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**Strategies For Developing a High Performance Structure With Typical Bridge Design Features on a Design-Build Project**

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**February 18, 2002**

# LEGACY PARKWAY SEISMIC DESIGN

STRATEGIES FOR DEVELOPING A HIGH PERFORMANCE STRUCTURE WITH TYPICAL BRIDGE DESIGN FEATURES ON A DESIGN-BUILD PROJECT

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## ABSTRACT

The legacy Parkway Project in Salt Lake City, Utah requires that the structures be designed to perform as “essential” structures and therefore perform under seismic loads such that they can be used soon after the design seismic event. The project is at a site with relatively high ground acceleration (0.6g) and soft soils. This results in applied spectral coefficients of 1.2g.

While this type of performance criterion is usually achieved through rather extravagant and costly designs, the Legacy Parkway design and construct team has achieved such seismic performance of the structures using solutions typical to more common bridges. The initial phase of the design-build process provided an opportunity to complete seismic evaluation and design of typical structures considering a variety of factors such as steel and concrete superstructures, single and multiple column bent configurations, and multiple site soil conditions.

This paper will discuss the approaches used to achieve a high level of seismic performance using typical bridge design elements, and also will discuss some of the value engineering concepts that were developed to achieve the high level of performance using typical, off-the-shelf bridge construction elements.



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## INTRODUCTION

The legacy Parkway Project in Salt Lake City, Utah requires that the structures be designed to perform as "essential" structures and therefore perform under seismic loads such that they can be used soon after the design seismic event. This paper discusses the seismic design approaches used to achieve this level of performance while using traditional and common bridge components.

### Project Description

The Legacy Parkway will be a four-lane, limited-access, divided highway extending approximately 21 kilometers (13 miles) from Interstate 215 (I-215) at 2100 North in Salt Lake City, Utah, northward to Interstate 15 (I-15) and U.S. 89 near Farmington City, Utah. The project will be located in flat topography between the existing I-15 and Union Pacific Railroad corridors and the wetlands east of the Great Salt Lake. The Fluor Ames Kramer Joint Venture began construction of the $330 Million design-build project in the summer of 2001.

The project includes 26 bridges with a combined deck area in excess of 64,000 square meters. All bridges on the project will be constructed with either prestressed concrete girders with maximum spans of 49 meters, or welded steel plate girders for spans of up to 76 meters. The structure type selected for a specific location depended on the bridge geometry, aesthetic considerations, and constraints on construction operations. Both of these structure types are relatively conventional types of construction in the Utah market, and have a proven track record with UDOT.

Substructure components, such as columns and bent caps, are of a standardized design to the maximum extent possible to provide for a maximum economy of repetition to design and construction. Bents are of two types:

- Single column bents with single 2.5 meter octagonal columns and post tensioned bent caps. This type of bent can accommodate cap widths of up to 15 meters.
- Multiple column bents with 1.82 meter octagonal columns and a reinforced concrete bent cap. This type of bent can accommodate cap widths between 15 and 30 meters.

Pot bearings are used on steel plate girder bridges while neoprene bearings are used on prestressed concrete girder bridges. The only exceptions to this are three bents where integral concrete bent caps were used with steel plate girders due to limited vertical clearance over I-15.

Integral abutments are used on all bridges with a total length of 125 meters or less, and seat-type abutments are used on bridges with greater overall lengths.

During the preliminary design of the bridges, efforts were made to eliminate skews on bridges wherever possible. A majority of the abutments and bents are normal to the bridge centerline or have skew angles of less than 15 degrees.

**Figure 1.** Typical two-span precast I-girder structure on the Legacy Parkway project.

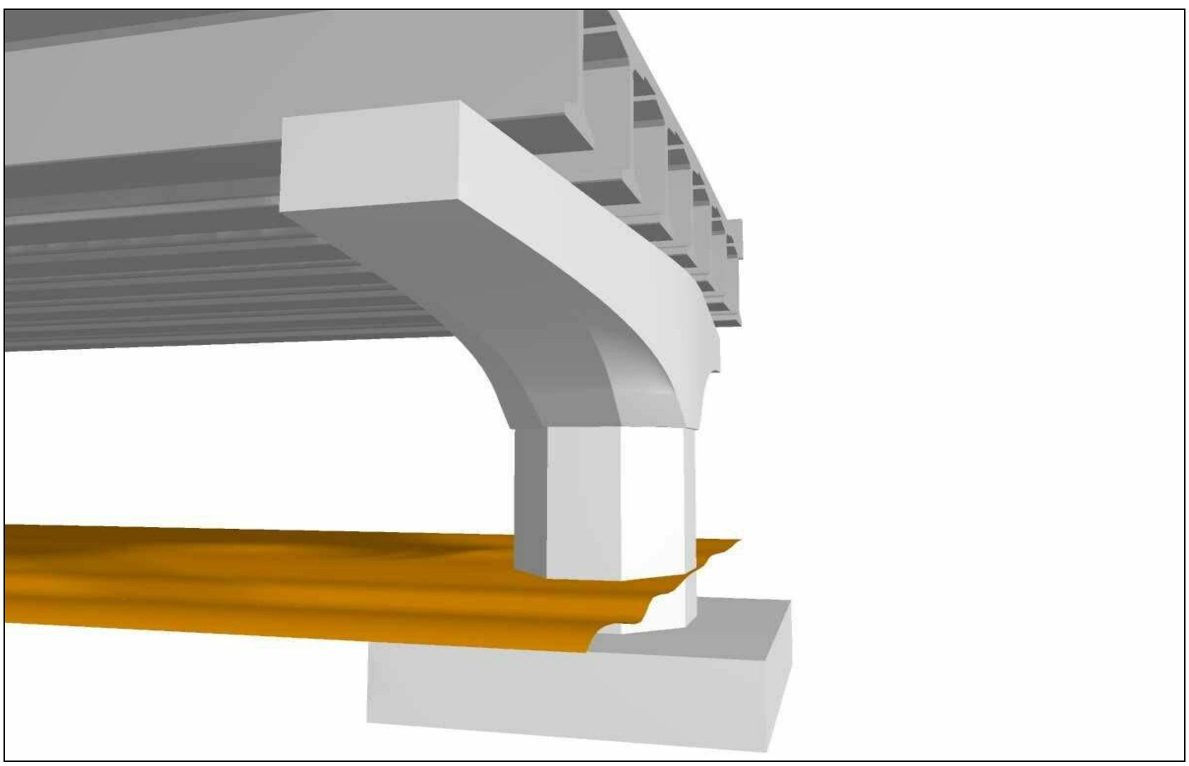

**Figure 2.** Typical Single column bent supporting continuous precast I-girder superstructure.

### Level of Performance

All of the structures are designed as "Essential Bridges" under the definition provided by AASHTO (Division 1-A). The seismic performance level of the structures is "Serviceability", following minor repairs, which may be required, after the event of the "Design Level Earthquake".

### Seismicity

The structures are designed for PGA = 0.6g. AASHTO curves for Type III soil are used to account for soil amplification.

### Seismic Design Strategies

Seismic design of the bridges for the Legacy Parkway project is primarily based on AASHTO, amended by project specific design criteria, which addresses issues not specifically accounted for by the AASHTO code.

In order to achieve the level of performance required three primary seismic design strategies were used:

1. For fixed-end simple span structures the piles were kept essentially elastic. This was achieved through a combination of seismic resistance by the piles and also by the soil at the abutments. In order to develop reliable lateral resistance of the soil in the transverse direction, abutment "fin walls" were incorporated.
2. For multiple span single column structures, a combination of sliding and minor, repairable column damage was permitted.
3. For multiple span, multi-column bent structures, sliding on standard bearing types was used as the fusing device to avoid damage to columns. This was used on structures that are relatively short, and therefore subjected to high shear loads in the columns and foundations if the superstructure to substructure connection is fixed or pinned.

These strategies were applicable in large extent because of the fundamental approach to have all continuous girder superstructures, hence displacements can occur without the possibility of a drop-off failure. The strategies are discussed further in the following brief case histories of some of the typical structures.

## CASE HISTORIES

### Case History 1: Bridge 29 – Multi-Span Precast I-Girder on Multi-Column Bents

### General Structure Description

The bridge is a 110.3-m long three-span (42.3-m - 34.0m – 34.0-m) multi-girder "regular" (no high skew) bridge with integral abutments that is 25.686-m wide. The superstructure consists of 12 Pre-cast Pre-stressed Concrete "I–Girders" made composite with a concrete deck, pier diaphragm and abutment end diaphragms. The superstructure is integral with the abutments and supported on 2-three-column reinforced concrete bents (see Figure 3).

The abutments are made integral with the superstructure and are supported on a single row of concrete filled steel pipe (406mm x 10mm) Piles. The abutment diaphragms feature fin walls (3.6-m x 3.72-m x 0.915-m with chamfers 0.38-m x 0.610-m at connection with diaphragm) to activate the passive resistance of the embankment during transverse EQ motions (max. pressure= 7.7ksf).

The approach slabs (15.44-m x 24.7-m x 0.580-m) are connected to the bridge deck at each end by reinforcing bar. The connection between the deck and approach slab allows in-plane rotation.

## Seismic Behavior

The seismic design strategy for this structure is to allow limited displacements at the piers (displacement and/or movement of the bearings before engaging shear keys), thus limiting the loads that can be transferred to the columns, and controlling seismic load distribution between bents and abutments. Overall displacement of the structure will be controlled by (1) mobilizing backfill soil behind the abutments in the longitudinal direction, and (2) mobilizing backfill soil in the transverse direction via fin walls. Gapped shear keys will be provided for the girder bearings at the pier cap, which will be engaged during higher-level seismic events.
The seismic design strategy for this structure consists of:

- Fused lateral load transfer to piers, via bearings
- Superstructure sliding over support seats

The strategy includes strength design of bearing connections to resist service loads such as wind, and braking forces, as well as a qualitative assessment for more frequent seismic loadings. In the event of design level earthquakes, the bearing connections are designed to fail and therefore act as a fuse limiting force transfer to the substructure.
Upon failure of the bearing connections, the load transfer through the bearings is through friction until the shear keys are engaged. The structure uses the bearing initial stiffness to take advantage of the softening effect of the bearings. This establishes the upper bound of expected seismic loads applied to the substructure, which is within the “essentially elastic” capacity of the pier columns. The “fused” bearing behavior results in superstructure sliding over the girder seats. Shear keys are provided at the bents to lock-up the columns after the superstructure has displaced far enough to use the available longitudinal resistance of the abutment, and as a failsafe mechanism.

### Influence of Approach Slabs on System Damping

Energy will be dissipated at the abutments from pushing the soil as well as dragging (pulling or pushing) the approach slabs, thus increasing the damping in the structural system. The viscous damping ratio for this type of behavior varies between 8% and 20%.

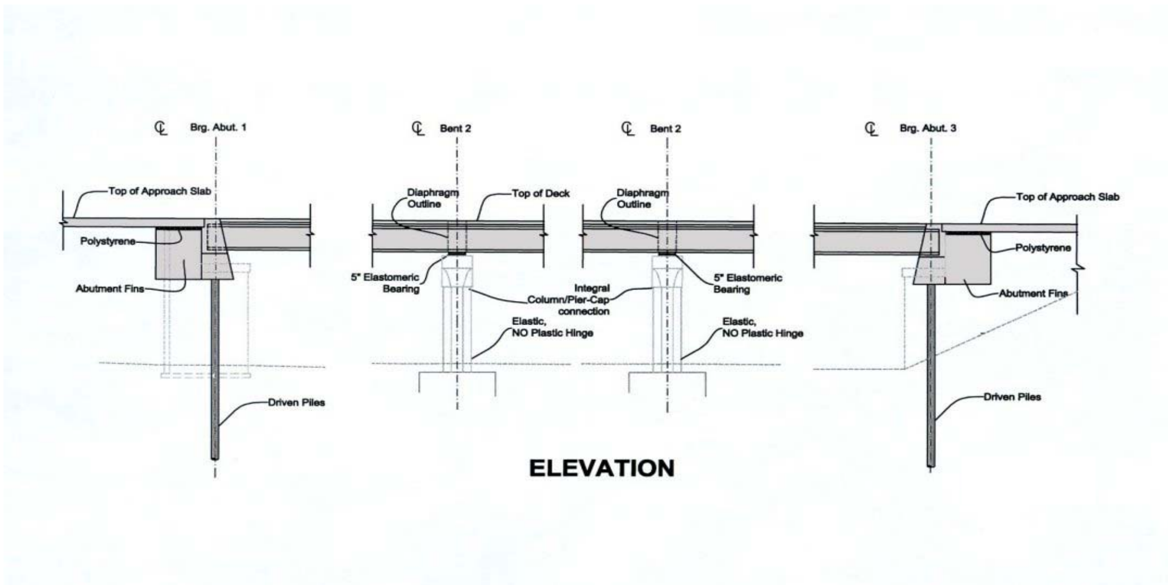


**Figure 3.** Typical multi-span multi-column bent supporting continuous precast I-girder superstructure.

The spectral acceleration for the range of likely natural periods for this structure resides on the plateau of the response spectrum and represents the maximum value. The results of the multi-modal dynamic analysis showed that the response was typical of that for a regular bridge. The primary response modes were the transverse and longitudinal. The effective seismic weight comprised the superstructure, abutment diaphragm & fin walls and the approach slabs (see Figure 3).

### System Capacity

The capacity of the system is understood to be the sum of the following resisting elements.

- Abutment Piles
- Back Wall and fin-wall Passive Pressure
- Approach Slab Friction
- Column-foundation strength (after bearing-key engagement)

### Expected Damage Under Design Event

The following are descriptions of the types of damage to be expected for Bridge 29.

| | |
|---|---|
| Bearings | Minimal damage. May require repositioning. |
| Superstructure | Essentially elastic response. May require repositioning. |
| Columns | Minimal repairable post-elastic response |
| Column Foundations | Piles remain essentially elastic |
| Exp. Joints | No expansion joints on the structure |
| Abutment | Potential settlement, piles remain essentially elastic. |

**Figure 4.** Seismic behavior to be expected for Bridge 29.

## Case History 2: Bridge 26 – Multi-span Steel Plate Girders on Multi-Column Bents

### General Structure Description

The structure is 168.8 m long with three-spans (43.5 m – 67.3 m – 58.0 m). Three of the supports are highly skewed, with a maximum skew of 55 degrees at Bent 3. The substructure consists of short seat type abutments and multi-column bents with non-integral caps. The abutments are supported by two rows of concrete filled steel pipe (406 mm diameter x 10 mm) piles. The columns are octagonal with a long dimension of 1820 mm. Each column is supported on piled footings, using concrete filled steel pipe piles. The superstructure consists of built up steel girders made composite with a concrete deck. Superstructure girders are supported on pot bearings.

### Seismic Behavior

The seismic design strategy for this structure consists of:

- Fused lateral load transfer to piers, via bearings
- Superstructure sliding over support seats, including the abutment

The strategy includes strength design of bearing connections to resist service loads such as wind, and braking forces, as well as a qualitative assessment for more frequent seismic loadings. In the event of design level earthquakes, the bearing connections are designed to fail and therefore act as a fuse limiting force transfer to the substructure.
Upon failure of the bearing connections, the load transfer through the bearings is accomplished through friction. This essentially establishes the upper bound of expected seismic loads applied to the substructure, which is well within elastic capacity of the pier columns, with a 1.5% longitudinal reinforcement ratio.
The "fused" bearing behavior results in superstructure sliding over the girder seats, for which adequate width is provided to prohibit unseating at the abutment. Shear keys in the transverse direction are provided at the bents. At the abutments, and primarily in the longitudinal direction, the backfill soil could provide additional resistance strength to limit the extent of superstructure movement. The backfill can contribute to resistance in the longitudinal as well as the transverse directions (i.e. through interaction with wing-walls). However, the seismic design for substructure forces and superstructure displacements has conservatively ignored this backfill resistance.

### Expected Damage Under Design Event

Due to the expected fuse at the superstructure – substructure interface, the majority of damage will be localized to the bearing elements. Damage to the abutments will be limited to expansion joint damage. While the entire superstructure is expected to displace at the supporting abutments and bents, unseating will not occur.

While the bridge can be opened to traffic following the immediate repair tasks, follow-up repairs can be performed to replace damaged bearings and connections.

The expected inspection and immediate repair which may be required, following a design level earthquake, will be centering the bridge near it's original position, and temporary repairs over bridge joints to allow for traffic.

| | |
|---|---|
| Abutment Piles | Essentially elastic pile response |
| Bearings | Expected elastic response with gapped shear key stoppers in the longitudinal and transverse directions. Bearings will break free from restraint system and slide on the top of the pier cap. . |
| Superstructure | Essentially elastic response. May require repositioning. |
| Columns | Minimal repairable post-elastic response |
| Column Foundations | Piles remain essentially elastic |
| Expansion Joints | Some Expansion Joint Damage |
| Abutment | Backwall damage/failure |

**Figure 5.** Seismic behavior to be expected for Bridge 26.

## VALUE ENGINEERING CONCEPTS

As a part of the seismic analysis and foundation design of the bridge for the Legacy Parkway project, the project team has undertaken activities that examine the potential options for savings in construction of the bridge foundations (Value Engineering). These areas of potential modification to standard designs are discussed herein:

### Pile Tension Capacity

A pile testing program was developed and conducted to evaluate the possibility of using higher axial (tension) pile capacities being used on the designs than is typically allowed by AASHTO. In both tests that were conducted, significantly larger tension capacities were documented than is currently permitted by AASHTO. Once concurrence had been obtained from UDOT to substantiate the validity of the tests, the results were incorporated into the design criteria and design process.

This VE study was successful in developing a design standard for the project that significantly increased the allowable tension capacity of piles for typical bent foundations. This resulted in a relatively large reduction in the number of piles required for bent foundations.

### Example of Potential Savings from the Pile load Testing

In order to demonstrate the savings that have resulted from the pile load testing, a foundation design has been prepared that ignores the results of the vertical pile load testing conducted by FAK for this project and instead uses the standard AASHTO value for tension capacity of 55% of the compression capacity.

| Bent | Footing size w/ Testing Results | Number of Piles w/ Testing results | Footing size without Testing Results | Number of Piles without Testing results |
|---|---|---|---|---|
| 2 | 8.5m x 8.5m x 2.6m | 32 | 8.5m x 8.5m x 2.6m | 49 |
| 3 | 8.5m x 8.5m x 2.6m | 32 | 8.5m x 8.5m x 2.6m | 49 |
| 4 | 8.5m x 8.5m x 2.6m | 32 | 8.5m x 8.5m x 2.6m | 49 |
| 5 | 18m x 5.5m x 2.6m | 34 | 20m x 6.1m x 2.6m | 56 |
| 6 | 8.5m x 8.5m x 2.6m | 32 | 8.5m x 8.5m x 2.6m | 49 |
| **Total** | **-** | **162** | **+28.6cu-m** | **252** |

**Figure 6.** Comparison of foundation designs with and without pile tension testing.

Based on the pile compression capacity provided by the geotechnical engineer for typical footing piles, the results from the analysis of the effect of reducing pile tension capacity are summarized above.

### Use of 65ksi Steel for Piles

Potential savings from the use of 65ksi steel instead of the traditional 50ksi steel was identified and evaluated for both bent and abutment foundations. This approach was significantly more effective than adding more piles in providing an elastic foundation. This VE study was successful in developing a design standard for the project that significantly decreased the number of piles for integral abutments and also worked in concert with the pile tension testing program to reduce the number of piles required to resist tension loads in the bent foundations.

### Fused Bearings

Fused sliding bearing strategies, particularly for the stiffer structures, provided several benefits:

- Reduced the seismic lateral loading due to softening effect on the dominant modes of vibrations
- Reduced the strength and reinforcement required at the fixed ends of columns
- Reduce the bending demands on pile group foundations at the base of the columns, and therefore, reduce the number of required piles.

For the 0.6g PGA loading, majority of the structures with periods of vibration less than 0.8 seconds, draw the maximum 1.2g spectral acceleration. The traditional force and deformation control methods provided minimal options to favorably alter the structure dynamic characteristics.

Seismic performance of stiffer structures, which converge at higher ranges of code-permitted “repairable damage”, was considerably improved by fused bearing strategies. (Note: While use of this approach using traditional bearing types proved to be effect for this application, if the required level of performance was for “no damage”, then use of true isolation devices would be a more appropriate design strategy.)

### Results of Fused Bearing Evaluation

As noted above, the seismic performance of some of the bridges, as well as their design and construction complexities and cost can considerably be improved using fused bearings.

| | **Non-Fused** | **Fused Bearings** |
|---|---|---|
| **Bearing properties** | Pinned | Fuse at 40%g |
| **Governing Column Moment demands (kips-ft)** | 38,000 | 8400 |
| **Column Plastic Moment Capacity (1.5% rebar, Kips-ft)** | 13249 | 13249 |
| **Foundation Size (footing, no. of piles)** **Seismic Load Design** | 21.3 ‘ x 21.3 ‘<br>25-150 Ton Piles | 20’ x 20’<br>12-150 Ton Piles |
| **Foundation Size (footing, no. of 150 ton piles)** **Service Load Design** | 18’ x 18’<br>8 - 150 ton piles | 18’ x 18’<br>8 – 150 ton piles |

**Figure 7 –** Comparison of column response of fused vs. non-isolated strategies for a typical bent of a multi-span, multi-column structure on the Legacy Parkway Project.

Figure 7 shows how column base moment demands will be reduced by 30%, relative to AASHTO permitted design, based on allowed elastic force-reduction factors. For this case, foundation strength was reduced up to 30% (e.g. less piles), and the column remained essentially elastic (e.g. no damage and fully serviceable).

The fused bearing strategy essentially allows for placement of a “weak-link fuse”, by design, in the seismic load path. It should be noted that the bridge structures within this project, the strategy of “weak-link fuse” is part of the design by use of traditional elastomeric bearing or pot bearing, in combination with shear keys with limited strength. This strategy benefits from the advantages of isolation design strategies at no additional cost for specialty devices.

### CONCLUSION

Seismic design strategies that use traditional, off-the-shelf bridge elements have been used to develop designs that result in serviceable behavior following the design seismic event. The designs cover a wide breadth of structure types and also address the difficult and often costly impacts of constructing highway structures in soft soil sites, where seismic loads are high.