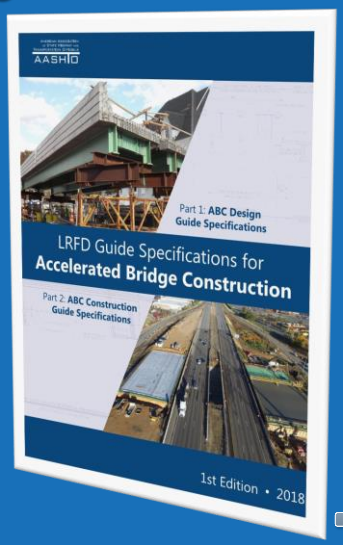
Module 4: Bridge Systems

This module covers:

- Self Propelled Modular Transporters
  - Designer/contractor responsibilities
  - Design of the bridge
  - Preliminary layout
  - Dynamics
- Lateral slides
  - Designer/contractor responsibilities
  - Preliminary layout
  - Recommended details



Module 4 covers Bridge Systems. This involves the installation of significant portions of the bridge in one element, typically the entire superstructure. In AASHTO terminology, this would be defined as a bridge “system”.

We will cover bridge systems installed using self-propelled modular transporters and lateral slide technologies.

We will cover responsibilities for the designer and the contractor, the design needs for the bridge, the preliminary layout by the designer, and methods for accounting for dynamics during the bridge move when using self-propelled modular transporters.

Section 1: SPMT Systems

Designer responsibilities

- Design the bridge
- Determine preliminary SPMT layout
- Specify pick points
  - Analyze structure for move
  - Include dynamic effects
- Verify that travel path is reasonable
- Determine and specify allowable deformations

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The Guide Specifications for ABC include provisions that outline the responsibilities of design between the designer and the contractor. Since significant portions of the construction involve temporary works and contractor means and methods, the contractor plays a significant role in the design.

The designer is responsible for the following :

1. First and foremost, the designer needs to design and detail the bridge structure including the superstructure and substructure.
2. The designer should complete a preliminary layout design for the SPMTs. This is an important step because the designer needs to determine the location of the allowable lift points on the superstructure. The location and spacing of SPMTs and the anticipated travel path plays into this determination.
3. The designer needs to specify the allowable pick points for the superstructure. In order to do this, the designer needs to analyze the bridge for the specified pick points.
4. The designer should identify a reasonable staging area and verify that the travel path from the bridge site to the staging area is adequate.
5. The designer should determine and specify the allowable differential deformations between support point in the superstructure when it is lifted.

Horizontal SPMT Dynamics: Example

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.

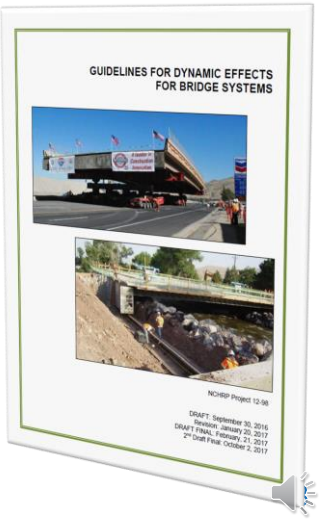
There are several dynamic effects that occur with each Bridge System that are the result of potential motions of SPMTs. Motions and associated accelerations can occur about all three axis of the SPMT (longitudinal, transverse, and vertical). Each of these motions will result in dynamic effects that will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

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.



The guide specification references work done under NCHRP Project 12-98. The green header on the top of the slide indicates that the following slides contain information from this research project and the guideline developed under that project.

The project included a study of dynamic effects during bridge moves with SPMTs. The deliverable of that research included the development of *Guidelines for Dynamic Effects for Bridge Systems*. This document is available for free download on line. Simply search “NCHRP Project 12-98” to get to the web page where this document is posted. The guideline is written in AASHTO specification format, therefore it is easy to incorporate into a design process.

This slide shows a portion of the guideline. It notes that the motions of an SPMT are similar to that of a seismic event. During a move, the SPMTs start and stop causing horizontal accelerations and decelerations. As the machines move over uneven terrain, vertical accelerations and decelerations are created. The research and this guideline provides means of calculating forces caused by these accelerations and decelerations.

The guidelines include provisions to account for the stiffness of the falsework and bridge and their impact on the dynamic forces. In the following slides, we will go through an example. You will see that this is similar to seismic analysis and design.

Horizontal SPMT Dynamics: Example

NCHRP Project 12-98

- Completed physical tests of SPMTs
- Measured accelerations under various maneuvers
- Varied the load to measure effect

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NCHRP Project 12-98 Included physical testing of SPMTs. The premise of the research was that the acceleration and decelerations of a bridge system during the actual bridge move were akin to a manmade earthquake. The top of the SPMT would be similar to the surface of the earth during an earthquake. The falsework and the bridge above would be the same as a flexible building or bridge on the ground.

The research consisted of loading SPMTs and driving the machine over varied terrain using typical maneuvers that are used during bridge moves.

The load on the SPMT was varied to measure the effects of load on the response of the machine.

SPMT Testing

Testing at Sarens Yard in Houston, Texas

- Utah State University provided accelerometers and data acquisition

This photo shows the test set up for the research. Crane weights for used to simulate load. The load shown consists of 50% capacity of the SPMT. Testing was also done with 25% capacity and 15% capacity in order to establish a relationship between load and acceleration.

Utah State University provided the gauging and data acquisition , as well as the post processing of the data. They also assisted with Development of design equations for the guidelines.

SPMT Testing

Sensor Placement

- Measured acceleration along all three axes
  - Longitudinal
  - Transverse
  - Vertical

Loads

- Three Cases (50T, 25T, 15T)
- Investigate is this has an effect on accelerations
  - Three data points define a curve
  - Extrapolate out to full load (100T)

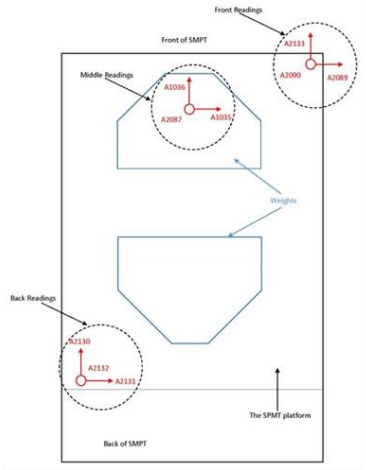


Figure 3.2.1-3: Schematic Plan of Sensor Placement

This diagram shows the placement of accelerometers on the SPMT. Accelerations were measured along all three axes of the unit.

As previously stated, three load cases were tested. This included 50 tons, 25 tons, and 15 tons. With these three load cases, a curve can be fit to the data that can be extrapolated out to a full load of 100 tons.

SPMT Testing

Travel Path

- Goal is to simulate all potential SPMT motions
  - Starting and stopping
  - Raising and lowering
  - Traversing rough terrain
  - Turning
  - Spinning
- All at highest speeds
  - Upper bound
- Rough terrain chosen
  - Upper bound

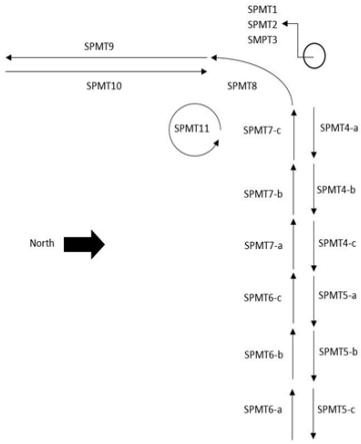


Figure 3.3.1-2: Schematic Map of Motion Cases for Heavy Load Case

For the testing, a travel path was established to simulate common maneuvers of SPMTs. They consisted of:

- Six sets of starting and stopping in both forward and reverse direction
- Raising and lowering in one position
- Traversing rough terrain in both directions
- Traversing a curve
- and Spinning in place, which is also known as carousel motion.

All of these maneuvers were executed at the highest speed possible and over rough terrain, in order to establish an upper bound for the accelerations.

SPMT Testing

Uneven Terrain

This is a video showing the traverse of rough terrain. You will note that part of the travel path included a soft area, and part of the path was over harder rough terrain.

SPMT Testing

Spinning

This video shows the spinning or carousel maneuver.

SPMT dynamics - Vertical

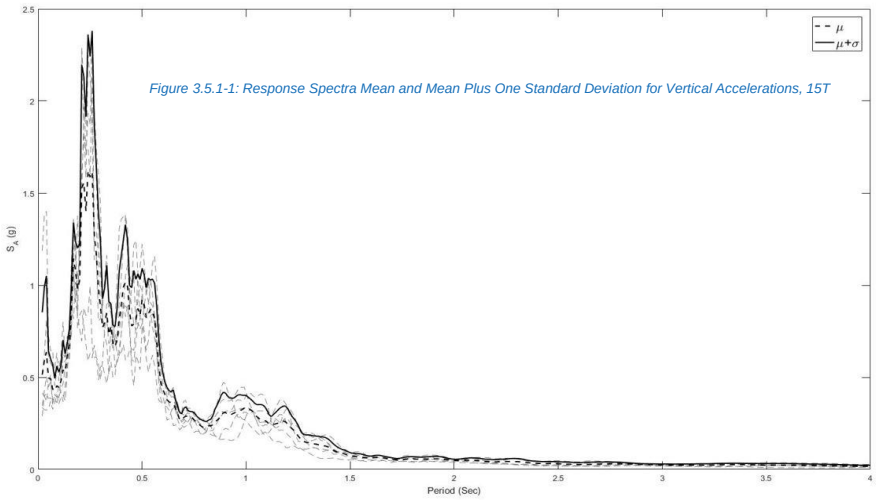


Figure 3.5.1-1: Response Spectra Mean and Mean Plus One Standard Deviation for Vertical Accelerations, 15T

The data gathered during the testing was refined into a response spectrum plot which is shown here. The X axis of this plot is the period of the structure, the Y axis is a response coefficient.

The dashed line represents the mean, and the dark line represents the mean plus one standard deviation. This plot was for vertical accelerations with the SPMT loaded with 15 tons of weight. Similar plots were developed for other loads and acceleration in the horizontal direction.

For those of you who have done seismic calculations, this should look familiar. It is very similar to the response spectrum for seismic design, which validated the premise of the research.

Design Spectra - Vertical

Idealized Spectra Curve

$$S_{Amax} = \begin{cases} 3 \times PPA_V & 0 \le T_n \le T_1 \\ 3\left(\frac{T_1}{T_n}\right) PPA_V & T_n > T_1 \end{cases}$$

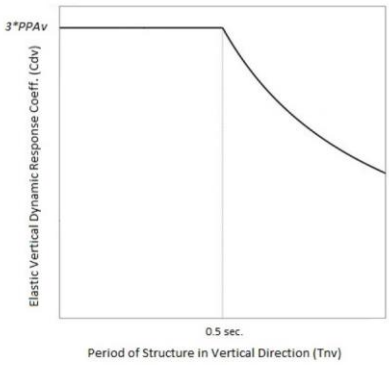


Figure 2.4.2-1 Vertical Design Response Spectrum

The data was refined to a simplified response spectrum curve that is shown to the right. This plot is for the vertical design response spectrum. Simplified design equations were also developed to represent this curve.

Design Spectra - Horizontal

Idealized Spectra Curve

$$S_{Amax} = \begin{cases} 2 \times PPA_H & 0 \le T_n \le T_1 \\ 2\left(\frac{T_1}{T_n}\right) PPA_H & T_n > T_1 \end{cases}$$

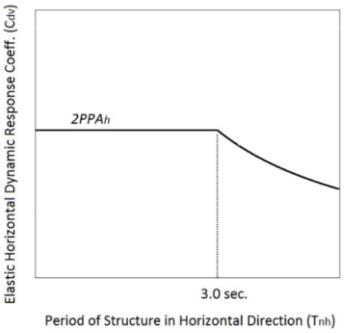


Figure 2.4.3-1 Horizontal Design Response Spectrum

This slide shows the idealized Spectral curve for horizontal accelerations.

Design for Horizontal Dynamics

- Design of falsework would be akin to design of bridge piers for seismic
- Use ultimate strength design method
  - The design horizontal accelerations would represent an “emergency stop” situation
- Design for acceptable damage, but no collapse
- Use R factors to account for different falsework systems
  - R = 2.0 for falsework with limited ductility
  - R = 2.5 for falsework with medium ductility
  - Similar to *AASHTO guide specifications for bridge temporary works*

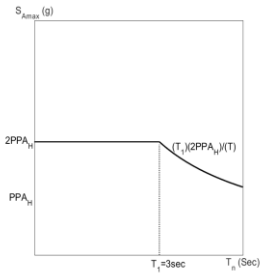


Figure 3.6.2-3: Proposed Design Spectrum for Horizontal Acceleration

Graphic from NCHRP 12-98 Report

The research team develop the design process for calculating dynamic forces in bridges and falsework during an SPMT move.

The design acceleration‘s were found to be significant, therefore an ultimate strength design approach is recommended. This is similar to seismic analysis where design earthquake is used for the calculations. This approach was chosen because there is potential for the operator to make an emergency stop during the move. An example of this might be a situation where an overhead power line was about to be struck.

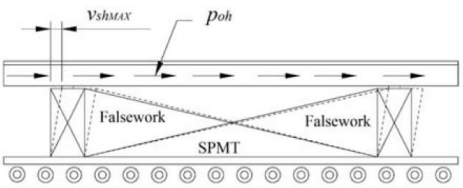
Use of force based design was recommended. The AASHTO Guide Design Specifications for Bridge Temporary Works includes R factors for seismic design of falsework. That specification recommends using an R factor of 2.0 for falsework with limited ductility, and 2.5 for falsework with medium ductility.

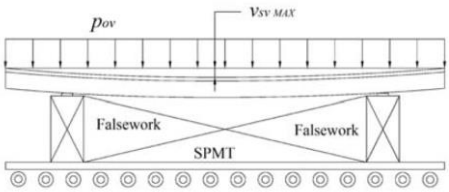
The same approach is proposed for the design of falsework four horizontal dynamics. The thought is that minor damage to the falsework during an emergency stop would be acceptable. A designer may choose to not use R factors, however this could increase costs significantly as these forces can be quite large.

Design Method – SPMT Dynamics

We need to account for stiffness of falsework and the bridge

- Use method based on the uniform load method in AASHTO LRFD
- Single mass-spring oscillator
- Apply a uniform load to superstructure at C.G. (vertical and horizontal)
- Calculate maximum deflection
- Calculate period
- Obtain dynamic response coefficient
- Calculate the dynamic load by multiplying the DLs by the dynamic response coefficient
- Analyze the bridge and falsework for the dynamic load





The guideline developed under NCHRP Project 12-98 recommends the use of a simplified method to calculate dynamics for SPMT bridge installations. The key to the analysis method is that it must account for the stiffness of the falsework and the bridge. That guideline recommends a process that is similar to the uniform load method specified in the AASHTO LRFD Bridge Design Specifications. This method is based on the assumption that the structure acts similar to a single mass-spring oscillator.

The process is as follows:

1. Apply a uniform load in the direction that you are studying
2. Calculate the maximum deflection under that load
3. Calculate the period of the structure based on that deflection
4. Determine the dynamic response coefficient
5. Calculate the dynamic load by multiplying DLs by the dynamic response coefficient
6. Then analyze the bridge for the dynamic load

Calculation of Vertical Dynamic Forces

Use a method similar to the uniform load method for seismic

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:

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

where:

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

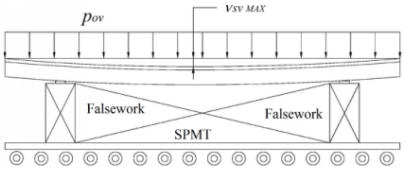


Figure C2.4.1-1 Vertical Loading for Uniform Load Method

We will now briefly go through this method of analysis for vertical dynamics. Again, the green header indicates that the specifications and equations are taken from the *Guidelines for Dynamic Effects for Bridge Systems.*

After application of the uniform vertical load , we calculate the vertical stiffness of the bridge and falsework using equation 2.4.1-1, which essentially is a spring stiffness calculation.

Calculation of Vertical Dynamic Forces

3. Calculate the total weight, W, 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.

4. Calculate the vertical period of the bridge and falsework, T_{nv}, using the expression:

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

where:

g = acceleration of gravity (ft/sec.^{2})

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The next step is to calculate the total weight of the bridge and falsework.

Once the weight and stiffness of the bridge are determined, the vertical period of the bridge can then be calculated using the equation 2.4.1-2.

Calculation of Vertical Dynamic Forces

5. Calculate the equivalent static vertical dynamic load, p_{ev} from the expression:

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

where:

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

$$C_{dv} = \begin{cases} 3 \times PPA_V & 0 \le T_{nv} \le T_{1v} \\ 3\left(\frac{T_{1v}}{T_{nv}}\right) PPA_V & T_{nv} > T_{1v} \end{cases} \qquad (2.4.1\text{-}4)$$

where:

$$PPA_V = 0.752\, e^{-0.03POC} \qquad (2.4.1\text{-}5)$$
$$T_{1v} = 0.5 \text{ sec.}$$

where:

POC = percent of capacity of the SPMT load

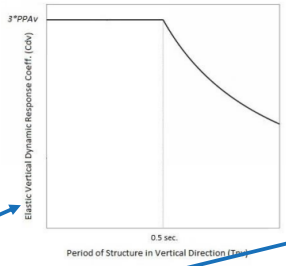

Figure 2.4.1-1 Vertical Design Response Spectrum

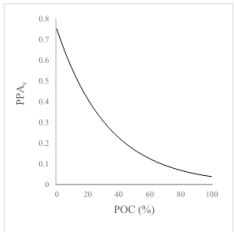

Figure C2.4.1-2 Peak Platform Acceleration in the Vertical Direction

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_v" 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.

The next step is to calculate the vertical dynamic response coefficient. There is one variable that needs to be calculated to determine this. It is the peak platform acceleration. This coefficient varies with the percent of weight on the vehicle. The research identified that accelerations decrease as the load increases. This is logical in that a fully loaded truck accelerates, decelerates, and bounces less than an empty truck.

The peak platform acceleration is calculated using equation 2.4.1-5. Once that is determined, the elastic vertical dynamic response coefficient can be calculated using equation 2.4.1-4.

The next step would be to calculate equivalent static vertical dynamic load using equation 2.4.1-3.

It should be noted that the equivalent static vertical dynamic response coefficient is essentially a percentage that is applied to the total weight of the bridge. If Cdv equals 0.10, you technically be applying 10% if the bridge weight to the system for the dynamic analysis.

Calculation of Vertical Dynamic Forces

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}.

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.

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The last step is to apply equivalent static vertical load to the bridge structure and falsework and analyze the system for those forces.

Calculation of Horizontal Dynamic Forces

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

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

where:

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

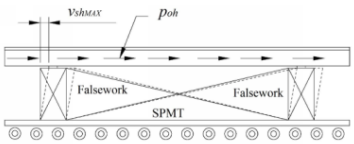


Figure C2.4.2-1 Horizontal Loading for Uniform Load Method

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 process for horizontal dynamics is similar, with just a few minor variations. The guideline notes that horizontal dynamic forces need to be calculated in both the transverse and longitudinal directions of the bridge. This is due to the fact that SPMTs can travel in any direction.

A uniform horizontal load is applied to the bridge and falsework, the maximum deflection is calculated, and the horizontal stiffness is calculated using equation 2.4.2-1.

Calculation of Horizontal Dynamic Forces

3. Calculate the total weight, W, 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.

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

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

where:

g = acceleration of gravity (ft/sec.^{2})

The weight of the bridge is then calculated.

Then the horizontal period of the bridge is calculated using equation 2.4.2-2.

Calculation of Horizontal Dynamic Forces

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

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

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

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

where:

PPA_h = $0.361\, e^{-0.014POC}$ (2.4.2-5)
T_{1h} = 3.0 sec.

where:
POC = percent of capacity of the SPMT load

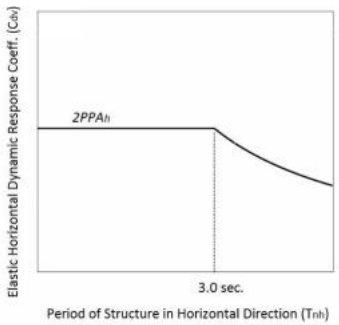


Figure 2.4.2-1 Horizontal Design Response Spectrum

The calculation for the equivalent static horizontal dynamic load is slightly different than the vertical calculation.

As previously stated, the use of R factors is recommended. The R factor is added to the denominator of equation 2.4.2-3.

As with the vertical calculation, the final load applied to the bridge can be expressed as a percentage of the total bridge weight W. The term C_{dh}/R would equate to a percentage of the total bridge weight that is applied to the analysis.

Calculation of Horizontal Dynamic Forces

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_h" 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 is the commentary for section 2.4.2. It describes the basis for the use of R factors for this calculation. It explains that the values in the guide specification are based on a worst case scenario , or an upper bound.

One might think that this approach is overly conservative, since the travel speed of the SPMT is less than the testing. It is important to note that deceleration is a function of the breaking capacity of the SPMT, and not a function of travel speed. The decelerations are similar when you drive slow, but they just occur over a shorter period of time.

This portion of the guide specification also includes recommendations for adjusting R factors for the design of the falsework.

Calculation of Horizontal Dynamic Forces

6. 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}.

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.

The last step in the design for horizontal dynamic forces includes applying an equivalent static horizontal force to the structure followed by an analysis of the structure and falsework.

Simplified method

Assume period of the structure and falsework is at the plateau

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:

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

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

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.

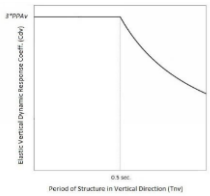


Figure 2.4.1-1 Vertical Design Response Spectrum

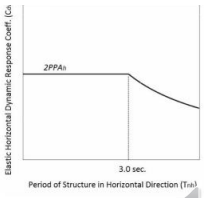


Figure 2.4.2-1 Horizontal Design Response Spectrum

A simplified method for calculating horizontal and vertical forces was developed in the guidelines from NCHRP Project 12-98. The basis of the simplified method is the fact that both the horizontal and vertical response spectra have a plateau at the structure lower periods.

The reality is that for most falsework designs, the frequency of the structure and falsework will fall within this plateau. If we assume that the frequency is within this plateau, the result will be conservative in all cases. A simple equation was developed for the horizontal and vertical dynamic analysis. This slide shows the equations for horizontal analysis. The vertical equation is similar. For this calculation we only need to calculate:

1. the weight of the bridge
2. The percent of capacity of the SPMT
3. The length of the bridge loading from the previous calculation (typically the length of the bridge being moved)
4. The desired R factor for horizontal dynamics

This simplified method should be used for preliminary layout by the design engineer, since the designer does not have specifics on the falsework during the design process.

Examples

- The published guideline includes a full design example
  - Vertical dynamics
  - Horizontal dynamics
- The following is an example of horizontal dynamic calculations

We will now go through a design example for dynamics. The guideline developed under NCHRP Project 12-98 contains sample calculations for both horizontal and vertical dynamics.

On the following slides we will go through example for horizontal dynamics in the guideline.

Horizontal Dynamic Calculations

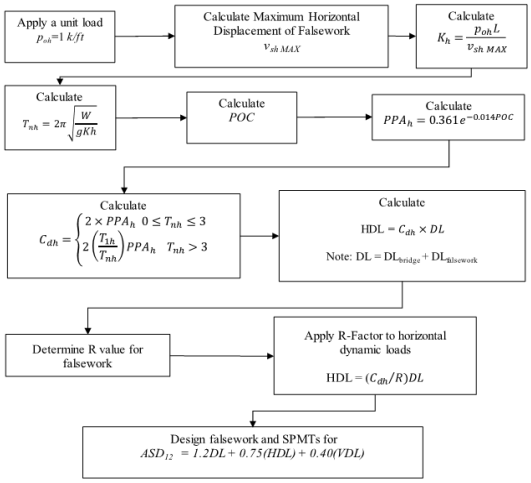


Figure A-5. Calculation Process of Horizontal Dynamic Load and Load Combination Checks to be Performed

This slide shows a flow chart for the calculations. It may seem complicated, but it is simply the steps we just reviewed in the previous slides.

Horizontal Dynamic Calculations

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

For example we will analyze a bridge move with the following givens:

Review list on the slide

Horizontal Dynamic Calculations

Horizontal Loading Diagram (Figure A-6):

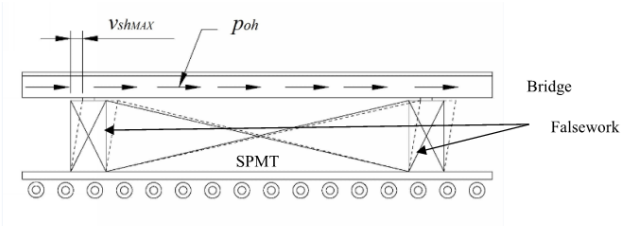


Figure A-6 Horizontal Loading for Uniform Load Method
Note: Longitudinal Loading shown, Transverse Loading similar

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

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

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

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.

We will first look at horizontal dynamics in the direction along the length of the bridge.

The first step is to apply a uniform load along the length of the bridge. It should simply be a unit load of 1 k/ft. The magnitude of the load does not matter as it will simply be used to calculate a spring coefficient.

We apply the load to the frame system of the falsework and calculate the maximum deflection under this load. For this example, we will assume that the deflection is two inches. In an actual example, this value would be calculated using frame analysis techniques.

The deflection is converted to units of feet, which equals 0.17 feet.

Horizontal Dynamic Calculations

Calculate percent of capacity of SPMT:

$$Weight\ of\ Bridge\ and\ Falsework = 1400\ kips$$

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

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

$$Therefore\ POC = 73$$

Calculate the horizontal stiffness of the bridge and falsework:

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

Calculate the horizontal period of bridge and falsework:

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

The next step is to calculate the percentage of capacity of the SPMT.

The weight of the bridge and falsework equals 1400 kips. This equates to 43.75 kips per axle. with an axle capacity of 60 kips, the percent of capacity is calculated at 0.73.

Therefore the term POC is equal to 73.

The next step is to calculate the horizontal stiffness of the bridge and falsework. It is simply the total load divided by the deflection. The calculated value is equal to 510 k/ft.

The next step is to calculate the period of the bridge and falsework. You simply plug the previous values into the equation shown to calculate the period. For this example, we get a value of 1.83 seconds.

Horizontal Dynamic Calculations

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*.

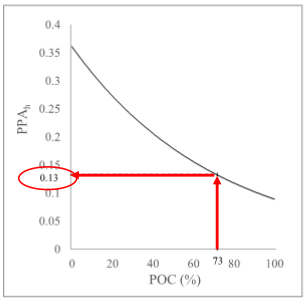


Figure A-7. Peak platform acceleration in horizontal direction

The next step is to calculate the peak horizontal platform acceleration. The guideline includes an equation for this . There is also a chart depicting this calculation.

With a POC equal to 73, the value for the peak platform acceleration is equal to 0.130

Horizontal Dynamic Calculations

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):

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

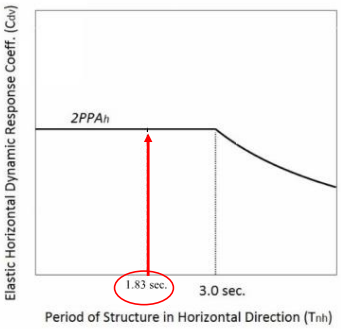


Figure A-8. Horizontal Design Response Spectrum

The next step is to calculate the elastic horizontal dynamic response coefficient.

With a period of 1.83 seconds, we fall within the plateau of the response spectrum. Therefore the elastic horizontal dynamic response coefficient is equal to two times the peak platform acceleration or 0.260.

Horizontal Dynamic Calculations

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

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

$$= 0.260 \times 1400 / (40 \times 2.5) = 3.64 \text{ k/ft}$$

The next step is to calculate the equivalent static horizontal dynamic load using equation 2.4.2-3.

We get a value of 3.64 k/ft.

Horizontal Dynamic Calculations

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_{12} 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:

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

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

$$VDL = 0.40*(0.101DL(bridge)) = 0.0404DL(bridge)$$

(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.

Design for horizontal force = 0.75*0.104 = .078

7.8% of dead load

We then use equation 2.4.3.3-1 to determine the factored load on the bridge and falsework.

The percentage of the bridge weight is equal to the elastic horizontal dynamic response coefficient divided by the R factor. In this case, Cdh divided by R equals 0.104. We then apply the load factor of 0.75 and get an equivalent percentage of total load of 7.8%

Horizontal Dynamic Calculations

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.

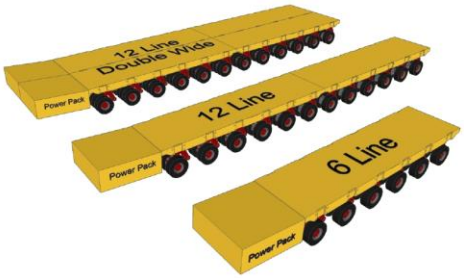
The previous calculation shows that the horizontal design force is equal to 7.8% times the weight of the bridge and falsework.

Prior to the development of this guideline, heavy lift contractors would use “rule of thumb” values of between 5% and 15% for this calculation. Those values were based on experience, which did not account for the stiffness of the structure. This method gives us results that are similar to those rule of thumb methods previously used. With this new method, we can calculate dynamic forces more accurately and ensure the stability of the bridge during the move.

Section 1: Preliminary SPMT Layout

Recommended assumptions

- Width of transporter: 8 ft
- Length of transporter: Sum of axles × axle spacing
- Length of power pack: 12 ft
  Number of axles line per unit: 4 and 6
- Number of tires per line: 4
- Axle line spacing within unit: 4.625 ft
- Axle line spacing between adjacent units: 4.625 ft
- Axle line load capacity: 30 tons
- Unit height: 48 in. min., 72 in. max.



The Guide Specifications for ABC include guidance to the designer for the preliminary layout of the SPMTs Using the recommended assumptions noted on this slide.

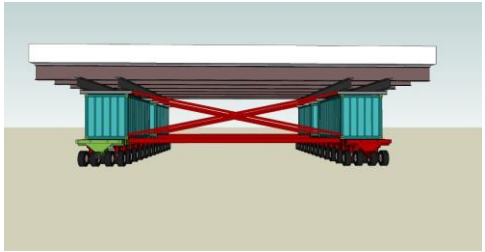
It is important to note that SPMTs are manufactured with certain numbers of axles, Which are typically four and six-axle units. Heavy lift contractors often refer to axles as “lines”. the graphic on the right shows several different configurations and the way they are typically referred to by contractors.

The top SPMT would be referred to as a 12-line double wide. The middle SPMT would simply be a 12-line, and the lower SPMT would be a six-line.

It is important to understand that SPMTS require power packs that are typically pinned to the end of the unit. The space needed to accommodate the power pack should be accounted for in the layout check. If space is limited, the Power Pack can be placed on an open space on top of the SPMT. It is recommended that designers contact heavy lift contractors prior to bidding for this scenario to ensure that the proposed layout and placement of the power pack are reasonable.

Section 1: Preliminary SPMT Layout

Example



- 650 Ton Bridge Weight
- Number of axles required = 650/30 = 21.7
- Use 24 axle lines (rounded up)
- Use two 12 line SPMTs
  - Width = 8 feet
  - Length = 4.625*12 = 55.5 feet
  - Power Pack length = 12 feet
  - Overall length = 67.5 feet
- Locate the SPMTs in a desired location under the bridge
  - Verify that the bridge can be picked at that location
- Check travel path to make sure the layout works along the path

We will now go through an example of a preliminary SPMT layout.

For this example, the total unfactored weight of the bridge was calculated at 650 tons.

By dividing 650 by the recommended 30 tons per axle, we get 21.7 axles.

We'll round that up to 24 axle lines. Two 12 line SPMT's can be used. The total length of each SPMT would be 55.5 feet. We then add in the length of the power pack, which is 12 feet , bringing the total length of the SPMT to 67.5 feet.

The designer would then determine the horizontal location of the SPMTs based on an analysis of the superstructure with the inward supports. As a general rule of thumb, the pick locations should be no more than 15% of the span length from the beam ends. The graphic to the right shows what this layout might look like. This is based on past experience.

The next step in the preliminary design process is to check the travel path to make sure the layout works. An important aspect of this is to check for the flatness of the travel path. SPMT wheel sets can vary in height to accommodate rough terrain, but there are limits. The Guide Specifications for ABC notes that the trailer elevation can vary by 24 inches. This is an absolute maximum for most SPMTs. It is recommended to check the footprint of the SPMT layout to vary by no more than 12 inches at any point in the travel path. This will limit the maximum profile grade that the system can traverse. If this cannot be met temporary filling and plating may be required along the travel path. This should be included in the project specifications.

Design & Load Factors for SPMT Systems

Design of the bridge

- Follow AASHTO LRFD Bridge Design Specifications
- There is a need to check the bridge in the lifted position
- Include the vertical dynamic forces previously discussed

The designer should follow several design checks for the SPMT move. During the move, the dead load of the bridge will be supported on the falsework at locations that differ from the final support points. Therefore, the loads for this design check include only the dead load of the bridge and the dynamic forces previously discussed.

Load Factors for SPMT Systems

2.4.2—BRIDGE SYSTEMS—SPMT INSTALLATION

Several load combinations shall be checked for the design of the bridge, falsework, and SPMTs to resist horizontal and vertical dynamic loads during installation.

The Designer is responsible for the checks on the beams and deck. The Contractor is responsible for the checks on the falsework and SPMTs.

Article 2.4.2 of the Guide Specifications for ABC includes load factors for SPMT Bridge Systems.

This notes that the designer should check the beams and the deck, accounting for dynamic effects.

Load Factors for SPMT Systems

2.4.2.1—Service Load Combination for the Bridge

The Service I Load Combination as specified in the *AASHTO LRFD Bridge Design Specifications* shall 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 load combination shall be used:

$$\text{Service I} = 1.0DL + 0.40(VDL) \qquad (2.4.2.1\text{-}1)$$

where:

DL = dead loads applied to the bridge, falsework, and SPMTs

VDL = vertical dynamic loads applied to the bridge, falsework, and SPMTs

Other applicable loads and load factors specified in the *AASHTO LRFD Bridge Design Specifications* for the Service I Load Combination shall also be applied.

C2.4.2.1

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 basis of this provision is the document *Guidelines for Dynamic Effects during Bridge System Installations* (Culmo, et al., 2017), which is recommended for use in calculating dynamic effects during SPMT bridge moves.

Research conducted for the development of this document involved establishing the upper bound for vertical dynamic loads with a loaded SPMT traversing uneven ground at a travel speed of approximately 4 miles per hour. The vertical dynamic effects are a function of the square of the travel speed of the SPMT. The load factor of 0.40 accounts for a travel speed value of approximately 2.5 miles per hour ($2.5^2/4.0^2$), 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.

The service limits state is recommended for the check of the deck for cracking during the move. A load factor of 1.0 is applied to the dead loads.

A load factor of 0.4 is recommended for the vertical dynamic load on the bridge. This lower load factor is used to convert the ultimate forces determined in the NCHRP research project to the service limit state. During that research project the SPMTs we're traveling at a high rate of speed of 4 miles per hour in order to establish an upper bound for dynamic forces. In the real world the SPMTs would be traveling much slower. The 0.4 value is to adjust for a reasonable maximum travel speed of 2.5 miles per hour. This is simply the ratio of the speeds squared.

Project specifications should limit the travel speed to 2.5 mph to provide adequate service limit state performance.

There is no load factor for horizontal dynamic forces since they will not affect the design of the bridge as it is considered a rigid body.

Load Factors for SPMT Systems

2.4.2.2—Strength Load Combination for the Bridge

The Strength I Load Combination as specified in the *AASHTO LRFD Bridge Design Specifications* shall be used to check the flexural capacity of the beams and the bridge. The following combination shall be used:

Strength Load = $\gamma_p DL + 1.0(VDL)$ (2.4.2.2-1)

where:

γ_p = dead load factor as specified in the *AASHTO LRFD Bridge Design Specifications*

DL = dead loads applied to the bridge, falsework, and SPMTs

VDL = vertical dynamic loads applied to the bridge, falsework, and SPMTs

Other applicable loads and load factors specified in the *AASHTO LRFD Bridge Design Specifications* for the Strength I Load Combination shall also be applied.

C2.4.2.2

The basis of this provision is the document *Guidelines for Dynamic Effects during Bridge System Installations* (Culmo, et al., 2017), which is recommended for use in calculating dynamic loads during SPMT bridge moves.

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.

The 0.40 factor for travel speed in Equation 2.4.2.1-1 is replaced with a load factor of 1.0 in this equation, since the loads calculated in Article 2.4.2.1 represent an upper bound for vertical forces.

Article 2.4.2.2 of the Guide Specifications for ABC includes strength limit state load factors, if the designer wishes to check the bridge for ultimate loads. This could be applied to a strength check for girders.

The standard load factors for dead load specified in The AASHTO LRFD Bridge Design Specifications would be used for this check. The load factor for vertical dynamic loads is 1.0, since the research used to develop the dynamic load effects was based on an upper bound, or ultimate load situation.

Load Factors for SPMT Systems

2.4.2.3—Load Combinations for Falsework and SPMTs

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

$$ASD_{SPMT} = 1.0DL + 0.75(HDL) + 0.40(VDL) \quad (2.4.2.3\text{-}1)$$

where:

DL = dead loads applied to the bridge, falsework, and SPMTs
HDL = horizontal dynamic loads applied to the bridge, falsework, and SPMTs
VDL = vertical dynamic loads applied to the bridge, falsework, and SPMTs

Other applicable loads and load factors as specified in Load Combination ASD_{12} shall also be applied to the falsework and SPMTs.

C2.4.2.3

The basis of this provision is the document *Guidelines for Dynamic Effects during Bridge System Installations* (Culmo, et al. 2017), which is recommended for use in calculating dynamic loads during SPMT bridge moves.

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 calculated in the cited guideline. This is similar to a seismic load; however the probability of occurrence is higher. Load Combination ASD_{12} of the *AASHTO Guide Design Specifications for Bridge 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.

See Article C2.4.2.1 for discussion regarding the 0.40 factor for vertical dynamic load.

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As previously stated, the design of falsework and the SPMT's fall under the realm of contractor means and methods. The Guide Specifications for ABC include load factors for items designed by the contractor.

Many contractors use allowable stress design for falsework, therefore an ASD load combination was developed. When checking falsework, horizontal forces can have an impact on the design. For this reason, a horizontal dynamic load factor is included. The research for horizontal dynamic loads developed an upper bound for these forces, which is similar to a seismic event. The AASHTO Guide Design Specifications for Bridge Temporary Works includes a load combination that covers seismic loading. That document recommends a load factor of 0.53 to convert seismic forces into ASD. Using this load factor was considered too liberal since the probability of an emergency stop is more likely than an earthquake. The load factor needs to be between 0.53 and 1.0. A decision was made to use a factor of 0.75 for this Guide Specification.

Section 1: Bridge Analysis

Two methods for support in staging area:

- Method A: End supported during deck casting
- Method B: Supported at pick points during deck casting
- Designer needs to specify this

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The designer should specify the support conditions for the bridge in the staging area. This has an effect on the stresses in the beams, stresses in the deck, and potentially the camber of the beams.

There are two common methods used in the US. Method A is the most common, Which includes supporting the beams on the ends in the staging area. Method B includes supporting the beams at the pick points in the staging area and during deck casting.

Section 1: Bridge Analysis

Method A: End supported during deck casting

Include vertical dynamic effects

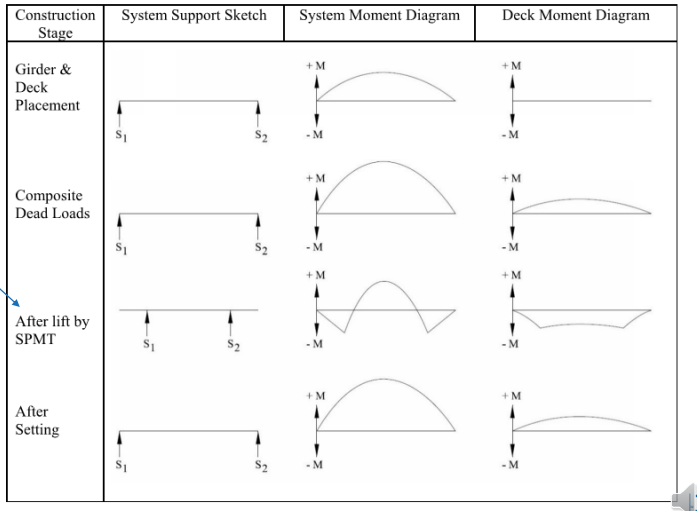

Figure C1.5.1.2.4-1—Method A Support Moments–Single Span Bridges

This diagram, which is included in the Guide Specifications for ABC demonstrates the impact of end supports on the stresses in the beams and in the deck.

During Deck Casting: The beam experiences positive bending. The deck has zero stress is the concrete is still plastic.

During application of composite dead loads: The beam and the deck experienced positive bending. This places compression in the deck.

After lift by SPMT: Both the beam and the deck experience negative bending at the pick points. This can place significant tension in the deck and parapets, potentially leading to cracking. This needs to be carefully evaluated by the designer.

After setting: The force is in the beam and the deck return to the pre-lifting condition.

Section 1: Bridge Analysis

Method B: Supported at pick points during deck casting

Include vertical dynamic effects

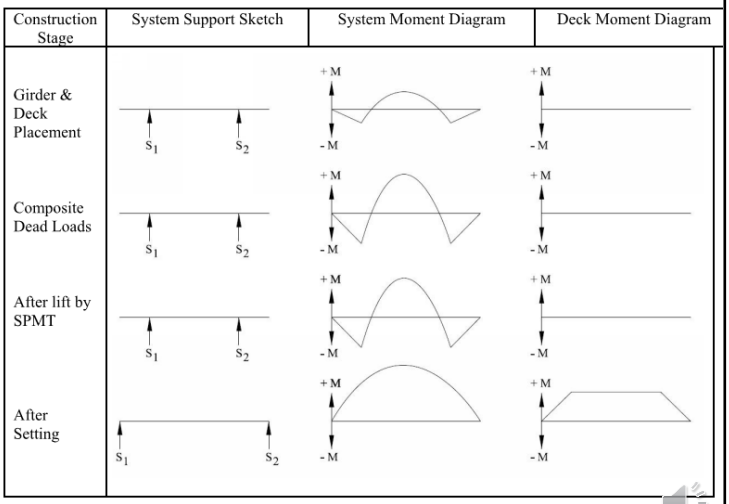

Figure C1.5.1.2.4-2—Method B Support Moments–Single Span Bridges

This diagram, which is also included in the Guide Specifications for ABC demonstrates the impact of interior support points on the stresses in the beams and in the deck.

During Deck Casting: The beam experiences positive and negative bending. the deck has zero stress is the concrete is still plastic .

During application of composite dead loads: The beam and the deck experienced positive and negative bending. The deck will experience minimal tension.

After lift by SPMT: Both the beam and the deck experience no change in stresses, with the exception of dynamic forces, which are typically not enough to cause cracking. This needs to be carefully evaluated by the designer.

After setting: The force is in the beam switches to positive bending. The deck experiences compression, which is beneficial.

At first glance it would appear that this is the preferred method of supporting a beam during casting. It should be understood that this method comes at a price. The contractor needs to design temporary supports that can accommodate picking with an SPMT. The photo on the left shows an example of this. The machines simply drive under the frame and lifted off the piling. This increases the cost and detailing requirements for the temporary supports, which should be weighed with the benefits. Another issue that needs to be studied is the impact of the stresses on the beams during deck casting. The negative moments shown in the diagram might be difficult to accommodate with a prestressed beam.

Section 1: SPMT Systems

Contractor responsibilities

- Design of all falsework
  - Staging area
  - Above the SPMTs
  - Include horizontal dynamic effects
- Final SPMT layout and travel path
- Determine preliminary SPMT layout
- Develop monitoring system (twist, deformations)
- Bridge analysis if different pick points are used

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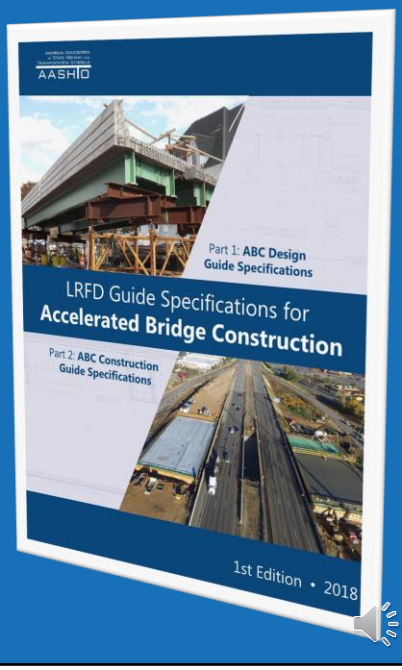
The responsibilities of the contractor are also outlined in the Guide Specifications for ABC. This includes the design of falsework including the temporary supports in the staging area, and the falsework between the SPMT and the bridge. Contract specification should require dynamic analysis of the falsework on top of the SPMTs. Dynamics lead to horizontal forces, primarily caused by starting and stopping of the SPMTs. By using a dynamic analysis, the contractor will be required to add bracing to resist the horizontal forces.

The contractor is also responsible for the final layout and travel path of the SPMTs, and the development of a deflection monitoring system if specified. The Guide Specifications for ABC only recommend an analysis of the bridge by the contractor if they choose to lift the bridge using pick points that differ from the designer's specified locations.

- Lateral slides
  - Designer/contractor responsibilities
  - Preliminary layout
  - Recommended details



This next section covers lateral slide bridge systems.

We will discuss the separation of responsibilities between the designer and the contractor. We will also discuss the preliminary layout that the designer should provide. Then we will follow up with recommended details for slide systems.

Lateral Slide Systems

How do lateral slide systems differ from SPMTs?

- Superstructure is typically supported at ends during all stages
- Results in no tension in the deck during the installation
- No significant twisting during the move
- No dynamic effects during the move

As previously discussed in this training, bridge systems are ABC technologies that involve prefabricating large portions of the bridge off-site, and installing them in one short-duration construction process.

The two most common technologies include SPMTs and Lateral Slides.

Lateral slides are becoming a very popular means of building a bridge with ABC. The lateral slide method results in no tension in the deck during the installation, no significant twisting during the slide, and no dynamic effects during the slide.

Section 1: Lateral Slide Systems

Designer responsibilities

- Design the bridge
- Identify preliminary jacking locations
  - Analyze structure for these jacking locations
- Determine preliminary friction forces
  - Verify that the bridge can resist these forces
- Develop schematic falsework layout
  - Specify method to resolve sliding forces

In any bridge system project, there is significant engineering required of the contractor. There is also engineering required on the part of the designer. The Guide Specifications for ABC includes provisions to better define responsibilities for both parties.

The designer is responsible for the design of all the permanent bridge elements. To ensure that the structure is not damaged during the slide, the designer should analyze the structure for prescribed jacking locations that need to be specified.

The designer should also investigate and specify locations where the bridge can be pushed or pulled. In order to do this, preliminary push or pull forces need to be calculated. Guide specification includes recommendations for estimating these forces. The designer should show the allowable push or pull locations on the plans, as well as the allowable jacking force.

The designer should also layout a schematic falsework plan and details. It is important to demonstrate to the contractor that there is sufficient room to build the bridge alongside the existing bridge. The designer also needs to specify the method for resolving sliding forces in the system, as it will affect the design forces in the permanent bridge. We will demonstrate the importance of this in the following slides.

Section 1: Lateral Slide Systems

Resolution of sliding forces – with connection to substructures

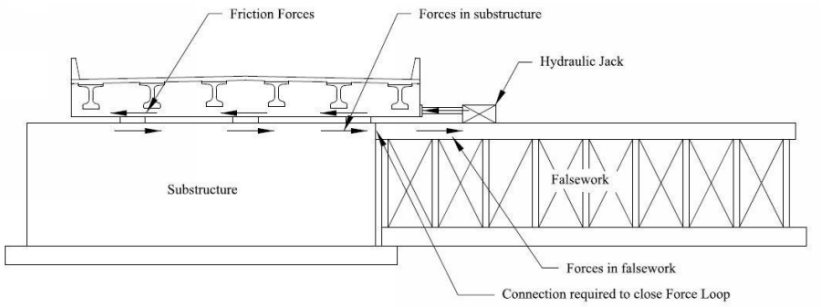


Figure 1.6.1.4-1—Falsework Connected to Substructure (Resolution of Friction Forces)

If the temporary falsework is horizontally connected to the permanent substructure, the friction forces induced in the system during the move are easily resolved, resulting in no horizontal forces in the falsework or the substructure.

Depending on the slide system used, there are several ways to achieve this. The falsework can be physically connected to the substructure. a continuous slide track can also be used to transmit the forces from the slide back to the jacking system.

If this approach is used, the designer needs to clearly specify this on the contract plans or in the specifications.

Section 1: Lateral Slide Systems

Resolution of sliding forces – without connection to substructures

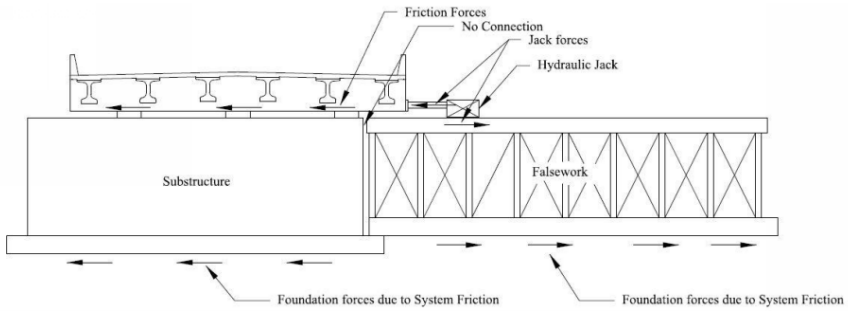


Figure 1.6.1.4-2—Falsework not Connected to Substructure (Resulting in Additional Foundation Forces)

If the falsework is not connected to the substructure, or if a continuous slide track is not used, the sliding process will induce horizontal forces into both the falsework and the substructure.

In this case, the designer would need to design the substructure elements for the horizontal friction forces. The contractor would also need to design the falsework for the horizontal friction forces.

For this reason, this option should only be used if necessary as it may increase the cost of the substructure and the falsework.

Section 1: Lateral Slide Systems

Contractor responsibilities

- Design of falsework and sliding system
- Final design of jacking forces and jacking locations
- Detail the sliding system
- Develop methods to monitoring movement during the slide

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Lateral slide systems involved a significant amount of temporary works. This falls under the realm of contractor means and methods, therefore there are design responsibilities for the contractor.

In general, the contractor needs to design the falsework and the sliding system. Once the jacking system is selected by the contractor, he/she would need to calculate the anticipated jacking forces and verify that they are within the specified limits determined by the designer.

The contractor is also responsible for detailing the sliding system, as well as developing methods to monitor movement during the slide. The loss of geometric control has been the source of issues with lateral slide projects. Through continuous monitoring during the move, these problems can be easily avoided. It should be noted that this requires continuous monitoring, but not excessive accuracy.

Load Factors for Lateral Slide Systems

2.4.3—BRIDGE SYSTEMS—LATERAL SLIDE INSTALLATION

Dynamic effects on the bridge structure for lateral slide installations are not significant due to the relative speed of the move and the systems 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 forces consist of static friction and dynamic friction.

Vertical dynamic effects associated with lateral sliding may be ignored in the design of the bridge and falsework. Horizontal sliding forces and vertical jacking forces can be considered construction loads as specified in the *AASHTO LRFD Bridge Design Specifications*.

C2.4.3

The document *Guidelines for Dynamic Effects during Bridge System Installations* (Culmo, et al. 2017), is recommended for use in calculating static and dynamic forces during lateral slide installations.

Article 2.4.3 of the Guide Specifications for ABC contains recommended load factors for lateral slide systems. This article notes that vertical dynamic effects can be ignored since the bridge is in a quasi static state during the entire slide.

This article also notes that the horizontal sliding forces and vertical jacking forces can be considered construction loads as defined in the AASHTO LRD Bridge Design Specifications.

Slide Equipment Technologies

Jacks

- Advantages
  - Can push and pull (reverse direction)
  - High capacity
- Disadvantages
  - Expensive
  - Can be slow as jacks need to reset often
  - Still relatively fast

We will now review the typical equipment that is used for lateral slide bridge systems. There is no one perfect system for sliding bridges. Each equipment type has advantages and disadvantages. The designer should allow the contractor to select the slide equipment in the project specifications.

The first is horizontal jacking equipment. This can be done with pull jacks and threaded rods, or push-pull hydraulic cylinders mounted on a slide frame or slide track. The two photos show two different Jack systems.

In the upper photo, the hydraulic ram anchors to the welded angles on the side of the slide track to push against. After a push is completed, the Jack will pull forward and reset to the next anchor. Then the process is repeated. The lower photo shows a similar system, with the Jack anchored to slots in the slide track.

The advantages of jacks is that they can produce large forces, and can operate in a push or pull direction. This is advantageous in the control of geometry during the slide.

The disadvantage of this equipment is that it can be more costly compared to other systems and it provides a relatively slow slide process as the jacks need to be reset on a regular basis. This is not a significant issue as the total slide time is still reasonable.

Slide Equipment Technologies

Cable Systems

- Advantages
  - Less expensive
  - Can be very fast
- Disadvantages
  - Can’t push on a cable (may need multiple winches)
  - Less fine control

The second type of equipment that is used for lateral slide systems involves the use of cables and winches.

The advantage to cable systems is that they are often less expensive and can move the bridge quickly if needed.

The disadvantages of cable systems as they only work in one direction. If the contractor needs to adjust the bridge during the slide horizontal jacks or a dual cable system may be required. Another disadvantage of cable systems is that there is less fine control of the slide. Stretching of the cables can make it very difficult to stop the bridge at a specific location. Again, horizontal jacks may be required to finetune the final stop position.

Slide Equipment Technologies

Slide bearings

- Advantages
  - No slide track required
- Disadvantages
  - Limited capacity
  - Can be difficult to control geometry

There are several different types of bearings used to support the bridge during the slide. One popular device are slide bearings manufactured with elastomer topped with PTFE. There are several different options for lubricating the bearings during this slide to reduce friction. These bearings can be used without lubrication, as PTFE is a low friction material. It is important to use a smooth stainless steel interface with the PTFE to reduce friction.

Often contractors will use lubricants to reduce friction forces. A popular choice is to use dishwashing liquid. Research completed under NCHRP Project 12-98 show that this liquid can reduce friction, however there are other options that work better, including motor oil and grease used to lubricate bridge bearings.

The advantages of slide bearings is that a slide track is not necessarily required. Some contractors have chosen to use a slide track with these bearings to control geometry.

The disadvantages of slide bearings is that they sometimes have limited vertical capacity, and a potential loss of geometry control if a slide track is not used.

Slide Equipment Technologies

Rollers

- Advantages
  - Low coefficient of friction
  - Works well with simple track
  - High capacity
- Disadvantages
  - Requires rental or purchase = $$

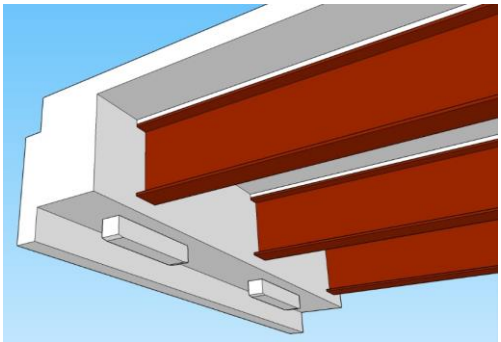
An option to slide bearings is the use of rollers. There are several manufacturers that make rollers to move heavy equipment including bridges.

The photo on the right shows a common roller system that is used. The roller system is similar to a tank tread. The device also has side rollers that can bear against the side of the track to control geometry.

The advantages of roller systems include low coefficients of friction and high vertical capacity.

The disadvantage is that they can be more expensive than slide bearings in some situations.

Recommended Details



The following slides show recommended details for bridge ends for lateral slide systems.

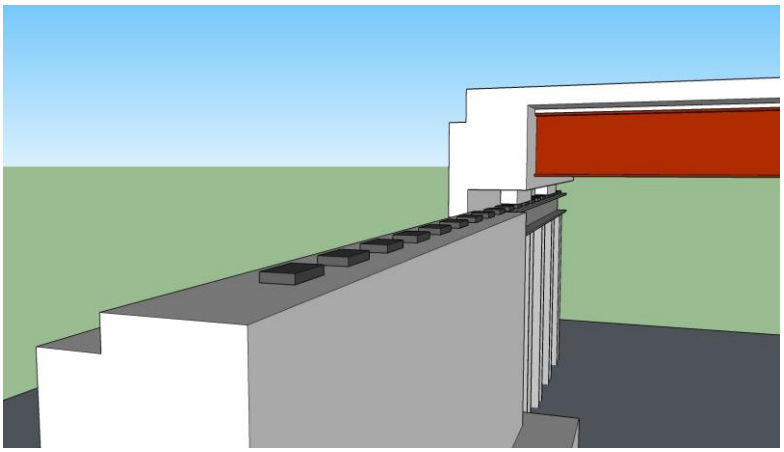
The sketch on the right shows a layout that was developed In Utah. These details facilitate the use of all the different slide systems shown on the previous slides. By using these details, the contractor is given options for designing the slide system, which can result in savings to the overall cost of the project. The underside of the end diaphragm is detailed with concrete slide shoes. These shoes are integrated into the diaphragm concrete via reinforcing. If slide bearings are used, they are typically located under the slide shoes. The permanent bridge bearings are also placed under the slide shoes. If rollers are used, they can be placed under the slide shoes or between the slide shoes. The space between the slide shoes can also be used for vertical jacking of the bridge when setting the permanent bridge bearings.

The projection of concrete at the back of the diaphragm overlaps the rear face of the abutment below. This prevents ground moisture from leaking onto the bridge seat.

Another advantage of this detailing is that the total number of bridge bearings can be reduced. The sketch shows three girders that can be supported by two bearings. Similar reductions would occur for wider bridges.

The photo to the left shows a bridge in Rhode Island being installed using these details.

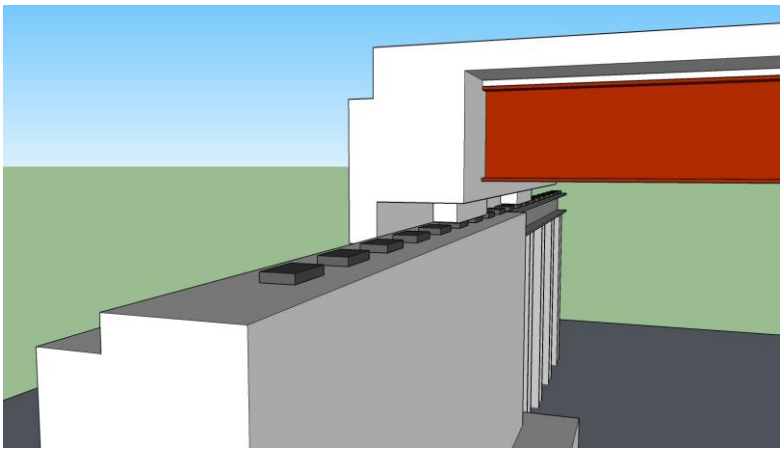
Simplified Lateral Slide Details



The following slides show the process of moving a bridge using these details combined with slide bearings. In this case, designers typically embed stainless steel plates on the bottom of the slide shoes to reduce friction. Designers can show stainless steel on the plans as an option. The stainless steel can be omitted if roller systems are used.

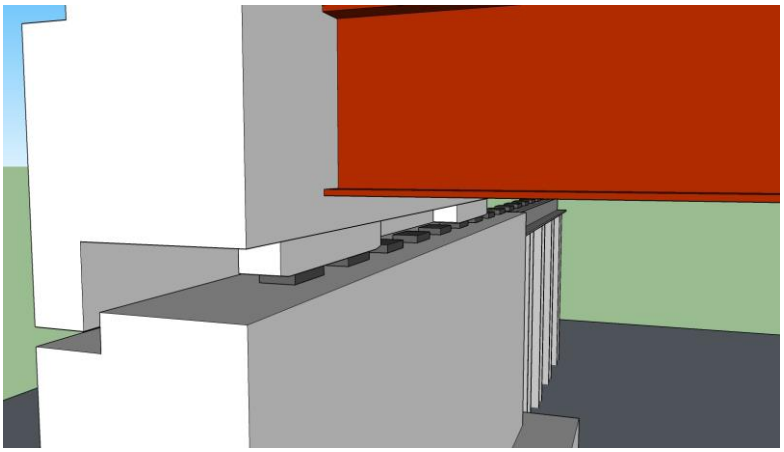
The bridge starts out on the temporary falsework with the slide bearings laid out in front of the move. It is important to note that these slide surfaces be detailed as level. This is to minimize slide forces and to provide better control of the slide.

Simplified Lateral Slide Details



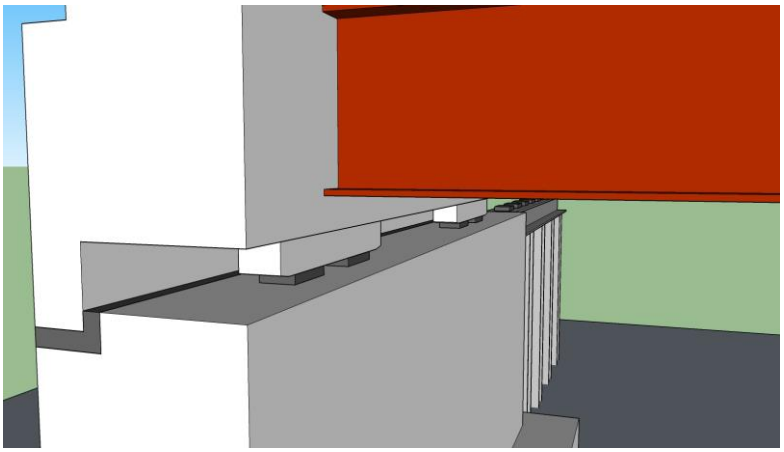
At this point the bridge is starting to move forward. Contractors typically move the bearings from the back to the front in a leapfrog fashion to reduce the total number of slide bearings.

Simplified Lateral Slide Details



At this point the bridge is in its final horizontal position. If a slide track is used, the contractor would then jack the bridge vertically and remove the slide track. If sliding bearings are used, the bridge would be jacked vertically and the temporary bearings would be removed.

Simplified Lateral Slide Details



This sketch shows the bridge in its final position after the installation of the permanent bridge bearings.

A compressible foam seat can be placed prior to setting, where the concrete diaphragm overlaps the abutment. Foam can also be placed in the gap between the diaphragm and the abutment seat after the bridge is set.

This sketch shows concrete below the concrete diaphragm overlap. This is not necessary as the diaphragm can be placed on the foam sitting on compacted soil. If this approach is used, the abutment detailing is quite simple, as it will be a rectangular pillar.

End of Module 4

Available Modules

Non-seismic

1. General Provisions and Common Connections
2. Substructure Design
3. Superstructure Design
4. Bridge Systems
5. Durability of ABC Designs
6. ABC Construction Specifications

Seismic

7. Introduction to ABC Seismic
8. Seismic Connection Design and Detailing
9. Seismic Pocket and Socket Connections
10. Seismic Integral Connections

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