DEVELOPMENT OF MULTIUSE SEISMIC DESIGN DIRECTIVE FOR UTA COMMUTER RAIL AND LIGHT RAIL PROJECTS

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ABSTRACT

Because of unique conditions at 31 bridge sites on Utah Transit Authority's (UTA) Mid-Jordan Light Rail and FrontRunner South Commuter Rail Projects, Parsons developed a Multiuse Seismic Design Directive that was used for the design of bridges on both rail lines. This paper presents the basis for the development of the 3-tier criteria which covers: 1) Bridges that carry E-80 Freight Rail loading - whether or not they may also carry Commuter Rail (CR) or Light Rail (LR) loading; 2) Bridges that carry CR or LR loading only – whether passing over streams, local roads or railroads; and 3) Bridges that pass over State (UDOT) roadways – which must also comply with common highway bridge seismic design criteria. The Multiuse Seismic Design Directive consolidated application of UTA's original seismic design criteria, AREMA Chapter 9 seismic design criteria, UDOT seismic design criteria, and national MCEER/ATC-49 seismic design criteria. This paper also presents case studies that will illustrate the design procedures, challenges and details utilized in applying the Seismic Design Directive to the site specific design of the various types of bridges on both rail lines.

INTRODUCTION

In 2008 the Utah Transit Authority (UTA) began an ambitious program of Light Rail (LR) and Commuter Rail (CR) expansion that they labeled “UTA Front Lines 2015 Projects –
Building 70 miles of rail in 7 years” (Figure 1). This program more than doubled the mileage of their current rail systems and involved 6 separate, but related projects, including four LR extensions, one CR extension, and one new Service Center or LR vehicle maintenance facility.
Parsons provided design services for the two longest rail segments, the 44 mile FrontRunner South Commuter Rail Line (FRSCR) extension from Provo to Salt Lake City, UT and the 10.6 mile Mid-Jordan Light Rail Line (MJLR) double track extension to Daybreak, UT. The MJLR Project has 7 track support bridges and the FRSCR Project has 24 that each required seismic design to various criteria.

Because the MJLR Line utilizes a former freight rail right-of-way and must continue to accommodate freight rail traffic, 4 of the 7 bridges support both freight rail and light rail traffic (Figure 2) while the remaining 3 bridges support light rail traffic only. One LR only bridge (Figure 3) and one dual traffic bridge pass over Utah Department of Transportation (UDOT) roadways.

The separate FRSCR Line closely parallels the Provo to Salt Lake City, UT portion of Union Pacific Railroad’s (UPRR) main line between Denver, CO and Salt Lake City, UT and utilizes a portion of UPRR right-of-way that UTA purchased from the UPRR in 2002. Because of tight geometric constraints under some overhead crossings and through the Jordan River Narrows canyon area, the UPRR main line had to be relocated at several locations. Because of these relocations and because of the need to maintain UPRR access to several industries on the opposite side of the FRSCR Line, 1 bridge on the FRSCR Project supports both freight rail and commuter rail traffic, 4 bridges support freight rail traffic only, and the remaining 19 bridges support commuter rail traffic only (Figure 4). Of these 24 FRSCR Line bridges, 12 pass over State highways (Figure 5).
Following UTA contract requirements, Parsons located the lead design team for both projects in UTA’s headquarters in Salt Lake City, UT. Due to the relatively large number of bridges on the two lines and the short time frame for design completion, Parsons also assigned design responsibility for many specific bridges to staff in several other Parsons and subconsultant design offices located throughout the US.

While all designers were experienced bridge engineers and worked under the direction of a Structures Design Manager, there were varying levels of experience with rail bridges and seismic design procedures. Even so, there still was a number of strong divergent opinions as to which seismic design criteria should be followed and on how they should be applied.

To complicate things, UTA’s original bridge design criteria stipulated that seismic design of all structures should follow the American Railway Engineering and Maintenance-of-Way Association (AREMA) Chapter 9 seismic design criteria and UDOT seismic design criteria, applicable to highway bridges. Ongoing discussions with UTA and UDOT confirmed that all structures that carry UTA rail traffic only and/or all structures that cross over UDOT right-of-way must comply with the UDOT seismic design criteria which referenced MCEER/ATC-49 at the time.

It soon became clear to the Structures Design Managers from both projects, that to eliminate confusion over the application of the various seismic design criteria and to unify as many of the strong opinions as possible, a consensus building seismic design workshop would have to be conducted. Thus, one or two lead bridge design engineers from each office were brought into the UTA Salt Lake City, UT Design Office for an all-day seismic design workshop.

This paper presents the basis for the development of the Multiuse Seismic Design Directive (MSDD) that resulted from the workshop and was used for both the MJLR and FRSCR Projects. This MSDD covers: 1) Bridges that carry E-80 Freight Rail loading,
whether or not they may also carry CR or LR loading; 2) Bridges that carry CR or LR loading only, whether passing over streams, local roads or railroads; and 3) Bridges that pass over State (UDOT) roadways, which must also comply with common highway bridge seismic design criteria. Thus the MSDD consolidated application of UTA’s original seismic design criteria, AREMA Chapter 9 seismic design criteria, UDOT seismic design criteria, and national MCEER/ATC-49 seismic design criteria.

THE UTA SEISMIC DESIGN DIRECTIVE

The UTA Multiuse Seismic Design Directive (MSDD), presented in Figure 6, was reviewed and approved by UTA and UDOT, led to compatibility revisions to the UTA design criteria, and was used to modify the UDOT seismic design criteria for the design of track support bridges on the UTA Mid-Jordan Light Rail and FrontRunner South Commuter Rail Projects. This directive also clarifies what design specification is applicable to each particular bridge and helped to resolve conflicts between guidelines.

THE MULTIUSE SEISMIC DESIGN DIRECTIVE BASIS OF DEVELOPMENT

General

The UTA MSDD was developed in 2008 and thus, was based on the 2007 AREMA Manual of Railway Engineering, Chapter 9 (2) and other design criteria current at the time. Even though little change is apparent to articles referenced by the MSDD in the 2013 edition of the AREMA Manual, some modification would likely be required to adapt it to current standards. The approach described herein, however, is reasonable for such an update and is also appropriate for an adaptation to accommodate the current requirements of UDOT, now AASHTO based (5), or any other specific State DOT’s seismic design criteria.

This section provides a description of the rationale or basis for each Article in the UTA MSDD presented in Figure 6.
1.0 INTRODUCTION

1.1 Multiple Use Criteria (Freight Rail, Commuter Rail, and Light Rail)

1.1.1 All Structures: AREMA Manual Chapter 9 seismic level 1 requirements must be satisfied for all structures. AREMA Manual Chapter 9 seismic level 3 detailing requirements shall also be satisfied for all structures.

1.1.2 Structures Impacting State Routes: UDOT “Life Safety” performance level requirements, per UDOT seismic design criteria and MCEER/ATC-49, shall be satisfied for underpasses crossing over state routes and walls within fifty feet of UDOT right-of-way.

1.1.3 Commuter Rail or Light Rail Only Structures: Structures carrying commuter rail or light rail only shall also be analyzed to ensure UDOT “Life Safety” performance level requirements are met.

1.2 Definition of Ordinary (Regular) Bridges – See MCEER/ATC-49 Table 5.4.2.1-1
2.0 DEMANDS ON STRUCTURE COMPONENTS

2.1 AREMA Chapter 9 Requirements for all Multiple Use Structures

2.1.1 Ground Motion Representation

2.1.1.1 Spectral Acceleration – Use site specific 40% probability in 50 year curves.
2.1.1.2 Vertical Ground Motion – Ignore for level 1 ground motions.
2.1.1.3 Load Combinations – per AREMA Manual 9-1.4.5.3.c, 9-1.4.5.4.c, & 9-1.4.6.
2.1.1.4 Damping – Use 10% Damping per AREMA Manual 9-1.4.4.2.

2.1.2 Force Demand

2.1.2.1 Level 1 Design – All elements shall be designed to remain elastic for all forces generated by level 1 ground motions. Response modification factors shall not be applied to forces generated by level 1 ground motions.

2.1.2.2 Level 3 Detailing Requirements

2.1.2.2.1 Moment Demand – Column design for level 3 moment is not required by AREMA.
2.1.2.2.2 Shear Demand on Concrete Columns – Determine by the lesser of the requirements of AREMA Manual 9-1.4.7.2.1.a.(7) & (8) or the level 3 shear.
2.1.2.2.3 Demands of Capacity Protected Members – Per AREMA Manual 9-1.4.7.3.1.

Figure 6 (Continued) – UTA Commuter Rail/Light Rail Seismic Design Directive
2.2 UDOT Requirements for Structures Impacting State Routes

2.2.1 Ground Motion Representation

2.2.1.1 Spectral Acceleration – Use site specific 2% probability in 50 year curves. This is the maximum considered earthquake (MCE). For determining seismic hazard levels: $F_{VS1}$ is determined from the site specific response spectra curve at a 1 second period. $F_{ASs}$ is determined from the specific response spectra curve at a 0.2 second period.

2.2.1.2 Vertical Ground Motion – Use site specific 2% probability in 50 year curves

2.2.1.3 Load Combinations – Per UDOT Structures Design Criteria Section 6.3. Include no live load.

2.2.1.4 Damping – Use 10% Damping per AREMA Manual 9-1.4.4.2.

2.2.2 Displacement Demand – Seismic Design and Analysis Procedure (SDAP) E may be used to reduce column size.

2.2.3 Force Demand

2.2.3.1 Moment Demand – Per SDAP D

2.2.3.2 Shear Demand – Per SDAP D

2.2.3.3 Demands of Capacity Protected Members – Per SDAP D

2.3 Commuter Rail or Light Rail Only Structures – Use procedures as outlined in 2.2.
3.0 BOUNDARY CONDITIONS FOR ALL MULTIPLE USE STRUCTURES

3.1 Abutments

3.1.1 Longitudinal stiffness – Use a passive pressure \((P_p)\) of \(2H/3\) ksf per foot of abutment length but no greater than 7 ksf. Use 0.005\(H\) as the soil displacement required to mobilize the full passive pressure. Determine effective stiffness using \(P_p/(0.005H + D_g)\) and account for the bilinear behavior of the soil (see Figure 7.5.2.2-2 in MCEER). Include gaps due to permanent soil deformation and compressibility of joint filler materials in \(D_g\). Include the stiffness of the abutment piles when appropriate.

3.1.2 Transverse Stiffness – Similar to longitudinal stiffness. See MCEER Section 7.5.3 for detailed discussion. Also see Section 7.8.2 of CALTRANS Seismic Design Criteria.

3.2 Piers

3.2.1 Exposed Pile Bents and Drilled Shafts – The soil-structure interaction shall be accounted for in determining stiffness.

3.2.2 Below Grade Pile Supported Foundations

3.2.2.1 Include foundation stiffness per MCEER Section 8.4 for structures impacting state routes and for commuter rail only or light rail only structures.

3.2.2.2 Foundation stiffness may be included for freight rail structures not impacting state routes.

*Figure 6 (Continued) – UTA Commuter Rail/Light Rail Seismic Design Directive*
Multiple Use Criteria (Freight Rail, Commuter Rail, and Light Rail)

Article 1.1.1 All Structures

For all types of rail traffic to be carried, UTA’s design criteria (1) requires that all structures supporting track be designed to meet AREMA Manual requirements, as a minimum, including the seismic design requirements of Chapter 9 (2). When applicable, UDOT requirements (3) are in addition to AREMA’s.

Article 1.1.2 Structures Impacting State Routes

This article is based on the UDOT requirement that bridges going over state routes must also satisfy their seismic design criteria (3). UDOT agreed that only their “Life Safety” requirements needed to be satisfied. While UDOT has a two level criteria for their bridges that references the MCEER/ATC-49 (4) requirements, they allowed us to follow AREMA Manual Chapter 9 requirements (2) for the lower level seismic design (level 1).

Article 1.1.3 Commuter Rail or Light Rail Only Structures

Vertical and lateral loads for commuter rail and light rail traffic are much lower than those for freight rail traffic. Many on the bridge design team were concerned that if we followed the AREMA Manual’s approach for seismic design of these lighter loaded bridges, the lateral resistance might be insufficient. Thus, to make seismic resistance consistent for all track support bridges on the two UTA Projects, this Article requires that bridges supporting only commuter rail or light rail must also satisfy UDOT “life-safety” requirements.

Ordinary Structures

Article 1.2 Definition of Ordinary (Regular) Bridges

Table 5.4.2.1-1 in MCEER/ATC-49 (4) defines what bridges can be analyzed using the simpler “uniform load” method” or whether a more complex “multi-modal dynamic” analysis must be performed. This table has three parameters:

- The angle subtended by a curved bridge.
- The span length ratio from span to span
- The bent/pier stiffness ratio from span to span

This definition was adopted so that the approach for analysis would satisfy UDOT’s seismic design criteria.

Demand on Structure Components

Part 2.1 AREMA Chapter 9 Requirements for all Multiple Use Structures

Article 2.1.1 Ground Motion Representation As stated in Article 1.1.1, AREMA requirements for level 1 analysis is used for all rail structures. The consensus at the
seismic design workshop was that the longest return period from AREMA’s level one criteria should be used which is a level 1 ground motion with a 40% probability in 50 years. The geotechnical engineers provided site specific response spectra for each bridge site covering this ground motion probability and recurrence interval (See example in Figure 13). Vertical ground motions for level 1 analysis are ignored since the vertical live load effects are greater even for LR loading. It was determined that 10% damping is appropriate in the longitudinal direction for all bridges with continuous rail across the bridge. See Commentary in AREMA Manual, Chapter 9.

**Article 2.1.2.1 Force Demand – Level 1 Design** Since the MSDD covers railroad or track support bridges in all cases, AREMA requirements for level 1 ground motion are to be followed. All elements are to respond elastically to the forces induced by the level 1 ground motions.

**Article 2.1.2.2 Force Demand – Level 3 Detailing Requirements** Also as stated in Article 1.1.1, AREMA detailing requirements for level 3 are to be followed for all track support bridges. During the seismic design workshop, we considered meeting the recently updated (prior to 2008) AASHTO guide specifications for seismic design and, even though it may be a relatively simple adjustment, the MSDD is applicable to railroad or track support bridges so AREMA Chapter 9 was used.

**Part 2.2 UDOT Requirements for Structures Impacting State Routes**

**Article 2.2.1 Ground Motion Representation** In this Part, the MSDD modifies and clarifies UDOT level 3 requirements that are not oriented toward railroad bridges. Some of AREMA Chapter 9’s criteria for level 3 analysis must be used.

**Article 2.2.1.1 Spectral Acceleration** This Article describes how the seismic hazard level values can be derived from the site specific response spectra curves for a level 3 ground motion with 2% probability in 50 year as required by UDOT. The geotechnical engineers provided site specific response spectra that covered this ground motion probability and recurrence interval for each bridge site impacting State Routes (See Figure 14).

**Article 2.2.1.2 Vertical Ground Motion** In accordance with UDOT seismic design criteria, this article requires the application of site specific vertical ground motions for level 3 design only.

**Article 2.2.1.3 Load Combinations** UDOT requires the inclusion of live load with seismic load in their load combinations. However, since the MSDD is applicable to track support structures where the probability of a train being on the bridge during a seismic event is low, AREMA Chapter 9 is followed so that the inclusion of live load with seismic load is not required.

**Article 2.2.1.4 Damping** UDOT requires the use of 5% damping, but that is not oriented toward railroad bridges supporting continuous rails. Thus again, 10% damping
is appropriate in the longitudinal direction for all rail bridges.

**Article 2.2.2 Displacement Demand** Seismic Design and Analysis Procedure E (SDAP E) is a displacement analysis approach defined in the MCEER/ATC-49 seismic design criteria that is accepted by UDOT. This provision allows the use of a displacement approach for level 3 seismic design that may result in a smaller column size. The current AASHTO guidelines (5) have simplified procedures for using a displacement analysis approach that may reduce the design effort further.

**Article 2.2.3 Force Demand** Seismic Design and Analysis Procedure D (SDAP D), Elastic Response Spectrum Method, is a one step design procedure using an elastic (cracked section properties) analysis that is also defined in the MCEER/ATC-49 seismic design criteria and is accepted by UDOT. This approach is stipulated in the MSDD to promote design approach uniformity and reduce design time.

**Part 2.3 Commuter Rail or Light Rail Only Structures**

To accommodate UTA's refined design criteria, this Article requires that commuter rail or light rail only bridges follow the same procedures as required for bridges impacting State routes. This also creates a loop hole for bridges carrying freight traffic that do not impact State routes. These need only satisfy AREMA Chapter 9 seismic requirements.

**Boundary Conditions for All Multiple Use Structures**

**Part 3.1 Abutments**

**Article 3.1.1 Longitudinal Stiffness** Section 3.0 of the MSDD defines what to use for boundary conditions. The effects of the rails are not included in the boundary conditions due to lack of guidance in any of the seismic design criterias. Only the effects of soil around the abutments and piles are included.

MCEER gives some appropriate guidance on how to account for the soil stiffness. Being railroad track support structures, however, the abutment backwalls invariably are very stout due to the high surcharge loads from daily train traffic which also causes continual compaction of the soil behind abutments. This will prevent the backwalls from breaking away during a level 3 earthquake to reduce the seismic loads transferred into the abutments. The passive resistance of the soil behind the full height of the abutment, however, is mobilized allowing most of the longitudinal seismic load to transfer directly into the soil. Because of the continual compaction, the geotechnical engineers recommended the use of the 0.005 factor, instead of MCEER's 0.02, in the formula for calculating the soil displacement required to mobilize the full passive resistance.

The MSDD also includes the stiffness of piles because the passive resistance behind the abutments will not always resist the entire longitudinal seismic load..
Article 3.1.2 Transverse Stiffness  In Article 3.1.2, the MSDD is directing the designer to guidance. CALTRANS Seismic Design Criteria (6) is helpful. The boundary conditions have a large effect on the design. More detailed guidance from AREMA on how to account for the rail would be helpful. Thus, the effects of the rails are ignored.

Part 3.2 Piers

Article 3.2.1 Exposed Pile Bents and Drilled Shafts  This Article delineates the appropriate approach for pier or bent design and multi-modal analysis.

Article 3.2.2 Below Grade Pile Supported Foundations  In this Article, the MSDD is directing the designer where to look for guidance and indicating that it is acceptable to also use this criteria for the design of freight rail track support structures.

APPLICATION OF THE UTA MULTIUSE SEISMIC DESIGN DIRECTIVE

Mid-Jordan Light Rail Line Case Studies

To illustrate the design procedures, challenges and details utilized in applying the MSDD to the site specific design of the various types of bridges on both rail lines, specific bridge case studies from the MJLR Line are presented herein. Essentially identical procedures and details were utilized on the FRSCR Line.

Three Types of Seismic Design

As addressed in the MSDD, there are three types of track support bridge seismic design that needed to be performed on the MJLR Line:

Type 1: Freight E-80/LRT Loading, AREMA Chapter 9 Seismic Design Only
Type 2: LRT Loading Only, AREMA Chapter 9 plus MCEER/ATC-49 (Light Rail) Seismic Design
Type 3: Over State Road, AREMA Chapter 9 plus MCEER/ATC-49 (Light Rail and/or Freight E-80) Seismic Design

Bridge Configurations and Girder & Bent Types

Type 1 – 3 Bridges

- Jordan River Bridge – Straight bridge with curved track – See Figures 7 & 8
  - 3 spans of 2 double cell concrete box girders per span.
  - 2 exposed pile bents with normal pile orientation including battered piles and cross bracing.
- Utah & Salt Lake Canal Bridge
  - 1 Span of 2 double cell concrete box girders per span.
  - No bents.
- Winchester Street Bridge
- 3 Spans of 4 staggered single cell concrete box girders per span.
- 2 exposed pile bents with 18 degree skew, normal pile orientation, non-battered piles, and cross bracing.

**Type 2 – 2 Bridges**

- 700 West Bridge
  - 4 Spans of 2 double cell concrete box girders per span.
  - 3 exposed pile bents with rotated pile orientation, non-battered piles, and no cross bracing.
- 7800 South Bridge – Straight spans corded along curved track
  - 5 Spans of steel wide flange rolled beams with cast-in-place composite concrete ballast deck.
  - 4 cast-in-place concrete bents with 2 columns, up to 50 degrees of skew, and drilled shaft foundations.

**Type 3 – 2 Bridges**

- 7200 South Bridge – See Figures 9, 10, 17 & 19
  - 4 Spans of 2 double cell concrete box girders per span.
  - 3 exposed pile bents with rotated pile orientation, non-battered piles, and no cross bracing.
- Bangerter Highway Bridge – See Figures 11, 12, & 18
  - 2 Spans of 4 staggered single cell concrete box girders per span.
  - 1 cast-in-place concrete bent with 1 column, 21 degree skew, and drilled shaft foundation.
Seismic Design Challenges

Different types of design challenges were encountered with each bridge configuration and with each type of seismic design that needed to be performed. The greatest challenges were with the Type 2 and Type 3 seismic designs. The primary challenges encountered included the following:

Type 1 Challenges

- Many designers needed to become familiar with AREMA Chapter 9
Limited detailing guidance for exposed pile bents

Type 2 & 3 Challenges

- Many designers needed to become familiar with MCEER/ATC-94.
- Ensuring all design offices working on the project understood and appropriately applied the UTA MSDD.
- Meshing MCEER/ATC-94 with AREMA Chapter 9 and UTA Light Rail Design Criteria.
- Ensuring AREMA Chapter 9 criteria was met at a minimum.
- Minimizing seismic design cost increase from base-line design – typically a 25% to 33% increase in number of piles was required.
- The need to increase pile or substructure capacity in the transverse direction – frequently accommodated by rotating the abutment and/or bent pile orientation by 90 degrees.
- The need to increase girder translation restraint capacity in the transverse direction – frequently accommodated by replacing the UPRR/BNSF Standard side restrainer brackets with stronger concrete shear blocks.
- The need to increase exposed pile bent capacity in the longitudinal and transverse directions and to ensure that piles remain elastic below grade during a major seismic event where inspections can not easily be performed – frequently accommodated by utilizing or increasing the depth of cast-in-place concrete bent collars to increase the passive resistance provided by the adjacent soil.
- Including and accommodating vertical acceleration into the seismic design.
- Many designers needed to become familiar with multi-modal analysis and software utilization.

Geotechnical Input and Seismic Design Procedures Utilized

Seismic Design Response Spectra

In conformance with the MSDD, the geotechnical engineers provided site-specific seismic response spectra curves for level 1 ground motion with a 40% probability in 50 years and for level 3 ground motion with a 2% probability in 50 years for each bridge site. These response spectra were adjusted for site coefficient, S, and for fault proximity. Vertical acceleration curves were included that were corrected for a minimum of 80% of horizontal. See Figures 13 and 14 for example site-specific seismic response spectra curves that were provided for the 7200 South Bridge.

Abutment Passive Pressure and Stiffness

In conformance with Article 2.2.2, Article 2.2.3, and Article 3.1.1 of the MSDD, MCEER/ATC-49 Seismic Design and Analysis Procedures D & E and the effective passive stiffness formula, $P_p/(0.005H+D_g)$, were used for level 3 seismic design of the Type 2 & 3 bridge abutments. This is also per the geotechnical engineer which
recommended that 0.005H deflection be used instead of 0.02H. These procedures are described in MCEER/ATC-49 Article 7.5.2.2 with MCEER/ATC-49 Figure 7.5.2.2-2 providing the “Characterization of Abutment Capacity and Stiffness” for “Seat Abutments” of the type used for rail bridges (See Figure 15).
**Figure 14 – MJLR Line 7200 South Bridge Design Response Spectra**

2% Probability in 50 Years

**Figure 15 – MCEER Figure 7.5.2.2-2 – Abutment Capacity and Stiffness**
Most of the bridges on UTA’s MJLR and FRSCR Lines are concrete box girder bridges patterned after the BNSF/UP Standard concrete trestle plans (7). As such, most bridges use joint filler packed tight between spans and abutments as shown in Figure 16. While this joint filler is slightly compressible and can not be initially installed perfectly tight in all joints, the high surcharge loads induced on the abutment backwalls by the everyday train traffic causes a continual tightening of the joint fillers. Because of this, the gap width, $D_g$, was assumed to be no greater than 1/8 inch to 1/4 inch. This allows the box girder spans to act as a strut between abutments and to transfer most of the longitudinal loads to the abutment backwall for passive resistance. This accounted for 60% - 80% of bridge longitudinal resistance.

![Figure 16 – UTA Concrete Box Girder Span Abutment Back Wall Configuration](image)

**Seismic Design Details Utilized**

**Type 1 Bridges**

All Type 1 concrete box girder span bridges essentially followed the BNSF/UP Standard concrete trestle plans (7) for all span, abutment, and bent elements and required no special details to accommodate seismic design criteria. See photos of the Jordan River Bridge in Figures 7 & 8 above.

**Type 2 & 3 Bridges**
Rotating Abutment and/or Bent Pile Orientation 90 Degrees  In order to increase pile or substructure capacity in the transverse direction to accommodate seismic design requirements, abutment or bent piles were rotated 90 degrees from the typical or standard orientation. See the partial Pile Plan for the 7200 South Bridge in Figure 17 and the bent photo in Figure 10 above.

**Figure 17 – 7200 South Bridge – Partial Pile Plan**

Concrete Shear Block Girder Restrainers  In order to increase girder translation restraint capacity in the transverse direction to accommodate seismic design requirements and to provide stability to deep single cell box girders, heavy concrete shear blocks were added beside the girders on bent cap ends. See the bridge Section View for the Bangerter Highway Bridge in Figure 18, the bridge Section View for the 7200 South Bridge in Figure 19, and the girder and bent photos in Figures 10 & 12.
Cast-in-Place Concrete Bent Collars  In order to increase exposed pile bent capacity in the longitudinal and transverse directions and to ensure that piles remain elastic below grade during a major seismic event, cast-in-place concrete bent collars were added or had their depth increased to provide additional passive resistance against the adjacent soil. The collars also will force the plastic hinge failure point of the pile to occur above grade and above the top of the collar where inspections can be performed following a major seismic event. See the bridge Section View for the 7200 South Bridge in Figure 19 and the girder and bent photo in Figure 10 above.
Figure 19 – 7200 South Bridge – Section View
CONCLUSION

When undertaking a large rail project involving the design of many track support bridges in a high seismicity zone, conducting a seismic design workshop to build consensus among the members of a large design team will save considerable design time and provide uniformity of seismic design process and details incorporated into the project. This should be conducted very early after project startup and lead to development of a Seismic Design Directive that will consolidate application of the rail client’s or agency’s seismic design criteria, AREMA Chapter 9 seismic design criteria, State DOT seismic design criteria, AASHTO’s seismic design criteria and national MCEER/ATC-49 seismic design criteria, as applicable.

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DEVELOPMENT OF MULTIUSE SEISMIC DESIGN DIRECTIVE FOR UTA COMMUTER RAIL AND LIGHT RAIL PROJECTS

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INTRODUCTION

Building 70 miles of rail in 7 years

- Begun in 2008
- Four Light Rail Expansions
- One Commuter Rail Expansion
- One Light Rail Service Center

PARSONS DESIGN SERVICES

FrontRunner South Commuter Rail
- 44 Miles
- Salt Lake City to Provo

Mid-Jordan Light Rail Line
- 10.6 Miles
- Double Track

Mid-Jordan Light Rail Line

Utilizes Former Freight Rail ROW
- Continues to accommodate freight rail
- 7 Track Support Bridges
- 4 Bridges support freight & light rail traffic
- 3 Bridges support light rail traffic only
- 2 Bridges (1 Each Type) pass over UDOT Roadways

FrontRunner South Commuter Rail Line

Parallels Union Pacific Railroad Main Line
- Separate UTA ROW purchased from UPRR
- Some UPRR Main Line Relocations Required
- 24 Track Support Bridges
- 1 Bridge supports freight & commuter rail traffic
- 4 Bridges support freight rail traffic only
- 19 Bridges support commuter rail traffic only
- 12 Bridges pass over UDOT Roadways
INTRODUCTION

FrontRunner South Commuter Rail Line

INTRODUCTION

What Seismic Design Criteria Should Be Used For Both Projects?

- Lead Staff In UTA’s SLC HQ Office
- Utilized Several Design Offices Nationwide
- Varying Levels of Experience With Seismic Design and Railroad Bridges
- Still, Strong Divergent Opinions
  - Which Seismic Criteria to Use
  - How to Apply the Criteria

INTRODUCTION

Seismic Design Workshop

- Lead Designers Brought In From All Offices
- All Day Workshop
- Unify Divergent Opinions
- Eliminate Confusion Over Application
- Initial Basis for Multiuse Seismic Design Directive
  - Foundation for Approval Discussions with UTA and UDOT

MULTIUSE SEISMIC DESIGN DIRECTIVE

- Reviewed & Approved by UTA & UDOT
- Led to UTA Design Criteria Compatibility Revisions
- Modifies UDOT Seismic Criteria for Railway Bridges
- UDOT Accepted AREMA Chapter 9 for Level 1
- UDOT Accepted Accommodation of “Life Safety” Requirements Only

MULTIUSE SEISMIC DESIGN DIRECTIVE

Basis of Development

- Developed in 2008
- 2007 AREMA Manual for Railway Engineering, Chapter 9
- UTA / UDOT Coordination Discussions
- UTA Design Criteria as Modified
- UDOT Seismic Criteria with Modification
  - MCEER/ATC-49 (Referenced by UDOT)
MULTIUSE SEISMIC DESIGN DIRECTIVE

1.0 INTRODUCTION

1.1 Multiple Use Criteria (Freight Rail, Commuter Rail, and Light Rail)

1.1.1 All Structures: AREMA Manual Chapter 9 seismic level 1 requirements must be satisfied for all structures. AREMA Manual Chapter 9 seismic level 3 detailing requirements shall also be satisfied for all structures.

Basis of Development

- UTA Minimum All Structures: AREMA Manual Chapter 9 – Level 1 Design, Level 3 Detailing
- UDOT/MCEER In Addition – When Require

1.1.2 Structures Impacting State Routes: UDOT Life Safety performance level requirements, per UDOT seismic design criteria and MCEER/ATC-49, shall be satisfied for underpasses crossing over state routes and walls within fifty feet of UDOT right-of-way.

1.1.3 Commuter Rail or Light Rail Only Structures: Structures carrying commuter rail or light rail only shall also be analyzed to insure UDOT “Life Safety” performance level requirements are met.

Basis of Development

- Over UDOT Roadways: UDOT/MCEER/ATC-49 Life Safety Performance Level Required
- CR/LR Only: UTA Revised - Require UDOT LS

1.2 Definition of Ordinary (Regular) Bridges – See MCEER/ATC-49 Table 5.4.2.1-1

Basis of Development

- Table 5.4.2.1-1 Defines When Simpler Uniform Load Method is Use or When Multi-Modal Dynamic Analysis is Required
- Adopted to Satisfy UDOT Seismic Design Criteria

2.0 DEMANDS ON STRUCTURE COMPONENTS

2.1 AREMA Chapter 9 Requirements for all Multiple Use Structures

2.1.1 Ground Motion Representation

2.1.1.1 Spectral Acceleration – Use site specific 40% probability in 50 years curves.

2.1.1.2 Vertical Ground Motion – Ignore for level 1 ground motions.

2.1.1.3 Load Combinations – per AREMA Manual 9-1.4.5.4.c, & 9-1.4.6.

2.1.1.4 Damping – Use 10% Damping per AREMA Manual 9-1.4.4.2.

Basis of Development

- Geotech Provided Site Specific Response Spectra For Each Bridge - 40% Probability in 50 Years.
- Example 7200 South Bridge

2.1.2 Vertical Ground Motion – Ignore for level 1 ground motions.

2.1.3 Load Combinations – per AREMA Manual 9-1.4.5.3.c, 9-1.4.5.4.c, & 9-1.4.6.

2.1.4 Damping – 10% Longitudinal Damping Appropriate With Continuous Rail Across Bridges.

Basis of Development

- Level 1 Vertical Ignored - Live Load Greater.
2.1.2 Force Demand
2.1.2.1 Level 1 Design – All elements shall be designed to remain elastic for all forces generated by level 1 ground motions. Response modification factors shall not be applied to forces generated by level 1 ground motions.

Basis of Development
- Level 1: AREMA Manual Chapter 9 to be Followed
- AREMA & UDOT: Elastic Response Required

2.1.2.2 Level 3 Detailing Requirements
2.1.2.2.1 Moment Demand – Column design for level 3 moment is not required by AREMA.
2.1.2.2.2 Shear Demand on Concrete Columns – Determine by the lesser of the requirements of AREMA Manual 9-1.4.7.2.1.a.(7) & (8) or the level 3 shear.
2.1.2.2.3 Demands of Capacity Protected Members – Per AREMA Manual 9-1.4.7.3.1.

Basis of Development
- Specific AREMA Manual Chapter 9 Requirements and Application Clarified

2.2 UDOT Requirements for Structures Impacting State Routes
(Also: 2.3 Commuter Rail or Light Rail Only Structures – Use procedures as outlined in 2.2.)

2.2.1 Ground Motion Representation

Basis of Development
- This Part Modifies & Clarifies UDOT Level 3 Requirements for Application to Rail Bridges.
- Some AREMA Chapter 9 Level 3 Criteria For Analysis Must be Used.
- UTA Design Criteria for CR & LR Only Bridges Revised to Match Modified UDOT.

2.2.1.1 Spectral Acceleration – Use site specific 2% probability in 50 year curves. This is the maximum considered earthquake (MCE). For determining seismic hazard levels: FvS1 is determined from the site specific response spectra curve at a 1 second period. FaSs is determined from the specific response spectra curve at a 0.2 second period.

Basis of Development
- 2% Probability in 50 Years - UDOT Level 3 Requirement.
- Describes Derivation of Seismic Hazard Level Values.

2.2.1.2 Vertical Ground Motion – Use site specific 2% probability in 50 year curves.
2.2.1.3 Load Combinations – Per UDOT Structures Design Criteria Section 6.3. Include no live load.
2.2.1.4 Damping – Use 10% Damping per AREMA Manual 9-1.4.4.2.

Basis of Development
- Level 3 Vertical - Use Site Specific
- Load Combinations - UDOT but No Live Load
- Damping - Modify UDOT for Rail Bridges - 10% Longitudinal Damping - Continuous Rail
MULTIUSE SEISMIC DESIGN DIRECTIVE

2.2.2 Displacement Demand – Seismic Design and Analysis Procedure (SDAP) E may be used to reduce column size.

Basis of Development
- SDAP E: Displacement Analysis Approach for Level 3 Seismic Design
- Defined in MCEER/ATC-49
- Accepted by UDOT

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2.2.3 Force Demand
- 2.2.3.1 Moment Demand – Per SDAP D.
- 2.2.3.2 Shear Demand – Per SDAP D.
- 2.2.3.3 Demands of Capacity Protected Members – Per SDAP D.

Basis of Development
- Defined in MCEER/ATC-49.
- Accepted by UDOT.
- Promotes Design Uniformity & Reduces Time.

MULTIUSE SEISMIC DESIGN DIRECTIVE

3.0 BOUNDARY CONDITIONS FOR ALL MULTIPLE USE STRUCTURES

Basis of Development
- Section 3.0: Defines Boundary Conditions
  - Soil Around Abutments
  - Soil Around Pier Collars
  - Pile Stiffness
  - Resistance Due to Continuous Rails Excluded Due to Lack of Specific Criteria

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3.1 Abutments
- 3.1.1 Longitudinal stiffness – Use a passive pressure (Pp) of 2H/3 ksf per foot of abutment length but no greater than 7 ksf. Use 0.005H as the soil displacement required to mobilize the full passive pressure. Determine effective stiffness using Pp/(0.005H + Dg) and account for the bilinear behavior of the soil (see Figure 7.5.2.2-2 in MCEER). Include gaps due to permanent soil deformation and compressibility of joint filler materials in Dg. Include the stiffness of the abutment piles when appropriate.

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Basis of Development
- Art. 3.1.1 Longitudinal Stiffness at Abutments:
  - Use Passive Pressure Resistance - 2H/3 ksf But Less Than 7 ksf Max.
  - Use 0.005H Soil Displacement to Mobilize Full Passive Pressure (< 0.02H in MCEER/ATC-49).
  - Geotech Recommended 0.005H Due to Continuous Active Compaction.
  - Gap Distance Dg: Include Permanent Soil Deformation and Joint Filler Compressibility.

MULTIUSE SEISMIC DESIGN DIRECTIVE

Basis of Development
- Art. 3.1.1 Longitudinal Stiffness Continued:
  - Use Pp/(0.005H + Dg) to Determine Effective Stiffness.
  - Account for Bilinear Behavior of Soil - See MCEER/ATC-49 Figure 7.5.2.2-2.

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Basis of Development

Art. 3.1.1 Longitudinal Stiffness Continued:
- With Railroad Surcharge, Abutment Backwalls Very Stout.
- Will Not Break Off During Level 3 Event.
- Full Abutment Height Mobilized for Passive Resistance.
- Most Longitudinal Seismic Load Transfers Directly Into Soil.
- Include Pile Stiffness When Required.

Basis of Development

Directs Designer to MCEER/ATC-49 Guidance.
Caltrans Seismic Design Criteria Helpful.
Transverse Resistance Due to Continuous Rails Excluded Due to Lack of Specific Criteria.

3.2 Piers

3.2.1 Exposed Pile Bents and Drilled Shafts – The soil-structure interaction shall be accounted for in determining stiffness.

Basis of Development

Delineates Approach for Pier or Bent Design.
Delineates Approach for Multi-Modal Analysis.

3.2.2 Below Grade Pile Supported Foundations

3.2.2.1 Include foundation stiffness per MCEER Section 8.4 for structures impacting state routes and for commuter rail only or light rail only structures.

3.2.2.2 Foundation stiffness may be included for freight rail structures not impacting state routes.

Basis of Development

Delineates Where to Find Guidance.
Acceptable to Use This MCEER/ATC-49 Criteria for Any Freight Rail Bridges.

Bridge Configurations and Girder & Bent Types

Type 1 - 3 Bridges (Freight + LR/CR)
- Utah & Salt Lake Canal Bridge:
  - 1 Span - 2 Double Cell Concrete Box Girders
- Winchester Street Bridge:
  - 3 Spans - 4 Staggered Single Cell Concrete Box Girders Per Span
  - 2 Exposed Pile Bents - 18 Degree Skew - Non-Battered Piles - Cross Bracing
**Bridge Configurations and Girder & Bent Types**

**Type 1 – 3 Br.**
- **Jordan River Bridge:**
  - 3 Spans - 2 Double Cell Concrete Box Girders Per Span

**Type 2 – 2 Bridges (LR Only)**
- **700 West Bridge:**
  - 4 Spans - 2 Double Cell Concrete Box Girders Per Span
  - 3 Exposed Pile Bents - Rotated Pile Orientation - Non-Battered Piles - No Cross Bracing - Concrete Base Collars

- **7800 South Bridge:**
  - 5 Spans - 2 Straight Steel Wide Flange Beams - Corded Along Curve - Composite Concrete Deck
  - 4 CIP Concrete Bents - 2 Columns - 50 Degree Max. Skew - Drilled Shaft Foundations

**Type 3 – 2 Bridges (Over UDOT Roads)**
- **7200 South Bridge:**
  - 4 Spans - 2 Double Cell Concrete Box Girders Per Span
  - 3 Exposed Pile Bents - Rotated Pile Orientation - Non-Battered Piles - No Cross Bracing - Concrete Base Collars

- **7200 S. Bridge:**
  - 3 Exposed Pile Bents - Rotated Pile Orientation - Non-Battered Piles - No Cross Bracing - Concrete Base Collars
MULTIUSE SEISMIC DESIGN DIRECTIVE

Application
Bridge Configurations and Girder & Bent Types

Type 3 – 2 Bridges (Over UDOT Roads)
Bangerter Highway Bridge:
- 2 Spans - 4 Staggered Single Cell Concrete Box Girders Per Span

Type 3 – 2 Bridges (Over UDOT Roads)
Bangerter Highway Bridge:
- 1 CIP Concrete Bent
- 1 Column
- 21 Degree Skew
- Drilled Shaft Foundation

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Application
Seismic Design Challenges

Type 1 Bridge Challenges (Freight + LR/CR)
- Becoming Familiar With AREMA Chapter 9
- Limited Exposed Pile Bent Detailing Guidance

Type 2 & 3 Bridge Challenges (LR/CR Only & Over UDOT)
- Becoming Familiar With MCEER/ATC-49
- Ensuring Understanding of UTA Multiuse Seismic Design Directive

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Application
Seismic Design Challenges

Type 2 & 3 Bridge Challenges (LR/CR Only & Over UDOT)
- Minimizing Seismic Design Cost Increase Over Base-Line Design (Typically 25% to 33% Increase in Piles)
- Need to Increase Transverse Pile or Substructure Capacity
- Need to Ensure That Transverse Girder Translation Restraint Capacity

MULTIUSE SEISMIC DESIGN DIRECTIVE

Application
Seismic Design Challenges

Type 2 & 3 Bridge Challenges (LR/CR Only & Over UDOT)
- Need to Increase Transverse & Longitudinal Exposed Pile Bent Capacity
- Need to Ensure That Exposed Pile Bent Piles Remain Elastic Below Grade During Level 3 Event to Accommodate Easy Inspection
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Application
Seismic Design Details

Abutment Passive Pressure Resistance and Stiffness

- Per Geotech and Seismic Design Directive, Passive Stiffness Formula \( P_p/(0.005H+D_g) \)
  Used for Level 3 Seismic Design
- Most Bridges Use Concrete Box Girder Spans Patterned After BNSF/UP Standards
- Joint Filler Packed Tight Between Girder Ends and Stiff Abutment Backwalls

Joint Filler Slightly Compressible

1/8” - 1/4” \( D_g \) Used

Spans Act as Strut Abut. to Abut.

Provide 60% - 80% Longitudinal Resistance

Rotated Abutment and/or Bent Pile Orientation 90 Degrees

- Increases Transverse Pile Capacity
- No Bent Bracing - Replaced by Concrete Collars

Concrete Shear Block Girder Restrainers

- Increases Transverse Girder Translation Restraint Capacity
- Provides Deep Girder Stability

Concrete Shear Block Girder Restrainers

Example: Bangerter Highway Bridge - Section
MULTIUSE SEISMIC DESIGN DIRECTIVE

Application
Seismic Design Details

- Cast-in-Place Concrete Bent Collars
  - Increases Transverse & Longitudinal Exposed Pile Bent Capacity
  - Ensures That Exposed Pile Bent Piles Remain Elastic Below Grade During Level 3 Event

Example: 7200 South Bridge - Section

CONCLUSIONS

- Conduct a Seismic Design Workshop
  - Early Step For Large Project in Seismically Active Zone
  - Builds Consensus With Multi-Office Team

- Develop a Seismic Design Directive
  - Reduce Design Time
  - Provide Uniformity of Seismic Design Process and Details
  - Consolidate Application of Rail Agency, AREMA Chapter 9, State, and National Seismic Design Criteria

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