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THE UTAH PILOT BRIDGE, LIVE LOAD AND DYNAMIC TESTING, MODELING AND MONITORING FOR THE LONG-TERM BRIDGE PERFORMANCE PROGRAM.

by

Steven M. Petroff

A thesis submitted in partial fulfillment of the requirements for the degree

of

MASTER OF SCIENCE

in

Civil and Environmental Engineering

Approved:	
Dr. Marvin Halling Major Professor	Dr. Keri Ryan Committee Member
Dr. Joseph Caliendo Committee Member	Byron Burnham Dean of Graduate Studies

UTAH STATE UNIVERSITY Logan, Utah

2010

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iii

ABSTRACT

The Utah Pilot Bridge, Live Load and Dynamic Testing, Modeling and

Monitoring for the Long-Term Bridge Performance Program

by

Steven Petroff, Master of Science

Utah State University, 2010

Major Professor: Marvin W. Halling

Department: Civil and Environmental Engineering

As part of the Federal Highway Administration's Long-Term Bridge Performance Program, Live Load and Dynamic tests were conducted. A long-term monitoring plan

was developed and presented for the Utah Pilot Bridge based on Live Load and Dynamic

tests. As one of seven pilot bridges, the Utah Pilot Bridge is one of the first bridges used

to initiate the LTBP Program. A formal permit approval process, with the Utah

Department of Transportation, was followed to gain permission to conduct the tests and

install long-term instrumentation. Analysis provided good results for each test completed,

with a summary of test results presented. A Finite Element Model was created and

refined based off test data. Instrumentation was installed and checked to ensure quality

data was streaming to the collection site.

(244 pages)

ACKNOWLEDGMENTS

I would like to thank the many people who made this work possible. As a national project, funded by the Federal Highway Administration under the Long Term Bridge Performance Program, the number of people involved prohibits the naming of each individual. A few stand out and deserve special recognition. I would like to thank Dr. Marvin W. Halling for allowing me to participate in this project. With his direction and approval I have been part of many incredible experiences that would not have been possible if he had not allowed me to try. In addition, Dr. Paul J. Barr deserves an equal amount of credit for allowing me to grow and mature as a professional by providing opportunities not feasible without his mentorship.

As I mentioned, this project is national in its scope. For that reason, I regularly worked with outstanding professors from Virginia Tech. Dr. Tommy Cousins and Dr. Carin Roberts-Wollmann are excellent team players with indispensable knowledge.

The main focus of my thesis required the permission of Utah Department of Transportation. UDOT Region 1 Office supplied excellent help and knowledge to allow access to the bridge in Utah.

I give special thanks for my friends, extended family, and colleagues who supported and encouraged me through this work. Most of all, I thank my loving wife for her support and confidence in me during the time needed to complete this work. None of this could have happened without her.

Steven Petroff

CONTENTS

Page
ABSTRACTiii
ACKNOWLEDGMENTSiv
LIST OF TABLESvii
LIST OF FIGURESviii
EXECUTIVE SUMMARY
REVIEW OF LITERATURE
Global Health Monitoring5WIM Sensor7Environmental Monitoring11Live Load Testing13Dynamic Testing16
BRIDGE DESCRIPTION
Selection Criteria20Bridge Background and Inventory23Bridge Description Summary28
LIVE LOAD
Structural Testing Procedures
Testing setup
Data Review45
Reproducibility45Elastic behavior46Load distribution46Dynamic effects47
Live Load Test Conclusions and Recommendations

Assembly of FEM	52
Results of FEM	
FEM summary	
DYNAMIC TESTING	64
LONG-TERM MONITORING AND INSTRUMENTATION	69
Long-Term Monitoring Sensors	69
Weigh-in-Motion (WIM)	69
Traffic camera	73
Weather station	74
Strain gauges	74
Velocity transducers (seimometer)	
Deck water saline content	
Tilt meters	76
Thermocouples	77
Service, maintenance, and replacement	
Analysis and Data Storage	79
Analysis	79
Data storage	79
Installation	80
Phase one	80
Phase two	90
Data Acquisition System	95
Long-Term Instrumentation Summary	97
SUMMARY	99
REFERENCES	100
APPENDICES	103
Appendix A: Live Load Strain and Displacement Plots	104
Appendix B: Live Load Permit Application	
Appendix C: Long-Term Application Document	
Appendix D: Instrumentation Plan	
Appendix E: Data Acquisition Code	
1 1	

LIST OF TABLES

Table		Page
1	LTBP study topics as defined in Task 1.2	8
2	Criteria used to select Utah Pilot Bridge	23
3	Structural description and testing information	33
4	Important truck information	40
5	Dynamic response summary	66
6	Distribution of instruments	98
7	Summary of sensors and their locations on the bridge	105

LIST OF FIGURES

Figu	are	Page
8	Visual inspection as conducted by USU and VT	22
9	Side view looking east. Aerial view from Google Maps, top is north	24
10	Type AASHTO IV girder.	25
11	Cracking at abutment.	25
12	Cracking on underside of parapet.	25
13	Measurement of asphalt overlay thickness.	26
14	View of deck looking south.	27
15	Schematic elevation drawing of Utah Pilot Bridge	27
16	Cross-sectional view. (Dimensions are in feet)	28
17	Location of Utah Pilot Bridge indicated by red bubble.	30
18	Surface mounted strain transducer, showing identification number	34
19	Deflection instrument, "Twanger."	34
20	Plan view of instrumentation showing sectional divisions.	35
21	Cross-sectional view of Section A-A with gauge identification numbers	36
22	Cross-sectional view of Section B-B with gauge identification numbers	36
23	Cross-sectional view of Section C-C with gauge identification numbers	36
24	Cross-sectional view of Section D-D with gauge identification numbers	36
25	Strain transducer at bottom flange and Twanger at midspan	37
26	Location of strain transducer at highest possible location on web.	37
27	Boom lift and weights used to provide initial deflection for "Twangers."	38
28	Researchers access instrument locations.	39
29	Installation tabs for Twanger and Strain Transducer.	39

30	Two dump trucks, provided by UDOT, each heavily loaded	41
31	Test vehicle #1 footprint, UDOT dump truck	41
32	Test vehicle #2, UDOT dump truck	42
33	Description of load paths.	43
34	Autoclicker mounted on a truck.	44
35	Slow-down produced by highway patrol officer.	45
36	Comparison of reproducibility for Load Path 3.	48
37	Second comparison of reproducibility for Load Path 3.	48
38	Lateral load distribution as seen in deflection record for Load Path 2.	49
39	Demonstration of unreliable results from Twanger 3.	49
40	Comparison of dynamic effects with static values.	50
41	Interior girder mesh for solid elements.	53
42	Exterior girder mesh for solid elements.	54
43	Completed cross-section with colors representing various sections	55
44	3D Representation showing all girders and sections represented by colors	55
45	Showing tendons and how they fit compared to 3D image of bridge	57
46	FEM vs. measured deflection for Twanger 01	59
47	FEM vs. measured deflection for Twanger 02	60
48	FEM vs. measured deflection for Twanger 03	60
49	FEM vs. measured deflection for Twanger 04	61
50	FEM vs. measured deflection for Twanger 05	61
51	FEM vs. measured deflection for Twanger 06	62
52	FEM vs. measured deflection for Twanger 07	62
53	Electromagnetic shaker used in Utah Pilot Bridge dynamic test	65
54	Velocity transducers as used on the Utah Pilot Bridge dynamic test	65

55	Instrument layout for the dynamic test on the Utah Pilot Bridge	66
56	Magnitude, unwrapped phase, and coherence function.	67
57	Half-power bandwidth method used for damping ratio calculation.	68
58	WIM sensor, www.cardinalscale.com	70
59	Quartz based WIM installed in lane leading to Perry, Utah Port of Entry	71
60	WIM installed in lane leading to Perry, Utah Weigh Station.	71
61	Showing two tiltmeters installed one on girder and one on abutment	78
62	Equipment and supplies for installation.	83
63	Trenching, starting point near bridge abutment.	83
64	Pad form and reinforcing steel.	84
65	Conduit running from pad to bridge.	84
66	Pouring of concrete.	85
67	Finishing concrete.	85
68	Insturment pad with installed tower and cabinet after grading.	86
69	Junction box loacted on abutment wing-wall.	86
70	Junction boxes showing water-tight fittings.	87
71	Conduit running along underside of deck.	87
72	Junction boxes providing access for instruments into supply line	88
73	Flexible conduit connects instrument boxes to supply line.	88
74	Traffic control seen under the bridge.	89
75	Traffic control seen on road leading to bridge.	89
76	Schematic drawing of vibrating wire strain gauges.	93
77	View of installation method for hitec foil strain gauges	93
78	Close-up view of installation method for vifoil strain gauges	94
79	Geokon MEMS 6160 Tiltmeter.	94

80	Side view installation of Geokon MEMS 6160 Tiltmeter.	95
81	Sensor B1032.	106
82	Sensor B1971.	106
83	Sensor B1972.	107
84	Sensor B1975.	107
85	Sesnor B1976.	108
86	Sensor B1977.	108
87	Sesnor B1980.	109
88	Sensor B1981.	109
89	Sesnor B1982.	110
90	Sesnor B1983	110
91	Sensor B1985	111
92	Sensor B1986	111
93	Sensor B1988	112
94	Sensor B1989	112
95	Sensor B1990	113
96	Sensor B1991.	113
97	Sensor B1992.	114
98	Sensor B1993	114
99	Sensor B1996	115
100	Sensor B2017.	115
101	Twanger 1.	116
102	Twanger 2.	116
103	Twanger 3.	117
104	Twanger 4	117

105	Twanger 5.	. 118
106	Twanger 6.	. 118
107	Twanger 7.	. 119

EXECUTIVE SUMMARY

Currently, the Federal Highway Administration's (FHWA) National Bridge Inventory (NBI) contains data on nearly 600,000 highway bridges, including culverts. The operational ability of the highway network requires a high level of performance from these structures. Given that characteristics for these bridges contain a wide range of structural types, material types, age, daily traffic and climatic conditions the management of highway bridges presents a situation where extensive knowledge in many areas is needed for improved life cycle cost effectiveness and maintenance strategies for the structures. Developing an approach with higher efficiency and breadth requires more knowledge from high quality quantitative performance data on bridges from which to base the new decisions for life cycle improvement and maintenance strategies. The FHWA has begun a program that will collect, store and analyze such data through a program called the Long Term Bridge Performance (LTBP) Program. This program will create databases of high quality quantitative data to be used for improved practices. There are three types of bridge monitoring and evaluation components to the LTBP program.

The first component is to periodically inspect the bridge through visual and advanced nondestructive evaluation techniques. Protocol for this inspection consists of three levels. The first being an "NBI Level" which is consistent with the current federally mandated inspection on a regular basis. The second level is called "Element Level Inspection: and is used in about 46 states. The third is an "as required" inspection based on needs of the bridge. This component of the LTBP will be carried out by Parsons Brinkerhoff. The only involvement that USU will have in this component is coordination and scheduling with the inspection group.

The second component of the LTBP program is that of instrumented bridges. Continuous monitoring of the bridge will be accomplished through the use of sensing technology installed on the bridge to measure and record certain bridge performance parameters under normal daily traffic loadings and to monitor for rare or extreme events. Other periodic testing of the selected bridges will be conducted to determine the change in global response of the bridge through time. Tests that are performed include extensive deck testing, live-load testing, dynamic load-testing and nondestructive testing and evaluation (NDE/NDT). Researchers from Brigham Young University (BYU) are contracted with researchers at Utah State University (USU) to conduct the deck testing. This testing will involve thorough crack propagation mapping, deck sampling, resistivity measurements, half-cell potentials, and corrosion of reinforcing steel evaluation. Liveload testing will aid researchers in determining the global effects of vehicle traffic. Dynamic load testing will aid researchers in understanding natural frequencies and damping ratios of the bridge. Both the live load and dynamic load testing will be conducted by researchers at USU. The NDE/NDT portion will be conducted by Rutgers University.

It is through a contract with the FHWA and the LTBP that researchers at USU are working to obtain higher quality quantitative data of bridge performance. USU is a contracted team member of the LTBP program to oversee the instrumentation and implementation of all monitoring and testing for bridges west of the Mississippi river. A Pilot Bridge Phase is currently in operation with the goal to instrument and test a small number of bridges in preparation for a larger, nationwide bridge monitoring and testing program. Among the first of the Pilot Bridges selected is a bridge in Northern Utah. This

first bridge will provide the groundwork upon which many other bridges will be monitored and tested.

In order to assure quality monitoring and testing, an instrumentation plan was proposed. The instrumentation plan provides a background of the bridge selected and the information expected to be learned from a bridge with the given characteristics. The instrumentation plan also served as a formal proposal to LTBP managers at FHWA of the testing and long-term monitoring arrangements. The instrumentation plan is included in this document as Appendix D.

After approval of the instrumentation plan was received, researchers at USU were given permission to conduct the live-load test on the bridge as well as prepare the long-term instrumentation. Preparations for the long-term instrumentation required more time than the testing to coordinate so the live-load testing occurred before the long-term instrumentation was installed. Conducting the test required approval from FHWA and UDOT. The approval from FHWA came via the instrumentation plan. Approval from UDOT came through the process of applying for and receiving an encroachment permit. Obtaining a permit required preparation of a Testing and Maintenance of Traffic Plan that was submitted to UDOT and subsequently approved, this document is included as Appendix B. Both the live-load and dynamic tests were conducted at the same time. An explanation of the testing and the process to receive the encroachment permit is given in the Live Load section. Once the tests were complete, data analysis and refinement of a finite-element model occurred for both tests, also contained in the Live Load section of this document.

A similar process to the live-load test was required for installation of the long-term monitoring equipment. Approval was first obtained from UDOT by submitting a document containing an explanation of work to be done through written explanation and computer aided drawings, included as Appendix C. After submittal and approval, UDOT awarded an encroachment permit to carry out the proposed installation. Details regarding the construction, installation and validation of the monitoring system along with the process of selecting an appropriate long-term structural health monitoring system are further explained in the section title Long-Term Monitoring and Installation.

Finally, a summary of the work done to test and monitor the Utah Pilot Bridge is given. Recommendations for future bridge work is provided in this section based off the experience gained while carrying out the work for this bridge.

REVIEW OF LITERATURE

Global Health Monitoring

Global bridge monitoring or Structural Health Monitoring (SHM) is used to describe many different forms of data collection and analysis. For most uses in civil engineering, the term global bridge monitoring or SHM is typically an identification process that considers the performance of a structure as a whole by evaluating all forms of performance characteristics (Brownjohn et al., 2005). For bridge SHM, the aforementioned definition is the primary objective for installing long-term instrumentation on the Utah Pilot Bridge. SHM requires the integration of a complex system of individual data collection and system response sensors joined together into a network that collects, then deposits data linked to a central location for later analysis and storage. No matter the structure type, each SHM system requires the use of a data acquisition system, data collection software, data storage, a selection of specific instrumentation, instrument protection, and a project goal (DeWolf et al., 2006; Farhey, 2005; Brownjohn et al., 2005; Lynch et al., 2005, 2002; Cheung et al., 1997).

Due to the rugged and harsh nature of field applications, adequate environmental protection is necessary for continuous long-term monitoring to be economical and reliable. Data acquisition equipment must be housed in a secure location, typically a cabinet of some type (DeWolf et al., 2006; Farhey, 2005; Brownjohn et al., 2005). Each of these articles explains that for reliable data a distinct determination of the project goals is necessary to select the correct equipment. The equipment selected on most bridge SHM systems involves some combination of strain monitoring, vibration monitoring,

environmental monitoring (temperature, wind speed, wind direction, radiation, relative humidity, etc.), and data storage (DeWolf et al., 2006; Farhey, 2005; Brownjohn et al., 2005). Most strain and vibration data collection/storage is conducted off of a triggered event (DeWolf et al., 2006). Temperature and tilt meter data is often taken at intervals of 15-30 minutes, a rate that follows expected variations. Vibration, or dynamic, data collection requires a Fast Fourier Transfer (FFT) function that will filter out white and background noise so that the bridge response can easily be determined. Once the system of instruments is selected, the research team can then determine the data collection and storage method to be used.

With increasing technology a high speed internet connection allowing direct communication with a data logger on site is fast replacing the previously accepted process of storing data on a memory chip or computer housed on site and manually retrieving the data through a site visit (DeWolf et al., 2006; Farhey, 2005; Brownjohn, 2005). Further advances in technology are allowing the use of wireless instruments during bridge testing (Lynch et al., 2005, 2002). According to Lynch et al. (2005) wireless technology, when understood and applied correctly, can yield results as reliably as cable-based systems. Wireless systems are most often applied for periodic short-term tests spanning a few days at the most. Application of wireless systems for long-term SHM has not yet been tested. An economic benefit to the wireless systems is there is no need for cabling or installing of protection for cabling. Intuitively, the greatest saving in this regard will occur on bridges that are substantially large.

A SHM system for the LTBP Program Utah Pilot Bridge was selected based off the aforementioned items, including a cabinet for data acquisition system as well as providing ample protection for instrumentation. Care will be taken to ensure proper installation and adequate protection is provided for each instrument. In the case of the Utah Pilot Bridge, no wireless instruments are used. The smaller size of the bridge prohibits the application of wireless instrumentation for budget reasons. Data collection will continue to occur via an internet connection. Data storage is managed by another LTBP Program contractor, Siemens America. Appropriate sample rates, filtering algorithms, and trigger events were created and implemented in the datalogger code.

WIM Sensor

Task 1.2 of the LTBP developmental phase is charged with developing an outline of specific data to be collected. This was accomplished by the use of focus groups from select state departments of transportation (DOT). A selection of LTBP team members have been assigned to interview at least twelve DOT's around the country to learn what information is the most important in those states. These interviews are held with a selection of DOT officials, considered as "Focus Groups." From the focus groups interviewed, a list of twenty specific study topics were chosen based on the level of need that the DOT's indicated (Brown et al., 2009). Table 1 lists the twenty study topics. Four items relate to deck needs. The deck category is the only category with four items and indicates that this is the area of the bridge that the DOT's are requesting the greatest amount of information.

The bridge wearing surface, or the deck, is the area of the bridge that will deteriorate and reach its life expectancy first. It is often assumed that a deck will wear out twice as fast as the superstructure that supports the deck. Therefore, additional

information about a deck and its mode of deterioration is influential in providing a longer life on the bridge.

Table 1. LTBP study topics as defined in Task 1.2

Number	Study Topic		
1	Performance of Untreated Concrete Bridge Decks		
2	Performance of Concrete Bridge Deck Treatments		
3	Performance of Bridge Deck Joints		
4	Protective Coatings for Steel Bridges		
5	Performance of Bare, Coated or Sealed Concrete Super- and Substructures		
6	Innovative Designs and Materials		
	Performance of Embedded or Ducted Pre-stressing and Post-Tensioning		
7	Tendons		
8	Performance of Bridge Expansion Bearings		
9	Precast Reinforced Concrete Deck Systems		
10	Performance of Jointless Bridges		
11	Alternative Reinforcement		
12	Direct, Reliable, Timely Methods to Measure Scour		
13	Performance of Weathering Steels		
14	Influence of Cracking on Serviceability of HPC Decks		
15	Performance of Scour Countermeasures		
16	Risk and Reliability		
17	Performance of Prestressed Concrete Girders		
18	Unknown Foundation Types		
19	Performance of Structure Foundation Types		
20	Performance of Functionally Obsolete Bridges		

For a bridge, there are principally two major inputs that affect the life and design of the deck: environmental conditions and traffic loads. Environmental conditions are discussed in a separate section. Traffic loading and its effect will be evaluated in this section.

Knowing the assumed traffic loads and traffic volume are vital to an adequate bridge deck design. The thickness and material for a given segment of highway is determined by the pressure applied to the pavement at that location. In some occasions,

information regarding the vehicle weight can actually save money by knowing which locations need thicker pavement or which sections suffice with less (Neidigh and Crawford, 2004).

Weigh-In-Motion (WIM) technology is a result of the need for axle load data. Traffic loads on pavement is one of the most important pieces of information required to determine the life-span of a pavement application. Typical loads expected on a stretch of pavement are necessary for accurate and reliable design. Vehicle weights can be determined through static scales or weigh-in-motion technology. Both methods have advantages and disadvantages. The advantage that static scales have over WIM sensors is their high level of accuracy. However, static scales require the truck to completely stop on the scale for a measurement to be taken. Some static scales allow the truck to still be moving at a very slow speed and thus not require a full stop. A static scale requires the time of the driver and the scale operator. The number of people required to operate a static scale is much higher than the number of people required to monitor and maintain a WIM station (Prozzi and Hong, 2007). In addition, WIM sensors are able to record date and time of passage, lane and direction of travel, vehicle class, speed, wheel and axle weight, and axle spacing automatically (Prozzi and Hong, 2007). At the same time, environmental effects, pavement conditions and many other factors provide opportunity for errors to enter into a WIM sensor reading. Currently, ASTM E 1318 provides standard specifications for design and building of WIM stations to assist in reducing the number and size of errors.

WIM sensors are most frequently used in a dynamic live-load situation, when the vehicle is still moving at either a low or high speed. There are multiple variations of the

WIM sensor to accommodate need for accuracy and price. The most commonly installed WIM sensors are piezoelectric and bending plate (Neidigh and Crawford, 2004). In a report by Zhang, Hass, and Tigne (2007) an evaluation and comparison of Piezoelectric, Bending Plate, Single Load Cell, and Quartz Piezoelectric WIM sensors were made. A table in the report presents initial installation cost, annual life cost, accuracy of GVW in a 95% confidence, sensitivity, expected life, reliability and applicability. The piezoelectric sensor has the lowest initial cost as well as the lowest life expectancy. The single load cell has the highest initial cost, second longest life and highest level of reliability. The bending plate is consistently in the middle for every category. The quartz piezoelectric sensor costs as much as the bending plate sensor, lasts the longest and provides medium reliable data. A decision of which sensor to use is likely to be based on the items listed in the table by Zhang, Hass, and Tigne (2007). In the concluding remarks of the report, the authors advise that the higher accuracy reported for the quartz piezoelectric sensor requires more data to confirm.

From the literature analyzed in this section, it is clear that WIM technology for vehicle load determination is well established. The level of accuracy is dependent on multiple factors. Among those factors are included the selection of WIM technology as well as the pavement conditions. Zhi, Middleton, and Clayton (1999) reports that WIM sensors that are not well maintained or provided with adequate surface condition before and after the sensor, will not yield reliable data.

For the data collection needs of the LTBP program, more specifically as conducted for the Utah Pilot Bridge, a quartz piezoelectric sensor is required for data collection. The Utah Pilot Bridge is located approximately one mile north of the Perry,

Utah weigh station. The weigh station is instrumented with two quartz piezoelectric sensors that are well maintained and installed according to ASTM specifications.

Therefore, a high level of confidence can be assumed with the data retrieved from this site. Due to the relatively high cost of the sensor and installation purchasing and installing a WIM sensor for the Utah Pilot Bridge is not possible. Therefore, an agreement was reached between USU and UDOT Motor Carrier Division to obtain the WIM data from the Perry, Utah Weigh Station. The USU research team will be able to use the WIM data to determine axle weights of the vehicles crossing the bridge along with other pertinent information.

Environmental Monitoring

Environmental effects significantly impact the structural health of a bridge.

Monitoring the effects of environmental impacts on the Utah Pilot Bridge will assist in determining the changes of global bridge characteristics due to structural damages and/or improvements or seasonal changes in the environment.

Researchers have evaluated the effect that temperature has on the modal parameters of bridges (Sohn et al., 1999; Peeters and De Roeck, 2001). Sohn et al. (1999) used data from two dynamic tests on the Alamosa Canyon Bridge in New Mexico to create a filter that correlated temperature to a change in bridge frequency. While researchers were successful in creating a filter that related temperature to frequency change, they admitted that the model required more data from more tests to further ensure that the results are accurate. Peeters and DeRoek (2001) developed a model that allowed researchers to determine if a bridge has undergone damage through an analysis of

temperature variation. In order to use this model, a baseline must be established from which subsequent temperature readings may provide damage report information. Peeters and DeRoek (2001) also found that asphalt will stiffen a bridge when below 0°C and have no stiffening effect affect when above 0°C.

Of all environmental data including: wind speed, wind direction, precipitation amount, precipitation form, radiation, and temperature; temperature is the most influential in global bridge response. Some correlation has been made to how the amount of moisture, and hence increased mass of a bridge, changes the natural frequency and mode shapes of a structure (Sohn et al., 1999) but little validity is given to that assumption. Even then, collecting data on wind, precipitation and radiation has important implications on bridge design, management and user safety. Suzuki et al. (2007) demonstrated the need to understand the faster cooling and freezing conditions of a bridge in regions of the world that experience icing of a bridge deck. Wind speed/direction and radiation were important factors in the time of freezing. Furthermore, radiation has been identified as a leading cause for extreme temperature differences on decks during summer months (Roberts-Wollmann, Breen, and Cawrse, 2002).

Additional research conducted on box girder bridges has shown the importance of thermal gradients in design considerations (Roberts-Wollmann, Breen, and Cawrse, 2002). Liu and DeWolf (2007) found a correlation between the changes in natural frequency to temperature variations. A 6% difference in natural frequency due to temperature was noted. Liu concluded that the use of natural frequency alone for damage detection is not reliable due to the influence of temperature effects on the frequency of the bridge. Huth et al. (2005) found results that supported Liu's findings. In his research,

Huth found that the effects of environmental changes had a greater influence on natural frequency than structural damage. Breña et al. (2007) determined the amount of rotation and deflection an integral abutment bridge experiences due to temperature changes through an entire year. Deck temperature changes were identified as the driving force.

Environmental effects, including temperature, radiation, wind speed/direction, and precipitation interact with a structure to change the behavior and global characteristics. The Utah Pilot Bridge is in a region that experiences extreme environmental changes. Temperature and radiation fluctuations are of important interest to the project. Since live-load and dynamic load tests will depend on the condition of the bridge, it is important to know what effects temperature has.

Live Load Testing

Live-Load testing has the ability to track changes in a bridge over time. Similar to a dynamic test, the live-load test provides data to establish a baseline that can be referred to in subsequent tests to determine the change in the global response of the bridge to factors affecting the bridge. Live load tests are typically considered in two categories: proof testing and diagnostic testing (Cai and Shahawy, 2003; Jauregui and Barr, 2004). A proof test is typically used when a bridge undergoes some sort of drastic change, such as corrosion or damage that cannot be completely determined. A proof test requires the bridge be loaded to a target load. From there the true load capacity of the bridge can be determined (Jauregui and Barr, 2004). A diagnostic test varies from a proof test in that it is preferred in situations where the target load cannot be reached due to lack of test vehicles with ample weight limits, the bridge cannot risk taking the target load, or the

traffic conditions do not allow for a full bridge closure as required by a proof test (Cai and Shahawy, 2003; Sartor, Culmo, and DeWolf, 1999). A diagnostic test allows for multiple lanes to be open during testing, which makes it a preferred option on busy interstate sections. Due to the high approximate daily traffic on the Utah Pilot Bridge, nearly 22,000 vehicles with 29% truck traffic (NBI, 2007), a diagnostic test will be conducted rather than a proof test. However, the quality of the load test improves if the only vehicle(s) on the bridge are the pre-weighed loading vehicle(s) selected by the researchers (Sartor, Culmo, and DeWolf, 1999).

Diagnostic live-load tests, referred to simply as live-load test or live-load testing, can take different forms. The most common is the quasi-static form. Also available is the dynamic truck load test. Quasi-static tests use a heavily loaded truck moving at a slow speed, less than five miles per hour, to avoid the effects of dynamic loading. A dynamic truck load test applies variable traveling speeds of the truck to evaluate the effect that speed has on the bridge (Darestani et al., 2007). Valuable information is obtained from each method. Both methods of live-load testing will be used on the Utah Pilot Bridge.

For either form of live-load testing, standard items are needed to provide a test with high quality data. The loading is provided by a heavily loaded truck, either a semi-truck and trailer or a heavily loaded dump truck (Barr, Eberhard, and Stanton, 2001; Roberts-Wollmann, Breen, and Kreger, 2001; Cai and Shahawy, 2003; Jauregui and Barr, 2004; Barr et al., 2006; Darestani et al., 2007). To accurately determine the bridge characteristics, pre-determined load paths are used to guide the truck as it crosses the bridge. Multiple load paths are recommended and multiple passes of the truck on one load path is needed to ensure quality data (Cai and Shahawy, 2003; Jauregui and Barr,

2004; Barr et al., 2006). Because parts of the bridge are still open to ambient traffic, which may disturb data, Cai and Shahawy (2003) recommend the use of as heavily loaded of a truck as possible.

Response of the truck is measured by an array of instrumentation that includes any form of strain gauge, located on the bridge in the area of most interest to each project, a deflectometer to determine the absolute deflection of the bridge, and temperature gauges to determine the influence of temperature induced strains. The instrumentation is connected to a data logger capable of high-frequency sampling for multiple data readings for each test conducted. The Utah Pilot Bridge will use a combination of strain gauges, deflectometers, and temperature sensors all connected to a quality data logger to ensure high fidelity data.

It is often the goal of the test to determine the true strength of a given bridge for various reasons. Many researchers have determined that the design strength is often an underestimate of the true bridge strength due to field factors that influence the bridge performance (Cai and Shahawy, 2003, 2004; Jauregui and Barr, 2004; Barker, 2001; Bakht and Jaeger, 1990). Another possible objective of a live-load test is to validate a finite element model (FEM). In fact, almost every live-load test will have an accompanying FEM to further carry out analytical tests for additional project goals or objectives (Barr, Eberhard, and Stanton, 2001; Roberts-Wollmann, Breen and Kreger, 2001; Cai and Shahawy, 2003; Jauregui and Barr, 2004; Barr et al., 2006; Darestani et al., 2007).

It is clear from the amount of information available that the theory and applications of a live-load test are well established. There are multiple variations on the

test that allow researchers to custom design the procedure to the needs of their bridge. The combination of a quasi-static live-load and dynamic truck live-load test with multiple instruments will provide adequate data for a FEM calibration. The results and analysis of the live-load test for the Utah Pilot Bridge will be used to establish a base line for future research and comparison as the bridge ages.

Dynamic Testing

Dynamic testing is viewed as a dependable technique to establish the vibration sensitive properties of a structure (Conte et al., 2008; Halling, Muhammad, and Womack, 2001; Paultre, Proulx, and Talbot, 1995). These properties include natural frequency, damping ratio, and mode shapes. These properties are vital to updating and validating analytical models of the structure to correspond more truly with the actual bridge response.

Periodic dynamic testing over a span of years allows researchers to develop a baseline, determined on the first dynamic test, and evaluate the change in modal shapes and natural frequencies as a result of environmental or natural deterioration or damage/retrofitting events (Brownjohn et al., 2005). Bolton et al. (2005) was allowed a unique opportunity to compare the modal properties of a concrete bridge before and after a seismic event that damaged the structure. Weeks prior to the Hector Mine Earthquake of September 1999 Bolton conducted a field modal test and compared the results to a test conducted three days after the seismic event. It was recorded that natural frequencies decreased by 18%. In addition to seismic events, repair or damage of a bridge structure changes the modal properties as reported by Halling, Muhammad, and Womack (2001).

Another study on a curved steel girder bridge by Mertlich, Halling and Barr (2007) reported that changes in boundary conditions also result in changes in modal shapes and natural frequencies.

Excitation for a dynamic test typically falls within two broad categories: 1) ambient vibration and 2) forced vibration. Selection of either or both methods of vibration depends on structure location and researcher preference. Conte et al. (2008) argued that forced vibration tests provide more accurate modal identification results than ambient vibration tests due to the fact that excitation is well-defined and can be optimized to excite certain vibration modes. Giving an explanation to the difficulty of using ambient vibration, Conte et al. (2008) clarified that advanced system identification methods are needed to determine the modal shapes from ambient tests as a result of the low signal-tonoise ratio in the data. DeWolf et al. (2006) confirmed that determining the natural frequency of a bridge is more difficult with ambient vibration than forced vibration. Liu and DeWolf (2007) used ambient vibration to collect continuous vibration data. From numerical analysis it was determined that there were eight significant modes in the bridge but due to the low excitation of the ambient traffic flow, only three modes were used in the research study because the ambient force was not sufficient to excite all eight modes. Bolton et al. (2005) used a custom-built drop-weight impact hammer to excite the structure. Halling, Muhammad and Womack (2001) and Mertlich, Halling, and Barr (2007) used an eccentric mass shaker capable of varying frequencies and forcing to excite the structure for their respective tests. Conte et al. (2008) used a combination of traffic load, vehicle-induced impact and ambient vibration to excite the structure. Paultre, Proulx, and Talbot (1995) employed the use of two heavily loaded dump-trucks with

trailers traveling at high speeds (90-100 km/h) to produce the needed vibration on the structure. However, the use of ambient vibration data is important on structures where input excitation cannot be directly measured or applied. This occurs on larger structures. Gul and Cutbus (2008) presented a system of analysis steps that employs multiple filtering and categorizing methods to use ambient vibration data to accurately record the dynamic response of a bridge structure.

Regardless of the method of excitation used, a detailed system of data collection must be implemented to collect needed data. Researchers typically use a system of accelerometers, velocity transducers, a high-rate sampling data-logger, data collection software and a portable field computer (Bolton et al., 2008; Conte et al. 2008; Halling, Muhammad, and Womack; 2001, Mertlich, Halling, and Barr, 2007; Ruth et al., 2005; Paultre, Proulx, and Talbot, 1995). The location of instruments on the bridge is often determined prior to testing by a finite element model. Each of the previously cited researchers used a finite-element model to either determine or assist in the placement of instrumentation on the structure.

For the tests conducted by USU researchers it is important to establish high-quality data that will be used to establish a baseline for future comparison. The LTBP program has an initiative to learn more about bridge deterioration with time. Periodic dynamic tests compared to a baseline will aid future researchers in evaluating bridge maintenance and rehabilitation methods. A test was conducted with the use of forced vibration from an electromagnetic shaker. For the Utah Pilot Bridge, a forced vibration test will occur using multiple force-balance velocity transducers and a rapid sampling data-acquisition system.

Few researchers have provided their data for future analysis and comparison. The method to collect quality data is well established by researchers around the nation and the world. This is evident in the varying ways for conducting a test with each test producing high fidelity results. The intent of this testing is to go beyond conducting a high-quality test that yields text-book like results. The intent is to catalog the data for future use by researchers to compare the bridges' change of dynamic response over time.

BRIDGE DESCRIPTION

To initiate the selection of the LTBP Utah Pilot Bridge, a portion of the National Bride Inventory (NBI) for Utah was supplied to the researchers at USU. Collaboration between researchers at USU and Virginia Tech produced a draft selection criteria table which was utilized as a starting point for focusing the search. The NBI database contains 116 different items, some with parts (a) and (b), by which the bridge is inventoried. Selection of a Utah Pilot Bridge was completed on approximately 15 of those items.

Selection Criteria

Among the 15 selection categories, a hierarchy of importance was applied during the initial search through the NBI. The 15 categories were given specific criteria for each search. Upon completion of each iteration, a visual analysis of the bridges that met all these requirements was compiled. Images through Google Maps were utilized to obtain an accurate evaluation of the bridge without requiring a site visit. These Google Maps provided aerial and street views of the bridges, which allowed the researchers the confidence to make informed decisions of whether or not to include the bridge on a short list for future site visits. Multiple ranges were applied to each selection category resulting in many iterations of the NBI database.

Selection categories that were not allowed to change were the superstructure type, percent truck traffic, deck condition, and number of lanes. Other selection categories were allowed to vary in magnitude to provide different search criteria and thus additional potential bridges. For instance, the bridge skew is one selection category that was varied

as the search progressed. By adjusting the allowed skew the number of bridges in the queue increased allowing researchers to investigate more possibilities.

After a thorough investigation of the bridges in the NBI database, five bridges were selected for further consideration. Site visits to each of the five bridges were conducted by a small number of researchers from USU to document each bridge with pictures and a personal assessment of the bridge conditions. From this initial site visit, the number of potential pilot bridges was reduced to four.

Subsequently, a second more in depth, investigation was conducted with the full USU research team and a small contingent of the VT research team. Together the group visited each bridge site to collect additional pictures and allow for a more in depth visual inspection of the bridges. This second visit occurred on March 5, 2009. Figure 1shows the USU and VT research team visiting the bridge that would eventually become the Utah Pilot Bride.

After the March 5, 2009 site visit, the LTBP team, including representation from the FHWA, conducted a discussion of each of those bridges. Strong and weak points of each bridge were reviewed along with what could be learned by selecting each particular bridge. The conversation resulted in the conclusion that deck conditions were of vital importance. The Utah Pilot Bridge has a thick asphalt overlay that could potentially cause difficulty in the deck evaluation portion of the LTBP Program. The Pilot Phase of the LTBP is in existence to develop protocols for future bridge testing. The asphalt overlay would challenge the ability of the deck testing teams to record pertinent data. While other characteristics of the Utah Pilot Bridge were not as desirable as others, the asphalt overlay created a significant interest in the LTBP team. The group that met on March 6,

2009 selected three bridges, which were then ranked in order of preference for consideration as the Utah Pilot Bridge.

Shortly after the March 6, 2009 meeting, the Utah Department of Transportation was contacted. Researchers from USU met with Chris Potter, the UDOT Bridge Maintenance Engineer, to discuss their willingness to allow access in order to monitor the bridges. The inspection reports and additional details on each bridge were supplied and reviewed at that meeting. From the discussion, it was determined that structure number 1F 205 would be the best bridge for the LTBP Program and the interests of UDOT. This bridge also corresponds to the first choice of the LTBP focus group. The final NBI criteria that were used for selection of the Utah Pilot Bridge are listed in Table 2.



Figure 1. Visual inspection as conducted by USU and VT.

Table 2. Criteria used to select Utah Pilot Bridge

Number	Description	Range	Actual Bridge Values
2	Highway District	1, 2	1
16	Latitude	> 40°20'59"	41°27'29.4"
17	Longitude	< 112°15'50"	112°3'18.6"
21	Maintenance Responsibility	1	1
27	Year Built	1970 < Year Built < 2000	1976
28A	Lanes On	2	2
28B	Lanes Under	< 3	2
29	ADT	> 5000	22,255
34	Degrees Skew	< 40	0
42A	Service On	1, 6	1
42B	Service Under	1, 4, 5, 6	1
43A	Structure Kind	5, 6	5
43B	Structure Type	2	2
45	Main Unit Spans	<5	1
109	Percent ADT Truck	≥ 6	29

Bridge Background and Inventory

The Utah Pilot Bridge, structure number 1F 205, is located 1.5 miles west of Perry, Utah; about 60 miles north of Salt Lake City, Utah. It was constructed in 1976, and carries two lanes of northbound traffic on Interstate-15. The structure carries the I-15 traffic over Cannery Road which lightly used dirt road that allows for local access for farmers to maintain their fields. A more detailed location is given by latitude and longitude coordinates: 41° 27' 25.92" and 112° 03' 18.72", respectively. A side view and aerial view of the bridge are given in Figure 2.



Figure 2. Side view looking east. Aerial view from Google Maps, top is north.

The superstructure consists of 5 prestressed Type IV AASHTO prestressed concrete girders, as indicated in Figure 3. The clear span length is 80 feet, from abutment to abutment. The actual girder lengths are 82.5 feet. The abutments are integral abutments. Inspection records indicate that all girders and the abutments appeared in good condition as of 2005. From the USU researchers' inspection it was found that the bridge abutments and parapets have experienced cracking, see Figure 4.

Other locations on the bridge show considerable wear. The undersides of the parapets, particularly at joints, have efflorescence to varying degrees. As seen in Figure 5, some cracking has created spalling of the parapet. Other damage to the parapet is limited to cracking that provides a pathway for chlorides to penetrate, as seen in the photo on the right of Figure 5.



Figure 3. Type AASHTO IV girder.



Figure 4. Cracking at abutment.



Figure 5. Cracking on underside of parapet.

An 8-inch thick concrete deck with a 3-inch thick asphalt membrane was applied at initial construction. Subsequent deck treatments have allowed a total accumulation of asphalt well over 3 inches thick. During the deck testing, sections of the asphalt were removed to test the concrete deck. Typical asphalt depths were found to be 6-8 inches as seen in Figure 6. Figure 7 shows the current deck with the asphalt overlay. In September of 1991 "major repairs" were undertaken to repair the deck surface and parapets from degradation and wear that was reported based on an inspection in September of 1982. During the 1995 inspection, it was noted that the repairs were completed and looked "good". In 1997, some transverse cracks with efflorescence at the south end of the bridge were noticed. The cracking and efflorescence remained minor until a report in 2003 that noted that the transverse cracking began to increase in density and the efflorescence increased as well. In 2005, a new wearing surface was applied to the deck. It was recorded that the parapets had some spalling and there was full transverse cracking every 5 to 7 feet with efflorescence. Figure 8 and Figure 9 show schematic drawings of the bridge elevation and cross section, respectively.



Figure 6. Measurement of asphalt overlay thickness.



Figure 7. View of deck looking south.

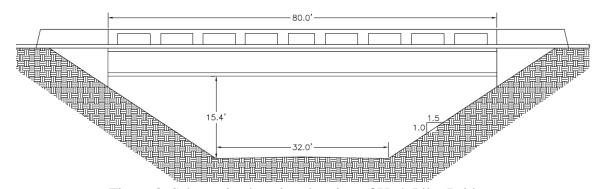


Figure 8. Schematic elevation drawing of Utah Pilot Bridge.

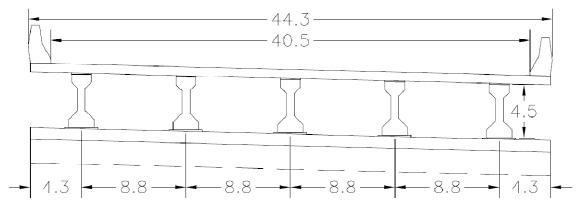


Figure 9. Cross-sectional view. (Dimensions are in feet)

Bridge Description Summary

A pilot bridge was selected in the State of Utah with the assistance of the NBI database and multiple site visits. Pictures were taken for ease of remembrance and to provide visual aids when discussing the bridge with other LTBP team members. Figure 10 shows the location of the Utah Pilot Bridge within the State of Utah. The bridge is located 60 miles north of Salt Lake City, Utah on I-15 northbound.

Specifications of the bridge include:

- 1. Two lanes of traffic carried.
- 2. Total structure length = 80 ft.
- 3. Single span, continuous structure.
- 4. Superstructure uses 5 AASHTO IV Precast Prestressed Concrete Girders
- 5. No Skew, 0°
- 6. NBI ratings of Deck = 7, Superstructure = 8, Substructure = 8 (2007).
- 7. Structure Inventory and Appraisal Sheet, electronic and paper copy of design and as-built plans available from UDOT.

- 8. Access to bridge is very high, rarely used local dirt road passes underneath.
- 9. High Truck Traffic, 29%, provides excellent candidate for a plethora of heavy load traffic.
- 10. Bridge deck has Asphalt Overlay.
- 11. Integral Abutment Construction.
- 12. Scheduled for removal of existing overly and replacement of overlay.



Figure 10. Location of Utah Pilot Bridge indicated by red bubble.

LIVE LOAD

Structural Testing Procedures

Based on criteria established by the LTBP Program, researchers selected UDOT structure number 1F 205 located near Perry, Utah. This bridge was selected because of its geographic location, structure type, deck type, traffic count, percent truck traffic, and excellent accessibility. Through load testing and continuous monitoring of the structure, LTBP researchers will be able to better predict maintenance schedules and models for bridge owners. Establishment of a baseline for future comparison is vital to understand the change with time. Load testing data provides an excellent source for refining a finite element model to be used in prediction of future bridge response.

A live-load test was performed on the structure. The scope of work required of the research team from USU included providing an testing plan, installation of instruments, load testing and data collection, as well as preliminary analysis of the live load data.

Table 3 provides a more detailed description of the structure and the testing information.

Instruments used for the structural testing included 20 surface mounted strain sensors,

Figure 11, and 7 "Twanger" vertical displacement (deflection) sensors, Figure 12.

A complete description of senor locations and identification numbers are provided in **Error! Reference source not found.** through Figure 17. Strain sensors were placed predominantly in two locations over the height of the girder. Those locations are at the extreme underside fiber of the girder, see Figure 18, and at a location near the top of the web, see Figure 19. Four sectional locations were used to place the sensors longitudinally along the structure, as seen in **Error! Reference source not found.**. Strain gauges at the

mid-span were placed three feet from the centerline to avoid diaphragm and harping-point disruption. Twangers were placed at 0.35L, or about 28 feet, from the north abutment and at mid-span. The deflection reading would not be affected by the diaphragms or harping point so the Twangers were left directly at mid-span requiring no adjustment similar to the strain transducers. The near-abutment location is five feet from the abutment. Placing the instruments right at the abutment would result in extremely low strain readings. Five feet was chosen as a location near to the abutment, but far enough away that readings would produce useable results.

Table 3. Structural description and testing information

Item	Description	
Structure Name	Cannery Street Undercrossing	
Testing Date	November 8, 2009	
UDOT Structure Number	1F 205	
Location	Perry, Utah	
Route	Interstate 15	
Structure Type	Pre-Cast, Pre-Stressed Concrete Girder	
Number of Spans	1	
Structure Length	80'	
Degrees of Skew	0	
Structure Width	44'	
Roadway Width	42'	
Wearing Surface	Asphalt	
Reference Location (X=0,	•	
Y=0)	South East corner	
Vehicle Travel Direction	North	
	Front Wheels 15' 3" From Test Reference	
Vehicle Beginning Point	Location	
Load Paths	See Figure 16	
Sample Rate	Quasi-Static Tests 50 Hz	
	Dynamic Tests 100 Hz	
Number of Test Vehicles	2	
Type of Test Vehicles	UDOT Dump Trucks	
Structural Access	D. I.G.	
Requirements	Boom Lift	
Access Provided By	UDOT/USU	
Traffic Control Provided By	USU/Interstate Barricade	
Total Field Testing Time	1 Day Set-Up, 1 Day to Conduct	
Field Notes	See Appendix B	



Figure 11. Surface mounted strain transducer, showing identification number.



Figure 12. Deflection instrument, "Twanger."

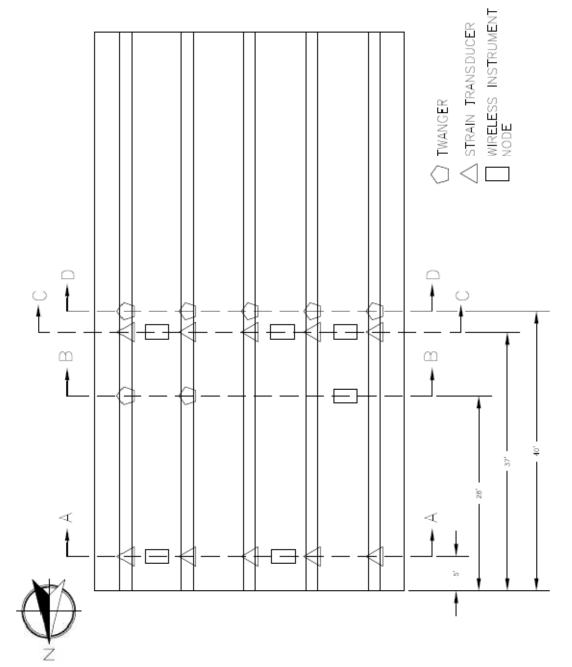


Figure 13. Plan view of instrumentation showing sectional divisions.

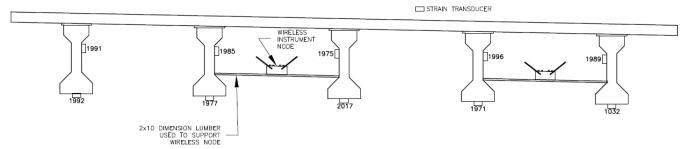


Figure 14. Cross-sectional view of Section A-A with gauge identification numbers.

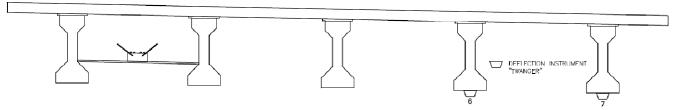


Figure 15. Cross-sectional view of Section B-B with gauge identification numbers.

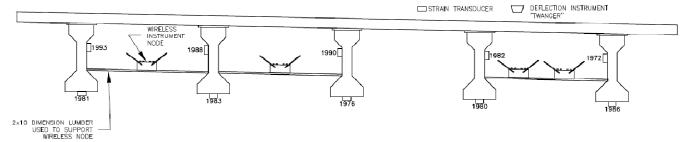


Figure 16. Cross-sectional view of Section C-C with gauge identification numbers.

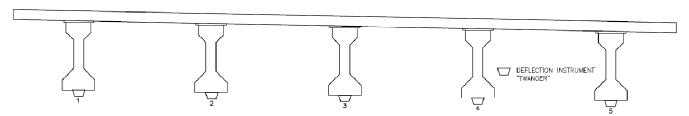


Figure 17. Cross-sectional view of Section D-D with gauge identification numbers.



Figure 18. Strain transducer at bottom flange and Twanger at midspan.



Figure 19. Location of strain transducer at highest possible location on web.

Testing setup

Instruments were installed with the use of a boom lift, see Figure 20. Near the abutment, personnel could access the instrument location with minimal difficulty.

Locations at the top of the web required that the researcher be elevated, either in the boom lift or on a 2x10 plank, see Figure 21. Individual sensors were attached to the concrete with the use of a fast-setting adhesive and specially designed mounting tabs. The strain transducers required two small tabs, while the Twangers required the use of four larger tabs. Figure 22 shows the four larger tabs used for the Twangers and a strain transducer attached using two smaller tabs. The Twangers were initially deflected and attached to a weight at the ground level, see Figure 20. For additional information on how the instruments were installed, see Appendix C.



Figure 20. Boom lift and weights used to provide initial deflection for "Twangers."

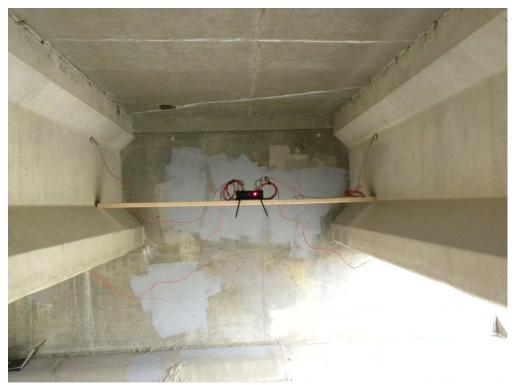


Figure 21. Researchers access instrument locations.

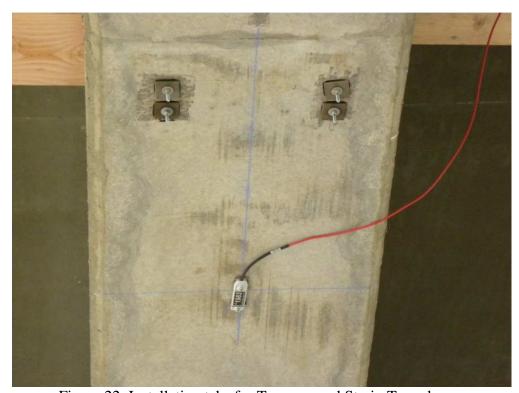


Figure 22. Installation tabs for Twanger and Strain Transducer.

The use of both strain and displacement measurements provides the researcher responsible for data analysis with an adequate picture of the structures behavior to loading. A finite element model can best be refined with the combination of deflection and strain data. Typically, a model will be refined to the deflection data and a check conducted by comparing the results to the strain readings.

Carrying out Live Load test

Following the installation of the instruments, a load-test was performed. This test was conducted during a time when traffic was at a minimum, as per requests by traffic safety personnel from UDOT and the Utah Highway Patrol. Semi-static tests were performed with the use of two heavily loaded UDOT dump trucks, see Figure 23. The vehicles' gross weights, wheel rollout distances and other important truck data are provided in Table 4. Figure 24 and Figure 25 provide a graphical representation of the vehicle footprint. Strains and displacements were recorded simultaneously at a frequency of 50 Hz.

Table 4. Important truck information

Item	Truck 1	Truck 2
Vehicle Type	Tandem Rear Axle Dump Truck	
Gross Vehicle Weight (GVW)	50,080 lbs.	51,460 lbs.
Front Axle Width	6' 8"	6' 8"
Front Axle Weight	17,100 lbs.	17,080 lbs.
Rear Tandem Pair Width	7' 2"	7' 2"
Rear Tandem Pair Weight	32,980 lbs.	34,380 lbs.
Spacing-Front Axle to 1 st Rear Axle Spacing-1 st Rear Axle to 2 nd Rear	13' 6"	13' 5"
Axle	4' 5"	4' 6"
5 Wheel Revolution Roll-Out	54' 0"	-

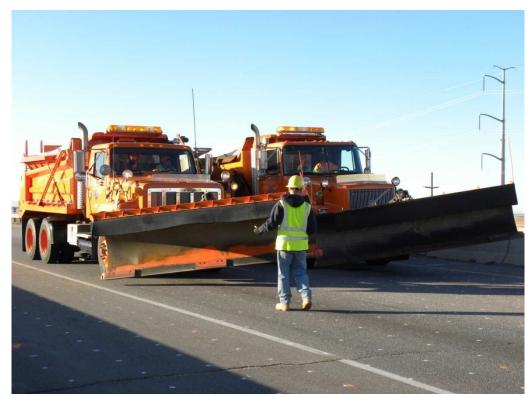


Figure 23. Two dump trucks, provided by UDOT, each heavily loaded.

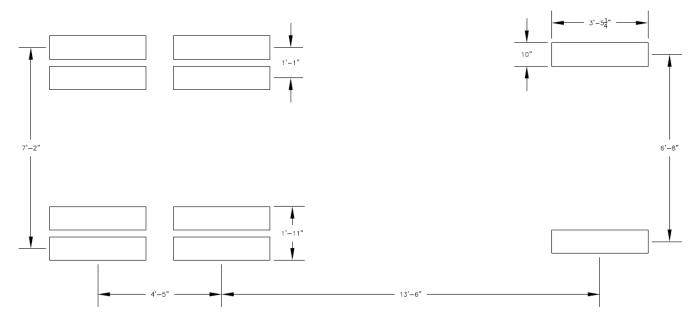


Figure 24. Test vehicle #1 footprint, UDOT dump truck.

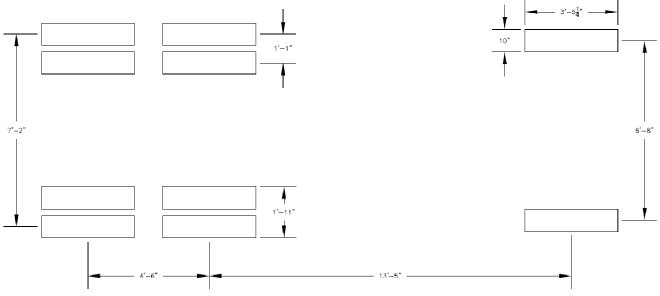


Figure 25. Test vehicle #2, UDOT dump truck.

Load paths

Six predetermined load paths were chosen, using a combination of one or two trucks. Figure 26 shows the six load paths. Load path six is not shown in the diagram because it was a full speed live load test with the truck driving down the center of the east-most lane. The exact position of the truck laterally and longitudinally can only be approximated due to the high traveling speed of the truck. The location of the truck on the bridge was determined by the horizontal distance from the south-east corner of the barrier to the driver side wheel. Since there is no skew in the bridge, no compensation was needed in that regard. The longitudinal position of the truck on the bridge was mapped with the use of a device called "AutoClicker." This is shown mounted to a truck in Figure 27. At each wheel rotation, the device would send a signal to the data acquisition system and set a mark in the data. This way, the exact location of the truck can be tracked as it crosses the structure.

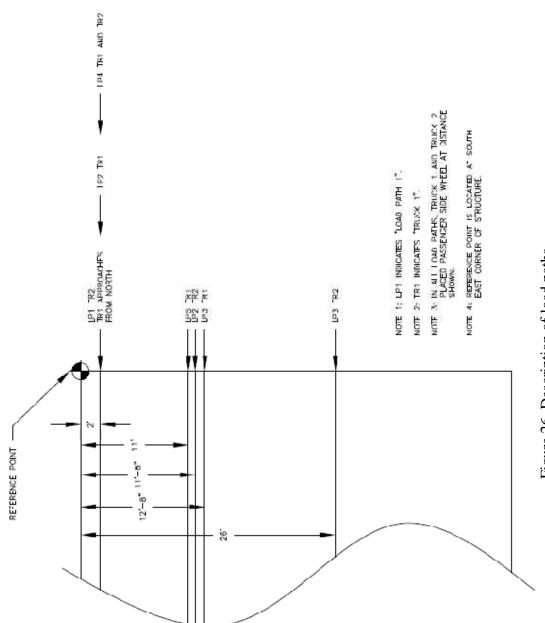


Figure 26. Description of load paths.

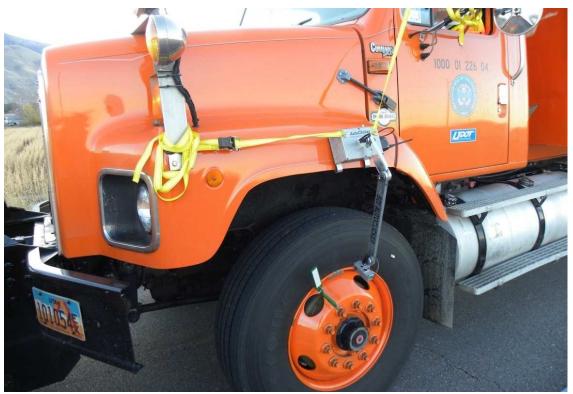


Figure 27. Autoclicker mounted on a truck.

Maintenance of traffic

Accurate and high-quality live-load test data requires that the only loading on the bridge be caused by the pre-measured and pre-weighed truck. To provide this type of access, the use of a single lane closure and highway patrol assistance were used. The bridge site did not provide staging room for both trucks to safely maneuver without the use of a lane closure. For each load case, a Utah Highway Patrol officer would create a slow-down, which is essentially a moving roadblock, as seen in Figure 28. This allowed a four to five minute window in which there was no traffic on the bride and researchers could safely maneuver trucks onto the structure and complete the load paths.



Figure 28. Slow-down produced by highway patrol officer.

Data Review

All processed data was plotted to graphically provide an assessment of the live-load response. Determination of high-quality data is assessed by the reproduction of the same bridge response for identical truck positions and elastic behavior (the strains returning to zero after truck leaves the structure). Comparison was made on quasi-static load paths (Load Paths 2-4). Appendix A contains a plot for each sensor.

Reproducibility

Data analysis showed that the reproducibility of test results from identical truck positions is very possible as seen in Figure 29 and Figure 30. The two figures display sensors B1971 and B1975 for Load Path 3. The trucks were driven across the bride on

Load Path 3 two times, providing a chance to compare the reproducibility of the test. Sensors B1971 and B1975 are located at the cross-section A-A, 5 feet from the abutment, on a girder flange and at the top of a web, respectively. The location explains the reversal seen in Figure 29 and the sporadic behavior seen in Figure 30. This shows that the integral abutment effects the response of the strain readings due to the moment developing at the end.

One sensor that does not have completely reliable results or sure confidence in its reproducibility is Twanger 3. As seen in Figure 32, most deflection records follow a smooth parabolic shape as is evident in Twangers 1,2,4, and 5. However, Twanger 3 was found to have sensor issues. After analysis in the lab, it was determined that a faulty strain gauge is the cause of the sporadic readings. Further testing with a calibration machine confirmed to researchers that recorded data from Twanger 3 is unreliable.

Elastic behavior

All strains showed linear behavior with respect to the loading applied by the subject trucks. All strains returned approximately to zero after the trucks left the bridge. This is seen in Figure 29 and Figure 30.

Load distribution

A vital piece of information to obtain from a Live-Load test is the lateral distribution of loads across the bridge. The AASHTO LRFD code spends a fair amount of time in design calculations predicting the load distribution of the bridge. Figure 31 shows the deflection curves of Twangers 1-5 for Load Path 4 run two. Twanger 5 is located on the far east side of the bridge and Twanger 1 on the far west side. The loading

is such that Twanger 5 will record the most deflection with each subsequent Twangers reading a lower value till the lowest value read at Twanger 1. Figure 31 shows this comparison with Twanger 1 showing a slight lifting of the bridge due to rotation. This implies load distribution across the width of the bridge.

Dynamic effects

An attempt to calculate a dynamic impact factor was not made for the Utah Pilot Bridge during this live-load test. To adequately determine an impact factor, multiple truck types and multiple truck speeds would be needed to make a confident conclusion on the impact that vehicle weight and speed have on the dynamic response of the bridge. However, a high-speed live-load test was performed on the Utah Pilot Bridge to identify any potential for dynamic effects caused by vehicles.

Truck 1 was driven across the bridge two separate times at a high speed, around 40 MPH. This loading scenario was labeled load path six. Figure 33 shows a comparison of the dynamic load path compared to one of the quasi-static load paths. The series are presented in their raw form, no smoothing or averaging. While the dynamic load path does have a few more variations, peaks and valleys, the absolute maximum strain value is no greater than with the static load path, and is actually slightly less. This shows conservatism in the design code for dynamic effects on a bridge and the small effect that this particular vehicular loading had on the dynamic response.

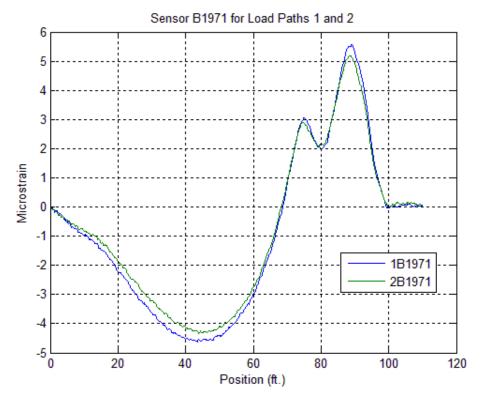


Figure 29. Comparison of reproducibility for Load Path 3.

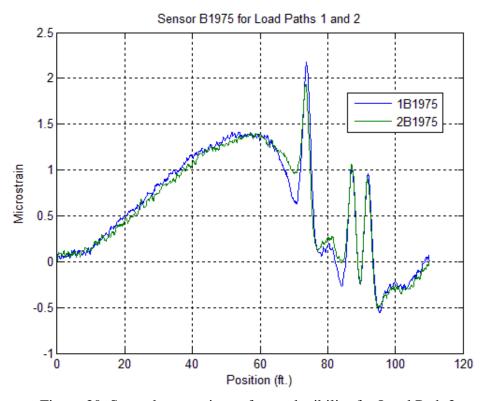


Figure 30. Second comparison of reproducibility for Load Path 3.

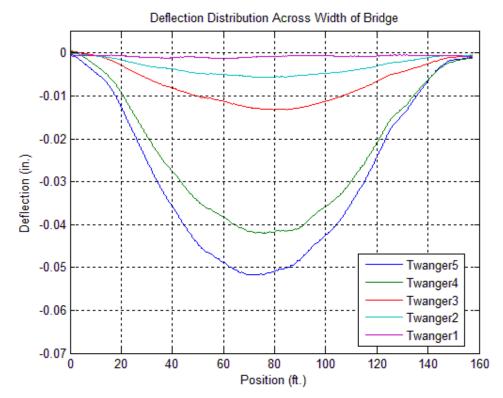


Figure 31. Lateral load distribution as seen in deflection record for Load Path 2.

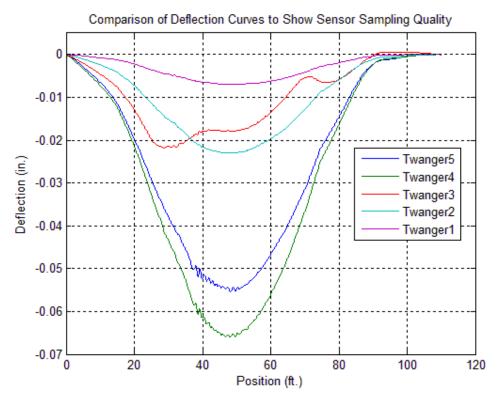


Figure 32. Demonstration of unreliable results from Twanger 3.

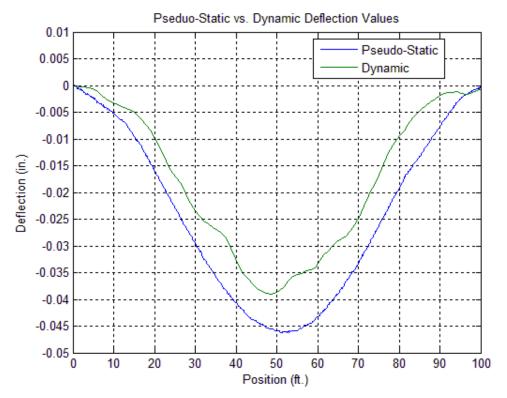


Figure 33. Comparison of dynamic effects with static values.

Live Load Test Conclusions and Recommendations

Analysis of the live-load test data reveals that the response magnitude of the sensors used is typical of the bridge type and size. The strains and deflections were relatively low due to the shorter length and stiffness of the structure. A slightly higher strain reading would result in more confidence of accuracy and prediction of bridge response. However, data recorded is of high quality. Comparison of various load paths and repeating various load paths multiple times produced data that indicates that the sensor readings are highly accurate. Refinement of a finite element model will provide an analytical tool for predicting the response of the bridge structure to various loadings.

It is recommended for additional live-load testing of this bridge that researchers use as heavily loaded dump-trucks as can be obtained. The trucks used for this test were loaded to the legal limit. An effort to find a heavier set of dump trucks would most likely result in higher strain readings. It is also recommended that researchers plan to test this bridge on a Sunday morning, or other low traffic time. The bridge selected has an estimated 22,000 average annual daily traffic count with approximately 30% of that being truck traffic. Attempting the test at a time of even moderate traffic is very difficult due to the number of vehicles accessing the road.

Finally, this test produced an excellent source of non-destructive testing to determine the structural response to real truck loading.

Finite Element Model

The formulation of a Finite Element Model (FEM) is a very important part of the analysis section for the Utah Pilot Bridge. There are various reasons for creating an FEM for the Utah Pilot Bridge. One reason is to document the current state of the bridge through an analytical model. Producing a model that replicates the bridge structure at the time of initial live load testing will allow researchers to compare future testing to the current state. This is considered a baseline. Another reason to create an FEM is to use it for comparison of girder distribution factors. A properly refined FEM has the capability of representing the bridge response from any truck loading. Therefore, a comparison of the AASHTO LRFD girder distribution factors can be made from the results obtained through the FE model. Calculation of distribution factors is not part of the scope of this study.

The following sections explain the assembly of the FEM, and present the results of the FEM compared with the live-load test.

Assembly of FEM

The finite element mode was created in SAP2000 Version 14. This program serves the purpose of creating a three dimension replica of a physical structure. Material and geometric properties are required input fields by the modeler. The initial analysis of the finite element model began by creating three separate models for comparison with measured live-load response. Since there are many different ways to model a bridge that will produce reliable results, a comparison of those types was made before detailed refinement began.

The three model types created for this bridge are first a model made of frame and shell elements, the second of solid elements, and the third a combination of frame and solid elements. Each of the models was checked for accuracy by comparing the moment due to an applied load at mid-span at any cross section of the bridge to the exact moment. Upon completion of the live-load test, rough analysis was completed to determine which model most accurately predicts the bridge behavior.

The chosen model uses solid elements for both the deck and the girders. Thus, the model that was refined is assembled completely of solid elements. Solid elements can perform well because they incorporate six stresses, three normal and three shear stresses. However, there are several drawbacks to using solids including the complexity of working with solids and the large number of elements used to model the bridge. This can greatly increase the runtime of the analysis or it can make the computation not feasible due to increased requirements.

The girders and deck are composites of tri-linear hexahedrons, or eight node bricks. These solid elements have 3 translational degrees of freedom per node. It was preferred that the solid elements were compact and regularly shaped to improve accuracy. Because of the design of the girders, the elements were shaped as rectangles. Figure 34 shows the mesh for the interior girders and Figure 35 shows the mesh for the exterior girders.

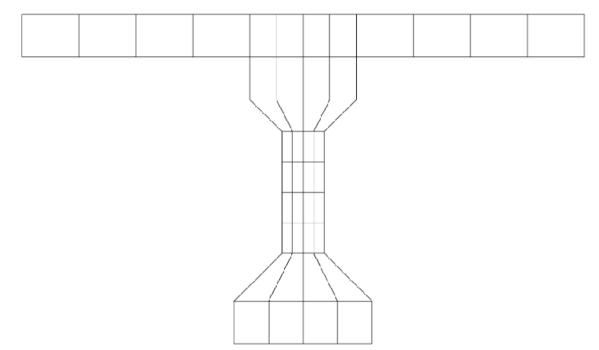


Figure 34. Interior girder mesh for solid elements.

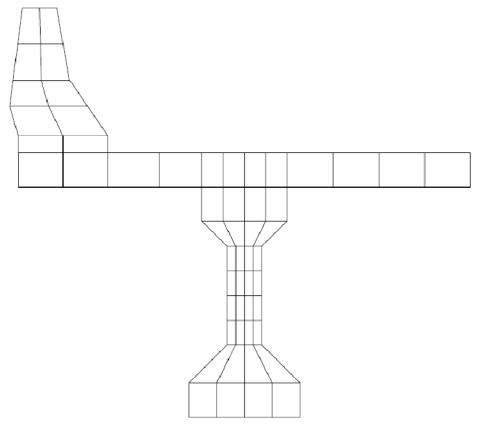


Figure 35. Exterior girder mesh for solid elements.

Formulation of the exterior and interior girder meshes was completed using the snap on grid option available in SAP 2000. A grid that coordinated with the shape of the cross-section was created and followed as a template for creating area elements. Once the cross-section was created, it was extruded at 1-ft increments for the total length of 80 ft. A deck mesh close to 1-ft by 1-ft was used to allow accurate placing of the truck load on the bridge deck. A larger mesh would have been preferred for modeling and computational ease. However, a finer mesh produces a result more close to the exact response and allows for more precise placement of the wheel loads. Figure 36 and Figure 37 show the completed bridge with the correct width, length, cross-section, and mesh discretization.



Figure 36. Completed cross-section with colors representing various sections.

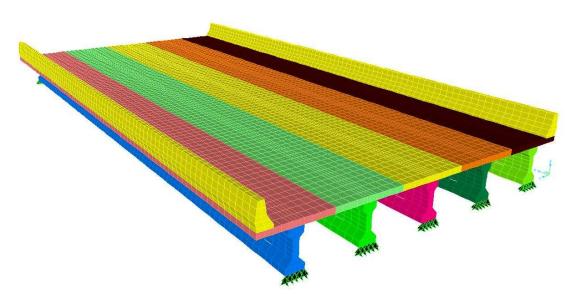


Figure 37. 3D Representation showing all girders and sections represented by colors.

Figure 36 and Figure 37 also shows the color scheme used to represent the different sections for material property modifications. Each color represents a different section where the material properties for each girder are specified separately. The deck is divided into five sections where the material properties are allowed to changed individually same as the girders. Both the east and west parapets are modeled using the same material properties. Dividing the bridge into multiple sections allows for accurate material adjustment during refinement.

Before beginning the refinement process and adding in bearing restrains, the model was checked for accuracy. A single point load was placed at the very center of the

bridge with a simple pin-roller support. Five individual groups were created at mid-span using the Group Command in SAP 2000 to determine the moment at that point. Section Cuts were used to output the moment at each location. The moments of all five groups were added together and compared to the theoretical maximum expected from the point load. The moment calculated by SAP was within a few percent of the expected value. Since the group command uses an approximation method of all the elements in the group, the accuracy obtained was enough to allow the author confidence that the model was assembled correctly. The final model consists of approximately 19,500 joints and 12,500 solids.

End restraints have a significant effect on the structural response of the bridge.

The design of the bridge uses integral abutments that act somewhere between a fixedfixed and a pin-pin support condition. Integral abutment behavior is modeled with the use
of horizontal and vertical springs at the girder and deck level. Vertical springs with
infinite stiffness were used to model the bearing support for the girders while horizontal
springs with varying stiffness's were applied at the girder base. Additional horizontal
springs were applied at the deck level to replicate the added stiffness of the approach.

The girders used on the Utah Pilot Bridge are prestressed, precast concrete Type IV AASHTO girders. They have a large number of prestressing strands with a centroid that forms a harping shape. At the girder ends, the centroid of the prestressing strands is located 13.50 inches from the bottom of the girder. The harping point is located 32.0 feet from the ends of the girder. At the harping point, the centroid of the prestressing strands is 4.08 inches from the bottom of the girder.

SAP2000 allows replication of a prestressing strands through the use of an element called a tendon. For this element, a Tendon section is defined starting with the material property and then physical sectional properties. Once the section is created, the tendon element can be created. Creation of a tendon in SAP2000 requires the selection of two points, the starting and ending of the tendon. Following this, a screen allowing for refined adjustment of the tendon appears. For the Utah Pilot Bridge, a Tendon with the exact harping shape was created along the centerline of the prestressing strands as shown in the drawings. When applying the prestressing load, SAP2000 allows for a point load or a stress. A point load, or force was used for the Utah Pilot Bridge. Friction and Anchorage losses are allowed inputs for tendon elements. Those values were set to zero for the Utah Pilot Bridge since those losses have already occurred. Additional loss parameters including Elastic Shortening Stress, Creep Stress, Shrinkage Stress, and Steel Relaxation Stress are inputs that were set at zero.

Figure 38 shows a 3D view of the tendons in the model, the right side, and the actual structure on the left side for comparison of location.

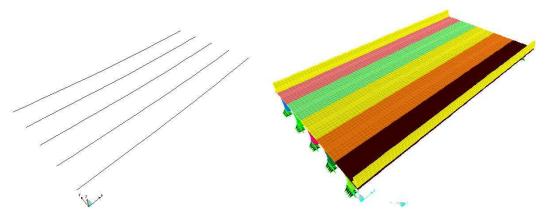


Figure 38. Showing tendons and how they fit compared to 3D image of bridge.

Results of FEM

For refinement purposes, only Load Path 2 was used to refine the model. As mentioned in the previous sections of the live-load test, two UDOT dump trucks provided the necessary excitation. The information on Load Path 2 and the truck dimensions and weights can be found in the Structural Testing Procedures section. This information was used to select the location of each wheel load.

Wheel loads were represented by single point loads, applied at the assumed centroid of the wheel. Point loads can only be applied at nodal locations. Nodes were only created at corners of solid elements. This limited the location of possible load application. Even with the given limitations, the application of the load was within a few inches of the load path. It is important to note that even though the load path is clearly defined and the axle dimensions do not change, the actual path the truck followed is impossible to record given driver capabilities and difficulty of moving such a large truck.

To be as accurate at possible, the truck position was mapped continuously as they crossed the bridge during the live-load test. For modeling simplicity, the truck was moved at increments of four feet along the length of the bridge. Therefore, the first few applications of load on the bridge include only the front axles of the trucks until the distance on the bride is far enough to include the rear axles. This same situation occurred as the truck left the bride, only in reverse. The last few loading applications are experienced only by the rear axles.

There are 25 different load cases in the finite element model. Each load case contains the two trucks as they travel in an assumed parallel formation across the length of the bridge. When checking the solution, all 25 cases were run. This allowed for actual

comparison of the duration of the load path. Values from each of the instrument locations were then extracted from the SAP2000 output and compared with the data from the live load test. Figure 39 through Figure 45 show a comparison of the deflection values for Load Path 2 between the actual test data and the finite element model analytical results.

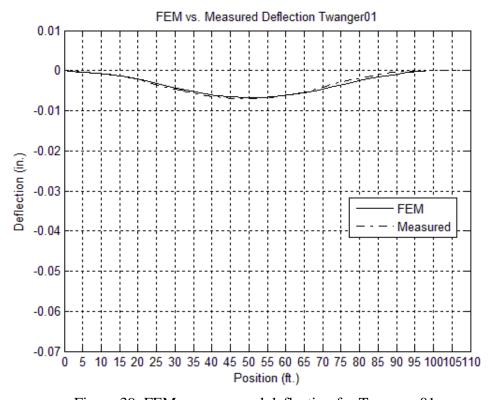


Figure 39. FEM vs. measured deflection for Twanger 01.

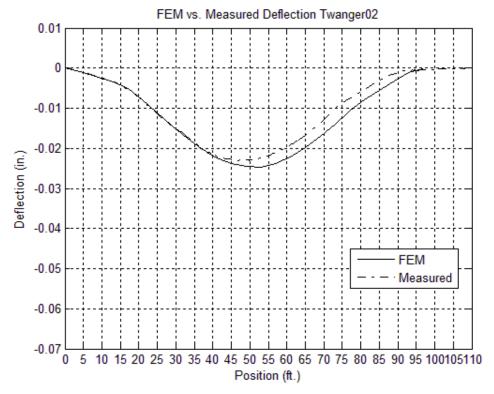


Figure 40. FEM vs. measured deflection for Twanger 02.

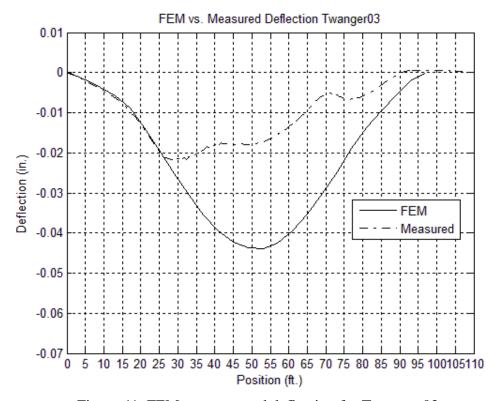


Figure 41. FEM vs. measured deflection for Twanger 03.

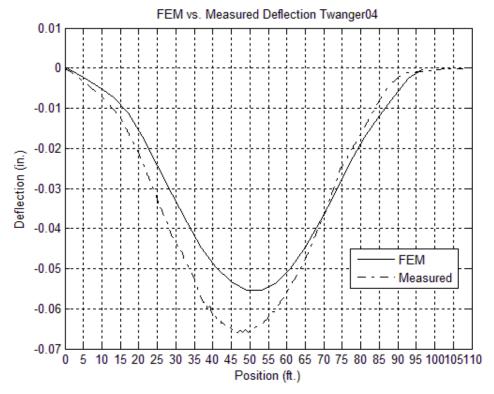


Figure 42. FEM vs. measured deflection for Twanger 04.

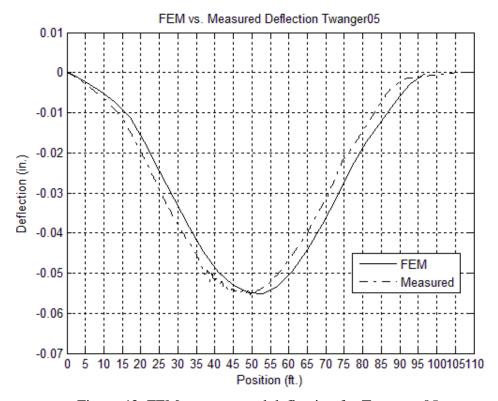


Figure 43. FEM vs. measured deflection for Twanger 05.

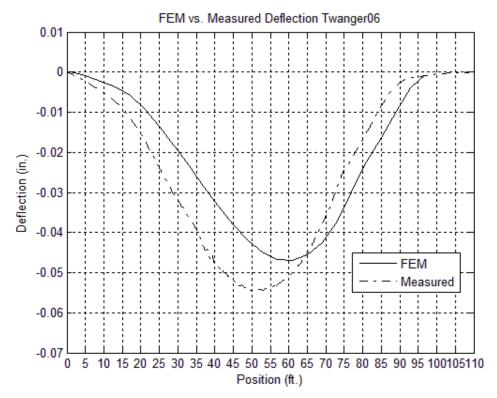


Figure 44. FEM vs. measured deflection for Twanger 06.

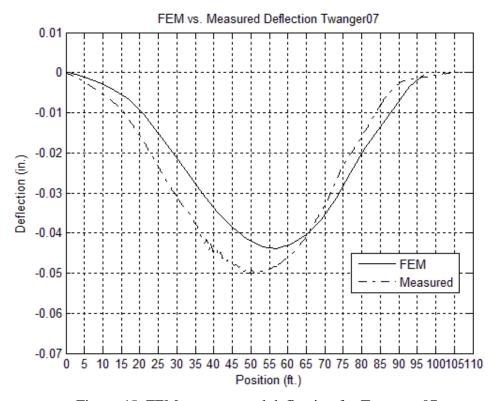


Figure 45. FEM vs. measured deflection for Twanger 07.

FEM summary

A finite element model was created for the Utah Pilot Bridge that employs solid elements to create a 3D representation of the physical bridge. The model was refined using data retrieved during a live-load test. Results showed a good correlation, see Figure 37 through Figure 43. This model will store the bridges condition through time to compare with future test results.

DYNAMIC TESTING

A dynamic test was conducted on the Utah Pilot Bridge at the same time as the deck testing and NDE/NDT testing. Timothy Thurgood is the student who conducted the dynamic test and provided analysis of the dynamic data. He has provided a small amount of information to explain the test setup and information learned during the dynamic test.

An electromagnetic harmonic force shaker was used to provide excitation for the dynamic test on the Utah Pilot Bridge, see Figure 46. A full scale dynamic test was not conducted on the Utah Pilot Bridge. Instead, the test was used as an in-field preparatory stage for a full scale dynamic test schedule for the California Pilot Bridge. A demonstration version of a data acquisition system was used to gather data and verify the usefulness of the system. This data acquisition system had a total capacity of four channels. One channel was dedicated to measuring the output of the electromagnetic shaker. The other three channels were used to measure bridge response as recorded by three velocity transducers, see Figure 47. Figure 48 shows the test set-up.

Traffic flow continued as normal on the bridge during the dynamic test. This resulted in a large amount of noise, especially due to the 29% truck traffic on the bridge. It was difficult for the noise to be filtered out of the data with only three channels measuring bridge response. Table 5 summarizes the modal frequencies, the change in phase for each mode and the damping ratio at each mode. Figure 49 shows a plot of magnitude in units of in/s, the unwrapped phase in units of degrees and the coherence function. The half-power bandwidth method was used to calculate the damping ratio for each mode, as seen in Figure 50.



Figure 46. Electromagnetic shaker used in Utah Pilot Bridge dynamic test.



Figure 47. Velocity transducers as used on the Utah Pilot Bridge dynamic test.

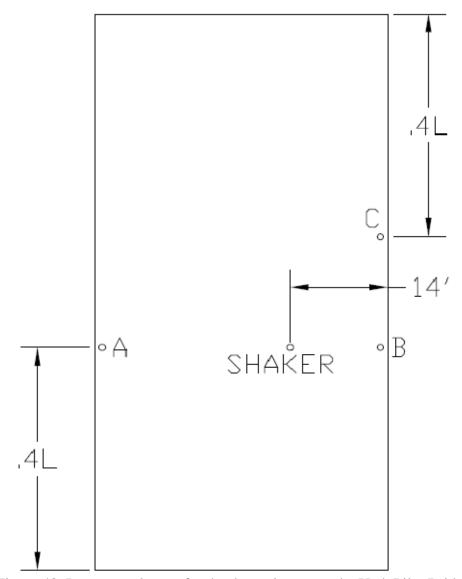


Figure 48. Instrument layout for the dynamic test on the Utah Pilot Bridge.

Table 5. Dynamic response summary

Mode	Frequency	Δ Phase	Damping
1	6.778	81.64	4.16%
2	7.861	199	3.89%
3	9.551	158	3.49%
4	14.36	152	2.99%

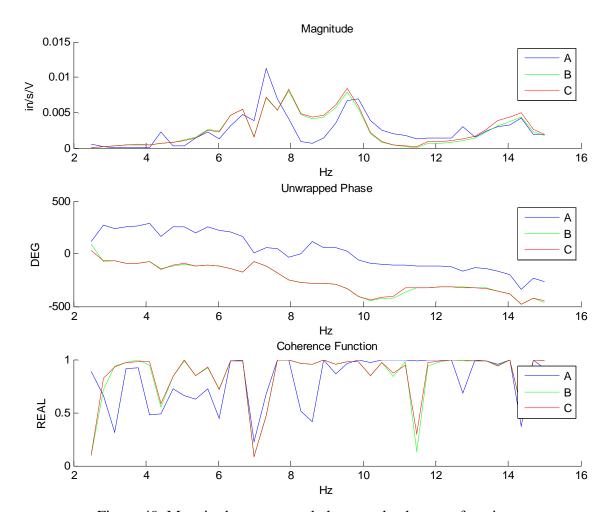


Figure 49. Magnitude, unwrapped phase, and coherence function.

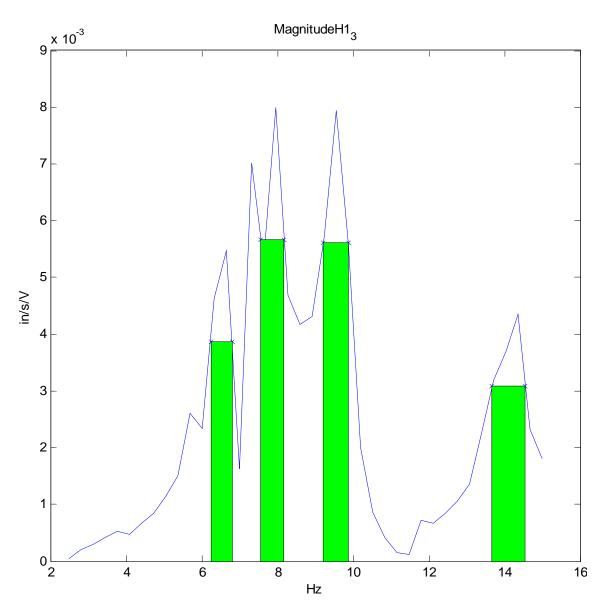


Figure 50. Half-power bandwidth method used for damping ratio calculation.

LONG-TERM MONITORING AND INSTRUMENTATION

For the monitoring life of the Utah Pilot Bridge, instrumentation was installed to provide data for bridge health evaluation. Monitoring of the Utah Pilot Bridge is exhaustive, in order to obtain maximum information. All factors that affect bridge performance are considered in the instrumentation plan and are categorized by the LTBP Study Topics. Monitoring over the project life will allow for changes in the bridge response to be recorded.

Monitoring equipment planned for installation on the Utah Pilot Bridge is listed and explained in the sections that follow.

Long-Term Monitoring Sensors

To provide a complete monitoring system that samples data from all possible bridge characteristic parameters, many different instruments were selected. The type of instruments selected and a brief description of each is provided in the following sections.

Weigh-in-Motion (WIM)

The WIM sensor preferred for the Utah Pilot Bridge is a quartz piezoelectric sensor. This sensor was chosen, among all possible WIM sensors, because it is capable of measuring vehicle weights at freeway speeds, 75 mph. A graphical representation of a Quartz WIM sensor is given in Figure 51. A WIM sensor is capable of recording traffic counts to inform researchers of the number of vehicles that use the bridge each day, as well as the percentage of the daily flow that is attributed to trucks.

Initially researchers planned to purchase and install this instrument. Further investigation found that a quartz piezoelectric sensor is installed near the Utah Pilot Bridge. A Port of Entry is located approximately one mile south of the Utah Pilot Bridge. It currently operates four WIM sensors, two for the southbound and two for the northbound traffic. Each direction of traffic has one WIM on the freeway, where vehicles travel at the posted freeway speed limit, and one along the lane leading to the port of entry where trucks travel at a speed much less than freeway speeds. Figure 52 shows the WIM sensor installed along the lane leading to the port of entry; showing sensors in parallel and an inductive loop. The WIM that is located along the lane is owned by the Utah Department of Transportation (UDOT) Motor Carrier Division (MCD). The WIM that is located on the interstate is owned by a private company, Pre-Pass. Figure 52 and Figure 53 show the instrument as installed in the roadway for the Perry, Utah Port of Entry.

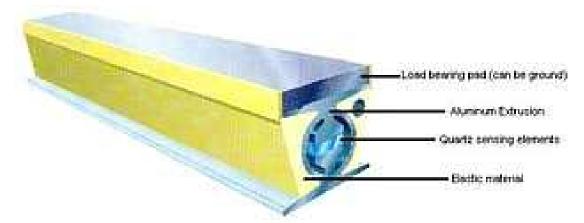


Figure 51. WIM sensor, www.cardinalscale.com



Figure 52. Quartz based WIM installed in lane leading to Perry, Utah Port of Entry.

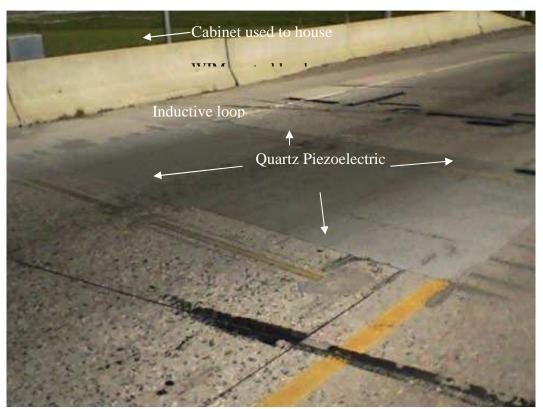


Figure 53. WIM installed in lane leading to Perry, Utah Weigh Station.

Researchers from USU were given a tour of the weigh station and shown how the WIM sensors work and record data. The WIM owned by UDOT is calibrated automatically every 100 trucks with comparison to the static scale. The computer algorithm knows when the 100th truck crosses and subsequently directs that truck to the static scales. A calibration is made from the static scale measurement to the WIM sensor so that the WIM sensor maintains a high level of accuracy. A sample of the data retrieved by the WIM was shown to the USU researchers. Representatives from the UDOT Motor Carrier Division lead the tour of the site.

Data from the WIM location in the northbound direction are available to the USU research team after discussions with the UDOT Motor Carrier Division and subsequent drafting of an agreement between USU and the UDOT Motor Carrier Division.

WIM sensor data will be monitored continuously and catalogued in a rain-fall histogram. Ideally, all other data will be sampled based on a triggered event from the WIM sensor. However, for the Utah Pilot Bridge, a triggered event from the WIM sensor data will not be possible. Most trucks will cross the WIM sensor then enter the weigh station. It is not known how long it will take for a particular truck to reach the bridge structure. A truck may have a Pre-Pass account and be allowed to travel past the weigh station at original speed, eliminating the requirement to enter the weigh station. However, if the truck must enter the weigh station, it will slow and may be stopped for inspection. Either way, travel speed is slower and unpredictable. Thus, a trigger is unlikely since a dependable time of arrival on the bridge structure cannot be calculated. Because of this difficulty, a streaming video camera is recommended to properly capture and document "unusual" or "significant" events.

The WIM sensor is important to obtain vehicle weights that lead to strain and deflection measurements. This will aid researchers gathering data for the following list of LTBP Study Topics. performance of bridge deck treatments (2), performance, maintenance and repair of bridge joints (3), performance of bare/coated concrete superand sub-structures (5), performance of embedded pre-stressing wires and tendons (7), performance of bridge bearings (8), performance of precast reinforced concrete deck systems (9), risk and reliability evaluation for structural safety performance (15), performance of pre-stressed concrete girders (17), performance of structure foundation types (19), and criteria for classification of functional performance (20).

Traffic camera

A traffic camera with the basic capability of a low resolution streaming video is necessary to understand traffic flows during significant events. When coupled with a WIM, a streaming video camera will provide adequate data to understand what caused a certain event. Since the WIM setup for the Utah Pilot Bridge is not capable of providing an accurate trigger of an event, a streaming video feed will facilitate in capturing traffic events.

A video data collection and recording system is necessary for analysis purposes. The system requires enough hard drive space to allow researchers opportunity to retrieve the data before a revolving rewrite process erases stored data. Not all video footage will be permanently recorded. Researchers will analyze long-term instrument data and note any unusual readings by the sensors. They will then use the time stamp on that data to retrieve the appropriate video footage from the temporarily stored files. Understanding the flow of traffic over the bridge will aid in understanding bridge response.

Weather station

Environmental effects ranging from expansion and contraction of materials through heating and cooling cycles due to daily temperature variations to the more extreme freeze-thaw conditions of seasons are important for determining bridge health. Seasonal temperature changes can cause joint movement, bearing movement and local strain variations. All of these parameters require attention. Knowing the response of the bridge to environmental conditions will help in understanding changes in stress and strain.

A weather station will include instruments to record the following data: precipitation, wind direction, wind speed, radiation, humidity, and ambient air temperature. All equipment for a weather station will be securely fastened to a pole located in a safe location. The location was selected based on approval from FHWA and UDOT according to standards, installation requirements and UDOT permission.

Strain gauges

In the category of strain gauges, the Utah Pilot Bridge has two Vibrating Wire Strain Gauges placed on the girders. The high accuracy and longevity of the vibrating wire strain gauges will provide a precise comparison of the structural response of the bridge over time and through deterioration. The slow sampling rate of the vibrating wire strain gauges will be recorded on a set time interval.

There are an additional six foil strain gauges placed on the bridge. They will aid in understanding the bridge response to excitation/loading scenarios. The data will be recorded on a much faster time interval than the vibrating wire strain gauges and only on triggered events. Collected data from the foil strain gauges will be stored following a

triggered event. Foil strain gauges have a tendency to "drift" over time, which will require periodic zeroing and eventual replacement to maintain data quality.

These strain sensors will address the following list of LTBP Study Topics: performance of bridge deck treatments (2), performance, maintenance and repair of bridge deck joints (3), performance of bare/coated concrete super- and sub-structures (5), performance of bridge bearings (8), and performance of pre-stressed concrete girders (17).

Velocity transducers (seimometer)

Three velocity transducers are placed on the bridge to record dynamic responses due to excitation from vehicles passing over as well as any possible seismic activity. In addition to vehicle loading, Utah is in a seismically active location and any seismicity will affect the bridges. It is important to know how the Utah Pilot Bridge responds to dynamic loading. Long-Term dynamic analysis will provide for an opportunity to see the change in bridge mode shapes, modal frequency and damping ratio through daily and seasonal changes as well as changes due to any deterioration or rehabilitation efforts.

The velocity transducers will address the following list of LTBP Study Topics: performance of untreated concrete bridge decks (1), performance of bridge deck treatments (2), performance, maintenance and repair of bridge deck joints (3), performance of bare/coated concrete super- and sub-structures (5), performance of bridge bearings (8), risk and reliability evaluation for structural safety performance (15), performance of pre-stressed concrete girders (17), performance of foundation types (19) and criteria for classification of functional performance (20).

Deck water saline content

The Utah Pilot Bridge experiences repeated freeze-thaw conditions with heavy snow fall during the winter season. It is well documented that bridge decks freeze before soil supported roadway surfaces. UDOT applies varying amounts of de-icing agents on roadways to provide for safe driving conditions with extra de-icing agents applied to bridge decks to keep the water from freezing. The most common de-icing agent used in Utah is salt. The chlorides in salt can result in differing levels of corrosion to the bridge superstructure.

It is of interest to determine the quantity of salt placed on the Utah Pilot Bridge in order to understand the effects that chloride application has on the deterioration of the superstructure. Two IRS21 Lufft Intelligent Road Sensors will be installed on the deck of the bridge to measure the saline content of the water on the bridge deck.

The IRS21 Lufft Intelligent Road Sensors will address following list of LTBP Study Topics: performance of bridge deck treatments (2), performance, maintenance and repair of bridge deck joints (3), risk and reliability evaluation for structural safety performance (15), and criteria for classification of functional performance (20).

Tilt meters

Four total tilt meters are used on the bridge to monitor the effects of an integral abutment behavior. To compare the change of abutment rotation to girder rotation, one tiltmeter was placed on the abutment while a second tiltmeter was placed a few feet off the abutment on the girder, as seen in Figure 54. A primary reason that the Utah Pilot Bridge was selected was because it is constructed with integral abutments. For this reason, monitoring of the abutment and near-abutment girder behavior is accomplished

through the use of four tilt-meters. The first interior girder on the east side, which also corresponds to the right or truck travel lane, will be the location of the tilt meters. A pair of tilt meters will be installed at the north and south ends of the bridge. At each location one tilt meters will be placed on the abutment wall between the east exterior girder and the first interior girder from the east side while the additional tilt meter will be placed on the first interior girder from the east side approximately two feet from the abutment wall. A pair will be installed on the north end of the bridge and a pair will be installed on the south end, thus four tilt meters.

These sensors will address the performance of bridge bearings (8), risk and reliability evaluation for structural safety performance (15), unknown foundation types (18), performance of structure foundation types (19), and criteria for classification of functional performance (20).

Thermocouples

Temperature sensors are installed on the bridge with the intention of measuring the temperature of the girders and abutments at select locations. Localized knowledge of thermal gradients will allow researchers to understand joint movements, bearing movements and local strain ranges as a result of the differential temperature reading across a girder.

A thermocouple will be placed in the same protective housing as each of the six foil strain gauges and the three velocity transducers. The vibrating wire strain gauges and tilt-meters have built in thermistors to account for temperature variations so the temperature will be known at those locations without the placement of a thermocouple.



Figure 54. Showing two tiltmeters installed one on girder and one on abutment.

While no study topics are directly answered with the installation of thermocouples, the temperature data provided is necessary to accurately report the measured response from each of the sensors planned to create the structural health monitoring system of the Utah Pilot Bridge.

Service, maintenance, and replacement

Through the duration of the monitoring period, certain costs will acrue. Some of these ways are through routine maintenance of the equipment placed on the bridge structure, service costs including communication/internet and maintenance costs including but not limited to site visits and datalogger/instrument software updates. It is likely that many unforeseen maintenance costs will arise due to the large amount of

equipment installed and difficulty in knowing all of what happens at a bridge site such as vandalism, weather occurrences, traffic incidents or bridge maintenance operations as performed by UDOT. It is expected and known that certain instruments will require replacement during the monitoring period. Preparation in planning for these costs will provide a much easier method of replacement.

Analysis and Data Storage

<u>Analysis</u>

Data processing will be conducted by the Utah State University Research Team.

A datalogger, capable of connecting to the internet or communication with a modem, will collect, deliver, and record raw data to a secure site for further analysis. Integration with the communication service and the datalogger will allow for constant real-time updating of data. A constant communication connection will remove the need for time consuming visits to the bridge site for data retrieval.

Data storage

A large amount of raw data will be collected through the project life of the Utah Pilot Bridge. This data will be stored by Siemens America as defined in Task 1.3 of the LTBP Program. Data access will be coordinated through Siemens American for accurate and consistent data retrieval. This system is not yet assembled and as such, an explanation of how it operates is not possible at this time.

Installation

Installation was divided into two phases due to time and resource constraints. The first phase consisted of the site preparation which included the installation of the instrument pad, instrument tower, instrument cabinet, conduits, junction boxes, and instrument boxes. The second phase included the installation of the sensors. The first phase occurred all at once, during the dates of March 15-20, 2010 which coincides with USU's Spring Break. Spring Break was more conducive to Phase One because no classes were held so students were able to spend larger amounts of time on the project with no interruptions. Phase two was carried out over multiple events dictated by arrival of instruments and determination of installation methods. The following two sections describe each phase and the work completed during both.

Phase one

All tools and materials for installation were purchased and shipped to the bridge site prior to phase one beginning. Shipping consisted of loading all equipment into the USU Structural Testing Laboratory trailer and driving it to the bridge site prior to the start of Phase One. Appendix C contains the computer aided drawings followed by installers during phase one. Slight modifications were made from the drawings with regard to the total number of sensors and the location of the conduit on the bridge. The instrument pad with the tower and cabinet remained the same. These drawings provided the necessary understanding of what work was to be done to allow for an estimate of the materials and equipment needed. Figure 55 shows all the equipment purchased, loaded in the trailer.

Installation progressed starting from the instrument pad and working toward the bridge. It was decided that this would ensure quality assembly and placement of all conduit. The instrument pad is the focal point of the installation, so its location was a top priority. The exact location was selected based on the ease of access for a ride-on-trencher to scale the steep slope safely and adequate room for tower maintenance and tower guy wires.

Once the location of the pad was selected, excavation for the pad and tower footing began. The trench for the conduit followed next, with the trenching beginning at the top of the hill, near the bridge, working toward the instrument pad, see Figure 56.

When the trench and footing were completely dug, the formwork for the pad and reinforcing steel for the tower and pad were placed, see Figure 57. Before pouring the concrete, the conduit running from the bridge to the cabinet and tower were placed since part of the conduit penetrates the instrument pad, see Figure 58. A ready mix concrete company was hired to provide and deliver the concrete which was poured into the form and finished, see Figure 59 and Figure 60. Installation of the cabinet occurred the day after the pour to allow the concrete time to cure, see Figure 61.

Manufacture installation recommendations for the instrument tower suggest installing the mounting stakes into the concrete during the pouring process with the bottom ten foot section connected to the mounting stakes. Attachment of the lower ten foot section guarantees exact location of the mounting stakes and provides a surface from which the tower is leveled.

Multiple junction boxes were installed to allow for easy transition of multiple turns and intersections due to the bridge geometry and instrument location. One large

junction box was installed on the abutment wing-wall that provides a transition from the underground conduit to the conduit installed on the bridge. Although only one length of conduit was needed to house all instrument cables, an additional three conduit lengths were placed in the trench to allow for growth or troubleshooting in the future without the need for extra trenching. Figure 62 shows the four buried conduit pipes entering the junction box on the wing-wall from the top and the single conduit leading to the instruments on the bridge at the bottom of the junction box.

Smaller junction boxes were used near the abutment to provide a transition from the east-west oriented conduit to the north-south oriented conduit. These boxes were modified with coring bits to provide a secure, water-tight connection between box and conduit, as seen in Figure 63. These smaller boxes were modified to act as instrumentation protection by cutting the backs. The main supply conduit runs a few inches under the girders with a junction box at each location where an additional line of conduit rises up to the deck level.

The conduit was installed on the deck between the girders to collect as many instruments as possible with the least number of conduit, see Figure 64. Additional boxes were used at instrument locations. These boxes allow for the main line of conduit to continue, if needed, while providing an easy access for each individual sensor cable, see Figure 65. Flexible PVC tubing was used to transition from the main feeding line to the individual instrument boxes, see Figure 66. Installation of the individual sensor boxes and connecting them via the flexible conduit was the last step in phase one. Adequate traffic control was used during the period of time researchers spent at the bridge site; see Figure 67 and Figure 68.

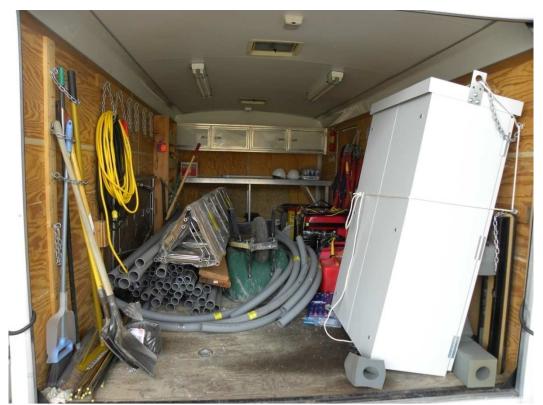


Figure 55. Equipment and supplies for installation.



Figure 56. Trenching, starting point near bridge abutment.



Figure 57. Pad form and reinforcing steel.



Figure 58. Conduit running from pad to bridge.



Figure 59. Pouring of concrete.



Figure 60. Finishing concrete.



Figure 61. Insturment pad with installed tower and cabinet after grading.



Figure 62. Junction box loacted on abutment wing-wall.





Figure 64. Conduit running along underside of deck.

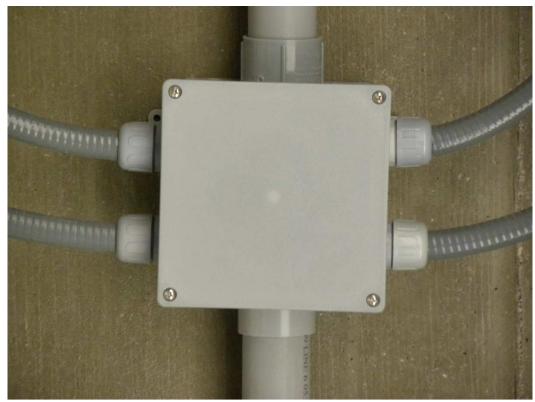


Figure 65. Junction boxes providing access for instruments into supply line.



Figure 66. Flexible conduit connects instrument boxes to supply line.



Figure 67. Traffic control seen under the bridge.



Figure 68. Traffic control seen on road leading to bridge.

Phase two

Phase two involved the installation of the instruments on the bridge, their assemblage into the data acquisition system, verification that all instruments are sampling correctly, and ensuring that data is streaming to the collection center.

The first instruments installed were the vibrating wire strain gauges, the full bridge foil strain gauges, thermocouples, and tiltmeters. Cabling was placed for the future installation of the velocity transducers. Purchase lead time did not allow for installation of the velocity transducers at the time of installation of the other instruments. The installation of the velocity transducers occurred shortly after receiving them.

The weather station, with it respective instruments, was installed once the solar panel system was decided on and in hand. Since both the solar panels and the weather station instrumentation are installed on the same tower, it was decided that their installation would occur concurrently to ensure the best fit. Also installed on the instrumentation tower is the traffic camera. The instrument tower was the last portion of the actual instruments to be installed.

The vibrating wire strain gauges are Model 4000 from Geokon. Installation of the vibrating wire strain gauges required the use of groutable anchors for concrete applications. A 1/2" hole is drilled for each of two anchors, see Figure 69. The hole is filled with an epoxy and the anchors are set in. To ensure accurate placement of the anchors, a spacing jig (provided by Geokon) was used. This jig provided the exact drill location.

Installation of the foil strain gauges by Hitec required an epoxy purchased from Vishay Microsystems, M-Bond AE-10, that is made for long-term applications. M-Bond

AE-10 has a 6-hour cure time, during which time a constant pressure of 5-20 psi is required. In order to apply the needed pressure to the strain gauges, a system of pressure application was devised. A bolt with a large nut was cut to the size needed to fit in the instrument box but long enough that with minimal rotation of the nut, pressure would be applied. Since the sensor location is ideally located in the middle of the box, a small wooden plank was cut to size that provided a bearing point. The wooden plank was placed on the metal lip of the box for support. A small piece of metal was cut to the exact size of the strain gauge, fitted with a foam pad, and covered with packaging tape to avoid any adhesion of the epoxy to either the metal or the foam. The metal provided for even distribution of the force applied by the nut and the foam padding provided a non-cutting application distributor. Figure 70 and Figure 71 show this mechanism from different angles and views.

Prior to applying the epoxy, the concrete surface was prepared by sanding the surface with fine sandpaper, degreasing the surface area, conditioning, then neutralizing the area. All products used for this process were recommended by and purchased from Vishay Microsystems.

The tiltmeters are Geokon Model 6160 MEMS Tiltmeters. Installation on the Model 6160 requires only one bolt mounted into the concrete as seen in Figure 72. The Model 6160 is sold with a mounting bracket and stainless steel anchor bolt. The anchor system requires one drilled hole. Leveling is accomplished through the zero adjust pins, see Figure 73.

Thermocouples were installed in all foil strain gauge boxes for a total of six on the entire bridge. The thermocouples were placed with the foil strain gauges to allow for any needed temperature compensation for strain. The wire was purchased in 1000 foot spools and cut to length on-site. Once installed in the box, the two leads were twisted and soldered together. Since the length from the instrumentation box to the thermocouple reaches approximately 200 ft., a thermocouple wire that is shielded was chosen. This allows for the most accurate temperature reading as possible. The thermocouple wire chosen was Type T, shielded.

Velocity transducers chosen are model L4 Seismometers, or Geophone, from Sercel. The L4 chosen has a 1000 gram suspended mass with moving dual coil. The instrument operates at 1.0 Hz. A significant reason for choosing this instrument is due to the small size and relatively nonexistent need for maintenance. The overall dimensions of the L4 are 5 1/8 in. tall and 3 in. in diameter, weighing just less than five pounds. Sercel provides the L4 completely sealed, therefore requiring no maintenance. In fact, the manufacture recommends that any maintenance needed be performed at their laboratory.

During the instrumentation development stage, it was determined that the physical location of the L4 along the cross-section of the bridge would be on the underside of the deck, equally spaced between the two girders. To secure the instrument in this location, a holding cradle was designed and manufactured at USU for installation. This cradle has the capability of leveling so that the L4 will produce accurate readings.

The solar panel and all weather station instruments were installed on the instrumentation tower by lowering the tower and installing each instrument individually according to manufacture recommendations. To protect the cable wires from the harsh environment, a combination of rigid and flexible conduit was used. The instrument tower

has a conduit that takes cables from the base of the tower to the instrumentation box. This is a separate conduit from the conduit used for the instruments from the bridge.

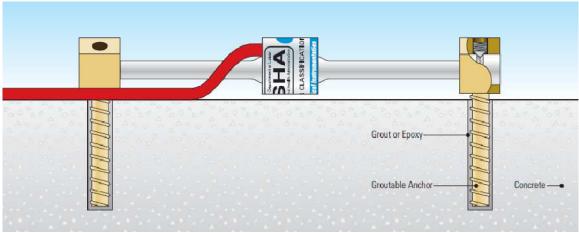


Figure 69. Schematic drawing of vibrating wire strain gauges.



Figure 70. View of installation method for hitec foil strain gauges.



Figure 71. Close-up view of installation method for vifoil strain gauges.



Figure 72. Geokon MEMS 6160 Tiltmeter.

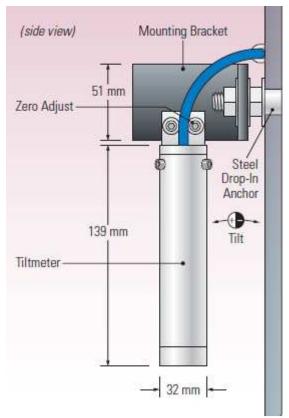


Figure 73. Side view installation of Geokon MEMS 6160 Tiltmeter.

Data Acquisition System

The chosen data acquisition system includes multiple modules purchased from Campbell Scientific as well as additional equipment from various vendors. The core of the data acquisition system is a Campbell Scientific CR5000. This system is capable of supporting almost any instrument and sampling at high rates. Due to the assortment of instruments selected for installation on the Utah Pilot Bridge, a data acquisition system capable of sampling data from all types of instruments was necessary. The CR5000 was selected and purchased based off of flexibility and performance.

To expand the number of sensors possible on the bridge, a multiplexer was used to increase the number of channels. The selected multiplexer is a Campbell Scientific

AM16/32 Multiplexer. The multiplexer serves as the reading unit for the thermocouples as well as the temperature reading from the Geokon Tiltmeters.

In order to relay information from the bridge site to a storing facility, a wireless CDMA router was selected. The router is a CalAmp LandCell 882-EVDO-VZW router. It is capable of operating at a frequency of 800 Mhz on a cellular bandwidth. With the option of using either a serial or Ethernet connection to the external device, the chosen router allows for direct connection with the CR5000, thus reducing additional modules or instrumentation requirements for a network interface. The router is activated with an account through Verizon Wireless and runs off of 12V DC, supplied through the CR5000.

With the guidance of personnel from Campbell Scientific, a code was developed to sample data through each of the sensors. The detailed, customized code allowed for individual settings on instruments including calibration values, sampling rates, channel location, trigger values, channel selection, recording location, automatic processing, and information delivery.

Upon complete installation of the instruments as well as the data acquisition system, a check for accuracy was made. Software purchased from Campbell Scientific allowed for real-time viewing of the data at the bridge site with a laptop computer. Verification was made that all sensors were sampling correctly and that they were all zeroed properly. A copy of the code is placed in Appendix E.

The majority of all code development was made previous to installing the system, some settings could not be made until everything was set-up on site and data was flowing. For instance, triggers for the foil strain gauges could not be determined until

real-time viewing of the data was possible. Strain ranges gathered during the Live-Load test were available, but it was unknown what the range would be based off of typical, everyday traffic. In addition, the trucks crossing the bridge on any given day are much heavier than the trucks used during the Live-Load test. Another area requiring specific attention once the system was complete was the Fast Fourier Transform calculated from the Velocity Transducers.

Long-Term Instrumentation Summary

Monitoring equipment includes: a weather station, a traffic camera, vibrating wire strain gauges, foil strain gauges, velocity transducers, tilt-meters, deck water saline content sensors and thermocouples. Table 6 provides a distribution of instrument location categorized by bridge anatomy. All of these instruments were linked to a datalogger that controls the sampling rate for each instrument. The datalogger is housed in a cabinet located within the right-of-way of the freeway but out of the "clear zone". The cabinet is securely fastened to a concrete pad. An instrumentation tower houses the weather station instruments as well as a video camera and internet satellite dish. It is located on the same concrete pad as the instrument cabinet. Computer aided drawings describing the construction of this system is included in the Appendix C.

Each instrument was installed according to manufacture recommendations for proper long-term durability. Cable transmitting data from the instrument to the data acquisition system is protected from the environment through the use of Schedule 40 Gray PVC conduit. This conduit is attached to the girders and abutment with the use of concrete anchors. From the abutment to the instrument cabinet, the conduit is buried for

additional protection and safety. At the instrument pad, the conduit enters the cabinet and connects with the data acquisition system. For additional information see attached drawings in Appendix C.

Table 6. Distribution of instruments

Tower

Wind Direction/Speed
Temperature/RH Probe
Precipitation Detector
Pyranometer (Radiation)
Traffic Camera
Solar Panel

Deck

Lufft Intelligent Road Sensor

Underside of Super Structure

Vibrating Wire Strain Gauge Foil Strain Gauge Tilt Meter Accelerometer

SUMMARY

As partial fulfillment of requirements for the degree of master of science in civil engineering, a bridge was selected for the Long-Term Bridge Performance Program. This bridge underwent specific testing and evaluation to establish a baseline for future comparison. The tests conducted include visual inspection, NDE/NDT, material testing, live-load test and dynamic load test. All of these tests aided in selecting correct and high-performing instruments for the long-term monitoring portion of the LTBP.

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APPENDICES

Appendix A: Live Load Strain and Displacement Plots.

Appendix A contains plots showing the strain and vertical displacement, deflection, for each individual sensor along load paths 2, 3, and 5. The specified load paths were selected due to the ease of tracking the location of the dump truck as it crossed the structure. As mentioned earlier, load path one consists of the trucks backing toward each other till they are at mid-span. Load path four has a time domain much longer than any of the other tests given that Rruck 2 followed after Truck 1. Having the longer time domain makes comparison more difficult. To show comparison of the sensors' ability to record and reproduce accurate data, load paths 2, 3, and 5 were selected. Sensors were located at specific distances from the abutment and along the height of the girder, see **Error! Reference source not found.** through Figure 17. Table 6 summarizes the sensor name and location on the bridge structure.

The y-axis, either microstrain or deflection, varies in the reported range, is fixed to allow for easy comparison of the magnitude each sensor experiences. The x-axis, distance along the bridge structure, was fixed at 120 ft. The bridge structure is 80 feet long. The extra length is required because "0" position is taken at two wheel rotations back from the start of the bridge structure, approximately 21.5 feet. Data returns to zero at approximately 100 feet from starting. Notation in the legend indicates the load path first and then the sensor. For instance, in Figure 74, line 2B1032 represents Load Path 2 Sensor B1032. Appendix A contains 27 Figures, representing the response of each instrument to three separate load paths.

Table 7. Summary of sensors and their locations on the bridge

Gage	Section	Distance (ft.)	Description
B1032	AA	5	Underside of girder flange.
B1971	AA	5	Underside of girder flange.
B1972	CC	37	Near top of web.
B1975	AA	5	Near top of web.
B1976	CC	37	Underside of girder flange.
B1977	AA	5	Underside of girder flange.
B1980	CC	37	Underside of girder flange.
B1981	CC	37	Underside of girder flange.
B1982	CC	37	Near top of web.
B1983	CC	37	Underside of girder flange.
B1985	AA	5	Near top of web.
B1986	CC	37	Underside of girder flange.
B1988	CC	37	Near top of web.
B1989	AA	5	Near top of web.
B1990	CC	37	Near top of web.
B1991	AA	5	Near top of web.
B1992	AA	5	Underside of girder flange.
B1993	CC	37	Near top of web.
B1996	AA	5	Near top of web.
B2017	AA	5	Underside of girder flange.
Twanger 1	DD	40	"Twanger" measuring deflection.
Twanger 2	DD	40	"Twanger" measuring deflection.
Twanger 3	DD	40	"Twanger" measuring deflection.
Twanger 4	DD	40	"Twanger" measuring deflection.
Twanger 5	DD	40	"Twanger" measuring deflection.
Twanger 6	BB	28	"Twanger" measuring deflection.
Twanger 7	BB	28	"Twanger" measuring deflection.

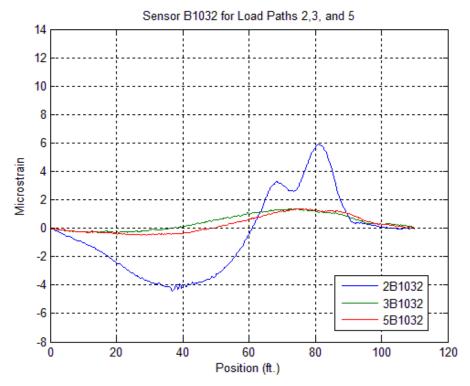


Figure 74. Sensor B1032.

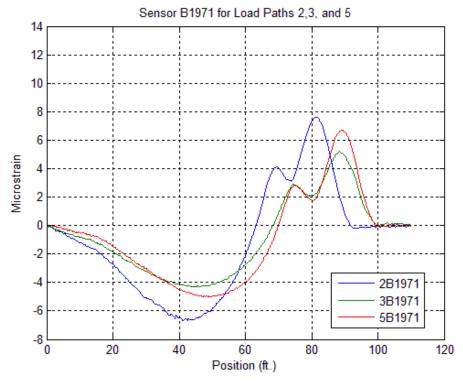


Figure 75. Sensor B1971.

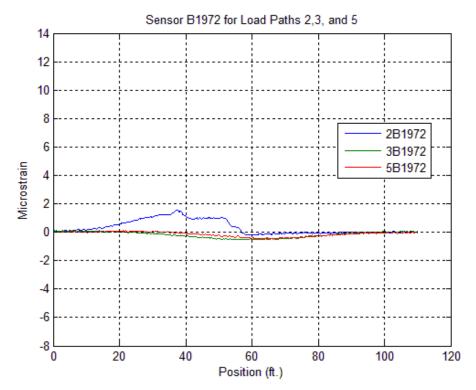


Figure 76. Sensor B1972.

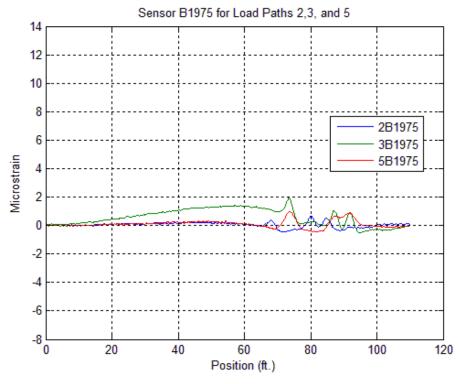


Figure 77. Sensor B1975.

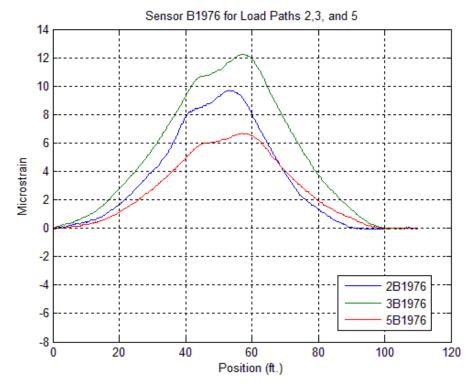


Figure 78. Sesnor B1976.

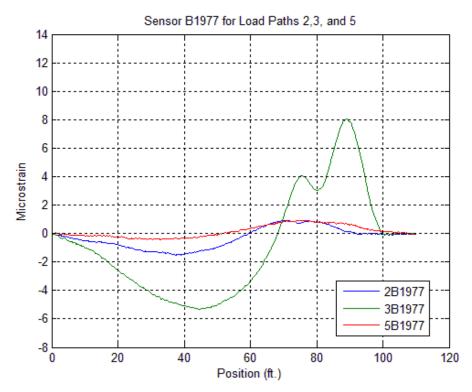


Figure 79. Sensor B1977.

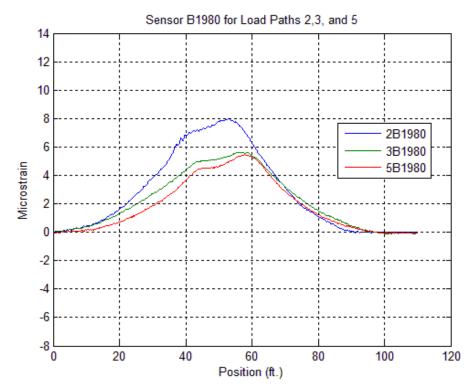


Figure 80. Sesnor B1980.

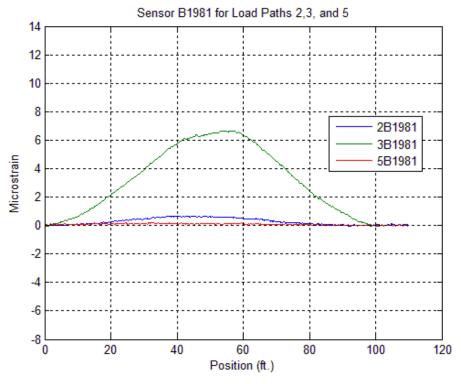


Figure 81. Sensor B1981.

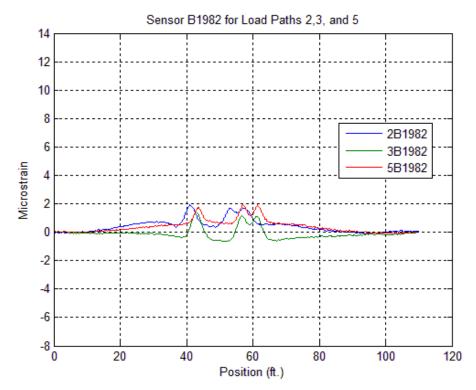


Figure 82. Sesnor B1982.

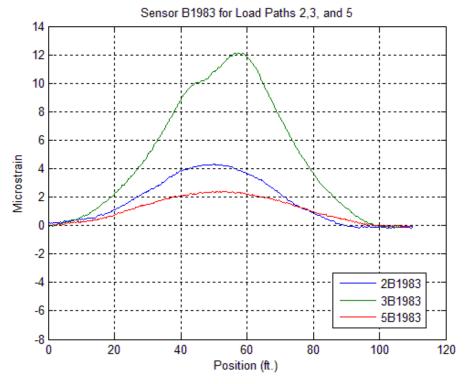


Figure 83. Sesnor B1983.

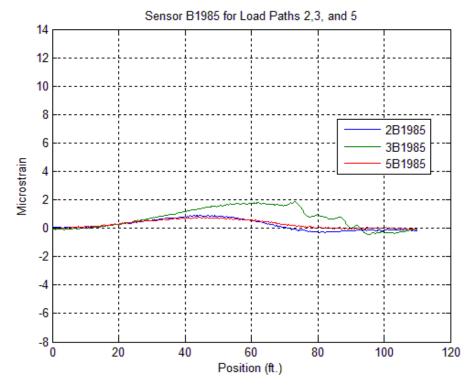


Figure 84. Sensor B1985.

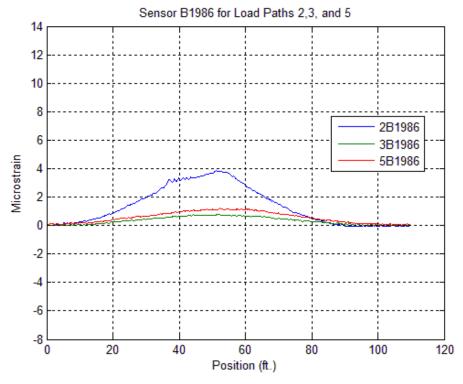


Figure 85. Sensor B1986.

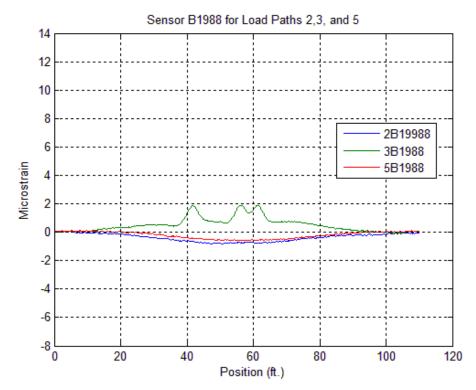


Figure 86. Sensor B1988.

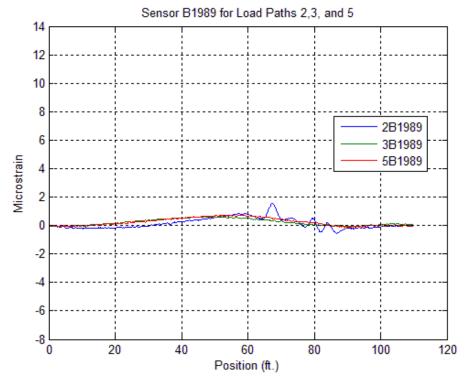


Figure 87. Sensor B1989.

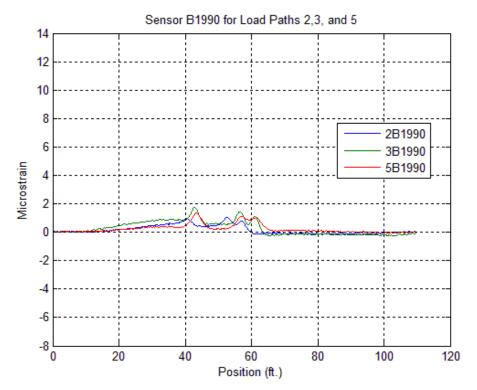


Figure 88. Sensor B1990.

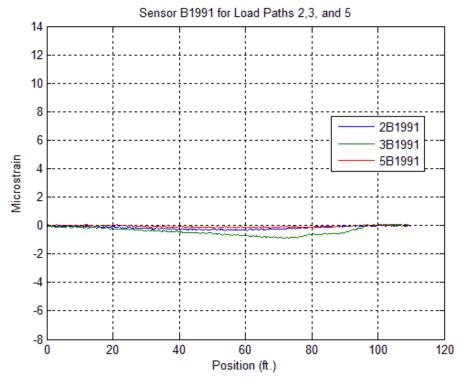


Figure 89. Sensor B1991.

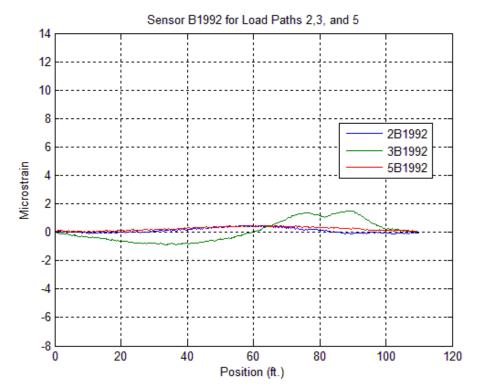


Figure 90. Sensor B1992.

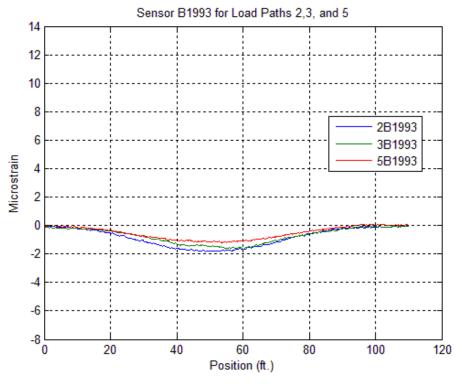


Figure 91. Sensor B1993.

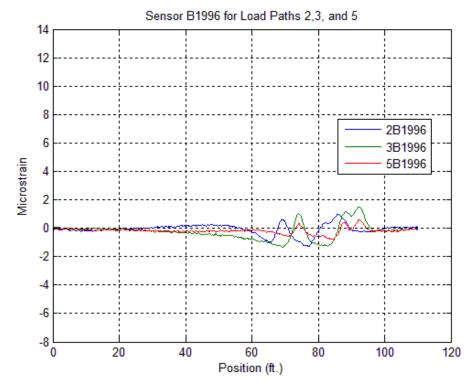


Figure 92. Sensor B1996.

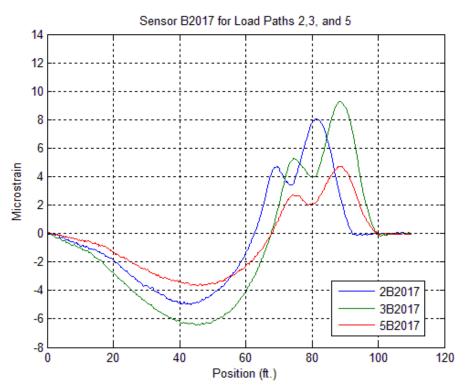


Figure 93. Sensor B2017.

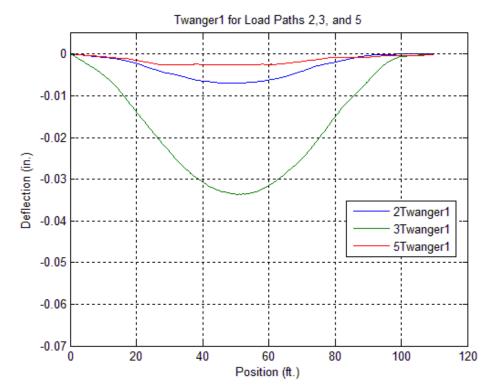


Figure 94. Twanger 1.

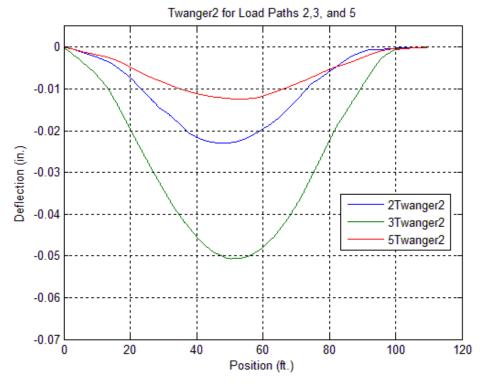


Figure 95. Twanger 2.

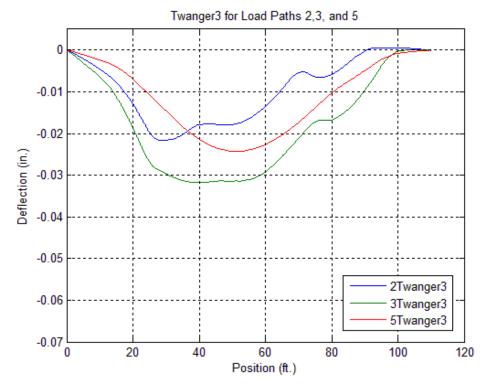


Figure 96. Twanger 3.

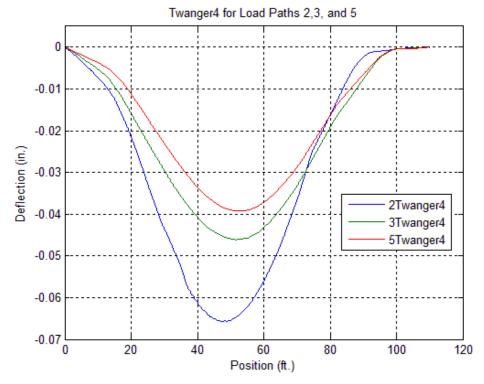


Figure 97. Twanger 4.

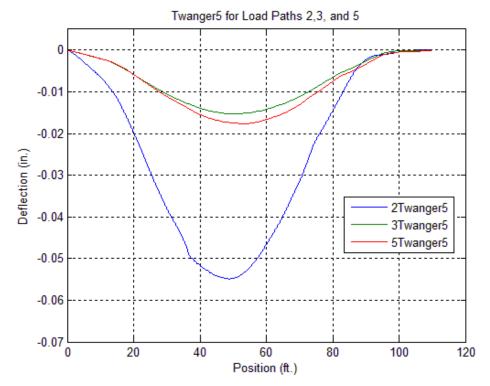


Figure 98. Twanger 5.

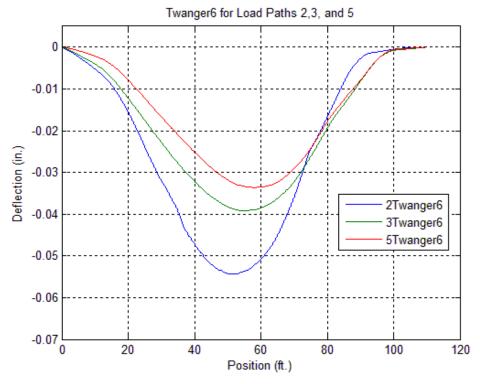


Figure 99. Twanger 6.

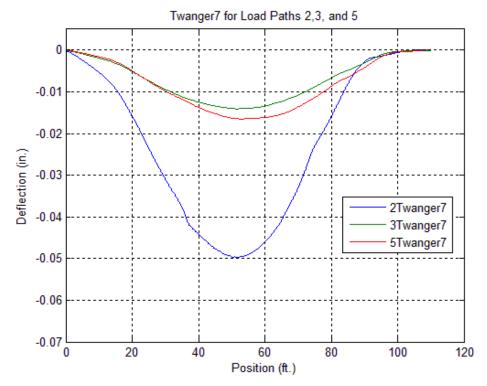


Figure 100. Twanger 7.

Appendix B: Live Load Permit Application

INSTRUMENTATION AND MAINTENANCE OF TRAFFIC PLAN FOR LIVE LOAD TESTING AND BRIDGE DECK TESTING

UTAH PILOT BRIDGE

SELECTED AS PART OF THE LONG TERM BRIDGE PERFORMANCE (LTBP) PROGRAM SPONSORED BY THE FEDERAL HIGHWAY ADMINISTRATION (FHWA)

STRUCTURE NUMBER 1F-205 NORTHBOUND 1-15/1-84 1 MILE NORTH OF PERRY UTAH WEIGH STATION

Utah State University September 25, 2009

Table of Contents

INTRODUCTION:
LIVE LOAD TESTING: 2
General Description: 2
Required Instrumentation:
Maintenance of Traffic:
DECK TESTING:
General Description:
Required Instrumentation: 5
Maintenance of Traffic:
Supporting Documentation:
APPENDIX A
APPENDIX B
Table of Figures
Figure 1: Approximate location of temporary live load testing equipment, plan view
Figure 1: Approximate location of temporary live load testing equipment, plan view
Figure 2: Approximate location of temporary live load instrumentation, girder cross-section
Figure 2: Approximate location of temporary live load instrumentation, girder cross-section view
Figure 2: Approximate location of temporary live load instrumentation, girder cross-section view
Figure 2: Approximate location of temporary live load instrumentation, girder cross-section view
Figure 2: Approximate location of temporary live load instrumentation, girder cross-section view
Figure 2: Approximate location of temporary live load instrumentation, girder cross-section view
Figure 2: Approximate location of temporary live load instrumentation, girder cross-section view
Figure 2: Approximate location of temporary live load instrumentation, girder cross-section view
Figure 2: Approximate location of temporary live load instrumentation, girder cross-section view
Figure 2: Approximate location of temporary live load instrumentation, girder cross-section view
Figure 2: Approximate location of temporary live load instrumentation, girder cross-section view

INTRODUCTION:

This document contains the intentions of researchers from Utah State University (USU) in collaboration with researchers from Brigham Young University (BYU) to conduct certain tests on bridge structure 1F 205, one mile north of the Perry, Utah, Weigh Station as part of the Federal Highway Administration's Long Term Bridge Performance Program (LTBP). It is the intent of the researchers to conduct live load testing and deck testing. An explanation of each test, a description of the instruments that will be utilized, and a plan for Maintenance of Traffic (MOT) is provided. An Appendix contains drawings describing the (MOT). It is our intention to perform this work as soon as possible during the Fall of 2009.

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LIVE LOAD TESTING:

General Description:

A Live-Load Test is a test that determines the response of a bridge subject to loading by a moving truck. It is recommended that the use of one heavily loaded UDOT gravel truck provide the loading for the live load test. The truck will be driven across the bridge at speeds in the range of 2-3 mph, on determined load paths. In addition to the slower speeds, the truck will be driven across the bridge at the posted speed limit to analyze the actual effects of traffic on the bridge. It may be desirable to park the truck at mid-span to gather the maximum deflection obtained in the most accurate manner. Since the overall structure length is relatively short, it is desirable to select a truck with the greatest maximum weight possible. The bridge will have temporary strain gauges mounted on the underside of the bridge while the UDOT gravel truck of known weight passes over. The instrumentation and proper maintenance of traffic is explained in the following sections.

Required Instrumentation:

For accurate strain measurements, approximately 20 strain gauges will be temporarily attached to the girders at mid-span and five feet from the abutment. Deflection instrumentation will be temporarily mounted at the mid-span on the underside of each of the five girders. Approximate instrument locations are shown in Figures 1 and 2. A data acquisition system will be set up and maintained under the bridge. All instrumentation can be installed with no MOT. The road underneath the bridge is approximately thirty two feet wide and carries little to no traffic. Therefore, instrumenting the bridge from underneath will not interrupt traffic on the bridge in any way. As mentioned, a data acquisition system and mobilization of personnel and equipment will also be located under the bridge.

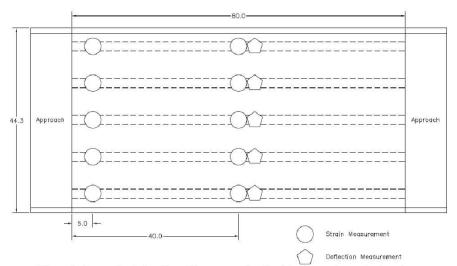


Figure 1: Approximate location of temporary live load testing equipment, plan view.

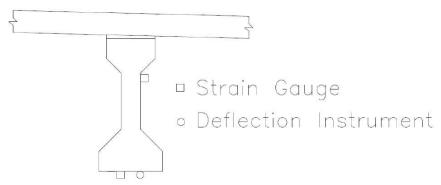


Figure 2: Approximate location of temporary live load instrumentation, girder cross-section

Maintenance of Traffic:

To provide adequate Maintenance of Traffic (MOT), Interstate Barricade will be contracted to provide signage consistent with the requirements established by the Utah Department of Transportation (UDOT). This includes, but is not limited to, reflective drums, arrow board, flags, truck mounted attenuator, message board, and other warning signage. Interstate Barricade

will provide personnel to deliver and set up all traffic control as well as provide any adjustments needed during testing. Drawings specifying the MOT plan are provided as an attachment.

Testing will require approximately four consecutive days for completion. The first day will be used to implement the Live Load test. The remaining three days will be used to conduct the Deck Testing. Researchers at USU and BYU are aware that the I-15 corridor along the Wasatch Front carries a large amount of traffic and certain times during the day are busier than others. For that reason, researchers request access to the bridge from Wednesday to Saturday with the times on the bridge being from 9:00 am to 4:00 pm on Wednesday, Thursday and Saturday with the time for Friday being reduced to 9:00 am to 3:00 pm.

It is anticipated that the east lane of traffic will be closed first. For the live load test, a duration of 1½ hours will be needed to complete all testing protocols per lane. At the conclusion of the test, Interstate Barricade personnel will modify the MOT system to close the west lane of traffic. Upon completion of the lane change, another 1½ hours will be needed to complete all testing protocols for this second and last lane. No MOT will be required under the bridge. The road under the bridge is a frontage road with little to no traffic. However, to provide warning to any vehicles that may approach the bridge, adequate signing and a number of orange reflective barrels will be placed around vehicles and the data acquisition system.

DECK TESTING:

General Description:

Deck testing will involve assessment of the present condition of the deck, including extent and severity of damage as well as evaluation of causal factors especially related to corrosion of the reinforcing steel. The following specific tests will be performed across the upper surface of the deck:

- 1. Distress survey, including identification and mapping of cracks, patches, potholes, and other defects and damage
- 2. Chaining survey to determine, if possible, areas at which the asphalt overlay is delaminated from the underlying concrete substrate
- 3. High-frequency ground-penetrating radar survey to image the reinforcing steel and detect compositional variations within the deck structure
- 4. Impact-echo testing to evaluate the integrity of the deck materials

In preparation for a second set of tests, the asphalt overlay present on the upper deck surface will be removed, either by milling or by sawing, to expose bare concrete at up to 10 discrete locations on the deck. The openings will be approximately 1 ft by 2 ft in size. Ideally, at least half of these test areas will be situated in wheel paths, with the remainder located in the shoulders. The following specific tests will then be performed in the exposed areas:

- 1. Cover depth measurements and determination of top-mat reinforcing steel location and orientation
- 2. Resistivity testing to evaluate the quality of the cover concrete
- 3. In-situ pulverization and sampling of concrete using a hammer drill and up to a 1.5-in.-diameter bit for laboratory determination of chloride concentrations to a maximum depth of between 3.5 in. and 8 in.
- 4. Half-cell potential testing to determine the state of corrosion of the reinforcing steel
- 5. Linear polarization and electrochemical impedance spectroscopy testing to determine the rate of corrosion of the reinforcing steel
- 6. Coring using a 4-in.-diameter bit to a depth of between 3.5 in. and 8 in. to facilitate strength, stiffness, permeability, and other materials characterization testing in the laboratory

The holes created in the concrete bridge deck will be filled using a high-strength, rapid-set, low-shrink grout, and the membrane under the overlay, if present, will be repaired using hot-pour asphalt sealant. New hot-mix asphalt will then be compacted in place using a sliding plate and/or a "jumping-jack" compactor. All materials will meet UDOT specifications, as applicable. According to UDOT personnel, this deck will then be rehabilitated within one or two years.

Required Instrumentation:

Accomplishment of half-cell potential, linear polarization, and electrochemical impedance spectroscopy testing will require a single, temporary, electrical connection to the reinforcing

steel at each location from which the asphalt overlay is removed. As the deck does not have an impressed-current cathodic protection system, the connections will not present any risks to research personnel, nor will the connections compromise the integrity of the deck. The purpose of the connection will be to ensure electrical continuity between equipment probes and the reinforcing steel in accordance with the test protocols.

Maintenance of Traffic:

To accomplish the deck testing, research personnel anticipate needing lane closures for four days. These four days of needed MOT for this work occur concurrently with the four days explained in the Live Load Testing MOT.

Supporting Documentation:

The following pictures document the tests proposed for this research:



Figure 3: Marking a grid pattern or deck testing.



Figure 4: Recording distress data in an electronic notebook.



Figure 5: Performing a chain drag test.



Figure 6: Conducting a ground penetrating radar survey.



Figure 7: Performing impact-echo testing.

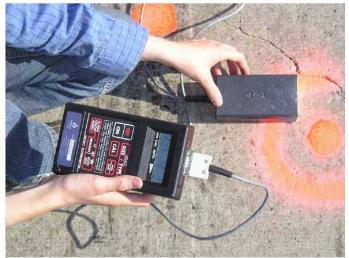


Figure 8: Measuring cover depth.

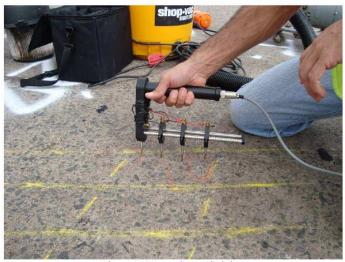


Figure 9: Measuring resistivity.



Figure 10: Pulverizing concrete samples with a hammer drill.



Figure 11: Removing pulverized concrete samples for laboratory analysis.



Figure 12: Conducting half-cell potential testing.



Figure 13: Measuring reinforcing steel corrosion rates.

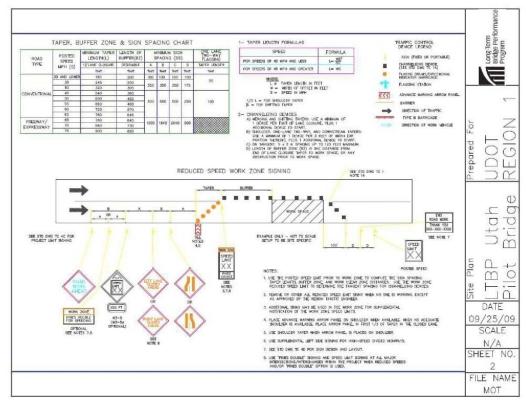


Figure 14: Coring.

APPENDIX A

MOT for Live Load and Deck Tests

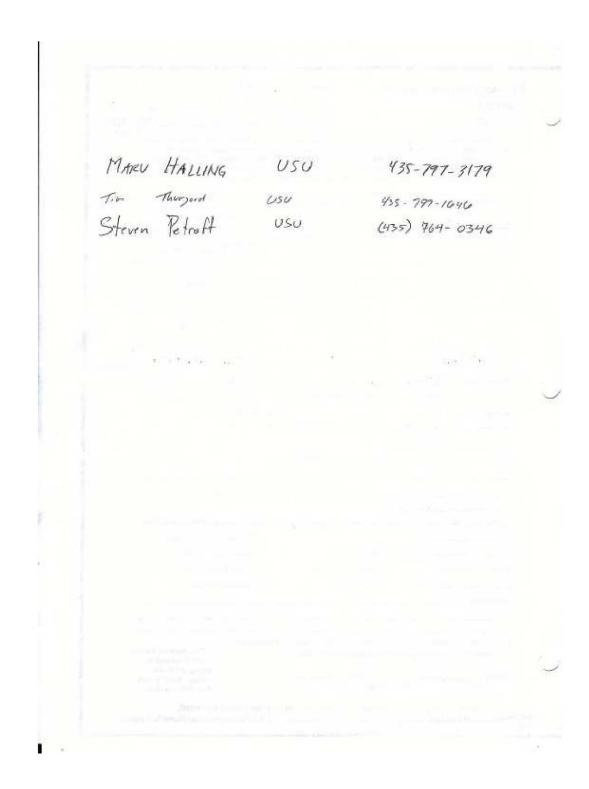
GENERAL NOTES (APPLIES TO ALL TC SERIES STANDARD DRAWINGS): USE CURRENT EDITION OF UDOT STANDARDS FOR TRAFFIC CONTROL USE THE MANUAL ON UNFORM TRAFFIC CONTROL DEVICES (MUTCD) FOR TRAFFIC CONTROL ELEMENTS NOT SHOWN IN THE TC STD DWG SERIES. Long-Term Bridge Perfo Program USE CURRENT EDITION OF STANDARD HIGHWAY SIGNS MANUAL FOR SIZE AND DESIGN OF STANDARD SIGNS. 3. SEE STD DWG TC 2A AND TC 2B FOR WORK ZONE SIGNING AND DEVICE REQUIREMENTS. 4. USE MINIMUM 48" x 48" SIZE FOR DIAMOND WORK ZONE WARNING SIGNS. 5. COVER OR REMOVE NON-APPLICABLE SIGNING, BOTH EXISTING AND WORK ZONE SIGNS. 6, REMOVE NON-APPLICABLE PAVEMENT MARKINGS FOR OPERATIONS LONGER THAN 3 DAYS. REMOVE OR RELOCATE NON-APPLICABLE PORTABLE SIGN SUPPORTS AND SIGNS TWICE THE WORK CLEAR ZONE (WCZ) DISTANCE, SEE SHEET TC 3. TABLE 1. 8. REFER TO STANDARD SPECIFICATION 01554 FOR FLAGGING REQUIREMENTS AT DEFERTING TRAFFIC SIGNALS. UDOT REGIO 9. USE A FULL LANE CLOSURE WHEN WORK ENCROACHES INTO A TRAVEL LANE. 10. CLEAN AND/OR RESTORE PAYEMENT MARKINGS AT THE END OF EACH DAY'S OPERATION, BOTH ON AND OFF THE PROJECT, THAT ARE OBSCURED BY WORK OPERATIONS. 11. OBTAIN APPROVAL FOR RECULATORY AND ADMISORY SPEED REDUCTIONS THROUGH THE REGION TRAFFIC ENGINEER, USE SPEED REDUCTIONS ONLY DURNG INFACTED THES AND AREAS. RESTORE EXISTING REGULATORY SPEED LIMIT PRIOR TO WORK A LIDICATIONS WHERE TRAFFIC IS NOT BEING IMPACTED BY WORK ACTIVITIES. SEE POLICY OSC-61. 12. USE THE POSTED SPEED LIMIT PRIOR TO WORK ZONE TO COMPUTE THE SION SPACING, PAPER LENGTH, BUPFER ZONE, AND WORK CLEAR ZONE DISTANCES, USE THE WORK ZONE POSTED SPEED LIMIT TO DETERMINE THE TANGENT SPACING FOR GHANNELIZING DEVICES. 0 Utah Brida(USE PLASTIC DRUMS FOR LANE CLOSURE TAPER DEVICES FOR SPEEDS OF 50 MPH AND GREATER. 14, USE A DOWNSTREAM TAPER FOR OPERATIONS LONGER THAN 3 DAYS. IS FLACE AN ARROW PANEL ON THE SHOULDER OF THE ROADWY OR, IF PRACTICAL, FURTHER FROM THE TRAVELD LANE, WHEN NO ADDUART SHOULDER IS AVAILABLE, PLACE ARROW PANEL NO FREST LOS OF TAPER IN THE CLOSED DATE IT SHOULD BE DELINEATED WITH RETROGREFICITIVE TEMPORARY TRAFFIC CONTROL (TIT) DEVICES, WHEN AN ARROW PANEL IS NOT BEEN USED, ITS SHOULD BE REMOVED, IT NOT THE OFFICE SHELDED, OR IF THE PREVIOUS THE OFFICE OF THE TRAVELD BE SHELDED, OR IF THE PREVIOUS THE OFFICE SHELDED, THE SHELDER THE OFFICE SHELDED. mo Ē 16. USE AN APPROVED WORK ZONE ATTENUATOR SYSTEM WITH TEMPORARY PRECAST CONCRETE BARRIER WHEN APPROACH ENDS ARE WITHIN THE ASSHTO CLEAR ZONE. APPROVED TRUCK MOUNTED ATTENUATIOR SYSTEM MAY BE USED FOR ONLY 24 HOLINS OR LESS. 17. USE PROPER LENGTH OF NEED FOR TEMPORARY BARRIER AS PER THE REQUIREMENTS OF THE CURRENT EXTRACT DESIGN CUIDE. USE POSTED SPEED LIMIT PRIOR TO FOR THE WORK ZONE FLARE RATE REQUIREMENT FOR THE WORK ZONE FLARE RATE REQUI DATE SCALE SPECIFY 18. USE BUMP SIGN (WB-1) WHEN METAL PLATES ARE PLACED ON THE ROADWAY. SHEET 19. USE SUPPLEMENTAL LEFT SIDE SIGNING FOR HIGH-SPEED DIVIDED HIGHWAYS. MAINTAIN PEDESTRIAN TRAFFIC AT EXISTING CROSSWALKS AND ON EXISTING SIDEWALKS. WHEN PEDESTRIAN TRAFFIC CANNOT BE MAINTAINED REPOUTE ACCORDING TO STD DWG TC 6. FILE NAME MOT



APPENDIX B

Pre-Application/Concept Meeting Form

Pre-Application/Conc Meeting	Project Locat	tion: I- 15	
UDOT Region One		Longterm Bridge Perfo	THEAL
"A preliminary meeting provides Departr access proposal with the applicant and it meeting provides an opportunity to discu- and agree on the necessary materials to	nent personnel and/or local authorities an e o consider whether it is permissible under th as alte specific conditions and options for si	Pr arty opportunity to examine the fessibility of the te Department's access standards. This te access location and design, access plans, rion. Prelimitary discussion of these matters	ogran
Attendees (Please Print)	Representing	Phone	
☐ Darin Duersch, P.E.	UDOT R-1 Traffic	620-1607 (Traffic Engr)	
☐ Brad Humpherys, P.E.	UDOT R-1 Precon	620-1605 (Preconstruction Engr)	
☐ Glen Ames, P.E.	UDOT R-1 Traffic	620-1619 (Asst. Traffic Engr)	
☐ Carrie Jacobson, P.E.	UDOT R-1 Traffic	620-1673 (Asst. Traffic Engr)	
☐ Tommy Vigil	UDOT R-1 Permits	620-1604 (Permits, Supvr)	
EP Rodger (Jay) Genereux	UDOT R-1 Permits	620-1639 (Permits Officer)	
o Kenni Grothin	* UDOT R-1	, 620-1683	
, Spencer Buthne	y BYU	≈ 901-422-3864	
Dan e d	200	UVE 242 - 6 249	
Access Category: 1 2 3 4 5 Permit Application (Impact) Lev	el: 1 II(100 to 500) II(500 to 30	nnce Required? Y: / N	e-
Project Scope: Rridge 3n STAIL 7 Access Category: 1 2 3 4 5 Permit Application (Impact) Lev Traffic Impact Study Required?	Performance (NoT Testing Equipment. 6789 Varie el: 1 11(100 to 500) 11(500 to 30	access) access) access) access) access)	er—
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Project Scope: Rrieby C 3 n STA N T Access Category: 1 2 3 4 5 Permit Application (Impact) Lev Traffic Impact Study Required? Study Area (As defined by Permi Requirements for Complete Plan Site Plan (including vicinity m & accesses, roadways, etc.)	Posternance (NoT Esting Equipment. 6 7 8 9 Varie el: 1 II(100 to 500) II(500 to 30 Y / N its Officer or Region Traffic Engine Set 1 ap, address, existing and proposed 8" UTBC, 18" GB)	access) access(Y) / N access details, adjacent property lines County Plat/Aerial Photo Curb & Gutter (GW 2)	et —
Project Scope: Rrieby C IN STAIL T Access Category: 1 2 3 4 5 Permit Application (Impact) Lev Traffic Impact Study Required? Study Area (As defined by Permit Requirements for Complete Plan Site Plan (including vicinity of the accesses, roadways, etc.) Typical X-section (6" HMA, 8 Sidewalk (GW 4)	Posternance (NoT esting Equipment. 6 7 8 9 Variet: 1 II(100 to 500) II(500 to 30 Y / N its Officer or Region Traffic Engine Set nap, address, existing and proposed 8" UTBC, 18" GB) □Driveway (GW 4)	access) Ince Required? Y / N 1000) III IV Beer): County Plat/Aerial Photo	et —
Project Scope: Rrisby C 3 n STall 7 Access Category: 1 2 3 4 5 Permit Application (Impact) Lev Traffic Impact Study Required? Study Area (As defined by Permit Requirements for Complete Plan Site Plan (including vicinity managements) Accesses, roadways, etc.)	Posternance (NoT Esting Equipment. 6 7 8 9 Varie el: 1 II(100 to 500) II(500 to 30 Y / N its Officer or Region Traffic Engine Set 1 ap, address, existing and proposed 8" UTBC, 18" GB)	access details, adjacent property lines County Plat/Aerial Photo Curb & Gutter (GW 2) ADA Ramps (GW 5)	et —
Project Scope: Rriely C In STAIL T Access Category: 1 2 3 4 5 Permit Application (Impact) Lev Traffic Impact Study Required? Study Area (As defined by Permit Requirements for Complete Plan Site Plan (including vicinity m accesses, roadways, etc.) Typical X-section (6" HMA, 8 Sidewalk (GW 4) Grading & Drainage Plan Disposition:	Posteronce (NoT esting Equipment. 6 7 8 9 Variet: 1 II(100 to 500) II(500 to 30 Y / N its Officer or Region Traffic Engine Set nap, address, existing and proposed 8" UTBC, 18" GB) Driveway (GW 4) Utility Plan es, Permit Applications, and TIS Re	access) access details, adjacent property lines County Plat/Aerial Photo Curb & Gutter (GW 2) ADA Ramps (GW 5) Pavement Profile	



Appendix C: Long-Term Application Document

INSTRUMENTATION AND MAINTENANCE OF TRAFFIC PLAN FOR INSTALLATION OF LONG TERM MONITORING EQUIPMENT

UTAH PILOT BRIDGE

SELECTED AS PART OF THE LONG TERM BRIDGE PERFORMANCE (LTBP) PROGRAM SPONSORED BY THE FEDERAL HIGHWAY ADMINISTRATION (FHWA)

STRUCTURE NUMBER 1F-205 NORTHBOUND 1-15/1-84 1 MILE NORTH OF PERRY UTAH WEIGH STATION

Utah State University
December 16, 2010

Table of Contents

INTRODUCTION:	1
LONG-TERM MONITORING:	1
General Description:	1
Required Instrumentation:	1
Maintenance of Traffic:	2
APPENDIX A	3
A PPENDIX B	4

INTRODUCTION:

This document contains the intentions of researchers from Utah State University (USU) to monitor bridge structure 1F 205, one mile north of the Perry, Utah, Weigh Station as part of the Federal Highway Administration's Long Term Bridge Performance Program (LTBP). It is the intent of the researchers to install long-term monitoring equipment on the bridge structure. An explanation of the monitoring, a description of the instruments that will be utilized, and a plan for Maintenance of Traffic (MOT) is provided. An Appendix contains drawings describing the installation of instruments and MOT. It is the intention of USU to perform this work as soon as possible.

LONG-TERM MONITORING:

General Description:

The LTBP is a 20-year program funded by the FHWA. The main goal is to record and store high-quality data on selected bridge characteristics that can reasonably be measured. Throughout the life of the project, instrumentation will be placed on the bridge to provide data for bridge health evaluation. Monitoring of the bridge will be extensive, in order to obtain the maximum information possible. Monitoring over the project life will allow for changes in the bridge response to be recorded.

Required Instrumentation:

Monitoring equipment includes: a weather station, a traffic camera, vibrating wire strain gauges, encapsulated foil strain gauges, accelerometers, tilt-meters, deck chloride sensors and thermocouples. Table 1 provides a distribution of instrument location. All of these instruments will be linked to a datalogger that controls the sampling rate for each instrument. The datalogger will be housed in a cabinet located within the right-of-way of the freeway but out of the "clear zone". The cabinet will be securely fastened to a concrete pad. The concrete pad will also be the location of the instrumentation tower that will house the weather station instruments as well as a video camera and internet satellite dish.

Each instrument will be installed according to manufacture recommendations for proper long-term durability. Many instruments require a small 1/4" to 1/2" diameter hole drilled into the bridge girder/abutment to install a fastening bolt or connector. The depth will not exceed 3" for any one connector. Other instruments will require the use of epoxy to mount the instrument on the bridge. Cable that connects the instrument to the data acquisition system will be protected from the environment through the use of Schedule 40 Gray PVC conduit. This conduit will be attached to the girders/abutment with the use of concrete screws to ensure a secure hold. Beginning at the abutment, the conduit will be buried for additional protection and safety. The conduit will run

1

from the bridge abutment to the instrument pad location (for additional information see attached drawings). At the instrument pad, the conduit will enter the cabinet and connect with the data acquisition system.

Table 1: Distibution of Instruments

- 1	n	W	0	r
	v	**	•	

Wind Direction/Speed
Temperature/RH Probe
Precipitation Detector
Pyranometer (Radiation)
Traffic Camera
Solar Panel

Deck

Lufft Intelligent Road Sensor

Underside of Super Structure

Vibrating Wire Strain Gauge Foil Strain Gauge Tilt Meter Accelerometer

Appendix A contains a set of drawings describing the long-term monitoring plans.

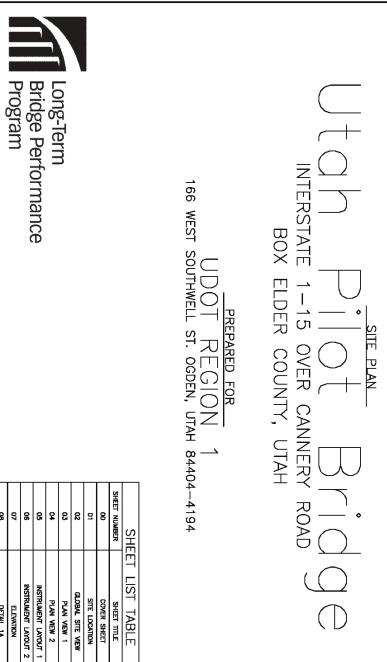
Maintenance of Traffic:

To provide adequate MOT, USU will contract with a Utah Department of Transportation (UDOT) approved contractor to provide signage consistent with the requirements established by the UDOT. This includes, but is not limited to, reflective drums, arrow board, flags, truck mounted attenuator, message board, and other warning signage. The contractor will provide personnel to deliver and set up all traffic control as well as provide any adjustments needed during testing. Drawings specifying the MOT plan are provided as in Appendix B. To ensure that a bottle-neck situation does not result from too long of a queue, at least one individual of the research team will be tasked with watching the traffic to notify the contracted traffic control operators of any additional signage that is needed.

The majority of the installation work will occur under the bridge, where traffic control is not needed. However, two-one-day lane closures will be needed to install chloride sensors. The chloride sensors are SR21 Lufft Intelligent road sensors. They measure the chloride concentration on a deck. Their application requires approximately a four inch diameter core into the deck of the bridge to a depth of approximately three inches and running a cable from the instrument to the edge of the bridge and to the instrument pad. The cabling will run through a small cut made in the deck by an asphalt/concrete saw and filled with non-shrinking grout. During those two days, USU will use the approved contractor to provide MOT. Preferred days are during the week, Monday – Friday between the times of 9:00 am to 3:30 pm.

APPENDIX A

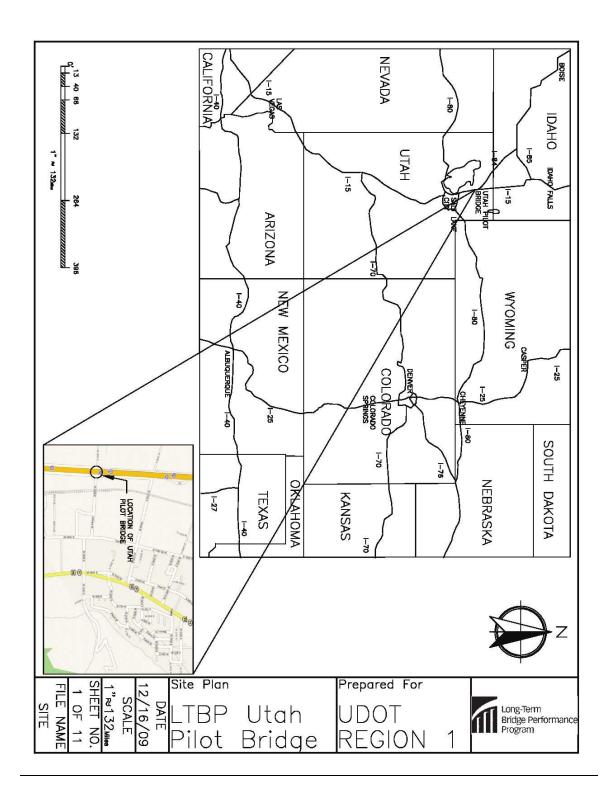
Drawings for Long-Term Instrument Installation

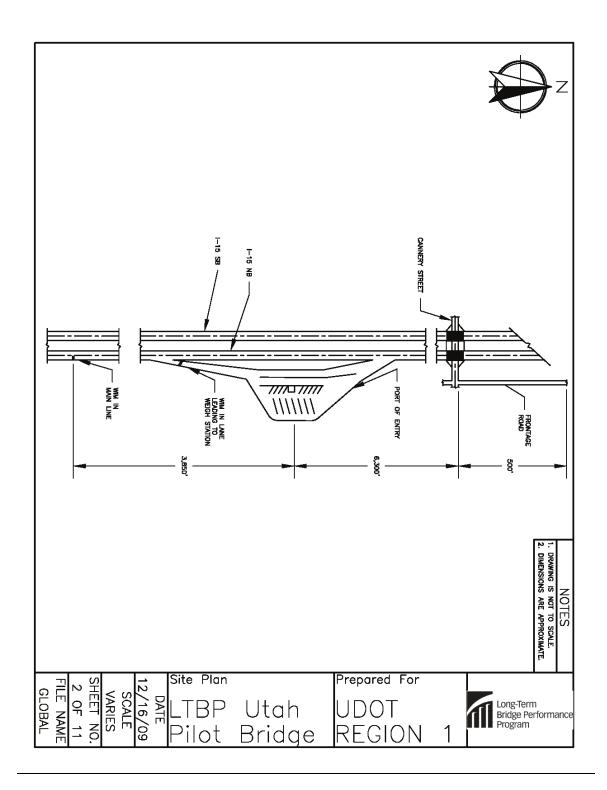


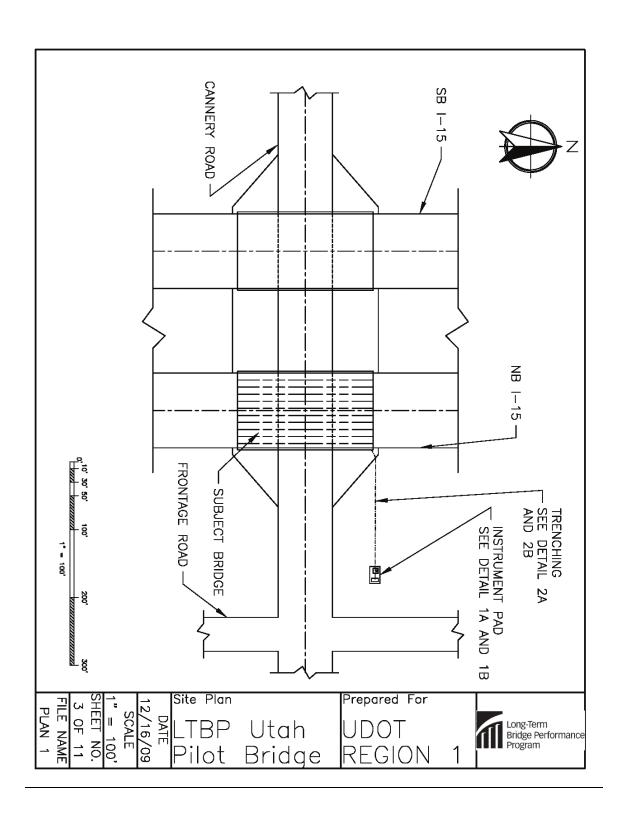
UtahStateUniversity

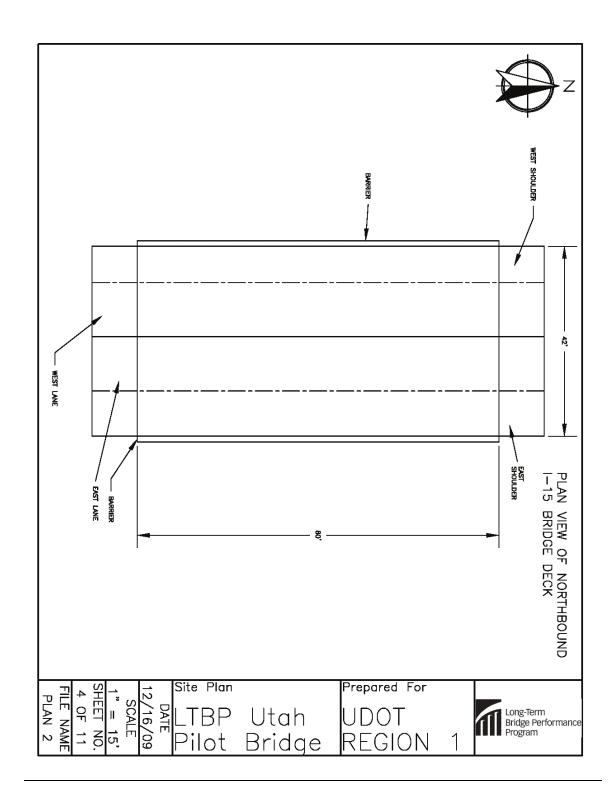
DETAIL 18

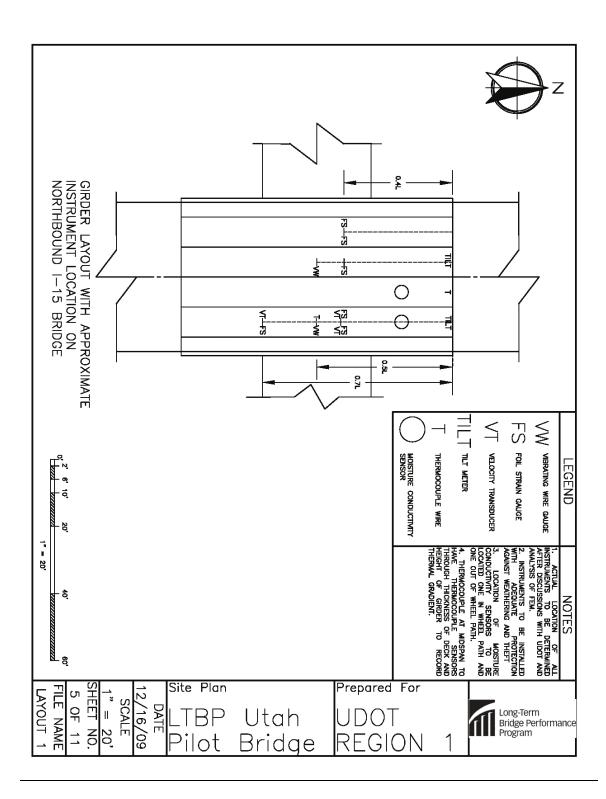
DETAIL 2A DETAIL 1A

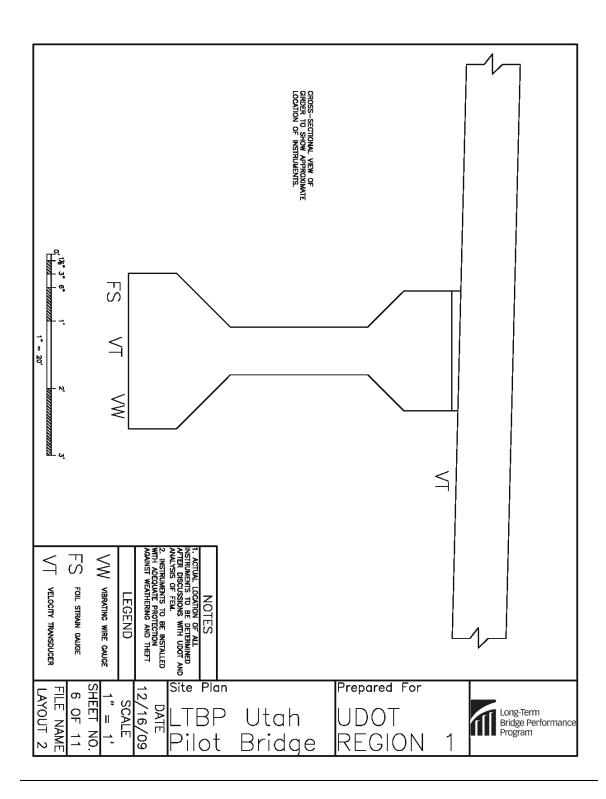


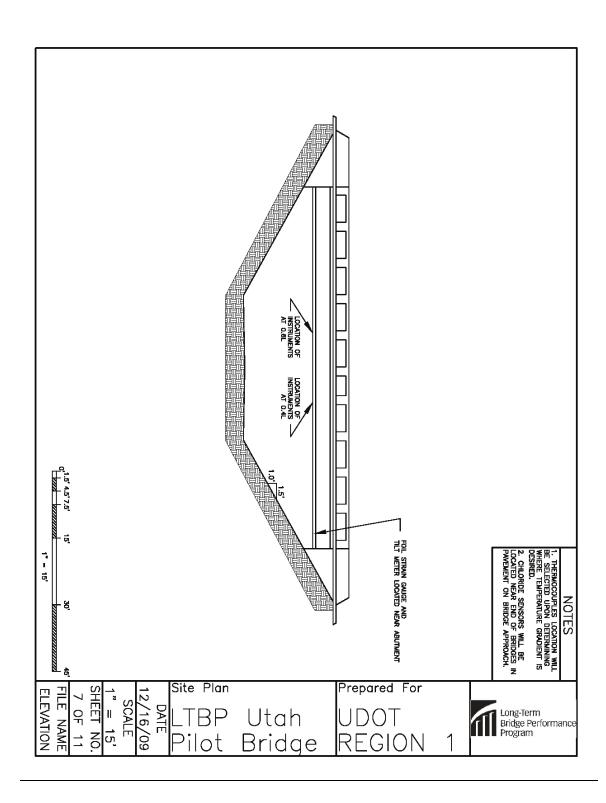


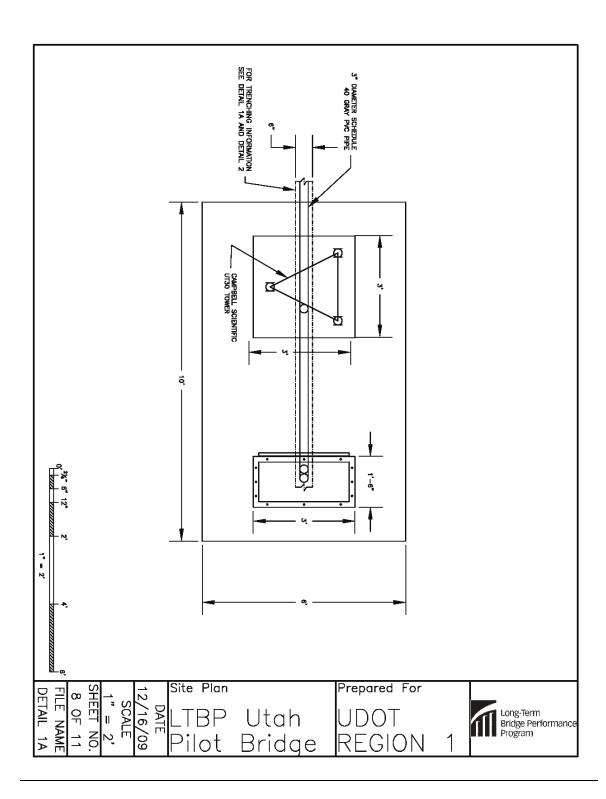


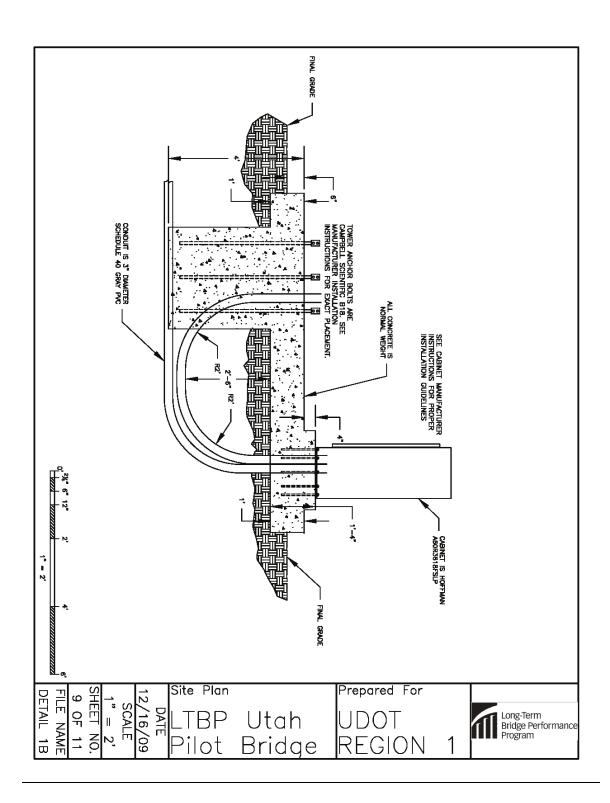


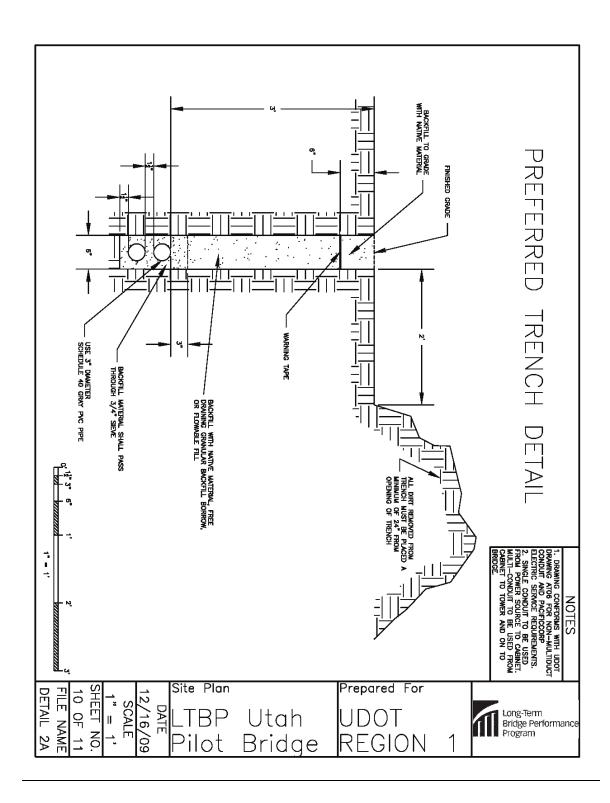


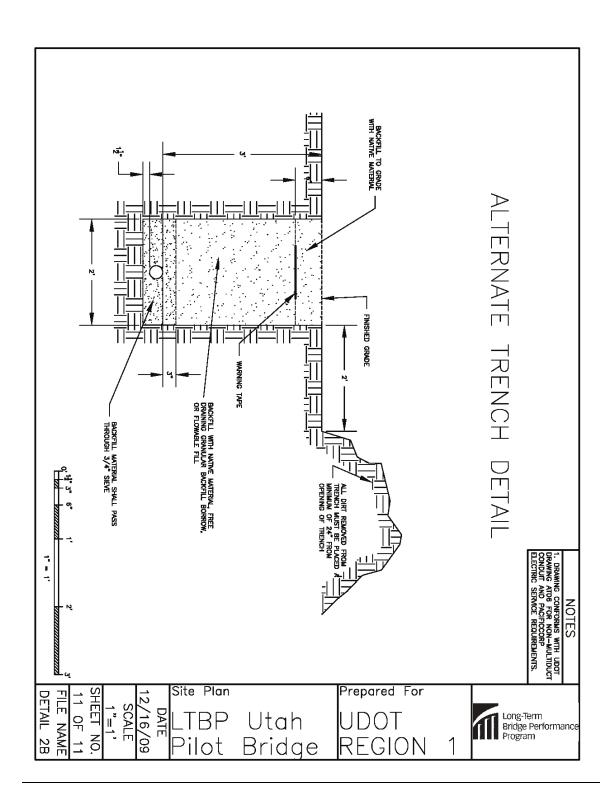










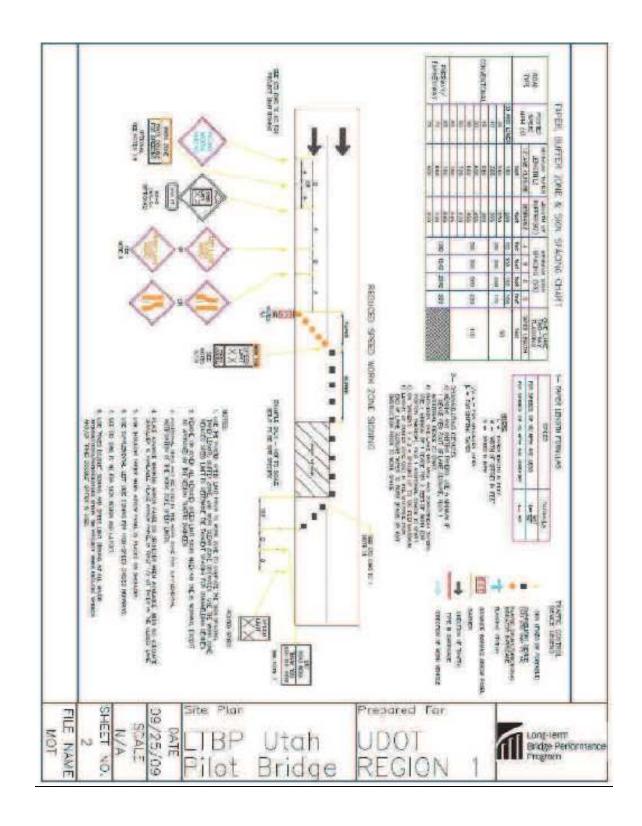


APPENDIX B

MOT

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Long-Term Sensor Installation Agreement

Researchers from Utah State University (USU) plan to ins 205 on 1-15 as part of the Federal Highway Administration Performance (LTBP) Program. USU received permission to install certain sensors on said structure. UDOT is not held replacement of sensors damaged by routine maintenance program 1.	n's (FHWA) Long-Term Bridge through UDOT Region 1 office to responsible to replace or finance the
The parties have agreed to this statement on	and shall be in effect till
Marvin W. Halling Associate Professor, USU	Tommy Vigil UDOT Region 1 Permit Director

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Utah Pilot Bridge Testing, Monitoring and Instrumentation Plan



Utah State University 28 January 2010

Dr. Marv Halling Dr. Paul Barr Dr. Kevin Womack Steven Petroff Dereck Hodson

Table of Contents:

1.0 Introduction:	1
2.0 Bridge Selection:	1
2.1 Selection Criteria:	1
2.2 Bridge Background and Inventory:	3
2.3 Summary	7
3.0 Study Topics	8
4.0 Finite-Element Modeling	9
5.0 Detailed Visual Inspection:	17
6.0 Periodic Testing:	17
6.1 Live Load Testing:	17
6.1.1 Static Live Load Test:	18
6.1.2 Dynamic Live Load Testing:	21
6.2 Dynamic Testing:	22
6.3 Deck Testing:	26
6.4 NDT/NDE:	30
6.5 Other Material Testing:	30
7.0 Monitoring:	30
7.1 Standard Monitoring:	30
7.1.1 WIM and Traffic Counter:	31
7.1.2 Traffic Camera:	34
7.1.3 Weather Station:	34
7.2 Specialized Monitoring:	37
7.3 Service, Maintenance, and Projected Replacement:	40
8.0 Analysis and Data Storage:	40
8.1 Analysis:	40
8.2 Data Storage:	41
9.0 Instrumentation Plan Summary:	41
APPENDIX A: BUDGET	42

Table of Figures:

Figure 1: Left-Side view of bridge looking East. Right-Aerial view of bridge from Google	
Image, top is North.	4
Figure 2: View underneath bridge. Left: Close-up to show Type IV structure. Right: Pan view	to
show all five girders	4
Figure 3: Cracking at Abutment.	
Figure 4: Cracking on underside of parapet	5
Figure 5: View of deck looking south	
Figure 6: Schematic elevation drawing of Utah Pilot Bridge	6
Figure 7: Cross-sectional view of Bridge deck and girders (All dimensions are in feet)	
Figure 8: Location of Utah Pilot Bridge in relation to state of Utah, indicated by red bubble	8
Figure 9: 3-D representation of the bridge model using Frame and Shell elements	
Figure 10: Shell elements for the deck and Frame elements for the girder	11
Figure 11: Cross section showing Solid element modeling method	12
Figure 12: Cross-Section showing Solid element deck and Frame element girder	12
Figure 13: Location of HS-20 wheel loads on bridge	13
Figure 14: AASHTO HS-20 truck with axle loads	14
Figure 15: Location of Strain and Deflection gauges for Static Live Load Testing	20
Figure 16: Sectional view of relative location of strain gauges on bridge girders.	20
Figure 17: Deflectometer on bottom flange of a girder.	
Figure 18: Pictorial representation of load paths for Static and Dynamic Live Load Tests	22
Figure 19: APS Electro-Seis Long Stroke Shaker Model 400	23
Figure 20:Dynamic Test instrument layout diagram.	25
Figure 21: IRS21 Lufft Intelligent Road Sensor	29
Figure 22: WIM Sensor, www.cardinalscale.com	31
Figure 23: Quartz based WIM as seen installed in a lane leading to Perry, Utah Port of Entry	32
Figure 24: WIM installed on lane leading to Perry, Utah Weigh Station. See labeling for part	
descriptions	33
Figure 25: Probable location of bridge instrumentation.	36
Figure 26: Location of specialized monitoring equipment.	
Figure 27: Cross section of girder showing proposed specialized monitoring sensor locations.	

List of Tables:

Table 1: Criteria used to select Utah Pilot Bridge.	3
Table 2: LTBP Study Topics.	
Table 3: Maximum deflection comparisons from Fixed-Fixed condition in each model	
Table 4: Maximum deflection comparisons between models using Frame/Shell as base line	. 15
Table 5: Modal Analysis with % Diff using Frame/Shell as baseline	
Table 6: Natural Frequency for Frame/Shell with %Diff comparing support conditions in each	1
model with Fixed-Fixed as baseline.	
Table 7: Natural Frequency for Frame/Solid with %Diff comparing support conditions in each	1
model with Fixed-Fixed as baseline	. 16
Table 8: Natural Frequency for Solid/Solid with %Diff comparing support conditions in each	
model with Fixed-Fixed as baseline	
Table 9: Frequency of Test Methods.	. 17
Table 10: Model 400 Specifications.	
Table 11: Bridge Deck Testing Methods and Occurrence Intervals	. 29
APPENDIX A: List of Tables	
Table A 1: Year Two Budget Summary	. 43
Table A 2: Detailed Personnel Budget	. 44
Table A 3 Live-Load Testing Equipment.	
Table A 4 Live Load: cost Per Test (utah)	
Table A 5 Live-Load: Cost Per Test (California).	. 45
Table A 6 dynamite Testing Equipment.	
Table A 7 Dynamic Testing: Cost Per Test (Utah)	
Table A 8 Dynamic Testiing: cost Per Test (California).	
Table A 9 Dynamic Testing: Cost Per test (Assistet With Birginia Pilot Bridge)	
Table A 10 Deck Testing: Equipment.	
Table A 11 Deck Testing: Cost Per Bridge (Utah).	
Table A 12Deck Testing: Cost Per Bridge (California)	
Table A 13 Long-Term Monitoring: Cost Per Bridge (Utah)	
Table A 14 Long-Terming Monitoring: (Installation).	
Table A 15 Annual Costs (Utah).	
Table A 16 Annual Costs (California).	. 53

1.0 Introduction:

The Utah State University (USU) Long Term Bridge Performance (LTBP) Program research team used the National Bridge Inventory (NBI) to help select a bridge for the pilot study in the state of Utah. A number of criteria were deemed important and significant for the bridge selection. Those criteria were used to filter the bridges in the NBI database to create a short list. The researchers from USU and Virginia Tech (VT) then made site visits to each of the bridges on the short list to further narrow the reduced group for selection through field investigations. As a result, the number of bridges was reduced to three. After approval from a Federal Highway Administration (FHWA) representative, the researchers then met with officials from the Utah Department of Transportation (UDOT) for their input. Based on the discussions with the UDOT officials, one bridge was selected for the Utah Pilot Bridge. An evaluation of the selected bridge was conducted to determine optimal instrumentation layout and locations. Explanations of detailed visual inspections, periodic testing, monitoring, data processing, and data storage for the Utah Pilot Bridge are contained in this document.

2.0 Bridge Selection:

To initiate the selection of the pilot bridge in the State of Utah, a portion of the NBI for Utah was supplied to the researchers at USU. Collaboration between researchers at USU and Virginia Tech produced a draft selection criteria table which was utilized as a starting point for focusing the search. The NBI database contains 116 different items by which the bridge is categorized. Selection of a Utah bridge was accomplished on approximately fifteen of those items.

2.1 Selection Criteria:

Among the fifteen selection categories, a hierarchy of importance was applied during the initial search through the NBI. The fifteen categories were given specific criteria for each search. When each iteration was completed, an analysis of the bridges that met all these requirements was compiled. A visual analysis of images through Google Maps was then utilized to obtain an accurate portrayal of the bridge without requiring a site visit. These Google Maps provided aerial and street views of the bridges, which allowed the researchers the confidence to make informed decisions of whether or not to include the bridge on the short list. Multiple ranges were applied to each selection category resulting in many iterations of the NBI database.

Selection categories that were not allowed to change were the superstructure type, percent truck traffic, deck condition, and number of lanes. Other selection categories were allowed to vary in magnitude to provide different search criteria and thus additional potential bridges. For instance, the bridge skew is one selection category that was varied as the search progressed. By adjusting the allowed skew the number of bridges in the queue increased allowing researchers to investigate more possibilities.

After a thorough investigation of the bridges in the NBI database, five bridges were selected for further consideration. Site visits to each of the five bridges was conducted by a small number of researchers from USU to document the bridge with pictures and a personal assessment of the bridge conditions. From this initial site visit, the number of potential pilot bridges was reduced to four.

Subsequently, a second more in depth, investigation was conducted with the full USU research team and a small contingent of the VT research team. Together the group visited each bridge site to collect additional pictures and allow for a more in depth visual inspection of the bridges. This second visit occurred on March 5, 2009. After the March 5, 2009 site visit, the LTBP team, including representation from the FHWA, conducted a discussion of each of those bridges. Strong and weak points of each bridge were discussed along with what could be learned by selecting each particular bridge. The discussion resulted in the conclusion that deck conditions were of vital importance. The focus group that met on March 6, 2009 selected three bridges, which were then ranked in order of preference for consideration as the Utah Pilot Bridge.

Shortly after the March 6, 2009 meeting, the Utah Department of Transportation was contacted. Researchers from USU met with Chris Potter, the UDOT Bridge Maintenance Engineer, to discuss their willingness to allow access in order to monitor the bridges. The inspection reports and additional details on each bridge were supplied and reviewed at that meeting. From the discussion, it was determined that structure number 1F 205 would be the best bridge for the LTBP Program and the interests of UDOT. This bridge also corresponds to the first choice of the LTBP focus group. The final NBI criteria that were used for selection of the Utah Pilot Bridge are listed in Table 1.

Table 1: Criteria used to select Utah Pilot Bridge.

Number	Description	Range	Actual Bridge Values
2	Highway District	1, 2	1
16	Latitude	> 40°20'59"	41°27'29.4"
17	Longitude	< 112°15'50"	112°3'18.6"
21	Maintenance Responsibility	1	1
27	Year Built	1970 < Year Built < 2000	1976
28A	Lanes On	2	2
28B	Lanes Under	< 3	2
29	ADT	> 5000	22,255
34	Degrees Skew	< 40	0
42A	Service On	1,6	1
42B	Service Under	1, 4, 5, 6	1
43A	Structure Kind	5, 6	5
43B	Structure Type	2	2
45	Main Unit Spans	<5	1
109	Percent ADT Truck	≥ 6	29

2.2 Bridge Background and Inventory:

The Utah Pilot Bridge, structure number 1F 205, is located 1.5 miles west of Perry, Utah. For this reason, it will be referred to as the Perry Bridge. It was constructed in 1976, has two lanes of traffic and is part of the I-15 corridor. It carries the I-15 traffic over Cannery Road. Cannery Road is not a busy road that allows for local access for farmers to maintain their fields. More detailed location is given by latitude and longitude: 41° 27' 25.92" and 112° 03' 18.72", respectively. A side view and aerial view of the bridge are given in Figure 1.



Figure 1: Left-Side view of bridge looking East. Right-Aerial view of bridge from Google Image, top is North.

The superstructure consists of 5 prestressed Type IV AASHTO prestressed concrete girders, as indicated in Figure 2. The clear span length is 80 feet, from abutment to abutment. The actual girder lengths are 82.5 feet. The abutments are integral abutments. Inspection records indicate that the all girders and the abutments appeared in good condition as of 2005. From the USU researchers' inspection it was found that the bridge abutments and parapets have experienced cracking, see Figure 3.



Figure 2: View underneath bridge. Left: Close-up to show Type IV structure. Right: Pan view to show all five girders.



Figure 3: Cracking at Abutment.

Other locations on the bridge show considerable wear. The undersides of the parapets, particularly at joints, have efflorescence to varying degrees. As seen in Figure 4, some cracking has created spalling of the parapet. Other damage to the parapet is limited to cracking that provides a pathway for chlorides to penetrate, as seen in the photo on the right in Figure 4.



Figure 4: Cracking on underside of parapet.

An 8-inch thick concrete deck with a 3-inch thick asphalt membrane was applied at initial construction. Figure 5 shows the current deck with the asphalt overlay. In September of 1991 "major repairs" were undertaken to repair the deck surface and parapets from degradation and wear that was reported based on an inspection in September of 1982. During the 1995 inspection, it was noted that the repairs were completed and looked "good". In 1997, some transverse cracks with efflorescence at the south end of the bridge were noticed. The cracking and efflorescence remained minor until a report in 2003 that noted that the transverse cracking began to increase in density and the efflorescence

increased as well. In 2005, a new wearing surface was applied to the deck. It was recorded that the parapets had some spalling and there was full transverse cracking every 5 to 7 feet with efflorescence. Figure 6 and Figure 7 show schematic drawings of the bridge elevation and cross section, respectively.



Figure 5: View of deck looking south.

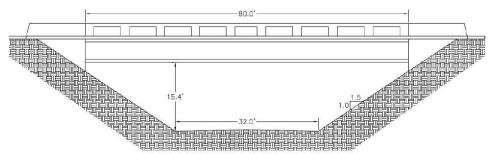


Figure 6: Schematic elevation drawing of Utah Pilot Bridge.

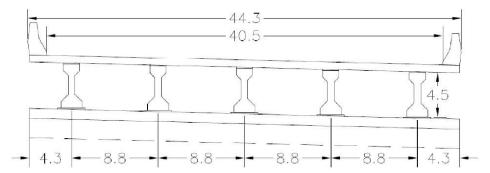


Figure 7: Cross-sectional view of Bridge deck and girders (All dimensions are in feet).

2.3 Summary

A pilot bridge was selected in the State of Utah with the assistance of the NBI database and multiple site visits. Pictures were taken for ease of remembrance and to provide visual aids when discussing the bridge with other LTBP team members. Figure 8 shows the location of the Perry Bridge within the State of Utah. The bridge is located 50 miles north of Salt Lake City, Utah on I-15 northbound.

Specifications of the bridge include

- · Two lanes of traffic carried
- Total structure length = 82 ft
- · Single span, continuous structure
- Superstructure is made of 5 AASHTO IV Precast Prestressed Concrete Girders
- No Skew, 0°
- NBI ratings of Deck = 7, Superstructure = 8, Substructure = 8 (2007)
- Structure Inventory and Appraisal Sheet, electronic and paper copy of design and as-built plans available from UDOT
- · Access to bridge is very high, rarely used local dirt road passes underneath
- High Truck Traffic, 29%, provides excellent candidate for a plethora of heavy load traffic
- · Bridge deck has Asphalt Overlay
- · Integral Abutment Construction
- · Scheduled for removal of existing overly and replacement of overlay



Figure 8: Location of Utah Pilot Bridge in relation to state of Utah, indicated by red bubble.

3.0 Study Topics

The USU research team used criteria contained in the LTBP Study Topics evaluation table to determine the most appropriate testing/loading methods and monitoring equipment. Twenty study topics have been outlined by the LTBP Program team and are listed in Table 2 in accordance with LTBP program Task 1.2. Each test or monitoring method suggested for use on

the Utah Pilot Bridge will provide information for multiple study topics. The range of testing methods and monitoring choices was determined in order to comply with specific study topics.

Table 2: LTBP Study Topics.

Rank	Issue
1	Performance of Untreated Concrete Bridge Decks
2	Performance of Bridge Deck Treatments
3	Performance, Maintenance and Repair of Bridge Deck Joints
4	Performance of Coatings for Steel Superstructure Elements
5	Performance of Bare/Coated Concrete Super- and Sub-structures
6	Performance of Innovative Bridge Designs and Materials
7	Performance of Embedded Prestressing Wires and Tendons
8	Performance of Bridge Bearings
9	Performance of Precast Reinforced Concrete Deck Systems
10	Performance of Jointless Structures
11	Performance of Alternative Reinforcing Steels
12	Direct, Reliable, Timely Methods to Measure Scour
13	Performance of Weathering Steels
14	Influence of Cracking on the Serviceability of HPC Decks
15	Risk and Reliability Evaluation for Structural Safety Performance
16	Performance of Scour Countermeasures
17	Performance of Prestressed Concrete Girders
18	Unknown Foundation Types
19	Performance of Structure Foundation Types
20	Criteria for Classification of Functional Performance

4.0 Finite-Element Modeling

For the Perry Utah Bridge, 3 distinct Finite Element Models (FEM) have been developed using SAP2000 version 11. SAP2000 serves as a productive and practical structural analysis program for 3-D modeling. Because there are several different ways to model a bridge that will produce acceptable results, three bridge models have been developed and will be analyzed using data collected from the live load and dynamic tests. The three types of bridge models that were

considered for this bridge are frame and shell elements, solid elements, and a combination of frame and solid elements. Each of the models was checked for accuracy by comparing the moment due to a 10 kip load applied at mid-span at any cross section of the bridge to the exact moment. The moments of the frame/shell model and frame/solid models were within .004% of the actual moment. The solid model was within .03%. Once the live load testing is complete, the data collected will be compared to that of the models. The model that behaves more closely to the live load data will be selected as the model used during the bridge study. The data will also be used to calibrate the bridge model. Figure 9 shows a 3-D representation of the bridge model using frame/shell elements.



Figure 9: 3-D representation of the bridge model using Frame and Shell elements.

The first model is composed of frame and shell elements. The deck was modeled by shell elements which were formed using bilinear quadrilaterals with four nodes. This element has 6 degrees of freedom (3 rotational and 3 translational) per node and the aspect ratio, a ratio of the longest dimension to the shortest dimension of an element, was kept under 3. This shell element was developed under the thick plate formulation to account for transverse shear. The shell element also considers out of plane bending effects, tension and compression during the formulation. One of the disadvantages of using shell elements is their inability to model pure bending by over stiffening the element. The girders were modeled by using 2 node frame elements. Frame elements are an efficient and simple model that is good for predicting the deflection and moments in the girders. Because it is assumed that the girders will behave identically to the portion of the deck above them, the frames were rigidly constrained to the deck as shown below in Figure 10. The frame and shell model will require fewer elements as compared to the other models. However, because of the simplification of using frame and shell elements for the bridge, the model is limited in predicting stresses due to local stress concentrations.

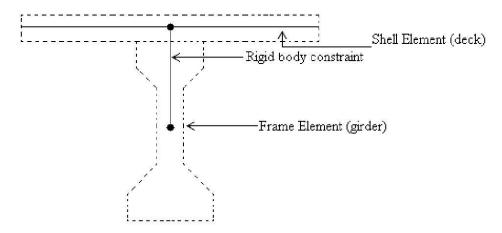


Figure 10: Shell elements for the deck and Frame elements for the girder.

The second model uses solid elements for both the deck and the girders. Solid elements can perform well because they incorporate all six stresses (three normal and three shear). However, there are several drawbacks to using solids including the complexity of working with solids and the large number of elements used to model the bridge. This can greatly increase the runtime of the analysis or it can make the computation not feasible due to the increased computational requirements. The girders and deck are composites of tri-linear hexahedrons, or eight node bricks. These solid elements have 3 translational degrees of freedom per node. It was preferred that the solid elements were compact and regularly shaped to improve accuracy. Because of the design of the girders, the elements were shaped as rectangles and near triangles. The aspect ratio was still kept near or below a ratio of four for both elements. Figure 11 shows how the elements were connected together.

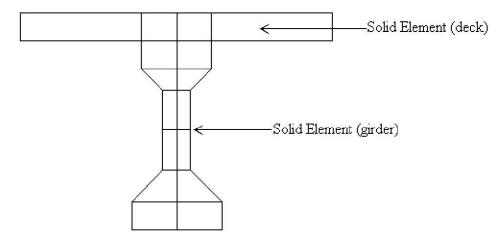


Figure 11: Cross section showing Solid element modeling method.

The third model was a combination of both frame and solid elements. The girders were developed as two node frame elements and the deck was modeled as tri-linear hexahedron solid elements. The aspect ratio for the deck was kept below three and the elements were compact and regularly shaped to improve accuracy. Rigid body constraints were used to attach the girders to the deck as seen below. This model allows the analysis to be run much faster than the solid model, but will employ the accuracy of using solid elements for the deck. Figure 12 shows the solid element deck and frame element girder connected together with a rigid body constraint.

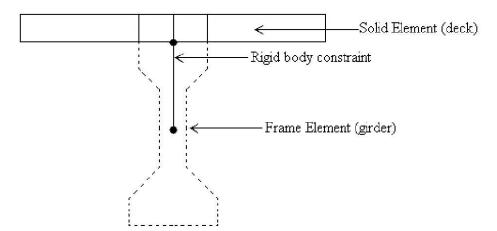


Figure 12: Cross-Section showing Solid element deck and Frame element girder.

An AASHTO HS-20 truck was loaded on the bridge at mid-span, see Figure 13, and the maximum deflection was found. Typical axle distribution and weights are shown in Figure 14. The truck has a spacing of fourteen feet between each axle and was loaded on the bridge at mid-span as seen below. Five different support conditions were taken into consideration for the analysis for each model. Although the roller support was considered in the model, it is not expected that the bridge support will behave as such because of the nature of the integral abutments.

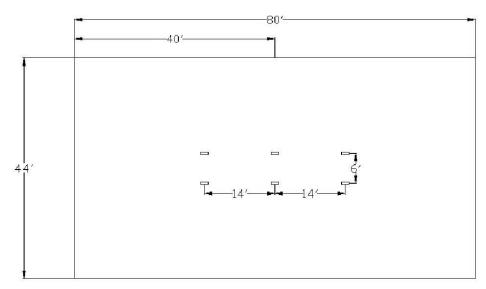


Figure 13: Location of HS-20 wheel loads on bridge.

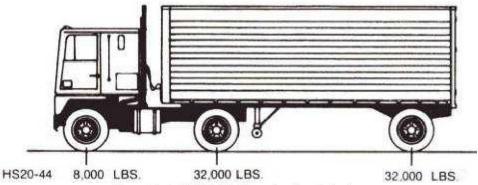


Figure 14: AASHTO HS-20 truck with axle loads.

Analysis for each of the three models was conducted using various support conditions. The support conditions selected and used for comparisons are fixed-fixed, fixed-roller, fixed-pin, pin-pin, and roller-pin. Each of these support conditions was selected in an attempt to see the response of the bridge as conditions change. Once results from the live load and dynamic testing are complete analysis of the data will allow for a comparison to be made with the model and support condition more similar to the actual bridge. Preliminary analysis of the bridge was conducted by running the three models with the given support conditions under the loading of an HS-20 truck. The results of the deflections are given in Tables 3 and 4. Table 3 contrasts the deflection due to the change in support conditions for each of the three models by comparing all other support conditions with the fixed-fixed scenario. Deflection can change over 100% due to variations of support conditions.

Table 3: Maximum deflection comparisons from Fixed-Fixed condition in each model.

	M	ax <mark>imum D</mark> eflec	tion (inches)			
Support Conditions	Solid	% Diff	Frame/Solid	% Diff	Frame/Shell	% Diff
	0.061		0.064		0.063	
-	0.095	57.200	0.100	57.943	0.098	55.857
<u> </u>	0.070	14.962	0.086	35.717	0.084	34.454
	0.073	20.823	0.115	80.528	0.113	80.279
<u> </u>	0.134	120.830	0.148	132.981	0.145	131.623

Table 4 shows the relationship between the deflection in the three models for any given support condition. In this table the percent difference is calculated for the frame/solid and solid models with respect to the frame/shell model. The results indicate that the frame/solid model behaves somewhat similar to that of the frame/shell model differing from 1.2%-2.6%. The solid model

behaves much stiffer. The deflection in the solid model differs over a wide range from about negative 3.6% to negative 35.4% with respect to that of the frame/shell model.

Table 4: Maximum deflection comparisons between models using Frame/Shell as base line.

Maximum Deflection (inches)								
Support Conditons	Frame/Shell	Frame/Solid	% Diff	Solid	% Diff			
	0.063	0.064	1.280	0.061	-3.656			
	0.098	0.100	2.605	0.086	-12.200			
	0.084	0.086	2.231	0.070	-17.624			
	0.113	0.115	1.420	0.073	-3 <mark>5.4</mark> 30			
G A	0.145	0.148	1.874	0.134	-8.146			

A modal analysis was completed on each model to find the natural frequencies for each set of support conditions. Table 5 contrasts the frequency due to the change in support conditions for each of the three models. Tables 6, 7, and 8 show the relationship between the frequency of the three models for any given support condition.

Table 5: Modal Analysis with % Diff using Frame/Shell as baseline.

				Na	atural	Freq	uenci	es							
	Fra	me/S	hell			Fram	e/Soli	d				So	lid		
Support Conditions	Mode 1	Mode 2	Mode 3	Mode 1	% Diff	Mode 2	% Diff	Mode 3	% Diff	Mode 1	% Diff	Mode 2	% Diff	Mode 3	% Diff
	8.65	8.78	9.77	8.42	-2.70	8.55	-2.61	9.56	-2.07	8.87	2.51	8.96	2.09	9.85	0.81
- 3	6.19	6.66	7.41	6.10	-1.36	6.59	-0.93	7.24	-2.35	6.663	7.69	6.85	2.97	7.86	6.09
<u> </u>	7.22	8.42	8.42	7.18	-0.57	7.22	-14.24	8.12	-3.53	8.07	11.76	8.41	-0.12	9.41	11.72
Ь————————————————————————————————————	5.80	6.25	7.60	5.76	-0.76	6.16	-1.41	7.34	-3.30	7.647	31.83	7.97	27.55	9.28	22.19
5 4	4.37	4.78	6.38	4.19	-4.03	4.77	-0.22	6.05	-5.24	3.771	-13.66	4.73	-1.16	7.75	21.44

Table 6: Natural Frequency for Frame/Shell with %Diff comparing support conditions in each model with Fixed-Fixed as baseline.

Natural Frequencies for Frame/Solid Model						
Support Conditions	Mode 1	% Diff	Mode 2	% Diff	Mode 3	% Diff
	8.42		8.55		9.56	
	6.10	-27.49	6.59	-22.88	7.24	-24.33
	7.18	-14.77	7.22	-15.54	8.12	-15.08
<u></u>	5.76	-31.62	6.16	-27.93	7.34	-23.21
5 4	4.19	-50.21	4.77	-44.18	6.05	-36.74

Table 7: Natural Frequency for Frame/Solid with %Diff comparing support conditions in each model with Fixed-Fixed as baseline

Natural Frequencies for Frame/Shell Model						
Support Conditions	Mode 1	% Diff	Mode 2	% Diff	Mode 3	% Diff
	8.65		8.78		9.77	
	6.19	-28.48	6.65	-24.19	7.41	-24.10
<u> </u>	7.22	-16.59	7.35	-16.32	8.42	-13.79
6	5.80	-32.95	6.25	-28.81	7.59	-22.23
5	4.37	-49.52	4.78	-45.52	6.39	-34.62

Table 8: Natural Frequency for Solid/Solid with %Diff comparing support conditions in each model with Fixed-Fixed as baseline

Natural Frequencies for Solid Model						
Support Conditions	Mode 1	% Diff	Mode 2	% Diff	Mode 3	% Diff
	8.87		8.96		9.85	
-	6.66	-24.87	6.85	-23.53	7.86	-20.13
	8.07	-9.06	8.41	-6.17	9.41	-4. 4 7
<u> </u>	7.65	-13.77	7.97	-11.05	9.28	-5.74
5	3.77	-57.48	4.73	-47.26	7.75	-21.24

From the results shown above, it is known that the boundary conditions and type of model used affect the deflection and natural frequencies of the bridge. Because of the large differences that can occur between the different models and support conditions it is important that careful consideration be given when selecting the final model once the live load and dynamic test data is retrieved.

5.0 Detailed Visual Inspection:

In order to determine the condition state of the instrumented bridge, periodic detail visual inspections will occur for the Utah Pilot Bridge. Parsons Brinkerhoff will conduct these inspections. The inspection will follow established LTBP protocols for visual inspection.

6.0 Periodic Testing:

Various forms of periodic testing will occur throughout the duration of the LTBP project. Estimated costs for testing are included in Appendix A. The different types of periodic testing include detailed visual inspection (see Section 5.0), live load testing, dynamic load testing, deck monitoring, non-destructive testing/evaluation (NDT/NDE), and material testing. The proposed occurrence interval of each test is listed in Table 9.

Table 9: Frequency of Test Methods.

Test Method	Occurrence (yr.)
Detailed Visual Inspection	2
Live Load Testing	6
Dynamic Live Load Testing	6
Deck Testing/Evaluation	6
NDT/NDE	4 or 6
Material Testing	TBD

6.1 Live Load Testing:

Live-Load Testing will provide necessary information to track the changes that the bridge undergoes with time. Changes that will be monitored are the overall global response of the bridge and critical system behavior of individual parts of the bridge. To know the cause of behavioral changes on the bridge, it is important to know the starting point of the bridge. This can be considered as a baseline. Therefore, the initial Live Load Test will be used in comparison with all subsequent live load tests.

The starting point, or baseline, will be defined by recording data from the live load test that includes longitudinal and vertical girder strains, vertical girder deflections, deck strains, joint movement, and bearing rotations. From the truck loads that will be used in the testing, wheel load distribution factors and dynamic load allowance will be determined.

The live-load testing will be a combination of both crawl (static) and full-speed (dynamic) tests. The Utah Pilot Bridge is a single span, simply supported bridge. The abutments are integral abutments so it is expected that this bridge will not respond as a perfectly pin-pin or a fixed-fixed connection. From the cracking that has been observed at the bridge site, it is believed that a fully fixed condition does not exist. At this time, estimation is that the bridge acts partially fixed with some rotation allowed due to the cracking observed. It is recommended that the Utah Pilot Bridge be tested with Static and Dynamic Live Load tests, as explained below.

Information necessary to understand bridge response gathered during the live load test will aid in answering the following LTBP Study Topics: performance of untreated concrete bridge decks (1), performance of bridge deck treatments (2), the performance, maintenance and repair of bridge deck joints (3), and performance of bare/coated concrete super- and sub-structures (5) are Study Topics that are better understood from a live load test. In addition, the change from the baseline over the duration of the project will provide information for performance of bridge bearings (8), performance of jointless structures (10), and performance of prestressed concrete girders (17). All of these listed study topics, and their analysis, will provide further development of criteria for classification of functional performance (20).

6.1.1 Static Live Load Test:

From fundamental beam theory, it can be shown that the maximum moment of a simply supported or fixed-fixed beam occurs at the midspan. The calculation of the moment for either condition is relatively straightforward. It is assumed that the Utah Pilot Bridge acts somewhere between a fixed-fixed and simply supported bridge. By knowing the correct theoretical applications of each boundary condition, field tests can produce results to clarify the actual support conditions that the Utah Pilot Bridge, and other bridges with its same construction, experiences.

Data collected from the static live load test will aid researchers in determining the correct boundary conditions for the bridge in addition to load duration properties. Instrumentation attached to the girders and bridge deck will provide the necessary data for researchers to calculate the maximum moment, deflection, and shear in various locations throughout the bridge. Data can then be analyzed and actual boundary conditions obtained. This data will be integrated into the FEM created for further analysis of the Utah Pilot Bridge.

Figure 15 and Figure 16 shows probable locations of strain gauges. Three strain gauges at each distance location are recommended on all five girders to provide an accurate strain distribution. The two strain gauges along the web will provide a strain distribution through that part of the girder providing a good basis for determining the neutral axis. The gauge located on the bottom of the girder will

provide a reading of the maximum strain and greatly aid in determining maximum moments in each girder.

Figure 15 also shows the probable locations of deflection instruments. Virginia Tech researchers have developed a deflection instrument, or deflectometer, that accurately measures the deflection of a bridge. The deflectometers used for live load testing, as shown in Figure 17, consist of a flat aluminum plate with a full bridge bonded foil strain gage applied to the surfaces. Connected as a cantilever to each girder and firmly tied to the ground with wire, strains are measured in the plate as the girder deflects. These strains can be used to determine the vertical deflection being experienced by the girder. The instruments have frequently been referred to as "Twangers".

It is recommended that the use of two heavily loaded dump trucks provide the loading for the static live load test. Since the overall structure length is relatively short, it is desirable to select trucks with the greatest maximum weight as possible. The trucks will be driven across the bridge at speeds not exceeding 5 mph, preferably in the range of 2-3 mph, for the three load paths, see Figure 19. It may be desirable to park the trucks at various locations at mid-span to gather the maximum deflection obtained in the most accurate manner. For accurate strain measurements, later analyzed to determine maximum moment and shear, approximately 30 strain gauges should be attached to the girders at midspan and five feet from the abutment. The instrument locations are shown in Figures 18 and 16. Temperature readings will be taken during the testing but the effects of temperature (i.e. expansion and/or contraction) will be minimized by zeroing between truck runs.

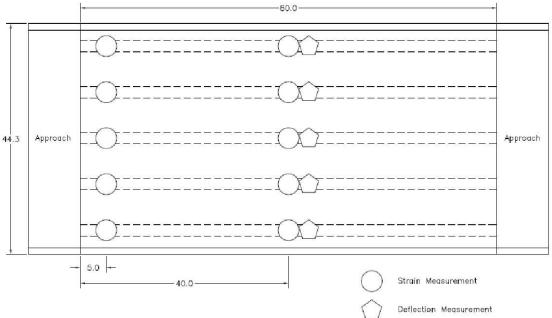


Figure 15: Location of Strain and Deflection gauges for Static Live Load Testing.

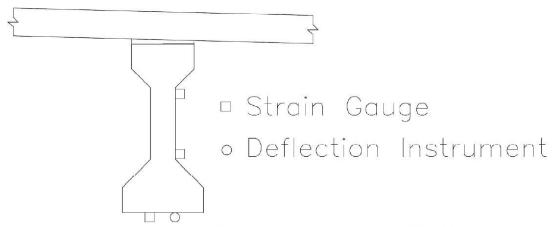


Figure 16: Sectional view of relative location of strain gauges on bridge girders.



Figure 17: Deflectometer on bottom flange of a girder.

6.1.2 Dynamic Live Load Testing:

Dynamic live load testing methods have preferred application in scenarios where the effect of vehicle speed on bridge performance is desired. Dynamic live load tests allow the researcher to monitor the bridge stiffness as a function of the speed of the traveling vehicle. These effects are related to the functional performance of the bridge, (20).

It is recommended that the Utah Pilot Bridge be subjected to a dynamic live load test with varying increments of vehicle speed. Measurements should be made with vehicle speeds at intervals similar to 5, 10, 20, 35, 45, 55, and 65 mph. Multiple tests will allow for greater comparisons of the effects that vehicle speeds have on bridge response. Further, it is recommended that the vehicle used in the test, drive along three predetermined paths at each of the nominal speeds. These locations are close to the East edge of the bridge, center line of the bridge and West edge of the bridge, Figure 19.

Instrumentation for the Utah Pilot Bridge for dynamic live load testing will be the same as that used for the static test. This will include strain gauges at the midspan and 5 feet from the end of each girder, see Figures 15 and 16 for schematic diagrams of instrument locations.

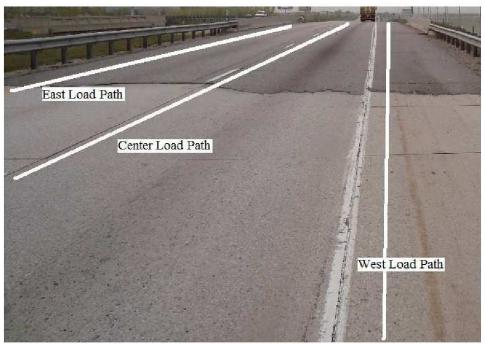


Figure 18: Pictorial representation of load paths for Static and Dynamic Live Load Tests.

6.2 Dynamic Testing:

The Utah Pilot Bridge will undergo a forced vibration test using an electro-magnetic shaker. This shaker will produce a harmonic force to the structure. Through measurement and analysis of the structures response, further understanding into the global characteristics of the structure can be obtained. With careful planning and consideration, the resonant frequencies and response shapes of the structure will be determined. The analysis will allow for multiple conclusions to be made. For instance, assumption of the static stiffness can be made, modal frequencies, shapes and damping ratios can be measured and specific trends in characteristics can be made over a range of response levels. The knowledge that is gained from dynamic load tests can provide values for calibration with the FEM. After calibration, the FEM has a greater degree of certainty and thus more confidence can be placed on the analytical results.

Conducting the dynamic test will provide information regarding Study Topics: performance of untreated concrete bridge decks (1), performance of bridge deck treatments (2), performance, maintenance and repair of bridge deck joints (3), performance of bare/coated concrete super- and sub-structures (5), performance of bridge bearings (8), performance of jointless structures (10), and performance of prestressed

concrete girders (17). From the change in the modal damping ratios, static stiffness and resonant frequencies, researchers can determine risk and reliability evaluation for structural safety performance (15) as well as define criteria for classification of functional performance (20).

Utah State University owns a number of forced vibration shakers. These shakers have the capability of running at various frequencies and producing a range of force on the bridge. The shaker recommended for use in Dynamic Testing of the Utah Pilot Bridge is any shaker of the equivalent to an APS Electro-Seis® Long Stroke Shaker. Figure 19 is a picture of a Model 400 and Table 10 displays specifications for the shaker.



Figure 19: Electromagnetic shaker with custom built frame.

Table 10: Model 400 Specifications.

Item	Value
Maximum Force, Vector	100 lb.
Maximum Velocity, Vector	30 in./sec
Maximum Stroke, p-p	6.25 in.
Armature Weight	6.1 lb.
Maximum Overhung Load at	
Armature Attachment Point	20 lb.
Total Shaker Weight	2 ohm
Overall Dimensions	160 lb.
Length	20.7 in.
Width	12.4 in.
Height	7.0 in.

The APS Model 400 is an electromagnetic forced vibration shaker. It is fundamentally a force generator. The force generation takes place in a magnetic field which is perpendicular to the current. The Model 400 Shaker is capable of generating any time waveform of force acting between its armature and body, in accordance with an identical time waveform of current supplied to it. The force magnitude is directly adjustable, independent of the frequency or time waveform of operation and it may be instantaneously terminated by interrupting the current.

Recommended minimum instrumentation for the Utah Pilot Bridge for the dynamic testing is sixteen 1 Hz velocity transducers and two accelerometers with a range of 2-4 g capabilities, for a total of eighteen channels. The location of the shaker on the bridge as well as placement of the instruments will be finalized upon completion of the FEM. Fundamental frequencies and mode shapes of the bridge will be considered when determining sensor locations. Figure 20 shows a schematic of proposed locations. For estimated costs for Dynamic Testing equipment see Appendix B.

Each circle and/or arrow on Figure 20 represents a sensor. A circle represents a vertical axis sensor. Each arrow indicates a direction axis. For example. Two arrows perpendicular to each other indicated that two sensors are placed at the location and record both transverse and longitudinal directions. Including a circle with the two arrows indicates that vertical motion is also measured. A bi-axial accelerometer is indicated by the circles with one arrow extending out. Figure 20 gives an approximate sensor layout for the dynamic testing.

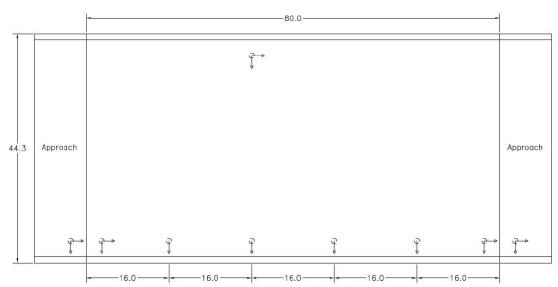


Figure 20:Dynamic Test instrument layout diagram.

Access to the underside of the bridge for both the live load testing and dynamic load testing instrument set-up will be easily obtained. The local road that passes underneath, Cannery Road, is a wide lightly traveled road that carries maintenance trucks or local farmer traffic. Therefore, due to the wide road and low traffic, no organized redirection or closing of local traffic is necessary. This allows researchers to access all areas of the bridge with little to no encumbrance.

Equipment capable of reaching the underside of the bridge will be rented for use in installing the live load and dynamic load testing equipment. This can be achieved through a combination of stationary scaffolding equipment and a mobile bucket truck. The use of this equipment will allow researchers to easily and safely access the girders and underside of the bridge deck for placement of gauges. Cables will be temporarily suspended from the bridge to keep them off Cannery Road. A data acquisition unit and computer will be set-up in a convenient and safe location for researchers. Installation can occur at most any time, given that access is available during all hours and no special closure is required. A cost estimate for the periodic testing equipment, scaffolding and a bucket truck is found in Appendix A.

Testing will likely occur on a Saturday or Sunday night, when traffic is the lightest. The I-15 corridor is heavily used for commuting and freight traffic, given the estimated 22,250 AADT and 29% truck traffic. A complete closure of the bridge is impossible even at night. During a discussion with UDOT bridge engineer officials, it is recommended that scheduled slow-downs and single lane closure occur to provide a ten minute

windows for researchers to conduct tests. A slow-down requires coordination with the UDOT and the Utah Highway Patrol. A police officer will start some distance away from the bridge and slow traffic to a crawl. Once past the bridge, the police officers will return to the position before the bridge and repeat the process. This will allow for traffic to flow at a near normal speed and provide researchers the availability of the bridge needed for quality data acquisition.

6.3 Deck Testing:

The deck testing plan is aimed at quantifying the material properties of the concrete and steel, namely the permeability of the concrete, the ability of the concrete to provide a protective environment for the reinforcing steel, the corrosion of the steel reinforcement, and properties that will affect these items (specifically cover depth of reinforcement, resistivity of the concrete, chloride contents, and carbonation). The specific tests to be performed are:

- · Chloride contents of concrete along the depth of the deck
- · Cover depths of reinforcing steel
- · Resistivity of concrete
- · Corrosion potentials of reinforcing steel
- · Corrosion rates of reinforcing steel
- · Carbonation of concrete
- · Coring of concrete

Chloride content of the concrete is perhaps the most important measure in determining the overall state of the deck. Chlorides are not only a problem in states where deicing salts are used, but also in coastal regions where structures are exposed to salt water or brackish water. As mentioned, chlorides are one of the main culprits in corrosion of reinforcing steel, destroying the protective passive layer on the reinforcing steel, allowing the steel to corrode, expand, and crack the concrete. Determining the chloride content at various depths will aid in determining the condition of the concrete both above and below the top mat of reinforcing steel. Chloride concentrations high enough to initiate corrosion below the steel is a precursor to both localized spalling of the concrete and large scale delaminations of the concrete. To obtain adequate data for statistical analysis a minimum of 30 tests at randomly selected locations should be performed. The test will include sampling at the following depths:

- 1/4" to 3/4"
- 3/4" to 1-1/4"
- 1-1/4" to 1-3/4"
- 1- ³/₄" to 2-¹/₄"
- 2-1/4" to 2-3/4"
- 2- 3/4" to 3-1/4"
- 3-1/4" to 3-3/4"

The top 1/4" of concrete will be discarded due to the inconsistency in the chlorides at this depth.

One of the simplest methods used to protect reinforcing steel is using the proper amount of clear cover concrete over the reinforcing steel. Inadequate clear cover can cause reinforcing steel to start corroding prematurely, and will exacerbate ongoing corrosion problems by allowing more chlorides to attack the reinforcing steel. Measuring the amount of clear cover allows comparisons to be made between the condition of steel with differing amounts of clear cover concrete. For statistical analysis purposes, the sampling size would be approximately 40 locations per span. The locations will include the wheel paths, in between the wheel paths, and the shoulder, and will be randomly selected along the length of the deck. The actual number of sampling locations will be determined by the UDOT.

Another measure of the protection afforded to reinforcing steel is the resistivity of concrete. Dry concrete serves as a good insulator against corrosion currents in the steel, but as the moisture in the concrete increases, the resistivity decreases. The increase in conductivity is due to the water in the capillary pores containing dissolved salts. The source of the salts is not only external, e.g. deicing chemicals or salt water, but also from the internal salts which exist in the cement or any admixtures added to the concrete. Resistivity measurements are also being studied as a possible method of determining the permeability of the concrete. Due to the variation of the resistivity values across the deck, a distribution is used for modeling purposes. To obtain a sample size large enough for statistical manipulation, a minimum of 30 readings should be taken. However, the final number of samplings will be determined by the UDOT.

To quantify the corrosion in the steel two tests are performed: corrosion potential and corrosion rate. Corrosion potentials give an indication of the condition of the steel with regards to corrosion activity, that is, the potential for corrosion to exist at the location of the test. While no direct information is given about the rate of corrosion, it generally increases as the potential becomes more negative. The corrosion rate of the reinforcing steel is measured using a device such as a 3LP or Gecor device. These devices will measure the instantaneous rate of corrosion at a given site, but this does not provide any information about the long-term variations in the rate of corrosion. To achieve a long-term overview of the corrosion activity of the structure these measurements will be part of the long-term testing plan, discussed later in this report. Corrosion potentials are taken at 2 ft spacing on a grid. While this is greater than the minimum required by ASTM C876, a smaller spacing is desired to determine if the ASTM standard is un-conservative. Corrosion rates will be taken in both the wheel path and away from the wheel path, with specific locations to be determined after the initial visual inspection.

Another factor that can cause reinforcing steel to lose its passivity is carbonation of concrete. The high pH of concrete (generally in the range of 12.5-13.5) is what allows for the steel to form its passive layer. If the pH of the concrete drops below approximately 10, the passive layer starts to break down, and corrosion begins, regardless of chloride concentration. Carbonation generally occurs at a very slow rate in high quality

concrete, but can be a severe problem in highly permeable concrete. Another factor that can cause the pH of concrete to drop is extended periods of saturation in the concrete. Water will leech calcium hydroxide from the cement, which causes the pH to fall. While the carbonation test does not determine the precise cause of lowered pH in concrete, information gathered from this test can be used in conjunction with the visual inspection, resistivity, and chloride contents to provide an overall view of what is occurring in the concrete. Since this test requires drilling a hole in the deck, it will be performed at the same locations as the chloride content tests.

The final component of the initial inspection will be to pull cores from the deck. A visual inspection will allow inspection of the surface, but coring through reinforcement allows for close inspection of not only the steel, but the concrete surrounding it. It will also allow for the necessary electrical connections required for the corrosion rate and corrosion potential tests. Coring quantities and locations will be determined after the initial visual inspection, but it is likely to be in the range of 6 to 8 cores. A discussion with the Region 1 Operation Manager at the UDOT indicated that any coring through steel will require specific permission from a UDOT bridge engineer in the structures department. It is likely that the number of cores through steel will be strictly limited.

In-field instrumentation for the deck will be limited to a roadway salt sensor. The sensor selected for this application is the Campbell Scientific IRS 21 Lufft Intelligent Road Sensor as shown in Figure 22. The IRS21 sensor will measure road surface temperature, percent salt in solution, freezing point, and water film height. The manufacturer recommends placing two sensors in close proximity (within several feet) of each other. The number and specific location of sensors will be determined following the initial condition inspection, but will likely be in the wheel path close to the approach slab. The specific interest in this sensor for the pilot study is to compare the salt content on the roadway to values provided by the UDOT. For future bridges, it is unknown if salt application data will be available for all the bridges, so the sensor can be used to provide a reasonable estimate of the amount of deicing salt placed on the bridge.



Figure 21: IRS21 Lufft Intelligent Road Sensor

In addition to the preliminary survey, follow up surveys will be performed in order to validate models for chloride ingress, as well as service life models relating to bridge performance. The results of the long term survey plan can also be used to give specific information about the performance of the deck. Comparisons can be made to the performance of both similarly constructed structures as well as structures with varying design and performance histories.

Since corrosion of reinforcement is a slow process, leaving monitoring equipment in place for years at a time would prove both extremely expensive and unreliable. Bearing this in mind, monitoring of the performance and condition of the deck would be better served by performing periodic inspections similar to the initial condition inspection. The tests to be performed at regular intervals are the ones which will change as the condition of the structure degrades (or improves, such as after repairs or rehabilitation). Data that will be collected at regular intervals for this task is shown in Table 11. For estimated costs of Deck Testing equipment see Appendix A.

Table 11: Bridge Deck Testing Methods and Occurrence Intervals

Test Method	Occurrence (yr.)
Chloride Contents	Initial, 6, reassess after 6
Carbonation	Initial, 6
Coring	Initial, 6
Corrosion Potentials	6
Corrosion Rates	6
Cover Depths	Initial Only
Resistivities	6
Visual Inspection, Chain	6
Drag, Sounding, and Crack	*

6.4 NDT/NDE:

The type of NDT/NDE will be determined by Rutgers University with input from the LTBP Program team members. The NDT/NDE program and testing method is projected to retrieve reliable and excellent data for bridge health evaluation.

6.5 Other Material Testing:

In addition to live and dynamic load testing, other non-destructive testing methods will be used to quantify the bridge condition state. A number of methods are currently available.

7.0 Monitoring:

Throughout the life of the project, instrumentation will be placed on the bridge to provide data for bridge health evaluation. Monitoring of the bridge will be exhaustive, in order to obtain the maximum information. All factors that affect bridge performance are considered in the instrumentation plan and are categorized by the LTBP Study Topics. Monitoring over the project life will allow for changes in the bridge response to be recorded. Monitoring will be divided into two categories. The first category will represent the group of instruments that bridges in every state will have installed and the second category will be determined for each bridge individually. The first will be referred to as Standard the second will be referred to as Specialized. Evaluations of this data will help researchers understand the needed occurrence of periodic testing. For estimated costs for Monitoring equipment see Appendix A.

Standard monitoring equipment will provide data for performance of untreated concrete bridge decks (1), performance of bridge deck treatments (2), performance, maintenance and repair of bridge deck joints (3), performance of bare/coated concrete super- and sub-structures (5), performance of bridge bearings (8), and performance of jointless structures (10). Specialized monitoring equipment will provide data for performance of untreated concrete bridge decks (1), performance of bridge deck treatments (2), performance, maintenance and repair of bridge deck joints (3), performance of bare/coated concrete super- and sub-structures (5), performance of bridge bearings (8), performance of jointless structures (10), performance of prestressed concrete girders (17), and performance of structure foundation types (19). As data is stored, analyzed and compared with baseline results, risk and reliability evaluation for structural safety performance (15) and criteria for classification of functional performance (20) can be determined.

7.1 Standard Monitoring:

Standard monitoring equipment includes: a Weigh-In-Motion (WIM) sensor, a Weather Station, a traffic camera and traffic count. Estimated costs to provide the specified

instruments are contained in Appendix A. A detailed explanation into the selection and application of each instrument is conducted in the subsequent sections.

Figure 26 displays probable locations of the monitoring equipment to be placed on the Utah Pilot Bridge. The location of the WIM sensor is near the Utah Port of Entry. Further explanation of this is in section 7.1.1. The traffic camera will be located approximately 100 feet north of the bridge to capture significant events.

7.1.1 WIM and Traffic Counter:

The WIM sensor is necessary to obtain vehicle weights that lead to strain and deflection measurements. This is an important step in determining the performance of untreated concrete bridge decks (1), performance of bridge deck treatments (2), performance, maintenance and repair of bridge joints (3), performance of coatings for steel superstructure elements(4), performance of bare/coated concrete super- and sub-structures (5), performance of innovative bridge designs and materials (6) performance of embedded pre-stressing wires and tendons (7), performance of bridge bearings (8), performance of precast reinforced concrete deck systems (9), performance of jointless structures (10), performance of alternative reinforcing steels (11), performance of weathering steels (13), influence of cracking on the serviceability of HPC decks (14), risk and reliability evaluation for structural safety performance (15), performance of prestressed concrete girders (17), performance of structure foundation types (19), and criteria for classification of functional performance (20).

An investigation of multiple WIM manufactures was conducted and most supply a quartz based WIM sensor. The sensor of choice is a quartz piezoelectric sensor. This sensor is preferred, among all WIM sensors, because it is capable of being installed in one day, can measure vehicle weights at freeway speeds (80 mph), is only two inches wide and the quartz WIM sensor is cheaper than installing other WIM sensor type. A graphical representation of a Quartz WIM sensor is given in Figure 23. Figure 24 shows how the instrument appears when installed in the roadway as taken from the Perry, Utah Port of Entry.

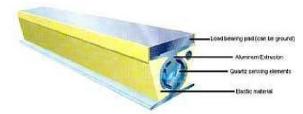


Figure 22: WIM Sensor, www.cardinalscale.com



Figure 23: Quartz based WIM as seen installed in a lane leading to Perry, Utah Port of Entry.

A WIM sensor is capable of recording traffic counts. Traffic counts will accurately inform researchers of the number of vehicles that use the bridge each day, as well as the percentage of the daily flow that is attributed to trucks. The WIM sensor has the capability of counting the daily traffic flow across a lane.

The Perry, Utah Port of Entry currently operates four WIM sensors, two for the southbound and two for the northbound traffic. Each direction of traffic has one WIM on the freeway, where vehicles travel at the posted freeway speed limit, and one along the lane leading to the port of entry/weigh station where trucks travel at a speed much less than freeway speeds. The WIM that is located along the lane is owned by UDOT Motor Carrier division. The WIM that is located on the interstate is owned by Pre-Pass. Figure 25 shows the WIM sensor installed complete with sensors in parallel and an inductive loop.



Figure 24: WIM installed on lane leading to Perry, Utah Weigh Station. See labeling for part descriptions

Researchers from USU were given a tour of the weigh station and shown how the WIM sensors work and record data. The WIM owned by UDOT is calibrated automatically every 100 trucks with comparison to the static scale. The computer algorithm knows when the 100th truck crosses and subsequently directs that truck to the static scales. A calibration is made with the scales and the WIM sensor so that the WIM sensor maintains a high level of accuracy. A sample of the data retrieved as trucks cross the WIM was shown to the USU researchers. Representatives from the UDOT Motor Carrier Division lead the tour of the site.

Data from both WIM locations on the northbound direction are available to the USU research team after discussions with the UDOT Motor Carrier Division. The UDOT Motor Carrier Division owns the data that is recorded from the WIM sensor in the lane leading to the weigh station. An agreement has been made for the USU researchers to receive this data. The WIM sensor that is installed in the interstate is owned by Pre-Pass.

WIM sensor data will be monitored continuously; ideally, all other data will be sampled based on a triggered event from the WIM sensor. This event will coincide with the measurement that the WIM sensor records when a truck crosses over the bridge. The event will trigger the sensors on the bridge to record measurements for further analysis. The WIM sensor is an important triggering

mechanism in this sequence and is necessary for determining the truck weights that cross the bridge. For the Utah Pilot Bridge, a triggered event from the WIM sensor data will not be possible.

Since trucks will pass the WIM sensor and then enter the weigh station it is not known how long it will take for a particular truck to reach the structure. A truck may have a Pre-Pass and be allowed to travel along at original speed. However, if the truck must enter into the weigh station, it may be stopped for inspection or it may pass through quickly. Either way, travel speed is slower than if there were no weigh station. Thus, a trigger is unlikely since a reliable time of arrival on the bridge structure can be calculated. Because of this difficulty, a streaming video camera and sophisticated software will be required to properly capture and document "unusual" or "significant" events.

7.1.2 Traffic Camera:

A traffic camera with the basic capability of a low resolution streaming video is necessary to understand traffic flows during significant events. When coupled with a WIM capable of recording a triggered event, a streaming video camera will provide adequate analysis data to understand what caused the event. Since the WIM setup for the Utah Pilot Bridge is not capable of providing an accurate trigger of an event, a streaming video feed will facilitate in capturing all events whatever traffic situation may occur.

Therefore, the use of a short video of traffic conditions will aid in bridge response analysis. A video data collection system will be necessary for collection and analysis. The system will need hard drive space that allows for a determined span of time to be recorded and easily accessed for later storage and analysis. The data storage space must be large enough to provide a time duration that will allow researchers opportunity to retrieve the data. Understanding the flow of traffic over the bridge will aid in analyzing capacities of the bridge.

The location of the traffic camera on the Utah Pilot Bridge will be determined upon selection of a camera and after consideration of manufacturer recommendations. A possible location is presented in Figure 26. A pole, for mounting, will be installed near the bridge for the camera. It is necessary that the camera have a clear shot of the bridge at all times. A pole of significant height is necessary to reduce vandalism.

7.1.3 Weather Station:

Environmental effects ranging from expansion and contraction of material through heating and cooling cycles due to daily temperature variations to the more extreme freeze-thaw conditions of seasons are important in determining bridge

health. Seasonal temperature changes can cause joint movement, bearing movement and local strain variations. All of these parameters require attention. Knowing the response of the bridge to environmental conditions will help in understanding changes in stress and strain.

A Weather Station will include gauges, or instruments, to record the following data: precipitation, wind direction, wind speed, radiation, humidity, and ambient air temperature. All equipment for a weather station will be securely fastened to a pole located in a safe location. The location will be in accordance with FHWA and UDOT standards and installed with UDOT permission.

For the Utah Pilot Bridge, it is recommended to install a weather station near an AC power unit. This will allow for a heated precipitation gauge. Utah receives much of its yearly precipitation in the form of snow. A typical precipitation gauge will incorrectly record the amount of precipitation that falls in the form of snow, if a heated gauge is not used. Discussions reveal that to record accurate precipitation readings, a heated precipitation gauge is recommended. The heated gauge uses a direct AC link. However, in the case that installation and connection costs are financially prohibitive to provide an AC connection, then a solar panel assembly with an energy reserve by way of deep cycle batteries should be used. If a solar panel is used, the precipitation gauge will require a different unit that requires less demand on the electrical power.

Figure 26 gives an approximate location for the traffic camera, chloride sensors (presented under the specialized monitoring equipment section), the WIM sensor and the weather station.

The items in the "Standard" instrumentation package are essential in adequately addressing all of the listed study topics. The combined effects of loading (WIM data), identifying unusual loads (Traffic Camera) and environmental effects (Weather Station) will provide the basis for comparison of all bridges included in the LTBP program.

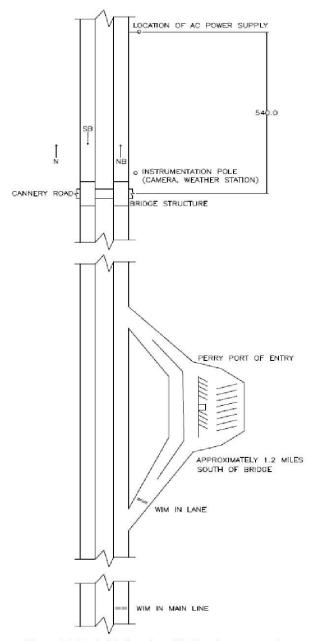


Figure 25: Probable location of bridge instrumentation.

7.2 Specialized Monitoring:

Depending on the type of bridge, its geographical location, and the interests of the LTBP Team; each bridge will undergo analysis for determining additional instrumentation beyond the Standard Monitoring Instrumentation package. For the Utah Pilot Bridge a number of additional instrumentation sensors are proposed. They are listed and explained in the following paragraphs. A cost estimate for the specialized monitoring sensors is given in Appendix A.

In the category of strain gauges, the Utah Pilot Bridge will have three Vibrating Wire Strain Gauges placed on the girders. The high accuracy and longevity of the vibrating wire strain gauges will provide a precise comparison of the structural response of the bridge over time and through deterioration. The slow sampling rate of the vibrating wire strain gauges will be recorded on a set time interval. There will be an additional five foil strain gauges that will be placed in select locations on the bridge to understand the bridge response to excitation/loading scenarios. The data will be recorded on a much faster time interval than the vibrating wire strain gauges. Recorded data from the foil strain gauges will be stored following a triggered event. Foil strain gauges have a tendency to "drift" over time, which will require periodic zeroing and eventual replacement to maintain data quality. These sensors will address performance of untreated concrete bridge decks (1), performance of bridge deck treatments (2), performance, maintenance and repair of bridge deck joints (3), performance of bare/coated concrete super- and sub-structures (5), performance of bridge bearings (8), and performance of pre-stressed concrete girders (17).

Two velocity transducers will be placed on the bridge to record dynamic responses due to excitation from vehicles passing over and if there is any seismic activity. Utah is in a seismically active location and any seismicity will affect the bridges in this area. It is important to know how bridges respond to dynamic loading. These sensors will address performance of untreated concrete bridge decks (1), performance of bridge deck treatments (2), performance, maintenance and repair of bridge deck joints (3), performance of bare/coated concrete super- and sub-structures (5), performance of innovative bridge design and materials (6), performance of bridge bearings (8), performance of jointless structures (10), influence of cracking ont he serviceability of HPC decks (14), risk and reliability evaluation for structural safety performance (15), performance of pre-stressed concrete girders (17), performance of foundation types (19) and criteria for classification of functional performance (20).

The Utah Pilot Bridge experiences repeated freeze-thaw conditions with heavy snow fall during the winter season. It is well documented that bridge decks freeze before earth supported roadway surfaces. The UDOT places varying amounts of de-icing agents on roadways to provide for safe driving conditions. The most common de-icing agent used in Utah is salt. The chlorides in salt can result in differing levels of corrosion to the bridge superstructure.

It is in the interest of the LTBP Program for the Utah Pilot Bridge to determine the quantity of salt placed on the bridge in order to understand the effects that chloride application has on the deterioration of the superstructure. A minimum of one chloride sensor will be installed on the deck of the bridge to measure the chloride quantity. For accurate recording, two sensors are recommended; see Figure 26 for possible instrument location(s). These sensors will address performance of untreated concrete bridge decks (1), performance of bridge deck treatments (2), performance, maintenance and repair of bridge deck joints (3), performance of coatings for steel superstructure elements (4), performance of bare/coated concrete super- and sub-structures (5), performance of innovative bridge design and materials (6), performance of bridge bearings (8), performance of precast reinforced concrete deck systems (9), performance of alternative reinforcing steels (11), influence of cracking on the serviceability of HPC decks (14), risk and reliability evaluation for structural safety performance (15), and criteria for classification of functional performance (20).

Two tilt meters, one placed on the abutment, will be used to measure any rotation or settlement of the bridge due to various loading conditions. Six temperature sensors will be installed on the bridge with the intention of measuring the temperature of the girders. Localized knowledge of thermal gradients will allow researchers to understand joint movements, bearing movements and local strain ranges as a result of the differential temperature reading across a girder. Figure 27 displays possible locations of the specialized instruments for the Utah Pilot Bridge. Figure 28 shows the possible location with respect to the girder cross section. These specialized monitoring instruments have a cost estimation provided in Appendix A. These sensors will address performance of bridge bearings (8), influence of cracking on the serviceability of HPC decks (14), risk and reliability evaluation for structural safety performance (15), unknown foundation types (18), performance of structure foundation types (19), and criteria for classification of functional performance (20).

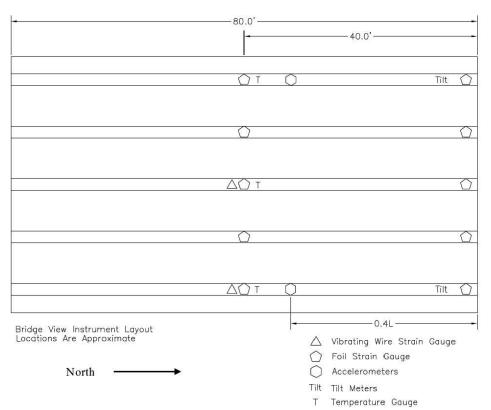


Figure 26: Location of specialized monitoring equipment.

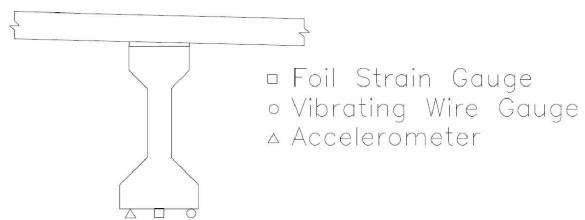


Figure 27: Cross section of girder showing proposed specialized monitoring sensor locations.

7.3 Service, Maintenance, and Projected Replacement:

Through the duration of the monitoring period, certain costs will be incurred through up keep of the equipment placed on the bridge structure. There will be a number of service costs which include AC power and communication/internet costs. In addition to that, there are maintenance costs including but not limited to site visits and datalogger/instrument software updates. It is likely that many unforeseen maintenance costs will arise due to the large amount of equipment installed and difficulty in knowing all of what happens at a bridge site. This may include but is not limited to vandalism, weather occurrences, traffic incidents or bridge maintenance crews. It is expected and known that certain instruments will require replacement after a certain number of years. Preparation in planning for these costs will provide a much easier method for payment. An estimation of these costs is contained in Appendix A.

8.0 Analysis and Data Storage:

8.1 Analysis:

Data processing will be conducted by the Utah State University Research Team. A datalogger, installed at the bridge site will collect, record, and deliver raw data to a secure site for further analysis. A communication connection, in the form of high-speed internet service, will be installed at the bridge site. Integration with the communication service and the datalogger will allow for constant real-time updating of data. A constant communication connection will remove the need for time consuming visits to the bridge site for data retrieval. This will save time and money over the life of the project.

Appendix A contains a cost estimate for purchasing a datalogger and the necessary equipment to record data.

Processing of collected data will be conducted by the Utah State University Research Team through the use of computer programs. Programs used will depend on the nature of the analysis, such as Microsoft Excel or MATLAB are likely candidates because of their universal acceptance, familiarity with the programs, and reasonable ease of use. Data processing will allow and decisions to be made for future bridge construction.

8.2 Data Storage:

A large amount of raw data will be collected through the project life of the Utah Pilot Bridge. This data will be stored by Siemens America and Parsons Brinkeroff, as defined in Task 1.3 of the LTBP program. Data access will be coordinated through Siemens American and Parsons Brinkerhoff. For accurate and consistent data retrieval, it is important that the USU research team have responsibility for the coding and programming of instruments installed on the Utah Pilot Bridge.

If a real-time viewing of data via an internet site is desired, coordination with Siemens American and Parsons Brinkerhoff is necessary. Adequate precautions for security and data access reasons must be considered in developing viewing via an internet web page.

9.0 Instrumentation Plan Summary:

An instrumentation plan is proposed for consideration. It is recommended that the proposed sensors, number of sensors, and data acquisition equipment be approved to produce the highest quality of data possible. Each individual sensor cost, equipment cost, and expected cost per periodic test is given in Appendix A.

Constant maintenance of the bridge instrumentation equipment must occur for accurate data acquisition. Continued costs will arise to replace or update instruments. Power must be supplied to instruments and payments need to be made for communication connection. The costs expected for the Utah Pilot Bridge on a yearly basis are given in Appendix A. Certain costs are averaged over a yearly period. These include chloride and other instrument replacement costs. The replacements for the chloride sensor are expected to occur every five years. The cost to replace at that interval is averaged over five years. Other unforeseen costs are likely to occur. A summary of the budget for the 2009 – 2010 fiscal year is displayed in Appendix A. Individual costs for each area shown in the table are further explained in Appendix A.

APPENDIX A: BUDGET

2.1 Instrumentation Systems

2.1 <u>Live Load Testing:</u>

Equipment*

Table A 3 Live-Load Testing Equipment.

Item	Quantity	Cost	Unit	Unit To	
STS-WiFi4 Channel Node	2	\$ 3,640.00	Each	\$	7,280.00
BDI Straintransducer w/Intelliducer	4	\$ 595.00	Each	\$	2,380.00
LVDT w/Intelliducer	4	\$ 715.00	Each	\$	2,860.00
Deflection Instrument (Twanger)	8	\$ 1,250.00	Each	\$	10,000.00

Total = \$22,520.00

2.1.1 Cost Per Test (Utah)

Table A 4 Live Load: cost Per Test (utah)

Item	Item Quantity Cost		Unit	Total		
Traffic Control	3	\$	2,000.00	Per Day	\$	6,000.00
Truck Rental	2	\$	600.00	Per Day	\$	3,600.00
Equipment Rental	1	\$	450.00	Per Day	\$	1,350.00
Travel (per diem - 4 people)	3	\$	200.00	Per Day	\$	2,400.00
Travel (Airfare - 4 people)	0	\$	500.00	Per Person	\$	達度
Travel (Vehicle Rental)	1	\$	100.00	Each	\$	100.00
Material and Supplies	1	\$	3,000.00	Each	\$	3,000.00

Total = \$16,450.00

2.1.2 Cost Per Test (California)

Table A 5 Live-Load: Cost Per Test (California).

Item	Quantity	Cost	Unit		Total	
BDI Sub-Contract	0	\$ 24,000.00	Each	\$	-	
Traffic Control	2	\$ 2,000.00	Per Day	\$	4,000.00	
Truck Rental	2	\$ 600.00	Per Day	\$	2,400.00	
Equipment Rental	0	\$ 450.00	Per Day	\$	1=1	
Travel (per diem - 2 people)	2	\$ 200.00	Per Day	\$	800.00	
Travel (Airfare - 2 people)	2	\$ 500.00	Per Person	\$	1,000.00	
Travel (Vehicle Rental)	1	\$ 100.00	Each	\$	100.00	
Material and Supplies	0	\$ 3,000.00	Each	\$	-	

Total = \$8,300.00

2.2 **Dynamic Testing:**

Equipment*

Table A 6 dynamitc Testing Equipment.

Item	Quantity	Cost	Unit	Total
Datalogger				
Datalogger	0	\$ 9,000.00	Each	\$ (4)
Field Enclosure	0	\$ 1,100.00	Each	\$ -
14/28 Input Module (Multiplexer)	0	\$ 1,000.00	Each	\$ ()
Filtered Analog Input Module (Antialias)	0	\$ 3,300.00	Each	\$ •
Excitation Module	0	\$ 1,100.00	Each	\$ (2)
2G Compact Memory Card	0	\$ 200.00	Each	\$ -
Shaker				
Long Stroke Shaker	0	\$ 7,800.00	Each	\$ -
Power Amplifier	0	\$ 5,800.00	Each	\$ 1 /1 /4
System Cable	0	\$ 400.00	Each	\$ 421
Reaction Mass Assembly	0	\$ 4,000.00	Each	\$ 1.75
Instrum entation				
Velocity Transducer	0	\$ 450.00	Each	\$
Cable 150' (2)	0	\$ 2.00	Per Foot	\$ (2)
Cable 300' (2)	0	\$ 2.00	Per Foot	\$ -
Cable 450' (2)	0	\$ 2.00	Per Foot	\$ 121
Accelerometer	0	\$ 950.00	Each	\$ (#)
Cable 300' (2)	0	\$ 2.00	Per Foot	\$ (10)
Mounting Base	0	\$ 50.00	Each	\$
		_	Total =	\$ _

2.2.1 Cost Per Test (Utah)

Table A 7 Dynamic Testing: Cost Per Test (Utah).

Item	Item Quantity Cost		Unit	Total		
Traffic Control	0	\$	2,000.00	Per Day	\$	살1
Equipment Rental	0	\$	450.00	Per Day	\$	2 0
Travel (per diem - 4 people)	0	\$	200.00	Per Day	\$	12 W
Travel (Airfare - 4 people)	0	\$	500.00	Per Person	\$	20
Travel (Vehicle Rental)	0	\$	100.00	Each	\$	-3
Material and Supplies	0	\$	4,000.00	Each	\$	= 0.

Total = \$ -

2.2.2 Cost Per Test (California)

Table A 8 Dynamic Testiing: cost Per Test (California).

Cost Per Test

Item	Quantity	Quantity		Unit	Total	
Traffic Control	3	\$	2,000.00	Per Day	\$	6,000.00
Equipment Rental	1	\$	450.00	Per Day	\$	1,350.00
Travel (per diem - 4 people)	3	\$	200.00	Per Day	\$	2,400.00
Travel (Airfare - 4 people)	4	\$	500.00	Per Person	\$	2,000.00
Travel (Vehicle Rental)	1	\$	100.00	Each	\$	100.00
Material and Supplies	1	\$	4,000.00	Each	\$	4,000.00

Total = \$15,850.00

2.2.3 Cost Per Test (Assist with Virginia Pilot Bridge)

Table A 9 Dynamic Testing: Cost Per test (Assistet With Birginia Pilot Bridge).

Ite m	Quantity	Cost	Unit	Total		
Traffic Control	0	\$ 2,000.00	Per Day	\$	29	
Equipment Rental	1	\$ 300.00	Per Day	\$	900.00	
Travel (per diem - 3 people)	3	\$ 200.00	Per Day	\$	1,800.00	
Travel (Airfare - 3 people)	3	\$ 500.00	Per Person	\$	1,500.00	
Travel (Vehicle Rental)	1	\$ 200.00	Each	\$	200.00	
Material and Supplies	1	\$ 2,000.00	Each	\$	2,000.00	

Total = \$6,400.00

2.3 Deck Testing:

Equipment*

Table A 10 Deck Testing: Equipment.

Item	Quantity	Quantity		Unit		Total
Titrator	1	\$	7,300.00	Each	\$	7,300.00
Specific Ion Probe	2	\$	700.00	Each	\$	1,400.00
Titrating Supplies	2	\$	300.00	Each	\$	600.00
Fabrication of Sample Collector	2	\$	200.00	Each	\$	400.00
Resistivity Meter	2	\$	6,000.00	Each	\$	12,000.00
Cover Meter	2	\$	3,000.00	Each	\$	6,000.00
Gecor 6	1	\$	20,000.00	Each	\$	20,000.00
Potential Survey Kit	2	\$	6,600.00	Each	\$	13,200.00
3LP Device	2	\$	3,500.00	Each	\$	7,000.00

Grand Total = \$ 67,900.00

2.3.1 Cost Per Bridge (Utah)

Table A 11 Deck Testing: Cost Per Bridge (Utah).

Item	tem Quantity Cost		Unit	Total		
Traffic Control	3	\$	2,000.00	Per Day	\$	6,000.00
Travel (per diem - 7 people)	3	\$	200.00	Per Day/Person	\$	4,200.00
Travel (Airfare - 7 people)	0	\$	500.00	Per Person	\$	1 7 7
Travel (Vehicle Rental)	2	\$	100.00	Each	\$	200.00
Material and Supplies	1	\$	6,000.00	Each	\$	6,000.00

Grand Total = \$ 16,400.00

2.3.2 Cost Per Bridge (California)

Table A 12Deck Testing: Cost Per Bridge (California).

Item	Quantity	3	Cost	Unit	Total
Traffic Control	3	\$	2,000.00	Per Day	\$ 6,000.00
Travel (per diem - 7 people)	3	\$	200.00	Per Day/Person	\$ 4,200.00
Travel (Airfare - 7 people)	7	\$	500.00	Per Person	\$ 3,500.00
Travel (Vehicle Rental)	1	\$	100.00	Each	\$ 100.00
Material and Supplies	1	\$	6,000.00	Each	\$ 6,000.00
33					

Grand Total = \$ 19,800.00

2.4 Long-Term Monitoring:

2.4.1 Cost Per Bridge (Utah)

Equipment*

Table A 13 Long-Term Monitoring: Cost Per Bridge (Utah).

Item	Quantity	Quantity Cost				Total	
Datalogger							
Datalogger	1	\$	4,200.00	Each	\$	4,200.00	
1G Compact Flash Memory Card	1	\$	140.00	Each	\$	140.00	
Anti-Alias Module	3	\$	420.00	Each	\$	1,260.00	
Cabling/Connectors AntiAlias	3	\$	30.00	Each	\$	90.00	
Multiplexer	2	\$	600.00	Each	\$	1,200.00	
Cabling/Connectors for Multiplexer	2	\$	30.00	Each	\$	60.00	
4-Channel Module (communicate with chloride		•	(00.00	T- d	•	600.00	
sensors and WIM)	1	\$	600.00	Eacn	\$	600.00	
Weather Resistant Enclosure and Foundation	1	\$	1,000.00	Each	\$	1,000.00	
Traffic Camera							
Streaming Video	1	\$	3,000.00	Each	\$	3,000.00	
Mounting/Connector Equipment	I	\$	700.00	Each	\$	700.00	
Infrared Illuminator	1	\$	1,200.00	Each	\$	1,200.00	
Software Package	1	\$	600.00	Each	\$	600.00	
Power and Communication Cable/Conduit	750	\$	1.50	Per Foot	\$	1,125.00	
Tower/Mounting Pole	1	\$	4,500.00	Each	\$	4,500.00	
Weather Station							
Wind Speed/Direction	1	\$	1,000.00	Each	\$	1,000.00	
Temperature/Relative Humidity	1	\$	400.00	Each	\$	400.00	
Shield for Temp/RH	I	\$	175.00	Each	\$	175.00	
Pyranometer (Radiation)	1	\$	360.00	Each	\$	360.00	
Pyanometer Install Equip.	1	\$	250.00	Each	\$	250.00	
Heated Precipitation Gage	1	\$	1,500.00	Each	\$	1,500.00	
Precipitation Leveling Base Mount	1	\$	250.00	Each	\$	250.00	
Use Mounting Pole for Traffic Camera		\$	=	Each	\$	=	
Vibrating Wire							
Sensor	4	\$	250.00	Each	\$	1,000.00	
Cable and Conduit	400	\$	1.50	Per Foot	\$	600.00	
Mounting Jig	1	\$	110.00	Each	\$	110.00	
Gauge Cover Plate	4	\$	35.00	Each	\$	140.00	
Cover Plate Jig	1	\$	30.00	Each	\$	30.00	
Gauge Protection	1	\$	100.00	Each	\$	100.00	

Foil Strain Gauges				
Sensor	10	\$ 100.00	Each	\$ 1,000.00
Cable and Conduit	2	\$ 500.00	Per 1000 ft	\$ 1,000.00
Mounting K it	1	\$ 100.00	Each	\$ 100.00
Gauge Protection	10	\$ 50.00	Each	\$ 500.00
Accelerometer				
Sensor	2	\$ 1,200.00	Each Axis	\$ 2,400.00
Cable and Conduit	300	\$ 2.00	Per Foot	\$ 600.00
Mounting Base	3	\$ 150.00	Each	\$ 450.00
Mounting Adaptor	1	\$ 130.00	Each	\$ 130.00
Chloride Sensor (Hockey Puck)				
Sensor	2	\$ 5,000.00	Each	\$ 10,000.00
Cable and Conduit	100	\$ 2.00	Per Foot	\$ 200.00
IRS21 Interface	2	\$ 700.00	Each	\$ 1,400.00
IRS21 Module	2	\$ 1,000.00	Each	\$ 2,000.00
Installation		\$ 5,000.00	Each	\$ 5,000.00
Tilt Meter				
Electromagnectic	2	\$ 600.00	Each	\$ 1,200.00
Cable and Conduit	300	\$ 1.00	Per Foot	\$ 300.00
Mounting	2	\$ 100.00	Each	\$ 200.00
Thermocouple				
Sensor	1	\$ 650.00	Per 1000 ft	\$ 650.00
Conduit	500	\$ 0.75	Per Foot	\$ 375.00
Mounting	1	\$ 200.00	Each	\$ 200.00

Equipment = \$ 53,295.00

Installation
Table A 14 Long-Terming Monitoring: (Installation).

Item	Quantity	Cost		Unit	Total		
Installation							
Traffic Control	3	\$	2,000.00	Per Day	\$	6,000.00	
Equipment Rental (High lift, Scaffolding, etc.)	1	\$	450.00	Per Day	\$	1,350.00	
Travel (per diem - 4 people)	3	\$	200.00	Per Day	\$	2,400.00	
Travel (Airfare - 4 people)	0	\$	500.00	Per Person	\$	_	
Travel (Vehicle Rental)	1	\$	100.00	Each	\$	100.00	
Permits and Connection Fee	1	\$	1,000.00	Each	\$	1,000.00	
Material and Supplies (Power Box, Conduit, etc.)	Î	\$	4,000.00	Each	\$	4,000.00	

Installation Costs = \$ 14,850.00

Total Cost of Monitoring Utah Pilot Bridge = \$68,145.00

i.

Cost Per Bridge (California)

To Be Determined Upon Selection of California Pilot Bridge

Equipment*

Installation

V. Service, Maintenance, and Replacement:

i. Annual Costs (Utah)

Table A 15 Annual Costs (Utah).

Item	Quantity	Cost	Unit		Total
Services					
AC Power	12	\$ 80.00	Per Month	\$	960.00
Communication/Internet	12	\$ 100.00	Per Month	\$	1,200.00
Maintenance	-207				
Maint. & Calibration Visit (per diem - 2 people)	3	\$ 200.00	Per Day	\$	1,200.00
Maint. & Calibration Visit (Airfare - 2 people)	2	\$ 500.00	Per Person	\$	1,000.00
Maint. & Calibration Visit (Vehicle Rental)	1	\$ 100.00	Each	\$	100.00
Datalogger Software Update	_ 1	\$ 500.00	Each	\$	500.00
Estimated Replacement Costs					
Chloride Instrument Replacement	1	\$ 18,600.00	Per 5 Years	\$	3,720.00
Instrument Replacement	1	\$ 3,000.00	Each	\$	3,000.00
				_	44 600 00

Total = \$ 11,680.00

i. Annual Costs (California)

Table A 16 Annual Costs (California).

Item	Quantity	38 (Cost	Unit		Total
Services	99					
AC Power	12	\$	80.00	Per Month	\$	960.00
Communication/Internet		\$	100.00	Per Month	\$	1,200.00
Maintenance						
Maint. & Calibration Visit (per diem - 2 people)	3	\$	200.00	Per Day	\$	1,200.00
Maint. & Calibration Visit (Airfare - 2 people)	2	\$	500.00	Per Person	\$	1,000.00
Maint. & Calibration Visit (Vehicle Rental)	1	\$	100.00	Each	\$	100.00
Datalogger Software Update	_ 1	\$	500.00	Each	\$	500.00
Estimated Replacement Costs	<u></u>					
Instrument Replacement	1	\$	3,000.00	Each	\$	3,000.00
	· ·			T 4 1	0	7.000.00

Total = \$ 7,960.00

Appendix E: Data Acquisition Code

'Created by Short Cut (2.8), modified in CRBasic Feb15,2010

'Modified Feb 23,2010 MGA.

'Changes include;

'Subcan measurement rate = 20 milliseconds

'Main scan rate = 2 seconds.

'Flag 6 Zeros offset of tiltmeter #1

'Flag 7 Zeros offset of tiltmeter #2

'Flag 8 Zeros offset of foil strain gages.

'verified SDI12 command returns both Channel 1 and Channel 2 Vibrating Wire sensors on AVW200

' Verfied Results from SDI-12 Option "M" are in this order:

'Results(1) = Vibrating wire frequency in HERTZ channel #1

'Results(2) = Thermistor Resistance in OHMS channel #1

'Results(3) = Vibrating wire milliVolt RMS amplitued channel #1

'Results(4) = Vibrating wire frequency in HERTZ channel #2

'Results(5) = Thermistor Resistance in OHMS channel #2

'Results(6) = Vibrating wire milliVolt RMS amplitued channel #2

'Converted thermistor resistance in Ohms to DegressC and DegreesF

'Bonded foil gages are being measured every 20 milliseconds 'Subscan rate = 20 milliseconds

'Verified subscan operation so that 100 subscan measurements are made

' for every 2 second main scan interval.

'Declare Variables and Units

Public BattV

Public WS mph

Public WindDir

Public AirTF

Public RH

Public SlrW

Public SlrMJ

Public Analog

Public Opn_col

Tiltmeter variables and offset zeroing variables

Dim BB

Const Num_tiltTherm =4

Public Therm_tilt(Num_tiltTherm)

Public DegC_Tilt(Num_tiltTherm)

Public Geo_Tilt1

Public Geo Tilt2

Public Geo Tilt3

Public Geo Tilt4

Const Vofset1=0.07988 'Assign default offest prior to zeroing the first time.

using the standard Geokon Polynomial coefficients.

Public tiltOfst 1 Public Vcalreps1 Const Vofset2=0.07988 Public tiltOfst 2 Const Vofset3=0.07988 Public tiltOfst 3 Const Vofset4=0.07988 Public tiltOfst 4 Public Vcalreps2 Public FlagMode4 Public FlagMode5 Public FlagMode6 'Use Flag 6 to zero Tiltmeter 1 Public FlagMode7 'Use Flag 7 to zero Tiltmeter 2 Public VcalIdx1 'variable for the tiltmeter calibration index. Public VcalIdx2 Public Flag(8) As Boolean 'Vibrating wire temperature coeffecients Const A = 1.4051e-3Const B = 2.369e-4Const C = 1.019e-7Dim LnR1 Dim LnR2 'Copy the following Public variables when creating a new code. Const BGF1 = 2.1' gauge factor for strain gage block Const BCODE1 = -4gauge code for full bridge strain Check for wrong polarity Const Brep1 = 6' set equal to number of strain gages. Public FieldcalAvgs 'Change in real time public table for the number of readings to derive the average value. Public CalFileLoaded As Boolean Public GBBLK1(Brep1) Public GBBlk1Raw(BREP1) Const Boset 1 = 0'Default offset of zero (0) for strain gages. Public BKnownVar1(Brep1) Public BcalMode1

Fublic Bealwiodel

Public Bcalreps1(Brep1)

Public BBLK1MV_V(Brep1)

Public BBLK1(Brep1)

Public BBLK1zeromv(Brep1)

Public CalStartIdx

Public K

Public K2

Const Size1 = 512

Const Size2 = Size1*2 'make large enough for imaginary numbers.

Public Velocity1(Size2)

Public Velocity2(Size2)

Public Velocity3(Size2)

Const VelCalFactor1=1

Const VelCalFactor2=1

Const VelCalFactor3=1

Thermocouple measurements

Public PanelTemp

Public AA

Const Num_TC=6 'Set up loop size

Public Ref_temp

Public TC(Num_TC)

Public ScanFlg1x(8) As Boolean

Const CalStrainZero = 10

Public FlagMode8

Const StrainFullShunt = 43

Dim I

Alias BBLK1(1) = Strain_1

Alias BBLK1(2) = Strain 2

Alias $BBLK1(3) = Strain_3$

Alias BBLK1(4) = Strain_4

Alias $BBLK1(5) = Strain_5$

Alias $BBLK1(6) = Strain_6$

Public opencollector

Public rainstart

Public rainend

Public rainstartflag 'Vaisala DRD11a wiring

Public Duration 'Delta time in seconds from beginning of rainstart till rainend (calculated from seconds at beginning of the year).

'blk - gnd

'brn - gnd

'ylw - analog into the logger

'blu - analog into rain on/off

'a 1k ohm pull up resistor is connected to the same input channel as the blue wire and 5 volts to 'provide a source voltage for the open collector output of the sensor

'red - 12 volts

'grn - not used

'wht - not used

'When creating or modifying a program in Shortcut, be sure to include this Vaisala code into the complete CRB code. Don't forget the accompanying data table.

Public Results(6)

Public VW1strain 'Frequency in Hertz

Alias Results(2) = VW1Therm_Res

Alias Results(3)= VW1_mVRMS 'millivolt RMS signal amplitude

Public VW2strain 'Frequency in Hertz

Alias Results(5) = VW2Therm_Res 'Thermistor resistance in Ohms Alias Results(6) = VW2_mVRMS 'millivolt RMS signal amplitude.

Public VWTempC_1,VWTempC_2 Public VWTempF_1,VWTempF_2

Units BattV=Volts

Units WS_mph=miles/hour

Units WindDir=Degrees

Units AirTF=Deg F

Units RH=%

Units SlrW=W/m^2

Units SlrMJ=MJ/m^2

Units Analog=mV

Units Opn_col=mV

Units Geo tilt1=deg

Units Geo_tilt2=deg

Units Geo_tilt3=deg

Units Geo tilt4=deg

Units VW1strain=Hz

Units VW1Therm_Res=Ohms

Units VW2strain=Hz

Units VW2Therm_res=Ohms

Units Duration = Seconds

'Define Data Tables

DataTable(Table1,True,-1)

DataInterval(0,15,Min,10)

Average(1,WS_mph,FP2,False)

```
WindVector (1, WS_mph, WindDir, FP2, False, 900, 0, 0)
      FieldNames("WS_mph_S_WVT,WindDir_D1_WVT,WindDir_SD1_WVT")
      Average(1,AirTF,FP2,False)
      Maximum(1,AirTF,FP2,False,False)
      Minimum(1,AirTF,FP2,False,False)
      Maximum(1,RH,FP2,False,False)
      Minimum(1,RH,FP2,False,False)
      Average(1,SlrW,FP2,False)
      Totalize(1,SlrMJ,IEEE4,False)
      Sample(1,Analog,FP2)
      Sample(1,Opn_col,FP2)
      Average(1,Geo_Tilt1,FP2,False)
      Maximum(1,Geo Tilt1,FP2,False,False)
      Minimum(1,Geo_Tilt1,FP2,False,False)
      Average(1,Geo Tilt2,FP2,False)
      Maximum(1,Geo_Tilt2,FP2,False,False)
      Minimum(1,Geo Tilt2,FP2,False,False)
      Average(1,Geo_Tilt3,FP2,False)
      Maximum(1,Geo_Tilt3,FP2,False,False)
      Minimum(1,Geo_Tilt3,FP2,False,False)
      Average(1,Geo_Tilt4,FP2,False)
      Maximum(1,Geo Tilt4,FP2,False,False)
      Minimum(1,Geo Tilt4,FP2,False,False)
      Sample(1,VW1strain,FP2)
      Sample(1,VW2strain,FP2)
      Sample(1,VWTempC_1,FP2)
      Sample(1,VWtempc 2,FP2)
 Sample(Num TC,TC(),FP2)
EndTable
DataTable(Table2,True,-1)
      DataInterval(0,1440,Min,10)
      Minimum(1,BattV,FP2,False,False)
EndTable
This is a data table for the Vaisala rain detector, it needs to be copied as well.
DataTable(start,1,360)
 Sample (1,rainstart,FP2)
EndTable
DataTable (end,True,360)
 Sample (1,rainend,FP2)
EndTable
DataTable(AMPPHA_3,1,100) 'FFT Table
```

```
FFT(Velocity2(K2),IEEE4,Size1,20, mSec,2)'amplitude & phase
 FFT(Velocity3(K2),IEEE4,Size1,20, mSec,2)'amplitude & phase
EndTable
DataTable(Dynamic,True,-1)
 Sample(brep1,BBLK1(),IEEE4)
                                 'dynamic table for fast repsonses of bonded strain gages and
tilt meters
 Sample(1,Geo_tilt1,FP2)
 Sample(1,Geo_tilt2,FP2)
 Sample(1,Geo_tilt3,FP2)
 Sample(1,Geo tilt4,FP2)
 Sample(1, Duration, IEEE4)
EndTable
 DataTable (histo,True,1000)
      DataInterval (0,2,Sec,10)
       Rainflow (Strain_1,IEEE4,False,1,10,-200,200,1,000)
  Rainflow (Strain_2,IEEE4,False,1,10,-200,200,1,000)
  Rainflow (Strain_3,IEEE4,False,1,10,-200,200,1,000)
  Rainflow (Strain 4,IEEE4,False,1,10,-200,200,1,000)
  Rainflow (Strain 5,IEEE4,False,1,10,-200,200,1,000)
  Rainflow (Strain_6,IEEE4,False,1,10,-200,200,1,000)
 EndTable
DataTable(CalHist,NewFieldCal,50)
 SampleFieldCal
EndTable
'Main Program DataLogger Measurements start below here and loop infinitely between
scan/nextscan.
Sequentialmode
BeginProg
      tiltOfst_1 = Vofset1 'assign default offset of 0 to tiltmeter1
 tiltOfst_2 = Vofset2 'assign default offset of 0 to tiltmeter2
      TiltOfst 3 = Vofset3
      TiltOfst_4 = Vofset4
      Vcalreps 1 = 1 'number of sensors per zeroing routine.
      Vcalreps2 = 1 'number of sensors per zeroing routine.
      For I = 1 To Brep1
                                                'Do the following to all of BBlk1
   GBBlk1(I) = BGF1
                                             'Assign default gauge factor (2) to GBBlk1
 Next I
                                      'Repeat above until finished
 For I = 1 To 8
```

FFT(Velocity1(K2),IEEE4,Size1,20,mSec,2)'amplitude & phase

```
ScanFlg1x(I) = True
Next I

For I = 1 To BREP1
GBBlk1Raw(I) = GBBlk1(I)
Next I

CalFileLoaded = false
CalFileLoaded = LoadFieldCal(1)
FieldCalAvgs = 1
CalStartIdx = 1
```

'Faster scan rate for dynamic measurements

'Code for Foil Strain Gauges, copy when creating a new program from shortcut. Scan(20,mSec,10,0)

BrFull(BBLK1MV_V(),Brep1,mv50,9,VX2,3,5000,False,True,0,1000,1,Boset1) 'Bonded Foil Strain start on Differential channel 9.

StrainCalc(BBLK1(),Brep1,BBLK1MV_V(),BBLK1zeromv(),BCODE1,GBBLK1(),0) 'Strain calculation

FieldCalStrain(StrainFullShunt,BBLK1(),1,GBBLK1(),0,BcalMode1,BKnownVar1(),CalStartId x,FieldcalAvgs,GBBlk1Raw(),0)

 $Field Cal Strain (Cal Strain Zero, BBLK1MV_V(), BCal Reps 1, 0, BBLK1 zeromv(), Flag Mode 8, 0, Cal Start Idx, Field cal Avgs, 0, BBLK1())$

'March 26,2010 Geokon Tilt meters measured dynamically for deflection, twist, ETC. VoltDiff (Geo_tilt1,1,mV5000,5,True,0,250,0.003631214,tiltOfst_1)' multiplier and offset based off calibration sheet and equation Y=MX+B

VoltDiff (Geo_tilt2,1,mV5000,6,True,0,250,0.003631214,tiltOfst_2)'Diff channel 6 VoltDiff (Geo_Tilt3,1,mV5000,7,True,0,250,0.003631214,tiltOfst_3)'Diff channel 7 VoltDiff (Geo_Tilt4,1,mV5000,8,True,0,250,0.003631214,tiltOfst_4)'Diff channel 8 PulseCount(WS_mph,1,1,1,1,0.2192,0)

'Velocity sensor 3 sensors filling an array defined as "size"

VoltDiff (Velocity1(I),3,mV5000,15,True,0,250,VelCalFactor1,0)'velocity on channel # 15. VoltDiff (Velocity2(I),3,mV5000,16,True,0,250,VelCalFactor1,0) VoltDiff (Velocity3(I),3,mV5000,17,True,0,250,VelCalFactor1,0)

```
If I = Size1 Then

K = SIZE1 + 1 'toggle buffers
```

```
End If
   If I = SIZE2 Then
     I = 0
                         'start all over
     K = 1
                          'toggle buffers
   End If
   I = I + 1 'increnment I
   If K2 <> K Then
                      'if buffers are full.
 'If Flag(7)= True Then 'remove flag control
 CallTable AMPPHA 3
                              'do amplitude & phase on k2 buffers
 K2 = K
 EndIf
  CallTable Histo
   CallTable Dynamic
       NextScan
       SlowSequence
       'Main body of program making environmental measurements and vibrating wire
measurements
       Scan(1,Sec,1,0)
                         'Flag 4 zeroing control for Tiltmeter # 1.
       If Flag(4) Then
     If ScanFlg1x(4) Then
       VcalIdx1 = 1 'start field call at #1
       FlagMode4 = 1
       ScanFlg1x(4) = False
     EndIf
     If (FlagMode4 \le 0) OR (FlagMode4 = 6) Then Flag(4) = 0
   Else
     ScanFlg1x(4) = True
   EndIf
                        'Flag 5 zeroing control for Tiltmeter # 2.
       If Flag(5) Then
     If ScanFlg1x(5) Then
       VcalIdx1 = 1 'start field call at #1
       FlagMode5 = 1
       ScanFlg1x(5) = False
     If (FlagMode5 \leq 0) OR (FlagMode5 = 6) Then Flag(5) = 0
     ScanFlg1x(5) = True
   EndIf
       If Flag(6) Then
                        'Flag 6 zeroing control for Tiltmeter # 3.
     If ScanFlg1x(6) Then
```

```
VcalIdx1 = 1 'start field call at #1
      FlagMode6 = 1
      ScanFlg1x(6) = False
     EndIf
     If (FlagMode6 \leq 0) OR (FlagMode6 = 6) Then Flag(6) = 0
   Else
     ScanFlg1x(6) = True
   EndIf
                       'Flag 7 zeroing control for Tiltmeter # 4.
      If Flag(7) Then
     If ScanFlg1x(7) Then
      VcalIdx2 = 1 'start field call at #1
      FlagMode7 = 1
      ScanFlg1x(7) = False
     If (FlagMode7 \leq 0) OR (FlagMode7 = 6) Then Flag(7) = 0
   Else
     ScanFlg1x(7) = True
   EndIf
             If Flag(8) Then
                              'Flag 8 zeroing control for the Strain Gages.
     If ScanFlg1x(8) Then
      CalStartIdx = 1
      BCalReps1 = Brep1
      FlagMode8 = 1
      ScanFlg1x(8) = False
     EndIf
     If (FlagMode8 \leq 0) OR (FlagMode8 = 6) Then Flag(8) = 0
   Else
     ScanFlg1x(8) = True
   EndIf
              'Default Datalogger Battery Voltage measurement BattV
             Battery(BattV)
             PanelTemp (Ref_temp,250)
              '05103 Wind Speed & Direction Sensor measurements WS_mph and WindDir
             BrHalf(WindDir,1,mV5000,1,1,1,5000,True,0,_60Hz,355,0)
             If WindDir>=360 Then WindDir=0
             'HMP45C (6-wire, constant power) Temperature & Relative Humidity Sensor
measurements AirTF and RH
              VoltSE(AirTF,1,mV1000,2,0,0,_60Hz,0.18,-40)
             VoltSE(RH,1,mV1000,3,0,0,_60Hz,0.1,0)
             If RH>100 And RH<108 Then RH=100
             'LI200X Pyranometer measurements SlrMJ and SlrW
```

VoltDiff(SlrW,1,mV20,3,True,0,_60Hz,1,0) If SlrW<0 Then SlrW=0 SlrMJ=SlrW*0.0002 SlrW=SlrW*200 'Start of Vaisala Code 'Generic Single-Ended Voltage measurements Analog VoltSE(Analog,1,mV5000,4,True,0,_60Hz,1,0) 'Generic Single-Ended Voltage measurements Opn col VoltSE(Opn_col,1,mV5000,7,True,0,_60Hz,1,0) 'Generic 4-20 mA Input measurement memtilt1 This is another Vaisala Code that needs to be copied over. 'rain start time routine - rainstartflag has to equal 0 If Analog < 1500 AND rainstartflag=0 Then rainstart=start.timestamp(2,1) 'Option 2 = seconds into the current year. 1 = # of records back. rainstartflag=1 EndIf 'rain end time routine - rainstartflag has to equal 1 If rainstartflag=1 AND Analog>1500 Then rainend=end.timestamp(2,1)'Option 2 = seconds into the current year. 1 = # of records back. rainstartflag=0 EndIf Duration = Rainend-rainstart 'March 26,2010 Rieker tilt meters replaced with Geokon 6160 Mems type. 'Reiker 4-20 mA tilt meter measurement. Sensor spec's at +/-10 degrees. 'VoltDiff(memtilt1,1,mV5000,5,True,0, 60Hz,0.799546,tiltOfst 1) 'Multiplier was changed from 0.0125 to the current value according to manufacturer calibration 'Generic 4-20 mA Input measurement memtilt2 VoltDiff(memtilt2,1,mV5000,6,True,0,_60Hz,0.799538,tiltOfst_2) 'Multiplier was changed from 0.0125 to the current value according to manufacturer calibration 'offset zeroing for Tiltmeter #1 Uses flag 4 FieldCal (0,Geo_Tilt1,Vcalreps1,0,tiltOfst_1,FlagMode4,0,VcalIdx1,FieldcalAvgs) 'offset zeroing for Tiltmeter #2 Uses flag 5 FieldCal (0,Geo Tilt2,Vcalreps2,0,tiltOfst 2,FlagMode5,0,VcalIdx2,FieldcalAvgs) 'offset zeroing for Tiltmeter #3 Uses flag 6

FieldCal (0,Geo Tilt3,Vcalreps1,0,tiltOfst 3,FlagMode6,0,VcalIdx1,FieldcalAvgs)

FieldCal (0,Geo_Tilt4,Vcalreps2,0,tiltOfst_4,FlagMode7,0,VcalIdx2,FieldcalAvgs)

'offset zeroing for Tiltmeter #4 Uses flag 7

```
'Generic SDI-12 Sensor measurements VWstrain1, VWtemp1,
VWstrain2, VWtemp2
             'NOTE: Returned Results from SDI-12 Option "M" are in this order:
             'Results(1) = Vibrating wire frequency in HERTZ channel #1
             'Results(2) = Thermistor Resistance in OHMS channel #1
             'Results(3) = Vibrating wire milliVolt RMS amplitued channel #1
             'Results(4) = Vibrating wire frequency in HERTZ channel #2
             'Results(5) = Thermistor Resistance in OHMS channel #2
             'Results(6) = Vibrating wire milliVolt RMS amplitued channel #2
            SDI12Recorder(Results(),4,1,"M!",1,0)'SDI-12 Physical address changed from 0
to Control port 4
                   'microstrain conversion
             VW1strain = Results(1)^2 *4.062e-3 'Geokon factor to convert frequency to
microstrain
             VW2strain = Results(4)^2 *4.062e-3 'Geokon factor to convert frequency to
microstrain
             Temperatre conversion to Degrees C and F
            LnR1 = LN(Results(2)) 'Get thermistor resistance (Ohms) from sensor 1.
            LnR2 = LN(Results(5)) 'Get thermistor resistance (Ohms) from sensor 2.
             VWTempC_1 = (1/(A+B*LnR1+C*(LnR1^3)))-273.2
             VWTempF 1 = VWTempC 1*1.8+32
             VWTempC 2 = (1/(A+B*LnR2+C*(LnR2^3)))-273.2
             VWTempF_2 = VWTempC_2*1.8+32
'AM16/32B
'Control port C8 = RES (Turns on the AM16/32B)
'Control Port C7 = CLK (advances or clocks the relays forward).
'Channel 20 Diff is the channel on the CR5000 for the measurements)
PortSet(8.1) Enable the AM1632B
  For AA = 1 To Num TC
                         'Num TC is constant for number of thermocouples)
        Delay(0.50,msec)
        PortSet(7,1)
        Delay(0.50,msec)
        PortSet(7,0)'Clock multiplexer
        TCDiff (TC(AA),1,mV20C,19,TypeT,Ref Temp,True,0,250,1.8,32)
        Next AA
      'Add Termistors from the Geokon Tilt meters
      For BB = 1 To Num tiltTherm
             Delay(0,50,msec)
        PortSet(7,1)
```

```
Delay(0,50,msec)
                                              PortSet(7,0)'Clock multiplexer
                                              BrHalf (Therm_tilt(BB),1,mV5000,39,Vx4,1,5000,True ,0,250,5,0)'need to verify
multiplier
'BrHalf3W (
                                                                           Therm Tilt,1,mV5000,1,Vx1,1,5000,True,0,250,10000,0)
                                        DegC_Tilt(bb) = 2412.6 - (3442.5 *Therm_tilt(bb)) + (1904.4 * (Therm_tilt(BB)^2) + (-1904.4 * (Therm_tilt(BB)^2)) + (-1904.4 * (Therm_tilt(BB)^2) + (-1904.4 * (Therm_tilt(BB)^2) + (-1904.4 * (Therm_tilt(BB)^2)) + (-1904.4 * (Therm_tilt(BB)^2) + (-1904.4 * (Therm_tilt(BB)^2)) + (-1904.4 * (Therm_tilt(BB)^2) + (-
435.97 * Therm tilt(BB)^3)
                                     ' DegC_Tilt(bb) = -104.78+(378.11*Therm_tilt(bb))+(-
611.59*Therm_tilt(bb)^2)+(544.27*Therm_tilt(bb)^3)+(-
240.91*Therm_tilt(bb)^4)+(43.089*Therm_tilt(BB)^5)
                                             Next BB
                                       ' Degreec_C_Old = 2412.6 - (3442.5 * Degreec_C_Old)+(1904.4 *
Degreec_C_Old^2)+(-435.97 * Degreec_C_Old^3)
            Degreec_COld = -104.78 + (378.11 * Degreec_COld) + (-104.78 + (378.11 * Degreec_COld)) + (-104.78 + (378.1
611.59*Degreec C Old^2)+(544.27*Degreec C Old^3)+(-
240.91*Degreec_C_Old^4)+(43.089*Degreec_C_Old^5)
                                    PortSet(8,0) 'Turn off the AM16/32B
                                                                          'Call Data Tables and Store Data
                                                                        CallTable(CalHist)
                                                                        CallTable(Table1)
                                                                        CallTable(Table2)
                                                                        CallTable(start)
                                          CallTable(end)
                                    NextScan
EndProg
```