Review of Design and Construction of Main Unit of the SR 204 Spur (Diamond Causeway) Bridge over Skidaway Narrows

Chatham County, GA

CSSTP-0008-00(651)

Prepared for

United Infrastructure Group

Prepared by

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1 PROJECT

The focus of the project is the three-span main unit of the Diamond Causeway Bridge over Skidaway Narrows located southeast of Savannah, GA. This unit consists of pretensioned precast concrete girder segments that are spliced and post-tensioned to form a continuous girder. A composite deck slab will be placed on the girders to complete the structure. The bridge is being constructed for GDOT as a design-build project for which United Infrastructure Group, Inc., is the contractor and Michael Baker (formerly the LPA Group) is the design engineer. It is anticipated that readers of this report will be familiar with project details, so they are not be repeated here.

Bridges of this type have been utilized in the southeastern part of the US for nearly 25 years, with the majority of the structures completed in Florida and the Gulf Coast states.

2 OBJECTIVE OF STUDY

In mid-December of 2012, the author was asked by United Infrastructure Group, Inc., to analyze the as-built data for the casting, erection and post-tensioning of the beams in the bridge main span unit and prepare a report summarizing the potential causes of the deviation of the beam orientation from the plans, as well as the effect of the deviations and related issues on the completion of the construction of the bridge.

Deviations in the beam orientation from the plans became evident following post-tensioning of the girders. Evaluation of a survey of the girders conducted shortly after post-tensioning indicated that the deviations in beam orientation would result in negative beam build-ups at a number of locations which was unacceptable to the Department.

The development of an approach to resolve the anticipated negative build-ups is not considered in this report.

3 INFORMATION USED

Information used for this study was obtained from conversations with the construction team and from design files, project plans, construction records and survey notes provided by United Infrastructure Group and Michael Baker.

Standard Concrete Products, the manufacturer of the girder segments, was asked to provide data on the initial cambers of the girder segments. They reported release cambers of 1.25" and 1.0" for two of the drop-in girder segments. They did not find any record of cambers for the end span beams but indicated that the theoretical release camber for those girders was about 1". They have not attempted to measure camber on the haunched girder segments. An evaluation of the design calculations indicates that these observed cambers agree well with what was anticipated in the design.

4 APPROACH

The approach taken in performing this study was to evaluate the information provided and confirm its validity where possible. Computations were then performed using the information to identify the source of the deviation in girder orientation from the plans and then to determine the impact of the change in construction approach in several ways.

Because of the complexity of the design and construction of this type of structure, there are many different ways to look at the bridge. A few key approaches were taken to attempt to demonstrate most clearly the effect of the change.

5 DEVIATION IN GIRDER ORIENTATION FROM PLANS

Evaluation of the available data indicates that the deviation in girder orientation from the plans was due to the method used for determining the orientation of the haunch girder segments.

The placement of the haunch girder segments will define the locations of the remaining girder segments as they are set. Therefore, the proper placement of these segments is important for the successful completion of the bridge. The towers provide a fixed elevation location only during segment erection and the subsequent placing of concrete closure pours to splice the girder segments. Once the closure pours have been completed, the relative geometry of the girder segments is fixed for all subsequent conditions. Therefore, the orientation of the girders prior to splicing is critical for establishing the proper girder profile.

At the application of the first stage of post-tensioning, the full length of the spliced girder functions as a single continuous girder. For this bridge, which is typical of spliced girders, the girders lifted off the temporary supports at the towers during first stage post-tensioning. Therefore, the elevation of the girder at the temporary supports is no longer fixed. Structure elevations are only fixed for the life of the structure at the permanent bearing locations at the bents, so build-ups can only be specified at the permanent bearing locations.

The customary method for setting haunch girder segments has been to use optical survey methods to set the elevations of the bearings at the temporary support towers. This provides the necessary control for the relative alignment of the girder segments. The project plans provided elevations at the temporary tower to which the haunch and end girder segments were to be erected. During design of the temporary towers, the Shoring Tower Designer identified an error in the haunch girder segment elevations shown on the plans. These were then corrected by the Engineer prior to any girders being erected on the project. The corrected elevations will be referred to as the plan elevations for the remainder of this report.

According to the contractor, the haunch girder segments for this bridge were not set using the bottom of girder elevations at the splice locations that were specified in the plans. Rather, a bubble level was used to set each segment so the bottom surface of the top bearing plate of the pot bearing assembly was level. When the segment was positioned so that the bearing plate was level, blocking was installed on the temporary tower to maintain the orientation of the segment and bearing plate. The segment was then secured to the tower. This method for

orienting the haunch girder segments was reportedly used because the Department believed that the top and bottom bearing plates for the pot bearings had to be level when the haunch girder segments were erected.

In the author's opinion, the orientation of the haunch girder segments should have been set using standard surveying methods. Then, if necessary, the orientation of the top bearing plate of the pot bearings could have been adjusted later using conventional methods.

6 BOTTOM OF HAUNCH GIRDER SEGMENT ELEVATIONS AT TEMPORARY SUPPORTS

Following erection of the haunch girder segments, a survey was made of the top flange of the segments on March 20, 2012. It is assumed that the survey was taken at or near the centerline of the top flange. Survey points were apparently not identified on the girders, so subsequent survey shots may not be taken at the same locations.

Documents reviewed provided conflicting information regarding whether only the haunches were in place at the time of the survey, or whether the end segments for Span 7 were in place. This apparent conflict is not significant because the elevations of the girder segments should not be affected by whether the end segments had been erected or not. However, if the Span 7 girder segments had been erected, the strongbacks would be in place at the splice locations at the time of the survey, making access to the center of that end of the girder difficult.

The source documents generally presented survey data with a precision of thousandths of a foot. However, the precision of surveying required and the site conditions make such a high level of accuracy unlikely. Therefore, survey data presented in this report is given to hundreds of a foot. A greater level of accuracy is not required for the construction of this bridge or for the purposes of this study.

Corrected elevations for the bottom of the haunch girder segments at the splice are shown in Table 1.

Table 1 – Bottom of Haunch Girder Segment Elevations at Temporary Supports

	Girder 1	Girder 2	Girder 3	Girder 4	Girder 5
Temporary Tower near Bent 8					
Plan Elevations [A]	70.75	70.93	71.12	70.93	70.75
Survey Elevations [B]	71.01	71.15	71.28	71.11	70.92
Difference [B-A] (ft)	0.26	0.22	0.16	0.18	0.17
Difference [B-A] (in)	3.1	2.6	1.9	2.2	2.1
Temporary Tower near Bent 9					
Plan Elevations [A]	70.75	70.93	71.12	70.93	70.75
Survey Elevations [B]	71.09	71.12	71.27	71.11	70.92
Difference [B-A] (ft)	0.34	0.19	0.16	0.18	0.17
Difference [B-A] (in)	4.1	2.2	1.9	2.1	2.0

Since the bottom of the haunch segments is sloped, the plans indicate that the elevation is to be taken at the very end of the segment. Survey elevations for the bearings shown in the table should be considered as approximate because they are computed by subtracting the nominal girder depth from the survey elevations at the top of the girder segments at the splice locations. Plots of the plan and survey elevations at the two bents appear below as Figures 1 and 2.

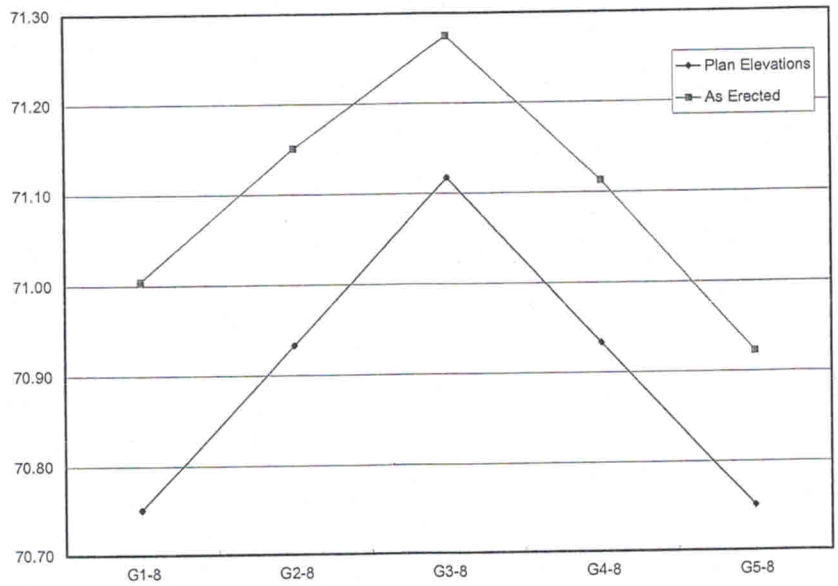


Figure 1 – Bottom of Haunch Girder Segment Elevations at Bent 8

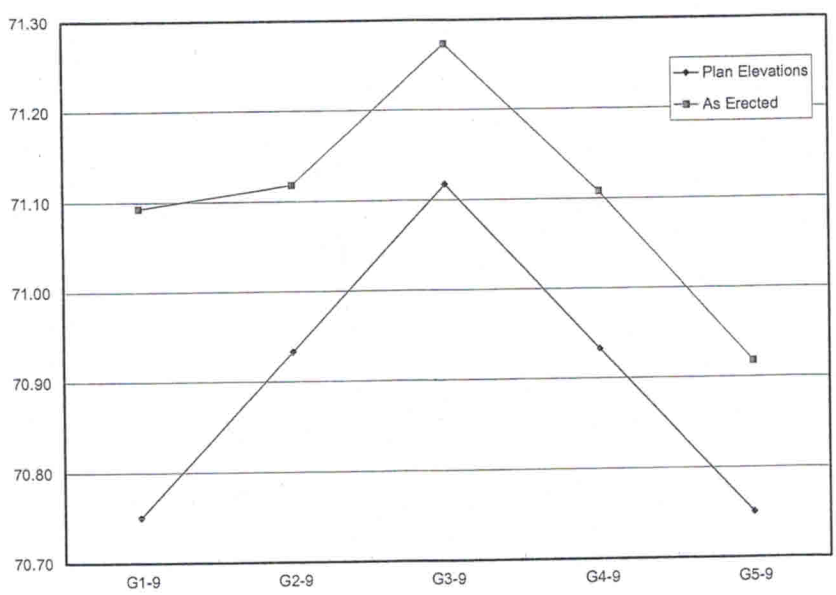


Figure 2 – Bottom of Haunch Girder Segment Elevations at Bent 9

The difference between the plan and survey elevations has been computed and is presented in Table 1 and is also presented graphically in Figure 3. The difference values indicate that the bottom of each haunch girder segment was set at a higher elevation than intended in the plans with the maximum difference being about 4 inches. Such a change in girder elevation will have a significant impact on the construction of the structure, since an increased elevation at the temporary support location will decrease the build-ups in this region, possibly putting the girder flange into the deck. Raising one end of a haunch girder segment will lower the other end of the segment since it will pivot across the fixed bearing at the bent. As a result, the drop-in girder will be lowered, which will affect the navigational clearance provided and will increase the build-up in the center span (which will increase the load on the girders).

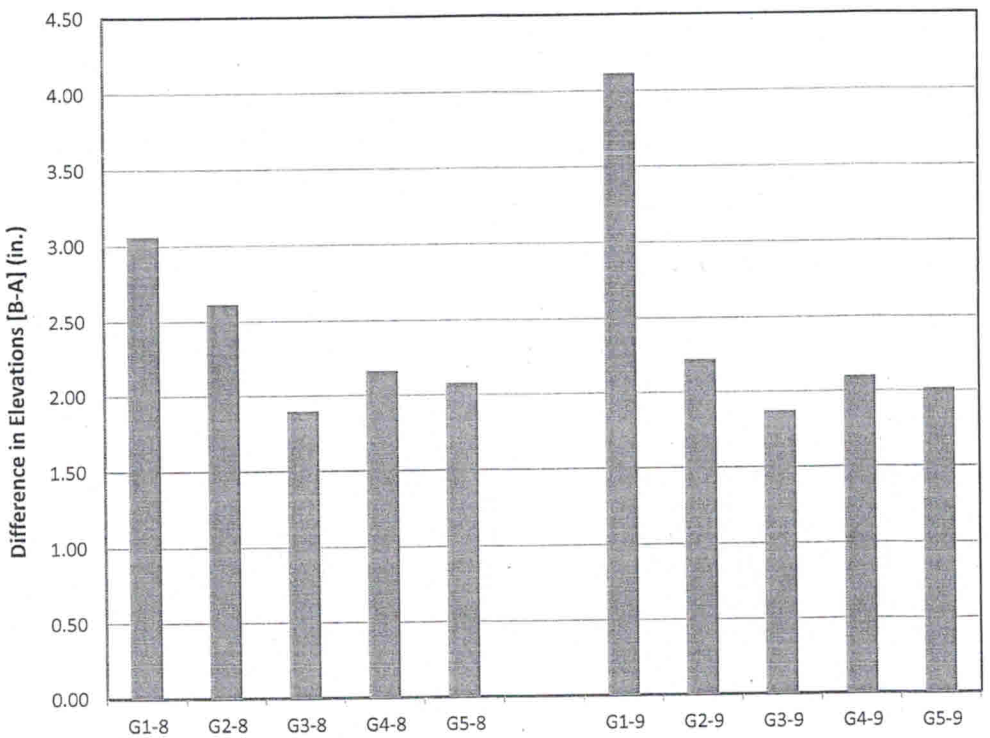


Figure 3 – Difference in Bottom of Haunch Girder Segment Elevations (inches)

7 Significance of Difference in Bottom of Haunch Girder Segment Elevations

Normal construction procedures and tolerances provide permanent bearing elevations that would typically be within a fraction of an inch of the elevations specified in the plans. Using standard surveying methods to set blocking elevations at the temporary supports should provide temporary bearing elevations with similar accuracy. Therefore, the magnitude of the difference in elevation between the actual and plan elevations at the bottom of the haunch girder segments at the temporary supports is surprising.

In the author's opinion, the observed difference in elevation should have raised significant concerns that should have resulted in a reevaluation of the situation including a look forward to the consequences of the differences on the completion of the structure, since the change in bottom of girder segment elevations will result in a fixed change in the relative position of the girder segments once the closure pours are completed at the splice locations. This reevaluation would have hopefully resulted in corrective actions being taken which would have avoided the current situation.

The effect of the change in relative position of the girder segments will be discussed later in this report.

8 Source of Difference in Bottom of Haunch Girder Segment Elevations

Two possible sources of the difference in elevation at the bottom of haunch girder segments have been identified and are considered in the following.

8.1 Use of Bubble Levels

Since a bubble level was used to set the orientation of the haunch girder segments, the possible accuracy of this method was evaluated. The contractor indicated that the bubble level used to set the haunched segments was a BOSTITCH 43-730 32-Inch Magnetic Level. A similar 24-inch level was also used. The manufacturer's specifications for this model found on the internet indicated that the block vials used in this model provide accuracy of up to 0.0005 in/in (0.5 mm/m). This accuracy is related to the vial and is the same regardless of the length of the level. Projecting this accuracy over the approximately 50 ft distance to the tower support, it could be expected that the haunch could be set to within 0.025 ft or 0.3 in under the best circumstances. Therefore, it is possible that a bubble level could be used to set the haunch segment to a reasonable accuracy. However, from photographs of the bearing locations and reports from the contractor, conditions may not have been optimal in this case.

From this analysis, it appears that while the use of the bubble level to orient the girder segments may have contributed to the observed increase in elevation at the temporary supports, it may not be the sole cause for the increase.

8.2 Tolerance in Embedded Plate Installation

Another possible source for the difference in elevation could be that the embedded plates in the haunch girder segments were tilted when cast. If this were the case, the segment placement method intended to make the pot bearing plates parallel would result in tilting the girder segments by the angle of the embedded plate. Sheet D1 of D5 in the Standard Concrete Products shop drawings for the girder segments provides a list of fabrication tolerances including the accepted tolerance for planeness of bearing areas, presented as either item H or Q, both of which have a tolerance of +/- 1/8". (Note: this sheet appeared in the drop-in girder set of shop drawings – a similar sheet was not found in the haunched girder or end girder sets).

The embedded plate is 4'-1" long, so a deviation of 1/8" over that length would project to a difference at the tower bearing location approximately 50 ft away of about 1.5".

If the embedded plate was tilted, standard erection methods using surveying to set the bottom of girder segment elevations would have placed the girder segments in the proper orientation and the issue of bearing orientation could have been addressed separately.

From this analysis, it appears that the orientation of the embedded plate in the haunch girder segments may have contributed to the observed increase in elevation at the temporary supports, but it probably may not be the sole source of the increase.

8.3 Conclusion

Based on this evaluation of two likely contributing factors to the observed increase in elevation at the temporary supports, neither appears to be the sole source of the change. However, it is expected that both factors, and possibly other unidentified factors, contributed to the changes.

It is interesting to note that the bottom of girder elevations at the temporary supports increased for all girders. It would seem that a difference in elevation introduced by the use of a bubble level would most likely be more random and would not result in changes in only one direction. It would also seem unlikely that all of the tilting in the plates would be in the same direction, unless the bottom of the form was deformed. Therefore, it may be possible that there may be other sources of the change in bearing elevations that have not been identified.

As stated above, it is the author's opinion that the haunch girder segments should have been set to the elevations at the temporary towers provided in the plans in order to produce the intended girder profile.

If the standard approach for setting the haunch girder segments using surveying methods were used, the orientation of the pot bearing plates could have been adjusted using various means, if required, to meet installation requirements for proper performance of the bearings. If this had been done, a rough preliminary assessment appears to indicate that the rotations to which the bearings would be subjected during the remaining phases of construction should not produce a rotation outside the working limits of the bearing.

9 Effect of Changes in Temporary Support Elevations on Girder Profiles

The change in the support elevations at the temporary towers, whatever the cause, resulted in permanent changes in the girder profiles. These changes will be illustrated by examining profiles of the haunched segments, cross-sections of the girders, and the overall profile of the girder which demonstrates how the girders relate to the deck slab. Other comparisons of data could also be made, but these seemed to be most instructive.

9.1 Haunched Segment Profiles

Survey data for the haunch girder segments are available for four different times:

- March 2012 — Only haunch segments in place (possibly some end segments)
- June 2012 — All segments in place and closures poured
- August 2012 — After stage 1 post-tensioning completed
- December 2012 — No change in structural condition since August

A comparison of the profiles of the haunched segments at these times indicates the differences in alignment of the girder segments, the movements that have occurred for each segment with post-tensioning, and the stability of the deflections with time.

Appendix A contains the simplified plots of the segment profiles. Each page presents data for one girder line with a separate plot for the segments at Bent 8 and Bent 9. These simplified profiles only show the elevations at the two ends of the haunch and at the center over the support. Location 1 is at the drop-in splice end of the haunch segment, location 2 is at the bent and location 3 is at the end span splice near the temporary tower.

These figures do not give any indication of the change in support elevation that occurred during erection of the haunch girder segments other than the difference in segment slopes that are evident between the data at the two bents, such as for Girder 1.

In most cases, the figures demonstrate that there has not been much change in rotation with the different conditions. It should be noted that there is some change in elevation at the center support location, which should not occur. Most of this variation is probably caused by the survey points not being the same for each survey.

A second set of figures is presented in Appendix B. These figures show the surveyed profile for the full length of the haunch girder segments from the December 2012 survey. All five segments at the indicated bent are shown in each figure. This data shows that some segments are definitely tilted differently from the other segments, such as Girder 1 at Bent 9. The figures also show the variation in the survey data along the top surface of the segment.

9.2 Cross-sections at Specific Locations

Differences caused by the changes in support elevations at the temporary towers are more evident by looking at the same data presented in Appendix A for each girder, but in this case, looking at the cross-section of all girders at a particular location. This data is presented in the three figures in Appendix C.

The cross-sections at the end splice location vary due to the changes in elevation at the temporary towers, but also because the girders lifted off of the temporary supports when the first stage post-tensioning was applied in July. Therefore, the sections for the last two surveys, August and December, should be higher than the other sections.

The cross-sections at the support location should theoretically be identical since the bearing is essentially unyielding for the loads being applied. The data reflects this pretty well, considering the limitations of the survey data available.

The cross-sections at the drop-in splice location should have the greatest variation, as is evident in the figures. This is because there is never an external support at this location so these elevations are affected by any changes to elevations both the temporary supports and permanent bearings. The changes in elevation at the tower supports are reflected in these figures as well as movements due to placement of the drop-in segment prior to the June survey and the effect of post-tensioning.

At all three locations, the plots should theoretically be shaped like a perfectly symmetrical inverted V, with the highest point in the center at Girder 3. This is fairly well reflected in the figure at the center of the bents, but is not as well represented at the other locations. Much of the variation can probably be related to the change in bearing selevation at the temporary towers, but other factors may also be involved.

9.3 Full Girder Profiles

Full length girder profiles based on the survey conducted in August 2012 provide the opportunity for a number of different comparisons. Appendix D contains figures with a plot of the data for each edge of each girder line where a deck will be place (no figure is provided for the exterior edge of exterior beams).

The figures also show a line representing the survey data that has been adjusted to account for expected future girder movements due to the placement of the deck, second stage post-tensioning, and the placement of the barrier rail, as tabulated in the camber table in the plans (Sheet 29). The adjustment is made by adding the cambers in rows B, C and D of the table to the survey data. This provides an estimate of the final girder location after construction is complete.

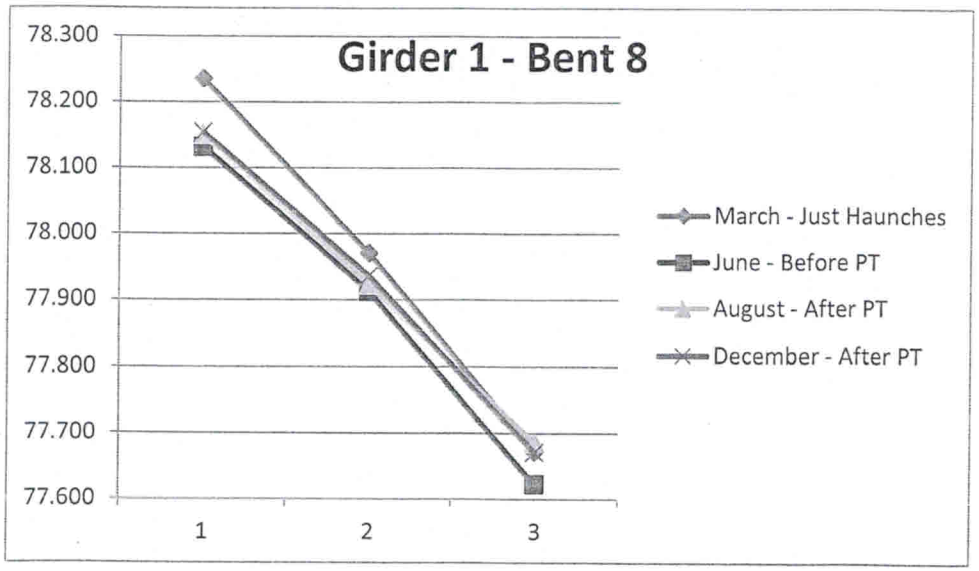
Based on the PGL and location of the girder edge, the bottom of deck slab elevation at each edge of the girder has been computed and plotted. This allows the relationship between the edge of girder and the bottom of deck to be identified. Such data is also available in tabular form. A comparison of this line with the line for the final girder location indicates that the girder will encroach into the deck slab at several locations for most girder lines.

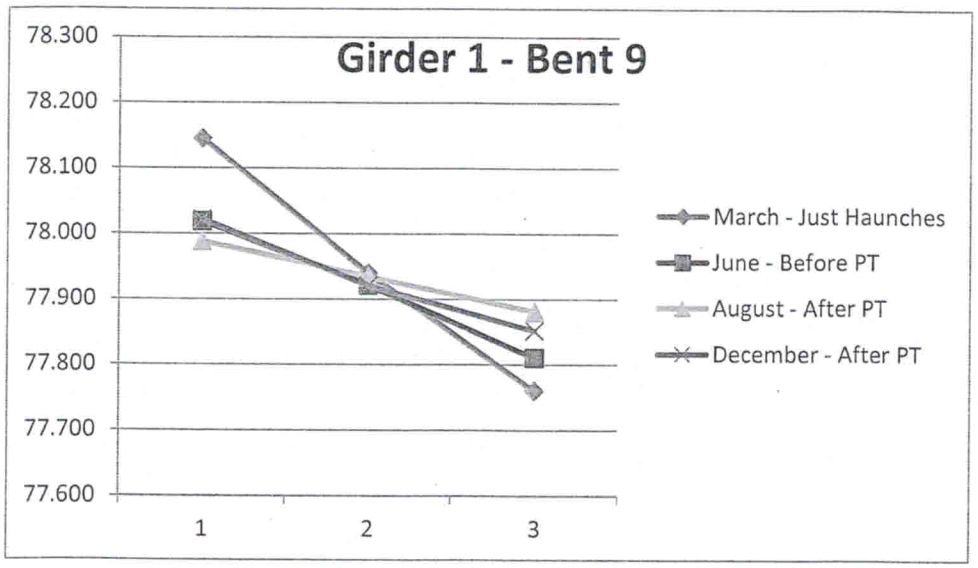
A final line shown in the figures represents an additional adjustment to the final elevation profile that removes the elevation difference from the plans to actual conditions at the temporary support for each girder line as shown in Table 1. The adjustment is made by lowering the elevation of the haunch girder segments at the tower, which raises the other end of the haunch segment an equal amount. Adjustments to intermediate points and the other segments are made using linear interpolation. This profile, which appears in the figures as the blue line, indicates that none of the edges of the girders, if they had been set to plan elevations, encroach into the deck slab at any location along any of the length of the girders.

APPENDIX A

Figures for Haunched Segment Profiles

Girders 1 through 5 (5 pages)


Girder 1 - Bent 8
78.300
78.200
78.100
78.000
77.900
77.800
77.700
77.600
1
2
3
March - Just Haunches
June - Before PT
August - After PT
December - After PT


Girder 1 - Bent 9
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78.200
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77.600
1
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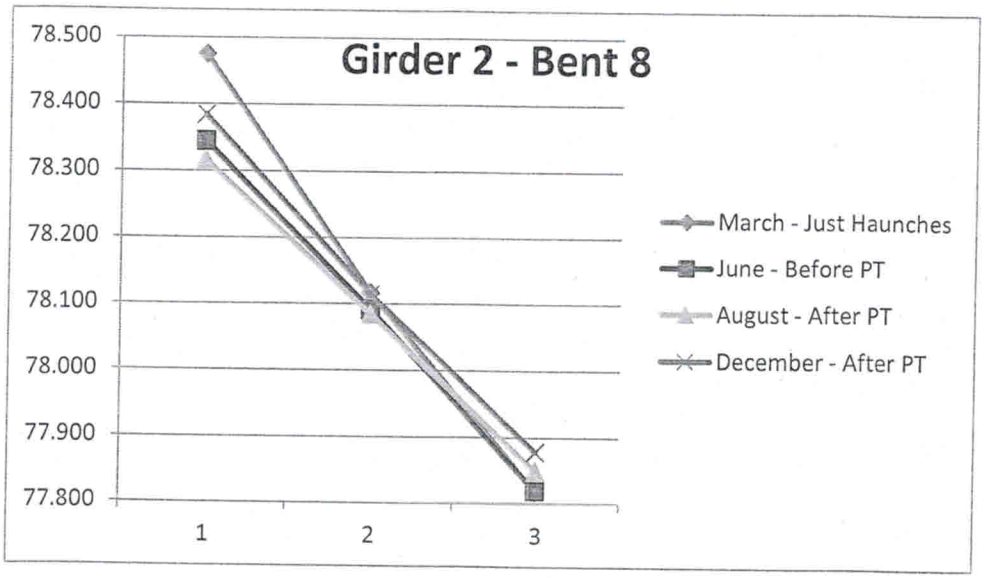
3
March - Just Haunches
June - Before PT
August - After PT
December - After PT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78.400
78.300
78.200
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78.000
77.900
77.800
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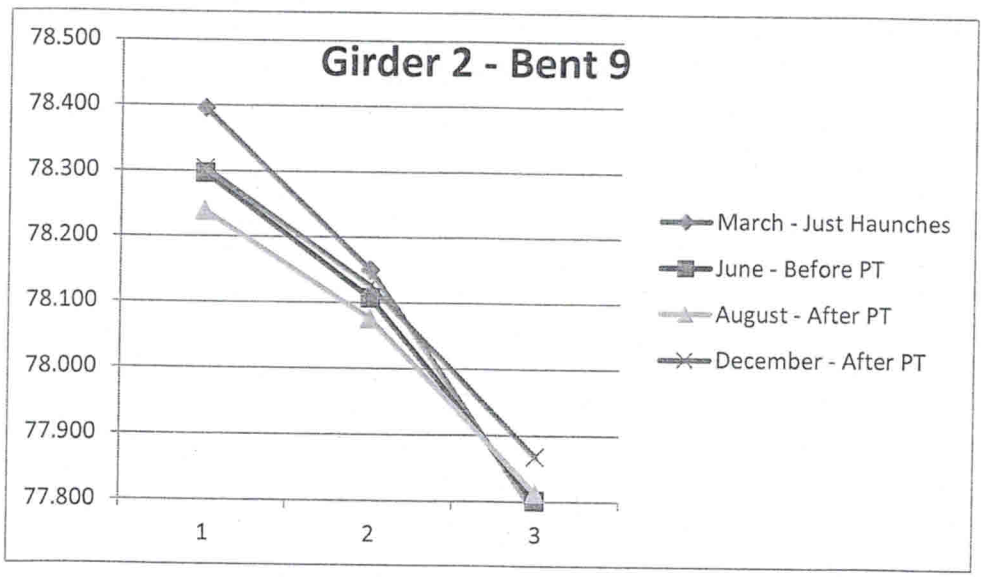
March - Just Haunches
June - Before PT
August - After PT
December - After PT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78.300
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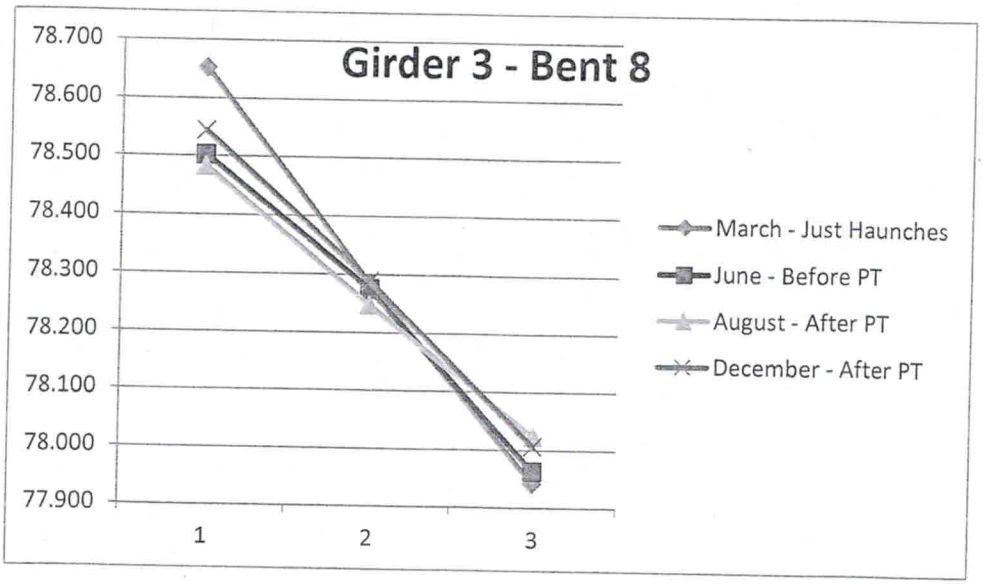
March - Just Haunches
June - Before PT
August - After PT
December - After PT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78.600
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78.400
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78.000
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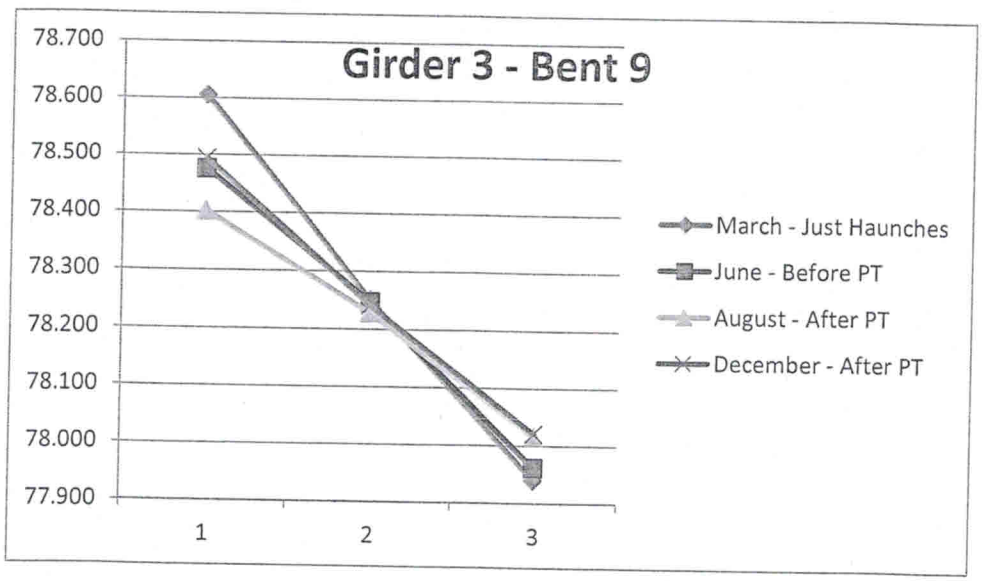
3
March - Just Haunches
June - Before PT
August - After PT
December - After PT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78.400
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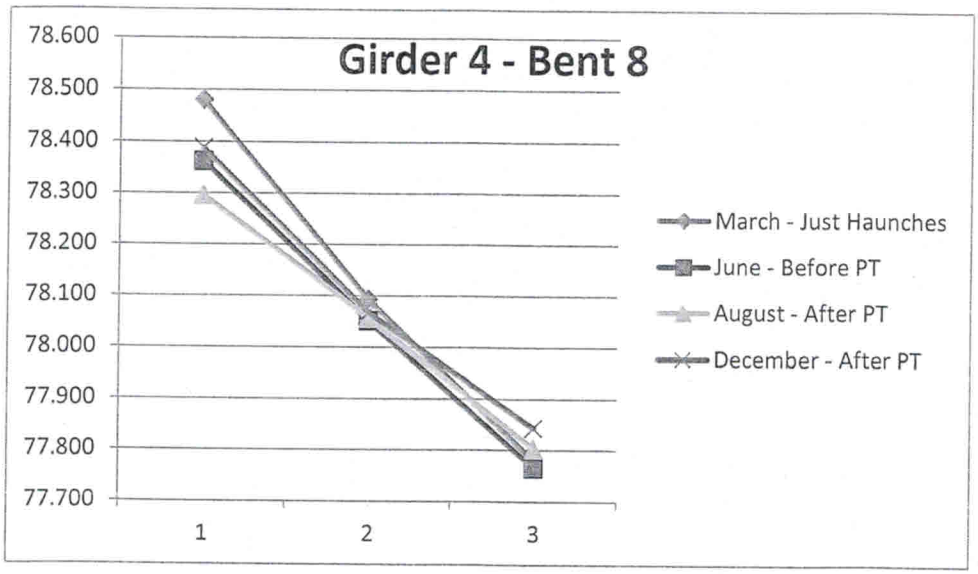
March - Just Haunches
June - Before PT
August - After PT
December - After PT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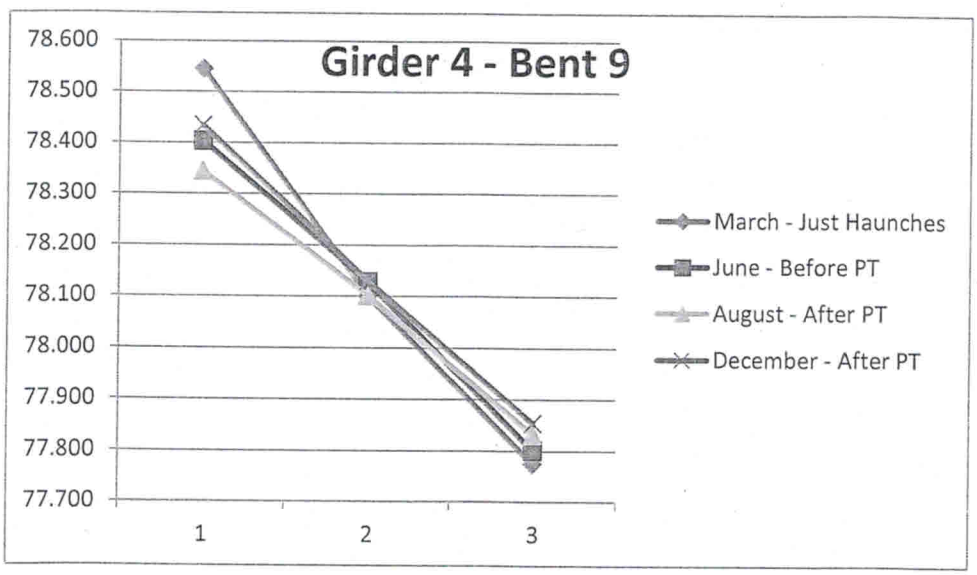
March - Just Haunches
June - Before PT
August - After PT
December - After PT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78.400
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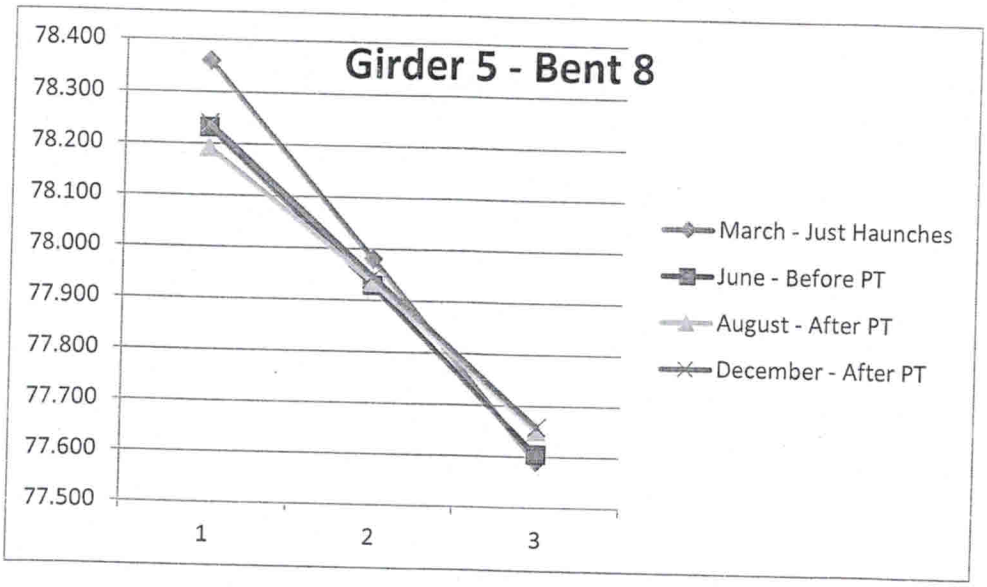
March - Just Haunches
June - Before PT
August - After PT
December - After PT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78.200
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78.000
77.900
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77.700
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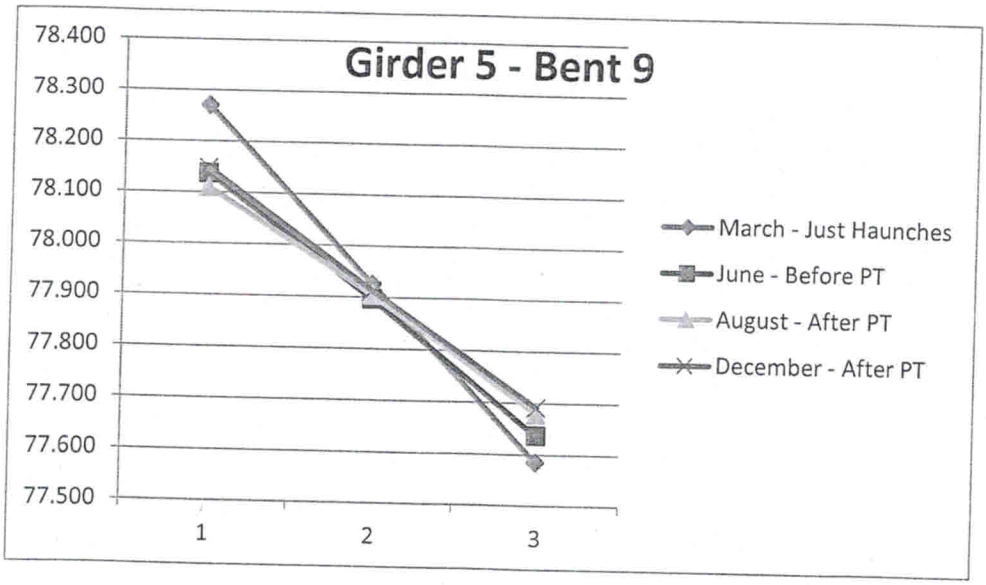
March - Just Haunches
June - Before PT
August - After PT
December - After PT


Girder 5 - Bent 9
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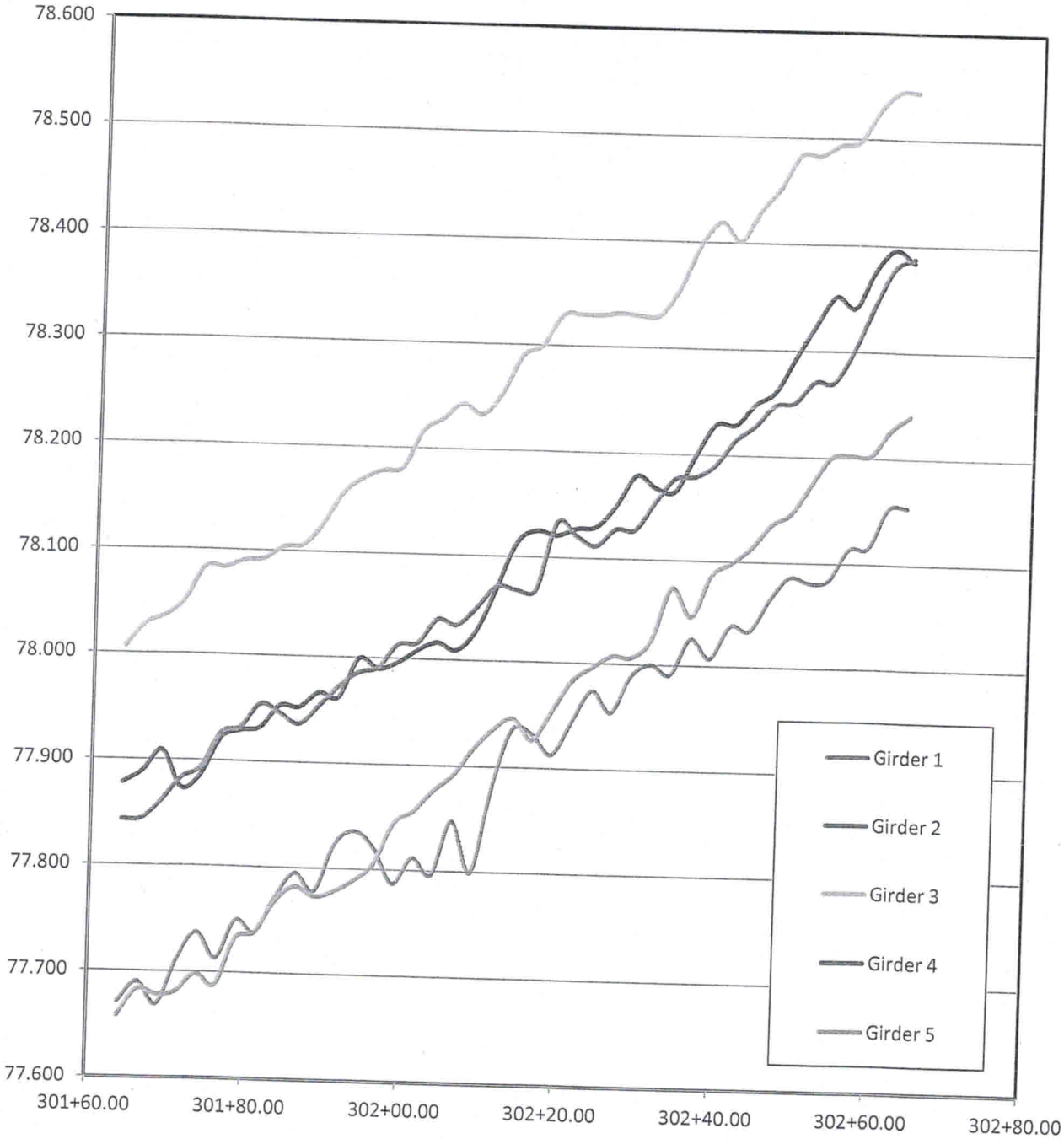
March - Just Haunches
June - Before PT
August - After PT
December - After PT

APPENDIX B

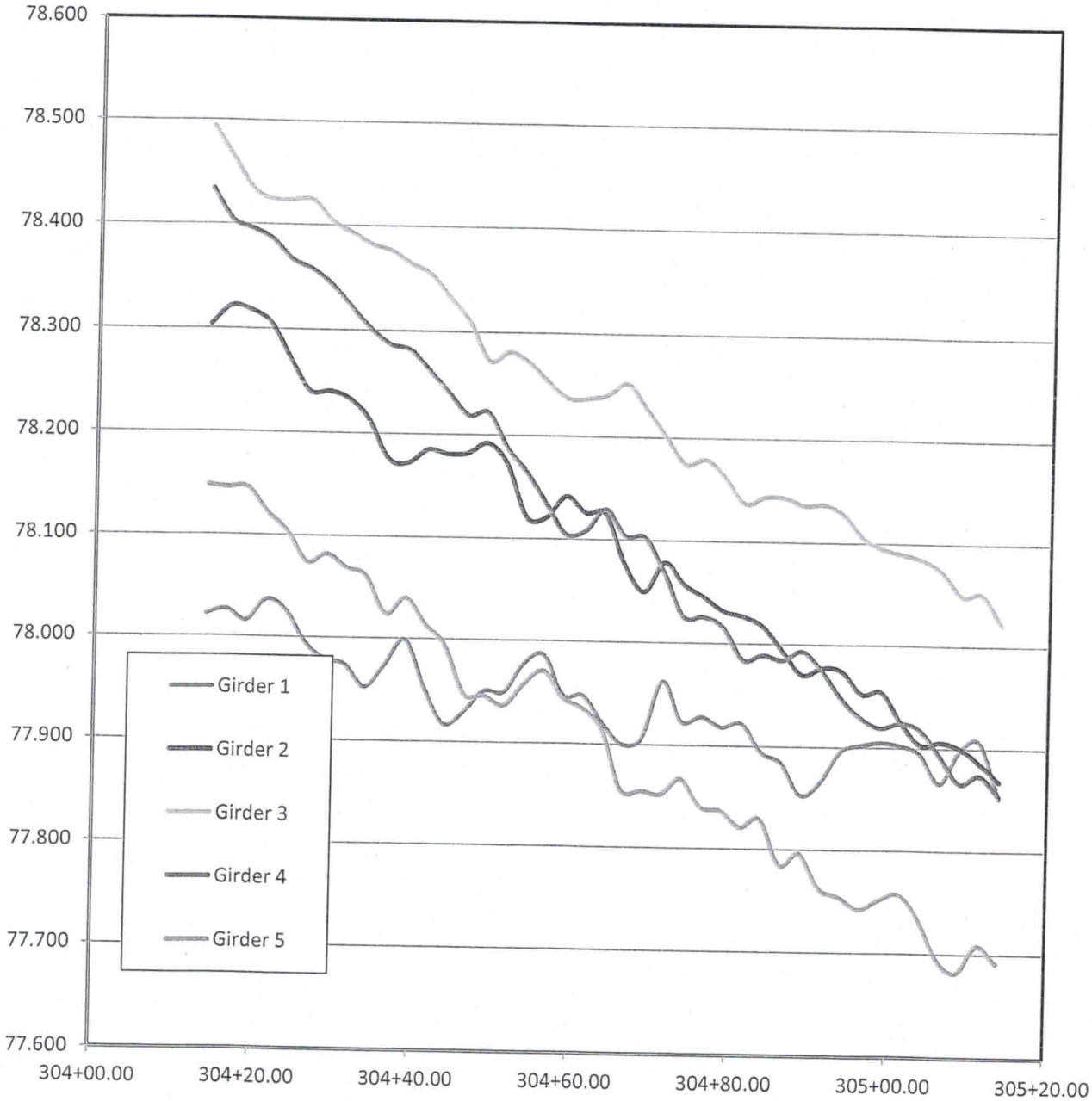
Figures for Profiles along Haunched Segments – Dec 2012 Survey

Bents 8 and 9 (2 pages)

Bent 8 - December 2012 Survey



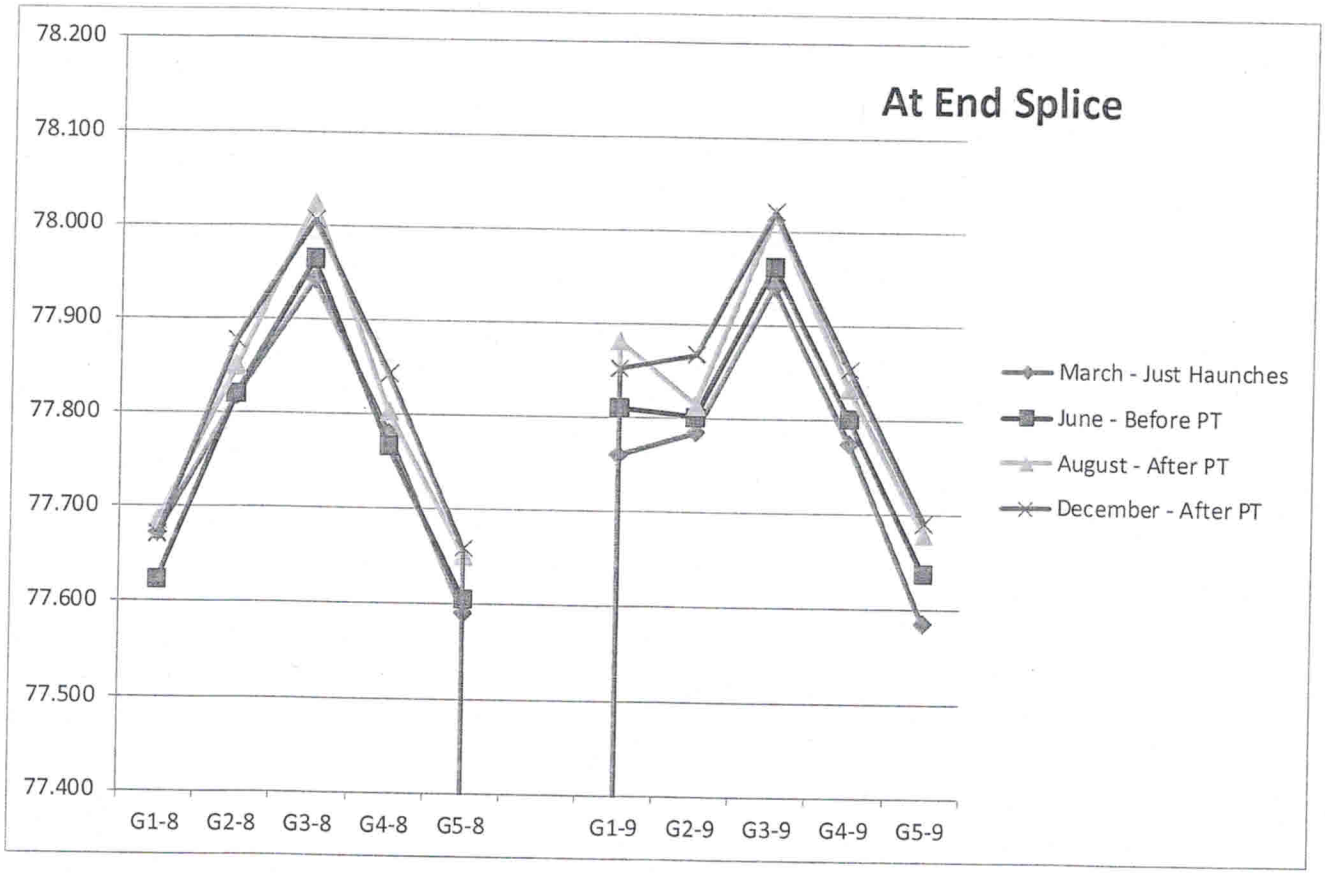
Bent 9 - December 2012 Survey

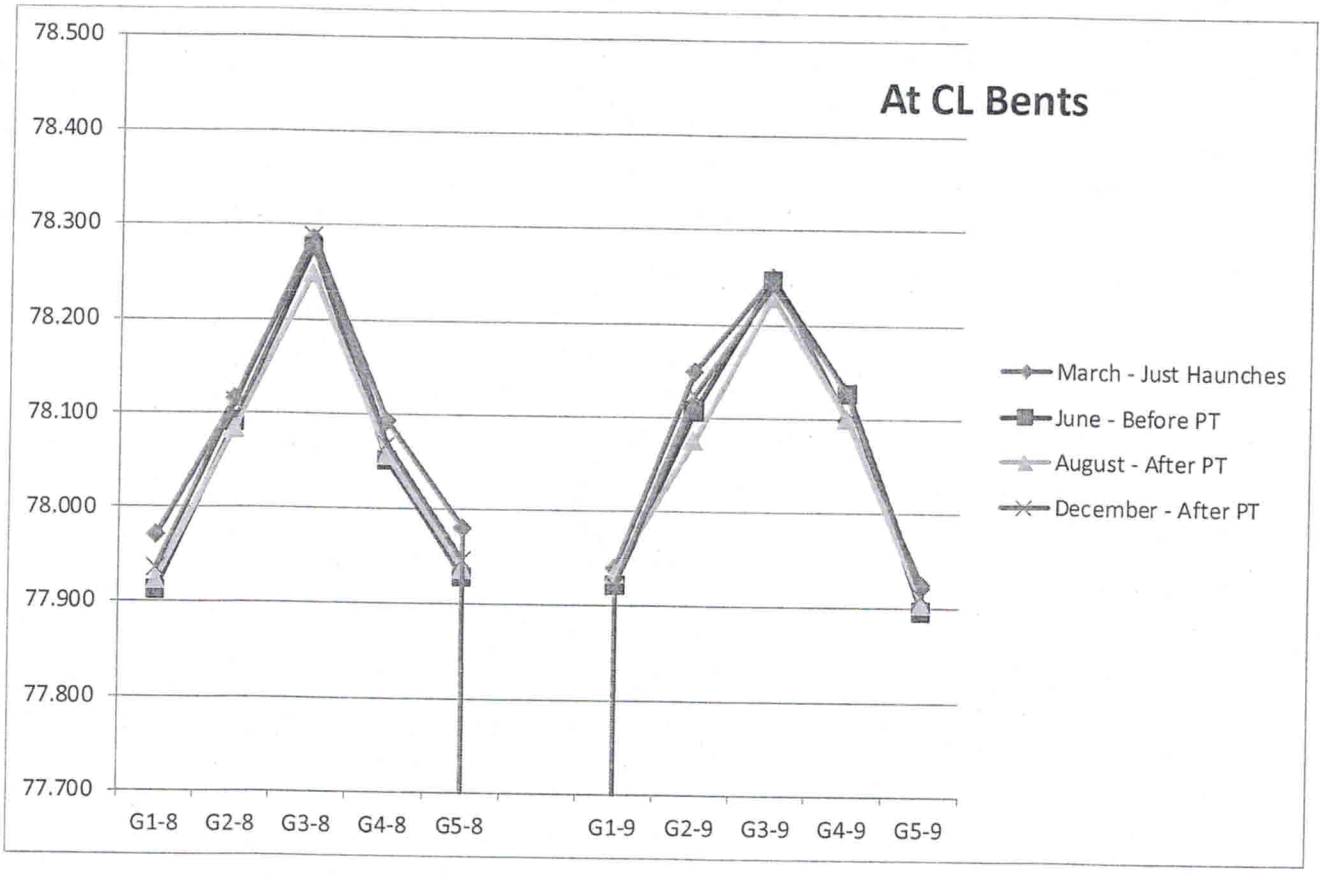


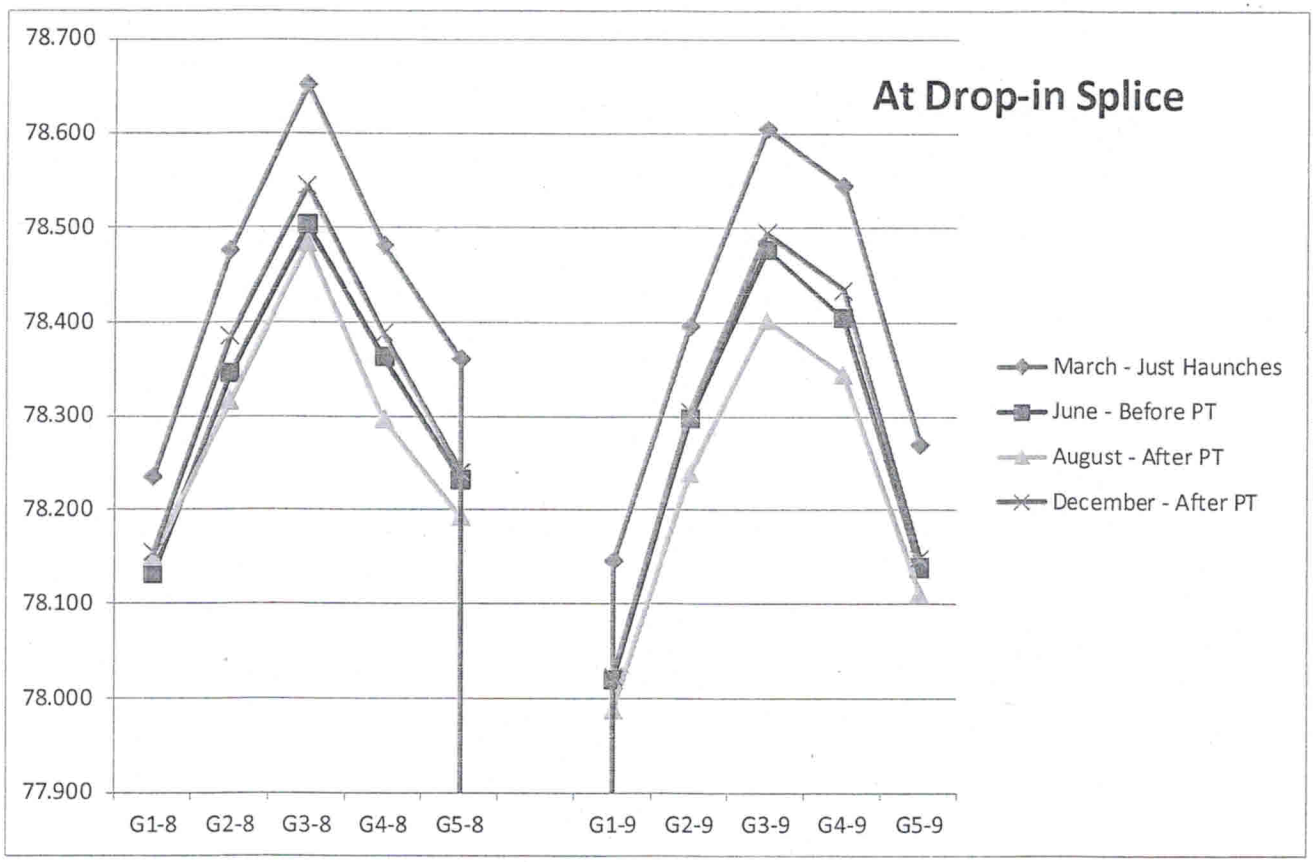
APPENDIX C

Figures for Cross-Sections of Haunched Segments

At End Splice, CL Bent and Drop-in Splice (3 pages)


At End Splice
78.200
78.100
78.000
77.900
77.800
77.700
77.600
77.500
77.400
G1-8
G2-8
G3-8
G4-8
G5-8
G1-9
G2-9
G3-9
G4-9
G5-9
March - Just Haunches
June - Before PT
August - After PT
December - After PT

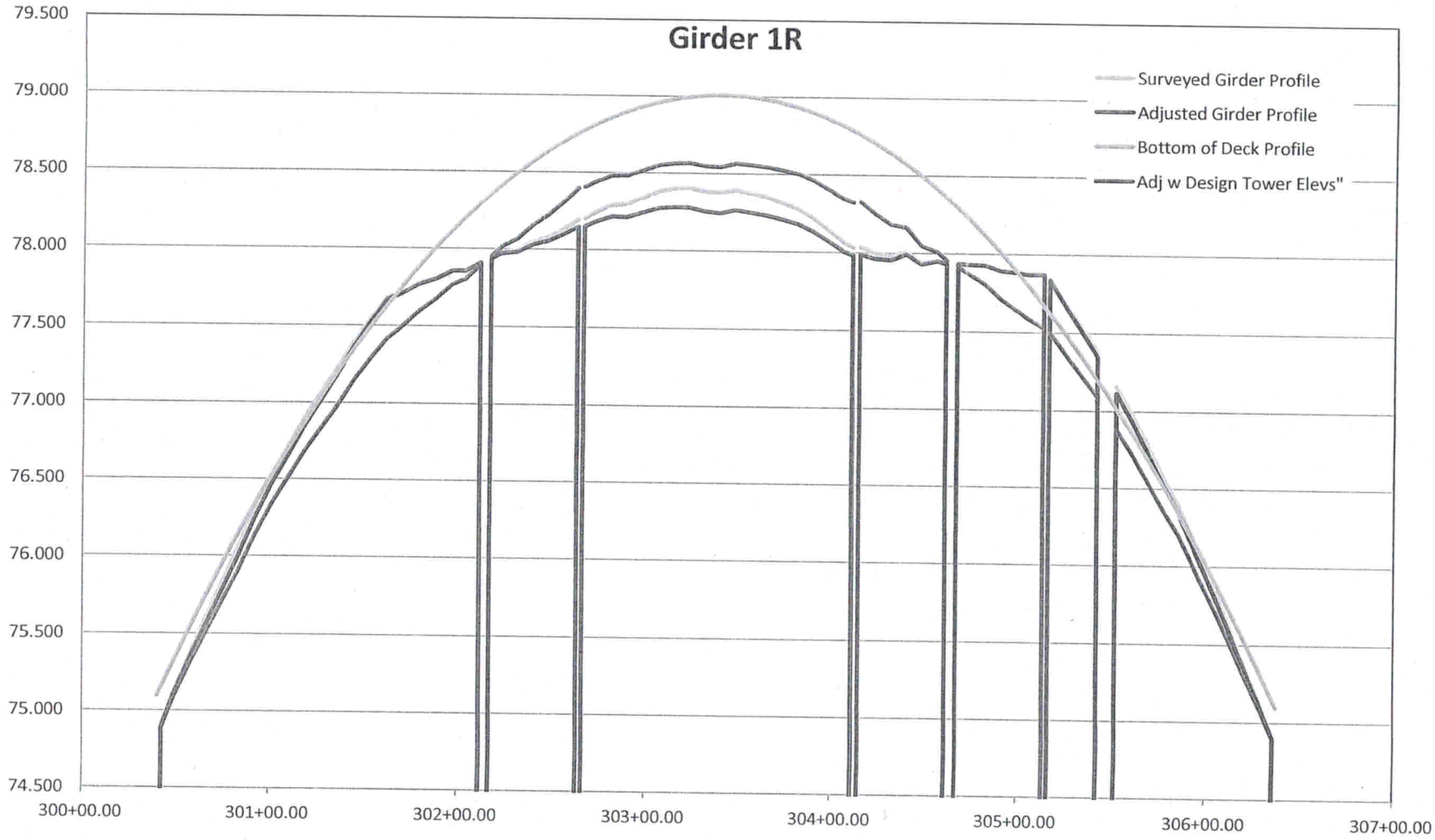

At CL Bents
78.500
78.400
78.300
78.200
78.100
78.000
77.900
77.800
77.700
G1-8
G2-8
G3-8
G4-8
G5-8
G1-9
G2-9
G3-9
G4-9
G5-9
March - Just Haunches
June - Before PT
August - After PT
December - After PT


At Drop-in Splice
78.700
78.600
78.500
78.400
78.300
78.200
78.100
78.000
77.900
G1-8
G2-8
G3-8
G4-8
G5-8
G1-9
G2-9
G3-9
G4-9
G5-9
March - Just Haunches
June - Before PT
August - After PT
December - After PT

APPENDIX D

Figures for Full-Unit Girder Profiles

At Edges of Girders supporting the deck (8 pages)


Girder 1R
Surveyed Girder Profile
Adjusted Girder Profile
Bottom of Deck Profile
Adj w Design Tower Elevs"
79.500
79.000
78.500
78.000
77.500
77.000
76.500
76.000
75.500
75.000
74.500
300+00.00
301+00.00
302+00.00
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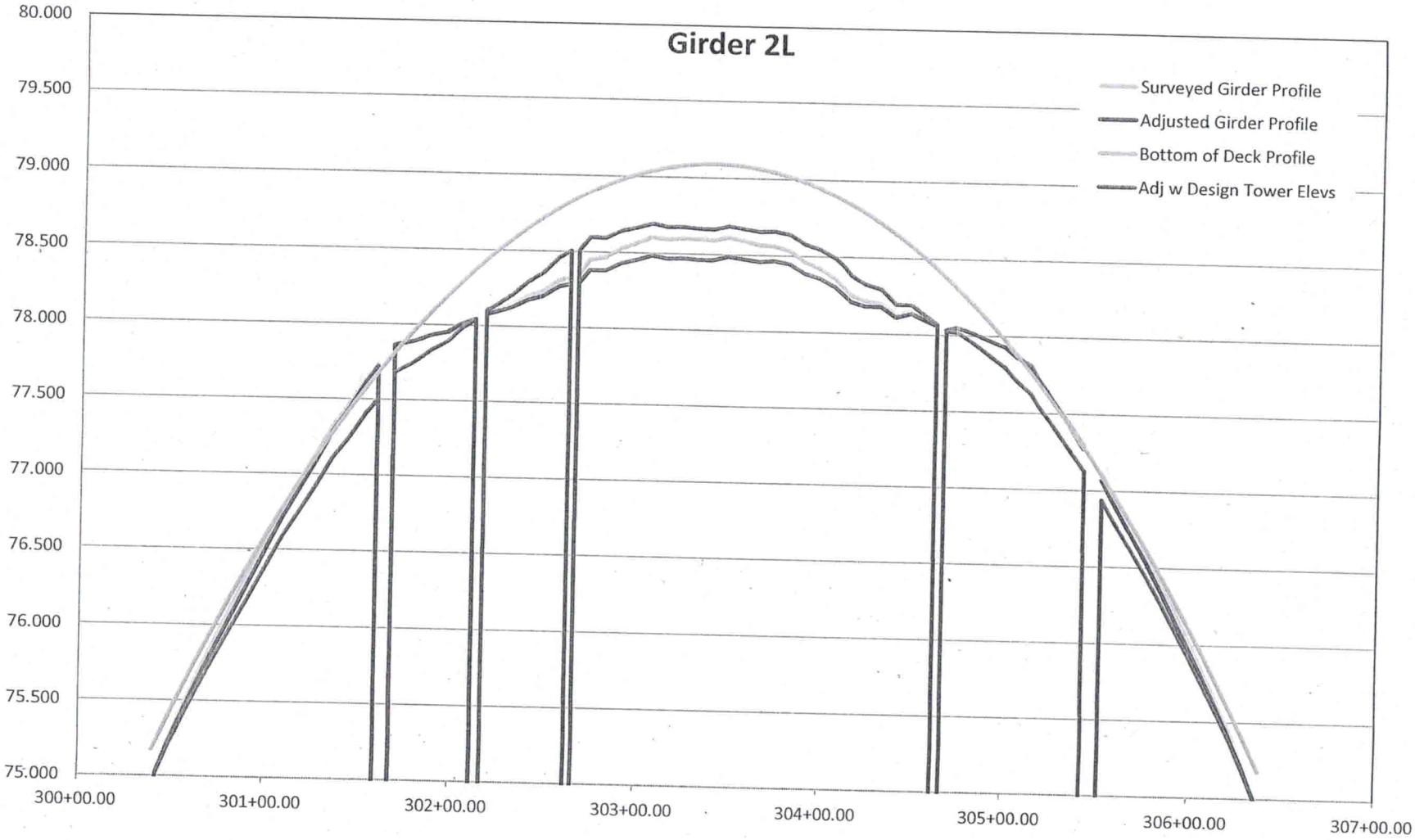
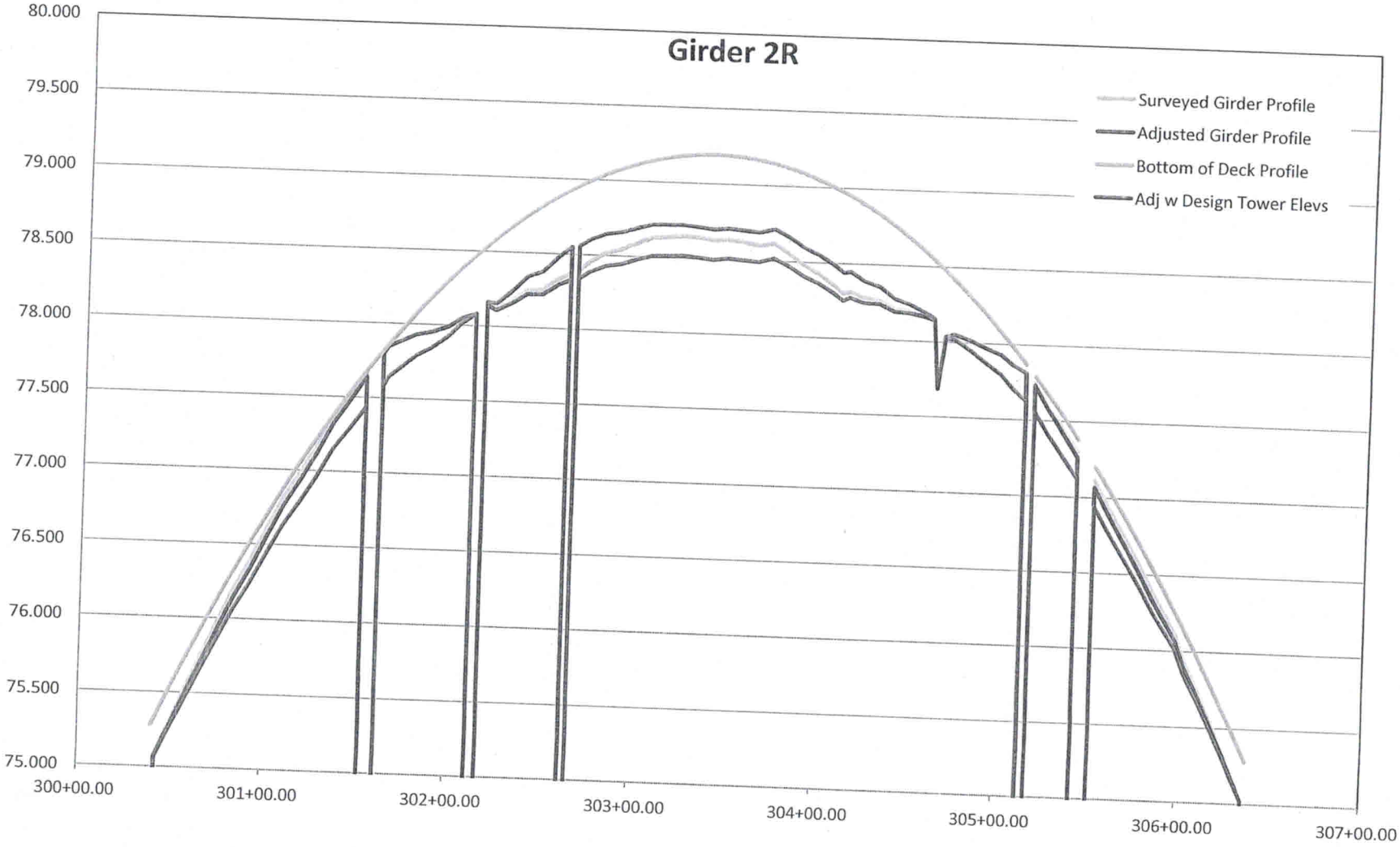
304+00.00
305+00.00
306+00.00
307+00.00



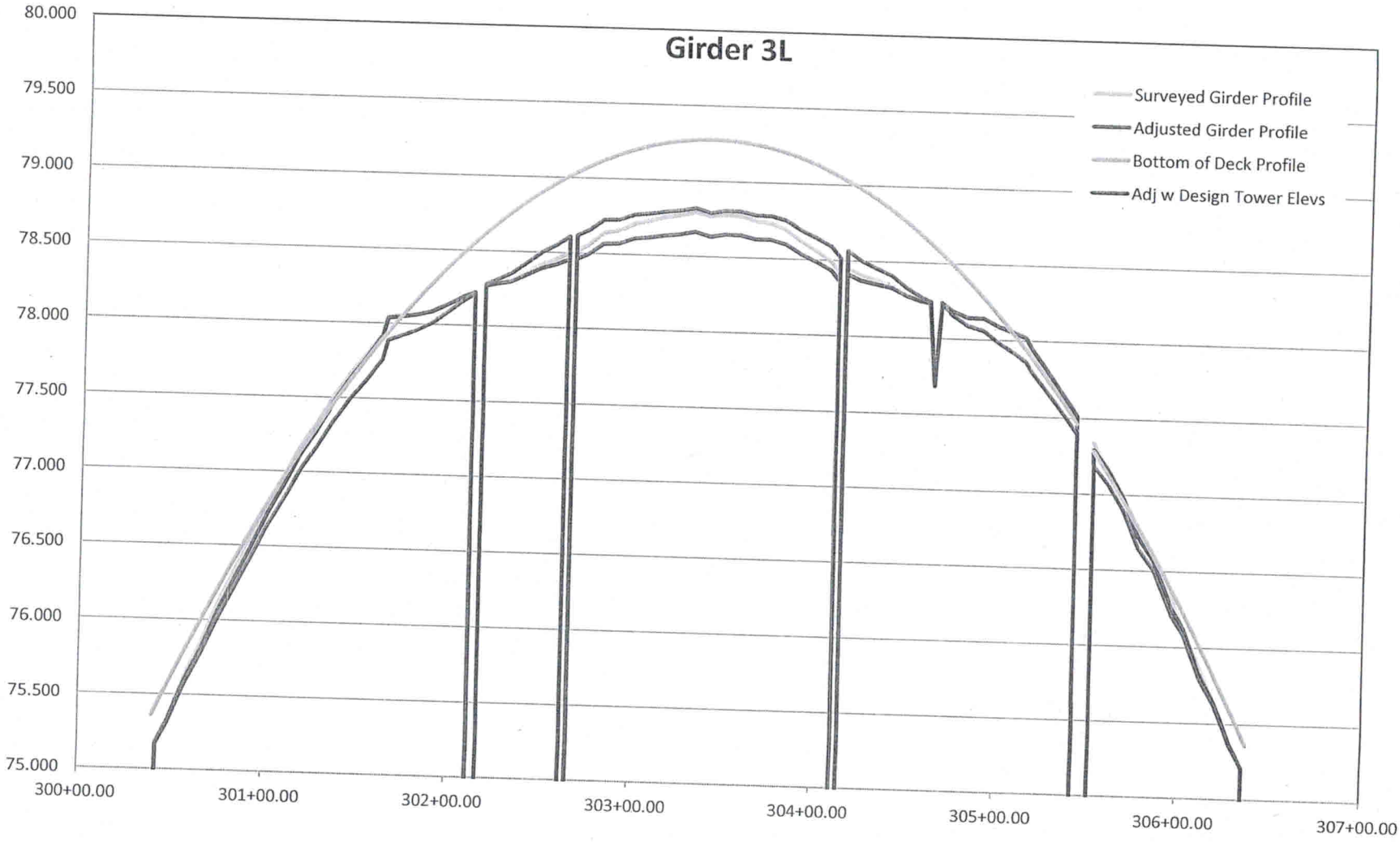
Girder Profiles w Consplice Adj - G2L

1/9/2013 4:54 PM



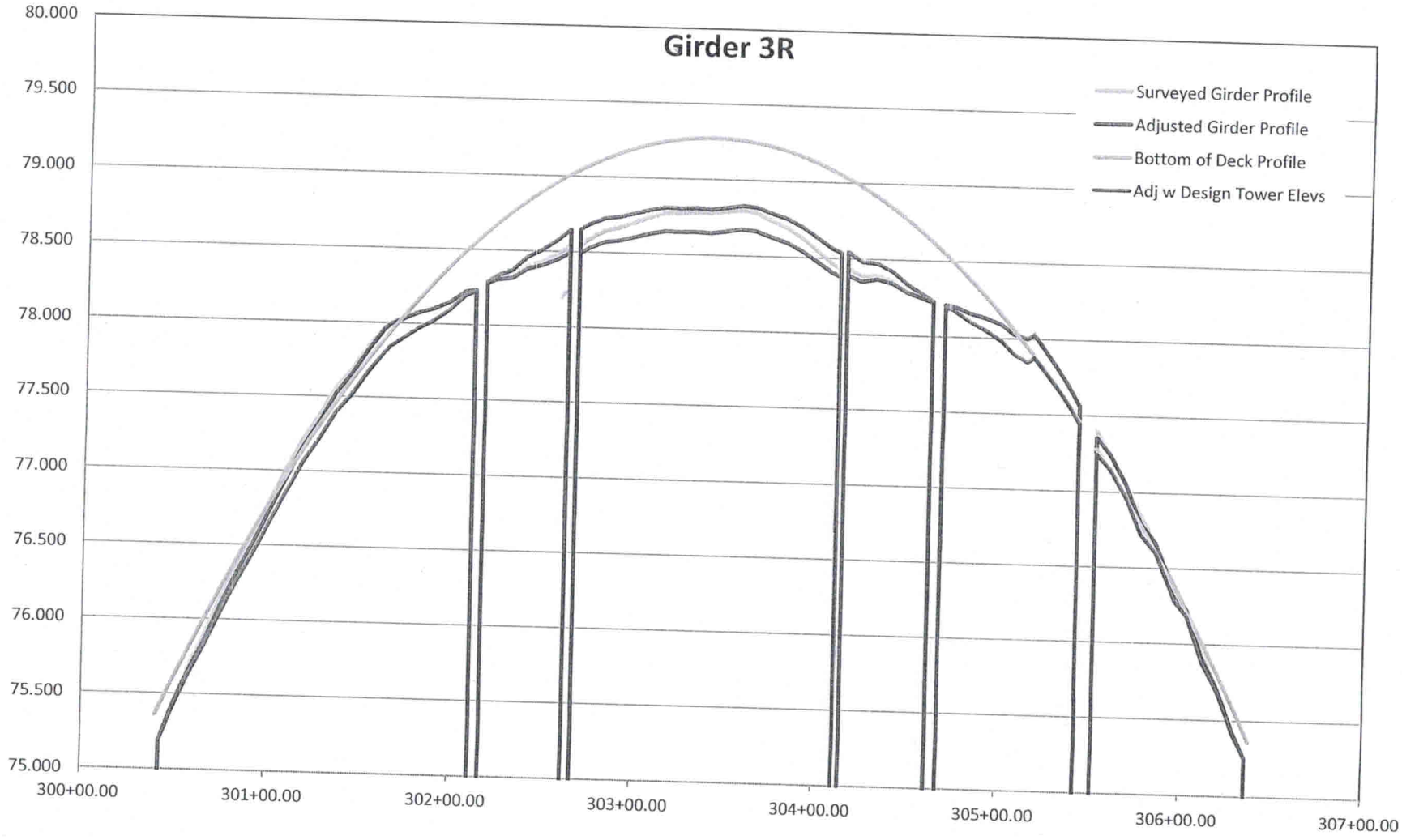
Girder Profiles w Consplice Adj - G2R

1/9/2013 5:34 PM



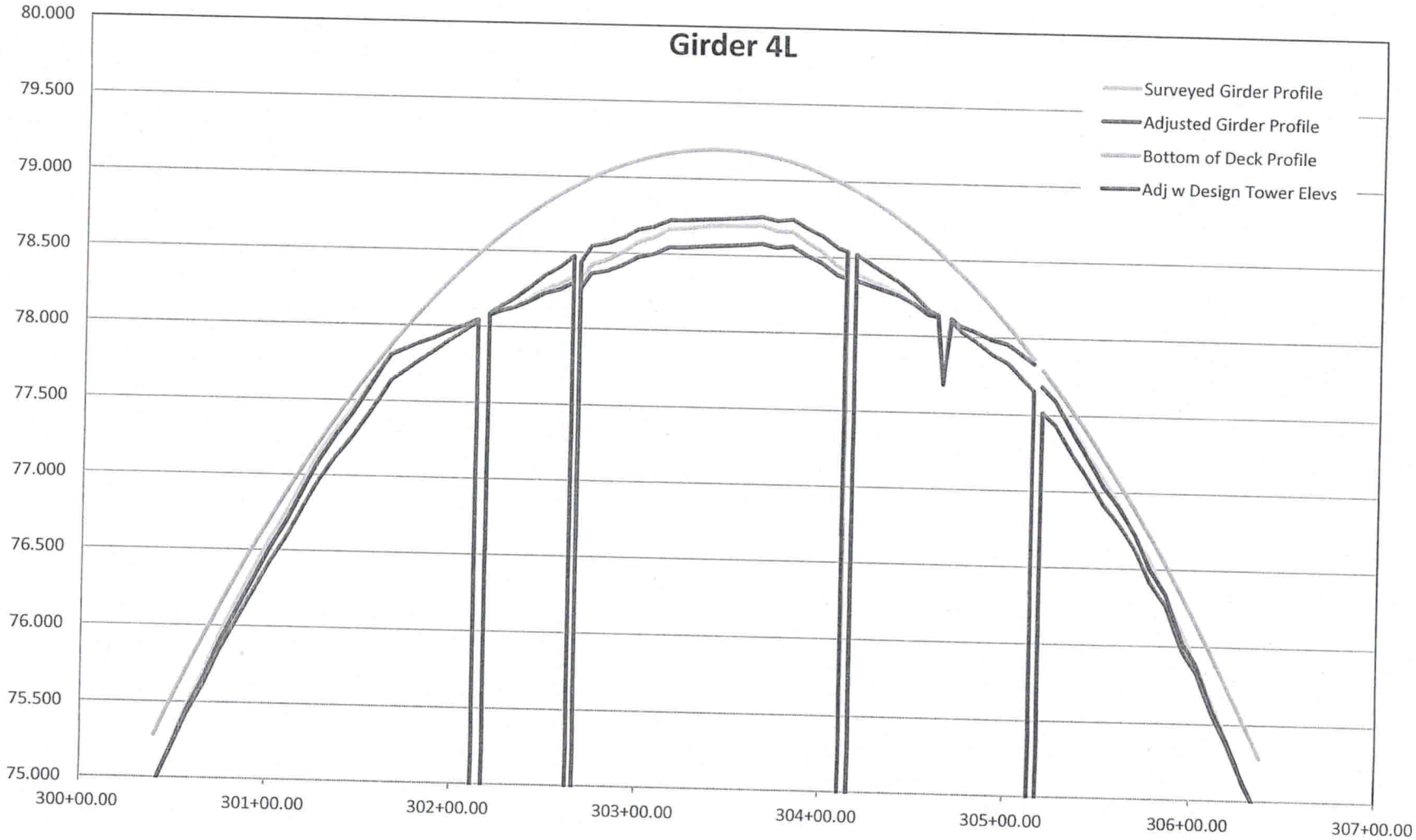
Girder Profiles w Consplice Adj - G3L

1/9/2013 4:58 PM



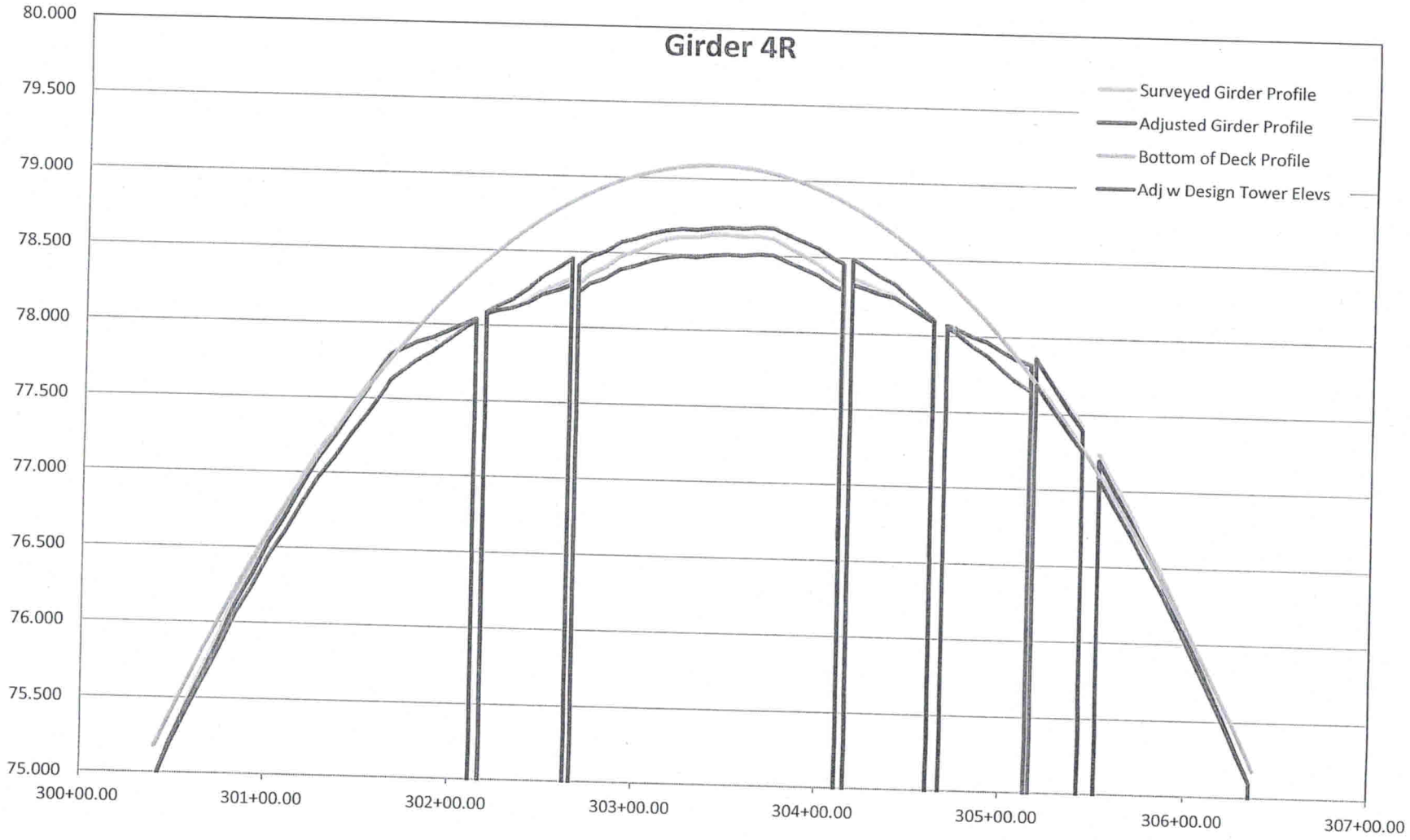
Girder Profiles w Consplice Adj - G3R

1/9/2013 5:01 PM



Girder Profiles w Consplice Adj - G4L

1/9/2013 5:11 PM



Girder Profiles w Consplice Adj - G4R

1/9/2013 5:13 PM

Girder Profiles w Consplice Adj - G5L

1/9/2013 5:16 PM