread footings on soils to support highway bridges and the states with limited or no use (less than 5%). Table 1.1 presents some of the results from the FHWA national survey, which illustrate that the use of spread footings is up to 50% in the Northeast, 30% in the Southwest, 20% in the Northwest, and 10% in the Midwest. The Southeast region as well as some states in other regions reported no or limited use. The survey also revealed that State DOTs have safely and economically constructed highway bridges supported on spread footings bearing

on competent and improved natural soils as well as engineered granular and MSE fills. Engineered granular fill is defined as a high quality granular soil selected and constructed to meet certain material and construction specifications (also called “compacted structural fill” and “compacted granular soil”).

Table 1.1. Lead States in Deploying Spread Footings for Bridges (2007 National Survey)

States	Spread Footings (%)		Deep Foundations (%)	
	Soil	Rock	Driven Piles	Drilled Shafts
Northeast				
Connecticut	50	25	20	5
Vermont	40	10	45	5
Massachusetts	35	15	20	27
New Hampshire	30	30	30	10
New York	30	15	47	3
New Jersey	30	20	40	5
Southwest				
New Mexico	30	10	30	30
Nevada	25	3	18	54
Northwest				
Idaho	20	10	60	10
Oregon	20	10	60	10
Midwest				
Michigan	10	5	80	5

The use of spread footings may not be suitable or economical under certain design conditions, for example, at sites with large scour or liquefaction depths. However, a number of State DOTs do not consider spread footings as an alternate foundation type under any circumstances, even when the design conditions are appropriate and spread footings would perform well. Reasons for not considering and using spread footings when they are appropriate are called “perceived obstacles” in this report. Based on the above, the FHWA concluded that State DOTs could save time and cost if spread footings bearing on soil are considered to support highway bridges.

The goal of this report is to promote the consideration and use of spread footings bearing on competent and improved natural soils as well as on engineered granular fills and mechanically stabilized earth (MSE) fills when appropriate to support highway bridges. This required identifying the State DOTs’ perceived obstacles in using spread footings and developing recommendations to address these obstacles and a guidance to implement these recommendations. To achieve this goal, two additional national surveys of State DOTs were

performed in 2009 to get more insight from State DOTs regarding their perceived obstacles and practices and experiences with the use of spread footings on soils to support highway bridges. One survey targeted geotechnical engineers and the other targeted bridge engineers.

The remaining sections in this chapter briefly discuss the valid design conditions that limit the use of spread footings on soils to support highway bridges, the perceived obstacles to their use, and recommendations to address these obstacles. Chapters 2 through 9 discuss the implementation of these recommendations. The national survey results revealed that excessive settlement of bridges is the main concern of State DOTs in using spread footings; Chapter 7 addresses thoroughly this concern. Based on the recommendations discussed in this report, Chapter 9 provides a technical resource for State DOTs to develop LRFD guidance for using spread footings that would allow selection of spread footings in the design when appropriate, and for developing more accurate and economical design methods than are commonly used.

This report continues and supplements FHWA's efforts published in two recent reports:

- Selection of Spread Footings on Soils to Support Highway Bridge Structures (FHWA, 2010b), which promoted the use of spread footings on soils to support highway bridges.
- Implementation of LRFD Geotechnical Design for Bridge Foundation (FHWA, 2010a). The goal of this report is to assist State DOTs in the successful development of LRFD design guidance for bridge foundations.

Note: In the remainder of this report, unless otherwise stated, “spread footing” refers to spread footings bearing on soils to support highway bridges. Although the report uses the term “spread footings,” to be consistent with recent technical references from the American Association of State Highway and Transportation Officials (AASHTO) and FHWA, the recommendations of this report are applicable to all types of shallow foundation systems.

1.2 LIMITATIONS DUE TO SCOUR AND OTHER CONDITIONS

The use of spread footings bearing on soils to support highway bridges may not be suitable or economical under certain design conditions, for example, presence of deep soft soil near the ground surface or very high lateral loads (e.g., due to a major earthquake), and at sites with large scour or liquefaction depths. These conditions need to be evaluated in the design during selection of the appropriate foundation type.

The 2007 and 2009 FHWA national surveys revealed that many State DOTs do not consider spread footings at water crossings, mainly due to concerns with scour. The recently updated FHWA Hydraulic Engineering Circular (HEC-18), Evaluating Scour at Bridges (FHWA, 2012), describes the scour evaluation and design procedures with the use of spread footings on soils to

support both piers and abutments. According to the 2012 AASHTO LRFD Bridge Design Specifications (referred to hereafter as “AASHTO LRFD”) and HEC-18, the majority of bridge failures in the United States are due to scour. To avoid these failures, both AASHTO LRFD and HEC-18 recommend placing the bottom of the spread footings below the total scour depths estimated for the flood at the extreme event limit state. This flood is called “check flood” or “superflood” in AASHTO LRFD and “scour design check flood” in HEC-18. Thus, the use of spread footings may be found appropriate and economical at stream crossings with a small total scour depth.

1.3 PERCEIVED OBSTACLES TO SPREAD FOOTINGS USE

The following obstacles were identified primarily from the results of the 2007 and 2009 FHWA national surveys:

- **Limited knowledge and use of the AASHTO and FHWA technical references and training courses for selection, LRFD design, construction, and performance of spread footings on soils to support highway bridges.** The AASHTO and FHWA technical resources allow for the use of spread footings on all types of soils (competent and improved natural soils as well as engineered granular fill and MSE fills to support bridges and provide the state of the practice for their selection, LRFD design, construction, and quality control. The following practices were collected from the FHWA national surveys and demonstrate that some State DOTs do not follow the FHWA technical references for selecting the most appropriate foundation type:
 - State DOTs only consider a standard or favorite foundation type to support bridges instead of all appropriate foundation alternatives.
 - Some structural engineers, who often control the selection of foundation type for structures, have unrealistic concerns or perceived higher risk in the use of spread footings for bridge support.
 - Costs are not considered in many cases during the selection of an appropriate foundation type. Deep foundations with higher costs are used in cases where the more economical choice is spread footings.
 - Communication between the structural and geotechnical engineers is one of the main impediments for increased use of spread footings. Geotechnical groups may not be consulted when the foundation type is selected. Several respondents indicated that education and training for both the structural and geotechnical engineers are required to clarify their roles in the design process.

Note that many of the obstacles listed next can also be attributed to the limited knowledge and use of AASHTO and FHWA technical resources.

- **Limited knowledge of the successful use by many State DOTs of spread footings as a safe and economical foundation alternative to support highway bridges with good performance.** This lack of knowledge may explain the variation in the use of spread footings, even among neighboring states with similar conditions, as will be discussed in Chapter 3.
- **Concerns about using spread footings bearing on engineered granular fill and MSE fill.** A number of State DOTs have allowed and constructed spread footings on natural soils but not on engineered granular and MSE fills. These State DOTs are concerned with the quality and uniformity of placed fill and their effects on the performance (settlement) of bridges. Colorado DOT used spread footings on MSE walls to support the abutments of the Bridge/Meadow Bridge and reported that this bridge required longer spans, which could make them cost more than using driven piles to support the abutments. Many State DOTs prefer to use abutments supported on piles placed in MSE walls.
- **Increased use of integral abutments.** In the integral abutments, the foundation and abutment are rigidly connected to the bridge superstructure. The primary concern with integral abutments is the cyclic seasonal movements (expansion and contraction) of the bridge superstructure and their effects on the bridge abutment, the fill behind the abutment, and on the abutment footing. Dunker and Liu (2007) and the 2007 and 2009 FHWA national surveys indicate that H-pile is the typical foundation type considered by DOTs to support integral abutments. This foundation type (H-pile) is considered flexible and therefore is selected to accommodate cyclic seasonal movements of the bridge superstructure with integral abutments. Spread footings are considered stiff foundations (Dunker and Liu, 2007), so special design details or limitations are needed for their use with integral abutments. Recently, State DOTs use of integral abutments has significantly increased, which has further reduced the use of spread footings.
- **Limited use of load tests on spread footings and bridge instrumentation programs to verify the design and performance of spread footings.**
- **Inadequate subsurface investigation programs, leading to construction and bridge performance concerns.** These concerns are perceived to be more critical for spread footings than for deep foundations. Mainly, some State DOTs are concerned with differing site conditions (DSC) during construction than those assumed in the design, such as the presence of soft soils not expected in the design that would require increasing the size or depth of the footings, and an unexpected rise of groundwater during construction that would require dewatering. These factors would require costly modifications during construction or result in poor foundation performance. Problems associated with DSC are often encountered in the case of a limited number of borings in the subsurface investigation, or when the subsurface investigation is performed in the

early stages of the project—not at the exact locations of bridge foundations, which could be finalized in the later stages of a project.

- **Inadequate construction quality program, leading to construction and bridge performance concerns.** These concerns, which could have an impact on bridge performance, are perceived to be more critical for spread footings than for deep foundations. An example of this obstacle is the unavailability of adequately experienced State DOT staff in the field who can verify bearing capacity of spread footings.
- **Use of conservative settlement analysis for bridges supported on spread footings.** The main concern of most State DOTs with the use of spread footings is bridge settlement and the potential for costly and difficult bridge repairs to address bridge settlement problems. This concern led to the use of conservative settlement analysis. For example, selection of unrealistic tolerable settlements (e.g., 0.5 inch), use of conservative methods to predict settlement, overestimating the loads considered to compute settlements, and not allowing the use of spread footings on cohesive soils. A conservative settlement analysis would lead to a more costly design and perhaps the exclusion of spread footings from consideration in the design.
- **Selection of conservative or presumptive bearing geotechnical resistances in the final design of spread footings.** Use of presumptive bearing geotechnical resistances may lead to a more costly design and perhaps the exclusion of spread footings from consideration in the design.
- **Problems with implementation of LRFD platform for spread footings.** The LRFD platform provides a rational approach for considering spread footings on soils, when appropriate, as a suitable alternative to deep foundations. Implementation of the LRFD platform provides an excellent opportunity for State DOTs to address the obstacles listed above, and improve their geotechnical selection and design practices for spread footings.

These perceived obstacles have resulted in the use of costlier and complex deep foundations for bridge projects where the more economical and simple spread footings could have been used.

1.4 RECOMMENDATIONS TO ADDRESS THE PERCEIVED OBSTACLES IN USING SPREAD FOOTINGS ON SOILS TO SUPPORT HIGHWAY BRIDGES

The following recommendations were developed based on AASHTO and FHWA technical resources, national survey results for the performance of bridges constructed on spread footings bearing on soils, the practices of State DOTs that frequently use spread footings, LRFD implementation for spread footings, published literature, and the authors' experiences and judgment.

1. **Deploy the AASHTO LRFD design specifications and FHWA technical references and training courses.** These technical resources:
 - Allow for the use of spread footings on competent and improved natural soils as well as engineered granular and MSE fills to support bridges by providing the state of the practice for their selection, LRFD design, construction, and quality control.
 - Require fair evaluation and consideration of all foundation types for bridges (including spread footings) in the preliminary design, and selection of the most appropriate (economical) foundation type in the final design.
 - Present more accurate and economical design methods for spread footings than commonly used in practice.
 - Provide training courses to address most of the State DOTs' perceived obstacles in using spread footings on soils. These courses cover a) application conditions and advantages of spread footings; b) rational design process for selecting the appropriate foundation type; c) roles of the project geotechnical and structural engineers in the selection and design of spread footings, including the importance of communication and cooperation between them (e.g., in the settlement analysis); d) appropriate settlement analysis of bridges supported on spread footings; and e) LRFD implementation for spread footing design (FHWA, 2005, 2010a, 2010b, and 2012).
2. **Review the FHWA national survey results for the a) extent of use and performance of highway bridges constructed on spread footings bearing on various types soils; and b) experiences and practices of State DOTs that frequently use spread footings for selection, design, and construction of spread footings.** State DOTs that have limited or no use of spread footings can benefit from the experiences and practices of State DOTs that frequently use spread footings.
3. **Consider spread footings on granular and MSE fills as well as with semi-integral and integral abutments.** This will help State DOTs deploy these applications when they are appropriate.
4. **Consider load tests on spread footings and instrumentation of bridges supported on spread footings, and review documented performance data from load tests and instrumented bridges.** This will help State DOTs verify the design, construction, and performance of spread footings, and address concerns about their use. Additionally, data from load tests and instrumentation program provide performance data for reliability calibration and improvements of the LRFD geotechnical design methods for spread footings (FHWA, 2010a). Additionally, these data are needed for implementation of many recommendations presented in this report.
5. **Deploy adequate subsurface investigation, construction, and quality control procedures.** This will help State DOTs to minimize risks and problems during construction as well as improve the performance of spread footings. One of the

advantages of spread footings over deep foundations is that they allow for visual inspection of the bearing area and foundation during construction so that improvements can be made, if needed.

- 6. Advance a rational procedure for settlement analysis of bridges supported on spread footings bearing on soils.** This will help State DOTs to develop and use more accurate and economical LRFD design specifications to address the service limit state for settlement of bridges supported on spread footings bearing on soils.
- 7. Advance a rational procedure to determine the LRFD design bearing resistances for spread footings bearings on competent and improved natural soils, and engineered granular and MSE fills.** This will help State DOTs to develop and use accurate and economical LRFD design specifications for spread footings.
- 8. Based on the above recommendations, develop LRFD guidance for spread footings that consists of:**
 - LRFD specifications and a process for selecting spread footings in the design when appropriate.
 - LRFD specifications and a process for accurate and economical design of spread footings.

Chapters 2 to 9 of this report are developed to assist State DOTs with implementation of, respectively, recommendations 1 to 8 listed above.

CHAPTER 2 AASHTO AND FHWA TECHNICAL RESOURCES

This chapter presents information to help State DOTs deploy AASHTO and FHWA technical resources (implementation of recommendation 1). These resources allow for the use of spread footings on all types of soils (competent and improved soils as well as engineered granular and MSE fill) to support bridges, and include state-of-the-practice procedures for their selection, LRFD design, and construction. These technical resources are employed in subsequent chapters to implement many recommendations developed to address DOT's obstacles in using spread footing on soils to support highway bridges.

2.1 AASHTO LRFD DESIGN SPECIFICATIONS FOR BRIDGE FOUNDATIONS

There are three principal differences between the AASHTO LRFD design platform and the allowable stress design (ASD) platform for bridge foundations (FHWA, 2010a): a) the incorporation of limit state designs; b) the use of load and resistance factors to account for uncertainties; and c) new and improved methods to determine foundation loads, displacements, and resistances. A limit state is a condition beyond which a bridge component ceases to satisfy the provisions for which it was designed. All possible structural and geotechnical failure modes for foundations that can lead to bridge failure are grouped into three distinct structural and geotechnical limit states (AASHTO, 2012):

- **Service limit states.** Failure modes are related to the function and performance problems of bridge foundations under loads and conditions applied continuously or frequently during the bridge design life. For example, the foundations must have adequate structural and geotechnical resistances to keep the bridge displacements less than the bridge tolerable displacements.
- **Strength limit states.** Failure modes are related to the strength and stability of the foundations under loads and conditions applied continuously or frequently during the bridge design life. For example, the foundations must have adequate structural and geotechnical resistances to resist the loads applied on them with an adequate margin of safety against damage or collapse.
- **Extreme event limit states.** Failure modes are related to the strength and stability of the foundations under loads and conditions applied during certain events that have a return period greater than the bridge design life (e.g., failures during major earthquakes or floods). For example, the foundations must have adequate structural and geotechnical resistances to withstand the extreme events that the bridge may experience during its life without causing the bridge to collapse. The design concern is survival of the bridge and protection of life safety. (Some damage to the structure is allowable.)

Section 10 in AASHTO LRFD (2012) presents LRFD design specifications for bridge foundations (spread footings, driven piles, drilled shafts, and micropiles) at all limit states. Computation of foundation loads at various limit states and foundation structural and hydraulic designs are briefly described in Section 10; more specific details are provided in Sections 2 to 8. Article 10.4 describes the determination and selection of soil and rock properties needed for foundation design and construction. Tolerable movement of bridge foundations at the service limit state are discussed in Articles 10.5.2. Resistance factors, ϕ , for bridge foundations at all limit states are described in Article 10.5.5.

2.1.1 AASHTO LRFD Design Specifications for Spread Footings

The design of spread footings at all limit states is discussed in Article 10.6 of AASHTO LRFD (2012). Service limit state design, discussed in Article 10.6.2, covers the settlement and overall stability of spread footings. Article 10.6.2.4 describes the methods that should be used to estimate settlement of bridge spread footings on cohesionless and cohesive soils. Strength limit state design, discussed in Article 10.6.3, covers the bearing resistance of soil, eccentric load limitations, and failure by sliding. Article 10.6.3.1 describes the methods used to determine bearing resistance of bridge spread footings on soils. The overturning stability in the ASD method has been replaced with the eccentricity limit under LRFD. Eccentricity provisions are different from those in ASD because they are based on factored loads. The tolerable eccentricity of loading at the strength limit for footings on soils was changed in 2012 AASHTO LRFD from one fourth (1/4) to one third (1/3).

2.2. FHWA TECHNICAL REFERENCES AND TRAINING COURSES FOR SPREAD FOOTINGS

FHWA developed several LRFD National Highway Institute (NHI) training courses and LRFD-based technical reports to help State DOTs implement the 2012 AASHTO LRFD design specifications for bridges with spread footings. Additionally, some of the FHWA ASD technical references and training courses on spread footings are still valuable resources because they include materials referenced in the AASHTO and FHWA LRFD technical references, and they cover issues (e.g., settlement analysis, construction) that did not change in the LRFD design platform. Following are brief descriptions of the FHWA technical resources on spread footings that include training courses:

- **NHI Reference Manual and Training Course 132083: “Implementation of LRFD Geotechnical Design for Bridge Foundation”** (FHWA, 2010a). The goal of this course is to assist State DOTs in the successful development of LRFD design guidance for bridge foundations based on the 2010 AASHTO LRFD Bridge Design Specifications and their local practices. The principal differences between the AASHTO LRFD platform and

the ASD platform are presented for all foundation types, including spread footings. The LRFD implementation options are thoroughly discussed, and a roadmap for developing LRFD design guidance for bridge foundations is presented.

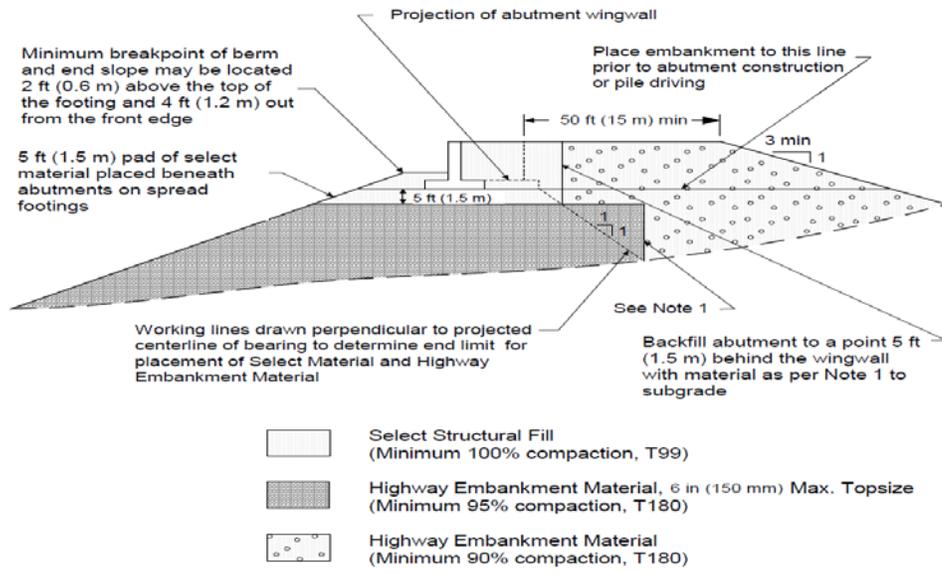
- **NHI Reference Manual and Training Course 132094: “LRFD Seismic Analysis and Design of Transportation Structures, Features, and Foundations”** (FHWA, 2011). This comprehensive course provides practical training in seismic analysis and design of transportation geotechnical features, including shallow foundations.
- **NHI Reference Manual and NHI Training Course 132042: “Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes”** (FHWA 2009). Section 6.1.1 of this manual presents a discussion of the design of spread footings on MSE walls to support bridge abutments.
- **NHI Reference Manual and Training Course 132012: “Soils and Foundations”** (FHWA, 2006a). Chapter 8 of this manual describes the design and construction of shallow foundations. Topics include settlement of spread footings, spread footings on compacted embankment fills, the effect of deformation on bridge structures, and construction inspection.
- **NHI Reference Manual and Training Course 132034: “Ground Improvement Methods”** (FHWA, 2006b). This course covers the selection, limitations, advantages, disadvantages, design, construction, and quality control and quality assurance of various ground improvement techniques.
- **NHI Reference Manual and Training Course 1320082: “LRFD for Highway Bridge Substructures and Earth Retaining Structures”** (FHWA, 2005). This course provides examples of LRFD design of spread footings bearing on soil. Note: This course is based on the 2006 AASHTO LRFD interim revisions.
- **NHI Reference Manual and Training Course 132037: “Shallow Foundations”** (FHWA, 2001). In 2012, the training course was updated in accordance with 2012 AASHTO LRFD. The course describes the state of the practice of LRFD design and construction procedures for spread footings, the selection and design process, the design and construction of spread footings on compacted and problematic soils, and the application of various ground improvement techniques.
- **NHI Reference Manual and Training Course 132041: “Geotechnical Instrumentation”** (FHWA, 1998). This course provides the necessary knowledge and skills to plan, select, and implement instrumentation programs in geotechnical features for construction monitoring and performance verification.

Following are brief descriptions of the FHWA technical manuals on spread footings:

- **Hydraulic Engineering Circular 18 (HEC-18): Evaluating Scour at Bridges, Fifth Edition** (FHWA, 2012). This manual provides guidance for scour evaluation and design procedures for the use of spread footings on soils to support both piers and abutments.
- **Geotechnical Engineering Circular 6: Shallow Foundations** (FHWA, 2002a). Topics discussed in this manual include shallow foundation selection, design process, materials and construction specifications for structural fill, and LRFD design of shallow foundations. This manual presents most of the FHWA materials and construction specifications for engineered granular fill (Table 3.1) and details of a spread footing on engineered granular fill (Figure 3.1).
- Design examples of spread footings on natural soil and compacted structural fill using ASD and LRFD design methods are discussed. Note: The LRFD examples are not based on the 2012 AASHTO LRFD design specifications.
- **Selection of Spread Footings on Soils to Support Highway Bridge Structures** (FHWA, 2010b). This report promotes the use of spread footings on soils to support bridges. Appendix E presents comprehensive LRFD guidance and examples for the design of spread footings.
- **Geotechnical Engineering Circular 5: Evaluation of Soil and Rock Properties** (FHWA, 2002b). This manual presents state-of-the-practice information about the evaluation of soil and rock properties for geotechnical design applications.

Table 2.1. FHWA Materials and Construction Requirements for Engineered Granular Fills (FHWA, 2002a).

Gradation (AASHTO T-27)	U.S. Sieve Size	Percent Passing (%)
	4 inch	100
	Sieve #40	0-70
	Sieve #200	0-15
Plasticity Index (PI) (%) (AASHTO T-90)	PI < 6	
Soundness	AASHTO T-104	
Compaction Level	100% of T-99 (standard proctor); moisture content should be $\pm 2\%$ of optimum moisture	



Note 1: Highway embankment material and select material shall be placed simultaneously of the vertical payment line

Figure 2.1. Details of a Spread Footing on Engineered Granular Fill (FHWA, 2002a)

CHAPTER 3

FHWA NATIONAL SURVEY RESULTS: USE, PERFORMANCE, AND SELECTION OF SPREAD FOOTINGS

This chapter presents and discusses results of the FHWA national surveys for the use, performance, and selection of spread footings for highway bridges (implementation of recommendation 2). This will help State DOTs that have limited or no use of spread footings to benefit from the experiences and practices of State DOTs that frequently use spread footings. This chapter includes three topics:

1. Use and performance of highway bridges constructed on spread footings bearing on soils.
2. Type of foundation soils considered acceptable by State DOTs.
3. State DOTs favorable and unfavorable conditions for using spread footings.

The FHWA national surveys were performed in 2007 and 2009, and it is possible that states might answer survey questions differently today. Nevertheless, the survey responses when aggregated show important use and performance trends.

3.1 USE AND PERFORMANCE OF HIGHWAY BRIDGES CONSTRUCTED ON SPREAD FOOTINGS BEARING ON SOILS

3.1.1 Overview

Tables 3.1 to 3.5 summarize the approximate use and performance of highway bridges constructed on spread footings bearing on soils in five regions of the United States: the Northeast, Midwest, Northwest, Southwest, and Southeast. These summaries suggest that use of spread footings varies significantly across the country and even among states located within the same region. Use of spread footings is up to 50% in the Northeast, 30% in the Southwest, 20% in the Northwest, 10% in the Midwest, and no or limited use in the Southeast. All of the regions have some states with very limited or no use of spread footings. The significant variation in using spread footings suggests that many State DOTs are missing an opportunity to save construction time and costs by not actively considering spread footings when appropriate. A small number of State DOTs (e.g., Ohio and Michigan) reported a decrease in the use of spread footing on soils due to the perceived obstacles discussed in Chapter 1. Other State DOTs (e.g., Delaware, Virginia, Minnesota, and Indiana) reported an increased use of spread footings and indicated they are more receptive to their use primarily because of the good performance of these foundations.

State DOTs reported good performance of their bridges constructed on spread footings bearing on competent and improved natural soils, and engineered granular and MSE fills. Some DOTs

(e.g., Michigan and New Mexico) reported that the performance of bridges supported on spread footings was similar to the performance of bridges supported on deep foundations.

Table 3.1. Use and Performance of Bridges with Spread Footings on Soils: Midwest States.

State	2007 Survey, Estimated Use (%), Spread Footings on:		2009 Survey: Use/Performance of Spread Footings on Soils
	Soil	Rock	
Michigan	10	5	Hundreds of bridges with spread footings on soils constructed in Michigan (70% before 1980, reduced to 50% by 1990, and currently 10%). “Their overall performance is adequate, as bridges with deep foundations.”
Illinois	5	10	Use with piers on hard tills and dense sand; one bridge with MSE abutments. “No performance or movement problems with these bridges.”
Wisconsin	7.5*	10	Roughly 75 bridges supported on stiff natural soils constructed in the last 10 years. Very limited use with MSE walls. Use with multispan bridges, piers, and abutments. “These bridges are performing well or as good as bridges with piles.”
Indiana	1	5	Recently allowed spread footers for interior pier support on some grade separation bridges only in glacial tills, IGMs, and engineered fills. In process to allow them over MSE walls. Successfully used in the Accelerate I-465 project. “There has been no visible evidence of excessive settlement.”
Minnesota	7	2	Recently used spread footing in simple span bridges (at abutments only) on dense sand and gravel, approximately four bridges per year, and with MSE walls. Use expected to increase in corridor and design-build projects. Employed with ground improvement in a value engineering project. “Bridges appear to be in fine shape and perform well.”
Ohio	5	1	Since 1998, built 244 bridges with spread footing on MSE walls and rocks. Presently, use of spread footings on MSE walls is not allowed. Current use is with dense sand and in few cases with very stiff clays. “No major problems are observed.”
Missouri	Little*	5	
Iowa	0	5	No use.

* From the 2009 survey (not 2007 survey).

**Table 3.2. Use and Performance of Bridges with Spread Footings on Soils:
Northeast States**

State	2007 Survey, Estimated Use (%), Spread Footings on:		2009 Survey: Use/Performance of Spread Footings on Soils
	Soil	Rock	
Connecticut	50	25	Used at every opportunity. Good performance.
Vermont	40	10	Good performance.
Massachusetts	35	15	Good performance.
New Hampshire	30	30	To support abutments and piers. On MSE wall abutments. Used at every opportunity. Good performance.
New York	30	15	To support abutments and piers. On MSE wall abutments. Good performance.
New Jersey	30	20	Used at every opportunity. On MSE wall abutments. Good performance
Delaware	13*	4*	Where feasible, more recent use. Good performance.
Pennsylvania	10	60	Good performance.
Rhode Island	10*	*	In glacial till. Good performance.
Maine	2	45	Used at every opportunity. Good performance.
Virginia	10	30	To support abutments and piers. On MSE wall abutments. Good performance.
Maryland	15*		Good performance.
West Virginia	0	20	No use.
District of Columbia	Rarely used*		

* From the 2009 survey (not 2007 survey).

Table 3.3. Use of Bridges with Spread Footings on Soils: Southeast States.

State	2007 Survey, Estimated Use (%), Spread Footings on:		State	2007 Survey, Estimated Use (%), Spread Footings on:	
	Soil	Rock		Soil	Rock
Tennessee	1	40	Kentucky	<1*	40*
Florida	1	0	Georgia	2-3*	7-8*
Alabama	5	10	Mississippi	5	0
North Carolina	0	10	South Carolina	Rarely used*	
Arkansas	1	22	Louisiana	0	0

* From the 2009 survey (not 2007 survey).

Table 3.4. Use and Performance of Bridges with Spread Footings on Soils: Southwest States.

State	2007 Survey, Estimated Use (%), Spread Footings on:		2009 Survey Use/Performance of Spread Footings on Soils
	Soil	Rock	
New Mexico	30	10	Extensive use of spread footings on MSE walls (30 of 55 bridges in the I-25/I-40 interchange). “Performed well, better than deep foundations as there is no bridge bump.”
Nevada	25	3	Considered with all types of bridges. Saved money. “No known issues. They are performing well.”
Arizona	20	5	Performance not reported, but expected to be OK.
California	5 (30% - 50% in Southern California)*		Significant savings. Considered with all bridge types. “Performed very well. No indications of poor performance.”
Utah	5	5	Mostly single-span bridges. “Performed well.”
Colorado	3 bridges on soils*		Two bridges on MSE walls, third bridge on 2:1 approach embankment. “All performing well.”
Oklahoma	Rarely used*		
Texas	0		No use.
Kansas	0		No use.

* From the 2009 survey (not 2007 survey).

**Table 3.5. Use and Performance of Bridges with Spread Footings on Soils:
Northwest States.**

State	2007 Survey, Estimated Use (%), Spread Footings on:		2009 Survey: Use/Performance of Spread Footings on Soils
	Soils	Rocks	
Idaho	20	10	Not aware of any performance issues with spread footings.
Oregon	20	10	For piers and abutments. Not aware of any performance issues with spread footings.
Washington	10	*	A very long history with successful use of spread footings on compacted granular embankments and with piers to support bridges. FHWA (1982) reported very good conditions of 148 bridges. Currently not aware of any performance issues with spread footings.
Nebraska	10*	*	Not aware of any performance issues with spread footings.
Montana	5	5	For piers and abutments. Not aware of any performance issues with spread footings.
Wyoming	5	17	Not aware of any performance issues with spread footings.
Alaska	30% for abutments; <10% for piers*		Mostly to support abutments on MSE wall embankments. With piers on very dense glacial till. Not aware of any performance issues with spread footings.
Hawaii	7	2	For piers. Not aware of any performance issues with spread footings.
South Dakota	0	5	No use.
North Dakota	*	*	No use.

* From the 2009 survey (not 2007 survey).

3.1.2 Midwest Region

The use of spread footings on soils to support highway bridges in the Midwest ranges from zero (Iowa) to 10% (Michigan), as shown in Table 3.1. State DOTs that constructed bridges with spread footings in this region reported good bridge performance. Minnesota DOT has successful experience with spread footings constructed on top of MSE walls. Indiana and Wisconsin DOTs also reported successful experience using spread footings on hard glacial tills and dense granular soils to support bridge piers.

In Michigan, hundreds of bridges with spread footings on soils were constructed successfully (around 70% before 1980, reduced to 50% by 1990). Michigan DOT reported that in past years,

the process used for design verification of spread footings during construction allowed for using allowable bearing pressure as high as 5 ksf. Currently, with fewer staff available to verify competent soil layer in the field, the allowable bearing pressure is reduced to around 3 ksf, which significantly reduced the use of spread footings to support bridges (approximately 10%).

Minnesota DOT has recently implemented instrumentation programs, extensive construction quality control, cone penetration tests (CPTs) and advanced settlement analysis to justify the use of bridges constructed on spread footings and to ensure their adequate design and performance. In a value engineering project, deep mixing and the “remove-and-replace” techniques were employed to improve foundation soils below spread footings. The monitoring data indicated good performance and supported the future consideration of spread footings bearing on improved soil. In a design-build project, spread footings were used to support seven bridges. The settlements occurred relatively quickly during construction, and postconstruction settlements were minimal (Bentler and Hoppe, 2010). The final abutment settlements were just under the allowed 1 inch. Due to the good performance of spread footings, their use in Minnesota to support bridges is expected to increase, especially in corridor projects and design-build contracts.

Between 1990 and 2006, Ohio DOT sponsored two major research projects on new highway bridges where 54 spread footings were instrumented to monitor their performance (Sargand and Masada, 2006; Sargand et al., 1997). Instrumentation monitoring results indicate good bridge performance and confirm that spread footings are a viable option for support of bridges. Ohio DOT chose not to allow spread footings on MSE walls because of problems with MSE walls (not with spread footing performance) that led to the adoption of much tighter construction requirements for MSE walls. This action increased the cost of MSE walls in Ohio and resulted in the increased use of conventional walls.

In the recent Indiana DOT Accelerate I-465 project, spread footings were used to support the piers located in the median of I-465. Excavation to a relatively deep depth was required to accommodate drainage in the median. This use of spread footings eliminated the need for pile driving equipment, assisted in accelerating construction, and provided cost savings.

3.1.3 Northeast Region

As indicated in Table 3.2, the use of spread footings on soils in Northeast states ranges from zero (West Virginia) to very high (Connecticut, 50%; Vermont, 40%). State DOTs that constructed bridges on spread footings reported good performance of these bridges. Spread footings are the preferred and most frequently used foundation type to support bridges by some State DOTs in this region. The extensive use of spread footings in this region is attributed to the presence of very competent natural soils near the ground surface, economics, deployment of good design and

construction procedures, and the long-term good performance of existing bridges supported on spread footings. Table 3.2 suggests State DOTs that have no use or very limited use (less than 5%) of spread footings on soils have extensive use of spread footings on rocks (e.g., West Virginia, Virginia, and Maine). The extensive use of spread footings on rocks by these states would help them to increase their use of spread footings on soils.

The FHWA report (1987) presents the long-term settlement performance of 21 bridges located in Connecticut, Massachusetts, New York, Rhode Island, and Vermont. These bridges were constructed with spread footings on natural cohesionless soils. The report describes the bridges, soils, loads, and the instrumentation and monitoring programs to measure the settlement and tilting of these bridges. The average settlement was 1 inch, with 0.75 inch (three-quarters of total settlement) occurring before placement of the bridge decks and only one-quarter settlement occurring after construction of the bridge deck. These results demonstrate the successful performance of spread footings to support highway bridges.

3.1.4 Southeast Region

The very limited use of spread footings on soils in the Southeast region (Table 3.3) is due to the presence of very poor soft soil conditions near the ground surface and problematic grounds such as areas with high sinkhole potential in central and south Florida. Other reasons are the large axial loads on foundations and the concerns with bridge movements. Based on the region's geology, however, some areas have subsurface conditions that are favorable for constructing spread footings on soils, as will be discussed in Section 3.2. Georgia reported the use of spread footings with bridges on both natural soils and well-compacted fill using allowable bearing capacity around 4 ksf. Kentucky has not used spread footing on well-compacted fill. Table 3.3 suggests there are states in the Southeast that have significant use of spread footings on rocks to support highway bridges (e.g., Tennessee and Kentucky, 40%; Arkansas, 22%; Alabama and North Carolina, 10%). The extensive use of spread footings on rocks by these states would help them to increase their use of spread footings on soils.

3.1.5 Southwest Region

As indicated in Table 3.4, the use of spread footings in the Southwest ranges from zero (Kansas and Texas) to 30% (New Mexico). State DOTs that constructed bridges on spread footings reported good bridge performance.

New Mexico's use of spread footings is considered to be very high (30% footings on soils), providing significant cost and time savings. New Mexico DOT reported extensive use of spread footings on MSE walls to support bridge abutments in many projects. Out of 55 bridges

constructed in the I-25/I-40 interchange in Albuquerque, 30 bridges were constructed using spread footings on MSE (FHWA, 2006a), which resulted in a significant cost savings. New Mexico reported that these bridges are performing well. Use of spread footings in this project eliminated the bump at the end of the bridge, thus providing better performance compared to bridges constructed on deep foundations.

Colorado's Founders/Meadows Bridge structure, constructed in 1998 over I-25, is considered the first built bridge in the United States where abutment spread footings were placed on top of geosynthetic-reinforced soil (GRS) walls with block facings, as shown in Figure 3.1 (Abu-Hejleh et al., 2001). Competent shale bedrock existed below the GRS wall and the piers of this two-span bridge. GRS fill was also placed behind the abutment wall. The reinforced soil zone extends gradually in length from the base of the GRS wall to the top of the GRS fill behind the abutment wall. This design integrated the support for the bridge structure with the approach roadway structure, and alleviated the differential settlement (bridge bump problem) between these structures. The structure was heavily instrumented to monitor its performance during and after construction. Data analysis revealed the design of this structure was conservative. Since 1998, the performance of the structure has been excellent, with spread footing settlement less than 1 inch in the first year of service, negligible movements after that, and no bridge bump problem.

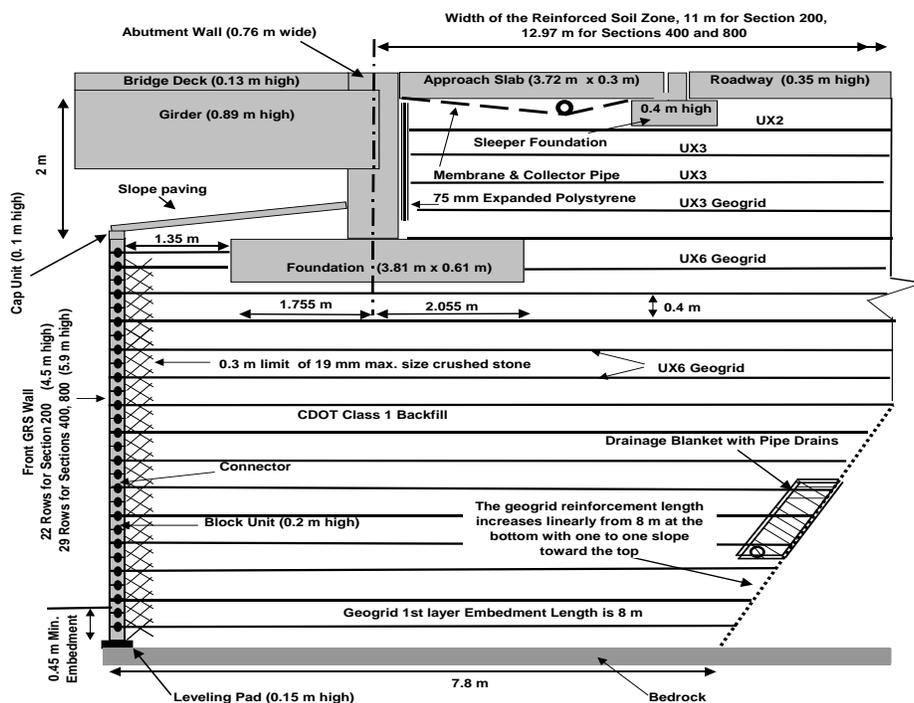


Figure 3.1. A Cross Section from the Colorado Founders/Meadows Bridge (Abu-Hejleh et al., 2001)

Texas DOT has not used spread footings on soils or rocks to support highway bridges, even at locations where spread footings are technically feasible. The primary reason is the low cost of drilled shafts in the state due to the availability of drilled shaft contractors. However, Texas and other State DOTs could increase their use of spread footings when appropriate if they a) deployed AASHTO and FHWA technical resources, b) followed the practices of State DOTs that use spread footings, c) constructed and monitored bridges with spread footings on a number of selected pilot projects, and d) required contractors to consider spread footings for bridges in design-build and value engineering projects.

3.1.6 Northwest Region

In the Northwest, the use of spread footings on soils ranges from zero (South Dakota) to 20% (Idaho and Oregon), as shown in Table 3.5. State DOTs that constructed bridges with spread footings reported good performance of these bridges.

Washington State DOT has a very long history with successful use of spread footings on compacted fill to support bridges. In this state, the performance of 148 bridges supported by spread footings on compacted fill were investigated (FHWA, 1982). The conditions of these bridges were visually inspected followed by detailed investigation of the foundation movements of 28 bridges. All bridges were in good to very good condition. Washington State DOT concluded that:

- Spread footings can provide a satisfactory alternative to piles, especially with high-quality compacted fill and with good foundation soils.
- Spread footings were 50% to 65% less expensive than piles.
- Bridges can easily tolerate differential settlements of 1 to 3 inches without significant distress.

3.1.7 Other Reported Performance Information for Spread Footings

Appendix B of the FHWA report (2010b) summarized the results from 78 instrumented highway bridges in five databases. The summary includes footing dimensions (width, length, and depth); the uncorrected and overburden corrected standard penetration test (SPT) values; maximum footing contact pressure; measured settlement, S , at service conditions; and computed values of settlement to footing width (S/B) expressed as a percentage. According to the findings:

- All bridges performed very well.
- The typical contact pressure under the footing varied from 3 to 6 ksf.
- The settlement of 69 bridges was less than 1 inch, between 1 and 2 inches for eight bridges, and 2.26 inches for one bridge.

- The S/B ratio ranged from 0.1% to 1.0% for footing widths greater than 10 ft.

The FHWA report (2010) also compared the settlement results for these instrumented bridges with the load test results reported by Akbas and Kulhawy (2009). It was concluded that spread footings for these bridges performed well with respect to settlement and have a large margin of safety with respect to the bearing failure since the measured service bearing pressures (3 to 6 ksf) were well below the foundation nominal (or ultimate in the ASD) geotechnical bearing resistance.

3.2 PRACTICES FOR SELECTING SPREAD FOOTINGS

According to the FHWA national survey results, State DOTs that used spread footings on soils to support highway bridges (i.e., states in the Northeast region along with Arizona, California, Minnesota, New Mexico, and Washington) consider conditions that are similar to those recommended in the AASHTO and FHWA technical references. These conditions are discussed in the following subsections.

3.2.1 Types of Foundation Soils for Spread Footings

State DOTs constructed spread footings on competent and improved natural soils, and on engineered granular and MSE fills.

Competent Natural Soils. State DOTs have used spread footings on:

- Hard and very hard glacial tills (many State DOTs).
- Dense to very dense granular sand and gravel soils (many State DOTs).
- Cemented sand (New Mexico).
- Very stiff cohesive soils (Washington State).

Based on a survey discussed in NCHRP Report 651 (Paikowsky et al., 2010), 28 states out of 39 responding states, or 72%, do not build spread footings on cohesive soils. In these states, cohesive soils will be removed to a maximum depth of 10 ft when using spread footings. (Piles will be considered for depths of cohesive soils exceeding 10 ft.) Only 12% of spread footings are built on cohesive soils and 88% are built on granular soils. Sixty percent (60%) of spread footings on cohesive soils are built without ground improvements. The State DOTs leading in building spread footing on cohesive soils are Washington State, Vermont, Idaho, Michigan, and Nevada. In Washington State, the cohesive soils used are very hard glacial soils with SPT-N values exceeding 30 blows per foot (bpf) for silt and between 40 and 100 bpf for clays. These materials can be considered intermediate geomaterials (IGMs).

Improved Natural Soils. This alternative is considered if unsuitable foundation soils were encountered at the footing location. However, many State DOTs avoid this option since it adds construction costs and time to the project and requires a more thorough subsurface investigation and construction quality control. The most common and simplest practices used by State DOTs to improve ground conditions are removing unsuitable (cohesive) soils and replacing them with granular compacted fill, and/or preloading unsuitable soils by using fill material or by lowering the groundwater for a period of time to allow the unsuitable soils to consolidate before placement of spread footings. These ground improvement techniques require adequate time during construction to allow foundation soils to settle and to reduce post-construction settlement to tolerable settlement. Minnesota DOT successfully used deep mixing with a remove-and-replace technique to improve foundation soils below spread footings.

Compacted Engineered Granular and MSE Fills. A number of State DOTs (including Washington State, New Mexico, and Minnesota) have successfully utilized these materials.

3.2.2 Favorable Conditions for Using Spread Footings

State DOTs that use spread footings cite the following favorable conditions for their use:

- Competent natural soils are present within shallow depth.
- Foundation width is expected to be relatively smaller (e.g., with relatively small axial compression loads; very small inclined, lateral, and uplift loads; and overturning moments).
- Spread footings can be placed at an economical depth, considered by many State DOTs as less than 10 ft.
- Groundwater is not an issue.
- Quality granular fill materials are available.
- Minimal constructability issues (e.g., deep shored excavations) exist. Adequate room for shoring may be needed with spread footings.
- To support both piers and abutments.
- To support single- and multi-span bridges (e.g., Arizona, Nevada, and New Mexico). Some states (e.g., Minnesota and Utah) prefer to use spread footings in simple span bridges to address concerns with differential settlements (e.g., Minnesota and Utah).
- For grade separation structures.
- At sites where erosion and liquefaction are not concerns.
- Stream crossings have low scour potential or low scour depth so the bottom of spread footings can be economically placed below scour depth. Many State DOTs (e.g., New York and Maryland) allow spread footings for bridges in waterways only if good rock is located near the surface. Oregon DOT allows spread footings for stream crossings when

the abutment is well above the stream, the stream is an incised channel that is not expected to migrate laterally, the foundation is nonerodible bedrock, or the estimated scour depth is low. In New Hampshire, a pier with spread footings can be placed in a river where it is totally surrounded by sheet piles for scour protection.

- There is an established need to excavate to deep depths to construct other structures (e.g., to accommodate drainage).
- Design-build contracts and value engineering projects, where contractors will be more interested in reducing project costs and accelerating construction time.
- At locations where there are concerns with using deep foundations. For example, pile driving may not be allowed in urban areas and locations near residential or historical buildings because of potential damage and noise concerns to the surrounding structures. In these and other similar cases, spread footings may be considered even if they are not the most economical alternative.

3.2.3 Unfavorable Conditions for Using Spread Footings

According to State DOTs that use spread footings, the following conditions are not favorable for spread footings:

- Thick, unsuitable soils are present near the ground surface that would require significant ground improvement (e.g., locations with underlying karst formations, such as Pennsylvania, or high sinkhole potential, such as Florida).
- Large size and deep spread footings are required, leading to significant costs.
- Locations require relatively large spread footings to resist inclined, lateral, or uplift loads and overturning moments.
- Steep slopes are present.
- Liquefaction is a concern and will not be economically addressed using ground improvement techniques.
- At water crossings due to scour (erosion) and constructability concerns. FHWA recommends placing spread footings below the maximum scour depth expected during the design life of the bridge. Therefore, spread footings may be appropriate and economical only at stream crossings with a small scour depth.
- Groundwater is an issue, especially where cofferdams are expensive.
- Locations have limited access such as the median of a busy freeway where lanes cannot be taken or due to right of way (ROW).
- Environmental concerns, for example where large excavation in contaminated soils is needed.
- Where use of deep foundations would result in the elimination of cofferdams, a reduction in ROW, and environmental concerns.

- Construction constraints such as deep excavation and/or large spread footings would require shoring.
- Deep frost is an issue.

CHAPTER 4

SPREAD FOOTINGS ON ENGINEERED GRANULAR AND MSE FILLS, AND WITH SEMI-INTEGRAL AND INTEGRAL ABUTMENTS

This chapter addresses concerns of some State DOTs with using spread footing on engineered granular and MSE fills and with semi-integral and integral abutments (implementation of recommendation 3). It will help State DOTs to consider these applications when they are appropriate.

Engineered granular fill is defined as a high quality granular soil selected and constructed to meet certain material and construction specifications (also called “compacted structural fill” and “compacted granular soil”).

4.1 CONSIDERATION OF SPREAD FOOTINGS ON ENGINEERED GRANULAR AND MSE FILLS

Many State DOTs that do not implement spread footings on granular and MSE fills have concerns related to the quality and uniformity of compacted fill materials as well as costly design and construction for footings on MSE walls. However, the AASHTO and FHWA technical references given in Chapter 2 describe state-of-the-practice procedures for selecting, designing, and constructing spread footings in these applications. They require high-quality material and construction specifications for fill materials and stringent quality control of placed fill considered in both embankments and MSE walls (see Table 2.1 and Figure 2.1). NCHRP Report 651 (Paikowsky et al., 2010) reported higher resistance factors for the compacted granular fill than the natural granular soil because of better control for compacted fill.

In addition, a number of State DOTs have successfully constructed spread footings on compacted granular and MSE fills, and have reported good performance. For example, based on a survey of 148 bridges in Washington, FHWA (1982) concluded that spread footings on compacted fill can provide a satisfactory alternative to deep foundations, especially if high-quality fill materials are constructed over competent foundation soil. New Mexico DOT reported extensive use of spread footings on MSE walls to support bridge abutments in many projects with good performance and significant cost savings.

Based on the instrumentation results of the Founders/Meadows Bridge (Figure 3.1), Abu-Hejleh et al. (2001) reported that the design of the MSE walls and spread footings in this bridge is conservative. Many of the design details used for the Founders/Meadows Bridge (e.g., distance of 4 ft from the edge of footing to the wall face) are more conservative than the recommendations presented in the FHWA (2009) manual on MSE wall.

To address the concerns about these applications, State DOTs should consider implementing the recommendations presented in this report, mainly:

- Deploy AASHTO and FHWA technical resources for selecting, designing, and constructing spread footings on compacted granular embankments and MSE walls.
- Incorporate the successful and cost-effective practices of State DOTs that have constructed spread footings on compacted granular embankments (e.g., Nevada, New Mexico, and Washington State) and on MSE walls (e.g., Arizona, Minnesota, New Hampshire, New Jersey, and New Mexico).
- Construct and monitor bridges with spread footings over compacted granular embankments and MSE walls on selected pilot projects.
- Allow contractors in design-build and value engineering projects to consider bridges with spread footings on compacted granular embankments and MSE walls.

4.2 CONSIDERATION OF SPREAD FOOTINGS WITH SEMI-INTEGRAL AND INTEGRAL ABUTMENTS

Initially, bridge designers should consider replacing integral abutments with semi-integral abutments, where only the abutment (not abutment footing) is rigidly connected to the bridge superstructure. In semi-integral abutment, the abutment footing is isolated from the abutment wall with an expansion material and/or bearing pad, so the footings will not be impacted with the thermal cyclic movements of the bridge superstructure. Many of the advantages of integral abutments can be achieved with semi-integral abutments. Many State DOTs, such as Nevada (FHWA, 2010b) and Colorado (Abu-Hejleh et al., 2001), have had success using spread footings with semi-integral abutments.

Integral abutment with spread footings can be considered where the cyclic seasonal (expansion and contraction) movements of the bridge superstructure are not significant, as with short-span bridges. To determine the conditions where these movements are not significant, the designers can consider the practices of State DOTs that successfully used spread footings with integral abutments. According to the survey reported in NCHRP Report 651 (Paikowsky et al., 2010), 25% of bridges with integral abutments are supported on spread footings (Utah, 100%; Tennessee, 90%; Wisconsin, 75%; Idaho, 10%; Maine, 6%; Georgia, 5%; Hawaii, 5%; Kansas, 5%). Dunker and Liu (2007) reported that the use of spread footings with integral abutments has been limited to relatively short bridges. In Maine, spread footings with integral abutments are considered for steel structures up to 80 ft (24 m) long and concrete structures up to 140 ft (42 m) long, with abutments up to 8 ft (2.44 m) tall and skews up to 25 degrees.

Finally, with both semi-integral and integral abutments, designers should consider implementing measures that minimize the impacts of significant cyclic seasonal movements of the bridge superstructure. For example, consider constructing a wrapped facing of GRS fill behind the abutment/spread footing, and allowing for a small gap filled with compressible material (which acts as a joint) between the abutment/spread footing and the GRS fill. In the Colorado Founders/Meadows Bridge (Figure 1.2), GRS fill was placed behind the abutment. A small gap was left between the abutment and the GRS fill, and filled with 75-mm-thick, low-density expanded polystyrene sheet (which acts like a joint) to reduce the impact of the cyclic thermal movements of the bridge superstructure. One of the abutment backfill alternatives developed by Colorado DOT is compacted quality granular fill reinforced with layers of geofabric wrapped at the facing that allows for a gap filled with compressible material between the abutment and the retained reinforced fill. Abu-Hejleh et al. (2006) described this alternative and concluded it is performing well.

CHAPTER 5

LOAD TESTS AND INSTRUMENTATION PROGRAMS

This chapter assists State DOTs with implementing load tests and instrumentation programs on bridges with spread footings, and reviewing documented performance data from load tests and instrumented bridges (implementation of recommendation 4). Load tests and instrumentation programs would help State DOTs verify the design, construction, and performance of spread footings, which could increase their use of spread footings to support highway bridges. Additionally, load tests and instrumentation programs provide foundation performance data needed in the LRFD reliability calibration to develop more accurate and economical design methods (FHWA, 2010a).

5.1 LOAD TESTS ON SPREAD FOOTINGS

Load testing is the most accurate design approach to determine and verify spread footing nominal bearing resistance (bearing capacity) at the strength limit and settlement at the service limit state. Load tests can also be considered to address design and construction uncertainties and concerns with spread footings and confirm their good performance. As an example, for a bridge over a railroad on I-359 in Tuscaloosa County in Alabama, load tests were performed to verify design and support the use of spread footings (FHWA, 2006a).

State DOTs are encouraged to compile existing load tests on spread footings that are relevant to their practices and consider new load tests in the preliminary design of large highway bridge projects. They might also benefit from reviewing documented results of load tests on other spread footings. To implement these recommendations, State DOTs should consider the following publications:

- FHWA (2010b) report: Selection of Spread Footings on Soils to Support Highway Bridge Structures.
- NCHRP Report 651 (Paikowsky et al., 2010) provides recommendations for changes in Section 10 of AASHTO LRFD (2012) for the strength limit state of shallow foundations. Resistance factors for the bearing resistance of footings placed on granular soils (natural and compacted fills) and rocks are recommended based on the reliability analysis of measured and predicted bearing resistances at load test sites. For granular soils, the effects of soil friction angle and loading conditions (eccentricity and load inclination) are considered in the calibration. At the same friction angle and loading conditions, the calibrated resistance factors are higher for the compacted granular fill than the natural granular soil because the conditions for the compacted granular fill are more controlled. Several LRFD design examples are presented in Appendix H of NCHRP Report 651.

- Akbas and Kulhawy (2009) described the results of 167 full-scale axial compression load tests at 37 sites on cohesionless soils. The report presents the results of the subsurface geotechnical investigation; dimensions of test foundations (width, length, and depth); and load tests. Note that the size of the footings in this study (less than 3 ft) is much smaller than the footing size often considered for highway bridges (approximately 10 ft). “Failure load” was defined at the point where a small increase in the load would generate significant settlement. Normalized load is defined as the ratio of applied load and failure load and normalized settlement is defined as the ratio of settlement and footing width. Normalized load settlement curves were developed for all load test results. The normalized settlement at failure load (normalized load = 1) was 5.39%, and the normalized load at settlement of 0.23% and 1% were 0.13 and 0.42, respectively. The study provides recommendations for estimating the bearing resistance (failure load).
- FHWA (1997) report: Large-Scale Load Tests and Data Base of Spread Footings on Sand. In this report, a database of load tests on spread footings was developed for use as a design tool as well as a research tool. Researchers performed five large-scale load tests on sand and analyzed the results to evaluate several settlement and bearing resistance prediction methods and identify the best methods.

5.2 INSTRUMENTATION OF BRIDGES WITH SPREAD FOOTINGS

Instrumentation and monitoring of bridges assist in understanding bridge performance and building confidence for increased future use of bridges supported on spread footings.

A number of resources are available for developing instrumentation programs, including the FHWA instrumentation manual (1998) and FHWA (2010b) report. Also, consider published research studies where bridges were instrumented; these studies are summarized in Chapter 3 (Minnesota, Ohio, Northeast states, and Washington State). To establish an effective instrumentation program, it is important to a) characterize fully the foundation soils from adequate subsurface investigation program; b) describe the different construction stages of the bridge and footings, and obtain the loads applied on the bridge footings at these stages; and c) compile and analyze the collected performance data from the instrumentation program (e.g., settlement) at various stages during construction, and after construction at various times.

Additionally, State DOTs would benefit from reviewing the documented performance of instrumented bridges with spread footings, as described in Chapter 3.

CHAPTER 6

SUBSURFACE INVESTIGATION AND CONSTRUCTION PROGRAMS

This chapter assists State DOTs deployment of adequate subsurface investigation, construction, and quality control procedures (implementation of recommendation 5). This will help to minimize risks during construction and improve the performance of spread footing.

The FHWA national survey results indicate that some State DOTs have concerns with construction and bridge performance concerns due to inadequate subsurface investigation and construction procedures. These concerns are perceived by some State DOTs to be more critical for spread footings than for deep foundations. However, these concerns should be less with spread footings since they provide the opportunity to visually inspect the bearing area and foundation directly during construction and improve them, if needed.

6.1 ADEQUATE SUBSURFACE INVESTIGATION PROGRAM

The goal of the subsurface investigation is to provide reliable soil, rock, and groundwater information needed in the design and construction of bridge foundations. Groundwater information includes the highest anticipated groundwater table at all applicable LRFD design limit states and during construction. When the quantity and quality of data collected during the subsurface investigation program increase, the reliability of the design increases, and this may lead to a more accurate and economical design and fewer problems during construction.

Several resources are available to support State DOTs as they develop adequate subsurface exploration programs, including the subsurface exploration program described Article 10.4, “Soil and Rock Properties,” of AASHTO LRFD (2012) and FHWA manuals (2001, 2002b, 2006a). The level of subsurface exploration in AASHTO LRFD Table 10.4.2-1 for the location, number, and depth of borings should be considered a minimum and can be increased based on variability in subsurface conditions, importance of the structure (interstate highways), past experience, and design and construction requirements. The FHWA manual on LRFD implementation (2010a) described a rational procedure for evaluation and addressing project site variability. CPT and geophysical tests could be considered to increase testing coverage of subsurface soils, as successfully implemented by many State DOTs (e.g., Louisiana and Minnesota).

For major structures, the FHWA manual on drilled shafts (2010c) recommend dividing the field exploration program into two phases: a preliminary phase (based on a few borings and geophysical tests) that provides sufficient information for planning and optimizing the subsequent more comprehensive investigation phase. A staged investigation program provides sufficient information for preliminary design (including preliminary selection of foundation

types) and defers much of the cost of the site investigation until the structure's exact location and layout are finalized.

The depth of significant influence (DOSI) below the base of the footing, where applied stresses are significant in the soil, varies from $2B$ for $L/B = 1$ to $4B$ for $L/B = 10$, where L and B are length and width, respectively, of the spread footing (FHWA, 2010b). The stiffness and strength properties of the subsurface soil within the DOSI zone affect the performance (e.g., settlement) of a spread footing. Therefore, it is important to increase the quality and quantity of subsurface data collected in this zone in the subsurface investigation, for example, by considering CPT soundings to supplement the SPT borings.

The subsurface exploration program should identify unsuitable foundation soils and problematic conditions. The types of unsuitable soils for spread footings are discussed in many FHWA publications (FHWA, 2001, 2010b) and include alluvial soils (fans), fluvial soils (flood plains), colluvial soils, swelling soils, collapsing soils (e.g., loess), liquefiable soils, soils in areas of potential karst activity and void formation (sinkholes), loose sand and silt, soft clays, highly plastic and organic soils (where creep settlement is a concern), nondurable or frozen fill materials, and soils at disposal sites. It is possible to improve unsuitable soils to become competent to support spread footings. Chapter 6 of the FHWA manual on shallow foundations (2001) discusses how to identify collapsible or swelling soils, karstic ground, and liquefiable soils, and how to consider them in the design and construction of spread footings with ground improvements.

Effective DOT Practices. Ohio DOT successfully used CPT to improve settlement predictions of spread footings on cohesionless soils (Sargand et al., 2003). In Minnesota, the soundings of seismic cone penetration testing (SCPT) and laboratory soil tests allowed for the use of spread footings to support seven bridges in design-build highway projects (Bentler and Hoppe, 2010). Researchers concluded that the SCPT allowed for economical, detailed, and accurate assessment of stratigraphy, depth, and settlement of the glacial till soils at bridge sites. Minnesota DOT attributed its increased use of spread footings to the deployment of more accurate tests, like CPT and flat plate dilatometer test (DMT).

6.2 ADEQUATE CONSTRUCTION AND QUALITY CONTROL PROCEDURES

Deployment of appropriate construction techniques and methods for construction quality control are critical to ensure that the foundations and their surrounding soils, especially the soil within the foundation DOSI, meet the design requirements; minimize construction problems and ensure successful completion of the project; and ensure adequate in-service performance of the spread

footings. Construction reliability impacts design reliability, and better construction procedures and quality control would lead to more accurate and economical LRFD design procedures.

FHWA manuals (2001, 2002a, 2006a) discuss construction inspection and monitoring of spread footings, and list construction inspector's responsibilities during footings construction. Chapters 9 and 10 of Geotechnical Engineering Circular 6 (FHWA, 2002a) describe the construction techniques for spread footings. Chapter 8 of the FHWA manual on shallow foundations (2001) discusses several construction techniques for spread footings such as excavation and subgrade preparation, cofferdams, backfilling, and groundwater control. Seepage analysis is needed in the design of foundations that will extend below the groundwater table and would require dewatering during construction. FHWA (2001, 2006b) describes the construction, quality control, and quality assurance of various ground improvements. AASHTO LRFD (2012) and FHWA manuals (2001, 2006a) emphasize the importance of proper selection criteria for fill materials and the application of adequate and uniform compaction to prevent uneven settlement of fill materials. Appendix A of Geotechnical Engineering Circular 6 (FHWA, 2002a) lists the materials and construction specifications for structural fill materials recommended by FHWA and a few other states (e.g., Michigan, Nevada, and Washington State). Proper foundation site drainage measures need to be implemented with compacted fill to prevent softening of subsoil due to improper drainage (FHWA, 2010b).

The construction specifications for foundations need to be consistent with the design specifications for bridge foundations. The design specifications should briefly describe the foundation construction specifications needed in the design (e.g., the degree of fill compaction).

Design and construction specifications should also address the potential for problems during construction and the corrective measures needed to resolve those problems. For example, differing site conditions (DSC) from those assumed in the design (see Section 1.3) is a common source of contractor claims on highway construction projects. Federal law requires that a DSC clause be incorporated into all Federal-Aid Highway projects. Geotechnical Engineering Notebook Issuance GT-15 (FHWA, 1996) was prepared to provide guidance on geotechnical DSC.

Effective DOT Practices. To support the use and ensure adequate performance of the deep-mixing technique with bridge spread footings, Minnesota DOT employed an extensive quality control program that incorporated pressuremeter test, CPT, and GeoGauge soil stiffness test. This or similar program could be used for spread footings even when ground improvement is not considered.

CHAPTER 7

SETTLEMENT ANALYSIS FOR BRIDGES SUPPORTED ON SPREAD FOOTINGS BEARING ON SOILS

This chapter presents a rational procedure for settlement analysis of bridges supported on spread footings bearing on soils (implementation of recommendation 6). The materials in this chapter will help State DOTs to develop and use more accurate and economical LRFD design specifications to address the service limit state for settlement of bridges supported on spread footings bearing on soils.

7.1 TYPES OF SETTLEMENTS AND BRIDGE PERFORMANCE PROBLEMS

For the purpose of this report, there are three types of settlement:

- Bridge foundation settlement, S_F .
- Bridge settlement at foundation locations, S_B , ($S_B \leq S_F$).
- Bridge settlement at foundation locations that impacts bridge performance, S_{BP} , ($S_{BP} \leq S_B$).

Bridge foundation settlement, S_F , is generated from loads transferred to the foundation soil:

- During construction of the bridge substructure, which may include placement of spread footings, columns for piers, abutment and wing walls, and earth fill behind the abutment.
- During construction of the bridge superstructure, such as girders and decks.
- After construction, due to traffic loads. Also in this stage, time-dependent foundation settlements may also develop from creep.

Bridge settlement (S_B) is equal to the settlements of bridge foundation (S_F) that is generated during and after placement of a bridge superstructure. The bridge settlements at various foundation locations during these stages lead to (Figure 7.1):

- **Bridge uniform settlements** due to uniform foundation settlements.
- **Bridge differential settlement** when the foundations do not settle uniformly. This differential settlement can be longitudinal, when developed between footings of adjacent bents (piers and abutments, Figure 7.1), or transverse, when developed between footings of adjacent columns within the same bent, or can be caused by the rotation of a single large footing.
- **Bridge angular distortion (or rotation)** defined as the differential settlement between any two points (often at the foundation locations) divided by the distance between these two points (span length), as demonstrated in Figure 7.1.

- **Differential settlement between the bridge and its associated structures** (e.g., the approach roadway, utilities on the bridge, wing walls, and drainage grades).

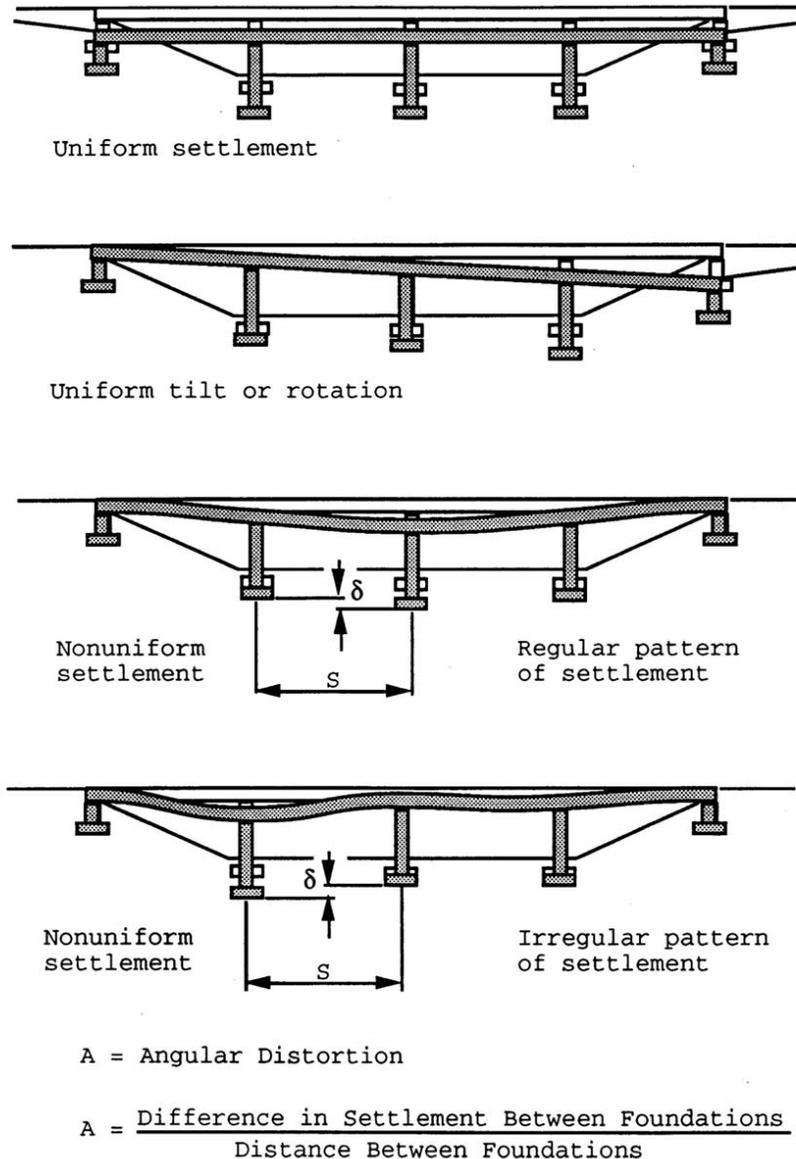


Figure 7.1. Types of Bridge Settlements (FHWA, 2006a; Duncan and Tan, 1991)

Excessive bridge settlements can lead to the following problems that may impact bridge performance

- Structural distress and cracking of components of the bridge superstructure. Excessive angular distortion may lead to increased internal structural shear and moment stresses,

and deformations in the bridge superstructure that are generally manifested by cracks in the bridge deck and/or girders or damage to the bearings at the support locations.

- Other bridge problems, including reduction of the bridge clearance; rideability problems within the bridge and between the bridge and approach roadway; and drainage, safety, and aesthetic problems.
- Damage to the structures associated with the bridge.

The project's structural, geotechnical, and construction engineers should work closely to address the bridge performance problems developed due to foundation settlement. For example, the bridge and foundation design elevations can be slightly raised to compensate for the anticipated foundation post-construction settlement. Note that the bridge bump problem is generated mainly from the approach embankment settlement (not the bridge foundation settlement), and the use of spread footings will help to alleviate this problem. Measures, like approach slab, should be considered to alleviate the bridge bump problem. The potential distress and cracking of the bridge superstructure due to bridge differential settlement and angular distortion often control the selection of bridge tolerable settlement. Bridge differential settlements often develop because of site variability, nonuniform applied stresses on foundations, and construction sequence. Bridge differential settlement can be minimized during:

- Design, by sizing the foundations for uniform bridge settlements at all foundation locations (S_B).
- Construction, by changing the construction sequence and adopting construction measures that could reduce bridge differential settlements and increase bridge tolerance to differential settlements.

The final type of settlement, bridge settlement that impacts bridge performance (S_{BP}), can be less than S_B because some of the bridge settlement that occurs during the placement of the bridge superstructure could be accommodated by the structure or corrected during construction with little or no consequence to the integrity of the bridge or structures associated with the bridge.

7.2 THE SERVICE LIMIT STATE FOR SETTLEMENT OF BRIDGES

In AASHTO LRFD (2012), load and resistance factors for the settlement analysis at the service limit state are assumed to equal 1 because reliability based load and resistance factors are not yet developed. Additional research is needed to develop reliability-based settlement analysis for bridges. Until that time, the settlement analysis should remain on the conservative side by adopting the following assumptions (see also FHWA, 2006a, 2010b):

- The computed bridge differential settlement between two footings equals the larger of the computed bridge settlement at both footings, as shown in Figure 7.2. This is equivalent to assuming zero settlement for the footing with the smaller settlement value.
- The bridge tolerable settlement, S_{BT} , equals the bridge tolerable differential settlement. Hence, S_{BT} at any foundation location can be estimated from the bridge tolerable angular distortion or bridge tolerable differential settlement.

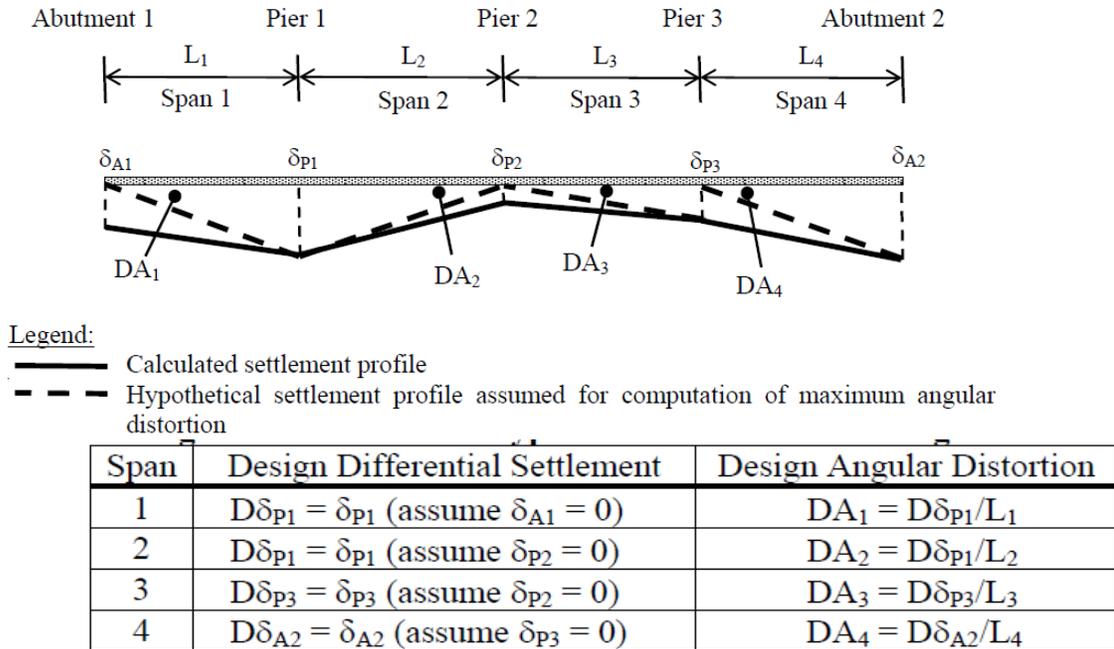


Figure 7.2. Conservative Assumptions for Computations of Bridge Differential Settlements and Angular Distortions (FHWA, 2010b)

By accepting these assumptions, the governing equation for the service limit state for settlement of a bridge can be simplified to:

$$S_{BP} \leq S_{BT} \quad (7.1)$$

where S_{BP} is the computed bridge settlement that impact bridge performance, and S_{BT} is the bridge tolerable settlement at the foundation location. With the above assumptions, this equation will ensure that the computed bridge differential settlement or angular distortion is smaller than the bridge tolerable differential settlement or angular distortion. Note that the purpose of the service limit state (Eq. 7.1) is to ensure adequate performance of the bridge and not the bridge foundation.

The remainder of this chapter will discuss the estimation of S_{BP} , S_F , S_B , and S_{BT} .

7.3 BRIDGE TOLERABLE SETTLEMENT AT FOUNDATION LOCATIONS (S_{BT})

The bridge tolerable settlement, S_{BT} , is defined as the bridge settlement that will not cause any performance and function problems to the bridge and its associated structures during their design service lives (see Table 7.1). These problems include:

- **Structural damage of the bridge superstructure components.** The concerns with bridge structural distress and cracking due to excessive angular distortion in both the longitudinal and transverse directions often govern the selection of S_{BT} , especially for continuous span bridges. To control this problem, develop the bridge tolerable angular distortion and use it with span length to develop the bridge tolerable differential settlement and S_{BT} . The tolerable differential settlement of a bridge between its adjacent columns within a single bent may be significantly smaller than between its adjacent piers. Bridge structural tolerance to differential settlement is a function of bridge stiffness; bridge type (simple or continuous); bridge materials (steel or concrete); length of bridge span; type of connections between the superstructure and support abutment or piers (pinned or fixed); type and tolerance of bearings; type and location of expansion and construction joints; and construction procedure, tolerance, and stages. The effect of these factors can be examined in the design through a structural analysis of the entire bridge structure when subjected to various settlements and angular distortions. For example, in the FHWA study of tolerable movement criteria for highway bridges (1985), researchers investigated the effect of bridge differential settlements on the development of stresses in continuous bridges. This effect was found to be a primary function of the bridge span length and stiffness. The following results are applicable to the conditions and assumptions used in that study. For continuous steel bridges, researchers determined that differential settlements of 1 inch or more would be intolerable for a span length less than 50 ft. With differential settlements of 3 inches, the increases in stresses were modest for span lengths between 100 and 200 ft, and negligible for span lengths in excess of 200 ft. Continuous concrete bridges with a span length less than 100 ft are very sensitive to differential foundation settlements, while those with span lengths of 200 ft or more can tolerate differential settlements as large as 3 inches with only a relatively small change in stresses. Paikowsky (2005) suggested preliminary tolerable settlement criteria based on type of materials (concrete or steel), construction stage (before or after bridge completion), and type of bent (abutment or pier).
- **Poor and unsafe riding quality within the bridge (function of the bridge).** In simple span bridges, no significant structural internal stresses will develop (FHWA, 1985), and rideability or aesthetics could be the primary concern (FHWA, 2010b). Develop S_{BT} based on the tolerable changes in slopes of the bridge riding surface induced by bridge differential settlements (consult with the project traffic engineer).

- **Bridge clearance problem.** Develop S_{BT} based on the bridge tolerance to this problem.
- **Drainage problems.** Develop the permissible S_{BT} to avoid drainage problems in and around the bridge (consult with the project hydraulic engineer).
- **Damage to structures associated with the bridge (e.g., wing walls, utilities, drainage structures).** Develop S_{BT} based on the tolerance of these structures to bridge settlement. As indicated by the FHWA (2006a), a re-sequencing of the construction of these structures may address their potential performance problems.

The performance problem with the smallest tolerable settlement at any span will control the selection of S_{BT} for that span. If one S_{BT} would be developed for the entire bridge, consider the smallest S_{BT} of all bridge spans. The above performance and function problems vary from project to project, depending on the type and details of the bridge and its associated structures. **Therefore, it is recommended that the project engineers develop in the final design a project specific bridge tolerable settlement that prevents the above performance problems.** In this development also consider the bridge design life, the importance of the bridge (e.g., traffic volume), aesthetics, and past successful experiences.

In the preliminary design, it is recommended to consider the following information (summarized in Table 7.1) just as a reference for an acceptable range of bridge tolerable settlements:

1. **Documented settlement measurements of bridges that performed well during their service life.** It is fair to assume that the bridges tolerate these settlements since no bridge performance problems are developed due to these settlements. Based on the measured movements of 28 bridges constructed with spread footings on compacted fill, FHWA (1982) concluded that bridges can tolerate differential settlements of 1 to 3 inches without significant distress. Based on measured settlements of 21 bridges on cohesionless soils, FHWA (1987) reported good performance of these bridges with settlement up to 1 inch. FHWA (2010b) presented the measured settlements of 78 bridges performing well during service, where 69 bridges had less than or equal to 1 inch settlement, eight bridges had settlement of 1 and 2 inches, and one bridge had settlement of 2.26 inch. Below is a definition of intolerable movement given in the 1985 FHWA report:

Movement is not tolerable if damage requires costly repair and/or repair and more expensive construction to avoid this would have been preferable.

According to FHWA (2006), this definition is somewhat subjective. The 1985 FHWA study analyzed the footing movement data (not the bridge movement data) of 280 bridges and determined the angular distortions for 56 simple span bridges and 119 continuous span bridges. They found that a longitudinal angular distortion of 0.004 is acceptable for

94% of the analyzed continuous span bridges (79 bridges), and 0.005 is acceptable for 97% of the analyzed simple span bridges (36 bridges). These tolerable angular distortions, which are referenced in AASHTO LRFD (2012), suggest that for a 100-ft span, a differential settlement of 4.8 inches would be acceptable for a continuous span and 6 inches would be acceptable for a simple span. Such relatively large values of tolerable differential settlements are often reduced due to concerns with these large values and to address other performance and function problems with the bridge and its associated structures (FHWA, 2006a).

2. Practices of State DOTs that successfully constructed bridges with spread footings.

Table 7.1 suggests that most State DOTs employed a tolerable settlement of 1 inch. A number of State DOTs that frequently use spread footings (Maine and Massachusetts) reported tolerable settlements as high as 2 inches. According to FHWA (2002a), bridges are often designed for tolerable differential settlements of less than 1 inch for continuous span bridges and 1.5 to 2 inches for simple span bridges.

It is important to note that the above information was developed for certain practices and conditions (e.g., certain structure types and details, type of bearings and connections, span lengths) that may not be appropriate for all bridges. Also, it is unfortunate that in many cases, settlement or differential settlements are reported with no information about span lengths that are needed to establish the angular distortion. Finally, in many cases, it is not clear if the reported settlements are for the bridges or for footings. Therefore, it is important to finalize the bridge tolerable settlements based on the project-specific conditions as discussed earlier. These tolerable settlements could be smaller or higher than those given in the information developed based on documented bridge settlement measurements and practices of State DOTs.

Table 7.1. Development of Bridge Tolerable Settlements (S_{BT})

<p>I. <u>Final Design.</u> Develop a project specific bridge tolerable settlement to prevent the following problems:</p> <ul style="list-style-type: none"> • Structural damage to all components of the bridge structure due excessive angular distortion (develop bridge tolerable angular distortion). • Bridge clearance • Poor and unsafe riding quality within the bridge • Drainage problems. • Damage to structures associated with the bridge (e.g., wing walls). <p>Also, consider the bridge importance, design life, aesthetics, and past successful experiences.</p>		
<p>II. <u>Preliminary Design.</u> Consider Documented Performance and Published Criteria:</p>		
<p>1. Settlement measurements of bridges that performed well during service</p>		
Reference	Reported Measurements	Conditions
FHWA (1985)	Tolerable angular distortions: <ul style="list-style-type: none"> • Simple span bridges: 0.005 • Continuous span bridges: 0.004 	See conditions in Section 7.3 of this report developed based on FHWA reports (1985, 2006).
FHWA (1982)	<ul style="list-style-type: none"> • Settlement: 1-3 in 	Based on 28 bridges with spread footings on compacted soils.
FHWA (1987)	<ul style="list-style-type: none"> • Settlement: ≤ 1 in 	Based on 21 bridges with spread footings on granular soils.
FHWA (2010b)	<ul style="list-style-type: none"> • Settlement: ≤ 1 in. in 69 bridges • Settlement: 1-2 in. in 8 bridges • Settlement: 2.26 in. in 1 bridge 	Based on 78 bridges.
Minnesota, Colorado bridges	<ul style="list-style-type: none"> • Settlement: ≤ 1 in 	See Chapter 3.
<p>2. Practices of State DOTs that successfully constructed bridges with spread footings:</p> <ul style="list-style-type: none"> • Settlement of 1 inch: Most states. • Settlement greater than 1 inch: Maine and Massachusetts (2 in.), Utah (1.5 in.). • Differential settlement (FHWA, 2002a): <ul style="list-style-type: none"> ○ ≤ 1 in. for continuous bridges. ○ ≤ 1.5-2 in. for simple span bridge. 		

7.4 ESTIMATION OF THE BRIDGE SPREAD FOOTING SETTLEMENT (S_F)

Total foundation settlement is the summation of elastic or immediate settlement, which occurs quickly within a short period of time (important to consider in granular soils), and time-dependent consolidation settlement, which occurs during and after construction (important to consider in cohesive soils). Spread footings for bridges are normally not advised for organic and

highly plastic soils that generate significant creep settlement. According to AASHTO LRFD (2012), transient live loads may be omitted in the time-dependent consolidation settlement of foundations bearing on cohesive soils but needs to be considered for granular soil. The FHWA manual on soils and foundations (FHWA, 2006a) discusses the estimation of consolidation settlements of cohesive soils and settlement of footings on structural fills.

Although AASHTO LRFD (2012) suggests using the elastic theory or the empirical Hough method to estimate the settlement of footings on cohesionless soils (in-situ soil or engineered fill), these methods generally generate conservative settlement estimates. FHWA (1987) compared various settlement prediction methods and concluded that the Hough method is the least accurate and most conservative method. Sargand et al. (2003) employed the measured settlement of spread footings at various bridges in Ohio to evaluate various settlement prediction methods using SPT and CPT data and found that:

- The modified Schmertmann method (Schmertmann et al., 1978) is more reliable than other methods for normally consolidated (loose) sands. The preloading effect (due to compaction) was incorporated by using higher soil stiffness.
- Using CPT data (continuous subsurface data) in the settlement prediction methods provides more accurate results than SPT data (series of isolated data).

Based on these findings, the modified Schmertmann method is recommended for estimating immediate settlement of spread footing on cohesionless soils. This method is described and demonstrated with examples in FHWA (2006a, 2001) using SPT data. It can more accurately be applied using CPT data. According to FHWA (2001), the use of SPT data with this method often overestimates settlement (conservative).

Effective DOT Practices. Minnesota DOT attributed its increased use of spread footings on soils to the deployment of more reliable field-testing procedures (e.g., CPT and DMT) and computer programs (e.g., SIGMA, FLAC) to predict settlement.

7.5 ESTIMATION OF THE BRIDGE SETTLEMENT THAT IMPACTS BRIDGE PERFORMANCE (S_{BP})

S_{BP} should be considered to address the service limit state for settlement of bridges and not the footing settlement (S_F) as considered by some engineers. As will be discussed next, S_{BP} is smaller than S_F and can be smaller or equal to the bridge settlement, S_B .

According to FHWA (1987), the average settlement of 21 bridges supported by spread footings on cohesionless soils was 1 inch, with 0.75 inch occurring before placement of the bridge decks and only 0.25 inch occurring after construction of the bridge deck. Bridge foundation settlement,

S_F , that occurs before placement of the bridge superstructure should not be considered when computing bridge settlements S_B and S_{BP} . To explain this point, FHWA (2010b) provides an LRFD design example for a 15-ft-wide bridge spread footing with a tolerable settlement of 0.9 inch, and where the computed foundation settlement, S_F , is 0.87 inch and the computed bridge settlement, S_B , is 0.36 inch (41% of S_F). Since 0.36 inch is much less than 0.87 inch, a foundation width smaller than 15 ft can be considered to meet the service limit state for settlement. In this case, most likely, the strength limit state would control the design footing width.

Several references (e.g., FHWA, 2001, 2006a) reported that some of the bridge settlements that occur during placement of the bridge superstructure, S_B , can be accommodated by the structure or corrected during construction with little or no consequence to the integrity of the bridge, depending on bridge type, construction method, and construction sequence. For example, it may be possible to correct for settlement of the spread footings due to the placement of girders in the final constructed grades. Then, this settlement would not impact performance of the bridge and should not be included in the computation of S_{BP} . FHWA (2010b) reported that settlements that are relevant to the bridge structure performance are often 25% to 50% of the footing settlement. In a related study (FHWA, 1987), FHWA reported that foundation settlements that occurred prior to bridge deck construction may not adversely affect the bridge, and for continuous span bridges, only post-deck settlement can cause bending moments and stresses in the structural frame. The settlement that may affect the bridge structure is the settlement that occurs after the girders are set and integrated as a structure. Based on the above, portions of the foundation settlements, S_F , that occur during placement of the bridge superstructure may not impact bridge performance (structural distress) or the performance of structures associated with the bridge. This portion of settlement should not be considered when estimating bridge settlement that impacts bridge performance, S_{BP} .

In summary, certain loads (not all the loads applied on the footings) and stages should be considered when estimating the bridge settlement that impacts performance, S_{BP} . It is recommended that the project geotechnical engineer computes the bridge foundation settlement, S_F , at various stages during and after construction. The project structural engineer need to discuss and agree with the project geotechnical and construction engineers on the stages that would impact bridge performance, and to use the settlements at these stages to compute the bridge settlement that impacts bridge performance, S_{BP} .

7.6 SUMMARY AND CONCLUSIONS

It is widely accepted that the service limit state for settlement would generally control the design for spread footings of highway bridges because:

- Tight bridge tolerable settlement is often required in the design (e.g., ≤ 0.5 inch). However, information presented in Section 7.4 demonstrates that bridges can tolerate larger settlements.
- Many State DOTs use the large foundation settlement, S_F , to address the service limit state. Large footings (>10 ft wide), often considered with bridges, generate deeper DOSI and larger footing settlements. However, the settlement that impacts bridge performance, S_{BP} , needs to be considered to address the service limit state, not the foundation settlements, S_F . This S_{BP} could be much smaller than S_F .

The presented rational procedure for settlement analysis demonstrates that the computed bridge settlement and bridge tolerable settlement, needed to address the service limit state for bridges, are smaller and larger, respectively, than commonly considered in practice. This rational procedure will help State DOTs develop more accurate and economical LRFD design specifications to address the service limit state for settlement of bridges supported on spread footings bearing on soils. It also may lead to a design (footing width) that is controlled by the strength limit or extreme event limit states, and not the service limit state for bridge settlement.

The settlement analysis presented in this chapter and the performance results of the national surveys presented in Chapter 3 demonstrate that spread footings bearing on soil can perform very well with respect to settlement. Therefore, concerns of bridge settlement should not limit State DOTs from considering spread footings on soils to support highway bridges.

CHAPTER 8

DESIGN BEARING RESISTANCES FOR SPREAD FOOTINGS ON SOILS

This chapter discusses development of appropriate design bearing resistances for spread footings bearing on competent and improved natural soils as well as on engineered granular and MSE fills (implementation of recommendation 7). This will help State DOTs to develop and use accurate and economical LRFD design specifications for spread footings.

8.1 REPORTED ALLOWABLE BEARING RESISTANCES

Bearing resistance at the service limit state (LRFD) is equal to the bearing pressure that will generate bridge settlement, S_{BP} , equal to the bridge tolerable settlement, S_{BT} . This bearing resistance is called allowable bearing resistance in the ASD platform.

Tables 8.1 and 8.2 list results from the FHWA national surveys for the allowable bearing resistances considered by State DOTs for the design of spread footings on natural soils and compacted fill materials. These bearing resistances can be conservative. AASHTO LRFD (2012) provides presumptive bearing resistances for spread footings on various types of soils at the service limit state. FHWA (2001, 2006a) recommends that presumptive bearing resistances are used only to estimate foundation dimensions in the preliminary evaluation of spread footings, not for final foundation design.

Table 8.1. Reported Allowable Bearing Resistances for Spread Footings

Natural Soils
<ul style="list-style-type: none"> • Table C10.6.2.6.1-1 in AASHTO LRFD (2012): Presumptive allowable bearing resistances. • Approximately 4 ksf: Most commonly used by State DOTs. • Up to 10 ksf: California, Idaho, Nevada, New Hampshire, Utah, Wyoming DOTs. • Varies depending on subsurface conditions: Many states, including Connecticut, Massachusetts, New Hampshire, New York, and Vermont.
Engineered Granular Fill
<ul style="list-style-type: none"> • FHWA (2001): 4 to 6 ksf. • Varies; many states. • Approximately 4 ksf: Most commonly used by State DOTs. • 2 ksf: Illinois DOT. • Up to 6 ksf: Maine, Virginia DOTs. • Up to 9 ksf: New Mexico, Wyoming DOTs. • Michigan, Nevada, Washington State DOTs (See Table 8.2).

Table 8.2. Reported Allowable Bearing Resistances for Engineered Granular Fills (FHWA, 2002a).

Agency	Allowable Bearing Capacity	Associated Anticipated Settlement	Fill Material Specified^{*,**}
Washington State DOT	290 kPa (3 tsf)	<40 mm (1.5 in.)	Gravel Borrow
Nevada DOT	190 kPa (2 tsf)	<32 mm (1.25 in.)	Type 1A Aggregate Base
Michigan DOT	170 kPa (1.75 tsf)	Not available	Granular Material Class III

*Specifications included in Appendix A of the FHWA report (2002a)

**Specifications must state levels of control quality for fill material (e.g., gradation, durability), lift thickness, and compactive effort.

8.2 DEVELOPMENT OF APPROPRIATE BEARING RESISTANCES

The estimated bearing resistances for spread footings at the service and strength limit states are a function of the strength and stiffness properties of the foundation soil; the footing size and depth; the bridge (not footing) tolerable settlement; the accuracy of the resistance and settlement determination methods; and other parameters for MSE walls and embankments, such as distances from the center and edge of the spread footings to the edge of the embankment or wall. FHWA reports (2010b, 2005, 2006a) discuss the development of bearing resistances at service and strength limit states based on this information.

The strength and stiffness properties of the natural foundation soils can be obtained from the subsurface investigation program. These properties need to be verified in the field during construction.

8.2.1 Bearing Resistances for Engineered Granular Fills and Improved Natural Soils

With these soils, certain strength and stiffness properties are often assumed in the design and later are verified during construction. The common practice is to assign certain material and construction requirements for the engineered fill and improved natural soils during design, and then require the contractor to meet these requirements during construction. Information about estimating the design bearing resistances for improved natural soils is available in the FHWA manuals on shallow foundations (2001) and ground improvement methods (2006b).

The strength and stiffness properties of the engineered fill materials can be measured either before construction using the direct shear or triaxial tests of compacted fill samples, or during

construction through in-situ tests (e.g., SPT, CPT) of the placed compacted fill. These measured stiffness and strength properties can be used to develop design bearing resistances at the strength and service limit states using the methods considered for natural soils. These properties are mainly a function of the characteristics of fill material (e.g., gradation and quality) and the degree of the compaction or density achieved in the field, which are specified in the fill material and construction specifications. For an engineered fill, it is recommended to develop a correlation between the fill material and construction specifications and its design strength and stiffness properties. Based on this correlation, appropriate design strength and stiffness properties should be developed. Table 2.1 lists most of the FHWA materials and construction specifications for engineered granular fill (FHWA, 2002a; 2009). If an engineered fill meets these FHWA specifications, a design friction angle of 34 degrees can be assumed in most cases. FHWA (2006a) also suggested using an SPT-N value (N_{160}) of 23 for estimating settlement with the Schmertmann's modified method (1978).

Effective DOT Practices. Michigan, Nevada, and Washington State DOTs developed allowable bearing resistance values (see Table 8.2) for compacted fill materials meeting their material and construction specifications, which are presented in Appendix A of the Geotechnical Engineering Circular on shallow foundations (FHWA, 2002a).

8.2.2 Bearing Resistances for MSE Abutment Fills

For MSE abutments, FHWA (2009) recommends:

- Up to a factored bearing resistance of 7 ksf at the strength limit state.
- Up to a factored bearing resistance of 4 ksf at the service limit state that would limit the postconstruction settlement within the reinforced fill to less than 0.5 inch. To determine the footing settlement, add the settlement of the reinforced fill to the foundation soil settlement.

These recommendations were developed based on successful experience with constructing bridge spread footings on top of MSE walls. Consideration of these factored resistances requires that all AASHTO (2012) and FHWA (2009) design and construction requirements for the MSE abutments are addressed and met, including:

- Design checks for spread footings and MSE walls at all applicable limit states (service, strength, and extreme events).
- Layout conditions of spread footings on top of MSE walls, such as minimum distance from the wall face to the edge of the footing.
- Material and construction requirements for granular fill and reinforcements.

CHAPTER 9

LRFD GUIDANCE FOR SELECTION AND DESIGN OF SPREAD FOOTINGS ON SOILS

Based on the recommendations discussed in previous chapters, this chapter implements recommendation 8 by providing a technical resource to help State DOTs develop LRFD guidance for spread footings that includes:

- LRFD specifications and a process for selecting the most appropriate foundation type, with a focus on selecting spread footings, when appropriate.
- LRFD specifications and a process for accurate and economical design of spread footings.

The materials in this chapter will help State DOTs with implementation of the new AASHTO LRFD bridge design specifications for spread footings. It will also help both the geotechnical and structural engineers understand their respective roles in the selection and design of spread footings.

9.1 A ROADMAP FOR DEVELOPING LRFD GUIDANCE FOR BRIDGE FOUNDATIONS

To develop LRFD design manuals for bridges, the FHWA manual on LRFD implementation (2010a) recommends that State DOTs follow the sequence presented in AASHTO LRFD (2012). State DOTs should develop sections to cover the LRFD design specification on loads and on hydraulic and structural designs based on information in Sections 1 to 8. These sections will be referred to in the development of LRFD guidance for bridge foundations that will focus on the geotechnical design.

The FHWA manual on LRFD implementation (2010a) provides recommendations for developing LRFD design guidance for bridge foundations based on Section 10 of AASHTO LRFD, the FHWA technical references, and local experiences and practices. Initially, the following principal changes in the AASHTO design specifications from the ASD to LRFD are discussed:

- Incorporation of limit state designs.
- Use of load and resistance factors to account for uncertainties in the estimated loads and resistances.
- AASHTO LRFD presents new and improved methods to determine foundation loads, displacements, and resistances.

Next, three options for LRFD implementation are suggested: adopting AASHTO's LRFD methods, developing local LRFD design methods by fitting them to ASD practices, or conducting a reliability analysis of data collected at load test sites. The implementation and comparison of these three options and selection of the most appropriate option are thoroughly discussed. A procedure for evaluating and addressing project site variability is also provided. Finally, recommendations for developing LRFD design guidance for bridge foundations are presented. These recommendations include materials needed for developing the guidance, the roles and responsibilities of various engineers (structural, geotechnical, hydraulic, and construction) in developing the guidance, and the contents that should be included.

There are two stages in developing LRFD guidance for bridge foundations:

- **Stage 1: Describe the common design issues among all foundation types.** Briefly describe the LRFD design platform for bridge foundations and the principal changes between AASHTO ASD and LRFD design platforms for bridge foundations (discussed earlier). Also, discuss the subsurface geotechnical investigation program (AASHTO Article 10.4, see Chapter 5 of this report) and the bridge tolerable settlements (AASHTO Article 10.5, see Chapter 6 of this report). Finally, develop LRFD guidance for selecting the most appropriate foundation type that consists of design specifications and a design process (*see Section 9.2 of this report*).
- **Stage 2: For each foundation type, describe the design specifications at all LRFD limit states and a design process to address these limit states** (*For spread footings, see Section 9.3 of this report*).

Design Processes. The design process presents a) tasks or steps needed in design, and b) roles and responsibilities of various members of the project team in performing these design tasks. It serves as a guide to all project engineers (structural, geotechnical, hydraulic, and construction) for selecting the most appropriate foundation type and for the LRFD design of the selected bridge foundation type. The project structural engineer is typically the engineer of record, who will finalize the foundation selection and design. The design process should ensure continuous, close, and effective interaction and communication among various members of the project team. LRFD implementation also requires strong interaction between all project engineers, especially the structural and geotechnical engineers, to address all applicable foundation structural and geotechnical limit states. A foundation design should not be considered complete until the foundation construction has been successfully completed. In the construction phase, the project structural and geotechnical engineers should work with the project construction engineer to ensure that all construction design requirements are met (e.g., quality control).

9.2 DEVELOPMENT OF LRFD GUIDANCE FOR SELECTION OF THE MOST APPROPRIATE FOUNDATION TYPE

AASHTO and FHWA technical resources do not endorse practices that rely on a standard or favorite foundation type. These resources promote evaluating and considering all foundation types for bridges, including spread footings, and selecting the most appropriate foundation. State DOTs need to develop a guidance for selection of candidate foundation types in the preliminary design and select the most appropriate (e.g., economical) foundation type in the final design phase. For all foundation types, this guidance needs to describe their applications, advantages and disadvantages, favorable and unfavorable conditions for consideration in the selection process, and the criteria for selecting the most appropriate foundation type (often costs). Such materials are described in the FHWA technical references on foundations (e.g., FHWA, 2010c).

The focus next is on the selection of spread footings as a candidate and most appropriate foundation type.

9.2.1 Design Specifications for Selection of Candidate and Most Appropriate Foundation Types

These design specifications need to cover for spread footings the applications, advantages (see Section 1.1) and disadvantages, and favorable and unfavorable conditions for consideration in the preliminary design. Most important, these specifications need to allow for fair selection of spread footings bearing on competent and improved natural soils, on granular and MSE fills to support highway bridges, and for using spread footings with semi-integral and integral abutments. This can be achieved by implementing the recommendations described in the previous chapters:

- Deploy the AASHTO and FHWA technical references (Chapter 2), which allow for the use of spread footings on all types of foundation soils (competent and improved soils, and engineered granular and MSE fills) to support bridges and describe the state-of-the-practice procedures for their selection.
- Deploy State DOTs practices for selecting spread footings that include:
 - Favorable and unfavorable conditions for considering spread footings (Sections 3.2.2 and 3.2.3 of this report).
 - Successful practices for using spread footings bearing on competent and improved natural soils, on granular and MSE fills (Sections 3.1, 3.2.1, and 4.1), and with semi-integral and integral abutments (Section 4.2).
- Deploy more economical design and construction procedures for spread footings (Chapters 5 through 8):

- Consider load tests on spread footings and an instrumentation program of bridges supported on spread footings (Chapter 5).
- Conduct appropriate subsurface geotechnical and construction quality programs (Chapter 6).
- Deploy a rational procedure for settlement analysis for bridges supported by spread footings bearing on soils (Chapter 7).
- Deploy a rational procedure to determine the LRFD bearing resistances for spread footings bearing on various types of foundation soils (Chapter 8).
- Consider using spread footings in selected pilot projects as well as in design-build and value engineering projects.

Additionally, consider the following selection factors to develop design specifications for selecting the candidate and most appropriate foundation types:

- **Bridge type and layout, structural details, location, importance, and design life.**
- **Design factors.** Spread footings become less favorable with increases in size and depth. Using the geotechnical design methods and procedures recommended in this report would lead to selecting spread footings with more economical sizes and depths. The sizes and depths of foundations are controlled by:
 - **Type, direction, and magnitude of foundation loads at all limit states.** Often, deep foundations are more economical for the support of relatively large inclined, lateral, and uplift loads and overturning moments.
 - **Results of the subsurface investigation program and the type of tests considered in this investigation** (Chapter 6). The results include strength and stiffness properties of the soil within the DOSI of spread footings and location of the groundwater table.
 - **Minimum embedment depth for spread footings, D_{f-min}** (Article 10.6.1.2 in AASHTO LRFD). This depth is determined based on depth to competent soil layers (from the subsurface investigation program); scour depth for check flood (Article 2.6.4.4 in AASHTO LRFD); depths for frost, erosion, and liquefaction; groundwater, seepage, and drainage issues; and slope stability. Spread footings are often considered when they can be placed at an economical depth, considered by many State DOTs as less than 10 ft.
 - **Design requirements.** These include types of geotechnical design methods and their resistance factors, bridge tolerable displacements, and design requirements for extreme events like earthquakes and scour.
 - **Consideration of load tests on spread footings (most accurate design method) and instrumentation of the bridge and its foundations** (Chapter 5).
- **Construction factors.** These include:
 - Available time for construction.

- Types of available construction techniques and construction quality control methods for different foundation types (Chapter 6).
- Impacts of construction space on traffic and ROW.
- Possible construction damage to adjacent foundations and structures.
- Construction noise in residential areas.
- Construction constraints (including overhead clearance; access; ROW; and the presence of shallow underground obstructions, structures such as utilities, or aquifers).
- Availability of local construction contractors and workforce, equipment, and materials. No special experience or equipment is required for construction of spread footings.
- **Environmental factors.** Environmental impact of foundation construction should be considered; for example, the disposal of contaminated excavated spoils can impact the foundation construction time and cost.
- **Maintenance factors.** Using spread footings will reduce the bridge maintenance costs, time, and traffic disruption. Using spread footings also alleviates the bridge bump problem, creating a safer and smoother transition between the bridge and approaching roadway.
- **Total costs of candidate foundation types considering all factors listed above.** To compare costs of various candidate foundation types and select the most economical foundation type, State DOTs should consider the foundation support concept (FHWA, 2006a), which divides the total cost of the foundation system by the load the foundation can support (dollar per ton load). For major projects, if the estimated costs of any candidate foundation types are within 15% of each other, then designs for these candidate foundations should be considered for inclusion in the contract documents. Spread footings, where feasible, are expected to save considerable costs over deep foundations in many cases.

9.2.2. Design Process for Selection of Candidate and Most Appropriate Foundation Types

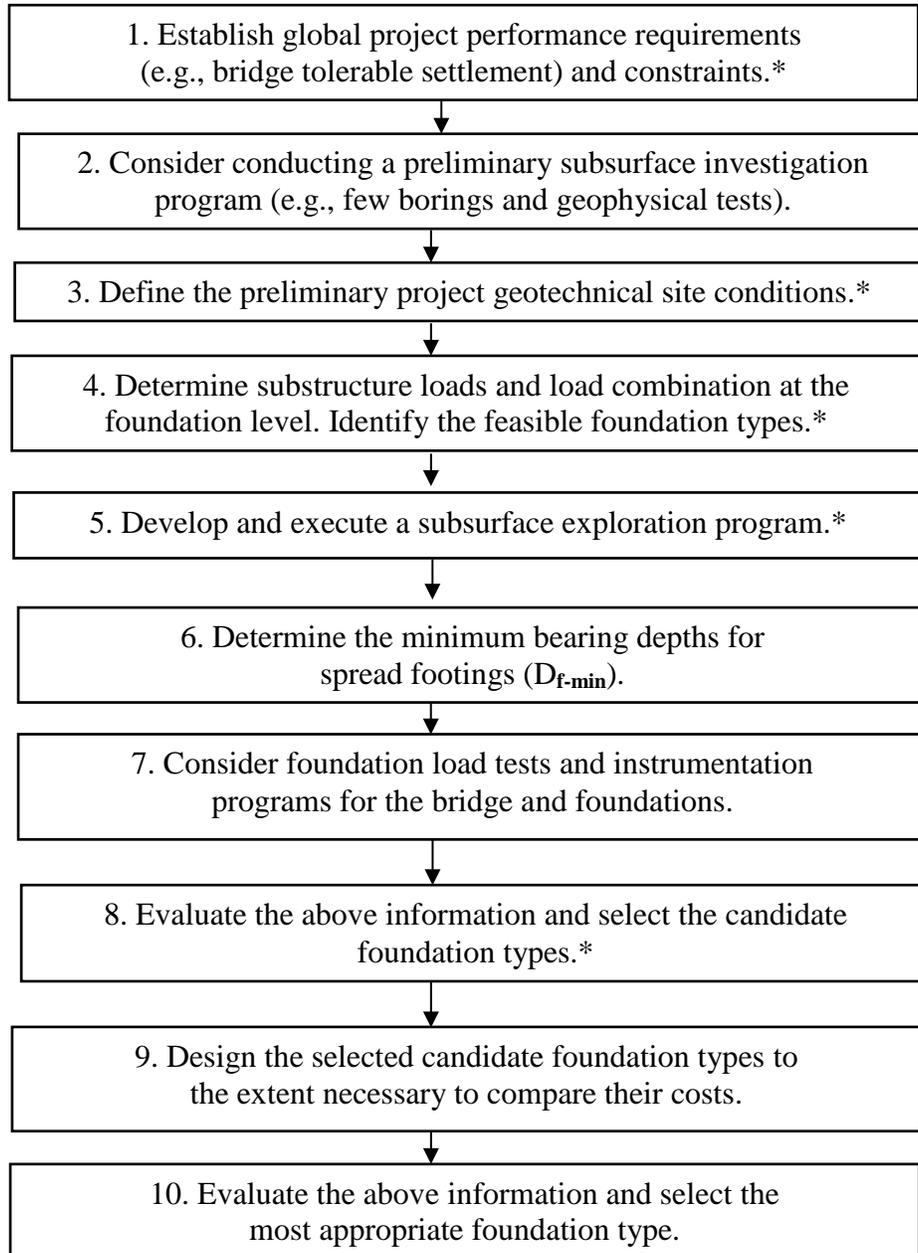
The flowchart for the design process should be developed based on the design specifications developed for selecting the most appropriate foundation type. Effective communications between the structural and geotechnical engineers should be emphasized in this process. Figure 9.1 provides a proposed general flowchart of the LRFD design process for choosing the most appropriate foundation type. Below is a summary of the stages and some steps in this flowchart:

- **Select feasible foundation types.** Per Step 4 (Figure 9.1), consider performing a preliminary subsurface investigation program (such as a few borings and geophysical tests). Based on the results of Steps 1 through 4, identify the feasible foundation types.

- **Select the candidate foundation types.** From the subsurface investigation (Step 5), obtain all of the soil, rock, and groundwater information needed for the design and construction of all feasible foundation alternatives. Decide if the subsurface conditions are favorable for using spread footings, even with ground improvements, and if special construction measures would be needed (e.g., cofferdams, groundwater control). Based on the results of subsurface investigation information and other factors discussed in Section 9.2.1., finalize the minimum bearing depths for spread footings, D_{f-min} (Step 6). Then, consider load tests and instrumentation programs (Step 7), as discussed in Chapter 5. If spread footings are appropriate as a candidate foundation type, the project geotechnical engineer should advise and discuss with the project structural engineer the viability, advantages, and good performance of spread footings. After evaluating all of the information collected in Steps 1 through 7 and the design specifications for selecting the most appropriate foundation type (see previous section), the project design and construction teams need to meet and decide if spread footings, even with ground improvements and/or over granular and MSE fills, should be considered as a candidate foundation type (Step 8).
- **Select the most appropriate foundation type.** Enlist the project structural and geotechnical engineers to work together to design all candidate foundation types to the extent needed to estimate approximate total costs (Step 9). Based on the information collected in Steps 1 through 9, the design specifications for selecting the most appropriate foundation type, and after consultation with the project geotechnical, construction, and hydraulic engineers, the project structural engineer shall finalize the selection of the most economical foundation type (Step 10). The project structural engineer should select spread footings if they are the most appropriate for the project.

9.3 DEVELOPMENT OF LRFD GUIDANCE FOR DESIGN OF SPREAD FOOTINGS ON SOILS

To develop this guidance, State DOTs need to review and deploy the AASHTO and FHWA technical references (Chapter 2), and implement other recommendations for the design of spread footings discussed in the previous chapters. FHWA report (2010b) presents comprehensive LRFD guidance and examples for designing spread footings.



*For more information about this step, see (FHWA, 2010c).

Figure 9.1. LRFD Process for Selecting the Most Appropriate Foundation Type

9.3.1 LRFD Specifications for Design of Spread Footings

Consider the following recommendations to develop these specifications:

1. Initially, develop a section that provides general considerations and specifications needed to design spread footings at all limit states. (See Article 10.6.1 in AASHTO LRFD.) Discuss the computation of eccentricity and effective footing dimensions at various limit

states (where B' is effective footing width and L' is effective foundation length), and use the effective dimensions to estimate the uniform bearing stresses at various limit states. For footings on soils, these uniform bearing stresses are needed in the design methods to address footing settlements at the service limit state and bearing failure at the strength limit state (AASHTO LRFD, 2012). Present the procedure to determine the minimum embedment depth for spread footings, D_{f-min} (discussed in Section 9.2.1).

2. Based on Article 10.6 in AASHTO LRFD (2012); FHWA manuals (2005, 2006a, 2009, 2010b, 2011); and the recommendations discussed in the previous chapters, identify and present the design methods and procedures for spread footings bearing on all types of foundation soils (competent and improved soils, as well as engineered granular and MSE fills) at all limit states. For example, deploy the settlement analysis described in Chapter 7 and procedures to determine bearing resistances described in Chapter 8.
3. Document the resistance factors for all geotechnical design methods at all limit states, and discuss the methods and conditions considered to develop these resistance factors. (See Article 10.5.5 in the AASHTO LRFD, and Chapters 4 and 5 in the 2010 FHWA manual on LRFD implementation).
4. Consider the effective footing dimensions (B' and L') to estimate the footing settlements at the service limit state and the footing bearing resistance at the strength limit state.
5. Develop the service limit state design (Article 10.6.2 in AASHTO LRFD). Cover settlement analysis (Chapter 7 of this report) and the overall stability of spread footings. Article 11.6.3.4 in AASHTO LRFD discusses the evaluation of overall stability. Note that FHWA (2005, 2010b) also requires the evaluation of eccentricity at the service limit state with tolerable settlement of one-sixth of footing width.
6. Develop the strength limit state design (Article 10.6.3 in AASHTO LRFD). Cover the methods and procedures to determine bearing resistance of spread footings (Chapter 8 of this report), eccentric load limitations, and failure by sliding.
7. Develop the extreme event limit state design (Article 10.6.4 in AASHTO LRFD). The design checks for spread footings at the extreme include bearing resistances, eccentricity, sliding, and overall stability. Articles 10.6.4.2 and 11.6.5 in AASHTO LRFD discuss tolerable eccentricity of spread footing at the extreme event limit states. FHWA (2011) discusses seismic analysis and design of spread footings.
8. Develop the structural design (See Article 10.6.5 in AASHTO LRFD.)

9.3.2 LRFD Process for Design of Spread Footings on Soils

Chapter 6 of the FHWA Geotechnical Engineering Circular on shallow foundations (2002a) presents a design process for spread footing that lists various design tasks and defines for each task the responsible party and any necessary communications with other parties. The FHWA manual on shallow foundations (2001) discusses an ASD process for spread footings; this

process was updated to the LRFD platform in 2012 (Figure 9.2) when the NHI training course 132037 was updated in accordance with the AASHTO LRFD (2012). The LRFD process for design of spread footings (Figure 9.3) is discussed in several FHWA reports (2005, 2010b). Figures 9.2 and 9.3 provide the most recent FHWA design processes for spread footings.

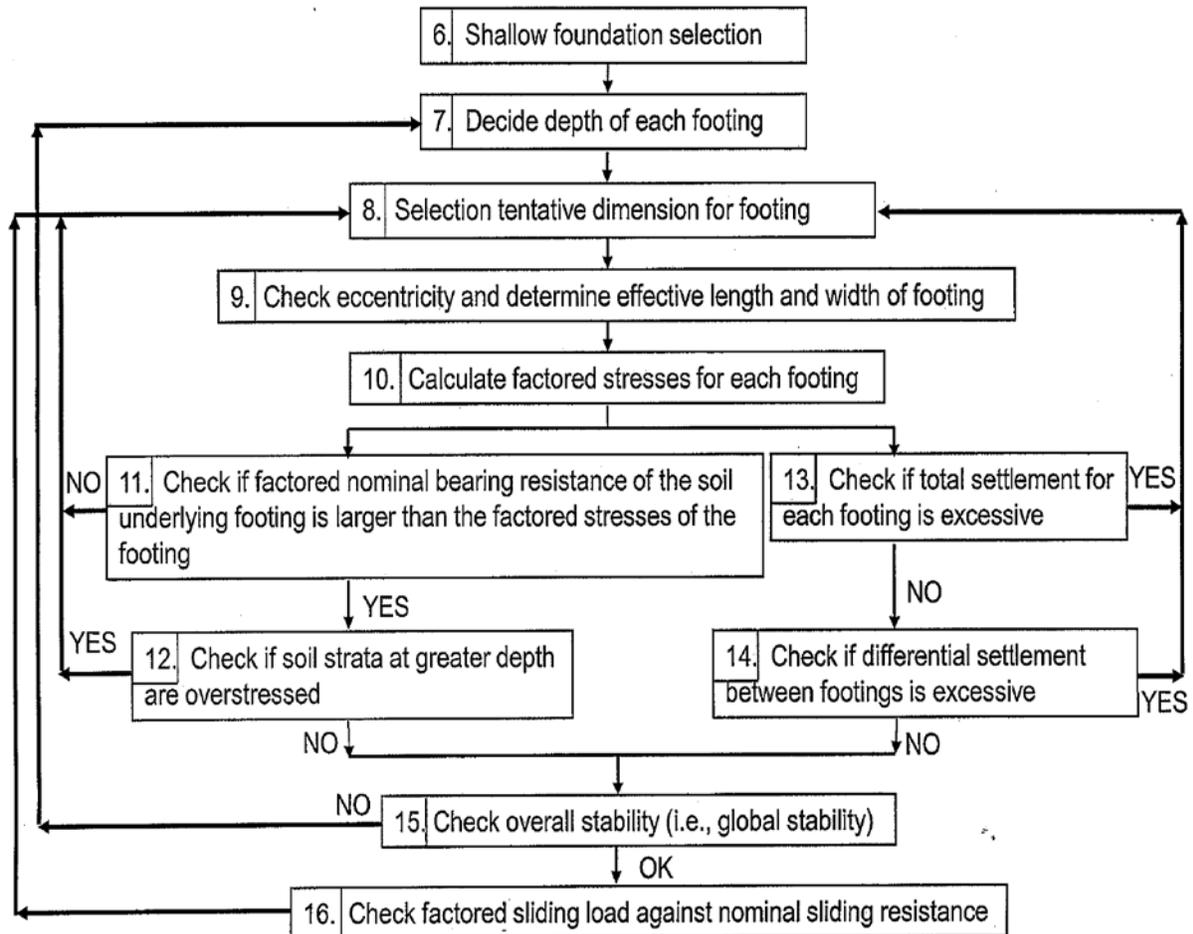


Figure 9.2. LRFD Process for Design of Spread Footings (FHWA 2001, 2012)

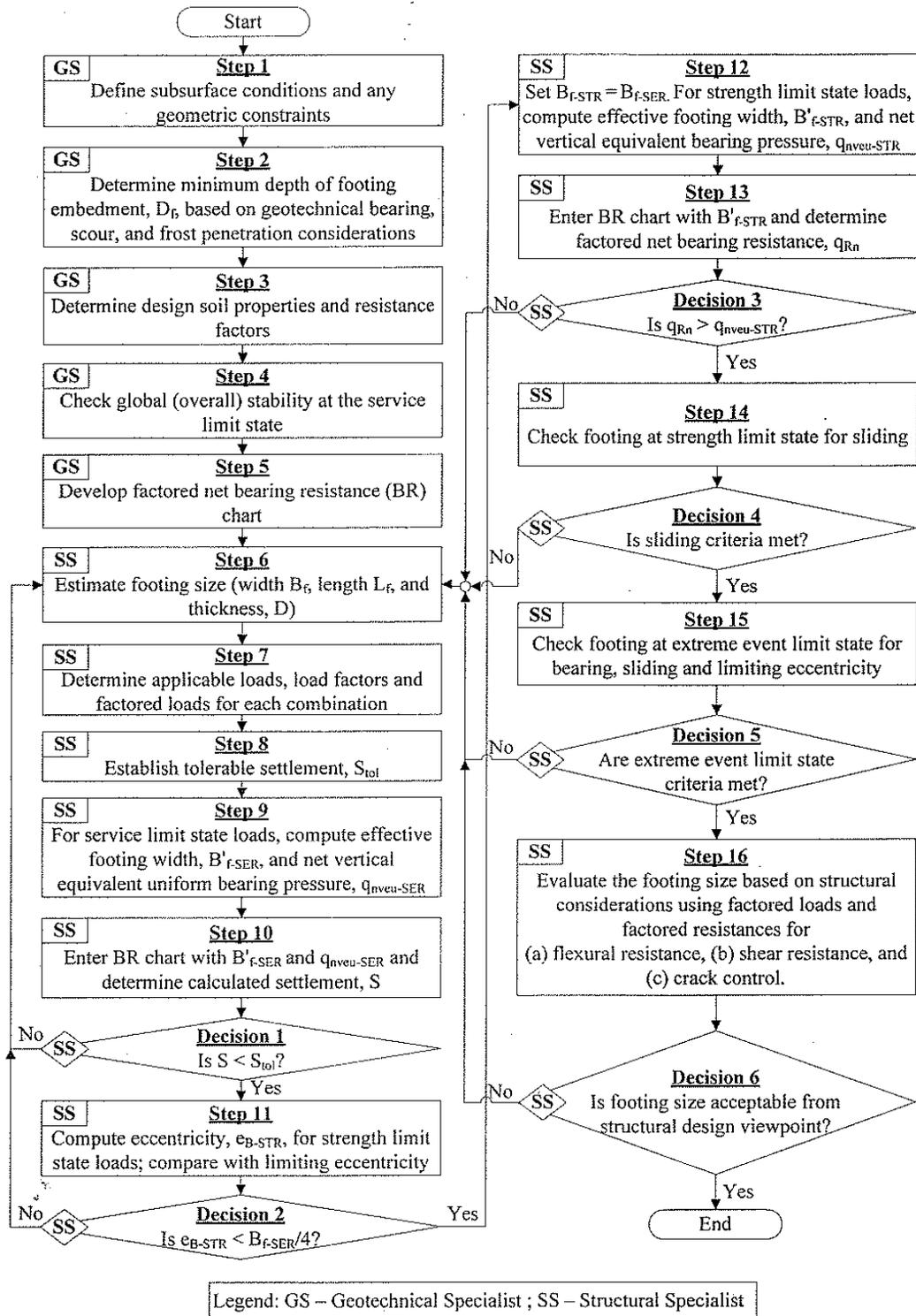


Figure 9.3. Flowchart of the LRFD Process for Design of Spread Footings (FHWA, 2010b)

Information Needed in the Design Process. Below is a summary of the primary design information needed in the design process of bridge spread footings and the party responsible for obtaining this information:

- **Project geotechnical engineer:** Provides the geotechnical design properties for the foundation soil. Identifies the geotechnical design methods and procedures for spread footings and their resistance factors (e.g., the methods to determine the nominal and factored bearing resistances of the footings at the strength limit state and the foundation settlement at the service limit state).
- **Project geotechnical and hydraulic engineers:** Determine the minimum embedment footing depth, D_{f-min} .
- **Project structural engineer:**
 - Develops the footing factored loads that are needed to evaluate all possible failure modes at the service limit state (eccentricity, overall stability, and settlement). These include the service axial compression loads that will be applied on the spread footings at various stages during and after construction (Q_{ser-1} , Q_{ser-2} , Q_{ser-3} , Q_{ser-4} , Q_{ser-5} , ... $Q_{ser-final}$), including placement of spread footings, columns for piers, abutment and wing walls, earth fill behind the abutment, girders, and decks, and after construction due to traffic loads.
 - Develops the footing factored loads that are needed to evaluate all possible failure modes at the strength and extreme event limit states. These include the factored axial compression load that will be applied on the spread footings at the strength limit state, Q_{str} .
 - Identifies the construction stages (or loads) where foundation settlement, S_F , will not impact bridge performance and need not be considered in the computation of S_{BP} , as discussed in Section 7.5.
 - Develops the bridge tolerable settlement, S_{BT} .
 - Develops the length of the footing, L . For sake of illustration, it is assumed that footing effective length, L' , equals footing length, L .
- **Project structural and geotechnical engineers:**
 - Develop the trial dimensions for the footing width, B , developed based on past experiences, any presumptive bearing resistances (Table 8.1), and layout of the bridge.
 - Develop footing depth, D_f , which needs to be equal to or larger than D_{f-min} . Trial footing depths, D_f , can be considered in the design process to allow selection of the most cost-effective footing depth and elevation. For sake of illustration, it is assumed that one footing depth, D_f , is considered in the design process.

Goal of the Design Process. The goal of the design process is to determine the minimum footing width, B , needed to meet all applicable limit states. In the evaluation of each limit state, the trial footing width, B , is increased, if needed, until the minimum footing width to meet all applicable limit states is determined.

Steps in the Design Process. AASHTO (2012) and FHWA (2006a) recommend initially sizing the footings based on settlement since settlement often controls the design. It is recommended to start the design by evaluating the failure mode that will most likely control the design or footing width. For example, if the spread footing is near to slope, start by evaluating overall stability; if the footing is subjected to large horizontal loads, start by evaluating failure by sliding. Hence, the sequence for addressing various failure modes for the footing in the design process may vary from project to project.

Below are the some general steps for developing the LRFD design process for spread footings:

Step 1. Select the footing length, L ; the footing depth; and the initial trial dimensions for footing width, B .

Step 2. Address the easy design checks:

- **Geotechnical engineer:** Address overall stability using Q_{service} load. Increase trial B , if needed, to meet the design requirements.
- **Structural engineer:** Address eccentricities at the service and strength limit state loads. Use the foundation service limit loads at various construction stages and the foundation strength limit loads to compute eccentricities and ensure they are smaller than the tolerable eccentricity values at the service limit state ($B/6$) and at the strength limit state ($B/3$). Increase trial B , if needed, to meet the design requirements.

Step 3. Determine the design stresses needed to check settlements at the service limit state and bearing failure at the strength limit state. The structural engineer:

- Use the computed eccentricities (Step 2) to compute the footing effective dimensions (B' and L') at the strength and service limit states.
- Use the computed footing effective dimensions to compute the footing factored total bearing stresses, $q_{\text{ser-1}}, q_{\text{ser-2}}, q_{\text{ser-3}}, q_{\text{ser-4}}, q_{\text{ser-5}}, \dots, q_{\text{ser-final}}$, at the service limit state, and q_{str} at the strength limit state as the factored axial compression loads acting on the foundation divided by the footing effective area (e.g., $q_{\text{ser-final}} = Q_{\text{ser-final}}/(B' \times L')$).
- Compute the footing factored net bearing stresses, $q_{\text{nser-1}}, q_{\text{nser-2}}, q_{\text{nser-3}}, q_{\text{nser-4}}, q_{\text{nser-5}}, \dots, q_{\text{nser-final}}$, at the service limit state, and q_{nstr} at the strength limit state as the total footing factored bearing stresses minus the factored soil overburden stress at footing base level.

Step 4. Check bearing failure at the strength limit state.

- **Geotechnical engineer:** For the updated trial foundation width, B , use its corresponding effective width, B' , at the strength limit state to compute the net nominal bearing resistances at the strength limit state, R_n , and the factored net bearing resistance of the spread footings at the strength limit states, ϕR_n . Note that ϕR_n represents that maximum factored net bearing stress that the footing can support at the strength limit. To expedite the process for meeting Equation 9.1, consider developing a curve relating B' to ϕR_n .
- **Structural engineer:** Address the bearing failure as:

$$q_{nstr} \leq \phi R_n \quad (9.1)$$

Increase trial B , if needed, to address this failure.

Step 5. Check bridge settlement at the service limits state.

- **Geotechnical engineer:** For the updated trial foundation width, B , compute the bridge foundation settlement, S_F , due to various footing service limit states factored net bearing stresses (q_{nser-1} , q_{nser-2} , q_{nser-3} , q_{nser-4} , q_{nser-5} , ... $q_{nser-final}$) at different construction stages, and summarize the results in a table as demonstrated in Table 9.1.
- **Structural engineer:** Discuss and agree with the project geotechnical and construction engineers on the construction stages that would impact bridge performance, and use the settlements at these stages to compute the bridge settlement that impacts bridge performance, S_{BP} . Then, develop for various net bearing stresses (q_{nser-1} , q_{nser-2} , q_{nser-3} , q_{nser-4} , q_{nser-5} , ... $q_{nser-final}$) at the service limit state the bridge settlements that impact bridge performance, S_{BP} , as demonstrated in Table 9.1 Use the final maximum computed S_{BP} value to check the settlement at the service limit state as:

$$S_{BP} \leq S_{BT} \quad (9.2)$$

Increase trial B , if needed, to meet Equation 9.2.

Step 6. Address all other applicable limit states. Use the updated trial foundation width based on previous steps to check all other applicable limit states, including the sliding resistance under the strength limit, all applicable extreme event limit states, and the structural limit states. If needed, increase this width to meet these limit states. Also, perform a structural design to finalize the details of the footings. After consultation with the project geotechnical and hydraulic engineers, the project structural engineer shall finalize the design of spread footing.

Table 9.1. Example for Estimating Bridge Settlement that Impacts Bridge Performance.*

Construction Stage	Footing Factored Net Bearing Stresses at the Service Limit State	Foundation Settlement (S_F)	Bridge Settlement that Impacts Bridge Performance (S_{BP})
1	q_{nser-1}	S_{F1}	0
2	q_{nser-1}	S_{F2}	0
3	q_{nser-1}	S_{F3}	$S_{F3} - S_{F2}$
4	q_{nser-1}	S_{F4}	$S_{F4} - S_{F2}$
5	q_{nser-1}	S_{F5}	$S_{F5} - S_{F2}$
Final	$q_{nser-final}$	$S_{F-service}$	$S_{F-service} - S_{F2}$

*Assuming foundation settlements up to Stage 2 will not impact bridge performance.

CHAPTER 10 SUMMARY

The use of spread footings on soils to support highway bridges has many advantages, mainly cost and time savings in the design, construction, quality control, and maintenance of foundations. Recent FHWA national surveys revealed that many State DOTs have safely and economically constructed highway bridges supported on spread footings bearing on competent and improved natural soils as well as on engineered granular and mechanically stabilized earth (MSE) fills, and that many State DOTs may be missing an opportunity to save time and costs by not actively considering spread footings to support highway bridges. The main concern of the State DOTs not considering spread footing is excessive settlement of bridges with spread footings bearing on soil. The goal of this report is to promote the consideration and use of spread footings on various types of soils (competent and improved natural soils, and engineered granular and MSE fills) when appropriate to support highway bridges. To achieve this goal, the report presents:

1. Perceived obstacles to using spread footings.
2. Recommendations to address the perceived obstacles.
3. Guidance to implement the recommendations.

National surveys of State DOTs in 2007 and 2009 identified several perceived obstacles to using spread footings on soils to support highway bridges. Sections 1.3 and 1.4 of the report present the perceived obstacles and the following recommendations to address them:

- **Deploy the AASHTO LRFD design specification and FHWA technical references and training courses.** These resources allow for the use of spread footings on all types of soils (competent and improved natural soils as well as engineered granular and MSE fills) to support bridges and provide the state of the practice for their selection, LRFD design, construction, and quality control, and for LRFD implementation.
- **Review the FHWA national survey results for a) extent of use and performance of highway bridges constructed on spread footings bearing on soils; and b) experiences and practices of State DOTs that frequently use spread footings for selection, design and construction of spread footings.** This will help State DOTs that have limited or no use of spread footings to benefit from the experiences and practices of State DOTs that frequently use spread footings.
- **Consider spread footings on granular and MSE fills as well as with semi-integral and integral abutments.** This will help State DOTs deploy these applications when they are appropriate.
- **Consider load tests on spread footings and instrumentation of bridges supported on spread footings, and review documented performance data from load tests and**

instrumented bridges. This would help State DOTs verify the design, construction, and performance of spread footings and address concerns about their use.

- **Deploy adequate subsurface investigation, construction, and quality control procedures.** This would help State DOTs to minimize risks and problems during construction and improve the performance of spread footings.
- **Advance a rational procedure for settlement analysis of bridges supported on spread footings bearing on soils.** This will help State DOTs to develop and use accurate and economical LRFD design specifications to address the service limit state for settlement of bridges supported on spread footings bearing on soils.
- **Advance a rational procedure to determine the LRFD design bearing resistances for spread footings bearings on competent and improved natural soils, and engineered granular and MSE fills.** This will help State DOTs to develop and use accurate and economical LRFD design specifications for spread footings.
- **Based on the above recommendations, develop LRFD guidance for spread footings that consists of:**
 - LRFD specifications and a process for selecting spread footings in the design when appropriate.
 - LRFD specifications and a process for accurate and economical design of spread footings.

Chapters 2 through 9 of this report assist State DOTs with implementing these recommendations. This implementation is mainly based on the deployment of AASHTO and FHWA LRFD technical references and the practices of state DOTs that used spread footings.

Chapter 3 presents the approximate use and performance of highway bridges constructed on spread footings in five regions of the United States: the Northeast, Midwest, Northwest, Southwest, and Southeast. The use of spread footings varies significantly across these regions and even among states located within the same region. In the Northeast, use of spread footings is up to 50 percent (%); in the Southwest, up to 30%; in the Northwest, up to 20%; in the Midwest, up to 10%; and almost no use in the Southeast. Many State DOTs reported good performance and economical use in hundreds or thousands of bridges. Chapter 3 also summarizes the favorable and unfavorable conditions for using spread footings.

Chapter 7 provides a rational procedure for settlement analysis of bridges supported on spread footings and includes a discussion of the following topics:

- **Types of settlements and bridge performance problems.** Three types of settlement are defined: a) settlement of the bridge foundation, S_F , b) settlement of the bridge at foundation location, S_B , and c) settlement of the bridge at foundation location that

impacts bridge performance, S_{BP} . Excessive bridge settlements can lead to a) structural distress and cracking of the bridge superstructure components due to excessive angular distortion; b) problems with bridge clearance, rideability, drainage, safety, and aesthetics; and c) damage to the structures associated with the bridge (e.g., wing walls) Several design and construction measures to address the bridge performance problems are presented.

- **Service limit state for settlement of bridges (not footings).** The recommended governing equation for this limit state is:

$$S_{BP} \leq S_{BT}$$

where S_{BT} is the bridge tolerable settlement at the foundation location. Note that this limit state is for the bridge, not the footing.

- **Bridge tolerable settlements at foundation locations (S_{BT}).** In the preliminary design, it is recommended to consider the following information just as a reference for an acceptable range of bridge tolerable settlements: a) documented settlement measurements of bridges that performed well during service life; and b) practices of State DOTs that successfully constructed bridges with spread footings. This information and its limitations and conditions are described in Section 7.3. In the final design, Section 7.3 of the report also discusses the development of the bridge-specific tolerable settlement, defined as the bridge settlement that will not cause any performance or function problems to the bridge and its associated structures (described before) during their service lives. The concerns with distress and cracking of the bridge superstructure components due to excessive angular distortion often govern the selection of S_{BT} , especially for continuous span bridges. Other factors to consider in the development of final S_{BT} are the bridge design life, the importance of the bridge (e.g., traffic volume), aesthetics, and past successful experiences.
- **Estimation of bridge spread footing settlements (S_F).** The Schmertmann's modified method FHWA (2006a, 2001) is recommended for estimating immediate settlement of spread footings on cohesionless soils.
- **Estimation of the bridge settlement that impacts bridge performance.** Some of the bridge settlements that occur during placement of the bridge superstructure (S_B) can be accommodated by the structure or corrected during construction with little or no consequence to the integrity of the bridge, depending on bridge type and construction method and sequence. Then, this settlement would not impact the performance of the bridge and should not be included in the computation of S_{BP} . Several references support this conclusion and suggest that S_{BP} could be much smaller than settlement of the footings, S_F .

The presented rational procedure for settlement analysis demonstrates that the computed settlements and tolerable settlements are smaller and larger, respectively, than commonly considered in practice. This procedure will help State DOTs develop more accurate and economical LRFD design specifications to address the service limit state for settlement of bridges supported on spread footings bearing on soils. The settlement analysis (Chapter 7) and the results of the national surveys for good performance of bridges (Chapter 3) demonstrate that spread footings bearing on soils can perform very well with respect to settlement.

Finally, Chapter 9 provides a roadmap for developing LRFD guidance to select and design spread footings based on the materials presented in the previous chapters. It discusses the development of:

- LRFD guidance for bridge foundations.
- LRFD guidance for selection of the most appropriate foundation type.
 - Design specifications for selection of spread footings.
 - Design process for selection of candidate and most appropriate foundation types.
- LRFD guidance for design of spread footings on soils.
 - Design specifications.
 - Design process.

The materials in Chapter 9 will help State DOTs to implement the new AASHTO LRFD bridge design specifications for spread footings, choose spread footings for the design when appropriate, and develop more accurate and economical LRFD design methods of spread footings than are commonly used in practice. The information in this chapter will also help the project's design and construction engineers (in particular, the geotechnical and structural engineers) understand their respective roles in the selection and design of spread footings. The project geotechnical engineer needs to advise the project structural engineer of the viability of spread footing in the preliminary design. The project structural engineer needs to understand the advantages and conditions of utilizing spread footings, and select them when they are the most appropriate to support highway bridges.

REFERENCES

AASHTO References:

AASHTO (2012). "AASHTO LRFD Bridge Design Specifications, 6th Edition." American Association of State Highway and Transportation Officials, Washington, D.C.

FHWA References:

FHWA (2012). "Evaluating Scour at Bridges, 5th Edition." FHWA-HIF-12-003, Authors: Arneson, L.A., Zevenbergen, L.W., Lagasse, P.F., and Clopper, P.E., Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

FHWA (2011). "LRFD Seismic Analysis and Design of Transportation Structures, Features, and Foundations." FHWA-NHI-11-032, Authors: Kavazanjian, E., Wang, J-N.J., Martin, G.R., Shamsabadi, A., Lam I., Dickenson, S., and Hung, C.J., Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

FHWA (2010a). "Implementation of LRFD Geotechnical Design for Bridge Foundations: Reference Manual." FHWA-NHI-10-039, Authors: Abu-Hejleh, N., DiMaggio, J.A., Kramer, W.M., Anderson, S., and Nichlos, S., National Highway Institute, Federal Highway Administration, Washington, D.C.

FHWA (2010b). "Selection of Spread Footings on Soils to Support Highway Bridge Structures." FHWA-RC/TD-10-001, Authors: Samtani, N.C., Nowatzki, E.A., and Mertz, D.R. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

FHWA (2010c). "Drilled Shafts: Construction Procedures and Design Methods." FHWA-NHI-10-016, Authors: Brown, D, Turner, J., and Castelli, R., Federal Highway Administration, Washington, D.C.

FHWA (2009). "Design and Construction of Mechanically Stabilized Earth Walls and Reinforced Soil Slopes." FHWA NHI-09-083, Authors: Berg, R.R., Christopher, B.R., and Samtani, N.C., Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

FHWA (2006a). "Soils and Foundations: Reference Manual." FHWA-NHI-06-088, Authors: Samtani, N.C., and Nowatzki, E.A., Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

FHWA (2006b). "Ground Improvement Methods." FHWA-NHI-06-019 (Vol. I) and FHWA-NHI-06-020 (Vol. II), Authors: Elias, V., Welsh, J., Warren, J., Lukas, R., Collin, J.G.,

and Berg, R.R., Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

FHWA (2005). “LRFD for Highway Bridge Substructures and Earth Retaining Structures: Reference Manual.” FHWA-NHI-05-094, Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

FHWA (2002a). “Geotechnical Engineering Circular 6, Shallow Foundations.” FHWA SA-02-054, Author: Kimmerling, R.E., Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

FHWA (2002b). “Geotechnical Engineering Circular 5: Evaluation of Soil and Rock Properties.” FHWA-IF-02-034. Authors: Sabatini, P.J., Bachus, R.C., Mayne, P.W., Schneider, J.A., and Zettler, T.E., Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

FHWA (2001). “Shallow Foundations: Reference Manual.” FHWA-NHI-01-023, Authors: Munfakh, G., Arman, A., Collin, J.G., Hung, J.C.-J., and Brouillette, R.P., Federal Highway Administration, U.S. Department of Transportation, Washington, D.C. In 2012, the training course was updated in accordance with the AASHTO LRFD Bridge Design Specifications, 5th Edition, 2010.

FHWA (1998). “Geotechnical Instrumentation.” FHWA-HI-98-034, Author: Dunicliff, J., Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

FHWA (1997). “Large-Scale Load Tests and Data Base of Spread Footings on Sand.” FHWA-RD-97-068, Authors: Briaud, J-L., and Gibbens, R., Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

FHWA (1996). “Geotechnical Differing Site Conditions.” FHWA Geotechnical Engineering Notebook Issuance GT-15, Authors: Cheney, R., and Muñoz, A., Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

FHWA (1987). “Spread Footings for Highway Bridges.” FHWA-RD-86-185, Authors: Gifford, D.G., Kraemer, S.R., Wheeler, J.R., McKown, A.F., Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

FHWA (1985). “Tolerable Movement Criteria for Highway Bridges.” FHWA-RD-85- 107, Authors: Moulton, L.K., GangaRao, H.V.S., Halvorsen, G.T., Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

FHWA (1982). “Performance of Highway Bridge Abutments on Spread Footings on Compacted Fill.” FHWA-RD-81-184, Author: DiMillio, A.F., Federal Highway Administration, U.S. Department of Transportation, Washington, D.C.

Other References:

- Bentler J.G., and Hoppe, M.J.L. (2010). "SCPT for Design of Shallow Bridge Foundations in Minnesota." 2nd International Symposium on Cone Penetration Testing, Huntington Beach, CA, USA, May 2010.
- Paikowsky, S.G., Canniff, M.C., Lensy, K., Kisse, A., Amatya, S., and Mugangam R. (2010). "LRFD Design and Construction of Shallow Foundations for Highway Bridge Structures." NCHRP Report 651, Transportation Research Board, Washington, D.C.
- Akbas, S.O., and Kulhawy, F.H. (2009). "Axial Compression of Footings on Cohesionless Soils. I: Load-Settlement Behavior," *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 135, No. 11, American Society of Civil Engineers, pp. 1562-1574.
- Dunker, K. F. and Liu, D. (2007). "Foundations for Integral Abutments." *Practice Periodical on Structural Design and Construction*, Vol. 12, No. 1, American Society of Civil Engineers (ASCE), pp. 22-30.
- Sargand, S.M., and Masada, T. (April 2006). "Further Use of Spread Footing Foundations for Highway Bridges." Final Report FHWA-OH-2006/8. Final Report to Ohio Department of Transportation.
- Abu-Hejleh, N., Hanneman, D., White, D.J., Wang, T., and Ksouri, I. (2006). "Flowfill and MSE Bridge Approaches: Performance, Cost, and Recommendations for Improvements." Report No. CDOT-DTD-R-2006-2, Colorado Department of Transportation.
- Paikowsky, S.G. (2005). "Serviceability in the Design of Bridge Foundation." ERTC10/Geo Tech Net WP2 Workshop: Evaluation of Eurocode 7, Trinity College, Dublin.
- Sargand, S.M., Masada, T., and Abdalla, B. (2003). "Evaluation of Cone Penetration Test-Based Settlement Prediction Methods for Shallow Foundations on Cohesionless Soils at Highway Bridge Construction Sites." *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 129, No. 10, American Society of Civil Engineers (ASCE), pp. 900-908.
- Abu-Hejleh, N., Zornberg, J.G., Wang, T., McMullen, M., and Outcalt, W. (2001). "Performance of Geosynthetic-Reinforced Walls Supporting the Founders/Meadow Bridge and Approaching Roadway Structures". Report No. CDOT-DTD-R-2001-12, Colorado Department of Transportation.
- Briaud, J-L., James, R.W., and Hoffman, S.B. (1997). "Settlement of Bridge Approaches." NCHRP Synthesis Report 234, Transportation Research Record, Washington, D.C.
- Sargand, S.M., Hazen, G.A., and Masada, T. (1997). "Field and Laboratory Performance Evaluations of Spread Footings for Highway Bridges." Report No. FHWA/OH-98/017. Final Report to Ohio Department of Transportation.

Duncan, J. M. and Tan, C. K. (1991). "Part 5 - Engineering Manual for Estimating Tolerable Movements of Bridges." NCHRP Report 343, Transportation Research Board, Washington, D.C, 219-225.

Schmertmann, J.H., Hartman, J.P., and Brown, P.R. (1978). "Improved Strain Influence Factor Diagrams." American Society of Civil Engineers, Journal of the Geotechnical Engineering Division, Vol. 104 (No. GT8), pp. 1131-1135.