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16. Abstract

During the construction of the I-295 cable-stayed bridge, an extensive array of mechanical strain gage points were installed in sections of the box girders, pylons, and piers. At each instrumented box girder section, five longitudinal gages were placed on the deck surface and three longitudinal gages were placed on the bottom flanges of the box girder. Instrumentation was concentrated on the cantilevered north span and the two adjacent side spans. Strain measurements were taken throughout the erection of the cantilever span. Measured strains are reported on in this study. The measurements revealed a complex strain pattern across the deck, reflecting the existence of shea lag in the box girder, but also the influence of multiple post-tensioning tendons across the deck.

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# FIELD INSTRUMENTATION AND MEASURED RESPONSE OF THE I-295 CABLE-STAYED BRIDGE

## INTERIM REPORT ON CONSTRUCTION MEASUREMENTS IN DECK SEGMENTS

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Virginia Transportation Research Council
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## INTRODUCTION

### Background

In June 1986, investigators at the Virginia Transportation Research Council began implementing an ambitious plan for instrumenting the I-295 cable-stayed bridge during the construction phase with the intent of continuing field measurements of response during the in-service phase. Originally, the plan was to instrument deck segments, piers, and pylons on the south side of the bridge using electrical resistance strain gages mounted on dummy reinforcing bars and thermocouples connected to an automatic data acquisition system. This instrumentation is complete. Data obtained are under analysis and will be the subject of future reports.

The overall objective of this study is to evaluate the behavior and response of the I-295 cable-stayed bridge over the James River near Richmond, Virginia. This overall investigation and program of instrumentation seek to address a number of questions regarding cable-stayed bridge response for which only limited experimental data are available. In this regard, the results will add significantly to the general body of knowledge on cable-stayed bridge technology.

In the summer of 1987, the Federal Highway Administration (FHWA) requested that additional instrumentation be installed to monitor stresses in the major components of the bridge during the construction period. The additional work was initially concerned with data measurements on the north side of the bridge and primarily required instrumentation of the deck segments with mechanical strain gages and instrumentation of selected cable stays with electrical resistance strain gages. A separate work plan covering this supplemental investigation was submitted in November 1987 and approved in December 1987. As construction had just begun on the north cantilever at the time of the FHWA request, investigators immediately began to implement the additional instrumentation in late July 1987.

## Objectives

The objectives addressed in this report are those initiated by the FHWA in their 1987 request for additional instrumentation. Specifically, the report focuses on the objectives of the north cantilever deck instrumentation: to obtain surface strain data using mechanical strain gages on selected deck segments, piers, and pylon in order to monitor overall force distributions in the critical elements of the bridge during construction and to evaluate stresses and stress resultants in typical deck segments as a means of predicting load carrying mechanisms. The results presented emphasize surface strain data in the deck segments as determined by the mechanical strain gages and strain data obtained from electrical resistance strain gages on selected cable stays on the north cantilever.

This report documents the work performed on a particular phase of this research investigation from July 1987 through April 1989. As of that date, the bridge erection was nearing completion but construction was still in progress on the south cantilever of the main span. Specifically, this report considers the strains measured in various deck segments during the erection of the north cantilever of the main span by a Whittemore demountable extensometer and a large number of gage points installed shortly after casting. Some mechanical strain gage data acquired during the erection of the south cantilever are also briefly discussed.

## Description of Bridge

The I-295 bridge is a segmentally erected, precast, post-tensioned, cable-stayed box girder bridge that consists of 31 individual spans, including approach spans. The approach spans are each 150-ft-long precast box girder segments with external post tensioning continuous over 6 spans and were constructed by the span-by-span method.

The portion of the structure that was the focus of this investigation consisted of the central 7-span continuous section, which includes the 630-ft main span over the river and the 3 approach spans on either side. An elevation sketch of this portion of the bridge is shown in Figure 1. The middle 5 spans of the bridge, including the main span, are supported by 26 cable stays arranged in a single plane harp configuration and emanating from two pylons, one on either side of the river. Cable-stay forces are transferred to the twin box girders through precast delta frame assemblies located between the girder segments at each stay location as shown in the cross-section sketch of Figure 2. Figure 3 illustrates the detail of the cross section at one of the main pier/pylon locations. The main span over the river was constructed as two cantilevers extending from the two piers located adjacent to

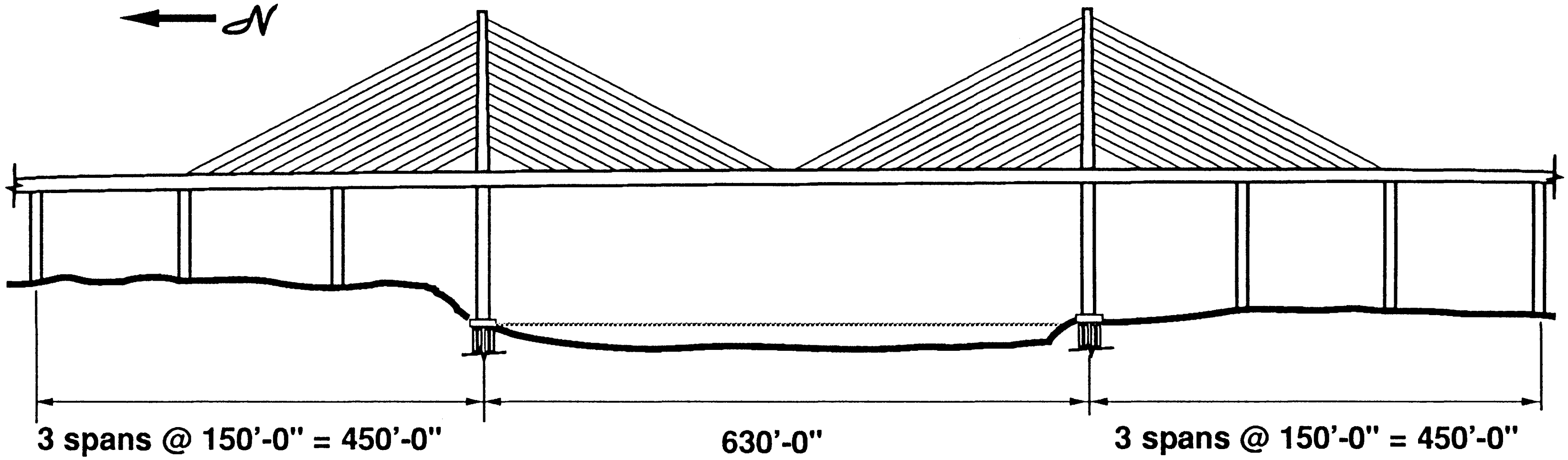


Figure 1. Elevation of the I-295 James River Bridge

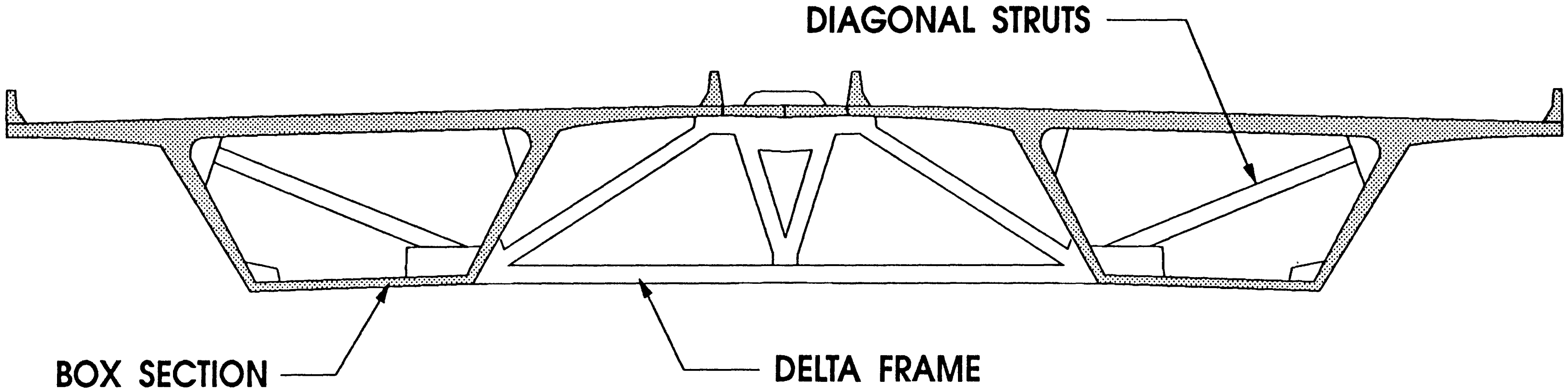


Figure 2. Transverse Cross Section at Stay Anchorage

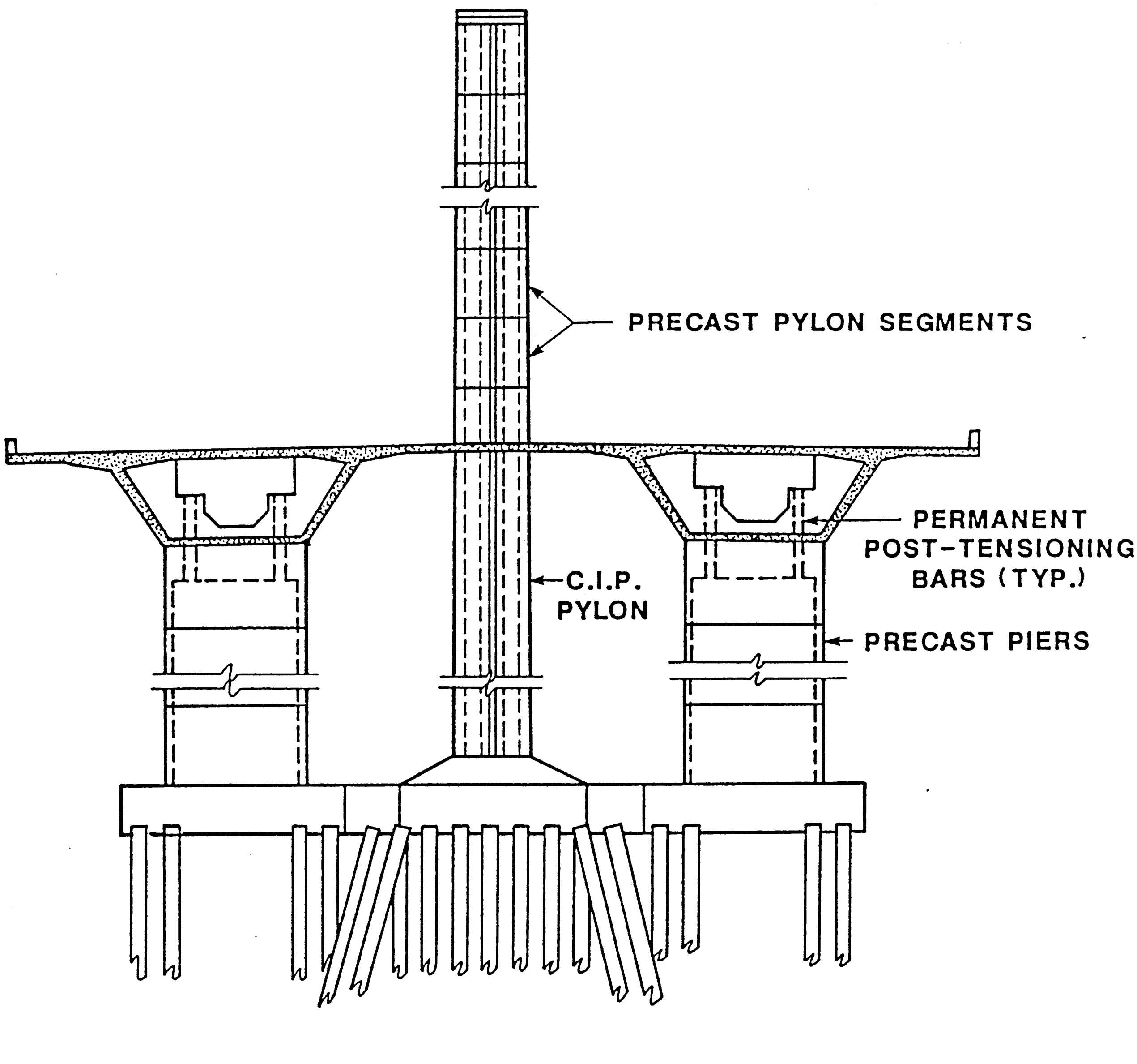


Figure 3. Bridge Cross Section at Pier/Pylon Locations

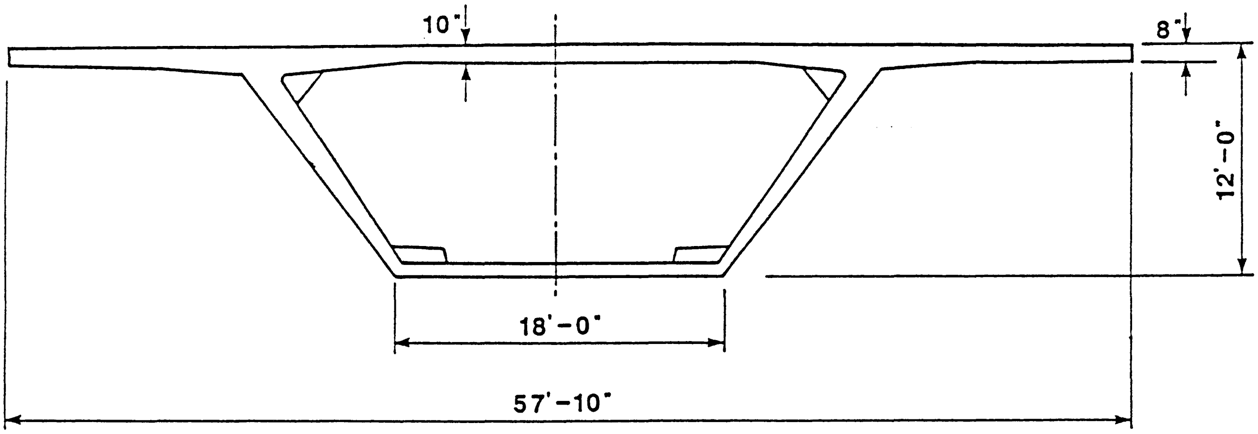


Figure 4. Typical Segment Dimensions

the pylons and made continuous by a midspan closure pour. Typical main span segments are 10 ft long, and cross-section dimensions are shown in Figure 4. Post tensioning consisted of two parts: temporary bars placed for tensioning to assist in construction and permanent strand post tensioning, located inside the box segments, installed after major erection was complete.

### Project Status

At this writing, construction on the bridge is complete. All transducers proposed in both the original and supplemental work plans have been installed, and the data acquisition system is operational.

## METHODOLOGY

### Mechanical Strain Gages

Instrumentation of the deck segments, piers, and pylon on the north cantilever using mechanical strain gages was undertaken to provide information relating to the behavior of the major components of the bridge during construction. The construction schedule required installation of this supplementary instrumentation to proceed immediately and, consequently, efforts of the research team were directed toward instrumentation on the north side of the bridge.

In order to permit instrumentation to proceed expeditiously, the investigators based the north side instrumentation on the use of an old Whittemore strain gage, which is essentially a portable, demountable extensometer with a gage length of 10 in. Gage points installed into the sections were constructed out of brass plugs. Installation consisted of drilling a slightly oversized hole into each deck segment at the location of the gage point, inserting the plug into the hole, and grouting with Duracal nonshrink grout. After the grout had dried, the precise locations of the holes for the extensometer were located by a scribing device provided with the Whittemore gage and drilled by an electrical drill and a small metal bit. A second extensometer with a gage length of 10 in purchased from Soiltest was found to be insufficiently accurate for the measurements being taken. Consequently, all measurements on the north cantilever were made with the Whittemore gage.

Similar, although less extensive, instrumentation was planned for the south side of the bridge as well. By the time instrumentation of the south side began, the durability, although not the accuracy, of the Whittemore gage had come into question, so two additional Demec demountable extensometers were purchased from the W. H. Mayes company in England. These gages were found to be excellent but could not be used on the north half of the bridge because they were based on a gage length of 250 mm. The 4-mm difference between this nominal gage point spacing and the spacing of the Whittemore gage points precluded interchangeable use of the gages.

The major portion of the instrumentation was concentrated in the deck segments in the main span and in the two adjacent approach spans, although limited instrumentation was installed in selected pier segments of piers 17 and 18 and in the pylon. This instrumentation was intended to supplement the electronic instrumentation already planned for the south side. It was also intended to provide additional information on construction stresses on the bridge and to permit some conclusions to be drawn regarding such factors as shear lag in the deck segments as a result of the introduction of stay forces.

A total of 20 deck segments, 2 box segments at each of 10 longitudinal sections along the deck on the north side, were instrumented with the mechanical strain gages. Of these 10 sections, 6 sections corresponding to 12 box segments were located in the main span cantilever, span 16; 3 sections (6 box segments) were located in the first adjacent approach span (span 17); and 1 section (2 box segments) was located in the next adjacent approach span, span 18. In each of the 20 deck segments, eight mechanical gage points were installed along a transverse section: five gage points located across the top surface of the deck and three gage points located inside the box segment across the lower flange. This gage layout, typical of the instrumentation in all box segments, is depicted in Figure 5. Figure 6 shows the locations of the instrumented box girder sections along the north cantilever

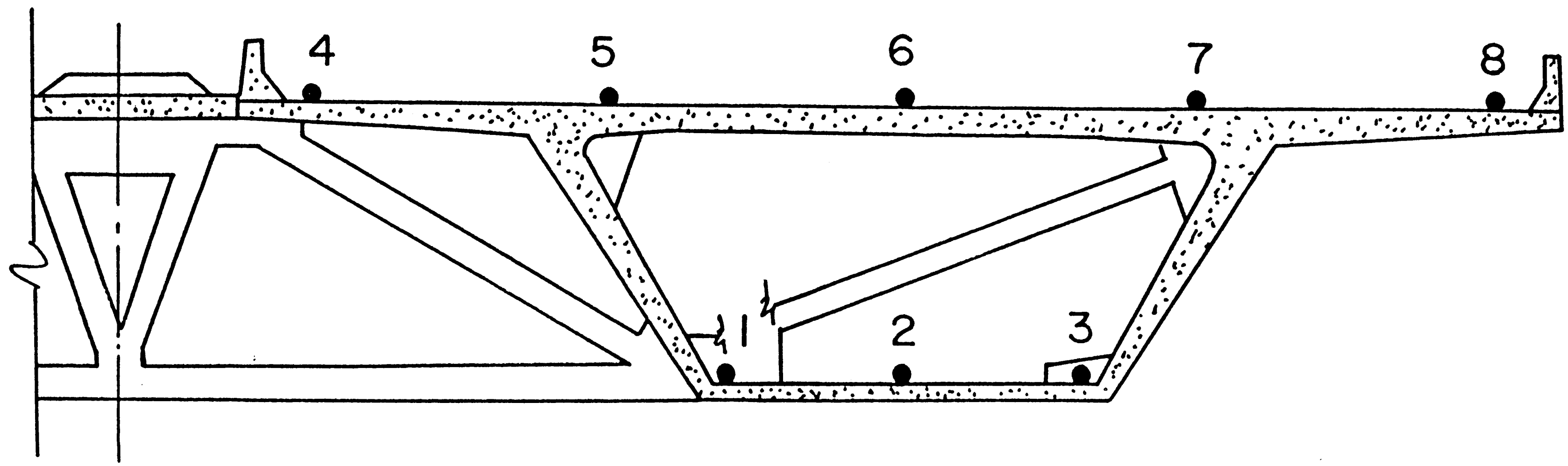


Figure 5. Location of Whittemore Gage Points on a Typical Instrumented Box Section

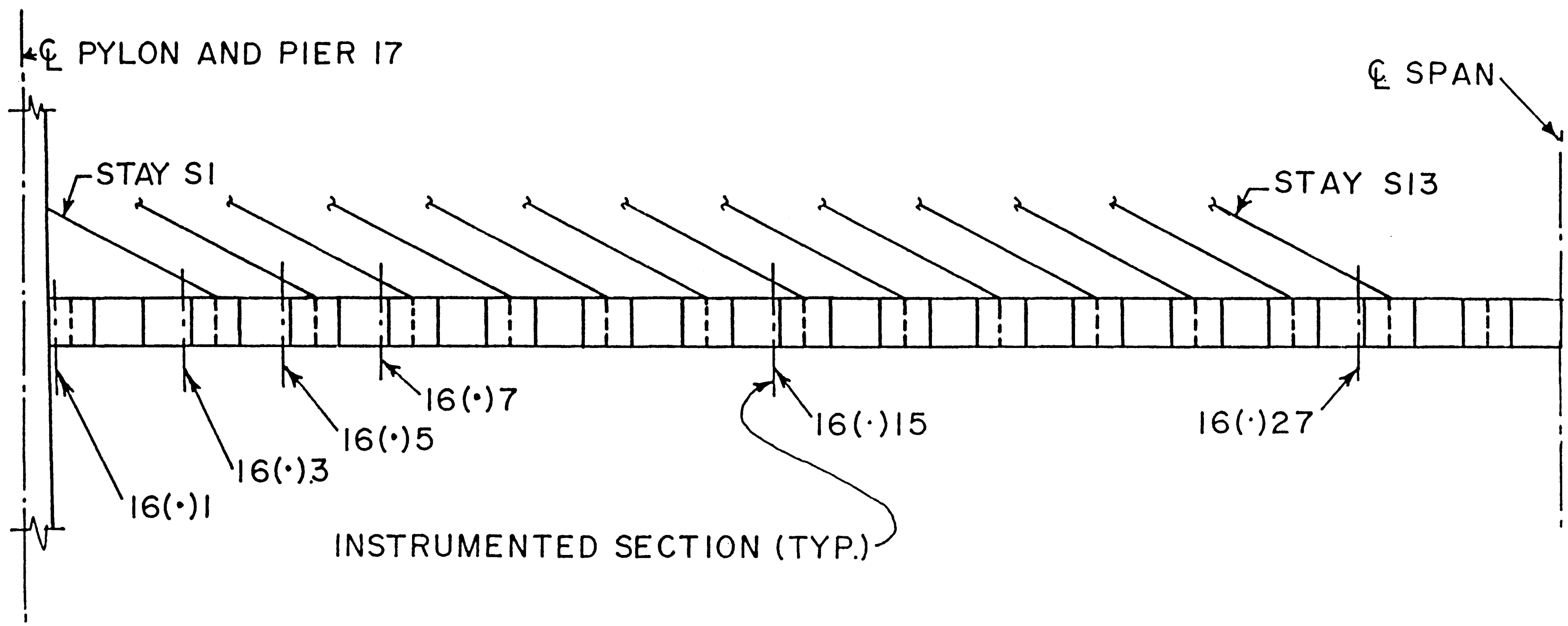


Figure 6. Location of Whittemore Gage Points on the North Cantilever of the Main Span

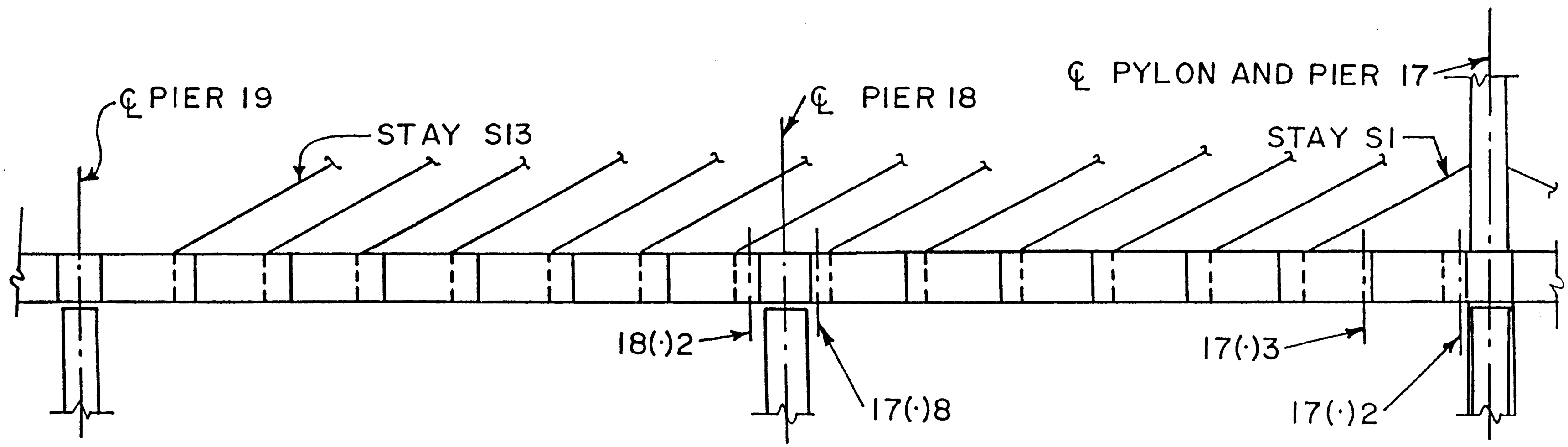


Figure 7. Location of Whittemore Gage Points on the North Shore Side Spans

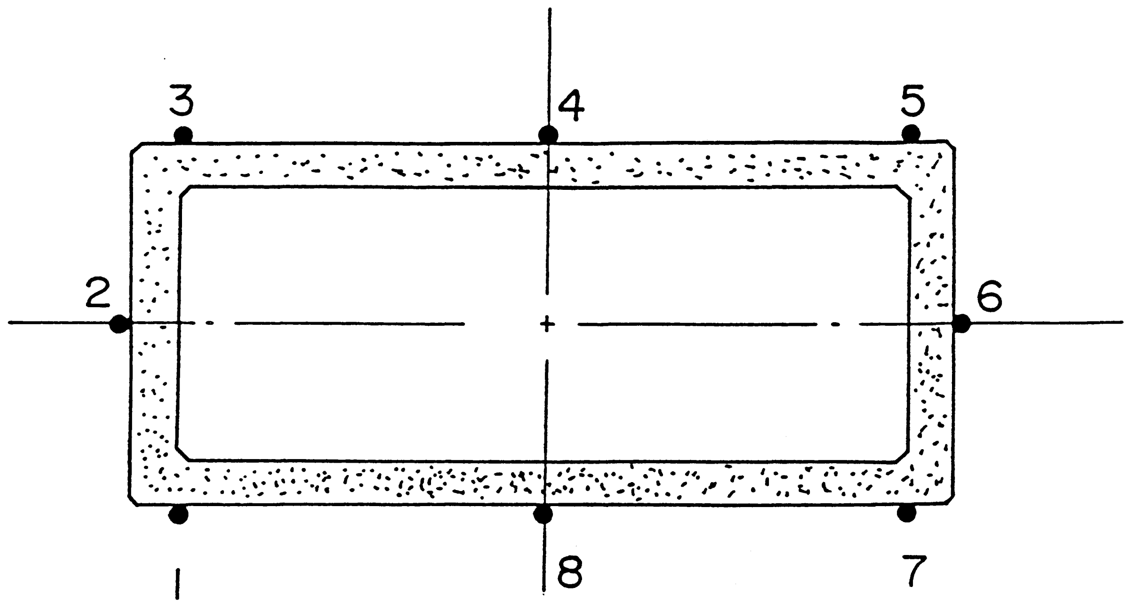


Figure 8. Locations of Vertically Oriented Whittemore Gage Points on Pier Sections

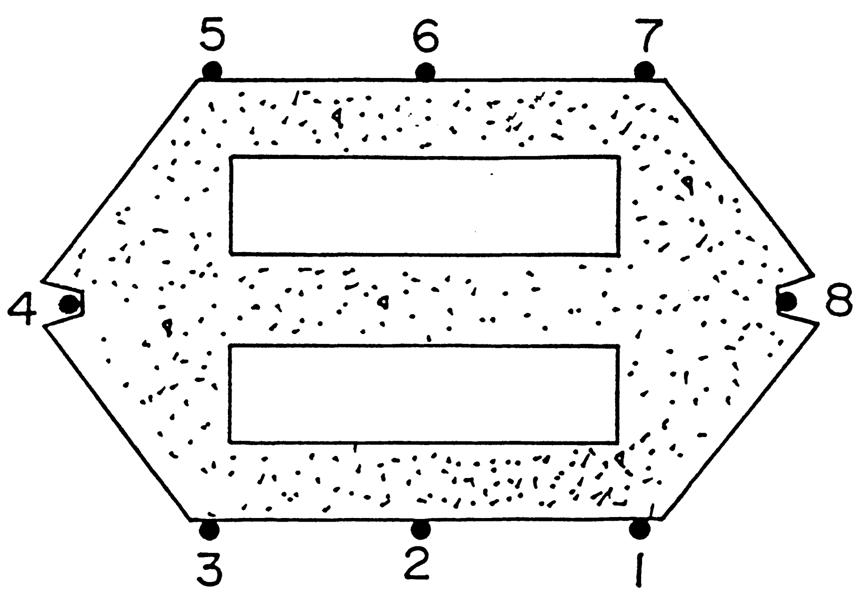


Figure 9. Locations of Vertically Oriented Whittemore Gage Points on Pylon Sections

of the main span, and Figure 7 illustrates the locations of the instrumented sections along side spans 17 and 18, directly north of the main span. The smaller number of segments on the side span correspond to a 20-ft segment length.

In addition to the 160 gages installed in the deck segments, four pier segments and one pylon segment were instrumented with mechanical strain gages. The pier segments consisted of one segment in each of the two piers comprising piers 17 and 18, thus providing two segments in each of the northbound and southbound lanes. Each of the pier segments instrumented was located at the base of the pier, providing easy access for installation and data collection from the ground. Eight mechanical gage points were installed in each pier segment approximately 5 ft above the footing at locations indicated in Figure 8.

Finally, two locations in the cast-in-place portion of the north side pylon were instrumented with mechanical gages. One segment was at ground level approximately 5 ft above the footing, and one segment was located just above deck level. Eight mechanical gages were installed in each of these two segments at the locations shown in Figure 9.

The longitudinal strains as determined by the gages installed on the box segments allow a reasonably complete determination of the longitudinal strain distribution throughout the deck and lower flange portions at the instrumented section of these elements as well as changes in strain that occurred as a result of the various construction and erection activities. In particular, the longitudinal strains along the top and bottom sections of the box girder permit a realistic estimate to be made of the axial compression developed in each section and the bending moments developed in these sections. These longitudinal strains, particularly those along the upper surface of the box sections, provide a clear picture of the distribution of the stresses in the deck segments as a result of axial loads produced by post tensioning of the spans or by tensioning of the stay cables. In the case of stay tensioning, which produces concentrated in-plane axial compression as well as bending of the section, the strains measured thus far permit an evaluation of the shear lag that can be expected in these segments when large in-plane forces are introduced in the precast, post-tensioned elements.

In evaluating and interpreting the strain data obtained from mechanical gages, certain characteristics of these gages as well as certain problems encountered in reading the gages should be kept in mind. Because of the very nature of mechanical strain gages, the data from these gages represent only surface strains in box segments whose flange and web thicknesses range from 8 to 12 in. Also, although strains were recorded periodically from the time of casting, it was not possible to obtain a consistent zero reading from all gages in the instrumented segments. In particular, several segments to be instrumented on spans 17 and 18 had already been erected at the time the FHWA requested the additional instrumentation. Consequently, most of the data are presented in terms of strain increments rather than absolute strains. The strain increments represent the difference between strain readings immediately preceding and following a particular construction activity, such as segment lifting or stay tensioning. In evaluating the effect of a certain activity on loads within the segment, it is the changes in strain that are of interest, so this is the more appropriate strain value to use in any case.

A number of minor problems encountered during the study contributed to the difficulties in analysis of the strain data. One unavoidable difficulty was the quality and reliability of the Whittemore mechanical strain gage used during the early stages of the investigation. When this phase of the study was initiated, construction was already in progress and data collection had to begin immediately. Until a new gage could be ordered and delivered, the only alternative was an old Whittemore gage which was available from an earlier field study. This gage was used until a new Demec gage, a much more reliable instrument, was acquired. Even after the Demec gage arrived, the difference in gage length dictated that the Whittemore gage continue to be used on those gages already installed. The Whittemore gage provided reasonably accurate readings of strain. However, the Whittemore gage extensometer points are separated by several small flat springs that over the period of the project showed a tendency to break. These springs were particularly sensitive to any impact but also appeared to develop tears after several months of routine use. It was found possible to replace these springs fairly easily, but each time it was necessary to repair the gage, at least one set of readings was lost. A more significant problem was that the gage behavior would slowly deteriorate as a spring tear developed, leading to a loss of accuracy. Moreover, whenever the springs had to be replaced, a shift in gage readings occurred. This shift could be measured and taken into account using the reference bar provided with the Whittemore gage but did prove to be inconvenient, at least.

Another minor problem involved the personnel used in data collection. The pace of construction required that gages be read quite frequently, which was not possible using only the staffing of the research team. State inspection trainees who were resident on the job site were made available to the project on an as-required basis. Although these individuals have provided much needed assistance in the overall data gathering operation, their inexperience with the research project and unfamiliarity with the use of the mechanical strain gage did create problems and contributed to the development of questions regarding the reliability of certain of the readings. Since that attempt, research staff have performed all of the gage readings with the assistance of the inspection staff.

Another difficulty in data collection and analysis was the construction and erection schedule of the contractor. There were frequent instances when the research team learned of a particular construction activity for which strain readings would have been desirable but had insufficient time to make arrangements for data collection prior to completion of the activity. One example is stay tensioning, which is of such a nature that the contractor's personnel themselves could not predict with any reasonable degree of certainty when an event would occur.

Actually taking the gage readings during construction activities could be quite time-consuming. Numerous difficulties were encountered as a result of inaccessible or difficult-to-find gage points. The contractor's equipment on the bridge (cranes, trucks, lifting cranes, generators, etc.) covered the gages at times, resulting in incomplete data collection. Moreover, many of the mechanical gage points, and especially those located inside the box segments, were grouted over on numerous occasions. In several cases, the gage points located near the lower web-flange junction were covered with up to 5 in of grout, which had to be chipped away. Several of these gage points tended to be flooded with water that had drained into the box from the deck above. When it was necessary to clear away grout or water covering a set of gage points, it was also necessary to clean out the gage point in question. This had to be done with extreme care to avoid damaging the gage points or changing the readings. It was difficult to ensure that the technicians involved in taking the readings were sufficiently careful in cleaning out the gage points or in getting all possible data, as this process could be quite time-consuming. On several occasions, teams of three or four people would be employed, two people taking readings, and one person clearing grout, water, dirt, and debris from the most badly obscured gage points. On such occasions, up to 5 hr might be required to obtain a single set of readings. Although none was employed on the present project, it appears that a removable cover for the gage points might be invaluable in terms of reducing time for gage cleanout and increasing the reliability of readings.

Proper evaluation and interpretation of the strain readings were complicated by the variety of activities that occurred within a very short period of time during construction. Since the process of taking the readings was quite lengthy, it was often difficult to isolate and identify the exact cause of changes in strain that were observed in readings taken only a few hours apart. For example, during the interval between strain readings, not only would stay tensioning have occurred, but partial post tensioning of the deck may have occurred, major equipment may have been relocated on the deck, and other changes may have occurred that could have had an effect on the strain readings finally recorded. In one instance, a set of readings begun immediately after stay tensioning was influenced by the repositioning of the four 35-ton Morgan lifters and the lifting of two 70-ton box segments, all of which occurred within the time period needed to take the readings. The investigators noted and recorded all such activities whenever possible, but such events are quite difficult to take into account in data analysis, since it was difficult to be sufficiently precise about the exact event time, the exact event nature, and the particular group of readings out of the total set that were actually effected. For example, relocation of a truck crane on the cantilever could be noted, but without exact knowledge of the positions before and after the move and the weight of the vehicle, quantitative assessment of the influence of the activity is difficult.

All data presented in the sections that follow are in terms of strain or strain increments, rather than stresses. However, if it is assumed that the stresses developed in the top deck surface and bottom flange of the box segments are predominantly uniaxial in nature (i.e., governed by beamlike behavior), a reasonable estimate of the stress or stress increment can be obtained by simply multiplying the strain value by the modulus of the concrete, which has been calculated to be between 4.0 and 4.46 million psi.

In the discussion that follows, it is helpful to understand the relative locations of the various segments and stay cables. The locations of the various bridge elements relative to each other are shown in Figures 6 and 7. The deck segments are designated by a number that identifies the span, the segment number within the span, and whether the segment is part of the northbound or southbound lane. Thus, for example, segment 16-N5 is the fifth segment in the northbound lane of span 16, which is the main span. Segments are numbered consecutively from the pier/pylon to the bridge center line, as are the stay cables. On the main span, stay 1 connects to a delta frame (shown dotted in Figure 6) located at segment 4 of the main span. Subsequently, delta frames and stay connections are located at every other segment. Thus the delta frame for stay 2 is located at segment 6, the delta frame for stay 3 is located at segment 8, etc., and finally the delta frame for stay 13 is located at segment 28.

## RESULTS AND DATA ANALYSIS

### Changes in Segment Strains Attributable to Stay Tensioning

Changes in strain as a result of the tensioning of a stay, and any associated prestressing that occurred at the same time, are presented in Figures 10 through 16 for a number of segments and several stays. Figures 10 and 11 depict the incremental strain produced in segments N1 and S1 of span 16 attributable to the tensioning of stays 6 and 9. These deck segments are immediately adjacent to the pier segments at pier 17 and thus likely reflect what the effects of stay tensioning might be at a support. As shown in the figures, the stressing of stay 6 had an essentially negligible effect on strains near the piers. However, tensioning stay 9 produced average compressive strains in the deck on the order of 100 to 200 microinches per inch. As will be observed later, the compression in the deck from stay tensioning was attributable in part to direct axial compression and in part to bending, as evidenced by tensile incremental strains in the lower flange. Delta strains in segment N3 for the tensioning of two stays are plotted in Figure 12. These results are similar to those observed for segment 1, indicating a relatively small effect from the tensioning of a single stay.

Changes in strain in segments N5 and S5 of span 16 attributable to the tensioning of representative stays are shown in Figures 13 and 14. In these cases, as with previous segments, the strain increments during these periods are compressive in nature and, in magnitude, less than 100 microinches per inch. In the light of the limited precision of the Whittemore gage, these delta strains are consistent with the loads imposed by the stays and are relatively small. In none of these cases is there any indication of shear lag in the transverse distribution of the strain increments. This may be attributable in part to the small magnitude of the strain changes or to the fact that certain of the changes recorded may have been attributable to both

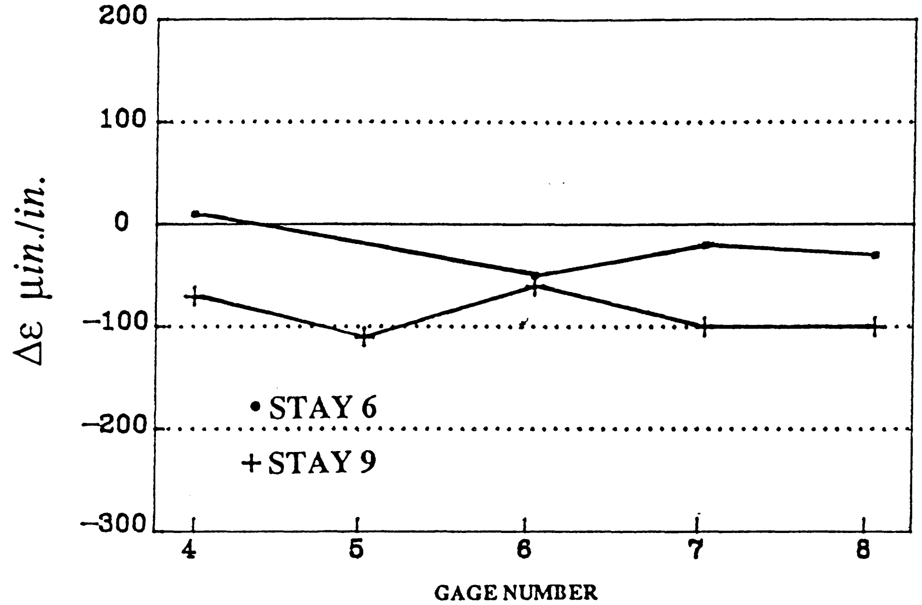


**Figure 10. Strain Increment in Segment 16-N1**

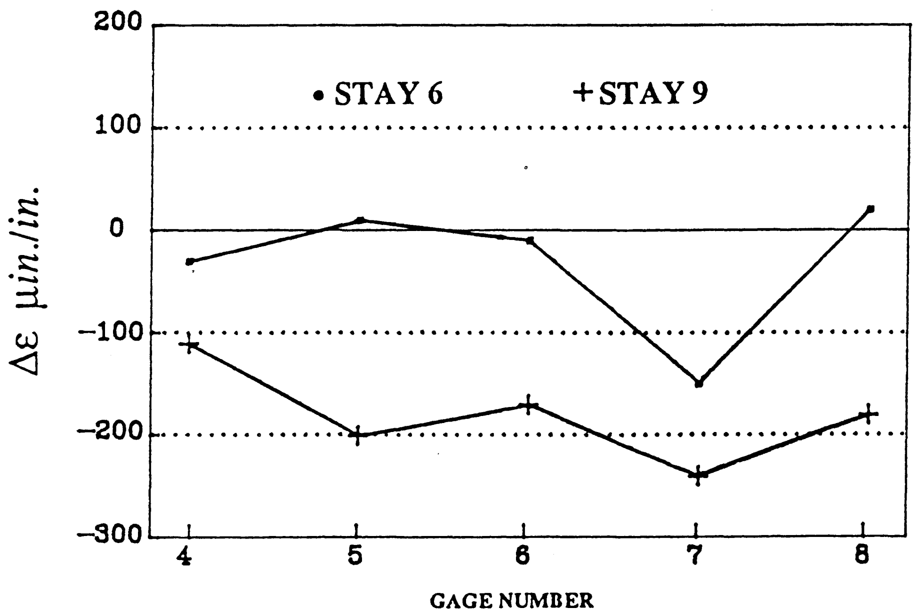


**Figure 11. Strain Increment in Segment 16-S1**

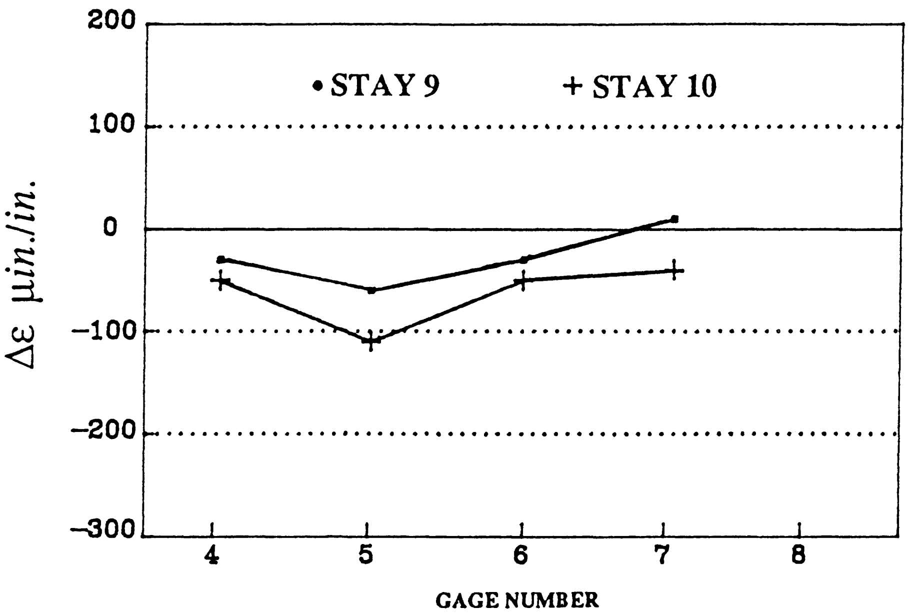


Figure 12. Strain Increment in Segment 16-N3

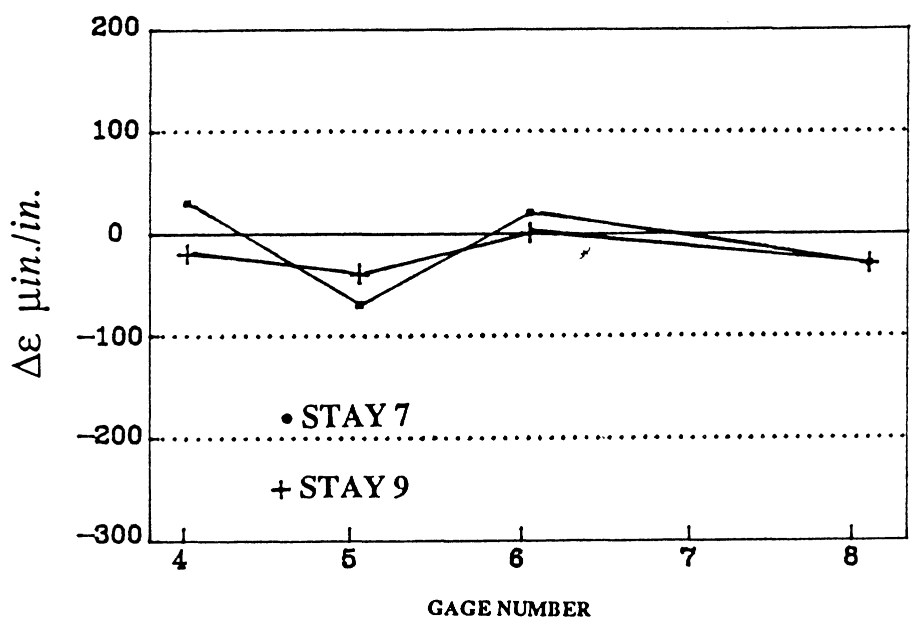


Figure 13. Strain Increment in Segment 16-N5

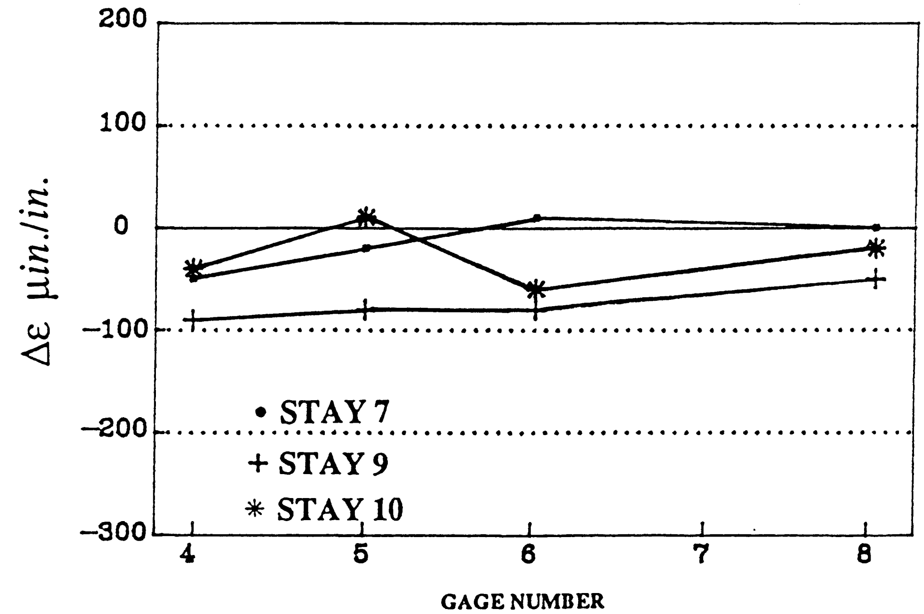


Figure 14. Strain Increment in Segment 16-S5

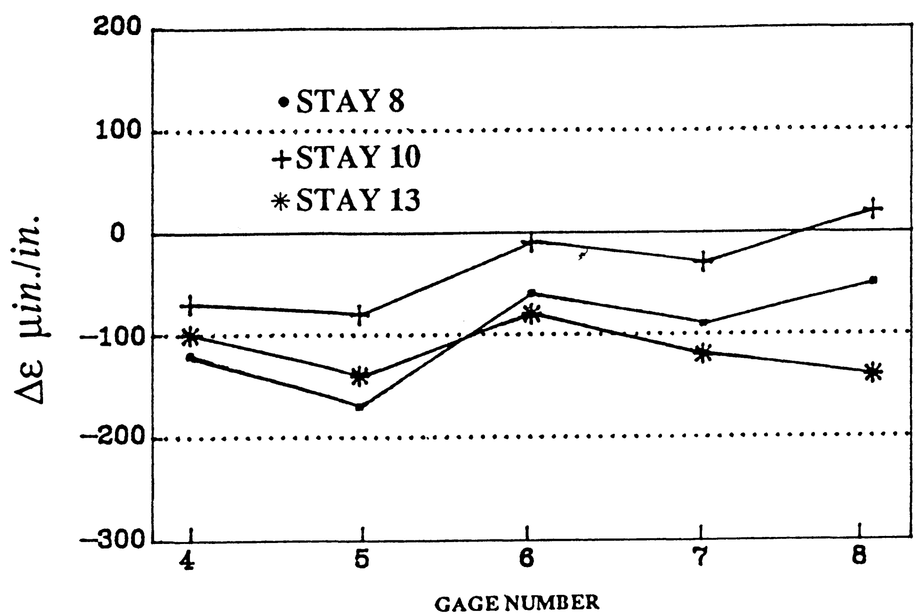


Figure 15. Strain Increment in Segment 16-N15

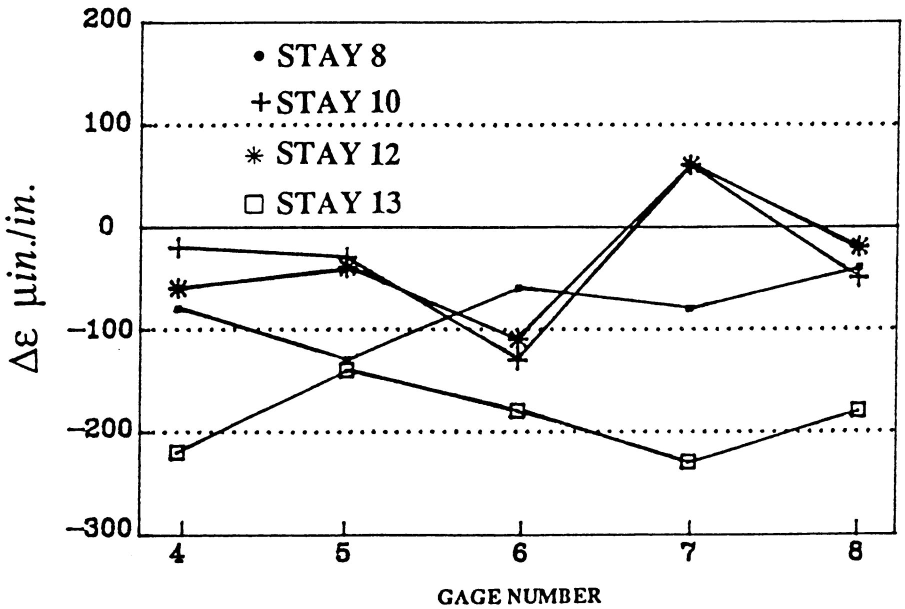


Figure 16. Strain Increment in Segment 16-S15

permanent and temporary post tensioning, which would produce a more uniform strain distribution. In fact, many of the strain readings show a somewhat larger strain increment over the web-flange junctions, which are near the location of some of the permanent longitudinal post tensioning.

Segments N15 and S15 near the quarterspan were also instrumented with mechanical gages. Results from these locations are shown in Figures 15 and 16. Figure 15 indicates the effect of the installation of stays 8, 10, and 13 on the longitudinal strains in segment N15. Figure 16 shows similar effects on segment S15 attributable to stays 8, 10, 12, and 13. The changes in strain at this location are somewhat more pronounced than observed nearer the pier, as evidenced by average compressive strain increments as much as 200 microinches per inch, and the changes are not so uniform across the segments as observed earlier. Also, in both of these segments, there is for the first time a definite suggestion of shear lag indicated by larger compressive increments closer to the interior. Even though there is considerably less uniformity, it is of interest to note the consistency of this variation for several of the stay installations. It is believed that a very complex pattern of shear lag has, in fact, developed, but that the stay cable horizontal components are not dominant relative to the longitudinal post tensioning.

## North/South Strain Symmetry

The strain data recorded for the deck and lower flange of the deck segments also permit an evaluation of the symmetry of the stay loading, i.e., whether or not similar strain patterns are observed in corresponding segments of both the northbound and southbound lanes. These data are presented in Figures 17 through 21.

Changes in strain in segments N1 and S1 of span 16 attributable to tensioning of stay 9 are shown in Figure 17. Although the magnitude of the strain increments is larger in S1, the pattern of strain distribution is very similar for both segments. Figure 18 depicts strain increments in segments N5 and S5 attributable to tensioning the same stay. In this case, also, the strain increments in the southbound lane segment are slightly larger, i.e., larger compressive strains, but there is still a fairly uniform distribution and the magnitudes, though different, are still close to the same level. Examination of the delta strains in segments N15 and S15 attributable to tensioning of stay 8, as shown in Figure 19, indicates not only the same pattern of strain distribution but almost identical magnitudes as well.

A similar response pattern emerges when strain changes in the lower flanges are considered. Figure 20 shows the changes in strain in the lower flanges of segments N15 and S15 when stay 10 is tensioned. These strain increments are all tensile in nature, indicating the bending introduced by the stay installation. The increments are also very similar in both magnitude and distribution. A similar conclusion can be drawn regarding the strain changes in these same two segments attributable to the tensioning of stay 13 as indicated in Figure 21, although the magnitudes are somewhat lower. This would seem to indicate that the effect of bending at this location is diminished when the stay being stressed is some distance away.

In many of the preceding figures, the fact that some segment post tensioning frequently occurred about the same time as the stay tensioning likely accounts for the nonuniform distribution of changes in strain during these particular activities.

## Strains in Deck and Lower Flange

To gain a more complete picture of the strain distribution that occurs in a box segment during stay or segment tensioning, it is useful to examine strain increments in both the deck and lower flange attributable to a particular event. Although construction activities and other typical impediments frequently made it difficult to obtain a complete set of gage readings on all gages in a segment, particularly those inside the box along the lower flange, sufficient readings were obtained to provide an indication of the behavior of the total segment during tensioning. These results are shown in Figures 22 through 27.

The distribution of change of strain in the deck and lower flange of segment S7 attributable to tensioning of stay 10 is shown in Figure 22. In this case, the stay is some distance from the segment and distribution of strain increment is fairly uniform. As may be observed from the figure, the deck strains are generally compressive whereas the strain increments in the lower flange of the box are always tensile, again indicating the bending that occurs in the box attributable to tensioning. These strain distributions also indicate that some shear lag does occur in both the top and bottom of the segments.

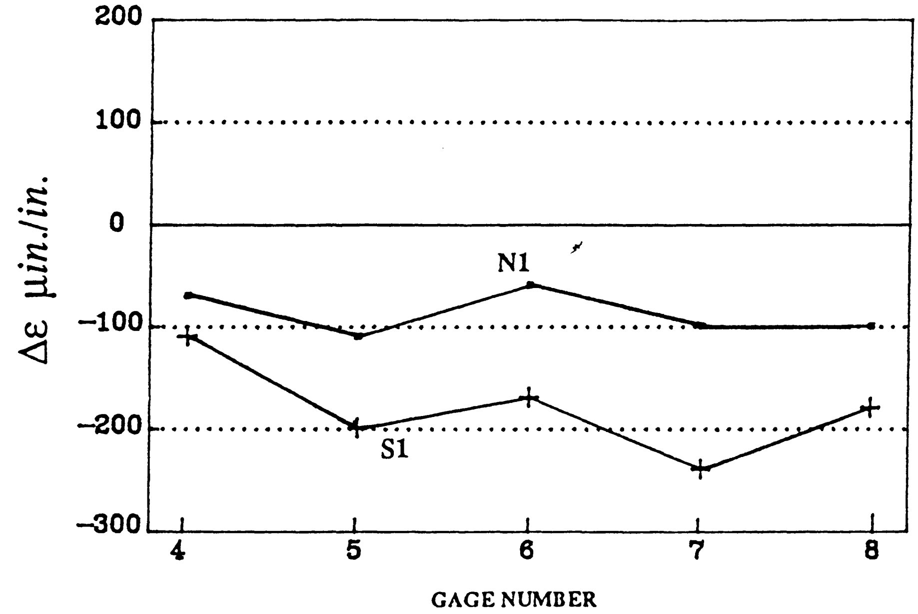


Figure 17. Strain Increment in Symmetric Segments

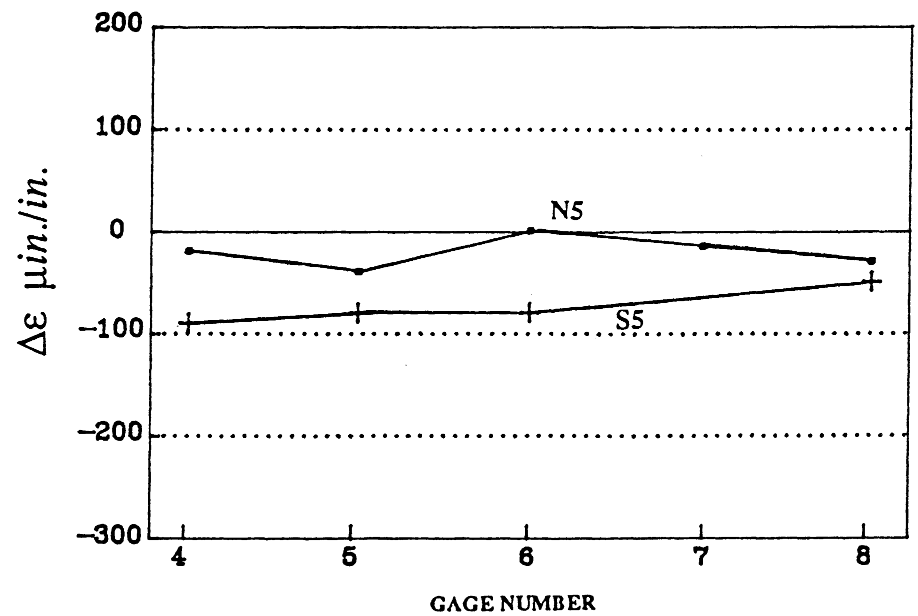


Figure 18. Strain Increment in Symmetric Segments

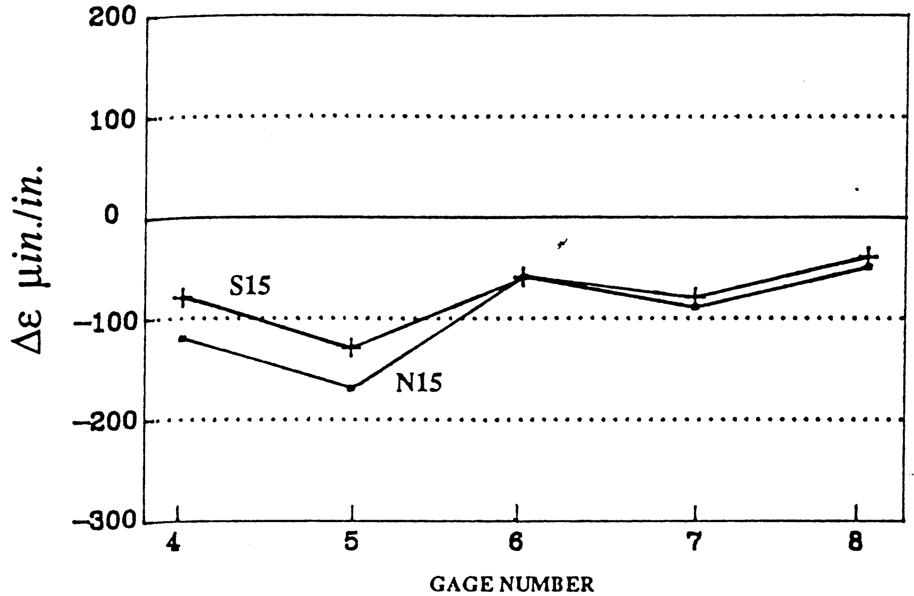


Figure 19. Strain Increment in Symmetric Segments

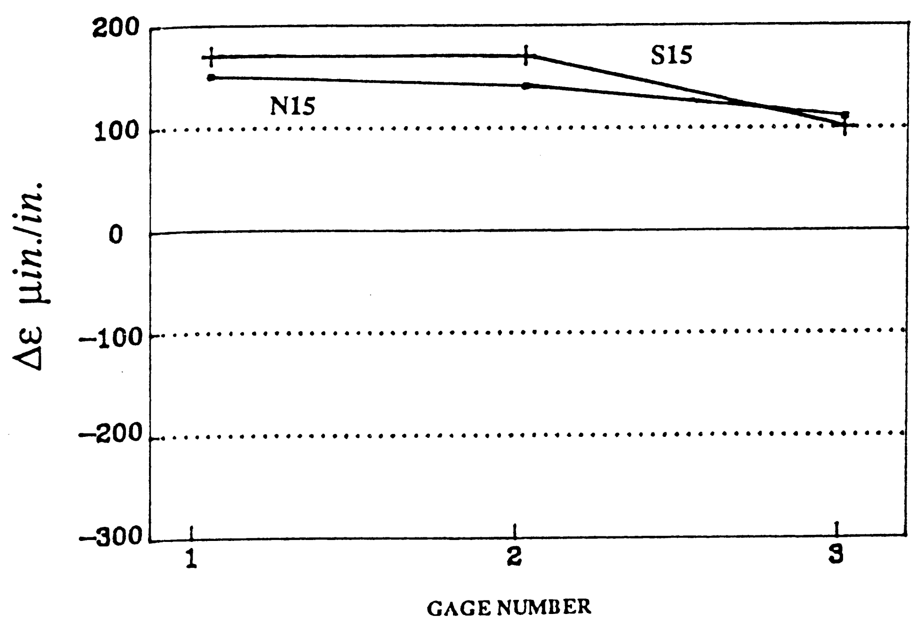


Figure 20. Strain Increment in Symmetric Segments

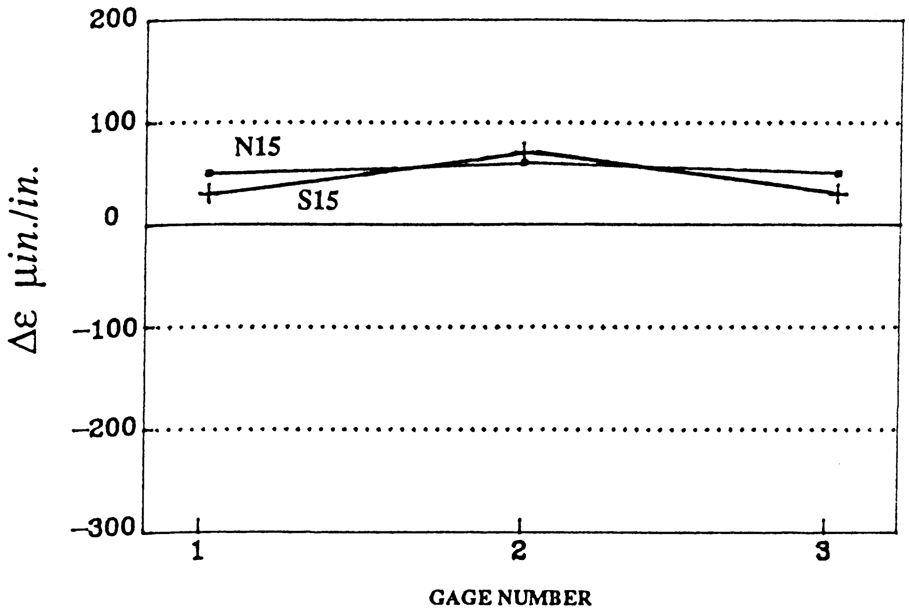


Figure 21. Strain Increment in Segment 16-S7

Figures 23, 24, and 25 show the distribution of strain increments in the top and bottom of segment N15 as a result of tensioning stays 8, 10, and 13. In this case, several features of the data are of interest. The tensioning of stay 8 produced higher compressive strain increments in the deck than did the installation of stay 10, whereas the tensile strain changes in the lower flange of the segment were slightly lower. This would seem to indicate the presence of slightly more axial force combining with the bending for the stay closer to the segment. However, the tensioning of stay 13, which was even further away from the segment, again produced significant compression in the deck along with diminished tensile strain increments. Another feature of interest, observed previously, is the nonuniform distribution of strain in the deck that is likely attributable to some degree of segment post tensioning during the time interval between strain readings. Again, the transverse distribution of strain changes seems to suggest the presence of some shear lag, although the effect is slight.

Finally, strain increments in segment S15 produced by tensioning of stays 10 and 12 are plotted in Figures 26 and 27. As noted in previous figures, the strain distribution across the deck is not uniform but is consistent for the different stays whereas the distribution across the lower flange is reasonably uniform. This is again likely attributable to temporary and permanent post tensioning of the segments, the effect of which is most noticeable in the deck portion of the structure.

The strain increments in a number of different segments attributable to the tensioning of a single stay are plotted in Figures 28 and 29. This is simply a

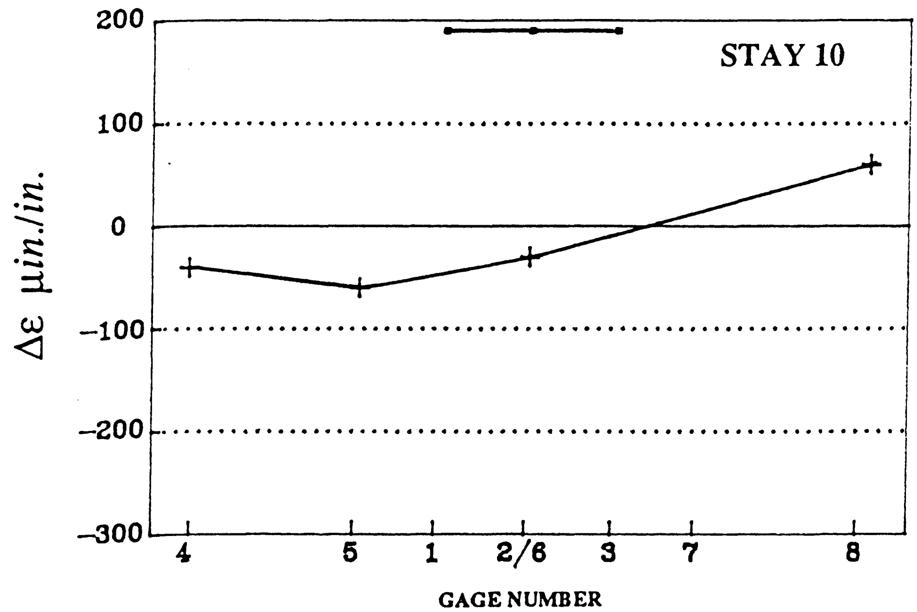


Figure 22. Strain Increment in Segment 16-S7

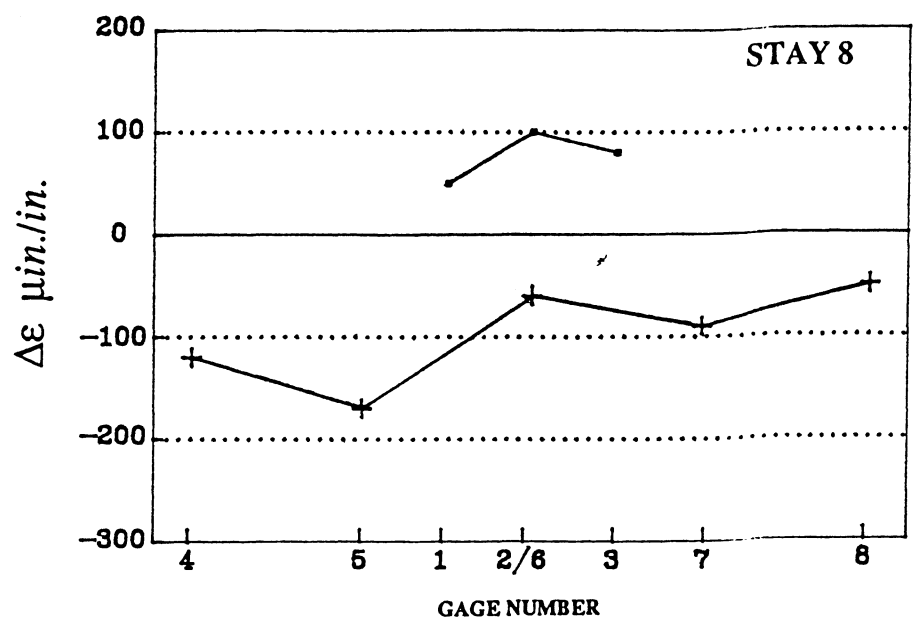


Figure 23. Strain Increment in Segment 16-N15

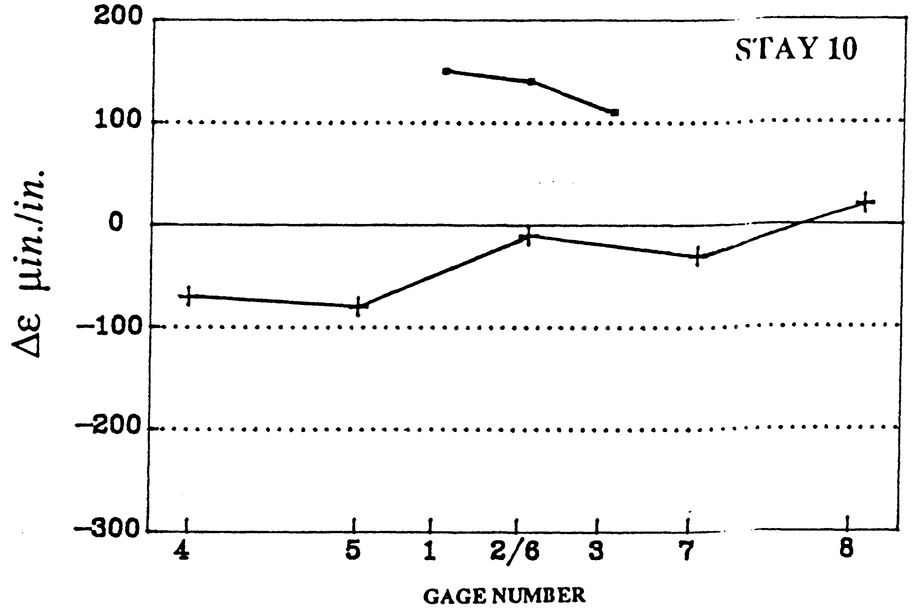


Figure 24. Strain Increment in Segment 16-N15

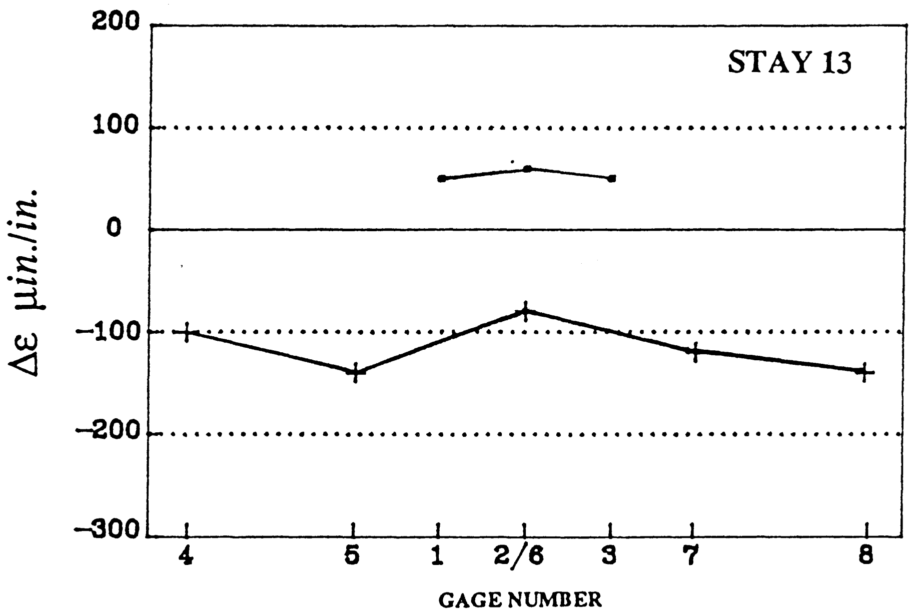


Figure 25. Strain Increment in Segment 16-N15

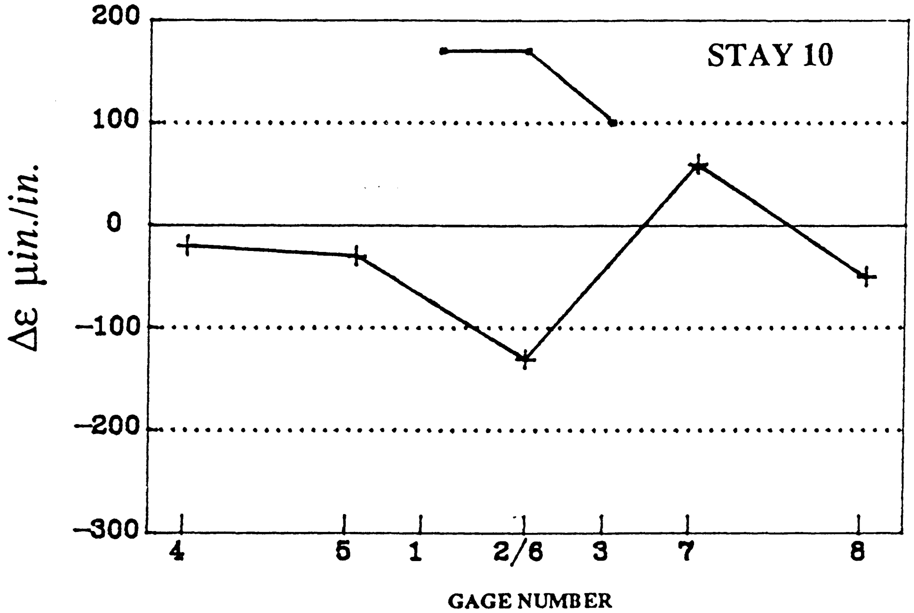


Figure 26. Strain Increment in Segment 16-S15

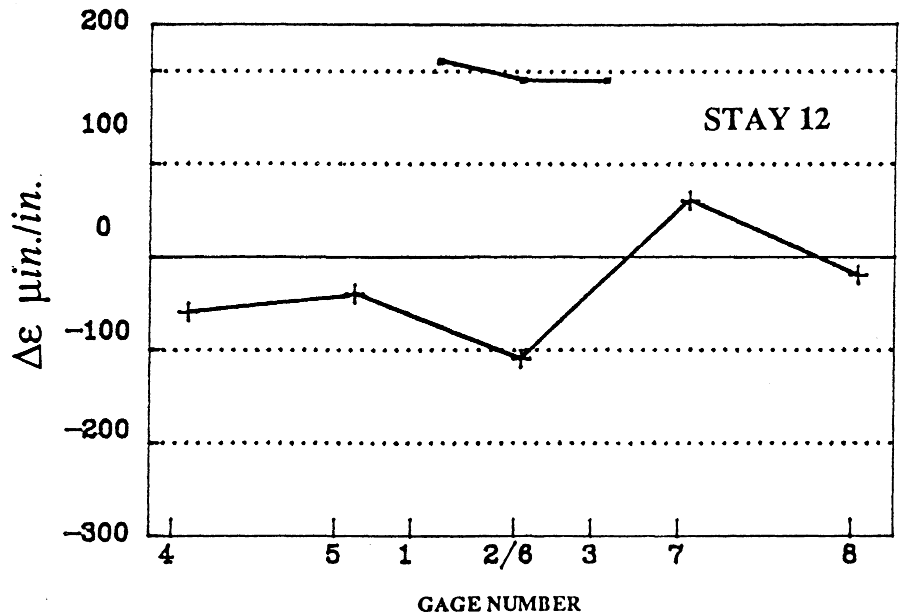


Figure 27. Strain Increment in Segment 16-S15

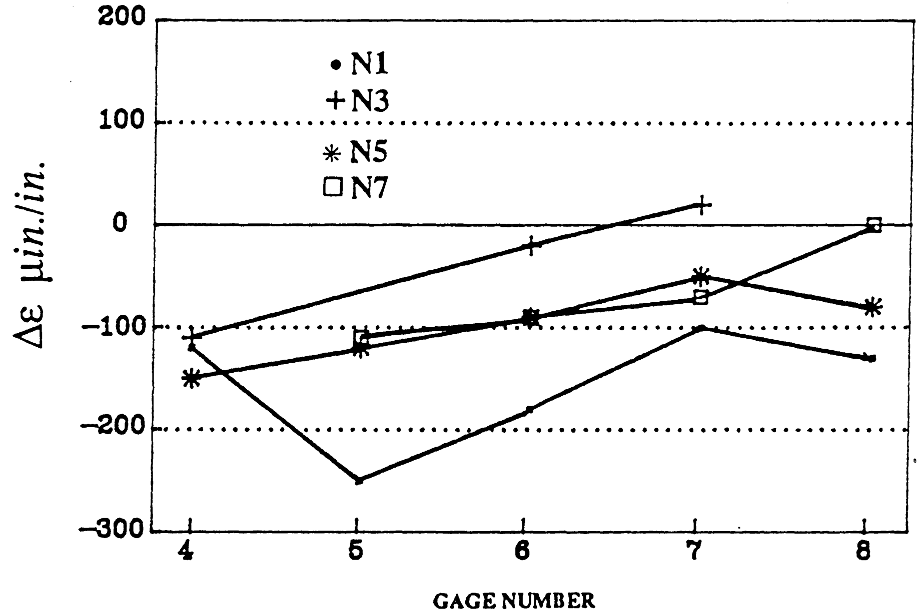


Figure 28. Strain Increment in Segment 16-N1, N3, N5, N7

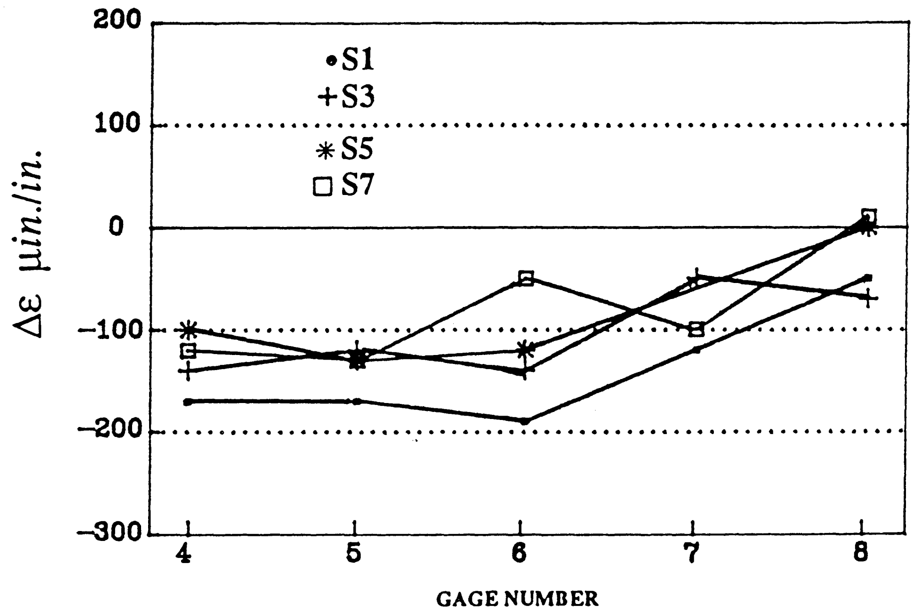


Figure 29. Strain Increment in Segment 16-S1, S3, S5, S7

different perspective on data that have been presented but does indicate that, although there is considerable variation in the distribution of the strain, the magnitudes are on the order of what would be expected given the level of stay forces and the magnitude of the temporary post-tensioning forces. In these figures also there is the indication that the axial compressive strains diminish toward the exterior edge of the segment.

## Absolute Strain Magnitudes

To provide additional insight into the behavior of typical deck segments during construction, Figures 30 through 35 show values of absolute strain, i.e., strain measurements relative to a zero value recorded in the segment prior to erection.

In Figures 30, 31, and 32, values of cumulative strain in segments N1, N3, and N7 are plotted for stages in the construction sequence corresponding to erection of two delta frames and a stay cable. As may be observed from these data, the maximum values of absolute strain recorded are, in all cases, less than 200 microinches per inch, or less than approximately 800 psi. These data would also seem to indicate that the loads in the various bridge elements as a result of the various construction activities are of the order of magnitude that would be expected given the magnitudes of the imposed loads.

Similar data for segments S1, S3, and S7 are shown in Figures 33, 34, and 35 for a slightly different set of construction activities. These data are similar in nature to those observed for the corresponding segments of the northbound lane except for some slight differences in the transverse distribution of the strain. However, it should be kept in mind that these strain values are relative to an earlier recorded zero reference. Any error or variation in the zero readings, for whatever reason, would be present in all subsequent values of strain recorded. The magnitudes of the strain readings are again within reason, although two gages, gage 4 of segment S3 and gage 8 of segment S7, indicate values of absolute strain on the order of 300 to 400 microinches per inch. However, the changes in strain from one sequence to the next are consistent with changes observed with other gages.

## South Side Strain Data

All of the strain data presented thus far were for segments on the north side of the bridge. During the erection of the south cantilever, somewhat more limited strain data were recorded from the south side gages. Unlike the north side gages, the south side mechanical gages were installed prior to erection of the approach spans. Thus, it was possible to obtain some indication of the behavior of the various segments in the approach spans. One example of this type of strain data recorded is presented in Figure 36. In this figure are plotted values of strain increments of

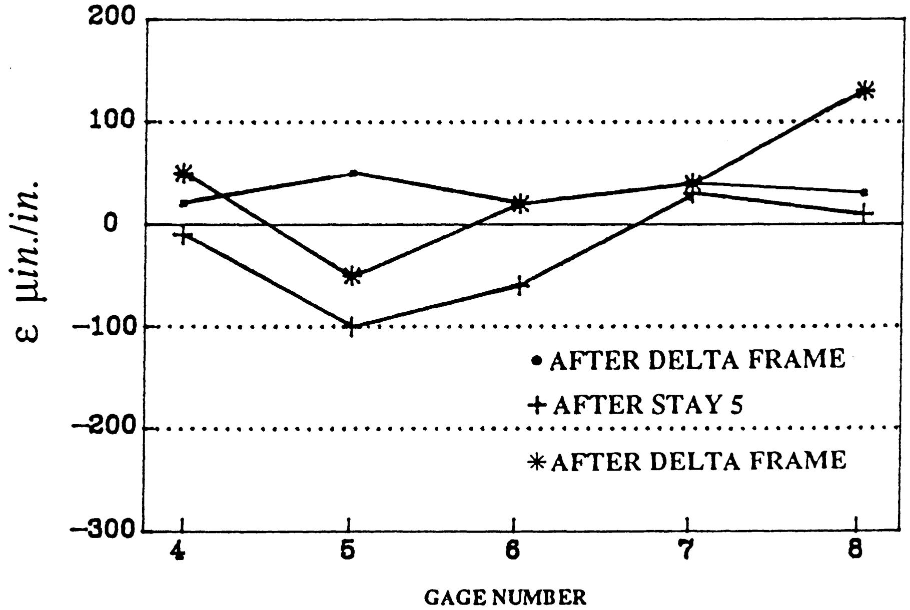


Figure 30. Absolute Strain in Segment 16-N1

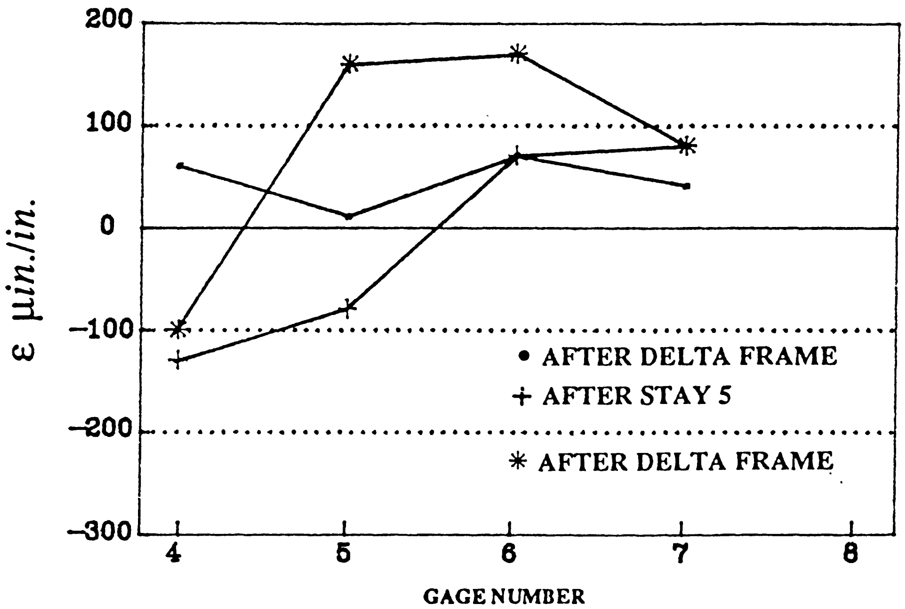


Figure 31. Absolute Strain in Segment 16-N3

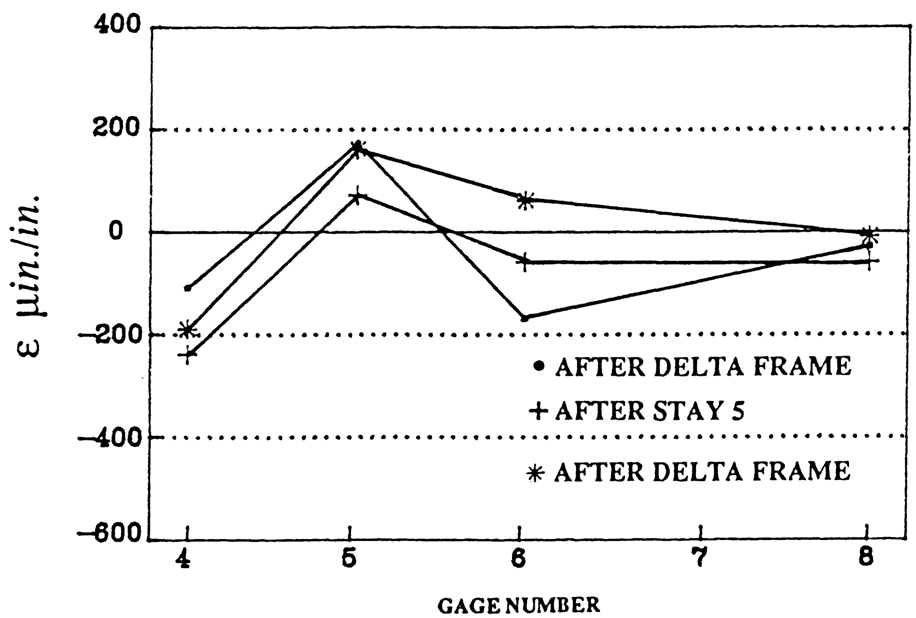


Figure 32. Absolute Strain in Segment 16-N5

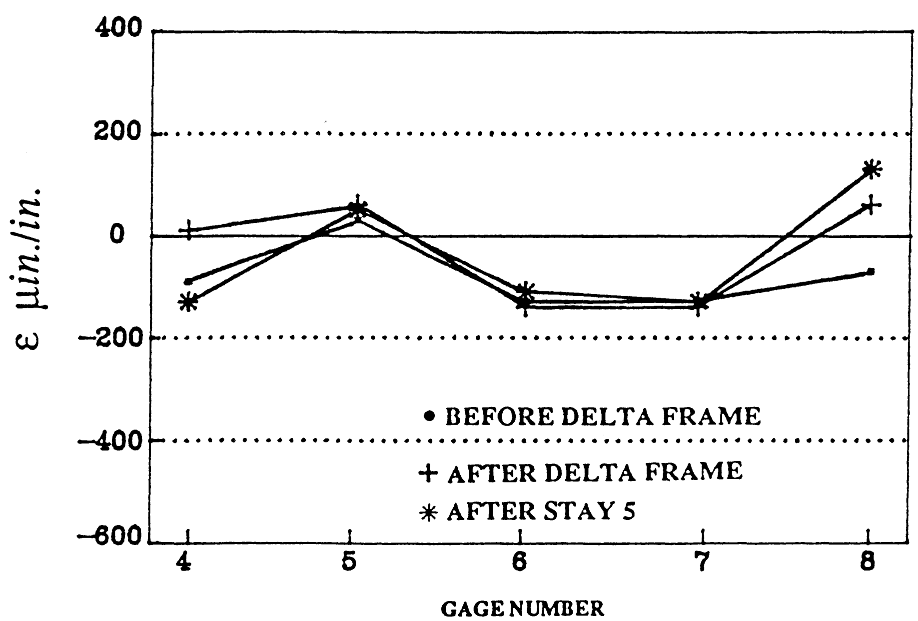


Figure 33. Absolute Strain in Segment 16-S1

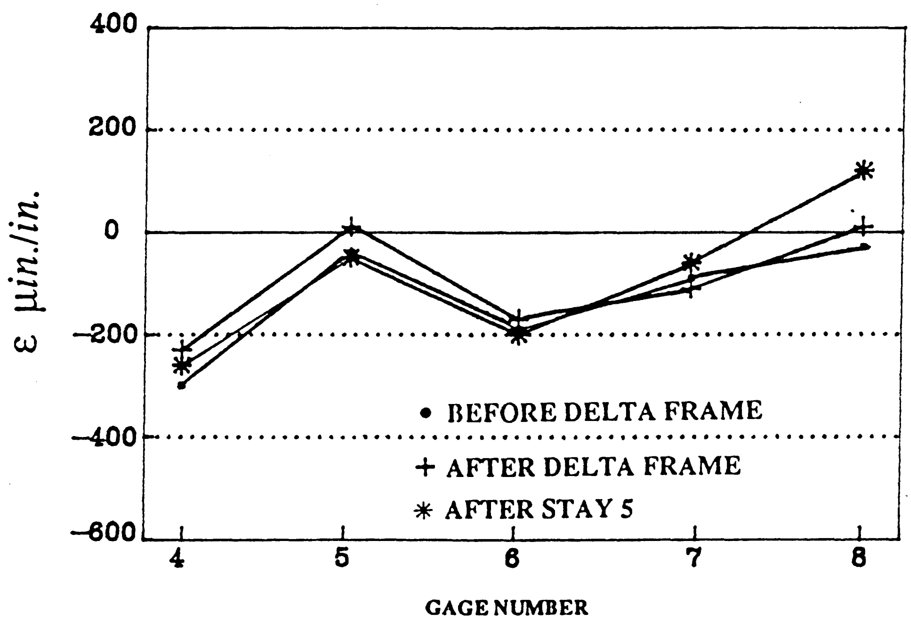


Figure 34. Absolute Strain in Segment 16-S3

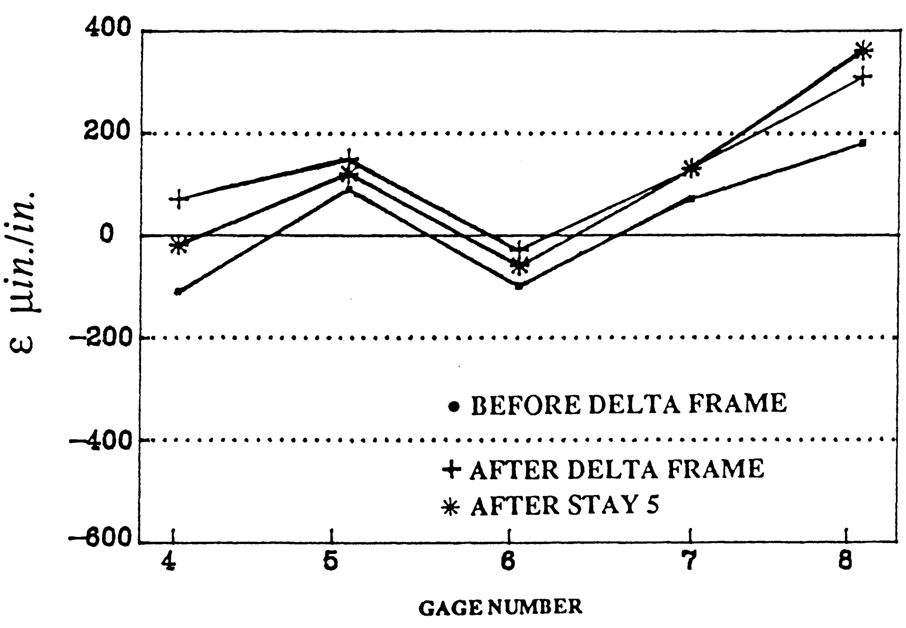


Figure 35. Absolute Strain in Segment 16-S7

segment S2 of span 15 caused by the post tensioning of that span after erection of all segments. The locations of the jacks are indicated in the figure, and the data clearly show the variation of strain experienced by the segment. The transverse distribution of the strain is essentially symmetric with respect to the segment center line. Also of interest is the fact that the post tensioning produced compression in the region of the jacks, as would be expected, but also resulted in slight tension in the regions of the segment edges. These measurements were taken prior to a closure pour, and hence the segment edges are effectively free. Additional data from the mechanical gages are continuing to be collected as construction proceeds on the south side.

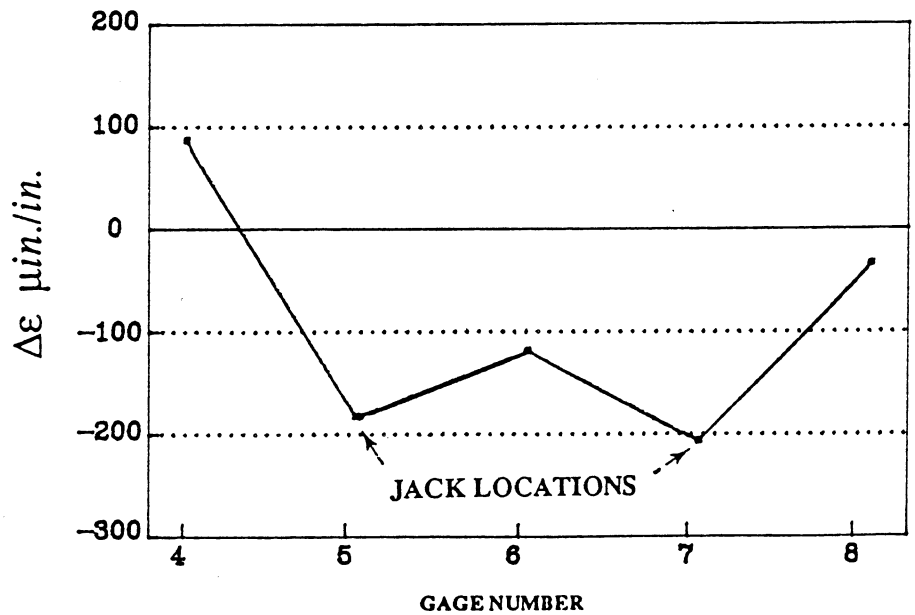


Figure 36. Strain Increment in Segment 15-S2

# SUMMARY AND CONCLUSIONS

This report documents the mechanical strain gage measurements taken as part of an ongoing research project on the field instrumentation of the I-295 cable-stayed bridge.

Analysis of the data presented is still underway at this time. However, based on the presented data, it is possible to draw some conclusions concerning the measured responses and the instrumentation scheme.

1. The mechanical gage points provided the investigators with a reasonable means of monitoring the strains during construction, although problems with dirt or grout in the gage points, gage points made inaccessible by construction activities, and limited reliability of the Whittemore gage complicated the data gathering procedure, and sometimes the proper interpretation of results. A significant improvement in installations of this point could be obtained if a relatively simple but rugged cover for the gage points could be devised.

2. The changes in box girder segment strains as a result of stay tensioning indicated that some shear lag occurs, which decreased as the distance of the tensioned stay from the instrumented segment increased. Gross section behavior included compression of the deck caused by the stay, together with bending of the section, and observable shear lag.

3. Observation of shear lag was complicated by the presence of numerous other prestressing loads in the deck, which were applied at nearly the same time as the cable-stay tensioning and which are of the same order of magnitude. Both northbound and southbound lane segments responded similarly.

4. The distribution of compressive strain increments across the bottom flange of the box segments tended to be more uniform than the strain increments across the top flange.

5. Observed strain increments during construction were of a magnitude consistent with the expected behavior of the structure.