MONITORING OF THE 4500 SOUTH POST-TENSIONED SPLICED GIRDER BRIDGE ON I-15

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ABSTRACT

The I-15 Northbound Overpass at 45th South Street in Salt Lake City has been instrumented with various instruments to monitor the bridge's performance over a period of five years. The instrumentation consists of 52 vibrating wire strain gages mounted internally on six girder segments comprising one complete girder (Girder A), segments of three other girders, and the parapet. Girder A has also been instrumented with eight load cells at the two ends of its four post-tensioned tendons. These instruments have been monitored for approximately two years, and readings indicate that the girders are behaving as expected. Information has been collected about the behavior of the bridge girders during erection, placement, tendon tensioning, and introduction to use. Time dependant losses have been calculated and compared to the actual measurements. In addition, a survey of deflections for Girder A is being conducted.

Keywords: Bridges, Diaphragms, Losses, Monitoring, Post-tensioning, Spliced Girders

INTRODUCTION

The Interstate 15 reconstruction in Salt Lake City, in preparation for the 2002 Olympic Winter Games, included 81 prestressed concrete I-girder bridges. For sixteen long span bridges, a segmental section of the new WSDOT deep girder[1] was used. This girder originated form the NU girder series[2] developed at the University of Nebraska. The I-15 Overpass at 4500 South is composed of two separate bridges, each consisting of eight post-tensioned (PT) spliced girders. Each girder has three segments with two diaphragm splices at approximately the third points. For the 4500 South Overpass, the W24PTMG section[1] was used that is 94.49 in. deep. The Overpass has a simple span of 200 feet with the middle segment of each girder spanning 82.6 feet and the two outer segments spanning 58.7 feet each. On top of the girders is a deck composed of precast concrete sections and a concrete topping surface.

Prior to casting the individual segments, the girders were instrumented with vibrating wire (VW) strain gages at various locations in December of 1999. Six girder segments were instrumented with a total of 42 VW gages. The parapet was also instrumented with ten VW strain gages. The east most girder (Girder A) was also instrumented with eight load cells, one on each end of its four post-tensioned tendons. The tendons were then tensioned and capped on the outer side of the load cell, thus allowing measurements to be taken of the actual losses in the tendons. This portion of the instrumentation was completed in April of 2000.

In addition to strain gage and load cell instrumentation, seven survey points were placed on the deck level along Girder A. The points were evenly spaced with the fourth point at the bridge midspan, one point above each support and two between the support point and the midpoint. These survey points were used to measure deck deflections beginning in April of 2000. The instrumentation will allow the investigators to monitor the tendon losses, deflections, rotation, shear, thermal effects, concrete creep and other properties of the concrete structure. The project is scheduled to have a five-year duration.

INSTRUMENTATION OF GIRDERS

On December 13, 1999, 21 VW gages were installed on the eastern-most girder of the bridge (Girder A). On December 18, 1999, three segments of a second girder (Girder B) were instrumented with 21 VW gages in a manner nearly identical to the first. Strain readings from the VW gages were taken prior to casting. Both girders were then cast in December of 1999 shortly after the instrumentation process. The girders were each cast in three separate segments at Basic Precast in Salt Lake City, with each girder having four PT tendon ducts as shown in Fig. 1. The sequence of events pertaining to the instrumentation, casting, and erection of the girders is shown in Table 1.

Fig. 1. Casting of Girder A

Table 1. Sequence of Events

DATE	EVENT
12/13/99	Strain Gage Placement Girder A
12/13/99	First Readings Taken Girder A
12/15/99	Cast Girder A
12/18/99	First Readings Taken of Cast Girder A
12/18/99	Strain Gage Placement Girder B
12/18/99	First Readings Taken Girder B
12/20/99	Cast Girder B
12/20/99	First Readings Taken of Cast Girder B
02/09/00	Girders Taken to Site and Set in Place
03/08/00	Splice Diaphragm placement
04/17/00 - 04/18/00	Deck Placement
04/27/00	P/T Tendons 1 thru 12
04/28/00	P/T Tendons 13 thru 25
04/27/00 - 04/28/00	Load Cells Placed & First Readings Taken
05/01/00	P/T Tendons 26 thru 32
05/04/00	Grout tendons
05/23/00	South End Diaphragm placement
06/03/00	North end Diaphragm placement
06/23/00	North and South Approach Slab Placement
06/29/00	First Deck Survey Readings Taken
07/28/00	East Bridge Barrier Placement
08/22/00	Initial Parapet Girder Readings Taken
11/07/00	West Bridge Barrier Placement
11/09/00	West Approach Slab Barrier Placement
12/17/00	Bridge Opened to Traffic

MATERIAL PROPERTIES

The material properties of the girders for design were as follows: concrete compressive strength at release, f'_{ci} = 5,500 psi; 28-day concrete compressive strength, f'_c = 7,500 psi. Each girder had four PT tendons with 31 low relaxation ½ in. diameter Grade 270 strands per tendon.

INSTALLATION OF VIBRATING WIRE STRAIN GAGES

The gages used to instrument the girders were model VCE-4200 by Geokon, Inc. The gages are composed of a 152 mm metal tube with two 19 mm diameter endplates. The VW gages convert frequency measurements to microstrain; they also give temperature readings, which allow the strain readings to be adjusted for temperature. The first step of the instrumentation process was to obtain initial strain readings of the gages for use as reference. The gages were then attached to the rebar of the girders in either a horizontal or vertical orientation as seen in Fig. 2. The method used to attach the gages is outlined in the Geokon VCE-4200 installation manual.

(a) (b)

Fig. 2. Typical Installation of VW Gages: (a) Horizontal VW gage, and (b) Vertical VW gage

The instrumented Girder A had all three segments placed adjacent to one another, thus allowing complete measurements from the eastern most girder, as shown in Fig. 3. For Girder B, the south section (G-B-1) was placed on Girder C, the center section (G-B-2) on Girder E, and the north section (G-B-3) on Girder F as shown in Fig. 3. The locations of the strain gages as well as their orientation for Girder A in each segment are shown in Fig. 4. Notation H means that the gage measures horizontal strain in the concrete, along the girder axis; notation V means that the gage measures vertical strain in the direction from top to bottom flange. Figure 2(a) shows a horizontal VW gage, and Fig. 2(b) a vertical VW gage.

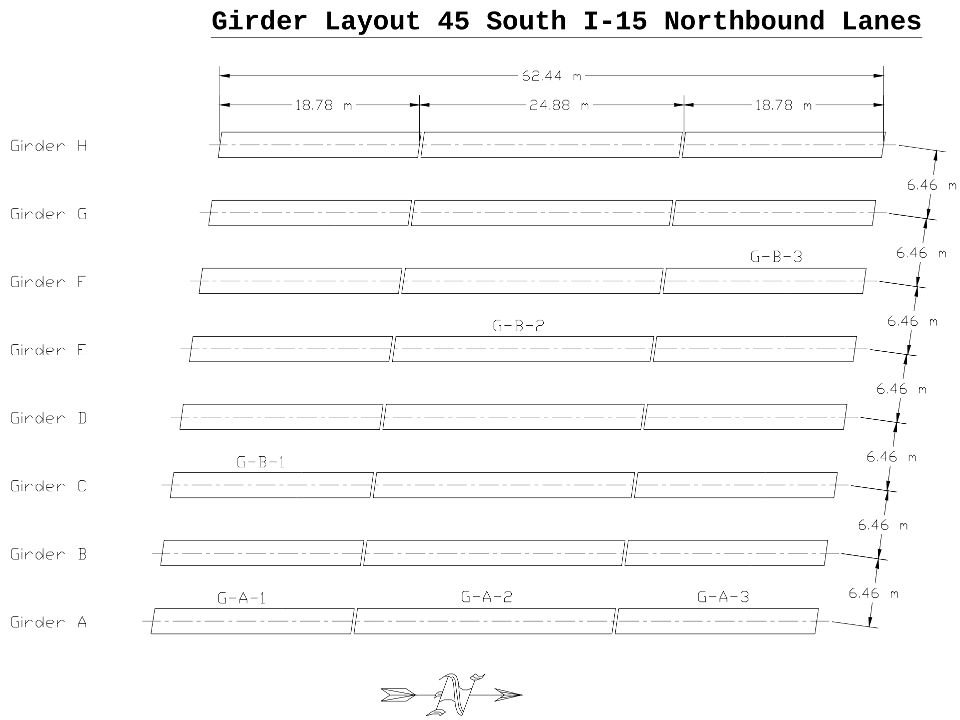

Fig. 3. Final Placement of Instrumented Girder Sections

INSTALLATION OF LOAD CELLS

Eight load cells were used in the study, custom manufactured by CTL, Inc., and installed on both ends of Girder A in the latter part of April, 2000. The load cells were numbered 1 through 4 from top to bottom on the north end of the girder, and 5 through 8 on the south end in the same manner, thus instrumenting every tendon at both ends. The metal bearing cap, which is normally placed at the face of the girder was placed on the outside of the load cell; the PT strands were then locked at the time of tensioning, which was from the north end of Girder A at load cells 1 through 4. Figure 5 shows load cells 1 through 4 during the construction process just after post-tensioning; the load cells were sealed and isolated from the concrete of the end diaphragms by encasing them in specially constructed tubes.

MEASURED DATA

Current readings from surveys of Girder A indicate that the deflected shape is a uniform parabola without discontinuities, with a maximum midspan deflection of 2.54 in. upwards. Readings from the load cells were taken on a regular basis during the last two years. Plots of the load cell data compared to the theoretical losses are shown in the next section.

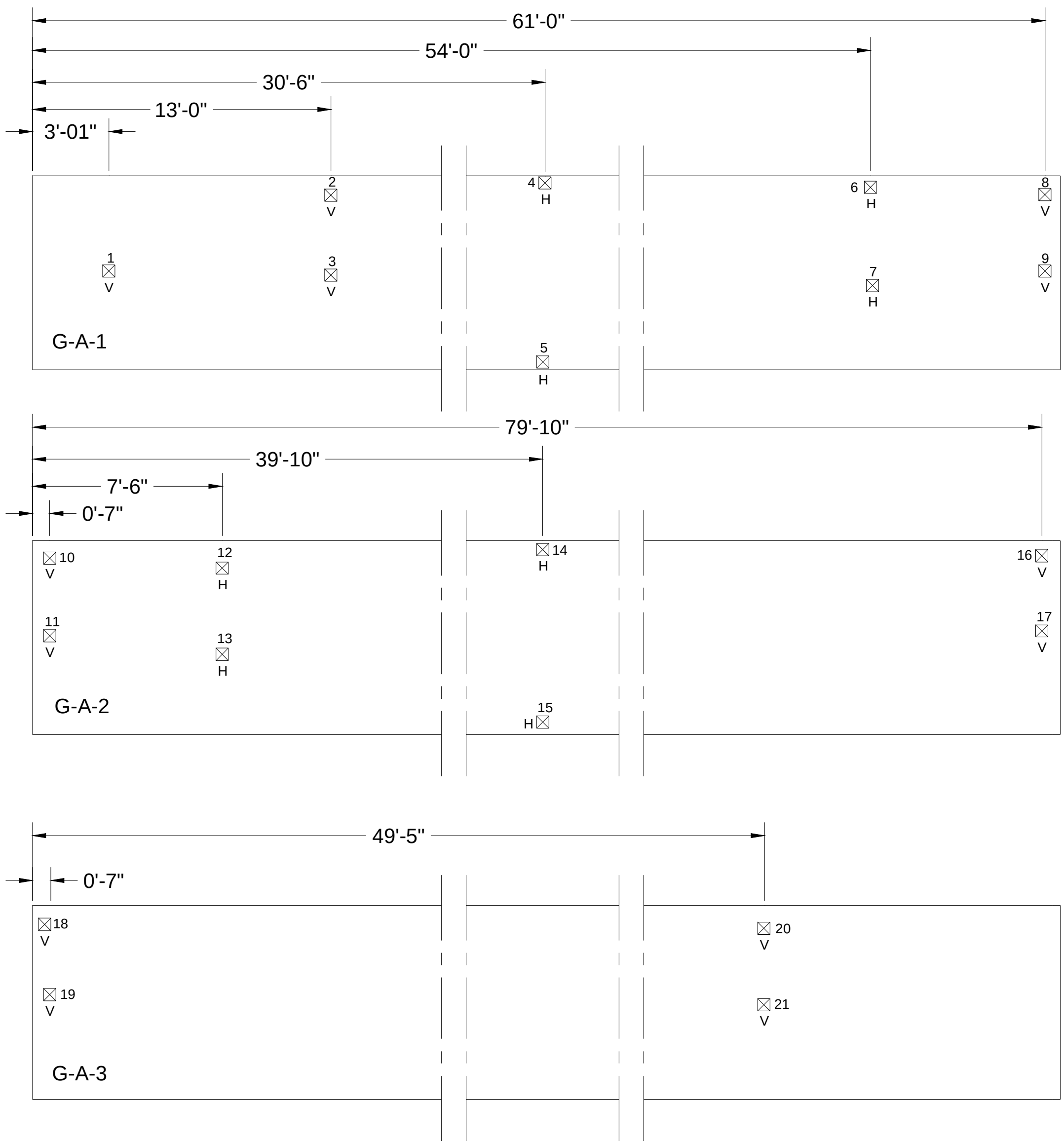

Fig. 4. VW Gage Locations and Orientations – Girder A

THEORETICAL LOSS CALCULATIONS

Time-dependent tendon losses were calculated in accordance with AASHTO LRFD Bridge Design Specifications[3] and standard procedures[4] for a period of five years. Time increments considered were initial losses, half-year, one year, two years, and five years. Losses considered were, seating loss, friction loss, elastic shortening, tendon relaxation, creep loss, and shrinkage loss. The first three mentioned losses were considered as time-dependent and

Fig. 5. Load Cells 1 thru 4 on the North End of Girder A after post-tensioning

are shown in Table 2 as load "At Seating". Creep losses were calculated as a lump sum loss and then 25% of the total applied at the first time increment, 50 % at the next, and so on. A summary of the estimated load remaining in the tendons after these losses at each of the above mentioned time periods and the percent total loss at the end of five years relative to the initial loading is given in Table 2.

The load cell values reported in Table 2 correspond to the load in the tendons at midspan. The numbering T1 through T4 is the same as that for the load cells themselves, with T1-C being the uppermost tendon and T4-C being the bottom tendon. Notation C refers to the fact that the value was calculated and not measured.

Table 2. Theoretical Load Remaining in Tendons due to Time Dependant Losses

	Jacking Force	At Seating	½ year	1 year	2 year	5 year	% Total Loss
T1-C (kips) =	960.00	836.40	776.35	766.32	757.58	749.04	22.0
T2-C (kips) =	960.00	857.30	796.40	786.30	777.50	768.86	19.9
T3-C (kips) =	960.00	878.27	816.48	806.31	797.42	788.69	17.8
T4-C (kips) =	960.00	899.28	836.56	826.31	817.35	808.52	15.8

For comparison of losses, the average of the measured load from the load cells at the two ends of a given tendon (average of load cells 1 and 5 for example) was plotted against the theoretical values of Table 2. One exception was load cell 8, which had not been functioning properly. In this instance, the values of load cell 4 only were used for comparison. Plots comparing actual load to calculated load are shown in Fig. 6 for all data recorded and in Fig. 7 for the first 200 days only. Load cell 4 has also given questionable data recently, which may be due to malfunctioning. It is observed that there is reasonable agreement between experimental data and the theoretical prediction of PT tendon losses for Girder A.

STRAIN GAGE READINGS

Strain readings were taken twice a week in the last two weeks of December 1999, the month of January, and the first week of February. At this point readings were taken on a weekly basis until the deck was placed in April of 2000. From that point forward, readings were taken on a monthly basis with some exceptions when the gages were not accessible or when only a portion of the gages was accessible.

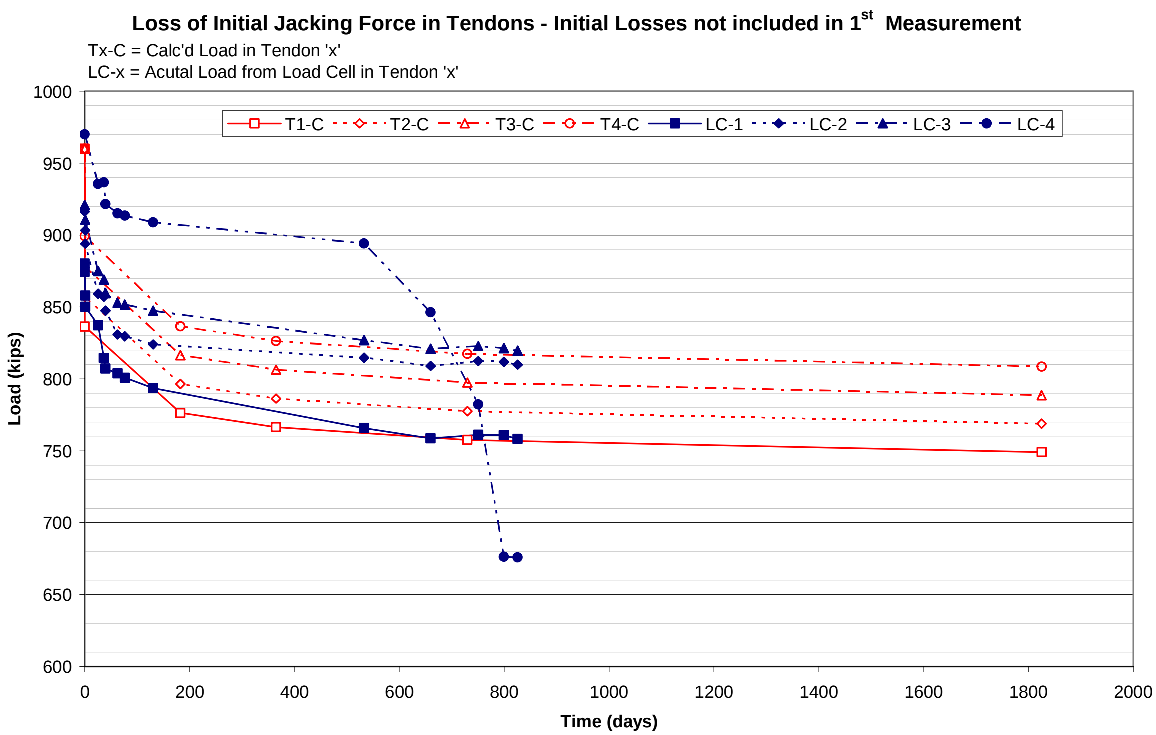

Fig. 6. Calculated Load in Tendons Compared to Actual Load from Load Cell

Vertical VW Strain Gage Readings

Vertical gages were installed to measure tensile and compressive strains in the concrete perpendicular to the girder axis in the plane of the girder web. The strain records including all readings taken to date for several of the vertically oriented VW gages shown in Fig. 4, are given in Figs. 8–11 and are discussed in what follows.

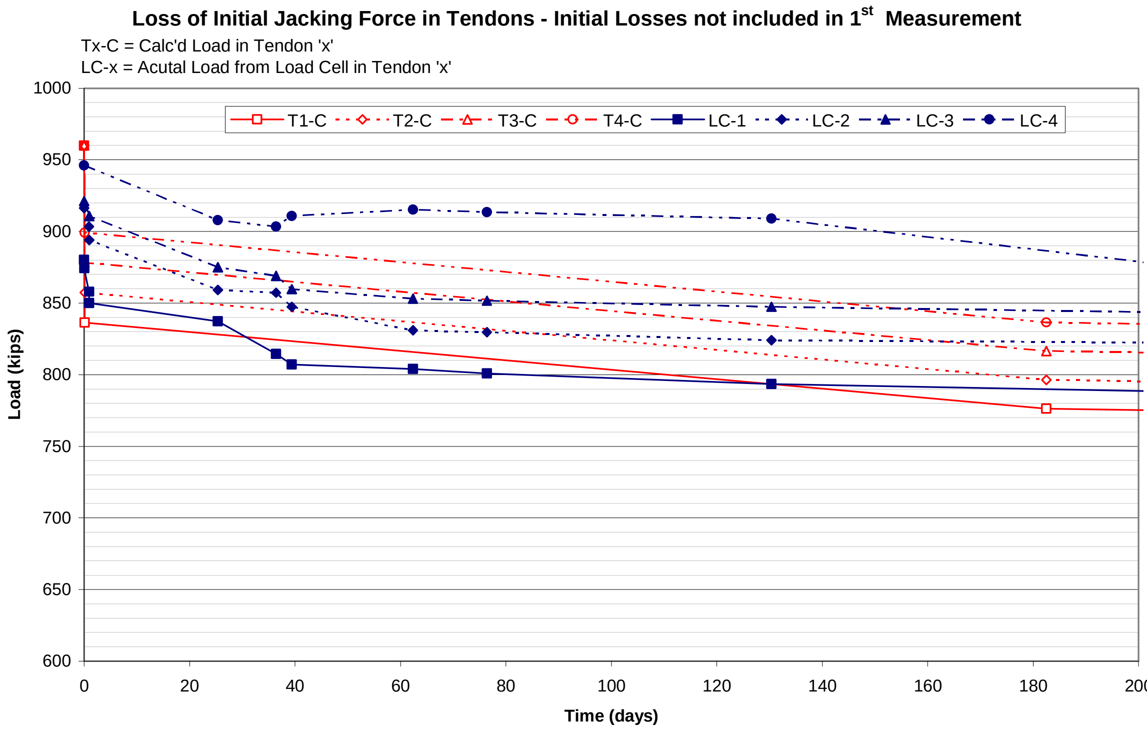

Fig. 7. Calculated Load in Tendons & Actual Load from Load Cell: First 200 Days

Figure 8 shows the uniformity of the measured strains and seasonal variation of the readings throughout the span for Girder A; more detailed views of these graphs are given in Figs. 9–11. The strain readings for Girder A are more closely grouped than those of the segments of Girder B, which are not shown for brevity. The diaphragm splices are performing well in their task of holding the precast girder segments together between the various girders of the bridge, as shown by the pairs of gages G8 with G10 and G9 with G11. This uniformity and consistency among the various girders would also indicate a lack of differential rotation at the diaphragm splices.

Figure 9 shows that at the time of post-tensioning (April 27-28, 2000) all gages experienced a negative jump in strain, indicating an increase in tensile strains. At this early stage, lack of strain uniformity is noticed at the diaphragm splices. In Fig. 11, gages G16 and G18, which are directly across the diaphragm at the top flange, show a much larger negative strain reading than gages G17 and G19, which are located below them near the girder centerline. Gages G16 and G18 drop well below their initial values, indicating that tensile stresses occur near the outer fiber as expected, while gages G17 and G19 remain above their initial values, indicating continued but considerably lower compressive stresses. These effects are controlled by the placement of the end diaphragms, which took place on May 23, 2000, for the south end diaphragm and June 03, 2000, for the north end diaphragm. After placement of the end diaphragms, the strain has a positive trend indicating that the girders reach their superimposed dead load condition.

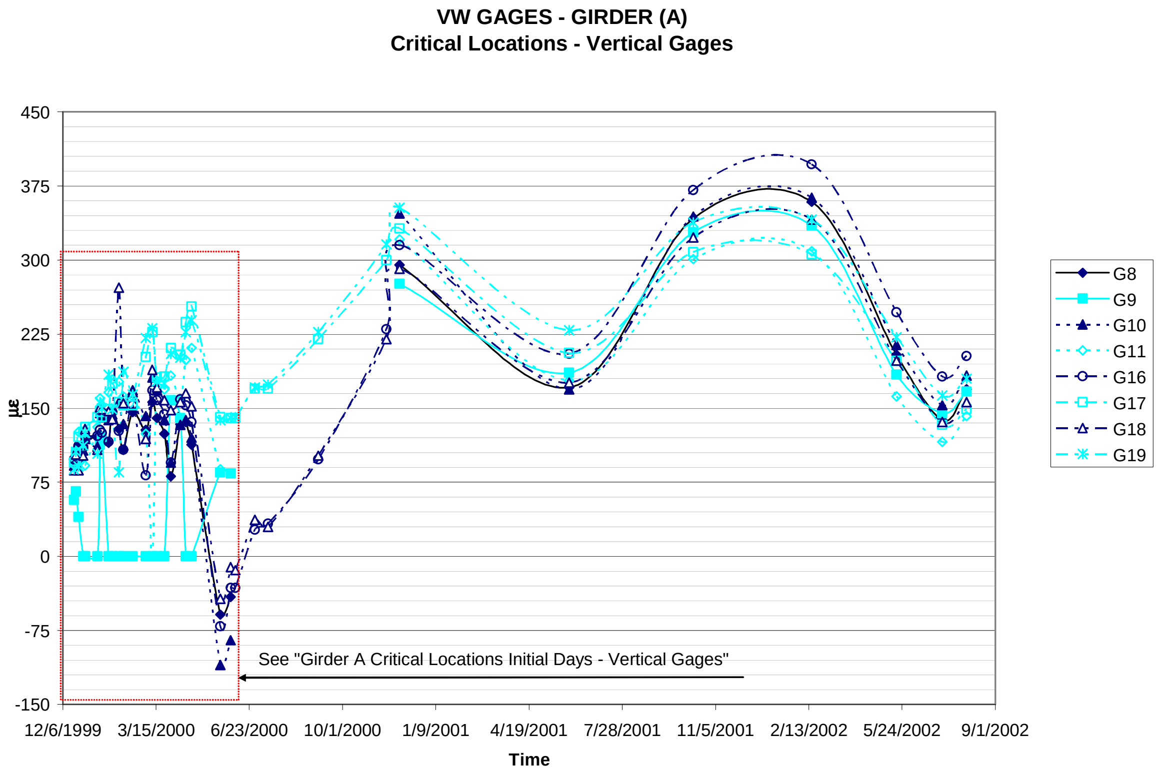

Fig. 8. Strain Readings of Selected Vertical VW Gages – Girder A

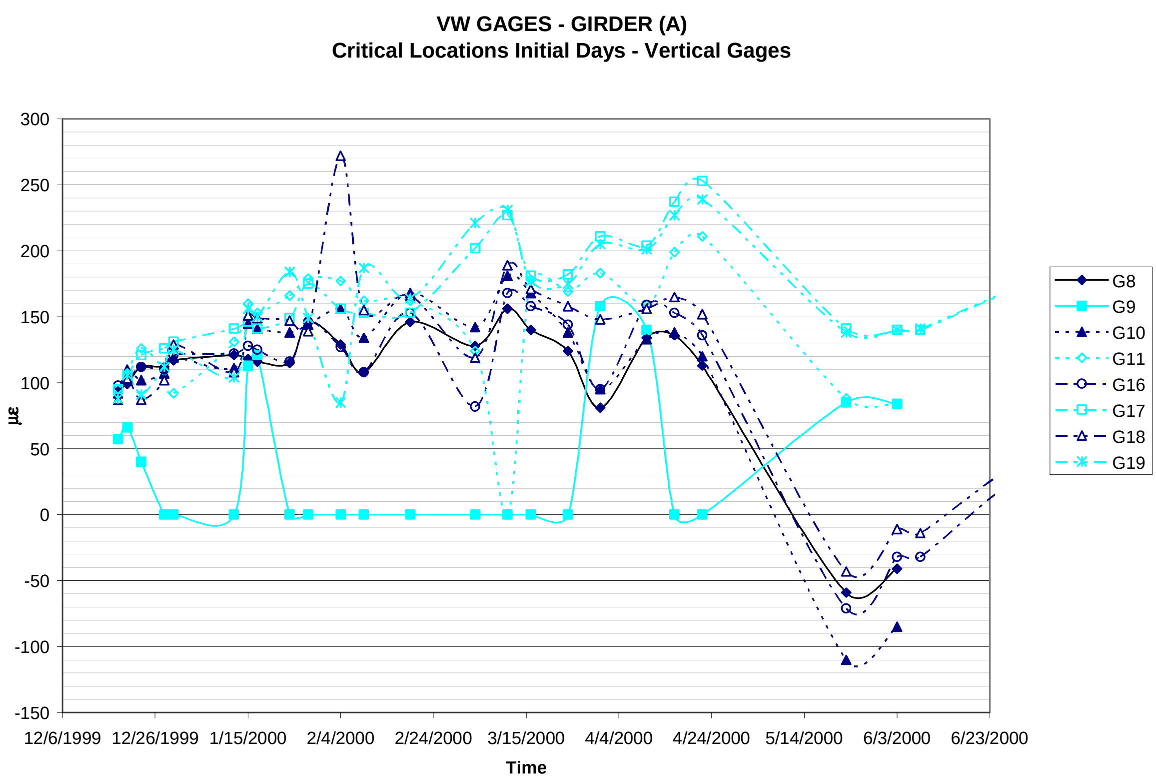

Fig. 9. Strain Readings of Selected Vertical VW Gages During Initial Days – Girder A

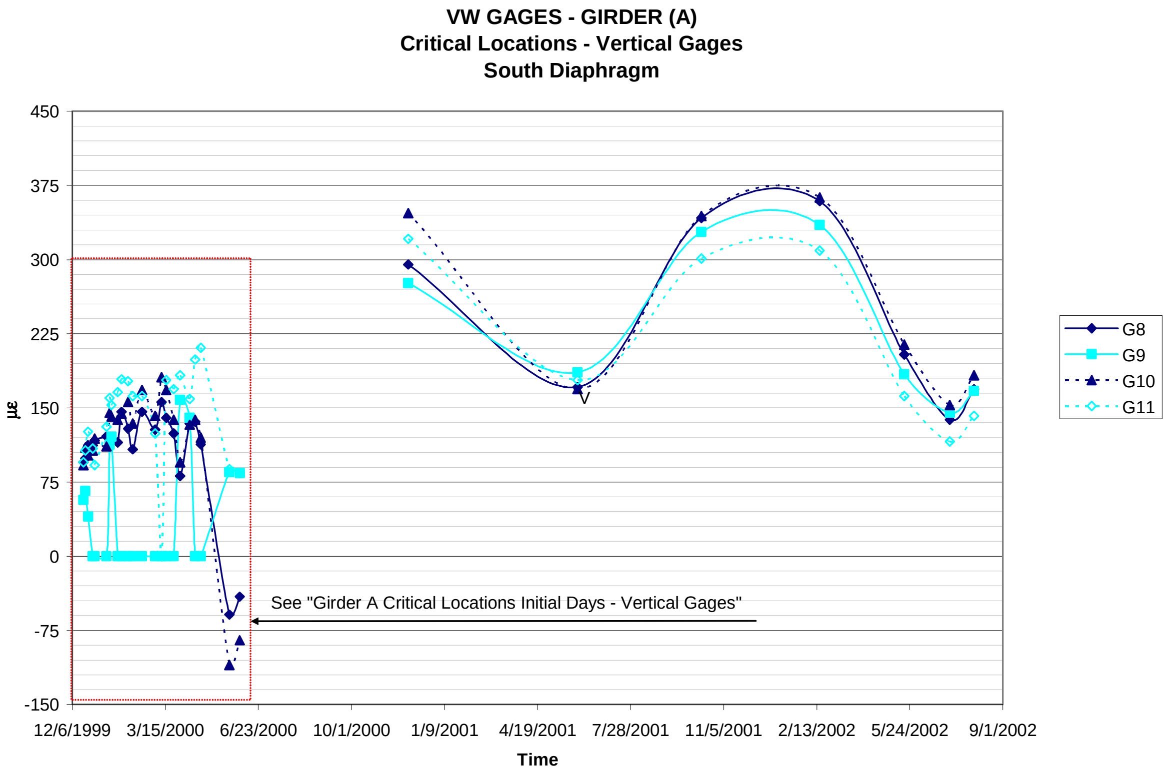

Fig. 10. Strain Readings of South Diaphragm Vertical VW Gages – Girder A

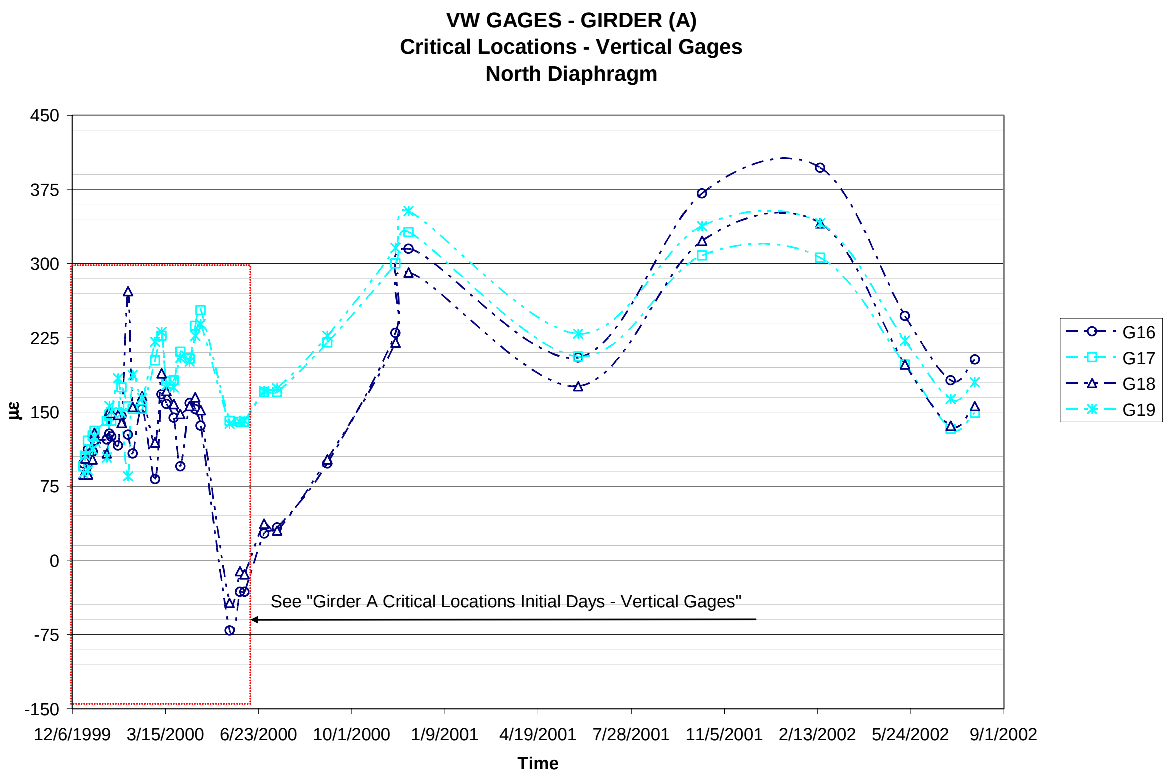

Fig. 11. Strain Readings of North Diaphragm Vertical VW Gages– Girder A

On December 17, 2000, the northbound overpass was opened to traffic. At this point the loading on the bridge was changed due to the presence of live load from automobiles and trucks on the bridge. The data for the north or south diaphragms at this time, show that a separation occurs between the readings of VW gages at similar locations on opposite sides of the diaphragms. In Fig. 11, gages G16 and G17 that are at the top flange on opposite sides of the north splice diaphragm, give a differential reading of 30 microstrain. This behavior is also seen in Fig. 10, for gages G8 and G10, which are placed at similar locations at the south splice diaphragm, with a differential reading of 50 microstrain. This behavior is due to the added live load from traffic acting across the diaphragm, which resists this action thus inducing a small differential strain. In both cases, the compressive strains at the gages near the upper flange are greater for those gages closer to midspan (gages G10 and G16 in the middle girder segment G-A-2) than for those gages on the two end girder segments G-A-1 and G-A-3 (gages G8 and G18). The gages near the centerline experience the opposite effect. The gages closer to midspan (gages G11 and G17) have smaller compressive strains than those gages located on the end girder segments (gages G9 and G19). These gages are located below the neutral axis of the girder/slab unit and therefore experience the opposite strain.

The non-uniformity of strain readings during initial days before April, 2000, as seen in Fig. 9, is considered to be due largely to construction processes such as placement of the precast deck sections, unbalanced loading due to use of temporary equipment and materials, and possible adjustment or modification of the temporary supports at the splice points.

Horizontal VW Strain Gage Readings

Along with the vertically oriented VW strain gages, horizontally oriented VW strain gages were installed in the girder as shown in Fig. 2(a), and Fig. 4. The purpose of the horizontally oriented VW gages was to measure compression and tensile strains in the concrete in a direction parallel to the axis of the girder; consequently most of these gages were placed at or near the top and bottom flanges of the girder. Measurements from these gages for Girder A are shown in Figs. 12 and 13.

Inspection of the gage readings in Fig. 13 shows that, just prior to post-tensioning (April 27-28, 2000), gages G4 and G14, which are located at the top flange of Girder A in the end segment G-A-1 and middle segment G-A-2 respectively, show larger compressive strains than their counterparts at the bottom flange, gages G5 and G15. This is consistent with the behavior of a simply supported beam under gravity loads. Further, it is seen that the compressive strain is larger at the top of the girder at midspan than at the end segment, as would be expected. This is also the case with the tensile strains at the bottom flange – the midspan shows larger tensile strain (or smaller net compressive strain) than the end segment. It should be noted that the girder segments were placed on temporary supports during erection until after post-tensioning; the girder segments were constructed with some pre-tensioning strands for dead load moment during transportation and erection and therefore never experience net tensile stresses in any of the readings during the erection stages.

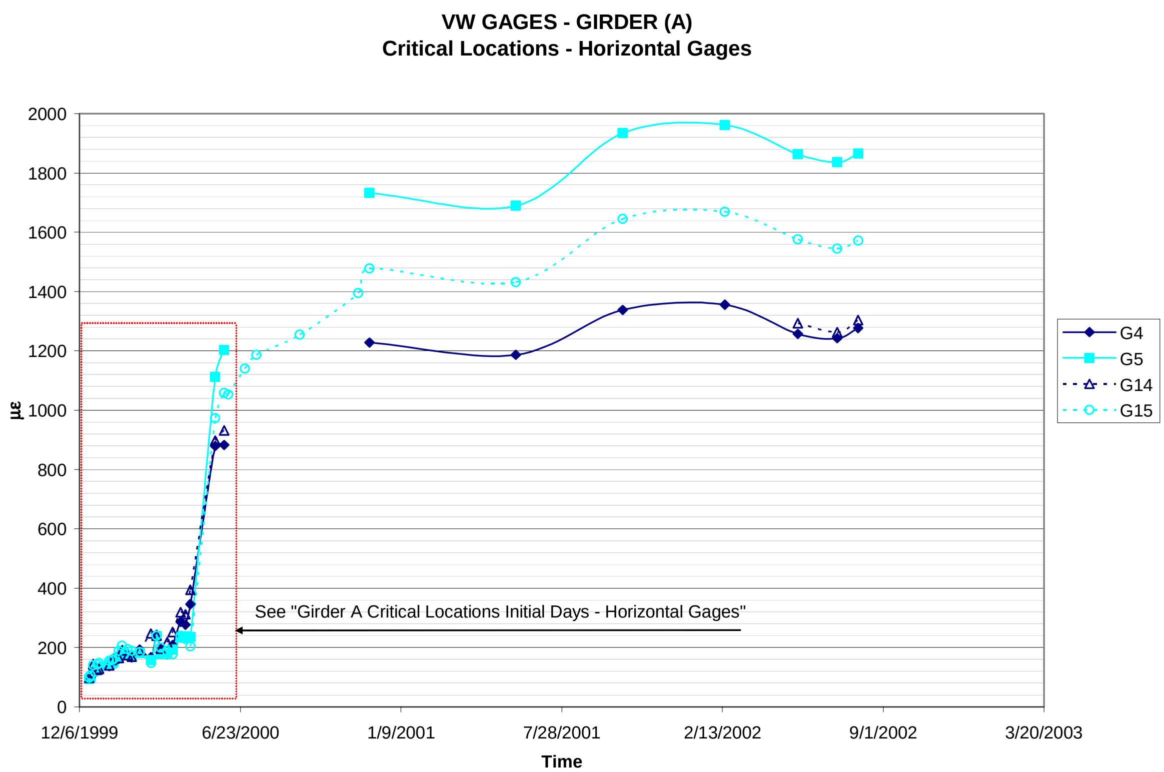

Fig. 12. Strain Readings of Selected Horizontal VW Gages – Girder A

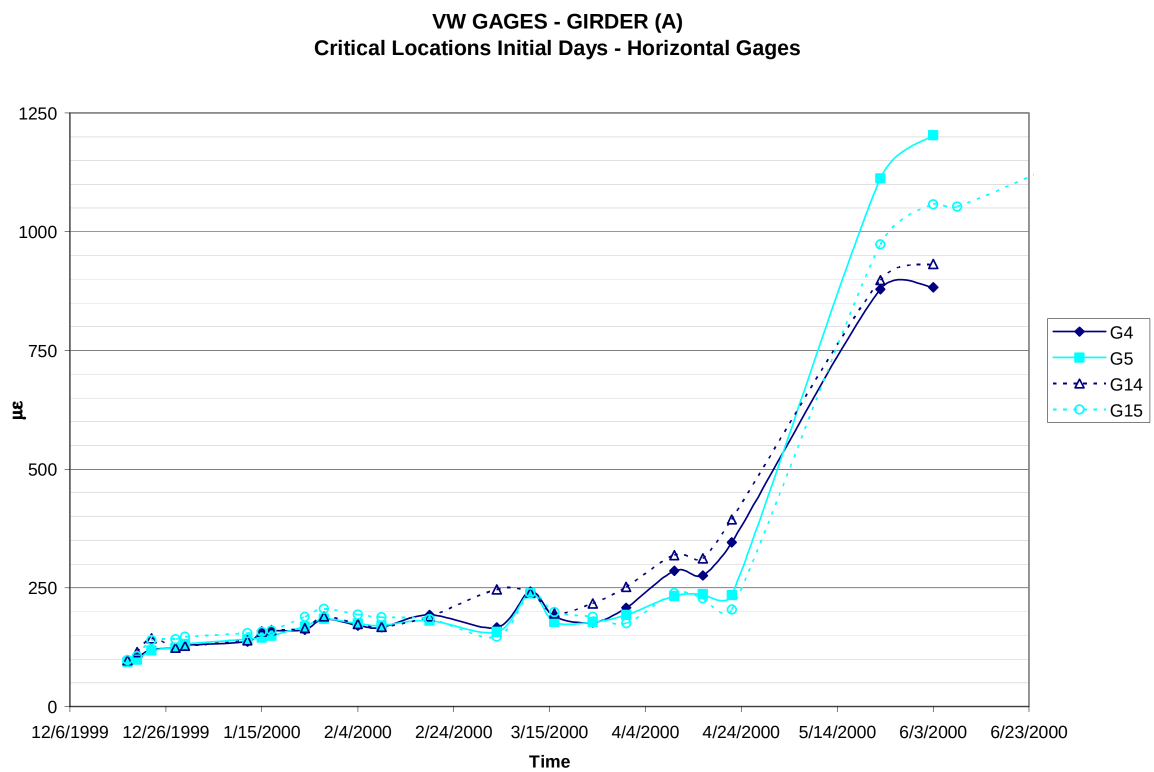

Fig. 13. Strain Readings of Selected Horizontal VW Gages During Initial Days – Girder A

At the time of post-tensioning (April 27-28, 2000), all gages indicate a large jump in compressive strain as was the case with the vertically oriented gages. Figure 13 shows that Girder A becomes cambered, concave up, after post-tensioning; this was confirmed from the survey of girder deflections. VW gages G4 and G14, which were previously reporting the largest compressive strains, report the smallest compressive strains after post-tensioning. VW gages G5 and G15 at the bottom flange report the largest compressive strains with the gage at midspan (gage G15) reporting a smaller compressive strain than the gage at the end segment, mainly due to the self weight stresses inducing a larger tensile stress at midspan. Figure 12 shows that this trend is continuing even with the seasonal fluctuations due to temperature variations. This behavior is similar for the segments of Girder B.

FUTURE INSTRUMENTATION

The bridge will be equipped with additional instrumentation to aid in monitoring the girders, as well as the whole bridge. To increase the rate at which data is collected, a data acquisition system will be installed, which will allow real-time data to be collected through use of a modem and an antenna.

Additional instrumentation to be installed includes thermocouples, which will be installed to measure the temperature gradient around the profile of the girder at mid span. The thermocouples will be placed at mid span of Girder A, which is exposed to the sun, on both the exposed and shaded sides. Tiltmeters will be installed on both sides of the diaphragms to measure any differential rotations. Externally mounted VW gages will also be added to the bridge at the middle and north most segments of Girder A (sections G-A-2 and G-A-3) to increase the number of horizontally oriented VW gages. A number of gages at locations on segment G-A-2 between the existing gages G14 and G15 will be installed, to obtain a complete strain gradient.

CONCLUSIONS

The I-15 Northbound Bridge at 45th South in Salt Lake City has been instrumented and monitored for two years. The east most spliced girder has been instrumented with load cells to measure the post-tensioned tendon losses. This girder and three other girder segments have also been instrumented with vibrating wire strain gages. Measurements from these gages have been recorded and analyzed. Measurements at the diaphragm splices indicate acceptable strain differentials induced by traffic loads. In addition, strain gage measurements at various stages of construction demonstrate that the behavior of the girder is as expected, and confirms the girder deflections observed in surveys that have been carried out. Calculation of theoretical tendon losses has been performed based on time-dependent behavior models. Comparisons with measured data indicate good agreement, which shows that the bridge is performing as designed.

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REFERENCES

1. Seguirant, S.J., "New Deep WSDOT Standard Sections Extend Spans of Prestressed Concrete Girders," *PCI Journal*, V. 43, No. 4, July-Aug. 1998, pp. 92-119.

2. Green, K.L., and Tadros, M.K., "The NU Precast/Prestressed Concrete Bridge I-Girder Series," *PCI Journal*, V. 39, No. 3, May-Jun. 1994, pp. 26-39.

3. AASHTO, "LRFD Bridge Design Specifications," Second Edition, Washington DC, 1998.

4. Nawy, N., "Prestressed Concrete: A Fundamental Approach," Third Edition, New Jersey, 2000.