

# PROPOSED GUIDELINES FOR DYNAMIC EFFECTS FOR BRIDGE SYSTEMS



NCHRP Project 12-98

FINAL: December 19, 2017



## **ABBREVIATED TABLE OF CONTENTS**

*Guidelines for Dynamic Effects for Bridge Systems*, First Edition contains the following sections:

1. Introduction
2. Dynamics of Bridge System Installations

## **FOREWORD**

Bridge system installations consist of constructing large portions of the bridge structure off site, and moving them into position using specialized heavy lift equipment. This technology has evolved from trial installations into mainstream use. To date, the design and construction of ABC projects using bridge system installations has been completed using engineering judgement and experience of the heavy lift contractors.

The majority of the design of the bridge system installation is covered with existing design and construction provisions that are contained in the AASHTO LRFD Bridge Design Specifications and the AASHTO LRFD Bridge Construction Specifications. The major gaps in knowledge for bridge system installations is the dynamic effects associated with moving the bridge systems. These dynamic effects have a significant effect on the design of temporary works, and a smaller effect on the design of the bridge. The basis of this document is research work completed under NCHRP Project 12-98. The final report for this project contains information on the research completed and the development of the recommended provisions.

These guidelines should be used to develop project special provisions or owner standard specifications. There is a companion NCHRP Project 12-102 that is being completed concurrently with this project that includes a document entitled "Guide Specification for Accelerated Bridge Construction", which is referenced in several provisions in this document.

# PREFACE

## Units

These guidelines use U.S. Customary Units only. Per a decision by the AASHTO Subcommittee on Bridges and Structures in 2009, SI units will no longer be included in specification documents.

## References

If a standard is available as a stand-alone publication—for example, the ACI standards—the title is *italicized* in the text and listed in the references. If a standard is available as part of a larger publication – for example, the AASHTO materials specifications – the standard’s title is not italicized and the larger publication - in this case, *Standard Specifications for Transportation Materials and Methods of Sampling and Testing*, 29th Edition - is listed in the references.

## Unit Abbreviations

Unit abbreviations in this document are consistent with the units in the AASHTO LRFD Bridge Design and Bridge Construction Specifications. Users of these guidelines should refer to these documents for frequently used abbreviations.

Please note the following:

- Abbreviations for singular and plural are the same
- Most units of time have one letter abbreviation. Unit abbreviations are always set in roman font, while variable and factors are set in *italic* font. Thus, “2 h” is the abbreviation for “two hours.”



## SECTION 1: INTRODUCTION

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## SECTION 1

**INTRODUCTION****1.1 SCOPE**

The provisions in this section serve as an introductory section of these guidelines. Included herein are definitions of common terms used in Bridge Systems and common terms used in Accelerated Bridge Construction (ABC) that are applicable to Bridge Systems.

The methods used to move Bridge systems can induce dynamic forces in the bridge and falsework during construction. The concept of dynamic behavior of a bridge that is in motion is understood, however, the magnitude of the dynamic effects is not well known. This document serves as a recommended guideline for the calculation and management of dynamic forces in Bridge Systems.

This document is a guideline with recommended criteria, not a specification. All provisions contained herein are subject to review and adjustment by the designer with approval by the owner. In some provisions, the term “shall” is included in the text. These provisions are intended to be used in construction or design specifications, where the term “shall” would be appropriate. Other provisions contained herein make use of the term “should” or “may”. The term “should” indicates a strong preference for a given criterion. The term “may” indicates a criterion that is usable, but other local and suitably documented, verified, and approved criterion may also be applied.

**1.1.1 Related Specifications**

These guidelines should be used in conjunction with the *AASHTO Guide Specifications for Accelerated Bridge Construction* as well as the *AASHTO LRFD Bridge Design Specifications*.

The design and construction of the bridge, falsework and the Bridge System equipment should be according to the provisions contained herein and the following documents:

**C1.1**

The commentary within this document is not intended to provide a complete historical background concerning the development of these guidelines, nor is it intended to provide a detailed summary of the studies and research data reviewed in formulating the provisions. The final report for NCHRP Project 12-98 (Culmo, et al, 2018) contains significant background information that can be used to detail the development of these guidelines.

**C1.1.1**

These guidelines define a specific solution to dynamic effects during construction of Bridge Systems. It is not intended to be an all-encompassing guideline on Bridge Systems. The cited documents when taken as a whole can be used for the design of the Bridge System.

- *AASHTO LRFD Bridge Design Specifications* This document should be used for general loads and capacities of elements.
- *AASHTO LRFD Bridge Construction Specifications* This specification should be used for general construction work.
- *AASHTO Guide Design Specifications for Bridge Temporary Works* This specification should be used for the design of falsework.
- *AASHTO Construction Handbook for Bridge Temporary Works* This specification should be used for the construction of falsework.
- *AASHTO Guide Specifications for Accelerated Bridge Construction* This new specification was developed under NCHRP Project 12-102. It covers all aspects of ABC design and construction, including provisions for Bridge Systems. This document should serve as the primary related specification for these guidelines.

## 1.2 DEFINITIONS

The definitions contained herein refer to common terms in use in Accelerated Bridge Construction and terms associated with Bridge Systems.

## C1.3

Many of the terms contained herein are for information only. Not all of the terms included are references in these guidelines.

### 1.2.1 General Accelerated Bridge Construction Definitions

Accelerated Bridge Construction (ABC)	Bridge construction that uses innovative planning, design, materials, and construction methods in a safe and cost-effective manner to reduce the onsite construction time that occurs when building new bridges or replacing and rehabilitating existing bridges.
Conventional Bridge Construction	Bridge construction that does not significantly reduce the onsite construction time that is needed to build, replace or rehabilitate a bridge. Prefabrication is typically limited to beams and girders in this form of construction.
Element	An individual structural component, such as a column, pier cap, footing, etc.
Lateral Slide	A method of moving a Bridge System built adjacent to the final bridge location using hydraulic jacks or cable winches. The bridge is typically built parallel to its final alignment, facilitating the installation.
Prefabricated Bridge Elements and Systems (PBES)	Structural components of a bridge that are built offsite that include features that reduce the on-site construction time that occurs with conventional bridge construction.
Prefabricated System	Prefabricated Systems are a category of PBES that consists of an entire superstructure, an entire superstructure and substructure, or a total bridge that is procured in a modular manner such that traffic operations can be allowed to resume after placement. Prefabricated systems are rolled, launched, slid, lifted, or otherwise transported into place, having the deck and preferably the parapets in place such that no separate construction phase is required after placement.
SPMT	Self-Propelled Modular Transporter. A high capacity transport device (trailer) that can lift and move prefabricated elements with a high degree of precision and maneuverability in all three directional axes without the aid of a tractor for propulsion.

SPMT Lines	A line on an SPMT refers to the transverse grouping of two wheel sets that are akin to an axle in a conventional transport trailer.
SPMT Power Pack	A module that is attached to the SPMT that provides hydraulic power for adjustments and movement.
SPMT Unit	An SPMT machine that contains a grouping of axles that are interconnected with a hydraulic system. Multiple units can be jointed together longitudinally and transversely in a modular fashion to create larger SPMT configurations.
SPMT Wheel Set	A grouping of wheels that are controlled by hydraulic systems. Each wheel set has the ability to raise and lower to adjust the height of the SPMT, and pivot to provide steering of the SPMT.

### 1.2.2 Systems

Systems	Prefabricated Systems are a category of PBES that consists of an entire superstructure, an entire superstructure and substructure, or a total bridge that is procured in a modular manner such that traffic operations can be allowed to resume after placement. Prefabricated systems are rolled, launched, slid, lifted, or otherwise transported into place, having the deck and preferably the parapets in place such that no separate construction phase is required after placement.
Superstructure Systems	A system that includes both the deck and primary supporting members integrated in a modular unit.
Superstructure/Substructure Systems	A system that includes either the interior piers or abutments which are integrated in a modular manner with the superstructure as described above.
Total Bridge Systems	A system that includes the entire superstructure and substructures (both abutments and piers) that are integral with the superstructure that are built off-line and installed as a unit.
SPMT Systems	A system that uses Self-Propelled Modular Transporters to move the structure.
Lateral Slide Systems	A system that uses Lateral Sliding equipment to move the structure.

## 1.3 BRIDGE SYSTEM TYPES

There are most common methods for construction of Bridge Systems are SPMTs and Lateral Slide. Recommended design requirements for dynamic analysis of Bridge Systems during construction are included in these guidelines.

Other methods of constructing a Bridge System have been used in specialized situations including float-in methods with barges and longitudinal launching. Design requirements for these construction methods are not covered in these guidelines.

## C1.3

The intent of these guidelines is to provide design guidance for the majority of Bridge Systems currently in use.

These methods of construction are viable in certain locations and should not be discounted. The design requirements for these methods should be handled with engineering judgement and proper planning. Many of the AASHTO publications noted in Article 1.1.1 will be applicable to these construction methods.

### 1.3.1 Self-Propelled Modular Transporters (SPMT) C1.3.1

The SPMT System can be applied to a variety of bridge types and span arrangements including, but not limited to:

- Single span bridges
- Multi-span bridges
- Trusses
- Arches

### 1.3.2 Lateral Slide

The Lateral Slide Systems are applicable to virtually any bridge type.

All of the structure types listed have been installed using SPMTs. Special care and temporary bracing may be required for complex structures such as arches and trusses as the lifting and moving of the Bridge System may result in reversal of forces within critical members.

### C1.3.2

The lateral slide systems have been used on simple bridges and very complex bridges. The ability to support the bridge at or very near the bearing lines results in a process where the main elements of the bridge are loaded in a similar fashion as in the final structure.

## 1.4 REFERENCES

*AASHTO LRFD Bridge Design Specifications*, Seventh Edition, American Association of State Highway and Transportation Officials, Washington, DC (2014)

*AASHTO LRFD Bridge Construction Specifications*, Third Edition, American Association of State Highway and Transportation Officials, Washington, DC (2010)

*AASHTO Guide Design Specifications for Bridge Temporary Works*, Second Edition, American Association of State Highway and Transportation Officials, Washington, DC (2017)

*AASHTO Construction Handbook for Bridge Temporary Works*, Second Edition, American Association of State Highway and Transportation Officials, Washington, DC (2017)

*AASHTO Guide Specification for Accelerated Bridge Construction*, First Edition, American Association of State Highway and Transportation Officials, Washington, DC (2017)

Culmo, M.P., et al, *Guidelines for Prefabricated Bridge Elements and Systems Tolerances and Dynamic Effects of Bridge Moves*, NCHRP Project 12-98, Final Report, National Cooperative Highway Research Program, Transportation Research Board, Washington, D.C. (2018)



## SECTION 2: DYNAMICS OF BRIDGE SYSTEMS

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## SECTION 2

**DYNAMICS OF BRIDGE SYSTEMS****2.1 SCOPE**

The provisions in this section apply to the calculation and application of dynamic loads in the design of Bridge Systems as part of Accelerated Bridge Construction (ABC) methods. This section covers Self-Propelled Modular Transporters (SPMTs) Systems and Lateral Slide Systems.

**2.2 DEFINITIONS**

See Section 1 of this document for definitions of common Prefabricated Bridge Elements and Systems.

**2.3 NOTATION**

$A_d$	=	area of the bridge deck (ft <sup>2</sup> ) (2.4.2) (2.4.2.1)
$ASD_{12}$	=	allowable stress design load combination specified in the <i>AASHTO Guide Design Specifications for Temporary Works</i> (2017) as modified by these guidelines (2.4.4.3)
$C_{dh}$	=	elastic horizontal dynamic response coefficient (dimensionless) (2.4.3)
$C_{dv}$	=	elastic vertical dynamic response coefficient (dimensionless) (2.4.2)
$DL$	=	dead loads applied to the bridge, falsework, and SPMTs (2.4.4.1) (2.4.4.2) (2.4.4.3)
$HDL$	=	horizontal dynamic loads applied to the bridge, falsework and SPMTs (2.4.4.3)
$K_h$	=	horizontal stiffness of the bridge and falsework (kips/foot) (2.4.3)
$K_v$	=	vertical stiffness of the bridge and falsework (kips/foot) (2.4.2)
$L$	=	length (or width) of the bridge corresponding to loading $p_{oh}$ (ft) (2.4.3)
$p_{eh}$	=	equivalent static horizontal dynamic load (kips/foot) (2.4.3)
$p_{ev}$	=	equivalent static vertical dynamic load (kips/square foot) (2.4.2)
$p_{oh}$	=	uniform horizontal load applied along the length (width) of the bridge (kips/foot) (2.4.3)
$p_{ov}$	=	uniform vertical load applied to the area of the bridge deck (kips/square foot) (2.4.2)
$POC$	=	percent of capacity of loading on an SPMT (percent) (2.4.2) (2.4.3)
$PPA_h$	=	peak SPMT platform acceleration in the horizontal direction (g) (2.4.3)
$PPA_v$	=	peak SPMT platform acceleration in the vertical direction (g) (2.4.2)
$R$	=	falsework response modification factor (2.4.3) (2.4.3.1)
$T_{nh}$	=	horizontal period of the bridge and falsework (sec.) (2.4.3)
$T_{nv}$	=	vertical period of the bridge and falsework (sec.) (2.4.2)
$v_{sh}(x)$	=	static horizontal displacement of the bridge and falsework due to an assumed uniform load applied along the length of the bridge at the center of gravity of the bridge (ft) (2.4.3)
$v_{sh,MAX}$	=	maximum value of $v_{sh}(x)$ (ft) (2.4.3)
$v_{sv}(x)$	=	static vertical displacement along the length of the bridge due to an assumed uniform load applied to the area of the bridge deck (ft) (2.4.2)
$v_{sv,MAX}$	=	maximum value of $v_{sv}(x)$ (ft) (2.4.2)
$VDL$	=	vertical dynamic loads applied to the bridge, falsework, and SPMTs (2.4.4.1) (2.4.4.2) (2.4.4.3)
$W$	=	total weight of the bridge and falsework (kips) (2.4.2) (2.4.2.1) (2.4.3) (2.4.3.1)

**C2.1**

Dynamics of Bridge Systems lead to forces acting on both the bridge and falsework. These provisions will be applicable to the Designer and the Contractor.

$\gamma_p$  = dead load factor (2.4.4.2)

## 2.4 SELF-PROPELLED MODULAR TRANSPORTER SYSTEMS C2.4

The process of lifting, moving and setting of a bridge that is supported by SPMTs is a dynamic process that results in forces acting on the bridge, the falsework and the SPMTs.

The design and construction of the Bridge System and falsework shall be according to the *AASHTO Guide Specification for Accelerated Bridge Construction*.

The design of Self-Propelled Modular Transporter (SPMT) Systems and falsework should account for dynamic effects due to the motions of these installations.

The design of a SPMT System is dependent on the stiffness of the bridge and the falsework. The design for dynamics of a SPMT System should be based on a Design Response Spectrum approach that accounts for the natural frequency of the structure being moved.

There are several dynamic effects that occur with each Bridge System that are the result of potential motions of SPMTs. Motions and associated accelerations can occur about all three axis of the SPMT (longitudinal, transverse, and vertical). Each of these motions will result in dynamic effects that will generate forces in the bridge and falsework.

The following guidelines contain recommendations for accounting for dynamics in the design and detailing of the bridge, falsework, and the SPMT units.

These guidelines are limited to dynamic effects and is not intended to be a manual on SPMT Systems. There are several other resources that are available that can be used for implementation and management of an SPMT System including definitions of roles and responsibilities and criteria for project implementation (Ralls (2007), UDOT SDDM (2015), SHRP2 R04 Addendum (2013)).

The cited specification was developed under NCHRP Project 12-102. It contains design information for both the bridge and falsework for SPMT Systems. Portions of these guidelines will reference this guide specification.

These guidelines contain recommendations for accounting for dynamics in the design and detailing of the bridge and falsework. This approach is similar to a seismic event where a structure is subjected to ground motions. The motions of an SPMT are similar in nature, with the predominant motions in the longitudinal and transverse directions (Culmo, et. al (2017)).

The design of falsework that supports the bridge is typically completed by the Contractor. Designs vary widely. The varying designs result in varying stiffness of the falsework.

Most SPMTs are capable of motion along all three local axis. Vertical motion is somewhat limited by the stroke of the hydraulic lifting systems. Horizontal motion is only limited by the travel path of the move.

Each bridge installation has different characteristics and details including direction of travel, travel path, terrain traversed, location of supports on the bridge, and the type of falsework employed. The design for dynamic effects should account for all potential characteristics of the anticipated move.

### 2.4.1 Vertical Dynamic Effects

Vertical dynamic effects are caused by the vertical motions due to traversing uneven terrain. The stiffness of the structure in the vertical direction shall be accounted for in the analysis for vertical dynamic effects.

The dynamic loads imparted on the Systems during the bridge move should be based on the fundamental mode of vibration in the vertical direction of the structure and falsework. The period of this mode of vibration can be considered to be that of a single mass-spring oscillator. The stiffness of the equivalent spring should be calculated using the maximum displacement that occurs when an arbitrary uniform load is applied to the bridge. The elastic vertical dynamic response coefficient,  $C_{dv}$ , specified below should be used to calculate the equivalent vertical force effects for the SPMT System.

The uniform load method of calculating equivalent vertical forces acting on the Systems is described in the following steps:

1. Calculate the static vertical displacement  $v_{sv}(x)$  due to an assumed uniform load  $p_{ov}$  as shown in Figure C2.4.2-1. The uniform loading  $p_{ov}$  is applied over the area of the bridge deck.
2. Calculate the vertical stiffness,  $K_v$ , of the bridge and falsework from the following expression:

$$K_v = p_{ov} A_d / (v_{sv,MAX}) \quad (2.4.1-1)$$

where:

$A_d$  = Area of the bridge deck (ft<sup>2</sup>)  
 $v_{sv,MAX}$  = maximum value of  $v_{sv}(x)$  (ft)  
 $p_{ov}$  = uniform vertical load applied to the area of the bridge deck (kips/square foot)

3. Calculate the total weight,  $W$ , of the bridge and falsework.
4. Calculate the vertical period of the bridge and falsework,  $T_{nv}$ , using the expression:

$$T_{nv} = 2\pi\sqrt{W/(gK_v)} \quad (2.4.1-2)$$

where:

### C2.4.1

This method of analysis is similar to the Uniform Load Method of seismic analysis. It is essentially an equivalent static method of analysis that uses a uniform vertical load that approximates the vertical dynamic effect during the bridge move based on the vertical stiffness of the bridge and falsework.

Appendix A contains an example of the uniform load method for calculating vertical dynamic loads.

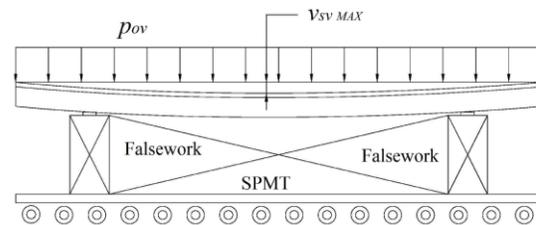


Figure C2.4.1-1 Vertical Loading for Uniform Load Method

The weight should take into account the dead weight of the bridge, falsework, and all other loads that might be on the SPMT during the bridge move. The weight of the SPMTs should not be included in this weight.

$g$  = acceleration of gravity (ft/sec.<sup>2</sup>)

- Calculate the equivalent static vertical dynamic load,  $p_{ev}$  from the expression:

$$p_{ev} = C_{dv} W / (A_d) \quad (2.4.1-3)$$

where:

$C_{dv}$  = the dimensionless elastic vertical dynamic response coefficient (also depicted in Figure 2.4.1-1).

$$C_{dv} = \begin{cases} 3 \times PPA_v & 0 \leq T_{nv} \leq T_{1v} \\ 3 \left( \frac{T_{1v}}{T_{nv}} \right) PPA_v & T_{nv} > T_{1v} \end{cases} \quad (2.4.1-4)$$

where:

$$\begin{aligned} PPA_v &= 0.752 e^{-0.03POC} \\ T_{1v} &= 0.5 \text{ sec.} \end{aligned} \quad (2.4.1-5)$$

where:

$POC$  = percent of capacity of the SPMT load

The “POC” term represents the load level on the SPMT. POC would be equal to 75 for an SPMT with vertical load of approximately 75% of the capacity of the SPMT. Research data showed that the dynamic response of the SPMT decreases with increased load on the unit.

The “PPA<sub>v</sub>” term is based on maximum accelerations measured during dynamic testing at a travel speed of approximately 4 miles per hour, which represents the approximate maximum travel speed of a loaded SPMT.

This vertical response spectrum was developed from accelerometer testing data on an SPMT unit with various loads applied. Vertical accelerations were measured while the SPMT traversed uneven terrain (Culmo, et. Al 2018). Figure C2.4.1-2 is a graphical representation of equation 2.4.1-5.

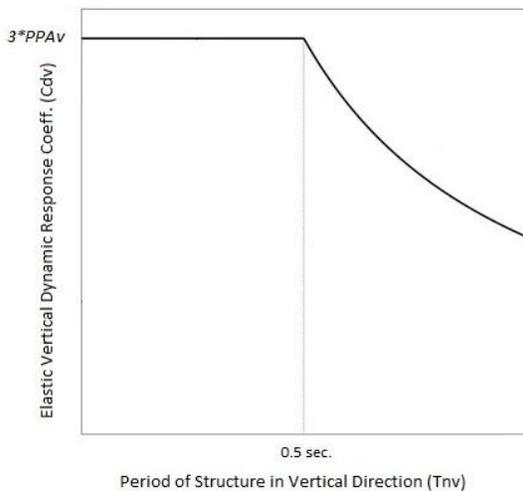


Figure 2.4.1-1 Vertical Design Response Spectrum

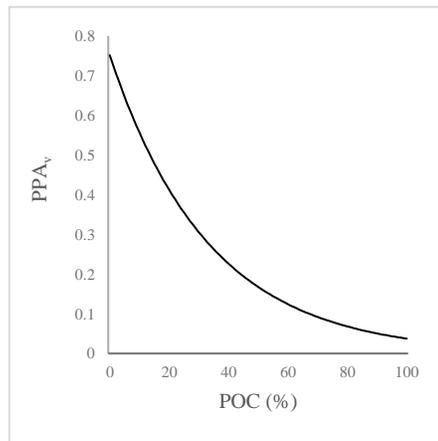


Figure C2.4.1-2 Peak Platform Acceleration in the Vertical Direction

6. Calculate the member forces for use in the design of the bridge and falsework by applying  $p_{ev}$  to the structure and performing a second static analysis or by scaling the results of the first step above by the ratio  $p_{ev}/p_{ov}$ .

#### 2.4.1.1 Optional Simplified Vertical Dynamic Analysis

In lieu of the methods described above, the equivalent static vertical dynamic load,  $p_{ev}$  may be taken as:

$$p_{ev} = (2.26 e^{-0.03POC})W/(A_d) \quad \text{--- (2.4.1.1-1)}$$

where:

$POC$  = percent of capacity of the SPMT load

$W$  = total weight of the bridge and falsework (kips)

$A_d$  = area of bridge deck (ft<sup>2</sup>)

#### 2.4.2 Horizontal Dynamic Effects

Horizontal dynamic effects are primarily caused by the horizontal motions due to accelerating and decelerating of the SMPT System. The stiffness of the falsework in all horizontal directions should be accounted for in the analysis for horizontal dynamic effects.

The dynamic loads imparted on the Systems during the bridge move should be based on the fundamental mode of vibration in each horizontal direction of the structure and falsework. The period of this mode of vibration can be considered to be that of a single mass-spring oscillator. The stiffness of the equivalent spring should be calculated using the maximum displacement that occurs when an arbitrary uniform load is applied to the bridge. The elastic horizontal dynamic response coefficient,  $C_{dh}$ , specified below should be used to calculate the equivalent horizontal force effects for the SPMT System.

The uniform load method of calculating equivalent horizontal forces acting on the System are described in the following steps:

1. Calculate the static horizontal displacement  $v_{sh}(x)$  due to an assumed uniform load  $p_{oh}$  as shown in Figure C2.4.2-1. The uniform loading  $p_{oh}$  is applied over the length (or width) of the bridge at the center of gravity of the bridge and falsework.

These forces represent a maximum anticipated forces due to vertical dynamics. See Article 2.4.4 for information regarding the application of these forces into the design of the bridge, falsework and SPMT.

#### C2.4.1.1

This simplified method is based on the assumption that the period of the structure is less than 0.5 seconds, which is conservative. This method still accounts for the percentage of load on the SPMT.

#### C2.4.2

Horizontal design forces should be calculated in all directions since the falsework will have unequal stiffness in each direction. The same methodology applies for each direction.

In most cases, the horizontal stiffness of the falsework is significantly smaller than that of the bridge structure, therefore it is conservative to assume that the bridge structure is a rigid body. The calculation of the horizontal dynamic forces would then be based on the stiffness of the falsework alone; however the forces would account for the weight of the entire structure and falsework.

Appendix A contains an example of the uniform load method for calculating horizontal dynamic loads.

2. Calculate the horizontal stiffness,  $K_h$ , of the bridge and falsework from the following expression:

$$K_h = p_{oh} L / (v_{sh,MAX}) \quad (2.4.2-1)$$

where:

$L$  = length of the bridge loading  $p_{oh}$  (ft)  
 $v_{sh,MAX}$  = maximum value of  $v_{sh}(x)$  (ft)

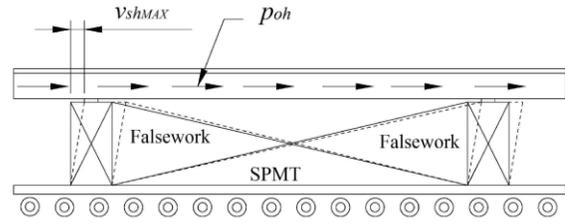


Figure C2.4.2-1 Horizontal Loading for Uniform Load Method

The loading  $p_{oh}$  should be applied in each direction under consideration, typically in the transverse and longitudinal direction of the bridge. If the bridge is considered to be a rigid body, the term  $p_{oh} L$  can be replaced by a concentrated unit load. The force should be applied at the elevation of the center of gravity of the bridge and falsework.

The weight should take into account the dead weight of the bridge, falsework, and all other loads that might be on the SPMT during the bridge move. The weight of the SPMTs should not be included in this weight.

3. Calculate the total weight,  $W$ , of the bridge and falsework.

4. Calculate the horizontal period of the bridge and falsework,  $T_{nh}$ , using the expression:

$$T_{nh} = 2\pi\sqrt{W/(gK_h)} \quad (2.4.2-2)$$

where:

$g$  = acceleration of gravity (ft/sec.<sup>2</sup>)

5. Calculate the equivalent static horizontal dynamic load,  $p_{eh}$  from the expression:

$$p_{eh} = C_{dh} W/(LR) \quad (2.4.2-3)$$

where:

$C_{dh}$  = the dimensionless elastic horizontal dynamic response coefficient (also depicted in Figure 2.4.3-1).

$R$  = Falsework response modification factor  
 = 2 for falsework with limited ductility  
 = 2.5 for falsework with medium ductility

$$C_{dh} = \begin{cases} 2 \times PPA_h & 0 \leq T_{nh} \leq T_{1h} \\ 2 \left( \frac{T_{1h}}{T_{nh}} \right) PPA_h & T_{nh} > T_{1h} \end{cases} \quad (2.4.2-4)$$

where:

$$\begin{aligned} PPA_h &= 0.361 e^{-0.014POC} & (2.4.2-5) \\ T_{lh} &= 3.0 \text{ sec.} \end{aligned}$$

where:

$POC$  = percent of capacity of the SPMT load

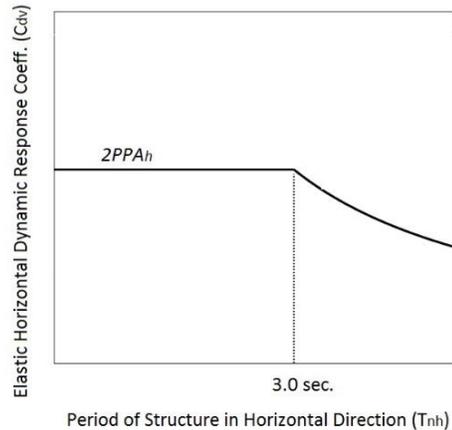


Figure 2.4.2-1 Horizontal Design Response Spectrum

The “POC” term represents the load level on the SPMT. POC would be equal to 75 for an SPMT with vertical load of approximately 75% of the capacity of the SPMT. Research data showed that the dynamic response of the SPMT decreases with increased load on the unit.

The magnitude of deceleration of an SPMT is not affected by the travel speed, therefore a simple reduction for travel speed is not appropriate. The intent of this provision is to treat this case as an ultimate load, similar to a seismic event. The assumption is that minor damage to the falsework during an emergency stop would be acceptable. The use of a response modification factor is recommended. The recommended factors are based on R-Factors used for seismic design of falsework as specified in the *AASHTO Guide Design Specifications for Temporary Works* (2017). Examples of “limited ductility” would be braced frames or rigid shipping container (which are commonly used). In this case, minor yielding of bracing or slipping of a rigid container might take place during an emergency stop. An example of a medium ductile falsework would be towers braced with cables that have significant ability to elongate.

The designer or owner may elect to use lower R Factors for critical bridges, bridges being moved over critical infrastructure, or for critical connections to the structure that are not ductile. In these cases, an R Factor as low as 1.0 may be justified. Designers can use different R Factors for each portion of the falsework. For example, an R Factor of 1.0 can be used for a critical connection, but higher R Factors could be used for the remainder of the falsework and SPMTs. Designers should consult with heavy lift contractors regarding the magnitude of forces resulting from this approach and the effect on the viability of the bridge move.

The “PPA<sub>h</sub>” term is based on maximum accelerations of an SPMT measured during dynamic testing at full speed. The measured maximum accelerations and decelerations were found to be quite large. The maximum accelerations would not normally be expected during a bridge move since acceleration is under the control of the operator. The concern is with regard to emergency stopping. During this situation, the operator may need to stop the SPMT very quickly to avoid an obstacle.

This horizontal response spectrum was developed from accelerometer testing data on an SPMT unit with

various loads applied. Horizontal accelerations were measured while the SPMT traversed uneven terrain (Culmo, etal 2018). Figure C2.4.2-2 is a graphical representation of equation 2.4.2-5.

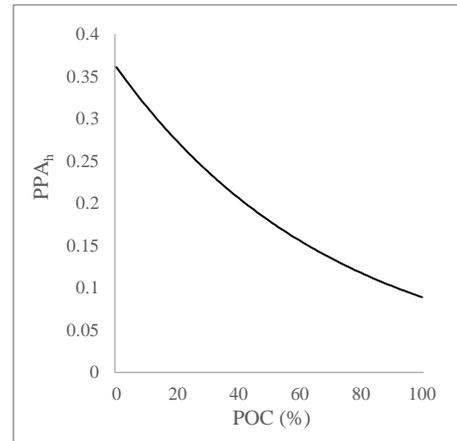


Figure C2.4.2-2 Peak Platform Acceleration in the Horizontal Direction

- Calculate the member forces for use in the design of the bridge and falsework by applying  $p_{eh}$  to the structure and performing a second static analysis or by scaling the results of the first step above by the ratio  $p_{eh}/p_{oh}$ .

#### 2.4.2.1 Optional Simplified Horizontal Dynamic Analysis

In lieu of the methods described above, the equivalent static horizontal dynamic load,  $p_{eh}$  may be taken as:

$$p_{eh} = (0.722 e^{-0.014POC})W/(LR) \quad (2.4.2.1-1)$$

where:

- $POC$  = percent of capacity of the SPMT load
- $W$  = total weight of the bridge and falsework (kips)
- $L$  = length of the bridge loading  $p_{oh}$  (ft)
- $R$  = falsework response modification factor
  - = 2 for falsework with limited ductility
  - = 2.5 for falsework with medium ductility

#### 2.4.3 Load Combinations for Dynamics

Several load combinations should be checked for the design of the bridge, falsework and SPMTs to resist horizontal and vertical dynamic loads. The Designer should be responsible for the checks on the beams and

If the bridge is considered to be a rigid body, an equivalent concentrated load equal to  $p_{eh}L$  can be used for the analysis of the falsework. These forces are based on an emergency stop situation, therefore they represent an ultimate load condition. See Article 2.4.3 for information regarding the application of this force for the design of the bridge, falsework and SPMT.

#### C2.4.2.1

This simplified method is based on the assumption that the period of the falsework and structure is less than 3 seconds, which is conservative. This method still accounts for the percentage of load on the SPMT.

See Article 2.4.2 for discussion on response modification factors.

#### C2.4.3

The recommended approach to the design and construction of the Bridge System and falsework is included in the document entitled *AASHTO Guide Specification for Accelerated Bridge Construction*.

deck. The Contractor should be responsible for the checks on the falsework and SPMTs.

#### 2.4.3.1 Service Limit State Check for Bridge and Falsework

The Service I Load Combination should be checked to control cracking in the deck during the bridge move, cracking in prestressed concrete beams subjected to negative bending during the move, and the bridge falsework (if designed using working stress methods). The following is the recommended load combination:

$$\text{Service I} = 1.0DL + 0.4(VDL) \quad (2.4.3.1-1)$$

where:

$DL$  = Dead Loads

$VDL$  = Vertical Dynamic Loads

#### 2.4.3.2 Strength Limit State Check for Bridge

The Strength I Load Combination should be used to check the flexural capacity of the superstructure. The following is the recommended load combination:

$$\text{Strength I} = \gamma_p DL + 1.0(VDL) \quad (2.4.3.2-1)$$

where:

$\gamma_p$  = load factor for permanent loading

$DL$  = Dead Loads

$VDL$  = Vertical Dynamic Loads

In general, the Designer is responsible for specifying the layout and approximate configuration of the SPMTs and the location of the lift points for the bridge. In order to complete the checks on the bridge beams and deck, the Designer needs to make certain assumptions. The Designer can calculate the approximate dynamic loads that are applied to the bridge using these guidelines. The Designer needs to assume the percent of capacity for the SPMTs and the approximate stiffness of the falsework to complete this analysis. A reasonable value of 75 percent load (POC) is typically a conservative estimate of the final load on the SPMTs. The simplified method of calculating horizontal and vertical dynamic loads specified herein can be used to conservatively calculate the dynamic loads.

#### C2.4.3.1

This limit state can also be used to check the SPMTs for working limit loads.

Horizontal dynamic forces will not affect the design of the bridge since it is considered a rigid body. Therefore they are excluded from this check.

The vertical dynamic effects are a function of the square of the travel speed of the SPMT. Testing was completed with a SPMT traveling at approximately 4 mile per hour, which is the approximate maximum speed that could be expected. The load factor of 0.40 accounts for a travel speed value of approximately 2.5 miles per hour ( $4^2/2.5^2$ ), which is a more realistic safe maximum travel speed. Designers and owners may elect to specify lower travel speeds along with corresponding load factors. Project specifications should limit the travel speed to this level in order to provide adequate service limit state performance.

#### C2.4.3.2

The dead load factors,  $\gamma_p$  should be according to those specified in the *AASHTO LRFD Bridge Design Specifications*. The vertical dynamic load calculated in Article 2.4.1 represents a maximum load, therefore a load factor greater than 1.0 is not necessary.

Horizontal dynamic forces will not affect the design of the bridge since it is considered a rigid body. Therefore they are excluded from the check.

### 2.4.3.3 Load Combinations for Falsework and SPMTs

The falsework and SPMTs should be designed according to *AASHTO Guide Design Specifications for Temporary Works* (2017). The following is the recommended load combination:

$$ASD_{SPMT} = 1.0DL + 0.75(HDL) + 0.40(VDL)$$

(2.4.3.3-1)

where:

*DL* = Dead Loads

*HDL* = Horizontal Dynamic Loads

*VDL* = Vertical Dynamic Loads

All applicable loads specified in Load Combination ASD<sub>12</sub> should also be applied to the falsework and SPMTs, along with the applicable load factors.

The design and detailing of the falsework should be consistent with the response modification factor chosen for the analysis.

## 2.5 LATERAL SLIDE SYSTEMS

Dynamic effects on the bridge structure for Lateral Slide Systems are not significant due to the relative speed of the move and the equipment used for the sliding. The primary forces that need to be accounted for are the horizontal sliding forces and horizontal and vertical jacking forces. The horizontal sliding forces consist of static friction and dynamic friction.

### 2.5.1 Vertical Dynamics Effects

Vertical dynamic effects associated with lateral sliding should be ignored in the design of the bridge and falsework.

### 2.5.2 Horizontal Dynamics Effects

### C2.4.3.3

The primary cause of horizontal dynamic load (HDL) is the acceleration and deceleration of the SPMT. An emergency stop would represent the largest horizontal dynamic force, which is the basis for the loads calculate in the cited guideline. This is similar to a seismic load; however the probability for occurrence is higher. Load Combination ASD<sub>12</sub> of the *AASHTO Guide Design Specifications for Temporary Works* (2017) accounts for seismic forces. A load factor of 0.53 is specified for seismic loads. The load factor of 0.75 in this provision is an approximate value based on the anticipated probability of occurrence. Other loads and load factors specified in Load Combination ASD<sub>12</sub> should be applied to the loads specified in this provision.

See C2.4.3.1 for discussion regarding the 0.40 factor for vertical dynamic load.

The Designer should consider placing cross frames or diaphragms at the temporary support points to ensure that lateral horizontal dynamic forces can be resisted by the bridge. The Designer can estimate preliminary design horizontal forces for this connection using Article 2.4.2.1 combined with the preliminary layout of SPMTs indicated on the plans. Project specifications should include provisions requiring that the Contractor check the connection based on the actual falsework design and SPMT layout.

## C2.5

The movement of a bridge during a lateral slide is a quasi-static event. The movement of the bridge is typically measured in inches per minute versus feet per second. Based on this, the dynamic forces calculated in Article 2.4 would not be applicable.

### C2.5.1

The process of lifting and setting of the bridge during the move is a very controlled operation and is considered a static process, therefore, dynamics effects can be ignored.

### C2.5.2

The process of moving a bridge laterally will typically generate horizontal static friction and dynamic friction forces in the slide equipment and the bridge.

The equipment most commonly used include slide devices and rollers. Both types of equipment have their advantages and disadvantages, and both produce static and dynamic forces.

### 2.5.2.1 Rolling Systems

If rollers are used, the horizontal forces or rolling resistance should be obtained from the manufacturer of the rolling devices. If a proprietary sliding equipment is to be used, the calculation of horizontal forces can be based on the manufacturer's specifications.

### 2.5.2.2 Slide Equipment

#### 2.5.2.2.1 *Materials for Slide Equipment*

The majority of typical Lateral Slide Equipment in use utilize PTFE (Polytetrafluoroethylene) combined with a sliding surface. Lubricants are also used to reduce the sliding friction.

The following materials are recommended for Lateral Slide Equipment:

#### PTFE:

- Dimpled Unfilled Virgin PTFE (lubricated)
- Smooth Unfilled Virgin PTFE (non-lubricated)

#### Steel Mating Surfaces:

- Stainless Steel - mirror finish
- Stainless Steel - #2B finish

Lateral Slide Systems generate forces via friction between the sliding surfaces. Rollers can generate lateral forces brought on by the rolling resistance of the wheels.

### C2.5.2.1

Virtually all rolling devices that are in use are proprietary. The manufacturers of these devices can provide accurate information on forces generated by the rollers. In general, rollers generate slightly lower static and dynamic forces when compared to sliding devices. The Designer should prepare preliminary slide plans based on the assumption that sliding equipment will be used, however rolling devices should be permitted in the project specifications.

#### C2.5.2.2.1

Polytetrafluoroethylene is a synthetic fluoropolymer of tetrafluoroethylene. It is a material with very low coefficient of friction that is commonly used in high load bridge expansion bearings, which makes it a suitable material Lateral Slide Equipment.

PTFE should satisfy the requirements of the *AASHTO LRFD Bridge Design Specifications*. Filled PTFE contains fibers that are used to improve long-term durability. The fibers tend to increase friction. The use of PTFE for a lateral slide is a short-term process that requires low friction, therefore filled PTFE is not recommended. Dimpled PTFE pads are recommended for Lateral Slide Systems that make use of lubricants. The dimples are designed to retain lubricant over longer movements. Smooth PTFE can be used for non-lubricated Lateral Slide Equipment.

Stainless steel should be Type 304 (ASTM A167 or A264). This material is manufactured with various surface finishes that affect the friction values. The type of stainless steel used in bridge bearings is manufactured with a mirror finish that corresponds to a surface finish

variation of 8.0  $\mu$ -in. RMS or better. This material is intended for long-term use. Stainless steel with a #2B finish is not as smooth as mirror finish, however is much less expensive and more appropriate for construction applications. This material still has very low friction coefficients.

#### Lubricants:

Dielectric Grease (SAE-AS8660)  
Motor Oil (10W-40 viscosity)

The dielectric grease noted is commonly used in bridge bearings and is included in the *AASHTO LRFD Bridge Design Specifications*. The motor oil used is standard motor oil with a viscosity value of 10W-40. Dish washing soap has been used for Lateral Slide Systems. It has good lubrication qualities; however it needs to be re-applied liberally to maintain the low friction values. There has been limited testing on friction of soap lubricants, therefore they are not recommended for use unless the Contractor has specific experience with the use of soap.

Other materials were tested, but found to have higher friction values. They include:

Cold rolled stainless steel  
Cold rolled (unfinished) carbon steel  
Graphite lubricant  
Non-lubricated PTFE

Proprietary sliding equipment is commonly used. Project specifications should allow the use of this equipment as an alternate to the non-proprietary materials shown on the plans.

Several contractors have used high capacity proprietary sliding equipment that has been developed in other industries (ship building, heavy load transport, off shore platform construction, etc.). This equipment is well suited for Lateral Slide Systems. If proprietary equipment is offered as an alternate to non-proprietary equipment, the need for competitive bidding is fulfilled.

#### 2.5.2.2.2 Friction in Lateral Slide Equipment

There are several options for Lateral Slide Equipment. The use of PTFE sliding material combined with stainless steel is recommended for Lateral Slide Equipment designed with sliding devices.

#### C2.5.2.2.2

All recommended sliding materials noted in these guidelines include the use of stainless steel in order to provide a smooth surface and to prevent corrosion that could affect the static and dynamic friction forces. The surface finish of the stainless steel has a significant effect on the sliding friction. Two types of stainless steel are recommended:

- Stainless Steel - mirror finish combined with various PTFE mating materials.

The *AASHTO LRFD Bridge Design Specifications* contain material specifications and friction values for Type 304 Stainless steel manufactured with a mirror finish (surface finish variation of 8.0  $\mu$ -in).

The sliding friction values specified in the *AASHTO LRFD Bridge Design Specifications* should be used for the design of the Lateral Slide Equipment.

The sliding friction values are for the maximum anticipated sliding friction during the slide. These values are based on research testing of various materials that are in use. In general, the initial static “break away” friction is the highest friction that the System will experience. Dynamic friction is less than the static friction, and long term-friction is less than the initial friction (Culmo et al. 2017).

- Stainless Steel - #2B Finish combined with dimpled, lubricated, and unfilled virgin PTFE.

This limitation is based on the testing performed.

The sliding friction values for this material combination should be as specified in Table 2.5.2.2.2-1.

The travel speed for the Lateral Slide System should be limited to 10 in./min.

<b>Table 2.5.2.2.2-1: Coefficient of Friction (%) for PTFE Combined with Stainless Steel</b>					
<b>Pressure (Psi)</b>	<b>500</b>	<b>1000</b>	<b>2000</b>	<b>3000</b>	<b>≥ 4500</b>
<b>Dielectric Grease Lubricant (SAE-AS8660)</b>	9.5	7.0	5.0	3.5	3.0
<b>Motor Oil Lubricant (10W-40 viscosity)</b>	7.0	5.0	4.0	3.5	3.0
Note: Values are for dimpled and lubricated unfilled virgin PTFE at approximately 50 degrees Fahrenheit combined with #2B Finish Stainless Steel					

## 2.6 REFERENCES

*AASHTO LRFD Bridge Design Specifications*, Seventh Edition, American Association of State Highway and Transportation Official, Washington, DC (2014)

*AASHTO Guide Specification for Accelerated Bridge Construction*, First Edition, American Association of State Highway and Transportation Official, Washington, DC (2017)

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FHWA, 2013, *Slide-In Bridge Construction Implementation Guide*, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C.

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Transportation Officials, National Cooperative Highway Research Program, and Florida Department of Transportation

Rosvall, E.; Halling, M. and Lindsey, R., *Induced Stresses from Lifting and Moving Highway Bridges with Self-Propelled Modular Transporters*, TRR, Journal of the Transportation Research Board, No 2200, (17-25) (2010).

SHRP2, *ABC Standard Concepts: The Lateral Slide –Addendum to Innovative Bridge Designs for Rapid Renewal, ABC Toolkit, SHRP2 Renewal Project R04*, Strategic Highway Research Program 2, Transportation Research Board, Washington D.C. (2013)

*Specification SAE-AS8660*, Society of Automotive Engineers, , SAE International, Warrendale, PA (1999)

Utah DOT, *Structures Design and Detailing Manual*, Chapter 20, Utah Department of Transportation (2015)

### Appendix A: EXAMPLE CALCULATIONS FOR SPMT DYNAMIC EFFECTS

#### I. Vertical Dynamics

The purpose of this calculation is to determine the vertical dynamic loads acting on the SPMT system during the bridge move.

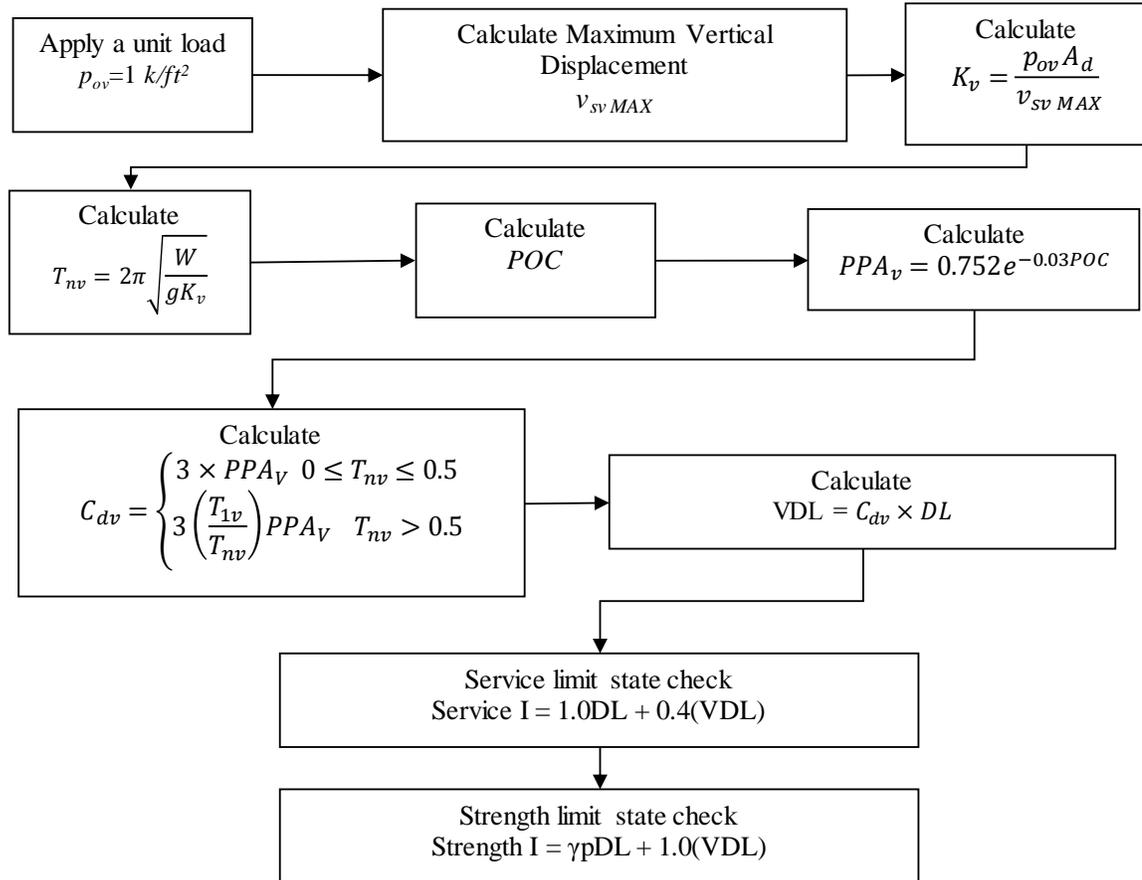


Figure A-1. Calculation Process of Vertical Dynamic Load and Load Combination Checks to be Performed

### Example Calculations: Vertical Dynamics

Givens:

1. Bridge Length: 85 ft
2. Bridge Width: 40 ft
3. Weight of Bridge and Falsework: 1400 kips
4. SPMT Layout: Two - 16 line units
5. Wheel line (axle) capacity of SPMT: 60 kips

#### Vertical Loading Diagram (Figure A-2):

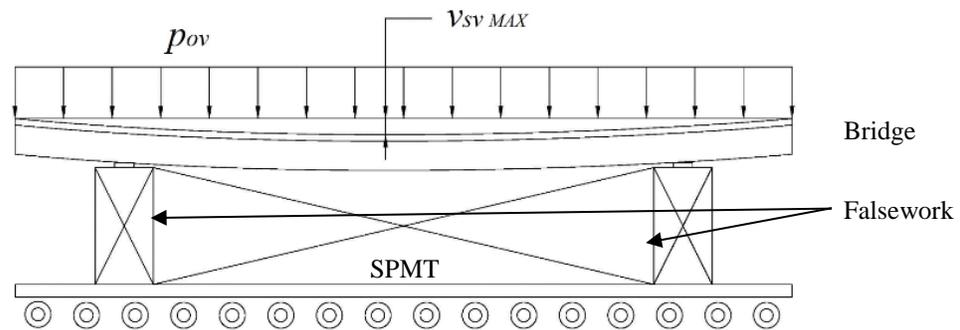


Figure A-2 Vertical Loading for Uniform Load Method

#### Calculate the vertical deflection of the bridge under a unit load:

$$p_{ov} = 1 \text{ k/ft}^2 \text{ (a unit distributed load)}$$

$$v_{sv \text{ MAX}} = \frac{2.5 \text{ inch}}{12} = 0.208 \text{ ft}$$

Note: 2.5 inches is an assumed vertical deflection of the bridge superstructure under the unit distributed load for this example. In an actual design, this would be calculated by the designer (or Contractor) using standard analysis procedures.

#### Calculate percent of capacity of SPMT:

$$\text{Weight of Bridge and Falsework} = 1400 \text{ kips}$$

$$\text{Load per SPMT axle line} = \frac{1400}{32} \text{ axles} = 43.75 \text{ kips per axle}$$

$$\text{Percent of SPMT Capacity} = \frac{43.75}{60} = 0.73$$

$$\text{Therefore POC} = 73$$

**Calculate the vertical stiffness of the bridge and falsework:**

$$A_d = 40 \times 85 = 3400 \text{ sf}$$

$$K_v = \frac{p_{ov} A_d}{v_{sv \text{ MAX}}} = \frac{1 \times 3400}{0.208} = 16320 \text{ k/ft}$$

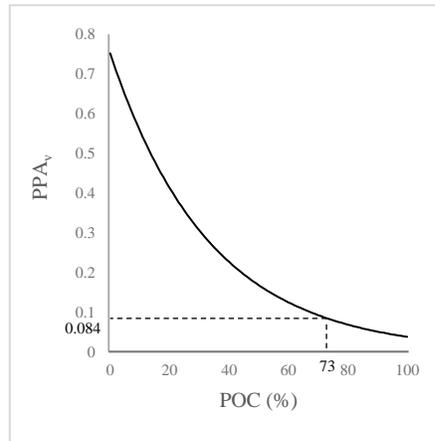
**Calculate the vertical period of bridge:**

$$T_{nv} = 2\pi \sqrt{\frac{W}{gK_v}} = 2\pi \sqrt{\frac{1400}{32.2 \times 16320}} = 0.324 \text{ sec}$$

**Calculate the peak platform vertical acceleration:**

$$PPA_v = 0.752e^{-0.03POC} = 0.752e^{-0.03 \times 73} = 0.084$$

This equation was derived from the empirical curve shown in *Figure A-3*.



*Figure A-3. Peak platform acceleration in vertical direction*

**Determine the elastic vertical dynamic response coefficient:**

Since the calculated period is less than 0.5 seconds, the elastic vertical dynamic response coefficient is calculated based on the plateau part of the vertical spectrum (shown in *Figure A-4*):

$$C_{dv} = 3PPA_v = 3 \times 0.0842 = 0.253$$

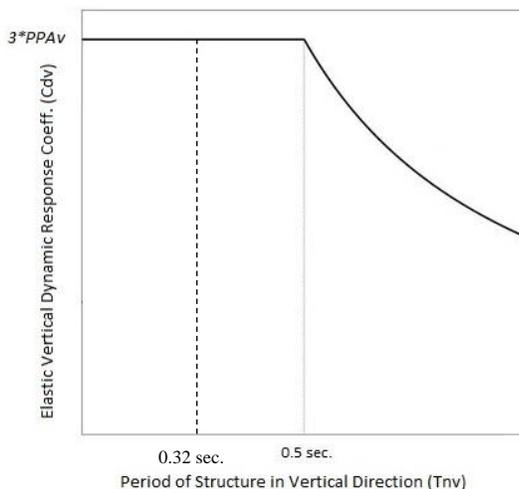


Figure A-4. Vertical Design Response Spectrum

### Check Bridge for Dynamic Loads:

The Service I Load Combination should be checked to control cracking in the deck during the bridge move, cracking in prestressed concrete beams (if used) subjected to negative bending during the move, and the bridge falsework (if designed using working stress methods). The following is the recommended load combination:

$$\text{Service I} = 1.0DL + 0.4(VDL) \quad (2.4.3.1-1)$$

$$VDL = \text{vertical dynamic loads} = C_{dv} \times DL = 0.253DL$$

0.4 in this equation is the load factor representing the SPMT speed reduction factor.

$$\text{Therefore: Service I} = 1.0DL + 0.101DL(\text{bridge})$$

The Strength I Load Combination should be used to check the flexural capacity of the beams and the bridge. The following is the recommended load combination:

$$\text{Strength Load} = \gamma_p DL + 1.0(VDL) \quad (2.4.3.2-1)$$

$$VDL = \text{vertical dynamic loads} = C_{dv} \times DL = 0.253DL$$

$$\text{Therefore: Strength Load} = \gamma_p DL + 0.253DL$$

### Discussion on Results:

This result can be compared to an impact type analysis, where the loads are increased by a percentage to account for dynamics. The *AASHTO LRFD Bridge Design Specifications* use a “dynamic load allowance” of 33% for most structures. This factor is applied to the live load to account for dynamic effects. A similar approach is used in this analysis, however, the dynamic factor is applied to the dead load. The results for this example indicate a dynamic load factor of 10.1%. This 10.1% increase in dead load is consistent with strain gage data collected from previous projects constructed by the Utah DOT.

## II. Horizontal Dynamics

The purpose of this calculation is to determine the horizontal dynamic loads acting on the SPMTs and falsework system during the bridge move.

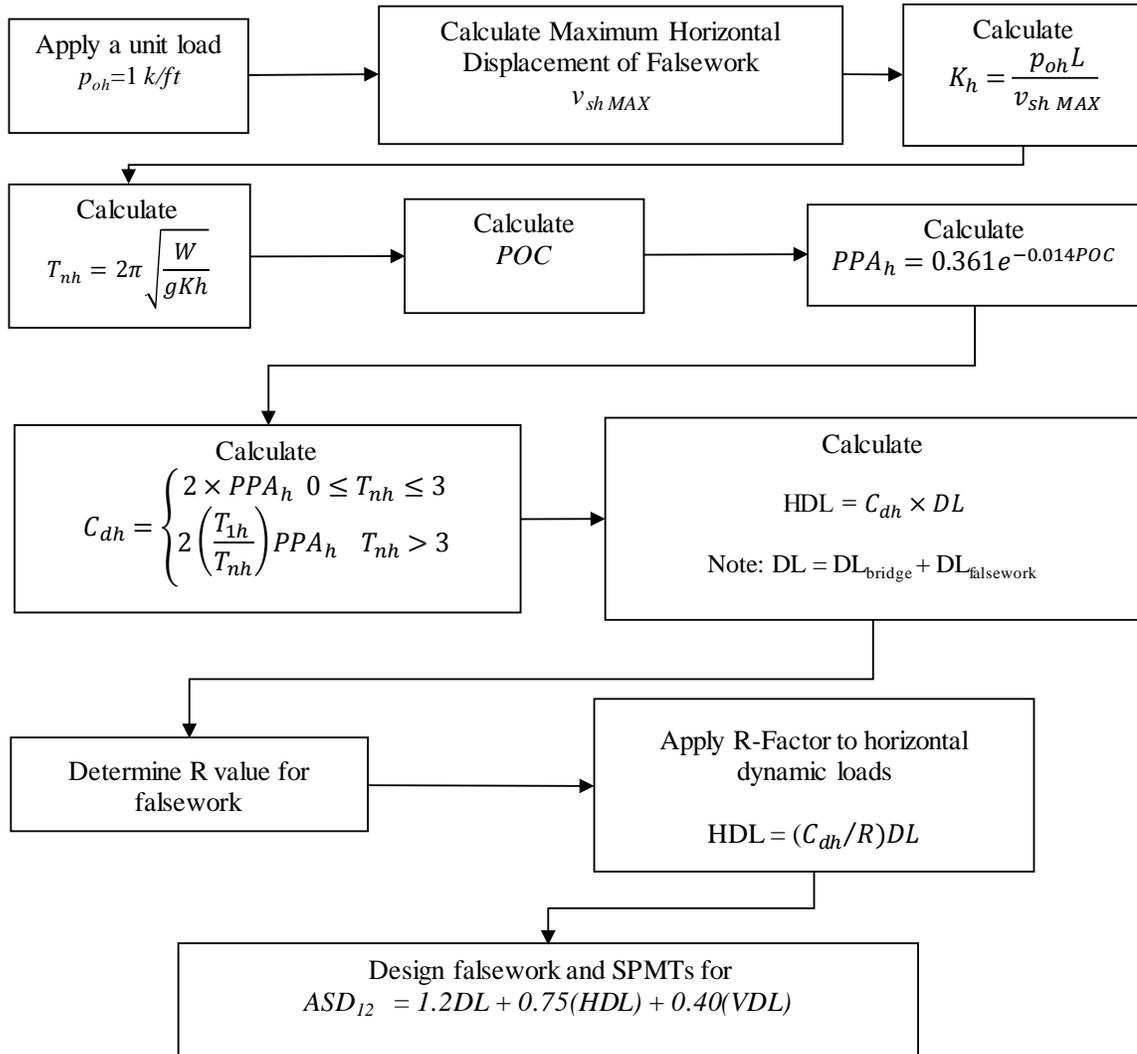


Figure A-5. Calculation Process of Horizontal Dynamic Load and Load Combination Checks to be Performed

### Example Calculations: Horizontal Dynamics

Note: This example is for longitudinal horizontal dynamic forces. A similar calculation would be required for transverse horizontal dynamic forces.

Givens:

1. Bridge Length: 85 ft
2. Bridge Width: 40 ft
3. Weight of Bridge and Falsework: 1400 kips
4. SPMT Layout: Two - 16 line units
5. Wheel line (axle) capacity of SPMT: 60 kips

### Horizontal Loading Diagram (Figure A-6):

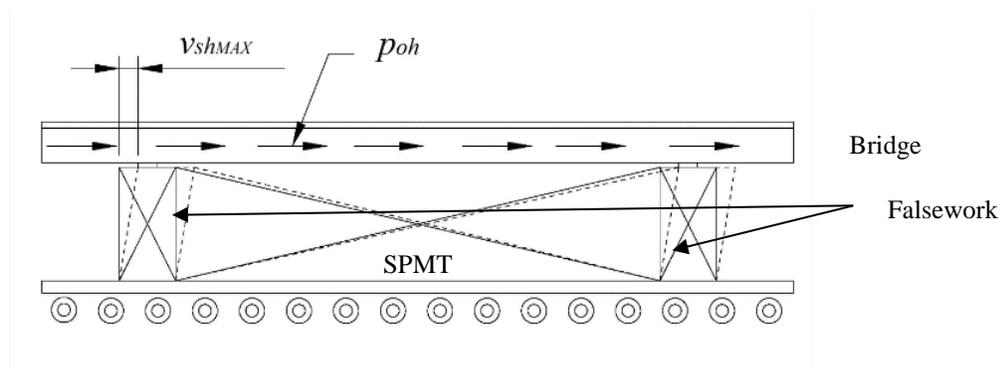


Figure A-6 Horizontal Loading for Uniform Load Method  
Note: Longitudinal Loading shown, Transverse Loading similar

### Calculate the horizontal displacement of the bridge and falsework under a unit load:

$$p_{oh} = 1 \text{ k/ft (a unit distributed load)}$$

$$v_{sh \text{ MAX}} = \frac{2.0 \text{ inch}}{12} = 0.17 \text{ ft}$$

Note: 2.0 inches is an assumed horizontal displacement of the bridge falsework for under the unit distributed load for this example. In an actual design, this would be calculated by the designer (or Contractor) using standard analysis procedures.

### Calculate percent of capacity of SPMT:

$$\text{Weight of Bridge and Falsework} = 1400 \text{ kips}$$

$$\text{Load per SPMT axle line} = \frac{1400}{32} \text{ axles} = 43.75 \text{ kips per axle}$$

$$\text{Percent of SPMT Capacity} = \frac{43.75}{60} = 0.73$$

Therefore  $POC = 73$

**Calculate the horizontal stiffness of the bridge and falsework:**

$$K_{vh} = \frac{p_{oh}L}{v_{sh\ MAX}} = \frac{1 \times 85}{0.17} = 510 \text{ k/ft}$$

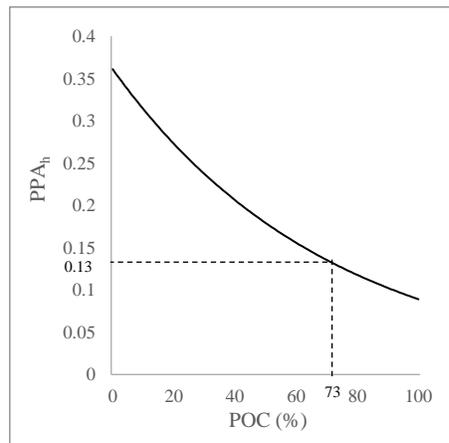
**Calculate the horizontal period of bridge and falsework:**

$$T_{nv} = 2\pi \sqrt{\frac{W}{gK_h}} = 2\pi \sqrt{\frac{1400}{32.2 \times 510}} = 1.834 \text{ sec}$$

**Calculate the peak platform horizontal acceleration:**

$$PPA_h = 0.361e^{-0.014POC} = 0.361e^{-0.014 \times 73} = 0.130$$

This equation was derived from the empirical curve shown in *Figure A-3*.



*Figure A-7. Peak platform acceleration in horizontal direction*

**Determine the elastic horizontal dynamic response coefficient:**

Since the calculated period is less than 3 seconds, the elastic vertical dynamic response coefficient is calculated based on the plateau part of the horizontal spectrum (shown in *Figure A-8*):

$$C_{dh} = 2PPA_h = 2 \times 0.130 = 0.260$$

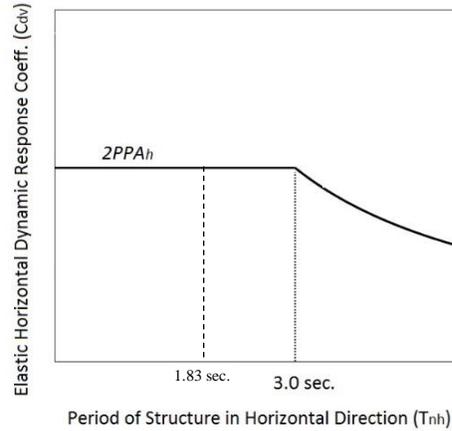


Figure A-8. Horizontal Design Response Spectrum

### Check Bridge and Falsework for Dynamic Loads:

The falsework and SPMTs should be designed using the load combinations specified in the *AASHTO Guide Design Specifications for Temporary Works* (2017). Load combination ASD<sub>12</sub> is recommended for use as the basis for the design of falsework and the SPMTs. Based on this, the following is the recommended load combination:

$$ASD_{12} = 1.2DL + 0.75(HDL) + 0.40(VDL) \quad (2.4.3.3-1)$$

The horizontal loads applied to the falsework shall be adjusted for system ductility by using a response modification factor (2.4.1.2). A value of 2.5 is assumed based on the assumption that the falsework is braced with flexible cables.

$$HDL = \left( \frac{C_{dh}}{R} \right) DL = \frac{0.260}{2.5} DL = 0.104DL$$

Where: R = 2.5 is the assumed ductility factor

$$VDL = 0.40 * (0.101DL(\text{bridge})) = 0.0404DL(\text{bridge})$$

(see previous example for calculation of VDL)

These horizontal and vertical loads would then be factored as noted in Eq. 2.4.3.3-1, and applied to the falsework and SPMTs.

### Discussion on Results:

The results for this example indicate a horizontal dynamic load factor of 7.8% (0.75\*0.104). This is consistent with typical assumptions used in the heavy lift industry. Values between 5% and 15% have been used in calculations, however these values were based on engineering judgement. This new method is a systematic approach that accounts for the weight of the load on the SPMT and the flexibility of the falsework.

