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Measurements and Assessment of Stresses in Structural Members of the Saw Mill Run Bridge, Pittsburgh, PA

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Introduction

In January 1999, the Port Authority of Allegheny County, PA, contracted with the firm of Parsons Brinckerhoff Quade & Douglas, Inc. (PB) in Pittsburgh to furnish engineering services associated with an inspection and analysis of the Authority's Saw Mill Run Bridge in Pittsburgh. To conduct part of their study, PB subcontracted the ATLSS Engineering Research Center at Lehigh University in Bethlehem, PA, to install and monitor (and later remove) strain gages at various locations along the main girders, sub-stringers, and floorbeams during morning and afternoon rush-hour revenue traffic and during early-morning travel of a special light rail test vehicle. Using the strain-gage data, ATLSS was asked to report live-load stresses and stress ranges, for both representative and fatigue-sensitive locations. ATLSS conducted their strain-gage installations and data collections at the bridge from February 4 through 17, 1999. The analysis of the data was performed subsequently at the ATLSS Center.

The Saw Mill Run Bridge is a steel I-girder bridge which crosses several roadways, railroad tracks, and a stream. Spans 4 through 10 are aligned north and south (Span 10 is most northerly) and carry both light rail vehicles and buses (and some other non-revenue vehicles). Spans 1, 2, and 3, known as the West Liberty Avenue Bridge, are aligned NW and SE and merge into Spans 4 and 5; Spans 1, 2, and 3 carry only rubber-tired vehicles. ATLSS' investigation included only the spans with LRVs: Spans 4 and 5, Spans 6 and 7, and Spans 9 and 10. Span 8 was omitted because it is similar to Span 7. A photograph of the bridge, with Span 8 nearest, is given in Figure 1a. A photograph of the bridge surface and one of the LRVs is given in Figure 1b.

The bridge typically has four main, parallel girders. However, Spans 4 and 5, and part of Span 6 near Pier 5, have irregular framing to assist a transition into Span 3. When constructed in 1977, the bridge had only these main girders with a concrete deck. It was strengthened in 1985 for LRVs. At that time, sub-stringers and new floorbeams were added, and coverplates and web doubler plates were added at some girder locations. Figure 2a shows the typical structure in Spans 6 through 9. Figure 2b shows a typical articulated LRV; the LRVs traveled as either 1-car or 2-car units during the measurements.

Bridge Instrumentation

Scope of Bridge Measurements

The bridge girders, sub-stringers, and floorbeams at selected locations in Spans 4, 5, 6, 7, 9, and 10 were instrumented with a total of 104 strain gages to obtain their response under the LRVs, buses and other vehicles that cross the bridge. The selections were based as being either (a) representative of highest nominal stress locations (such as midspans) or (b) potentially fatigue sensitive (such as near fill plates and seal welds). The measurement data were also to help ~~PB~~ validate a separate computer-based structural analysis of the bridge.

In Span 4, there were 12 gages, Table 1, at or near midspan; they were on the top and bottom flanges of Girders 1 to 4, the sub-stringer between Girders 1 and 2, and a floorbeam between Girders 1 and 2. Figure 3 illustrates representative gages on a girder and on a floorbeam.

In Span 5, there were 12 gages, Table 2, at about the third-point of the span where the installed floorbeams and sub-stringer terminate; they were also on the top and bottom flanges of Girders 1 to 4, and the sub-stringer and a floorbeam between Girders 1 and 2. Figure 4 illustrates representative gages on a girder and on a floorbeam.

In Span 6, there were 18 gages, Table 3. Six were on girder flanges or coverplates about 83 ft south of Pier 6 where a fill plate abuts the existing girder bottom flange on Girders 2 and 3 and is seal welded. Twelve were placed about 24 ft south of Pier 6 at the cross section corresponding with the termination of the existing web doubler plates on Girders 2 and 3. Figure 5 illustrates gages at the fill plate/seal weld area and Figure 6 illustrates gages on the upper web at the end of a doubler plate and on the bottom flange below the end of the doubler plate.

In Span 7, there were 30 gages, Table 4. Twelve were near midspan on the flanges of the four girders and two sub-stringers. Fourteen were on girder flanges and coverplates at seal weld/fill plate cross sections and four were nearby on the flanges of a substringer and a floorbeam. Figure 7 is a sketch of the gage locations on Girder 2 in the two fill plate/seal weld areas. Figure 8a illustrates the gages shown in Detail A in Figure 7, while Figure 8b illustrates the side of the girder opposite to these gages. Both sides of the girder have seal welds in this area. Figure 9 is similar to Figure 7 but applies to Girder 3. Figure 10 illustrates the east face of the fill plate area corresponding to Detail A in Figure 9, and shows that no seal weld was used at the end of the fill plate. There is only an open junction. Figure 11 illustrates the east face of the area corresponding to the east face of Detail B in Figure 9. There is no seal weld above the thinner fill plate, and only corrosion product appears to be between the thin and the thick fill plates. Figure 12, on the other hand, which illustrates gages on the west face of the Detail B in Figure 9, shows that the west face of Girder 3 was fully seal welded. Thus, Girder 3 without seal welds on the east face of the fill plate areas is distinctly different than Girder 2, which has two-sided seal welds.

In Span 9, there were 20 gages, Table 5. Twelve were on the flanges of the four girders and two sub-stringers about 66 ft south of Pier 9, and eight were on the flanges of the four girders at the seal weld/fill plate cross section about 19 ft south of Pier 9. Figure 13 illustrates gages on top and bottom girder flanges, and Figure 14 illustrates an open fill-plate junction on Girder 3. This junction was open across the entire width of the flange.

In Span 10, there were 12 gages, Table 6. Four were on the flanges of Girders 2 and 3 at the seal weld/fill plate section about 5 ft north of Pier 9, and eight were at or near midspan on the flanges of the four girders and the sub-stringer and a floorbeam between Girders 3 and 4. Figure 15 illustrates the fill-plate/seal weld area in Girder 2. Figure 16 shows a mitered rail joint (which is scheduled for repair) in one of the inbound-track rails that caused a loud, distinct thump with every LRV traversing it, thus adding a potential for transmitting impact stress into Girders 3 and 4.

Measurement Variables

The only controlled variables during the measurements were: (a) date of measurements, (b) the use of morning (6:00 am – 9:00 am) and afternoon (3:00 pm – 6:00 pm) rush-hour periods for collecting data during revenue traffic and (c) the use of one light rail test vehicle loaded with

840 salt bags @ 50 lb/bag that traveled both tracks (between midnight and 2:00 am) at two nominal speeds of 10 and 25 mph. The salt-bag load was equivalent to 280 riders @ 150 lb each.

Uncontrolled variables during the measurements were:

- Normal vehicle speed, direction, and type.
- LRV composition being one or two articulated units.
- Passenger load.
- Ambient weather.

Table 7 summarizes the known variables.

Instrumentation Details

The 104 strain gages installed for the measurements were a standard product of the Micro-Measurements Division of Vishay Measurements Group (P.O. Box 27777, Raleigh, NC 27611, tel: 919-365-3800, fax: 919-365-3945). The gage designation was CEA-06-W250A-350, which is a general purpose, uniaxial, weldable gage with a 350-ohm resistance and a 0.25-inch gage length, and is temperature-compensated for use on carbon steel. (Temperature-compensated strain gages are manufactured to be used with test materials having specific thermal expansion ranges, in order to avoid temperature-induced apparent strains.)

The analog strain-gage signals were transmitted at the bridge site to a Campbell Scientific Model CR9000 multi-channel 16-bit digital data acquisition / conditioning system housed in a Lehigh van. There, they were digitized for on-site processing (with ID 2000 software from Campbell) and inspection with a laptop computer. The digitized files were also saved to ZIP ® disks, and later to CD's. The digitizing rates varied, but were never less than 25 samples/sec/channel. Neither the analog signals nor the digital signals were filtered on-site, but light digital smoothing was performed in later processing (using moving averages involving 3 data points on either side of the center point). The processed data were transcribed into hard-copy graphs using a computer and laser printer. Figure 17 shows the data acquisition system and the van during measurements at Spans 9 and 10.

Measured Bridge Stresses With Test Vehicle

Test Vehicle Description and Records

The Port Authority and Parsons Brinckerhoff arranged for one articulated LRV to make several runs over the bridge during early morning hours when revenue vehicles were not operating. The LRV was loaded with salt bags to simulate a fully-loaded vehicle of 280 riders each weighing 150 lb, or a total rider load of 42,000 lb. The empty LRV weighed 88,000 lb, for a total test vehicle weight of 130,000 lb. The LRV with salt bags is illustrated in Figure 18.

Table 7 lists the various runs made by the test vehicle. Runs were made at two speeds; the desired speeds were 5 mph and 25 mph. The time-data records gathered for each strain gage, when evaluated with the LRV truck spacings, showed that the speeds were more nearly 10 mph and 25 mph.

The movement of the test vehicle was recorded by each strain gage. However, as indicated in Table 7, gages in each pair of spans – 4&5, 6&7, and 9&10 -- were monitored separately. This was done because the data acquisition system (DAS) did not have the capacity to connect to all 104 gages at one time. Moreover, using separate setups eliminated a need for excessively long cable runs (with concomitant signal noise) between the gages and the DAS. (ATLSS' wireless remote monitoring system has a lesser gage capacity, and was already in use on the Williamsburg Bridge in New York City.)

Tables 8 through 13, for Spans 4, 5, 6, 7, 9, and 10, respectively, list the stress ranges recorded at each gage for each test-vehicle run. The maximum measured stress range at each gage is shaded for emphasis, when the range is significant. Selected time-data records are shown in Figures 20 through 24 to illustrate behavior. From these tables and figures, there are the following observations. For further reference, complete time-data records are included in the Appendix.

Maximum Stress Ranges

- There was negligible difference in stress range for the two nominal speeds of 10 and 25 mph.
- The maximum measured test-vehicle stress ranges never exceeded 4.6 ksi. In individual spans, the maximum stress ranges and the gages where they occurred were:

  Span 4: 2.05 ksi @ Gage 4.1 | Span 7: 4.60 ksi @ Gage 7.22
  Span 5: 1.58 ksi @ Gage 5.1 | Span 9: 3.10 ksi @ Gage 9.1
  Span 6: 2.60 ksi @ Gage 6.6 | Span 10: 2.25 ksi @ Gage 10.8

- The largest stress ranges in Spans 6 and 7 were at the fill plate/seal weld junctions shown in Figure 5 for Span 6 and in Figures 7 to 12 for Span 7 . Gage 7.22 on Girder 3 in Span 7 provided the singularly largest stress range of 4.6 ksi, about 1 ksi greater than the next largest. Figure 20 shows the time-data records for Gages 7.22-7.24 on Girder 3 in Span 7, at the fill plate junction. The higher stress range at the stress concentration of the 1-¼" fill plate (Gage 7.22) is apparent.
- Excluding the fill plate junctions in Spans 6 and 7, the largest stress ranges in all spans occurred in the bottom flange of the exterior Girders 1 and 4.
- Sub-stringer stress ranges were small under the test vehicle; ranging from 0.65 ksi in Span 5 to 1.20 ksi in Span 4. Sub-stringer stresses were not measured in Span 6.
- Floorbeam stress ranges were small under the test vehicle; ranging from 0.70 ksi in Spans 5 and 7 to 0.92 ksi in Span 4. Floorbeam stresses were not measured in Spans 6 and 9.

Note: In the end Spans 4 and 10, the sub-stringers frame into the webs of the floorbeams, and each are W18x55 shapes. In Spans 5 through 9, however, the sub-stringers are above the floorbeams, with bolted connections between their flanges. Each, again, are W18x55 shapes.

Other Characteristics

Composite Action. Significant composite action occurred between the bridge deck and the main girders. This action was not unexpected, because the main girders had been equipped with shear studs in the bridge's original construction. Composite action was also significant, however, between the deck and the sub-stringers, which rely on expansion anchors that were installed up into the deck during the 1985 bridge strengthening.

The composite action is evident by comparing data from strain gages on the top and bottom flanges of the girders and sub-stringers. In the absence of composite action, that is, when a member behaves as a simple flexural member, the gages on the top and bottom flanges would sense nearly equal and opposite values. But, using Table 8 for Span 4 as an example, Gages 4.1 and 4.2 on the bottom and top flanges, respectively, of Girder 1 exhibited measured stress ranges of about 2.00 ksi and 0.10 ksi for a vehicle on the outbound track. These data indicate that the girder is not a simple flexural member and (since both gages exhibited positive stress) indicate that the neutral axis for the girder section (acting compositely with the deck) was in the top flange of the girder. All other pairs of Span 4 girder and sub-stringer flange gages (4.3 and 4.4, 4.5 and 4.6, 4.7 and 4.8, etc) exhibited similar behavior.

Composite action also occurred in the other spans and is observed again by comparing the data from the top and bottom flange gages on the girders and sub-stringers. In some cases, the neutral axis for the girder and sub-stringer sections was slightly below the top flange in the web of the girder or sub-stringer, since the top flange gage sometimes exhibited a small negative stress. However, the degree of composite action was significant in the girders and sub-stringers.

Figure 21, for Span 4, shows stresses for Girders 1 and 2 at the top and bottom flange and confirms the significant composite action between the deck and the girders. It also illustrates a larger stress in the exterior Girder 1 relative to interior Girder 2; a fact attributed to less load shedding at the exterior girders.

Nature of Cyclic Load. Figure 22, for Span 4, shows stresses for a sub-stringer and floorbeam at their top and bottom flanges. Each record shows three peaks, corresponding to the three trucks on the LRV. Thus, the fatigue cycles from an LRV consist, as defined in the top record in Figure 22, of a primary cycle and two lesser, secondary cycles. Also observable is that the floorbeam behaves as a simple flexural member, since the top and bottom flange gages recorded opposite and nearly equal values. Figure 23 shows Span 10 data supporting the above observations about the nature of the LRV load.

Web Doubler Plates. In Figure 24, data are shown for gages at the ends of the web doubler plates in the interior girders in Span 6 near Pier 6. The stresses in Girder 3 were quite similar on opposite sides of the web, as would be expected. However, in Girder 2 the stresses on opposite sides of the web were significantly different in character suggesting that some web bending might be occurring.

Outbound vs. Inbound Track. Characteristically, when the test vehicle traveled on the outbound track (the track centerline is between Girders 1 and 2), the maximum stress ranges occurred in Girders 1 and 2 and smaller stress ranges occurred in Girders 3 and 4. When the test vehicle traveled on the inbound track (the track centerline is between Girders 3 and 4), the

reverse was true. However, vehicle travel direction on a track had only a minor effect on the stress range. These results are examined for each span.

- Span 4. With a vehicle on the outbound track (OT), the maximum stress range, Table 8, in Girder 2 (Gage 4.3) varied from 1.05 to 1.15 ksi while the simultaneous stress range in Girder 3 (Gage 4.5) was approximately 50 percent less, ranging from 0.50 to 0.55 ksi. The same result, with larger difference, occurred for Girders 1 (Gage 4.1) and 4 (Gage 4.11): 2.00 to 2.05 ksi for Girder 1 and 0.50 to 0.55 ksi for Girder 4. In contrast, with a vehicle on the inbound track (IT), Girder 3 (Gage 4.5) had a maximum stress range varying from 0.85 to 0.92 ksi while Girder 2 (Gage 4.3) had a lower stress range, varying from 0.35 to 0.55 ksi. Girders 4 (Gage 4.11) and 1 (Gage 4.1) exhibited the same trend, 1.10 to 1.30 ksi vs 0.40 to 0.47 ksi. Thus, in Span 4, the maximum stress ranges in Girders 1 and 2, with a train on the OT, consistently exceeded the maximum stress ranges in Girders 4 and 3, respectively, with a train on the IT. This undoubtedly was influenced by the lack of symmetry of the framing in Span 4 about the centerline between the OT and the IT.

- Span 5. Table 9 shows the girder stresses in Span 5, which was another non-symmetrical span. A vehicle on the OT caused larger stress ranges in Girders 1 and 2 (Gages 5.1 and 5.3, respectively) than in Girders 3 and 4 (Gages 5.5 and 5.7, respectively). A vehicle on the IT caused larger stress ranges in Girders 3 and 4 than in Girders 1 and 2. And, overall, a vehicle on the OT caused larger stress ranges in Girders 1 and 2 than one on the IT caused on Girders 3 and 4.

- Span 6. This span has a skewed pier at its south end but otherwise is nearly symmetrical about the centerline between the OT and the IT. The gages were nearer the north end of the span where the skew effect was not great. Hence, with a vehicle on the OT, the measured maximum stress ranges in Girders 1 and 2 were essentially the same as those in Girders 3 and 4 with a vehicle on the IT, Table 10. Again, a vehicle on the OT caused larger stress ranges in Girders 1 and 2 than in Girders 3 and 4, and a vehicle on the IT caused larger stress ranges in Girders 3 and 4 than in Girders 1 and 2; compare Gages 6.1 and 6.4, 6.2 and 6.5, 6.3 and 6.6, 6.10 and 6.14, and 6.15 and 6.17.

- Span 7. This span is nearly symmetrical about the centerline between the OT and the IT. Consequently, the maximum stress ranges with a vehicle on either the OT or the IT were about the same, Table 11. However, at the fill plate areas, some specific results occurred due to the fill plate conditions. For example, with a vehicle on the OT, Gages 7.19 and 7.22 on Girder 3 had stress ranges equally high as the counterpart Gages 7.13 and 7.16, respectively, on Girder 2. This was due to these Girder 3 gage sites having high strain concentrations at the fill plate areas.

- Span 9. This span is also nearly symmetrical about the centerline between the OT and the IT. Therefore, its stress results were quite regular, Table 12. Stress ranges with a vehicle on the OT were greater in Girders 1 and 2 than in Girders 3 and 4; the reverse being true with a vehicle on the IT. The maximum stress ranges for a vehicle on either OT or IT were about equal; compare Gages 9.1 and 9. 11, Gages 9.5 and 9.7, Gages 9.13 and 9.15, and Gages 9.17 and 9.19.

- Span 10. This span has a skewed abutment at its north end which causes Girders 3 and 4 to be longer than Girders 1 and 2. The extended length of Girders 3 and 4 causes their maximum stress ranges to be equal to or somewhat greater than those in Girders 1 and 2; compare in Table 13, Gages 10.1 and 10.3, Gages 10.5 and 10.8, and Gages 10.6 and 10.7. The effect of vehicles being on the OT or the IT was the same as in the other spans.

Measured Stresses With Revenue Vehicles

Type and Number of Vehicles

Strain gage data were collected continuously (for 3-hour periods) during both morning and afternoon weekday rush-hour periods. Table 7 shows the number of vehicles, both light rail and off-rail, that crossed the bridge spans during data collection. During the morning rush-hour period, it was observed that, as expected, most inbound vehicles were standing-room only and the outbound vehicles were sparsely occupied. A reverse situation was observed during the afternoon rush-hour period.

Some rush-hour period light rail revenue vehicles consisted of one articulated car while others consisted of two articulated cars. The distinction was observed in the strain signals characteristic to one- and two-car vehicles. Overall, however, one-car light-rail vehicles outnumbered two-car vehicles by about 2 to 1, and each recorded 3-hour rush-hour period consisted of 43 to 54 LRVs (1- and 2-car) and from 52 to over 200 off-rail vehicles. In a later section, these vehicle counts are converted to numbers of loading cycles and stress histograms.

Characteristics of Recordings

To illustrate the overall nature of a stress-time record during a rush-hour period, the complete morning record for Gage 6.6 on the bottom coverplate of interior Girder 3 in Span 6 is depicted in Figure 25, sheets a to d. Girder 3 is beneath the inbound track, and the large stress excursions in Figure 25 correspond to LRV traffic on that track. Smaller stress excursions in the record correspond either to LRVs on the opposite track or to off-rail vehicles. The largest stress excursion due to a single vehicle occurred near time 5150 sec (7:31 am), Figure 25 sheet b, and was 3.8 ksi. This rush-hour-period stress with revenue vehicles is almost 50 percent greater than the maximum stress range of 2.6 ksi measured at this gage with the test vehicle.

Figure 26 shows the stress data for adjacent interior Girders 2 and 3 earlier in the same rush-hour period. The stress excursions at Girder 3 gages 6.5 (bottom flange) and 6.6 (bottom coverplate) at time = 230 sec are greater than the corresponding stress excursions at Girder 2 gages 6.1 (bottom flange) and 6.3 (bottom coverplate) indicating that the vehicle at that time was an inbound LRV, because Girder 2 is beneath the outbound track. Similar results occur at times = 400 sec and 870 sec. The same observation occurs at times = 300 sec and 670 sec, but the lower stress indicates that the vehicle was an off-rail vehicle. Conversely, at times = 360 sec and 720 sec, the stress excursions at Girder 2 are greater than those at Girder 3 indicating that outbound LRV and off-rail vehicles, respectively, were crossing the span. In this latter comparison, the off-rail vehicle caused a stress range of about ½ that of the LRV.

Figure 27 illustrates the different cyclic stress responses at top and bottom flange Gages 5.13 and 5.14 on a Span 5 floorbeam between Girders 1 and 2 during the PM rush. The top two

records show the response at time = 275 sec for a 1-car outbound LRV. There is one primary stress cycle and two smaller cycles between vehicle trucks (there are three trucks per car). The bottom two records show the response at time = 2415 sec for a 2-car outbound LRV. Again, there is one primary cycle but now there are five smaller cycles since the 2-car LRV has six trucks. The top two records also show the response at time = 300 sec as an inbound 2-car LRV passed on the opposite track. The records also illustrate the simple flexural behavior of the floorbeam, with nearly equal and opposite responses of the flange gages.

Figure 28 illustrates, for Span 4, the variation of simultaneous stress in Girders 1, 2, 3 and 4 as, with increasing time, a 1-car inbound LRV, a 2-car outbound LRV, and an outbound off-rail vehicle crossed the span. Evident are the shifts in location of the maximum stress excursions and the number of secondary cycles depending on type of vehicle. In this example, the outbound off-rail vehicle caused a stress range of about 2/3 that of the outbound LRV.

Stress Record Analyses

To interpret the revenue-vehicle data, these data were analyzed using a computer-aided rainflow counting technique. This technique determined (a) the maximum stress range in the 3-hour period, (b) the histogram of the variable amplitude stress ranges recurring during the 3-hour period, and (c) the equivalent constant amplitude stress range for the period.

The equivalent constant amplitude stress range is determined as the root-mean-cube of the stress ranges identified in the histogram, that is

$$S_{re} = \left[\frac{1}{N}\sum nS_r^{\,3}\right]^{1/3} \qquad (1)$$

where S_{re} = the equivalent constant amplitude stress range
S_r = a particular recurring stress range
n = number of recurrences of S_r
N = total number of cycles in the data period

S_{re}, the equivalent constant amplitude stress range, is an important calculation because fatigue life determination is generally based on the constant amplitude fatigue limit.

The rainflow cycle counting method is an accepted method for converting a random-amplitude load spectrum into an equivalent constant-amplitude load spectrum. The program used was one written by ATLSS personnel using an algorithm documented in Reference 1. A useful explanation of the method is given in Reference 2, particularly the text related to Figure 4 of that reference. A simplified graphical explanation is provided here in Appendix Section A.

For a rainflow analysis to generate useful histograms, the data must be free of spurious data, such as random "noise" spikes caused by electrical interference or other sources. Though the data collected on-site were rather free from such noise, the data were further processed using a program called "DPLOT" developed by the USAE Waterways Experiment Station, Structures Laboratory, Vicksburg, MS. Using DPLOT, the data were "smoothed" to remove any spurious spikes. The smoothing window (the number of points over which the data was smoothed) was set

to 10 or 20 data, depending on the sampling rate at which data had been collected. After smoothing, the data were plotted to ensure that there was no attenuation of the peaks and valleys of the time histories. Next, in order to reduce the volume of data that would have to be passed through the rainflow counting algorithm, the data were depopulated by using a decimation algorithm which keeps every 10th data point. The data were again plotted and compared to the original time history; and it was determined that the characteristics of the time history were unaltered. Thus, the accuracy of the final results was not decreased by the process. The smoothing and decimation of the files was possible and effective because the sampling rates used in collecting the data were greater than was required to accurately capture the time history of the passing train.

The data were then submitted to the rainflow counting algorithm, and stress-range histograms were developed. The rainflow algorithm ignored any stress range less than 290 psi (10$\mu\varepsilon$). A cut-off such as this is appropriate for two reasons. First, the accuracy of measurements less than this is questionable since it is difficult to distinguish between real data and signal noise. Secondly, if these low stress ranges are included, the calculated effective stress range would be fictitiously low.

Stress Summaries

Table 14 lists the critical stress ranges at selected strain gages during the rush-hour periods with revenue vehicles. The gage sites selected for this analysis are those that, during the test vehicle excursions, exhibited the largest stress ranges. It was judged that gages experiencing high (or low) stress ranges with the test vehicle would similarly experience high (or low) stress ranges with revenue vehicles.

Table 14 shows the maximum stress range at a gage site during the revenue periods, as determined from the rainflow analysis. In many cases, it was possible to identify this maximum stress range with a specific vehicle passage, but in other cases, the maximum rainflow stress cycle developed from the minimum stress caused by one vehicle to the maximum stress caused by a later (or earlier) vehicle. This is seen by comparing results for Gage 6.6 in column 4 of Table 14 with the complete time record for Gage 6.6 in Figure 25. As cited earlier, the largest stress excursion due to a single revenue vehicle was 3.8 ksi, whereas the rainflow analysis yielded a maximum stress range of 4.3 ksi. For the gage sites shown in Table 14, the maximum stress ranges identified (shown highlighted in Table 14) by the rainflow analysis of the gage records were 2.1 ksi in Span 4, 1.4 ksi in Span 5, 4.6 ksi in Span 6, 6.6 ksi in Span 7, 3.7 ksi in Span 9, and 2.5 ksi in Span 10.

Table 14 also shows the equivalent constant amplitude stress ranges that were computed in the analyses for the gage sites. As expected, these latter stress ranges are less than the maximum stress ranges. For the maximum-stress-range cases listed above, the corresponding constant amplitude stress ranges were 1.3 ksi in Span 4, 1.0 ksi in Span 5, 1.4 ksi in Span 6, 2.5 ksi in Span 7, 1.5 ksi in Span 9, and 0.9 ksi in Span 10.

An observation from the data in Table 14 is that the maximum stress ranges in the central Spans 6 and 7 and in Span 10 generally were greater during the AM rush-hour periods than during the PM rush periods. There was close equality, however, in the equivalent constant amplitude stress ranges. In Spans 5 and 9, the maximum stress range occurrences were more

balanced between the AM and PM rush-hour periods. In Span 4, side-by-side vehicles on the OT and the IT influenced the result. A cause for the inequalities between the stress-range magnitudes for the AM and PM data was not determined, but may relate to: (a) more frequent transient presence of side-by-side vehicles on the OT and the IT, as was observed to influence the Span 4 data, or (b) greater passenger loads during the AM measurements.

Histograms

Histograms depicting the number of stress cycles at recurring rainflow stress ranges for several of the highest stress gages are shown in Figures 29 to 31. Superposed on the histograms is the equivalent constant amplitude stress range, which is the effective stress range. Figure 29 applies to Span 6; Figure 29a for Girder 2 and Figure 29b for Girder 3. Figure 29b shows the histogram that corresponds to the stress-time record shown in Figure 25, sheets a to d. In these histograms, the range of the abscissa corresponds to the total number of cycles (rounded to a number allowing four grids) counted in the analysis, whereas the numbers beside each bar correspond to the number of cycles at the stress range represented by the bar. The broken line is the rainflow-calculated equivalent constant amplitude or effective stress range.

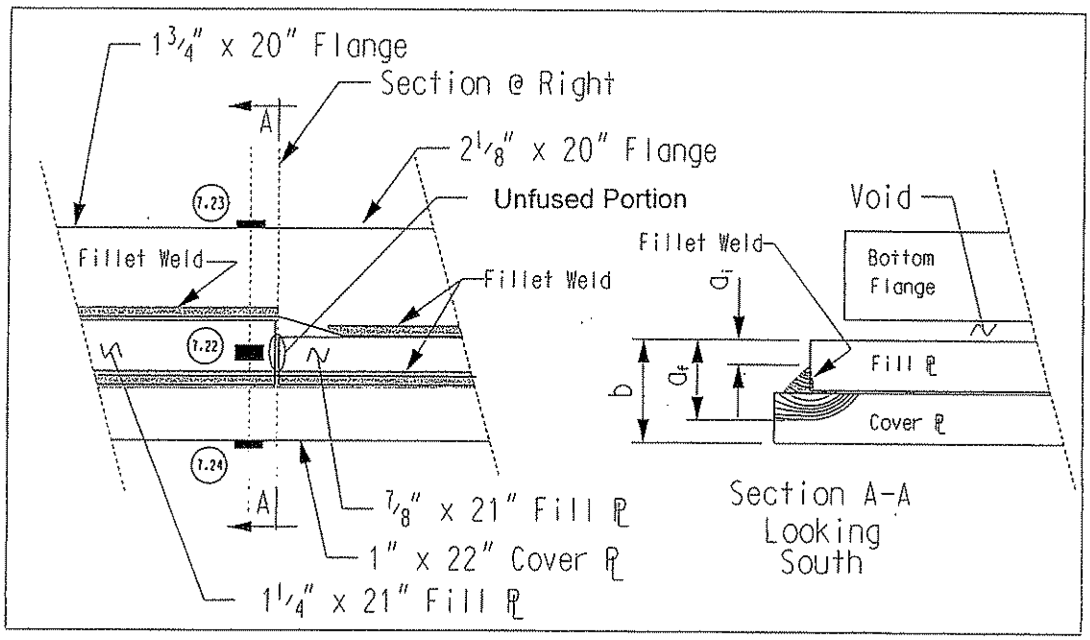
Figure 30 applies to Girder 3, Span 7, at the fill plate junction where maximum stresses resulted. Results for both AM and PM rush-hour periods are given. The results illustrate, as shown in Table 14, that, in Span 7, the AM rush-hour period maximum stress range and equivalent constant amplitude stress range were greater than during the PM rush-hour period. Figure 31 shows other representative histograms, specifically for exterior Girder 4 in Spans 7, 9, and 10.

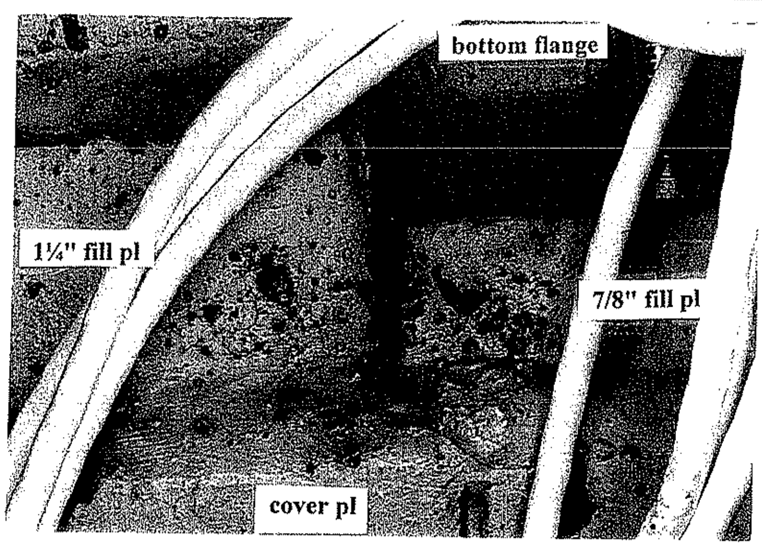
All of the histograms exhibit the skewed distribution that is characteristic of girder-type bridge structures, with the peak-stress range in the variable-load spectrum being two to four times larger than the effective stress range.

Fatigue Life

Fatigue Damage Model

There are several potentially fatigue-critical details in the bridge spans. In order of decreasing severity, these include the fill-plate terminations (Category E′; fatigue limit stress range = 2.6 ksi), coverplate terminations (Category E′), doubler plate fillet welds (Category E, fatigue limit stress range = 4.5 ksi), web stiffener to flange welds (Category C, fatigue stress limit range = 10 ksi), and welded girder splices (Category B, fatigue limit stress range = 16 ksi). Of these, the fill-plate terminations led to the maximum measured cyclic stress ranges and, therefore, a fatigue damage model is developed for this governing fatigue-critical detail. Sketches of elevation and transverse sections for the fill plate in Girder 3 at Section 7/22, Span 7, near Gages 7.22 - 7.24 are given below, along with the photograph of the section as shown earlier in Figure 11b. This section had the maximum cyclic stress ranges that were recorded in the study.





Assuming a crack initiates in the fill plate/weld zone at the base of the unfused portion of the terminating fill plate and propagates from there, the stress-intensity-factor, ΔK, for the crack is related to the crack length, a, and the stress range, S_r, by Eq. 2. (References 3, 4 and 5 provide background on this and subsequent equations.)

$$\Delta K = F_e F_s F_g F_w S_r \sqrt{\pi a} \qquad (2)$$

where F_i are coefficients in which:

F_e corrects for crack shape as a function of crack size,
F_s corrects for effects of free surface,
F_g corrects for stress gradients acting on the crack, and
F_w corrects for the width of the element with a crack.

Numerous tests on welded A36 steel have shown that if ΔK exceeds a crack-growth threshold value of $\Delta K_{th} = 2.75$ ksi $\sqrt{\text{in.}}$, then a crack will propagate under cyclic load. This value of ΔK_{th} corresponds to the least value of ΔK_{th} that results when considering the maximum stress condition to be at the yield point. Thus, it represents the threshold for the maximum combination of dead load stress, residual stress, and cyclic stress range.

Using Eq. 2 for a damage model with a penny-shaped crack (a crack advancing with a circular-arc front) in which crack length or depth, a, (the rise of the circular arc) is half its width, 2c (the chord width of the circular arc), that is a/2c = 0.5, and in which the thickness of the cracking element (in this case, the assembly of a fill plate and a coverplate) = b; the coefficients F_i are approximated

$$F_e = 1/E(k), \quad \text{where } E(k) = 3\pi/8 + (a/c)^2\pi/8$$
$$= 0.637$$

$$F_s = 1.211 - 0.186\sqrt{a/c} = 1.03$$

$$F_g = 1$$

$$F_w = [\sec(\pi a/2b)]^{1/2}$$
$$\cong 1$$

then $$\Delta K = 0.656 \; S_r\sqrt{\pi a} \qquad (3)$$

Two Abutting Fill Plates. For the case illustrated in the preceding sketches, a reasonable assumption is that the initial crack length, a_i, is represented by the unfused portion between the fill plates and is here taken as half the thickness of the thinner fill plate. Then, for the case illustrated, a = 7/8" ÷ 2 = 0.438 in. Also, based on the maximum stress ranges shown in Table 11 for the fill plate and coverplate stresses, Gages 7.22 and 7.24, on Girder 3, and conservatively approximating S_r as the nominal stress represented by the average of these gage values:

$$S_r = (4.60 + 3.55) / 2 = 4.1 \text{ ksi}$$

Inserting a and S_r into Eq. 3 yields

$$\Delta K = 3.16 \; ksi \sqrt{in}, \qquad \text{which is} > \Delta K_{th}$$

Because $\Delta K > \Delta K_{th}$, crack growth is possible at this Span 7 fill-plate location, and will occur towards the bottom coverplate, rather than towards the bottom flange where the cyclic stress range is less.

As mentioned earlier residual stresses from welding and dead-load stresses are accounted for in these calculations by the choice of ΔK_{th}.

<u>One Fill Plate.</u> A similar calculation can be made for the case with a single fill plate; for example, for the fill-plate area at Gages 6.4, 6.5, and 6.6 on Girder 3 in Span 6, Section 6/4. At this site, the single fill plate has a thickness of 3/4". Because, at the fill plate, the maximum stress ranges in the bottom flange of the girder (2.4 ksi at Gage 6.4) and in the coverplate (2.6 ksi at Gage 6.6) are about equal, crack propagation, if it develops, could progress not only into the coverplate but also into the flange. With these data, a = ¾" ÷ 2 = 0.375 in, and S_r can be approximated as

$$S_r = (2.40 + 2.60)/2 = 2.5 \text{ ksi}$$

Inserting a and S_r into Eq. 3 yields

$$\Delta K = 1.78 \; ksi\sqrt{in}, \qquad \text{which is} \leq \Delta K_{th}$$

Because ΔK is $< \Delta K_{th}$, crack growth is not likely at this fill-plate location in Span 6.

<u>Estimation of Fatigue Life</u>

Because crack propagation is possible at the Span 7 fill-plate location cited above, an estimation of the number of cycles to drive the crack deeply into the bottom coverplate is needed. To do this, the following conservative assumptions are made:

F_e, F_g and F_s remain constant throughout the cracking process, and
$F_w = [\sec(\pi a/2b)]^{1/2}$

But with the conservative assumption that one value of F_w applies from the initial through the final crack size and with

b = the total distance through the coverplate
= (7/8 " fill-plate thickness + 1 " coverplate thickness)
= 1-7/8 "

and a = new crack length;
for a crack that has progressed half through the coverplate,
a = (7/8 " + ½ ") = 1-3/8 "

then $F_w = 1.57$.

The number of cycles, N, to propagate the crack from its initial length a_i to its new length a_f is given by the equation:

$$N = \frac{10^{10}}{3.6} \int_{a_i}^{a_f} \frac{da}{\Delta K^3} \tag{4}$$

which becomes, in a general way, after using Eq. 2

$$N = \frac{10^{10}}{3.6\, S_r^3} \int_{a_i}^{a_f} \frac{da}{\left(F_e F_g F_s F_w \sqrt{\pi a}\right)^3} \tag{5}$$

and, further, after integrating Eq. 5

$$N = 10^{10} \times \left[2\left(a_i^{-1/2} - a_f^{-1/2}\right)\right] \div 3.6 S_r^3 \left(F_e F_g F_s F_w\right)^3 \pi^{3/2} \tag{6}$$

Substituting the values for F_e, F_g, F_s, F_w, $a_i = 0.438$, and $a_f = 1.375$ yields

$$N = \frac{6.01 \times 10^8}{S_r^3}$$

Here, however, since fatigue life rather than crack-growth threshold is being examined, S_r should be the equivalent constant amplitude stress range, or effective stress range, S_{re}, so that

$$N = \frac{6.01 \text{ x } 10^8}{S_{re}^3} \tag{7}$$

The value of S_{re}, noted in Figure 30 for Gage 7.22, is about $S_{re} = 2.5$ ksi. Using this value in Eq. 7 yields

$$N = 38.4 \text{ x } 10^6 \text{ cycles}$$

that is, 38.4 million cycles are needed for a crack to grow through half the thickness of the coverplate.

The data gathered for revenue vehicles during the 3-hour AM and PM measurement periods, and the subsequent rainflow analysis of that data, indicates that no more than 335 variable stress cycles occurred during any 3-hour period at any gage site in Span 7. (Only cycles

with greater than a 0.29-ksi stress range, which had been selected as a lower cutoff, were counted.) Conservatively assuming that the two 3-hour rush periods constitute 50 percent of the traffic in the 18-hour daily revenue period; there is a maximum daily frequency of 1340 cycles. The Port Authority has provided data [5], however, on vehicle frequency based on their published list of scheduled transit vehicles. The Port Authority data indicates that the daily frequency is less than 1340 cycles. A summary of the Port Authority data is shown below:

Type Vehicle	**Daily Bridge Crossings**			
	Weekdays	**Saturdays**	**Sundays/ Holidays**	**Weekly**
LRV	416	203	171	≤2460
Bus	635	237	90	≤3500
Other	nil	nil	nil	nil
LRV + Bus	1051	440	261	≤5960
	No. Days / Year			
	250	52	63	
	Annual Bridge Crossings (daily crossings x no. of days / yr)			**Annual Total**
LRV	104,000	10,560	10,780	≤125,340
Bus	158,750	12,320	5,670	≤176,740
LRV + Bus	262,750	22,880	16,450	≤302,080

Comparing the Port Authority's maximum annual cyclic frequency (302,080 cycles / yr) to the above value of N indicates that 127 years of operation at this frequency would be needed for the assumed crack at the critical Span 7 fill-plate location to grow to the half-thickness of the bottom coverplate. Inasmuch as the sub-stringers and floorbeams were installed 14 years ago in 1985 when LRVs started using the bridge, and probably since then had no greater vehicle frequency than indicated above; another 113 years of operation at the same vehicle frequency and weight would be needed for the assumed crack growth.

Thus, at this time, the main recommendation is to continue biennial inspections, with *special* attention to the fill-plate locations. *Routine* attention during inspections should be continued for the other aforementioned fatigue-sensitive details at the coverplate terminations, doubler plates, and girder splices, where the maximum measured stress ranges were below the fatigue limit and there is unlikely possibility for crack initiation and growth.

Finally, it should be noted that were a crack to form in the bottom coverplate as hypothesized, there is no danger of fracture of the girder cross-section. While crack instability in the coverplate would crack the coverplate, it would not have a path to enter into the bottom flange. The stress in the bottom flange would increase but, based on the level of stress measured in this investigation, would not attain a level critical either for fatigue or ductile yielding.

References

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2. P.H. Wirsching and A.M. Shehata, "Fatigue Under Wide Band Random Stresses Using a Rain-Flow Method," Journal of Engineering Materials and Technology, Transactions of the American Society of Mechanical Engineers, pp 205-211, July 1977.

3. J.W. Fisher, Fatigue and Fracture in Steel Bridges, John Wiley & Sons, Inc., 1984.

4. R.J. Dexter and J. W. Fisher, "Fatigue and Fracture," Chapter 24 in Handbook of Structural Engineering, W.F. Chen, ed., CRC Press, 1997.

5. D. Broek, Elementary Engineering Fracture Mechanics, 4th ed., M. Nijhoff Publishers, 1987.

6. H.B. Elsasser, letter to D.A. Charters, "LRS-99-02, Saw Mill Run Bridge Renovation Transit Loading Frequency," June 17, 1999.

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Tables

Table 1

Gage Locations for Span 4, Saw Mill Run Bridge

Span. Gage	Span /Section	Member	Location in Span	Location on Member
4.1	4/a	Girder 1 (G1)	Midspan: ~33' from Pier 4	top of bottom flange (TBF) 5" from E tip
4.2		G1		bottom of top flange (BTF), above 4.1
4.3		G2, W30 x 108		TBF, 3" from E tip
4.4		G2		BTF, above 4.3
4.5		G3, W30 x 108		TBF, 3" from W tip
4.6		G3		BTF, above 4.5
4.11		G4		TBF, 5" from E tip
4.12		G4		BTF above 4.11
4.9		Floorbeam (FB), W18 x 55 between G1 & G2		℄ BBF Midpt between G1 & G2
4.10				BTF, 2" from S tip, above 4.9
4.7	4/aa	Sub-stringer, W18 x 55 between G1 & G2	~5' N of midspan, midway between FBs	TBF, 2" from tip
4.8				BTF, above 4.7

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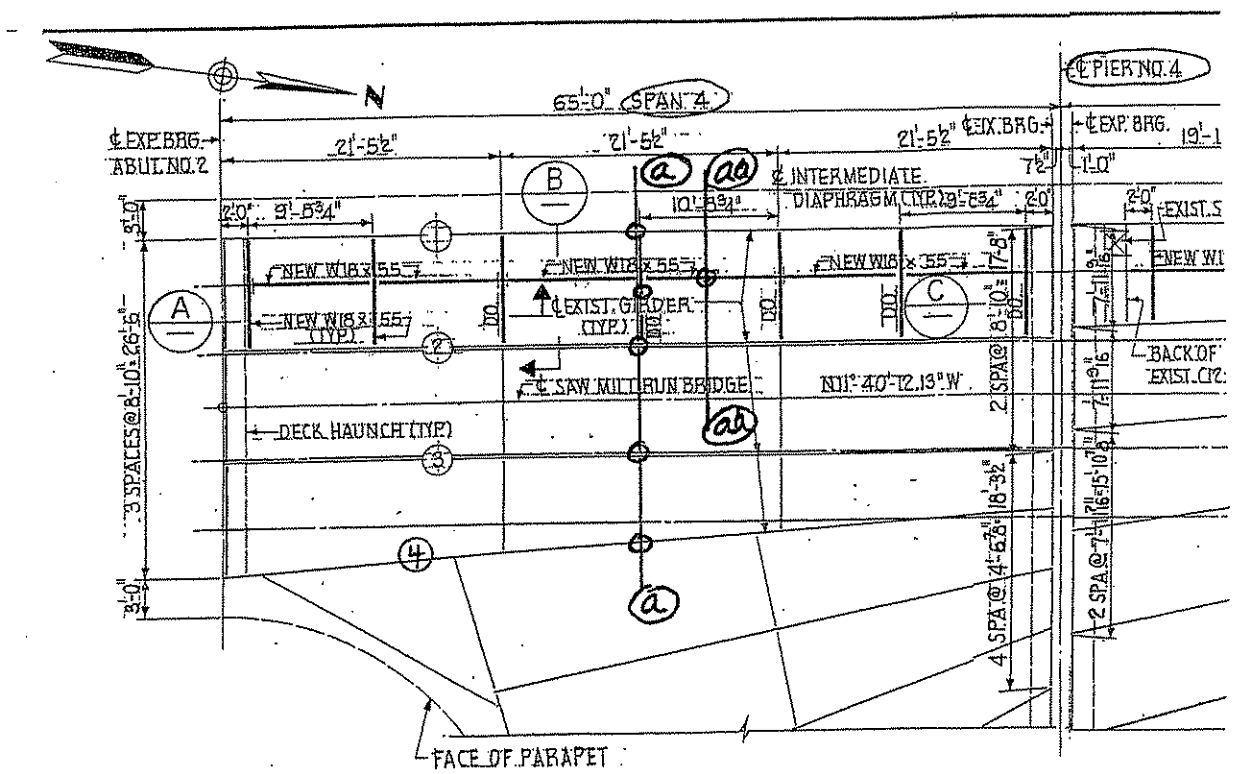

Table 2
Gage Locations for Span 5, Saw Mill Run Bridge

Span. Gage	Span /Section	Member	Location in Span	Location on Member
5.1	5/b	G1	~34' N from Pier 4, midway between 2 new FBs.	TBF, 5" from E tip
5.2		G1		BTF, above 5.1
5.3		G2		TBF, 5" from tip
5.4		G2		bottom of top fl pl, above 5.3
5.5		G3		TBF, 5" from tip
5.6		G3		bottom of top fl pl, above 5.5
5.7		G4		TBF, 5" from tip
5.8		G4		BTF, above 5.7
5.9		Blank		Blank
5.10		Blank		Blank
5.11		Sub-stringer, W18 x 55 between G1 & G2		TBF, 2" from W tip, 3" N of str. midpt
5.12				BTF above 5.11
5.13	5/bb	FB, W18 x 55 between G1 & G2	4' N of girder gages, 3" W of FB midpt	TBF, 2" from S tip Midpt between G1 & G2
5.14				℄TTF, above 5.13

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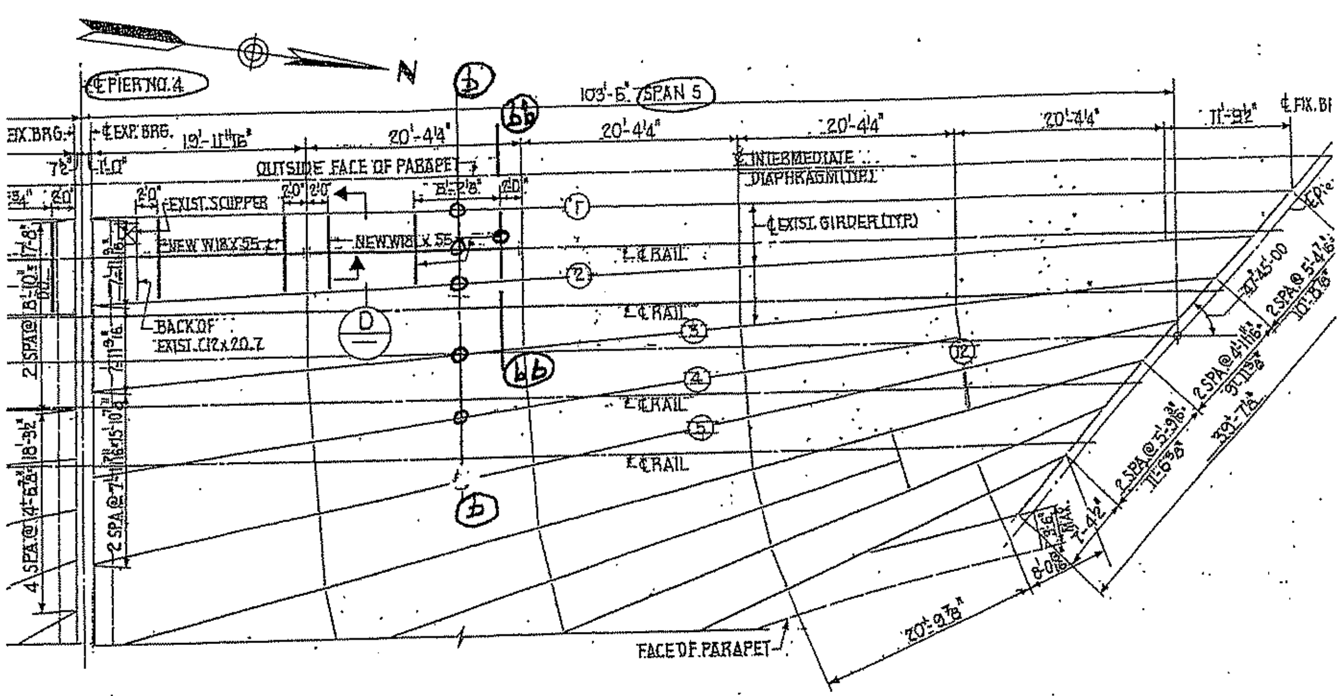

Table 3

Gage Locations for Span 6, Saw Mill Run Bridge

Span. Gage	Span /Section	Member	Location in Span	Location on Member
6.1	6/4	G2	~85' S of Pier 6	E Bottom flange edge above Seal weld for ¾" fill plate
6.2		G2		W bottom flange edge, Similar to 6.1
6.3		G2		Edge of bottom CP below 6.1
6.4		G3		E bottom flange edge above Seal weld for ¾" fill plate
6.5		G3		W bottom flange edge. Similar to 6.4
6.6		G3		Edge of bottom CP below 6.5
6.7	6/3	G2	~ 24.2' S of Pier 6, at end of web doubler pls, on web 1" above top edge of doubler pl., and ~2" from web stiffener	At end of web doubler plate, 7" below E top flange
6.8		G2		TBF, 3" from tip, below 6.7
6.9		G2		W side of web, similar to 6.7
6.10		G2		TBF, 3" from tip, below 6.9
6.11		G3		At end of web doubler plate, 4" below E top flange
6.12		G3		TBF, 3" from tip, below 6.11
6.13		G3		W side of web, Similar to 6.11
6.14		G3		TBF, 3" from tip, below 6.13
6.15		G1		TBF, 3" from E flange tip
6.16		G1		BTF, above 6.15
6.17		G4		TBF, 3" from W flange tip
6.18		G4		BTF, above 6.17

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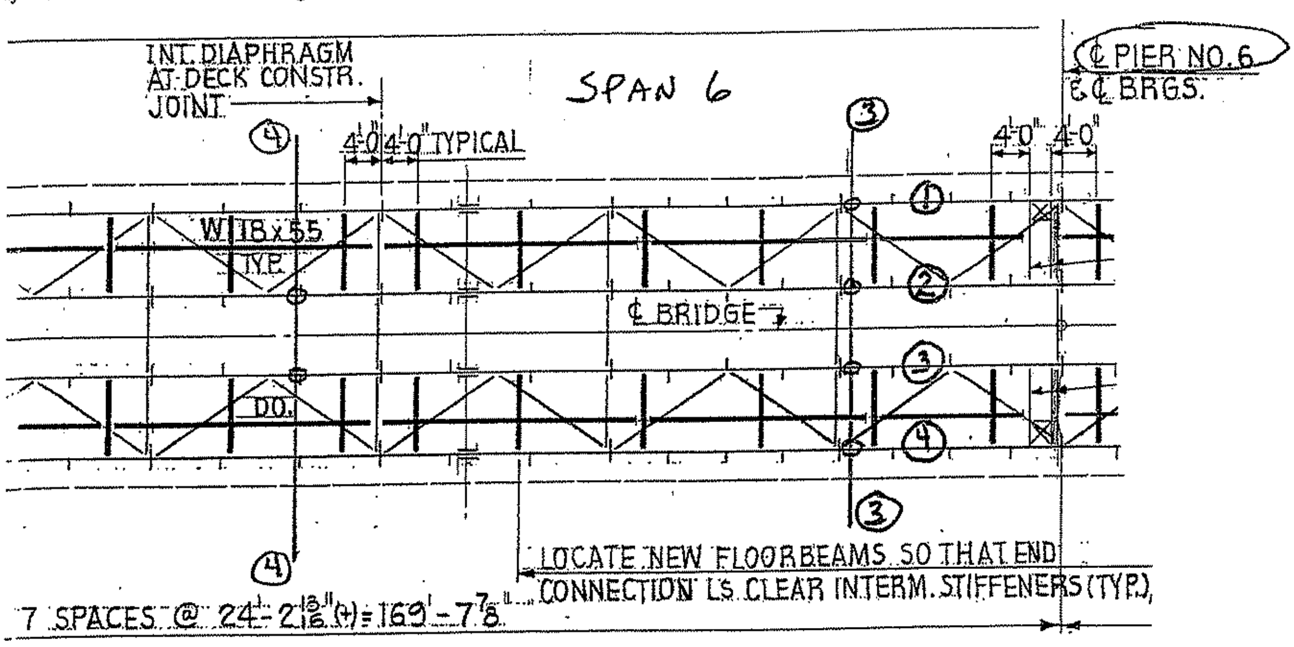

Table 4

Gage Locations for Span 7, Saw Mill Run Bridge

Span. Gage	Span /Section	Member	Location in Span	Location on Member
7.1	7/1	G1	~2' S of midspan and 6" S of x-bracing, near midlength of sub-stringers	TBF, E side, 5" from tip
7.2		G1		BTF above 7.1, 8" from tip
7.3		G2		TBF, W side, 8" from tip
7.4		G2		BTF above 7.3, 8" from tip
7.5		Sub-stringer, W18 x 55 between G1 & G2	63.5" S of midspan FB	TBF, W side, 2" from tip
7.6				BTF above 7.5, 2" from tip
7.7		G3		TBF, E side, 8" from tip
7.8		G3		BTF above 7.7, 8" from tip
7.9		G4		TBF, W side, 8" from tip
7.10		G4		BTF above 7.9, 8" from tip
7.11		Sub-stringer, W18 x 55 between G3 & G4	Midspan of stringer	TBF, E side, 2" from tip
7.12				BTF above 7.11, 2" from tip
7.13	7/2	G2	~26' N of girder splice closest to Pier 6 in fill pl area	W edge of 7/8" fill plate, near seal weld to existing fl.
7.14		G2		TBF (2-1/8" thick) above 7.13
7.15		G2		bottom of bottom CP, below 7.13
7.19		G3		like 7.13
7.20		G3		like 7.14, but above 7.19
7.21		G3		like 7.15, but below 7.19
7.16	7/22	G2	~15' N of girder splice in fill plate area	W edge of 1-1/4" fill pl near seal weld to 7/8" pl
7.17		G2		TBF (1-3/4" thick) above 7.16
7.18		G2		edge of bottom CP, below 7.16
7.22		G3		like 7.16
7.23		G3		like 7.17, but above 7.22
7.24		G3		bottom of bottom CP, below 7.22
7.25		G1	6" S of weld splice in bottom flange	TBF, E side, 8" from tip
7.26		G4		TBF, W side, 8" from tip
7.27	7/222	Floorbeam, W18 x 55 between G1 & G2	midlength of first FB N of girder splice	TBF, 2" from tip
7.28				℄ of top flange
7.29	7/2222	Sub-stringer, W18 x 55 between G1 & G2	6" N of midlength between FBs flanking girder splice	TBF, W side, 2" from tip
7.30				BTF, above 7.29, 2" from tip

(Sheet 1 of 2)

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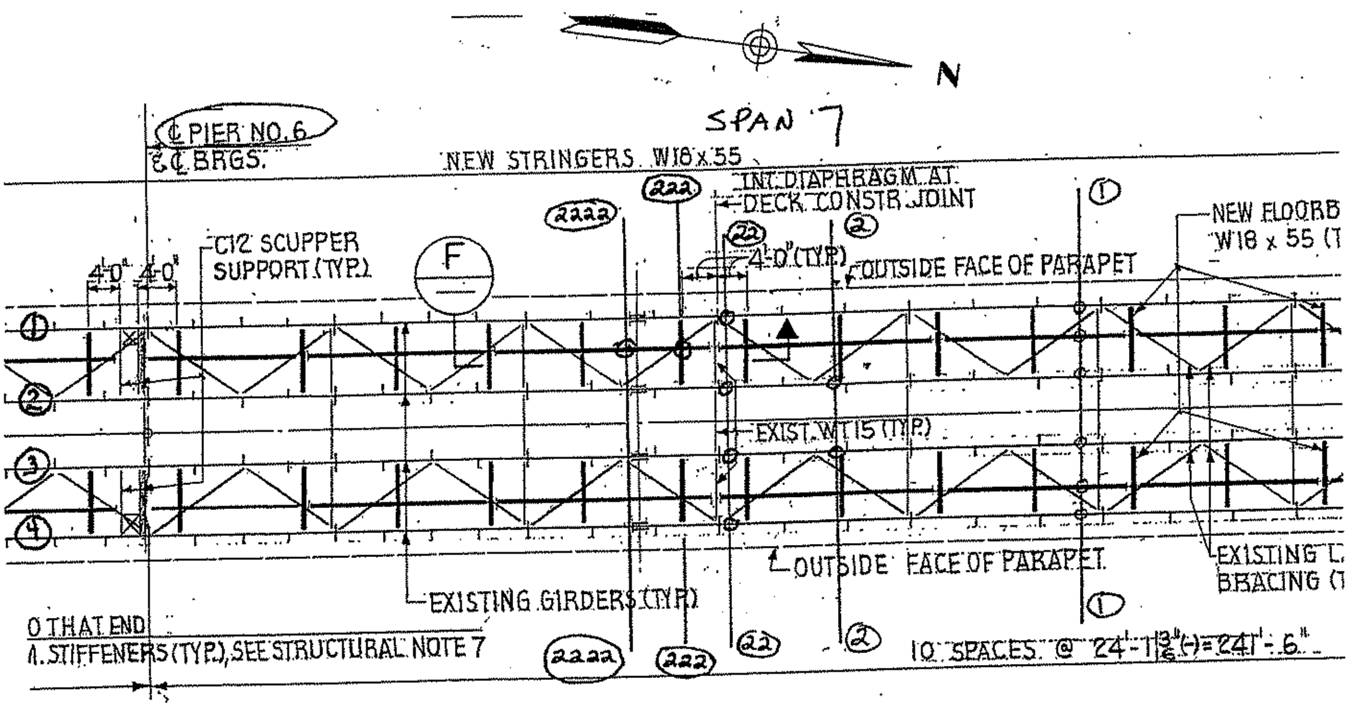
Table 4 (continued)

Gage Locations for Span 7, Saw Mill Run Bridge



(Sheet 2 of 2)

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Table 5

Gage Locations for Span 9, Saw Mill Run Bridge

Span. Gage	Span /Section	Member	Location in Span	Location on Member
9.1	9/c	G1	~66' S of Pier 9 at midlength of new stringer, 15" N of stiffener near diaphragm	TBF, 8" from flange edge
9.2		G1		BTF above 9.1
9.3		Sub-stringer W16 x 57 between G1 & G2		TBF, 2" from flange edge
9.4				BTF above 9.3
9.5		G2		TBF, like 9.1
9.6		G2		BTF above 9.5
9.7		G3		TBF, like 9.1
9.8		G3		BTF above 9.7
9.9		Sub-stringer W16 x 57 between G3 & G4		TBF, like 9.3
9.10				BTF above 9.9
9.11		G4		TBF, like 9.1
9.12		G4		BTF above 9.11
9.13	9/5	G2	~19' S of Pier 9 in fill plate area	TBF above gap where seal weld is omitted; on ℄ of flange weld 8" from edge of flange
9.14		G2		BTF above 9.13
9.15		G3		like 9.13, but 1/8" from edge of flange
9.16		G3		BTF above 9.15, but 8" from fl. edge
9.17		G1		TBF
9.18		G1		BTF above 9.17
9.19		G4		TBF
9.20		G4		BTF above 9.19

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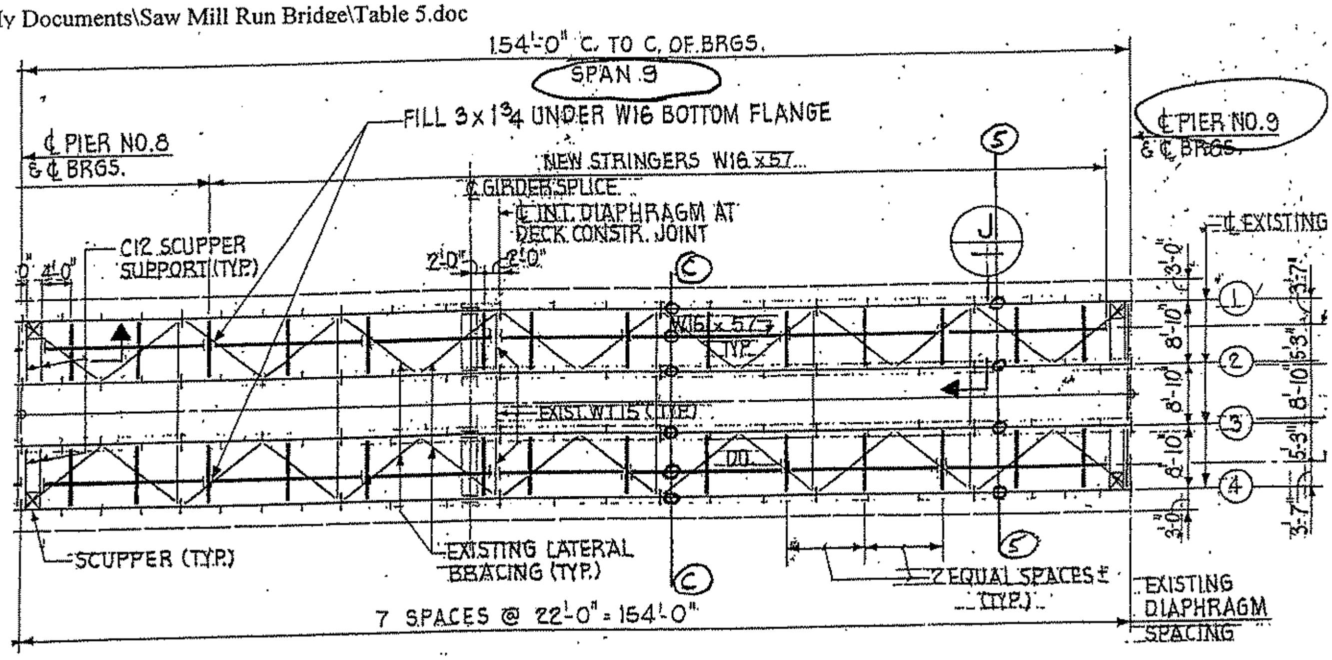

Table 6

Gage Locations for Span 10, Saw Mill Run Bridge

Span. Gage	Span /Section	Member	Location in Span	Location on Member
10.1	10/6	G2, W30x99	~59" N of Pier 9 in fill plate area	TBF above E seal weld at end of 1¼" fill plate
10.2		G2		BTF above 10.1
10.3		G3, W30x99	~63" N of Pier 9 in fill plate area	like 10.1
10.4		G3		BTF above 10.3
10.5	10/7	G1	at midspan, relative to bridge	℄ BBF
10.6		G2		℄ BBF
10.7		G3		℄ BBF
10.8		G4		℄ BBF
10.9		FB, W18 x 55 between G3 & G4		℄ BBF at midlength
10.10				BTF above 10.9, 2" from N flange edge
10.11		Sub-stringer, W18 x 55 between G3 & G4	12" N of str. midpt, due to lateral bracing. ~6' N of midspan FB	℄ BBF
10.12				BTF above 10.11, 2" from E tip

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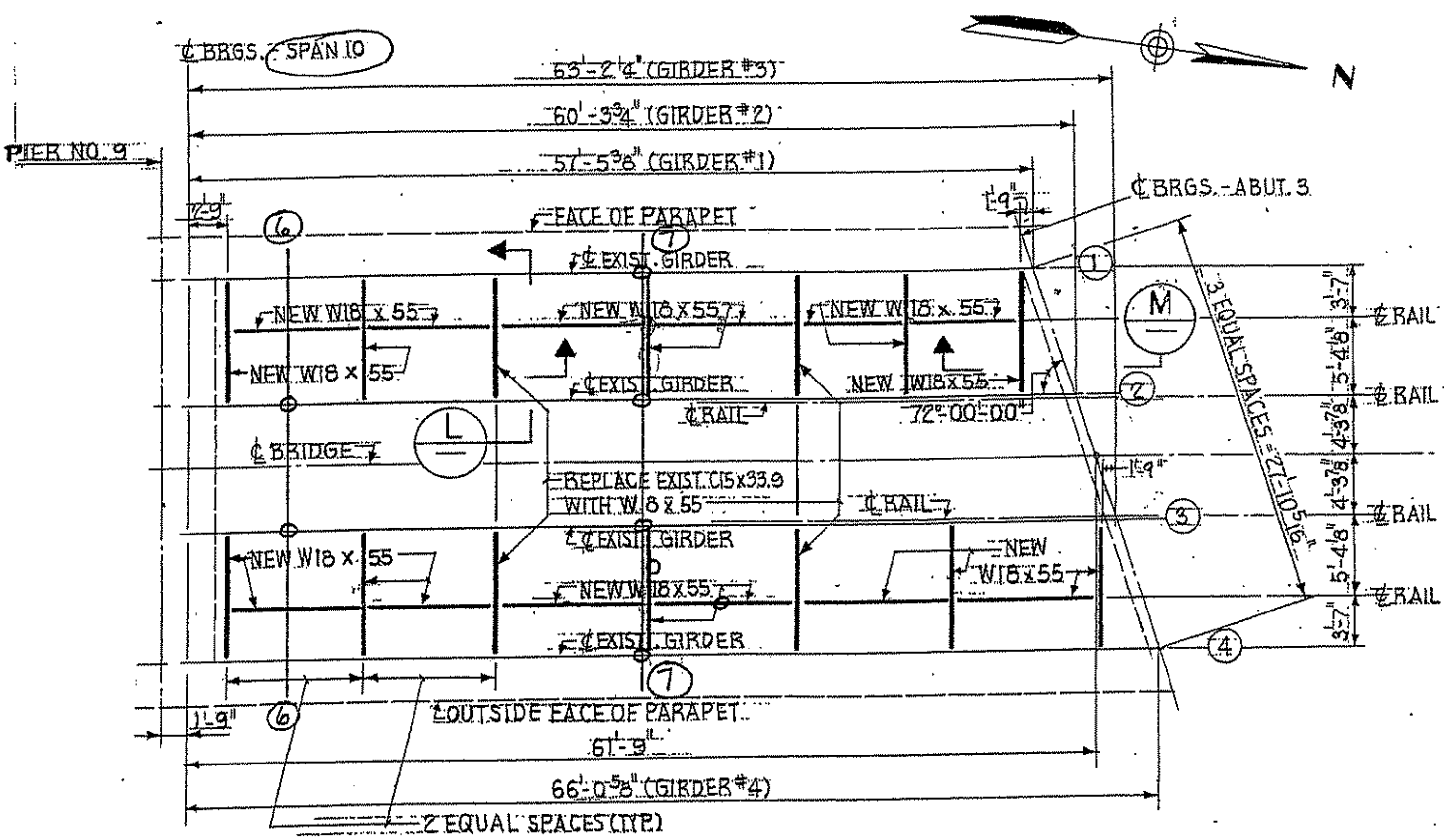

Table 7
Variables During Strain-Gage Measurements, Saw Mill Run Bridge

Revenue Traffic

Spans	Date	Time and Temperature	No. Rail Vehicles				No. Off-Rail Vehicles	
			NB		SB			
			1 car	2 cars	1 car	2 cars	NB	SB
4 & 5	10 Feb 99 (Wed.)	6:40 - 9:40 am 21-50 F	27	16	28	18	26	26
	10 Feb 99 (Wed.)	3:00 - 6:00 pm 47-49 F	38	16	37	15	28	30
6 & 7	11 Feb 99 (Thurs.)	3:00 - 6:00 pm 65-71 F	32	16	31	15	69	111
	16 Feb 99 (Tues.)	6:10 - 9:10 am 30-40 F	30	20	30	17	121	97
9 & 10	16 Feb 99 (Tues.)	3:00 - 6:00 pm 59-60 F	32	17	32	16	82	115
	17 Feb 99 (Wed.)	6:00 - 9:00 am 51-48 F	29	19	28	18	121	92

Test Vehicle Excursions

Spans	Date	Time and Temperature	Vehicle Description and Procedure
4 & 5	15 Feb 99 (Mon.)	1:00 - 2:00 am ° F nr	• one car loaded with 840 salt bags @ 50 lb/bag (equivalent to 280 riders @ 150 lb) • Runs on inbound* track (above G3 & G4) • Inbound at nominal 10 mph • Outbound at nominal10 mph • Inbound at nominal 25 mph • Outbound at 25 mph** • Runs on outbound* track (above G1 & G2) • Outbound at nominal 10 mph • Inbound at nominal10 mph • Outbound at nominal 25 mph • Inbound at 25 mph**
6 & 7	16 Feb 99 (Tues.)	2:00 - 3:00 am 35 F	
9 & 10	17 Feb 99 (Wed.)	2:00 - 3:00 am 52 F	** Supplemental run only made on 17 Feb.

nr = not recorded

*Inbound is NB towards downtown:
Outbound is SB away from downtown.

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Table 8
Span 4 Stress Ranges During Test-Vehicle Runs

Gage No.	Member	Stress Range[1], ksi					
		VO-OT-10[2]	VI-OT-10	VO-OT-25	VI-IT-10	VO-IT-10	VI-IT-25
4.1	G1	+2.05	+2.00	+2.00	+0.40	+0.47	+0.43
4.2		+0.10	0	*0.15	0	+0.07	+0.07
4.3	G2	+1.15	+1.05	+1.10	+0.35	+0.55	+0.50
4.4		0	0	0	0	-0.04	-0.06
4.5	G3	+0.55	+0.50	+0.55	+0.90	+0.92	+0.85
4.6		-0.10	-0.08	-0.07	0	-0.08	-0.10
4.7	Sub-str	+1.15	+1.10	+1.20	+0.20	+0.20	+0.18
4.8		*0.14	+0.18	-0.14	0	0	+0.07
4.9	FB	+0.92	+0.90	+0.85	-0.20	-0.16	-0.22
4.10		-0.75	-0.75	-0.68	+0.20	+0.17	+0.17
4.11	G4	+0.55	+0.50	+0.55	+1.30	+1.20	+1.10
4.12		0	-0.05	0	0	-0.10	-0.10

[1] Most stress cycles included some stress reversal. Positive (+) stress range was greater in tension than in compression. Negative (-) stress range was opposite. A fully reversed stress range is indicated by *.
[2] VO-OT-10 = Vehicle Outbound on Outbound Track @ nominal 10 mph.
VI-IT-25 = Vehicle Inbound on Inbound Track @ nominal 25 mph.

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Table 9
Span 5 Stress Ranges During Test-Vehicle Runs

Gage No.	Member	Stress Range[1], ksi					
		VO-OT-10[2]	VI-OT-10	VO-OT-25	VI-IT-10	VO-IT-10	VI-IT-25
5.1	G1	+1.50	+1.58	+1.5	+0.38	+0.30	+0.35
5.2		-0.25	-0.25	-0.23	-0.10	-0.10	-0.10
5.3	G2	+1.40	+1.25	+1.37	+0.60	+0.55	+0.55
5.4		0	0	0	0	0	0
5.5	G3	+0.87	+0.85	+0.90	+0.75	+0.80	+0.80
5.6		-0.20	-0.19	-0.20	-0.15	-0.15	-0.14
5.7	G4	+0.60	+0.60	+0.60	+1.22	+1.20	+1.22
5.8		-0.20	-0.18	-0.12	-0.10	-0.13	-0.13
5.11	Sub-str	+0.65	+0.65	+0.52	+0.10	+0.10	+0.15
5.12		-0.18	-0.20	-0.15	-0.10	-0.06	-0.12
5.13	FB	+0.62	+0.70	+0.68	-0.10	-0.10	-0.10
5.14		-0.50	-0.50	-0.45	+0.10	+0.10	+0.14

[1] Most stress cycles included some stress reversal. Positive (+) stress range was greater in tension than in compression. Negative (-) stress range was opposite. A fully reversed stress range is indicated by *.

[2] VO-OT-10 = Vehicle Outbound on Outbound Track @ nominal 10 mph.
VI-IT-25 = Vehicle Inbound on Inbound Track @ nominal 25 mph.

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Table 10
Span 6 Stress Ranges During Test-Vehicle Runs

Gage No.	Member	Stress Range[1], ksi					
		VO-OT-10[2]	VO-OT-25	VI-OT-10	VO-IT-10	VI-IT-10	VI-IT-25
6.1	G2	+2.55	+2.55	+2.55	+1.85	+1.90	+1.95
6.2		+2.55	+2.55	+2.55	+1.95	+2.00	+2.00
6.3		+2.30	+2.20	+2.25	+1.60	+1.60	+1.60
6.4	G3	+1.60	+1.65	+1.60	+2.35	+2.35	+2.40
6.5		+1.55	+1.55	+1.55	+2.45	+2.45	+2.45
6.6		+1.70	+1.75	+1.70	+2.60	+2.60	+2.60
6.7	G2	+0.25	*0.40	*0.25	-0.60	-0.60	-0.57
6.8		-1.20	-1.25	-1.22	-0.80	-0.80	-0.80
6.9		-0.92	-0.90	-0.92	+0.20	+0.18	+0.17
6.10		-1.04	-1.06	na	na	-0.83	-0.83
6.11	G3	+0.37	*0.40	*0.40	-0.36	-0.33	-0.32
6.12		bad gage					
6.13		+0.18	+0.17	+0.18	*0.30	-0.30	*0.34
6.14		-0.71	-0.75	na	na	-1.20	-1.20
6.15	G1	-1.28	-1.25	-1.37	-0.62	-0.60	-0.60
6.16		+0.42	+0.45	na	na	+0.15	+0.12
6.17	G4	-0.40	-0.47	-0.55	-1.27	-1.25	-1.30
6.18		+0.15	+0.15	na	na	+0.49	+0.49

[1] Most stress cycles included some stress reversal. Positive (+) stress range was greater in tension than in compression. Negative (-) stress range was opposite. A fully reversed stress range is indicated by *.
[2] VO-OT-10 = Vehicle Outbound on Outbound Track @ nominal 10 mph.
VI-IT-25 = Vehicle Inbound on Inbound Track @ nominal 25 mph.
na = not acquired or not reliable.

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Table 11
Span 7 Stress Ranges During Test-Vehicle Runs

Gage No.	Member	Stress Range[1], ksi					
		VO-OT-10[2]	VI-OT-10	VO-OT-25	VI-IT-10	VO-IT-10	VI-IT-25
7.1	G1	+2.20	+2.20	+2.20	+0.80	+0.80	+0.85
7.2		-0.16	-0.15	-0.14	-0.14	-0.15	-0.18
7.3	G2	+1.85	+1.85	+1.90	+1.25	+1.30	+1.30
7.4		-0.45	-0.45	-0.45	-0.40	-0.36	-0.40
7.5	Sub-str	+0.70	+0.70	+0.70	+0.05	+0.05	+0.05
7.6		-0.60	-0.50	-0.50	-0.35	-0.35	-0.37
7.7	G3	+1.35	+1.27	+1.35	+1.90	+1.85	+1.90
7.8		-0.40	-0.37	-0.37	-0.50	-0.48	-0.40
7.9	G4	+0.95	+0.90	+0.97	+2.30	+2.40	+2.35
7.10		-0.17	-0.23	-0.20	-0.25	-0.28	-0.18
7.11	Sub-str	+0.20	*0.10	-0.10	+0.50	+0.55	+0.50
7.12		-0.30	-0.27	-0.30	-0.50	-0.50	-0.50
7.13	G2	+1.45	+1.45	+1.45	+1.05	+1.10	+1.05
7.14		+2.15	+2.15	+2.15	+1.60	+1.55	+1.65
7.15		+2.50	+2.55	+2.55	+1.80	+1.80	+1.80
7.16		+2.90	+2.85	+2.90	+2.40	+2.30	+2.30
7.17		+1.80	+1.80	+1.90	+1.60	+1.55	+1.60
7.18		+2.60	+2.65	+2.70	+2.20	+2.20	+2.20
7.19	G3	+1.50	+1.48	+1.50	+2.40	+2.40	+2.30
7.20		+1.10	+1.15	+1.20	+1.80	+1.80	+1.85
7.21		+1.60	+1.62	+1.65	+2.60	+2.60	+2.65
7.22		+2.90	+2.90	+3.00	+4.60	+4.55	+4.60
7.23		+1.00	+1.00	+1.00	+1.70	+1.65	+1.75
7.24		+2.20	+2.20	+2.25	+3.55	+3.55	+3.55
7.25	G1	+3.30	+3.35	+3.40	+1.35	+1.35	+1.35
7.26	G4	+1.35	+1.30	+1.35	+3.35	+3.45	+3.40
7.27	FB	+0.70	+0.70	+0.70	-0.22	-0.22	-0.23
7.28		-0.65	-0.70	-0.70	+0.20	+0.30	+0.30
7.29	Sub-str	+0.70	+0.65	+0.67	-0.10	-0.15	*0.20
7.30		-0.40	-0.38	-0.40	-0.30	-0.30	-0.30

[1] Most stress cycles included some stress reversal. Positive (+) stress range was greater in tension than in compression. Negative (-) stress range was opposite. A fully reversed stress range is indicated by *.

[2] VO-OT-10 = Vehicle Outbound on Outbound Track @ nominal 10 mph.
VI-IT-25 = Vehicle Inbound on Inbound Track @ nominal 25 mph.

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Table 12
Span 9 Stress Ranges During Test-Vehicle Runs

Gage No.	Member	Stress Range[1], ksi					
		VO-OT-10[2]	VI-OT-10	VI-OT-25	VI-IT-10	VO-IT-10	VI-IT-25
9.1	G1	+3.00	+3.00	+3.10	+1.20	+1.20	+1.20
9.2		-0.47	-0.44	-0.42	-0.18	-0.18	-0.20
9.3	Sub-str	+0.80	+0.80	+0.85	+0.20	+0.20	+0.20
9.4		-0.40	-0.40	-0.60	-0.20	-0.13	+0.15
9.5	G2	+2.50	+2.50	+2.50	+1.70	+1.65	+1.65
9.6		-0.40	-0.38	-0.40	-0.32	-0.32	-0.35
9.7	G3	+1.60	+1.60	+1.65	+2.30	+2.30	+2.30
9.8		-0.29	-0.28	-0.28	-0.39	-0.38	-0.38
9.9	Sub-str	-0.20	-0.17	-0.20	+0.70	+0.70	+0.75
9.10		-0.17	-0.17	-0.15	-0.37	-0.32	-0.36
9.11	G4	+1.20	+1.20	+1.20	+3.10	+3.10	+3.10
9.12		-0.20	-0.20	-0.17	-0.49	-0.48	-0.54
9.13	G2	+1.18	+1.18	+1.30	+0.59	+0.60	+0.60
9.14		-0.14	-0.21	-0.15	-0.12	-0.12	-0.12
9.15	G3	+0.40	+0.50	+0.52	+1.20	+1.15	+1.15
9.16		-0.13	-0.15	-0.12	-0.21	-0.21	-0.22
9.17	G1	+1.45	+1.40	+1.45	+0.30	+0.35	+0.35
9.18		-0.25	-0.25	-0.20	-0.15	-0.13	-0.15
9.19	G4	+0.32	+0.32	+0.38	+1.55	+1.55	+1.60
9.20		-0.15	-0.10	-0.05	-0.25	-0.27	-0.25

[1] Most stress cycles included some stress reversal. Positive (+) stress range was greater in tension than in compression. Negative (-) stress range was opposite. A fully reversed stress range is indicated by *.

[2] VO-OT-10 = Vehicle Outbound on Outbound Track @ nominal 10 mph.
VI-IT-25 = Vehicle Inbound on Inbound Track @ nominal 25 mph.

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Table 13
Span 10 Stress Ranges During Test-Vehicle Runs

Gage No.	Member	Stress Range[1], ksi					
		VO-OT-10[2]	VI-OT-10	VI-OT-25	VI-IT-10	VO-IT-10	VI-IT-25
10.1	G2	+0.65	+0.75	+0.85	+0.35	+0.35	+0.38
10.2		-0.05	-0.07	-0.05	0	+0.04	+0.04
10.3	G3	+0.40	+0.45	+0.50	+0.80	+0.80	+0.85
10.4		0	*0.02	0	-0.12	-0.10	-0.08
10.5	G1	+1.80	+1.75	+1.85	+0.40	+0.38	+0.40
10.6	G2	+1.40	+1.40	+1.40	+0.80	+0.81	+0.75
10.7	G3	+0.65	+0.70	+0.72	+1.65	+1.62	+1.60
10.8	G4	+0.40	+0.45	+0.50	+2.25	+2.20	+2.25
10.9	FB	-0.15	-0.16	-0.15	+0.85	+0.84	+0.85
10.10		+0.15	+0.16	+0.20	-0.85	-0.80	-0.80
10.11	Sub-str	+0.15	+0.16	+0.20	+1.00	+0.98	+1.05
10.12		+0.07	+0.07	+0.10	0	+0.13	+0.05

[1] Most stress cycles included some stress reversal. Positive (+) stress range was greater in tension than in compression. Negative (-) stress range was opposite. A fully reversed stress range is indicated by *.
[2] VO-OT-10 = Vehicle Outbound on Outbound Track @ nominal 10 mph.
VI-IT-25 = Vehicle Inbound on Inbound Track @ nominal 25 mph.

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Table 14
Critical Stress Ranges Due to Revenue Vehicles

Span	Member	Gage No.	Stress Range, psi+			
			AM Rush Period		PM Rush Period	
			Rainflow Maximum	Equivalent Constant Amplitude	Rainflow Maximum	Equivalent Constant Amplitude
4	G1	4.1	1690	1170	2060*	1300
	G2	4.3	1270	660	1280	750
	G3	4.5	860	nd	1050*	nd
5	G1	5.1	1250	840	1370	1000
	G2	5.3	1260	770	1180	760
6	G2	6.1	4560	1350	3200	1410
	G2	6.2	4560	1420	3370	1380
	G2	6.3	3770	1160	2760	1220
	G3	6.4	3900	1330	2950	1220
	G3	6.5	3990	1310	3080	1240
	G3	6.6	4320	1430	3220	1340
7	G2	7.13	2200	880	1770	890
	G2	7.14	3370	1230	2510	1230
	G2	7.15	3980	1400	2920	1410
	G2	7.16	4650	1620	3450	1620
	G2	7.17	3050	1100	2300	1110
	G2	7.18	4250	1500	3060	1460
	G3	7.19	3340	1400	2890	1190
	G3	7.20	2720	1140	2370	1010
	G3	7.21	3830	1550	3050	1320
	G3	7.22	6590	2510	5510	2250
	G3	7.23	2530	1040	2110	890
	G3	7.24	5150	1990	4040	1720
	G4	7.26	4380	1780	3690	1610
9	G1	9.1	3200	1360	3710	1530
	G2	9.5	3190	1270	3490	1300
	G3	9.7	Bad gage			
	G4	9.11	3500	1660	3180	1390
10	G1	10.5	2480	940	1680	1040
	G2	10.1	850	480	660	460
	G3	10.3	1050	540	800	540
	G4	10.8	2400	1340	1980	1180

+ Stress ranges determined from rainflow analysis; see text for description.
* Inbound LRV passed while outbound LRV was stopped on span.
nd = not evaluated with rainflow analysis

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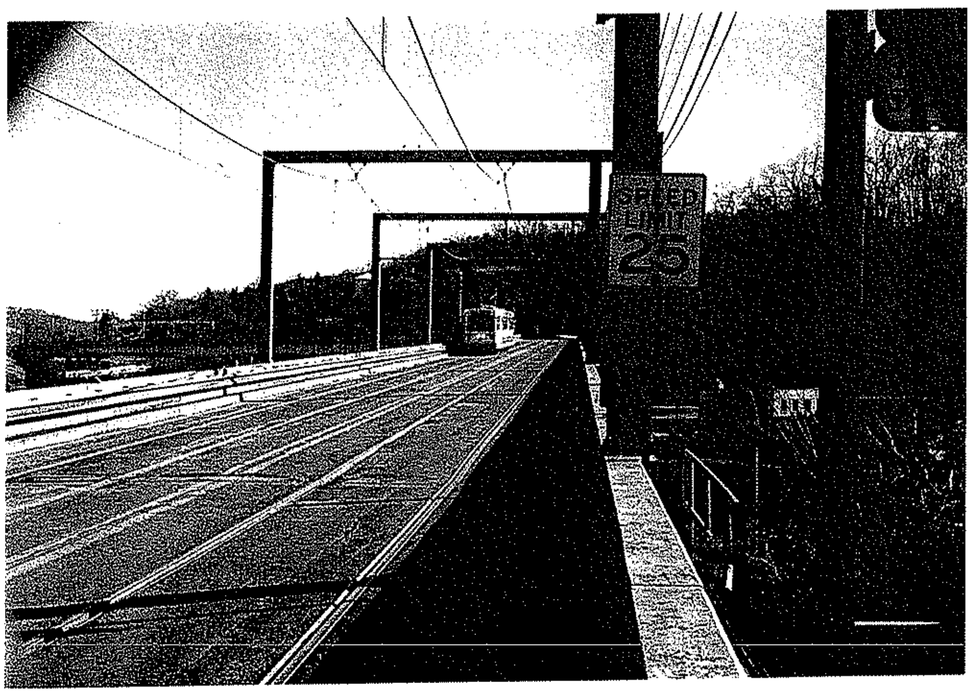
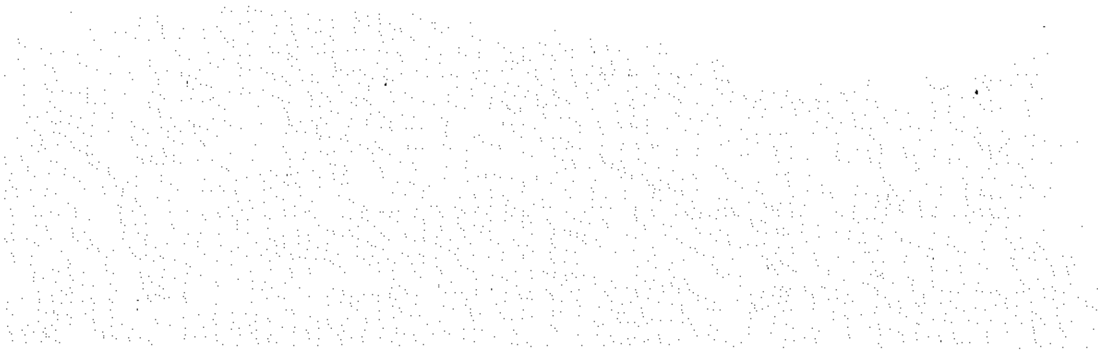
Figures

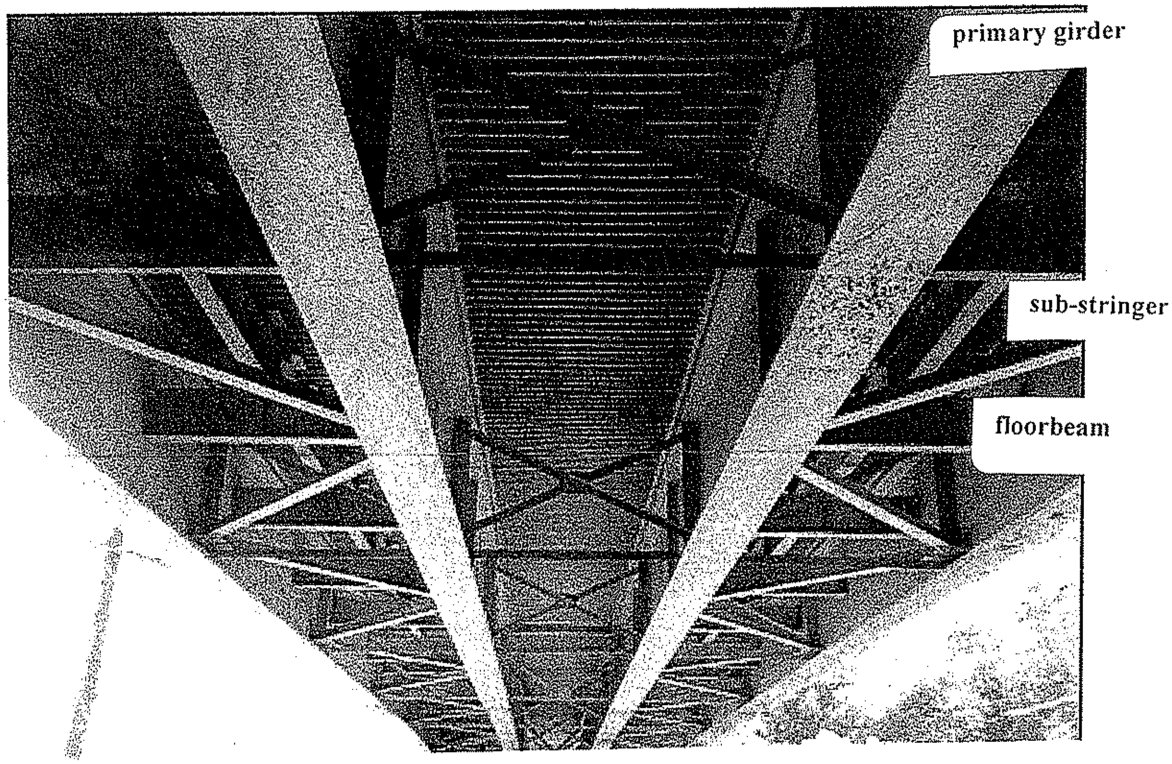
a) **Looking SW at bridge with Span 8 nearest. Pier 7 (between Spans 7 and 8) has bifurcated drainpipe.** (photo courtesy of Parsons Brinckerhoff)



b) **View of Bridge Surface looking south from Span 10** (2/99/16-8)
(Spans 1 to 3 veer to the left in background)

Figure 1: Saw Mill Run Bridge

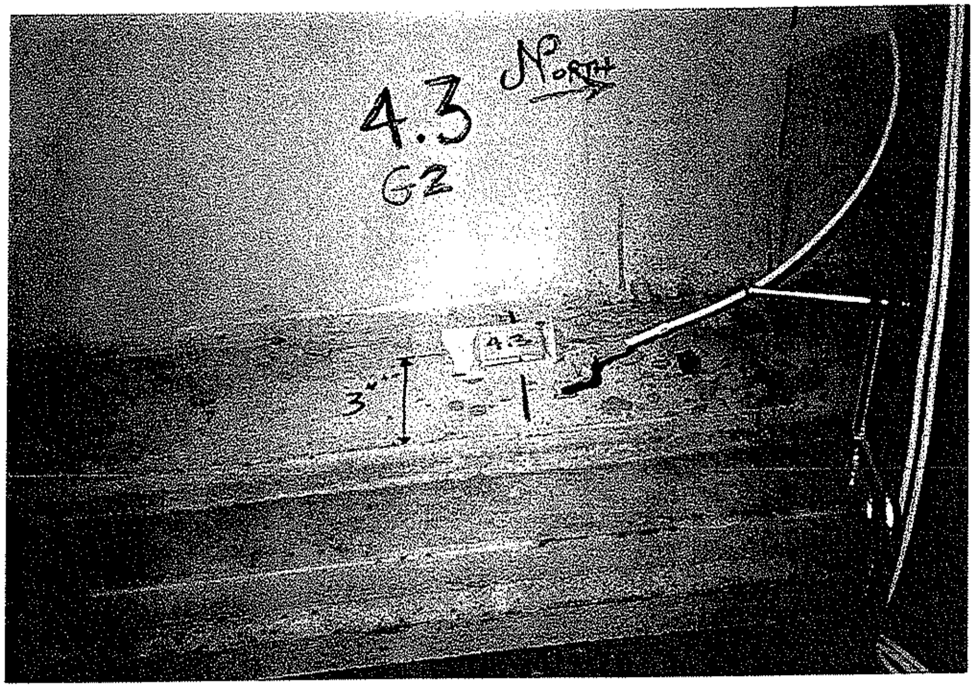




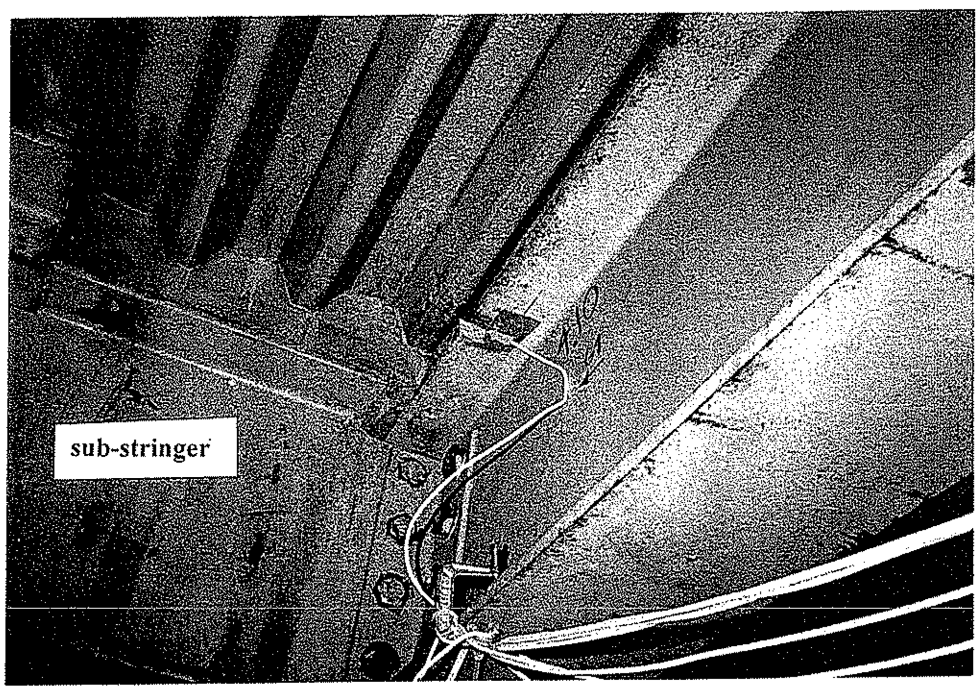
a) **Structure in Spans 6 through 9** (photo courtesy of Parsons Brinckerhoff)

b) **The typical articulated light rail vehicle (LRV)** (2/99/25-18)

Figure 2: Bridge Structure and Light Rail Vehicle

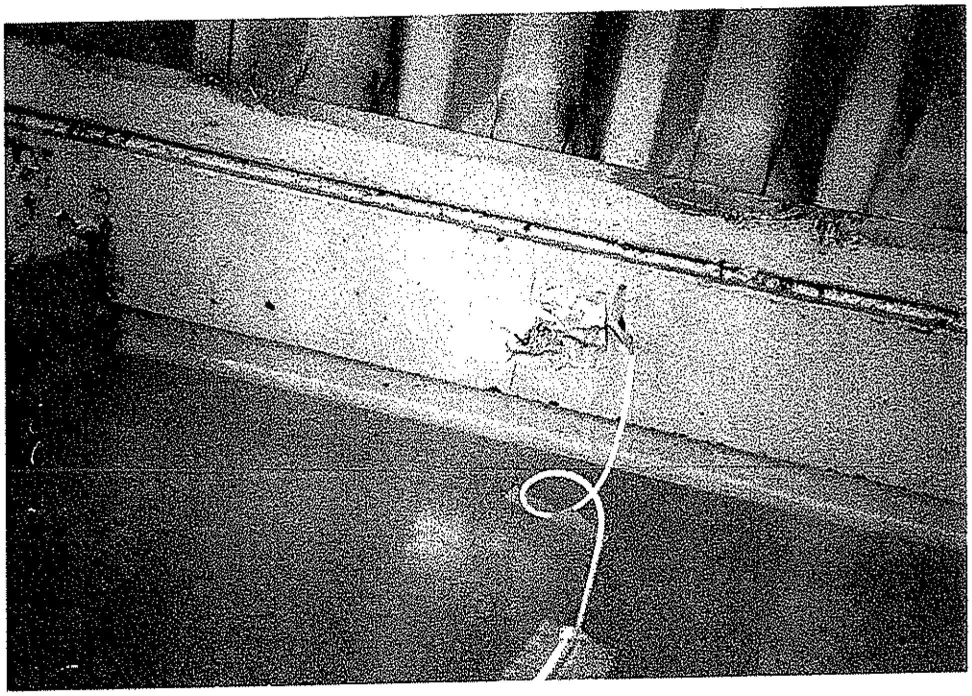


a) Gage 4.3 atop the bottom flange of Girder 2 (W30x108). Two coverplates are below flange (1 ¼"-top and 1"-bottom). (3/99/11-7a)

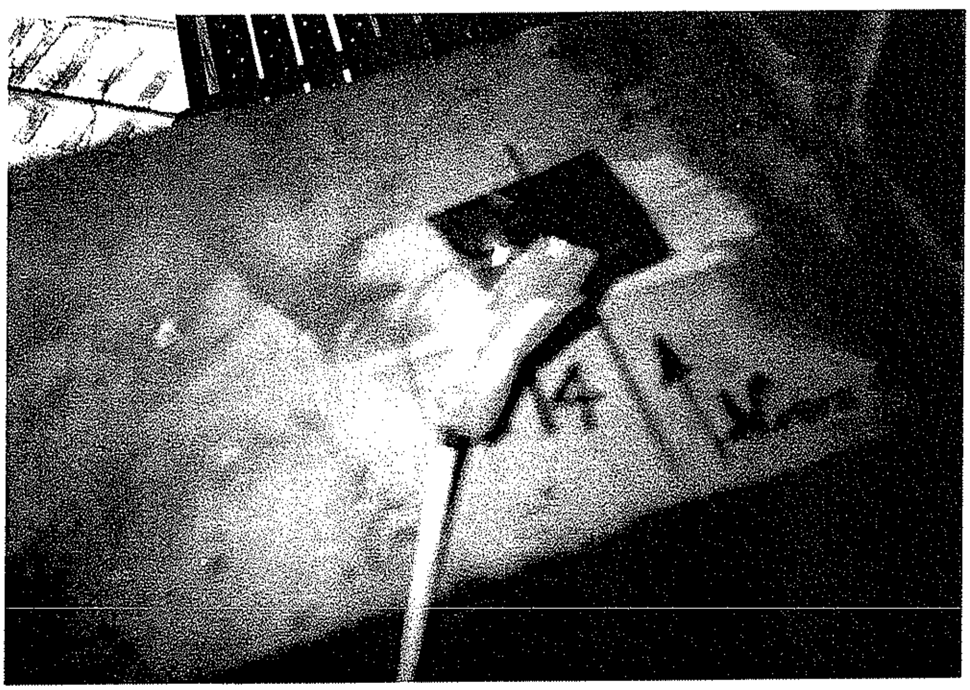


b) Gage 4.10 on the top flange of the floorbeam (W18x55) between Girders 1 and 2. Sub-stringer frames into the floorbeam. (3/99/11-10a)

Figure 3: Representative Gage Installations in Span 4, Section 4/a

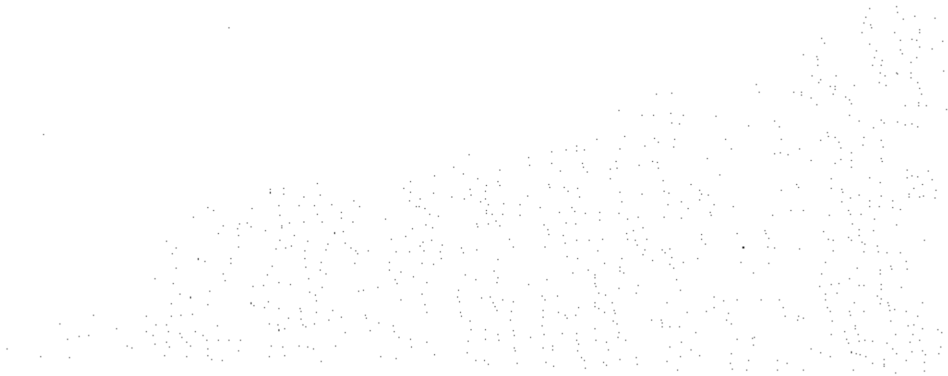


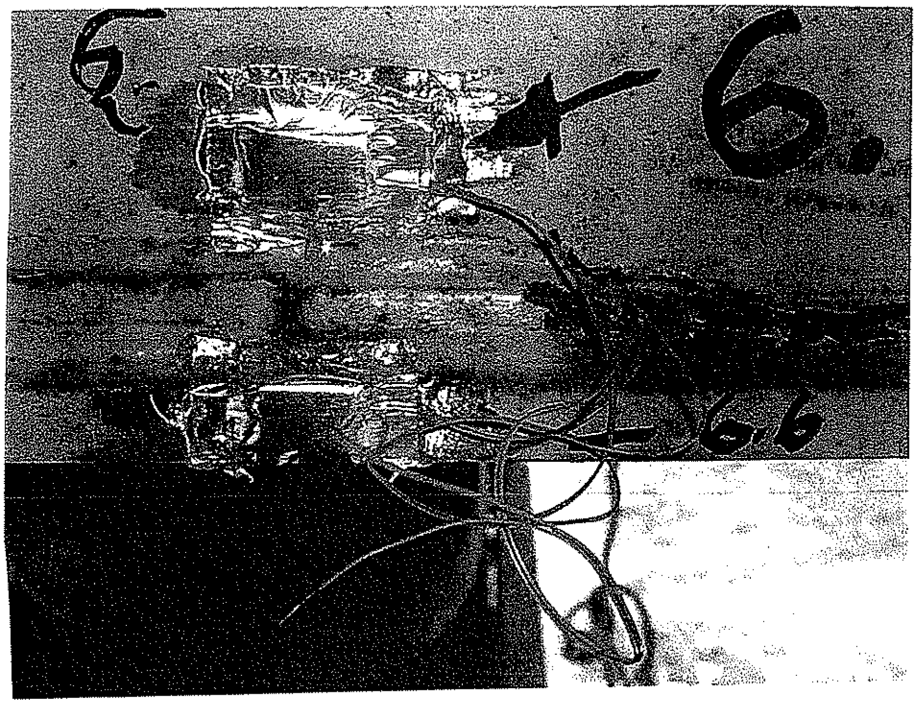
a) **Looking up at Gage 5.4 on underside of plate below top flange of Girder 2 at Section 5/b.** (3/99/11-18a)



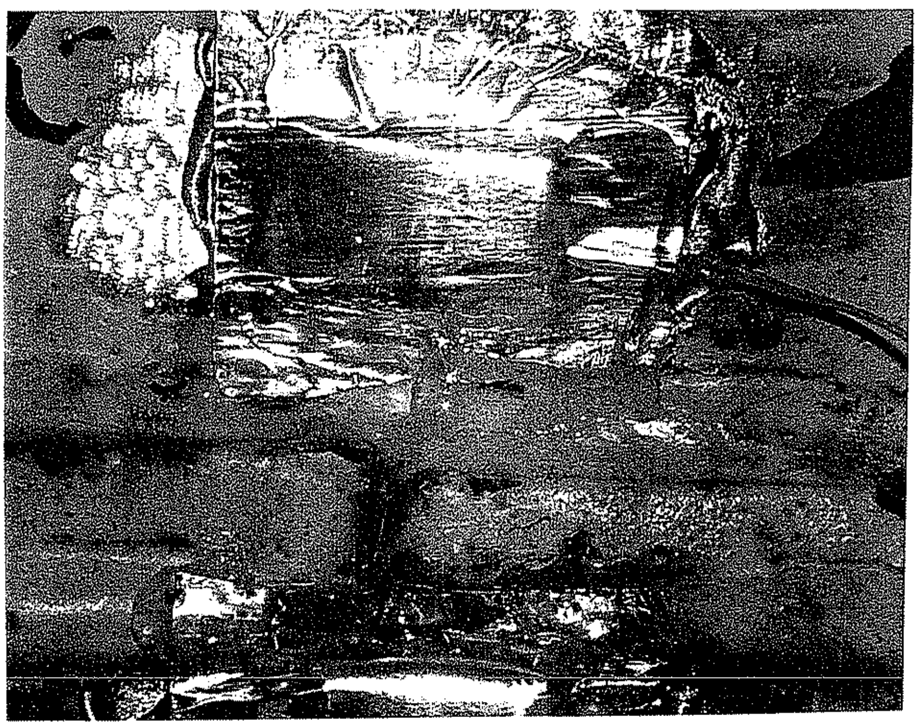
b) **Gage 5.14 at the ℄ of the top flange of floorbeam (W18x55) at Section 5/bb.** (3/99/11-22a)

Figure 4: Representative Gage Installations in Span 5



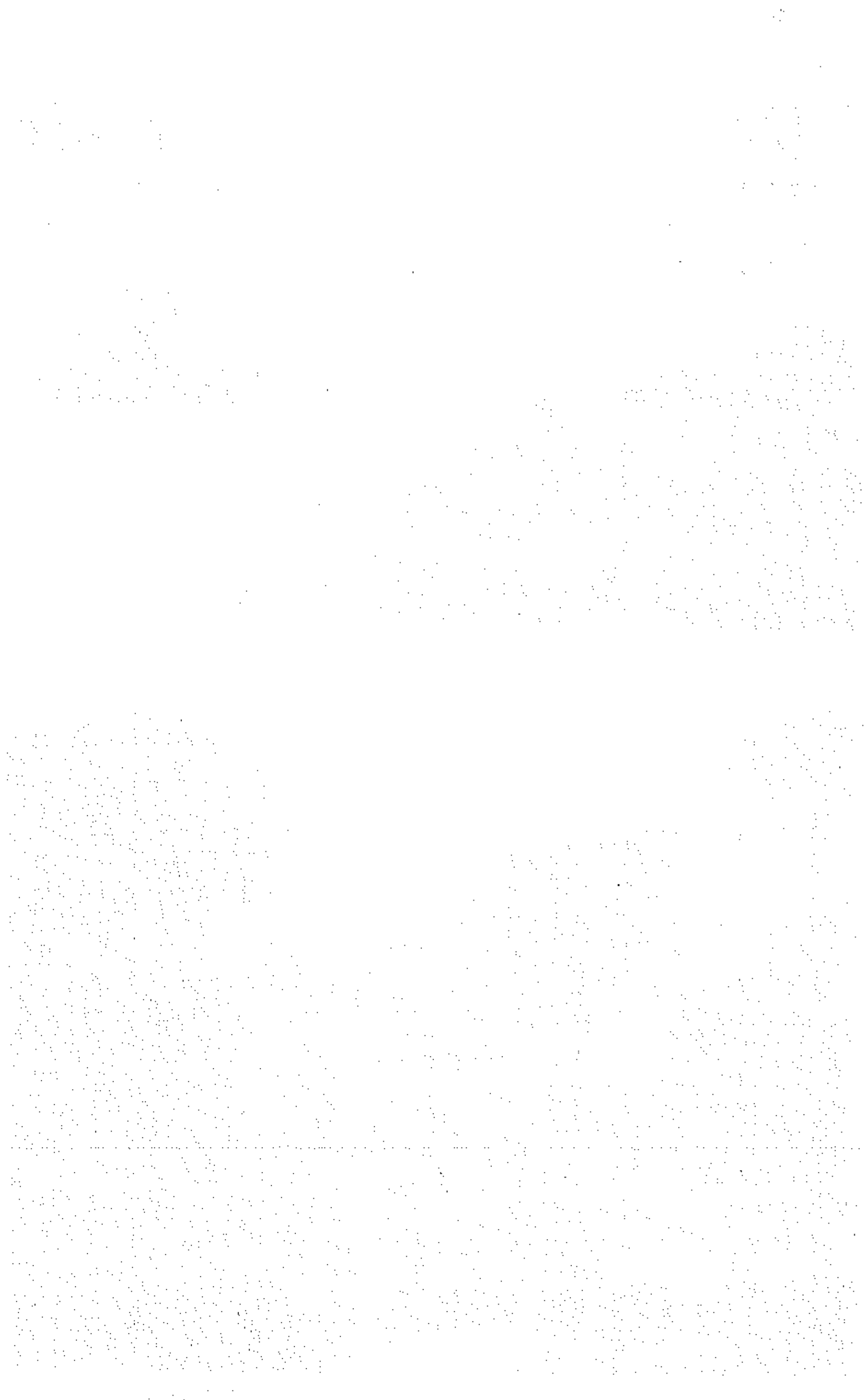


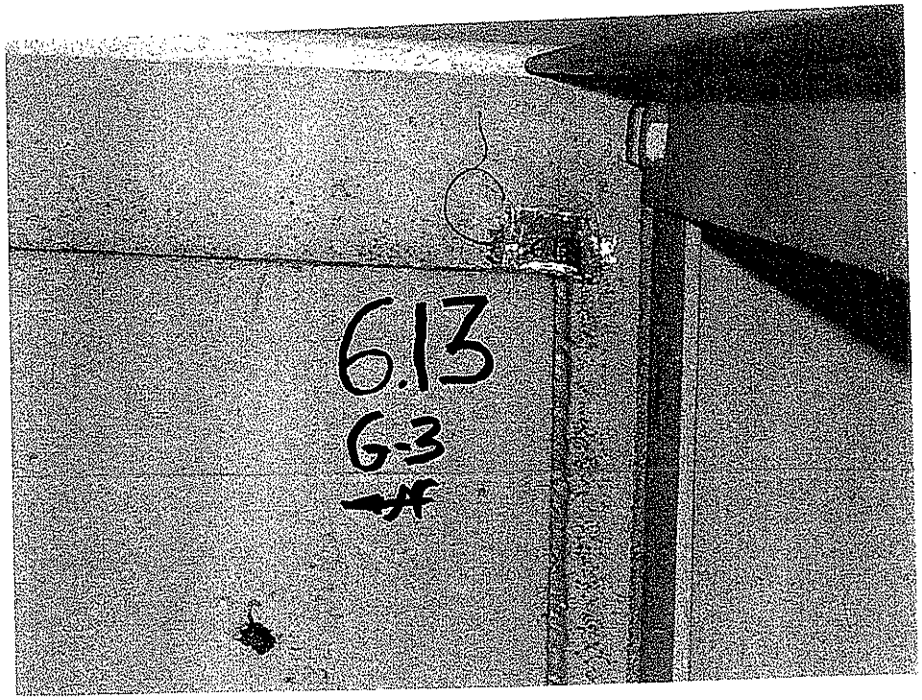
a) Gages 6.5 and 6.6 on west side of Girder 3 above and below seal weld. (P000 1038)



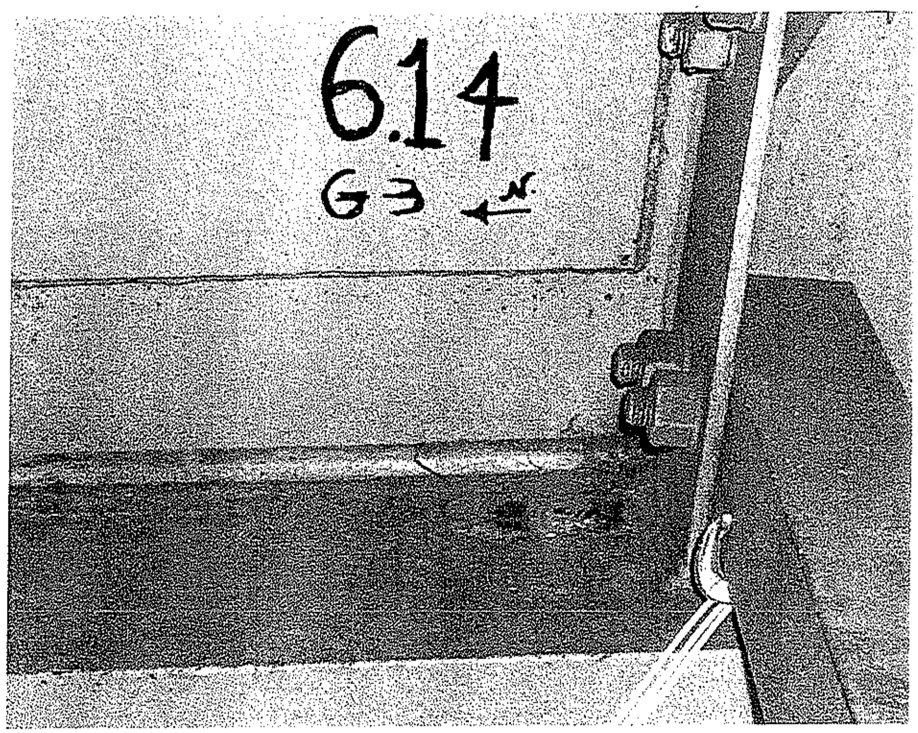
b) Close-up of seal weld area with Gages 6.5 and 6.6. (P000 1041)

Figure 5: Gage Installations in Span 6, Section 6/4, at Girder 3 Seal Weld





a) Gages 6.13 on web of Girder 3 at end of web doubler plate. (P000 1046)



b) Gage 6.14 atop bottom flange of Girder 3
below end of web doubler plate (P000 1047)

Figure 6: Representative Gage Installations in Span 6, Section 6/3, at end of Web Doubler Plate

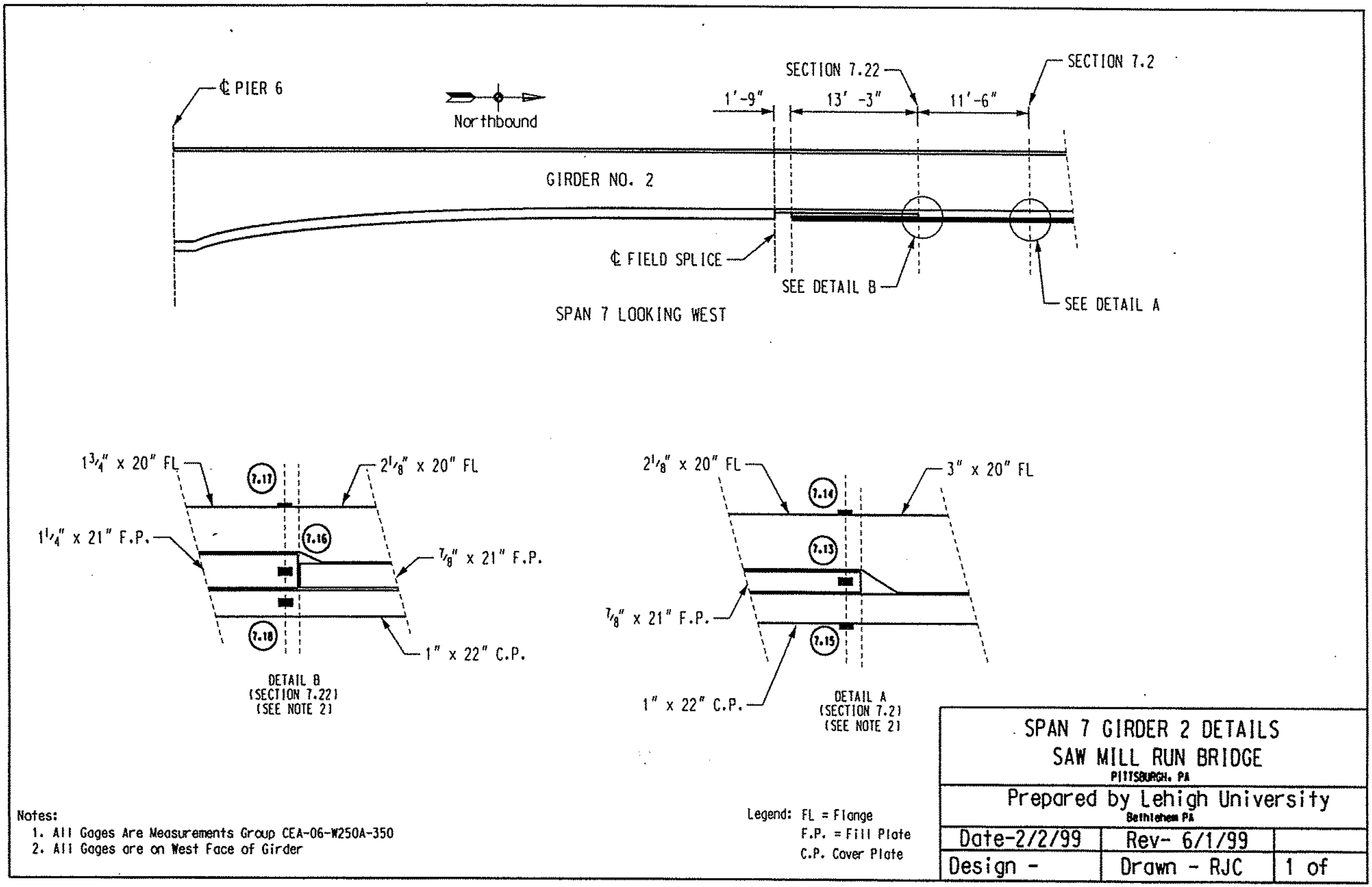
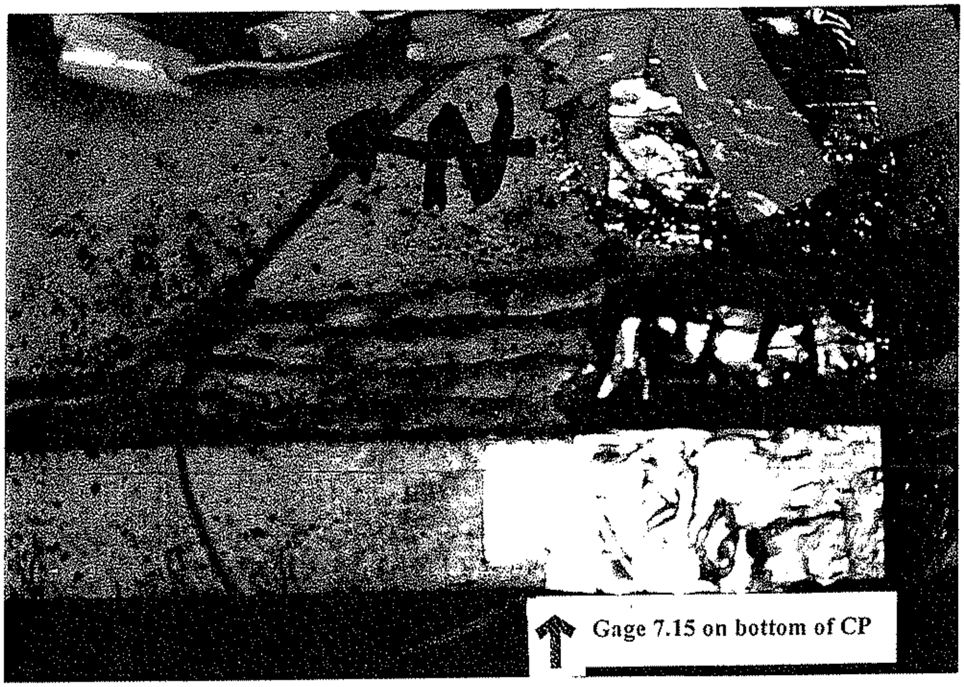


Figure 7: Sketch of Gages Near Fill Plates in Girder 2, Span 7



a) **Gages 7.14 (on bottom flange), 7.13 (on 7/8" fill plate), and 7.15 (on coverplate). West side of girder at Section 7/2.** (2/99/15-2)

b) **View of fill-plate region on East side of girder at Section 7/22, opposite Gages 7.16-7.18.** (2/99/15-3)

Figure 8: Fill Plate/Seal Weld Areas in Girder 2, Span 7

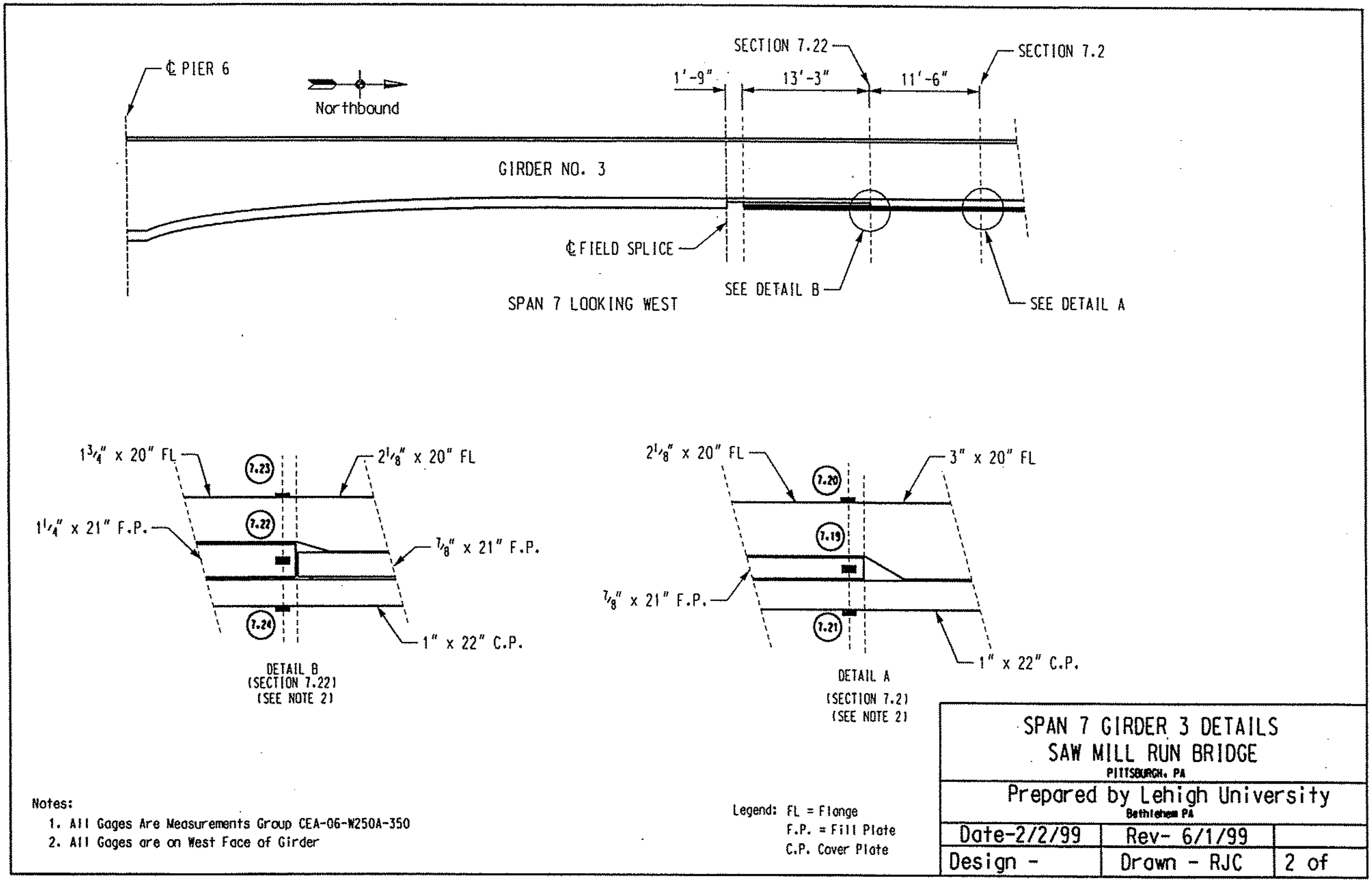
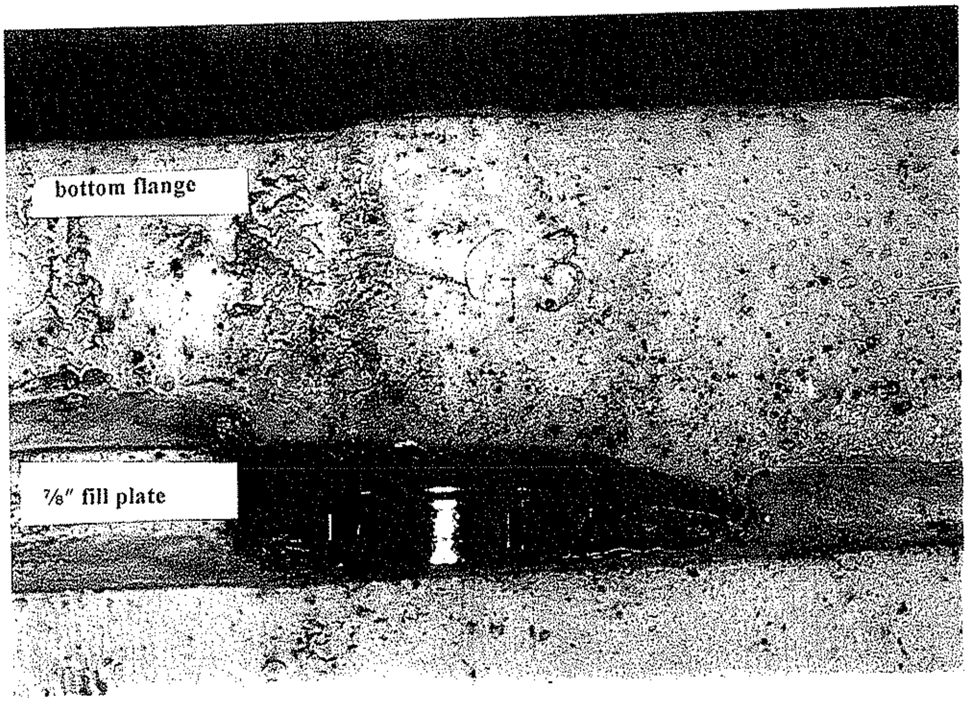


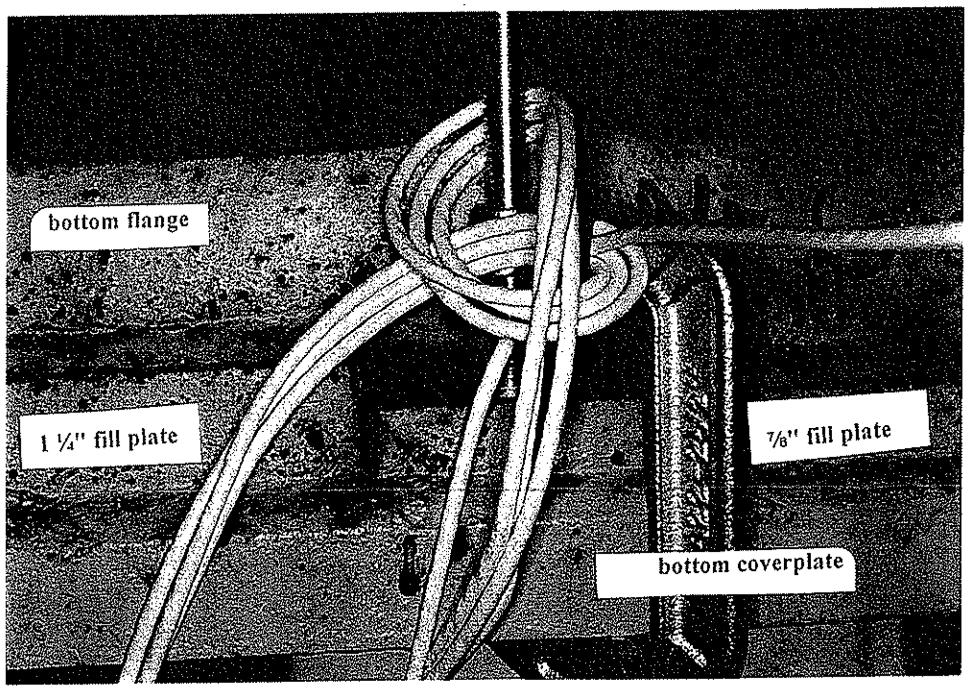
Figure 9: Sketch of Gages Near Fill Plates in Girder 3, Span 7



a) East Face of Open Fill-Plate Junction. Tape placed in junction for scale. Gage 7.19, 7.20, and 7.21 were placed opposite on west face. (2/99/15-4)

b) Closeup of Junction shown in (a) (2/99/15-6)

Figure 10: In Span 7, Open 7/8" Fill-Plate Junction in Girder 3 at Section 7/2

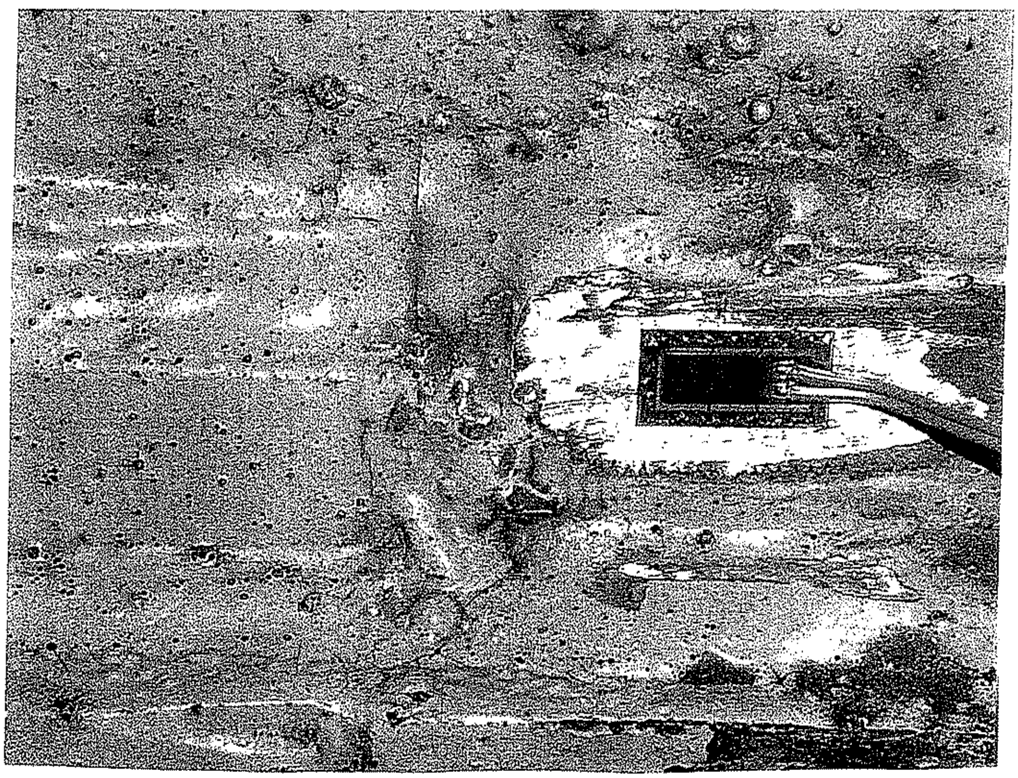


a) View of open fill-plate region on East side of girder opposite Gages 7.22-7.24
(2/99/15-1)

b) Closeup of seal weld area shown in (a) (2/99/15-0)

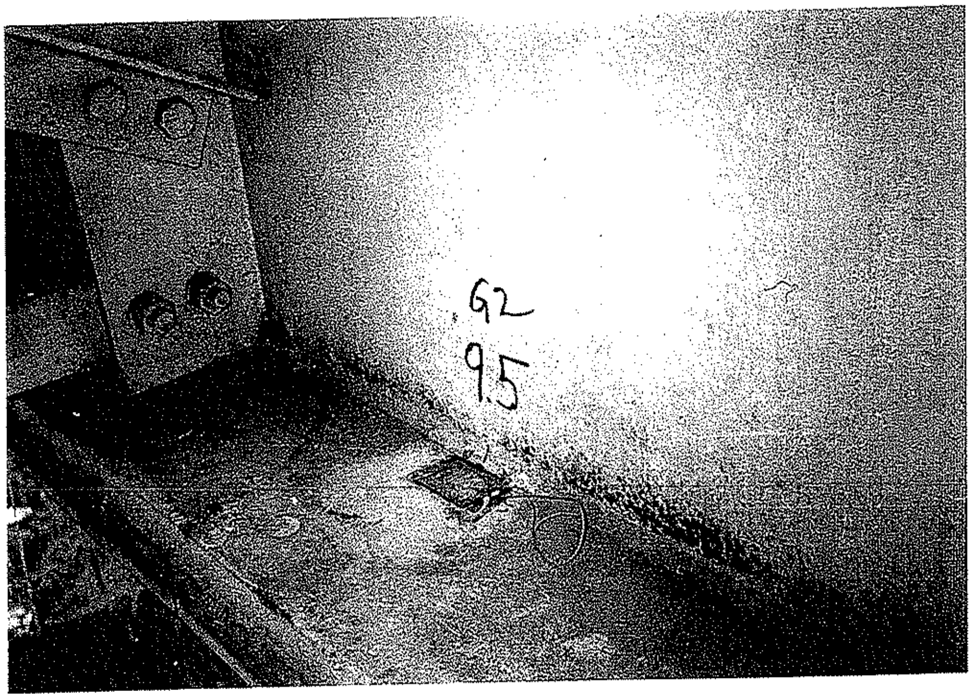
Figure 11: In Span 7, Open 1 ¼ " Fill-Plate Junction at East Side of Girder 3 at Section 7/22

a) Fill-plate area before gages were placed (P000 1062)

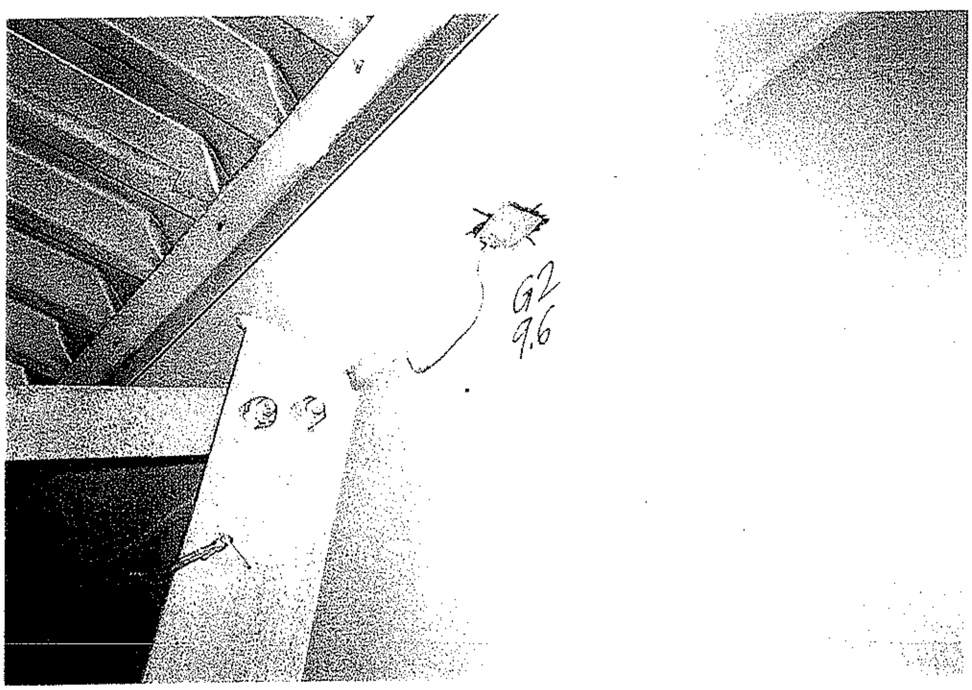


b) Gage 7.22 installed on 1 ¼ "fill plate (P000 1068)

Figure 12: In Span 7, 1 ¼ " to 7/8 " Fill-Plate Junction at West Side of Girder 3 at Section 7/22



a) **Gage 9.5 on Bottom Flange of Girder 2** (3/99/12-3)



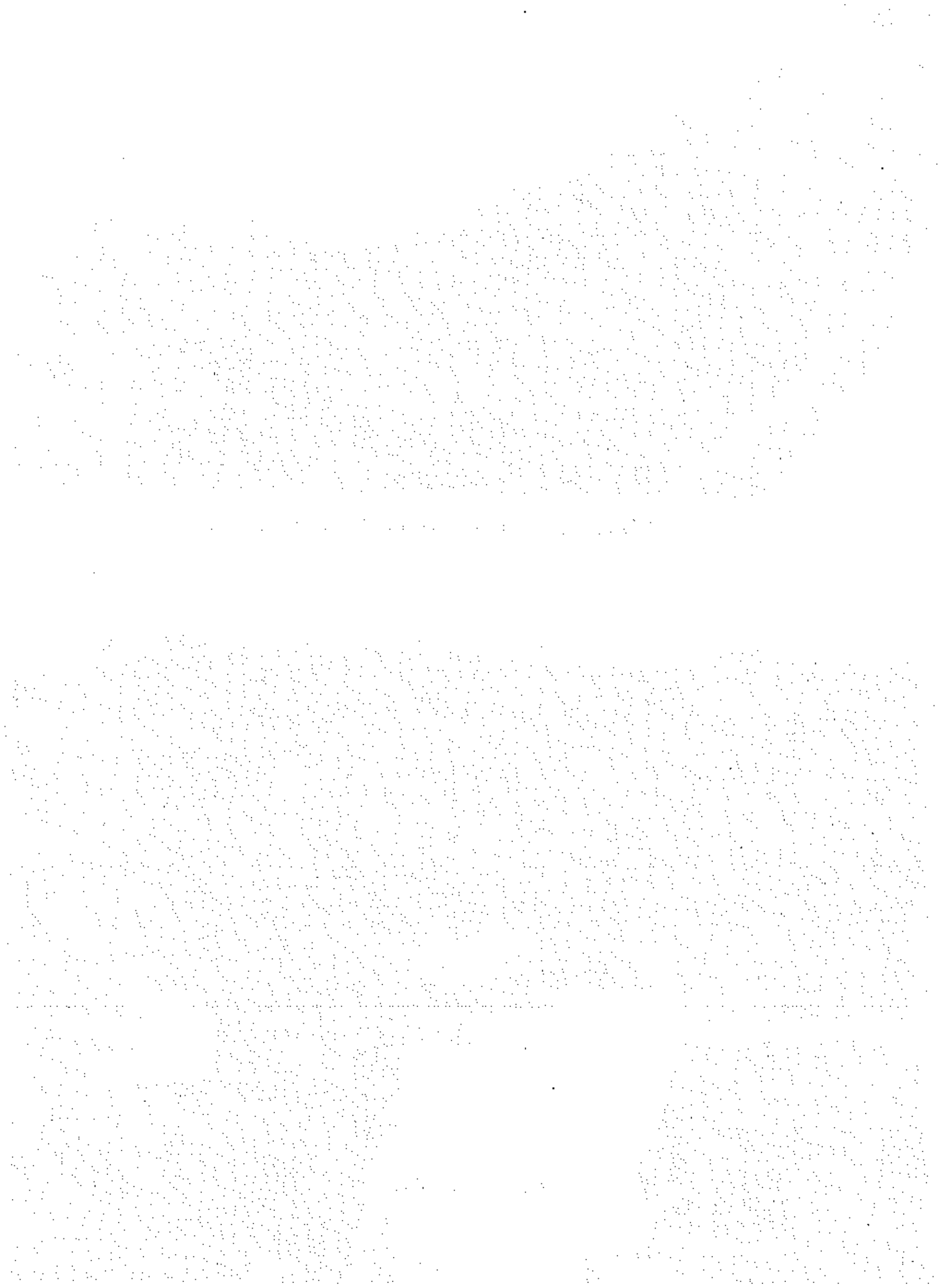
b) **Gage 9.6 on Top Flange of Girder 2** (3/99/12/-4)

Figure 13: Representative Gage Installations on Span 9 Girders at Section 9/c

a) **Gage 9.15 atop the bottom flange of Girder 3 above the open fill-plate junction** (3/99/12-15)

b) **Open fill-plate junction before Gage 9.15 was installed** (2/99/25/-21)

Figure 14: Gage Installation in Span 9 at Girder 3 Open Fill-Plate Junction at Section 9/5



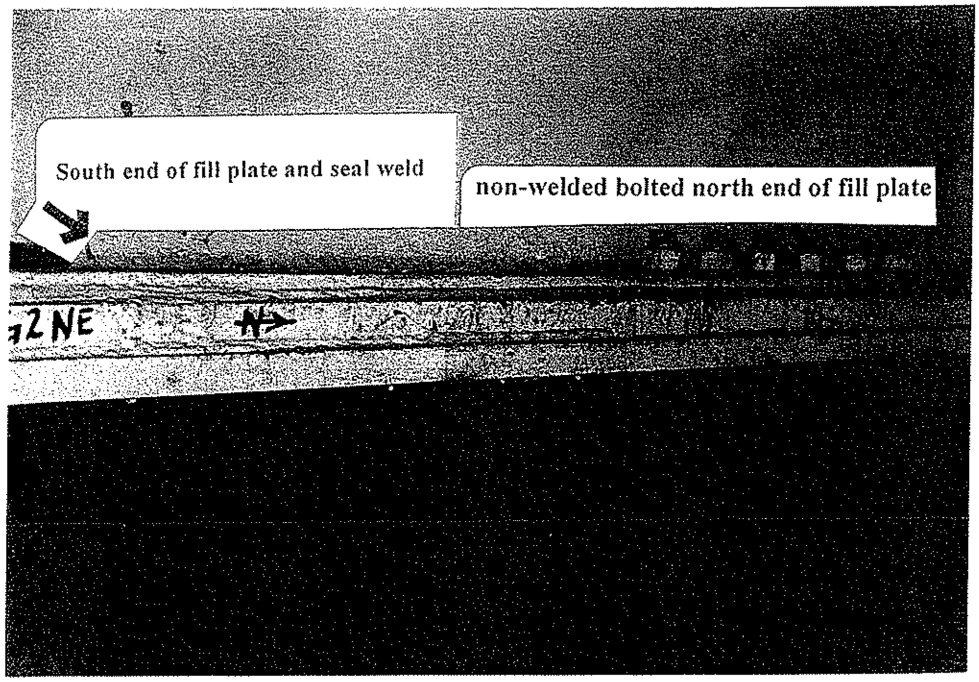
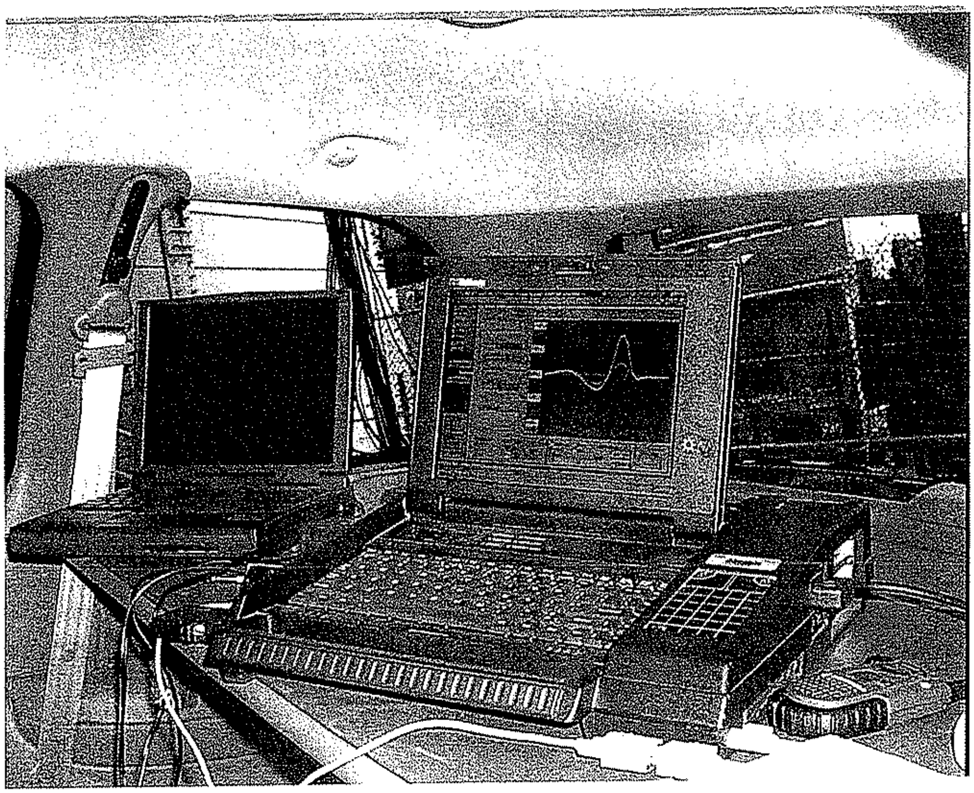
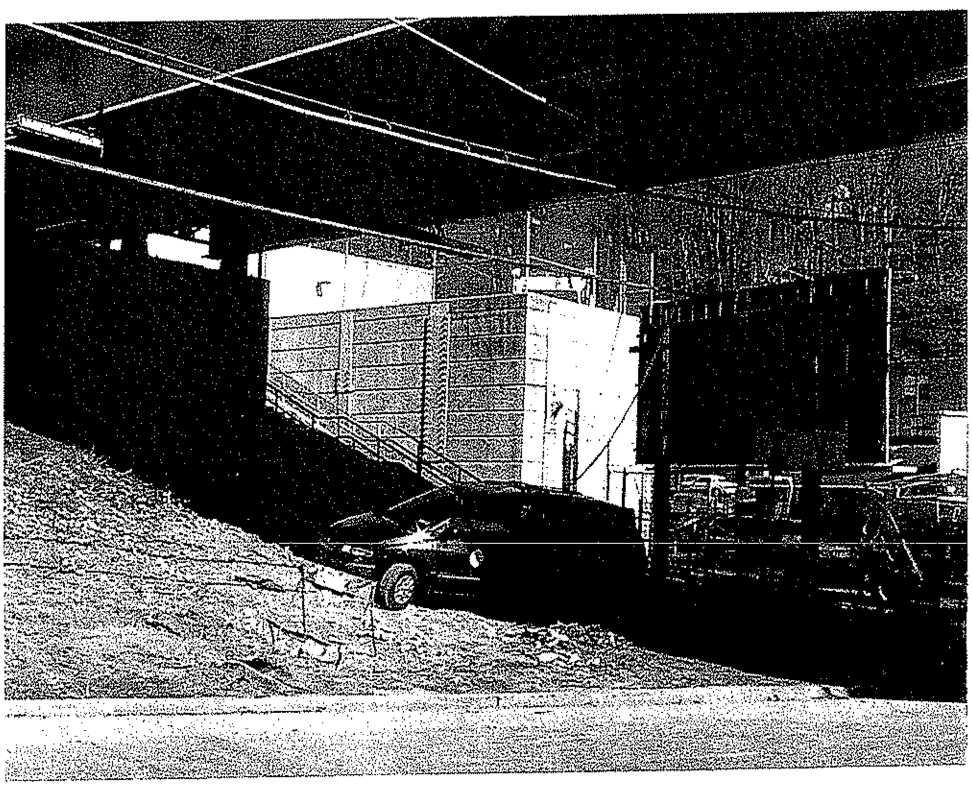


Figure 15: Span 10, Girder 2, North End Fill Plate Region at Section 10/6 (2/99/15-24)

Figure 16: Mitered Rail Joint on Inbound Track in Span 10 (2/99/15-9)

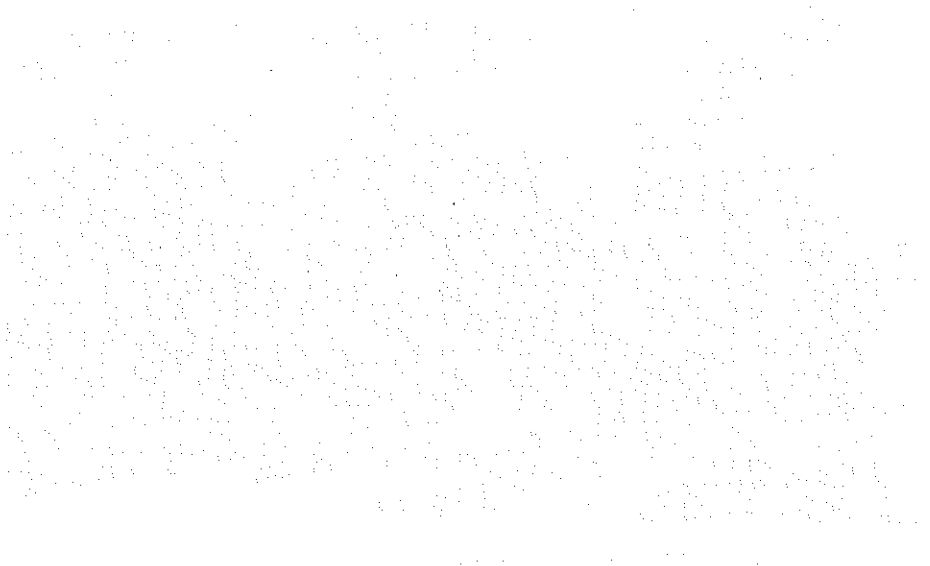


a) **Data acquisition system** (P000 1163)



b) **Van beneath Span 9** (P000 1153)

Figure 17: Data Acquisition Equipment and Equipment Van



a) Exterior View of Test Vehicle (P000 1144)

b) Interior View of Test Vehicle (P000 1142)

Figure 18: LRV with Salt Bags Used as Test Vehicle

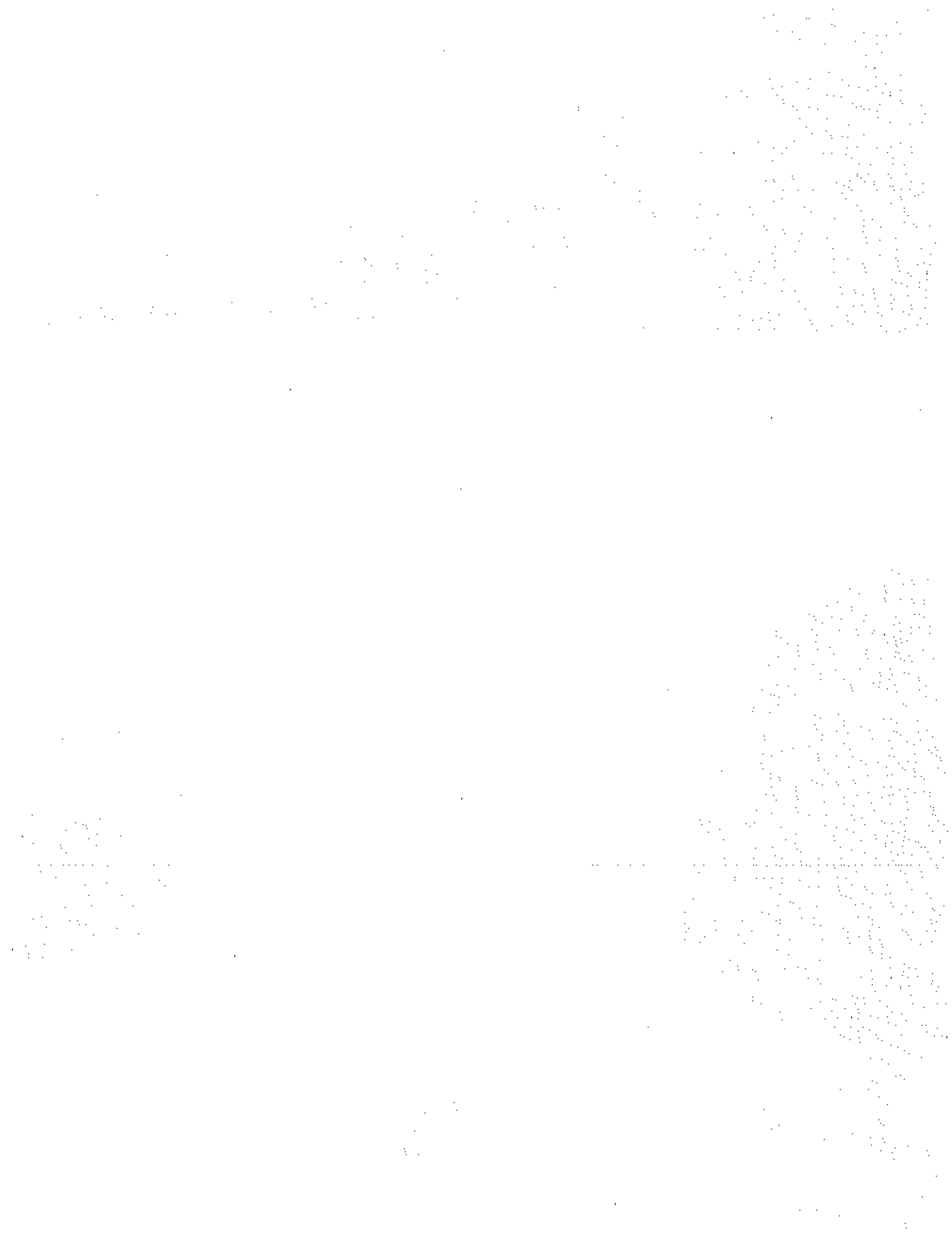
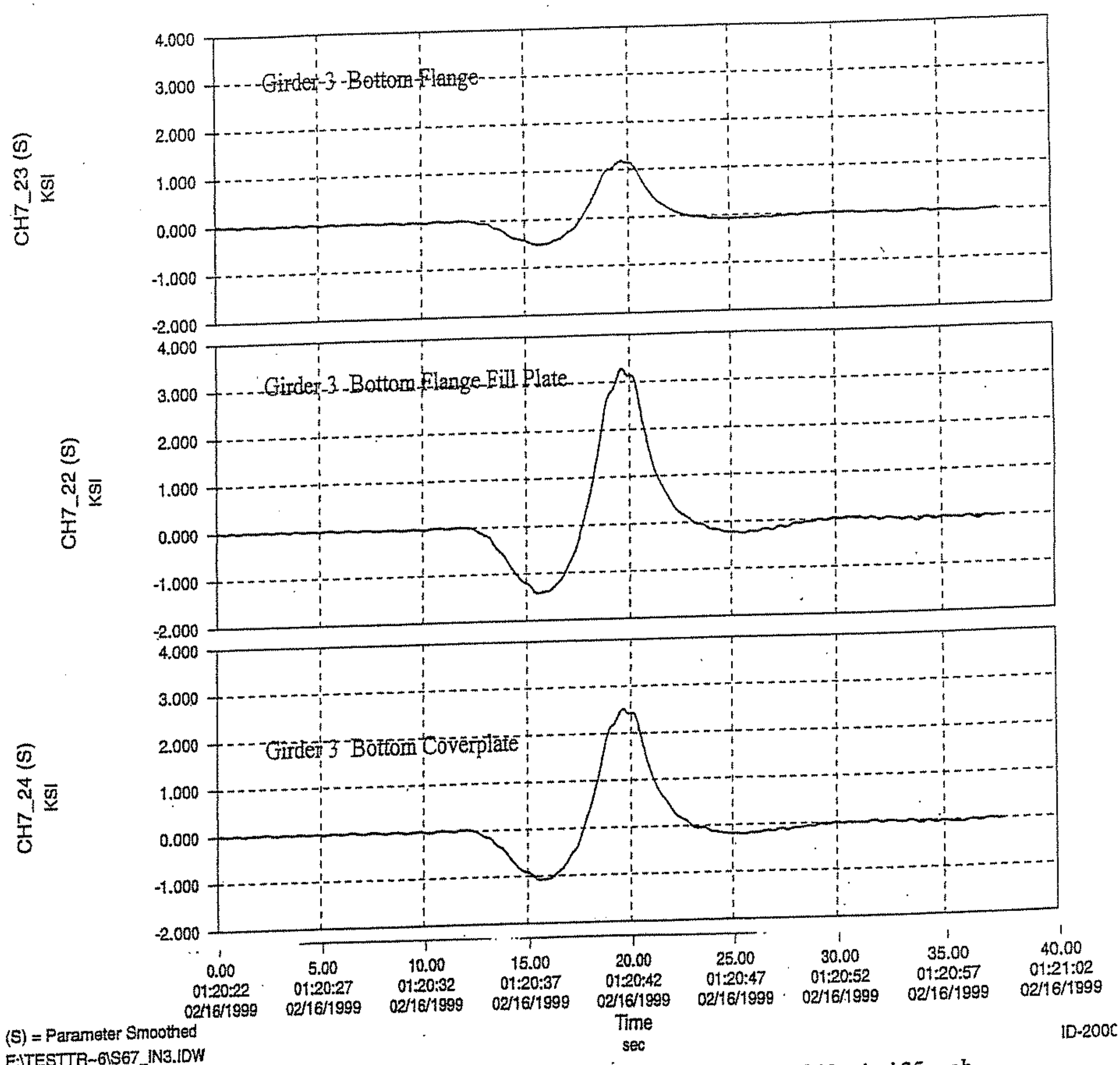
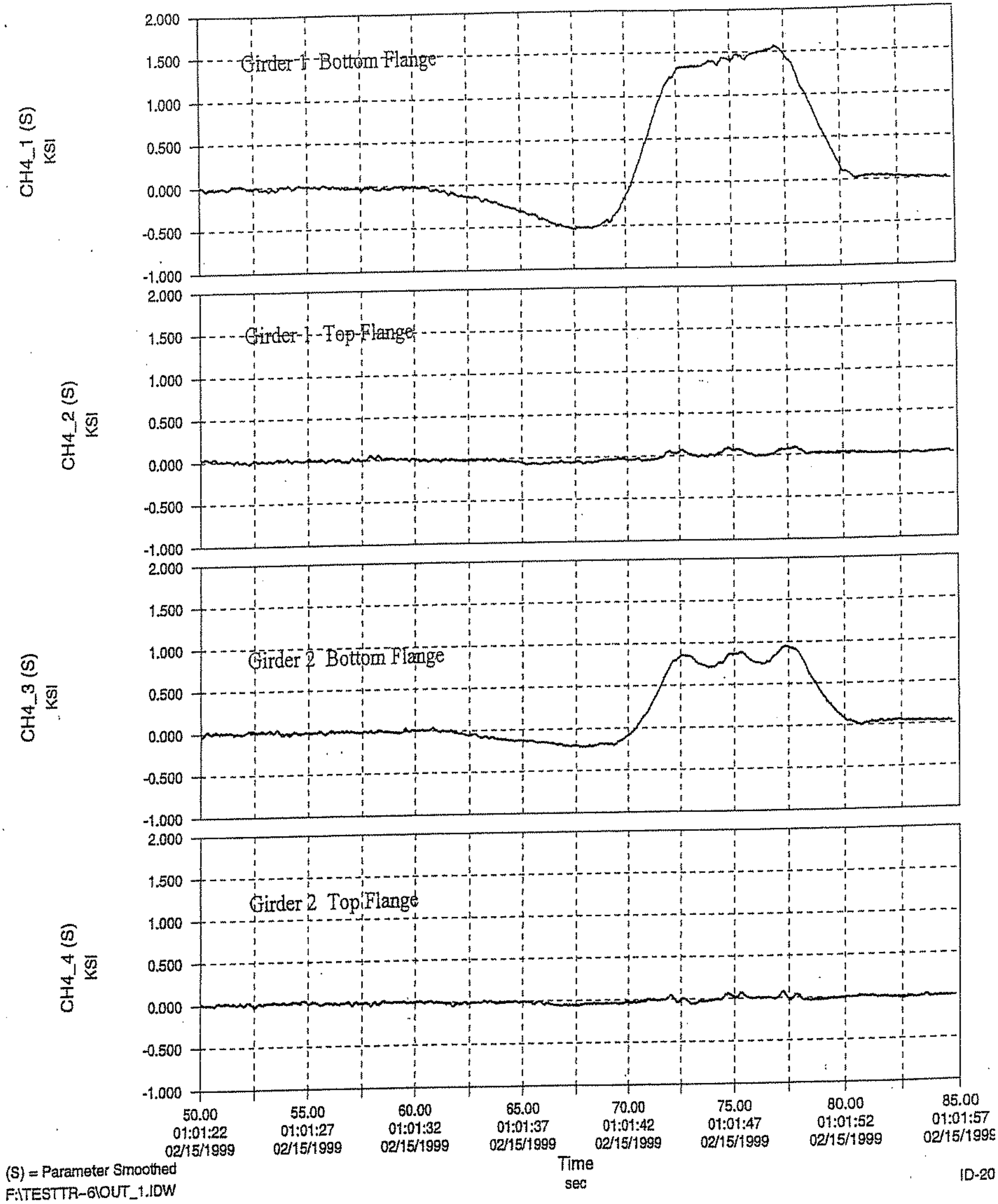


Figure 19 is blank



Test Vehicle at Span 7/Section 22: Vehicle Inbound on Inbound Track @ Nominal 25 mph

Figure 20



Test Vehicle at Span 4/Section A: Vehicle Outbound on Outbound Track @ Nominal 10 mph

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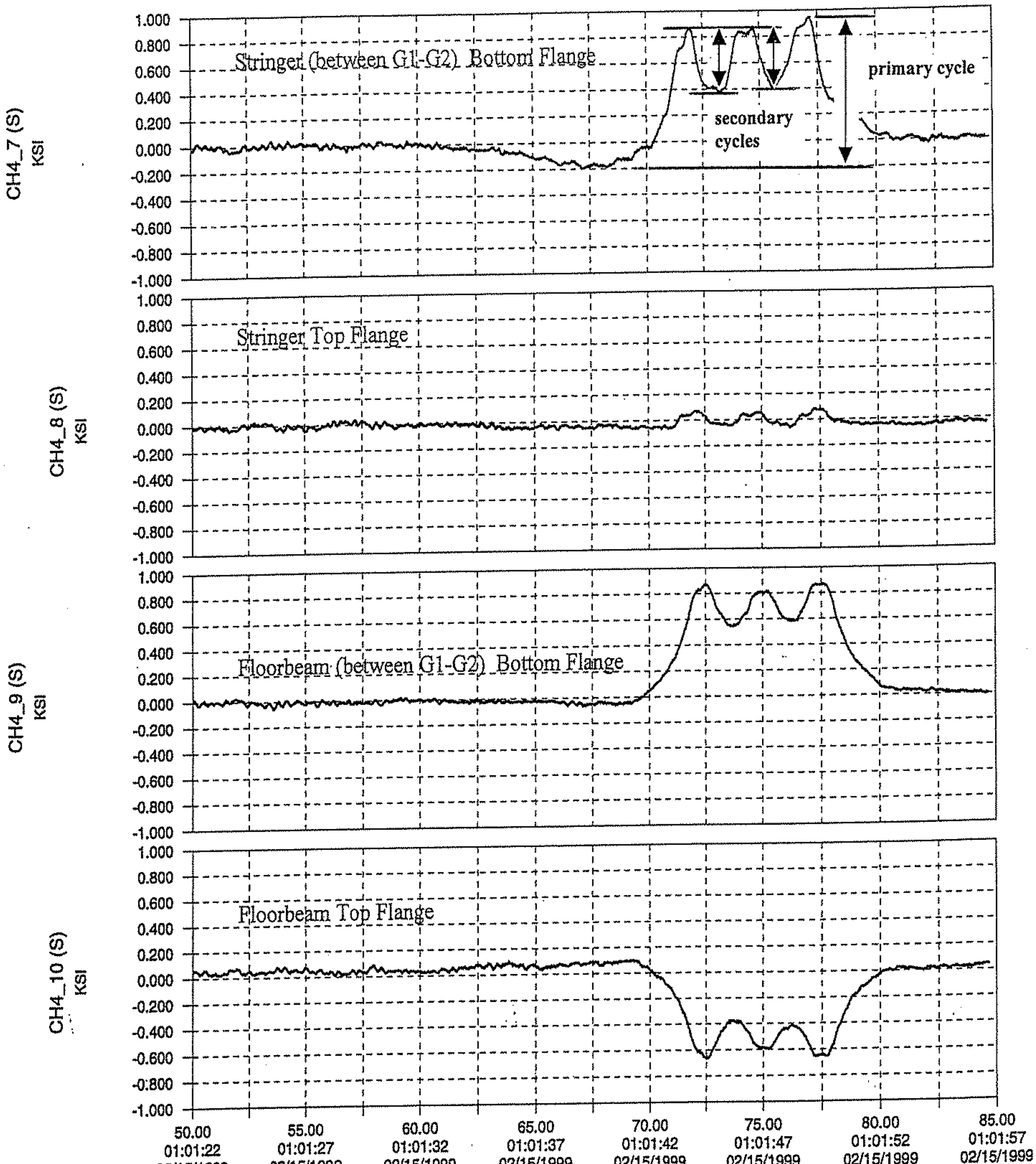
Figure 21



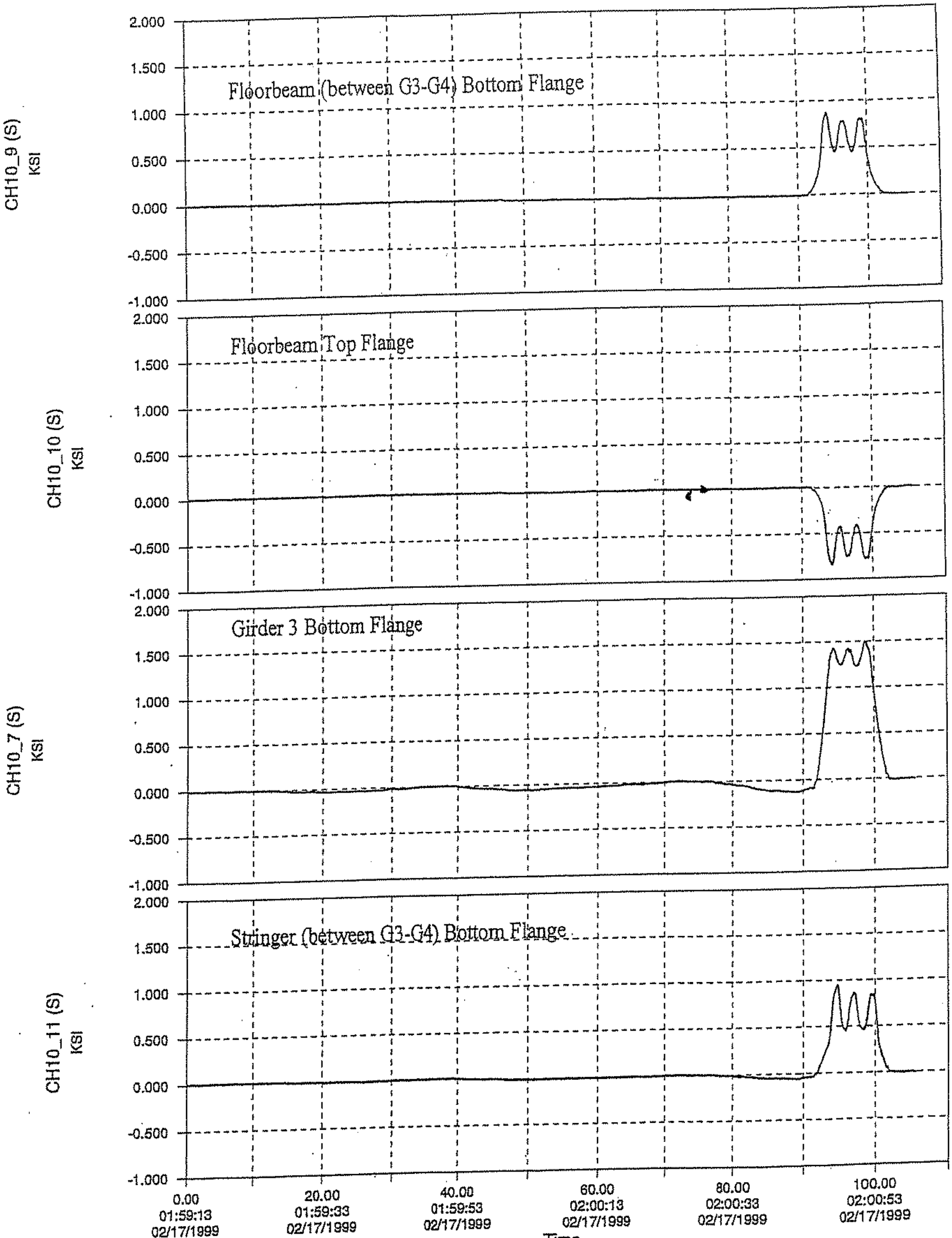
S) = Parameter Smoothed
:\TESTTR~6\OUT_1.IDW

ID-20

Test Vehicle in Span 4: Vehicle Outbound on Outbound Track @ Nominal 10 mph

- **Top 2 records/Section aa**
- **Bottom 2 records/Section a**

Figure 22

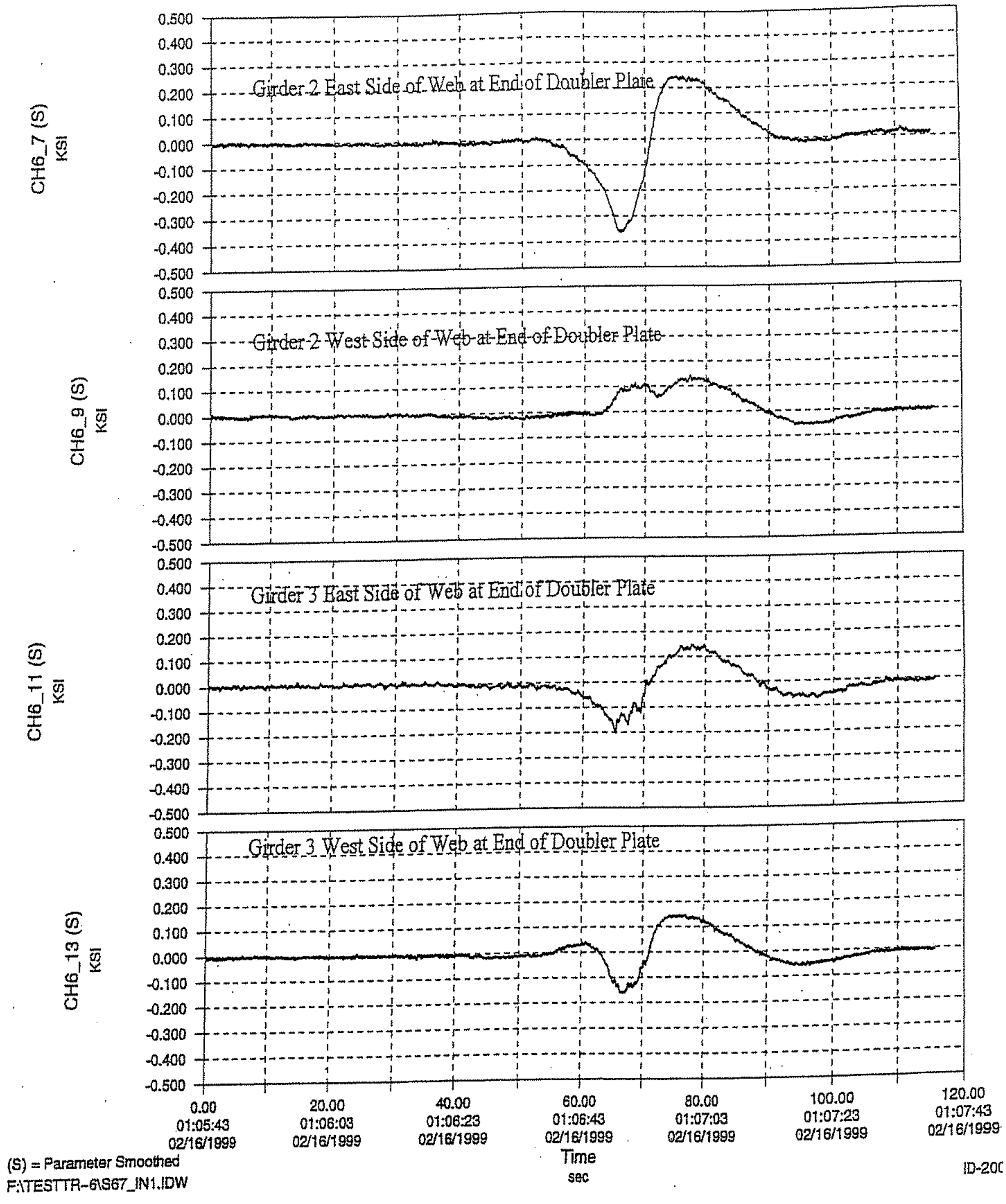


(S) = Parameter Smoothed
F:\TESTTR~6\S910_IN4.IDW

ID-20

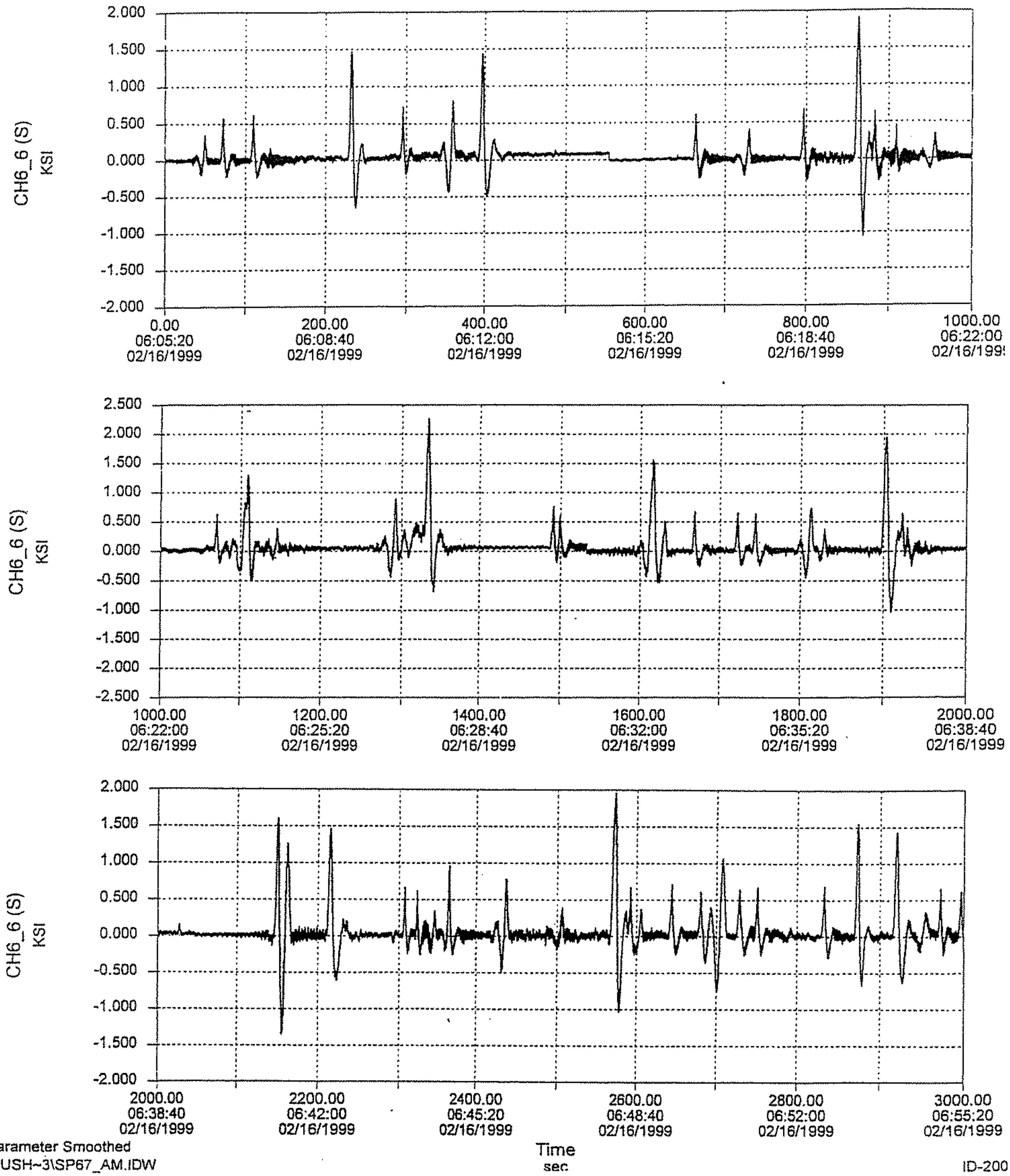
Test Vehicle at Span 10/Section 7; Vehicle Inbound on Inbound Track @Nominal 10 mph

Figure 23



Test Vehicle at Span 6 / Section 3; Vehicle Inbound on Inbound Track @ Nominal 10 mph

Figure 24



(S) = Parameter Smoothed
F:\AMRUSH~3\SP67_AM.IDW

ID-200

Figure 25. AM Rush-Hour Period Record for Gage 6.6, Span 6
Sheet a: Time = 0 to 3000 sec

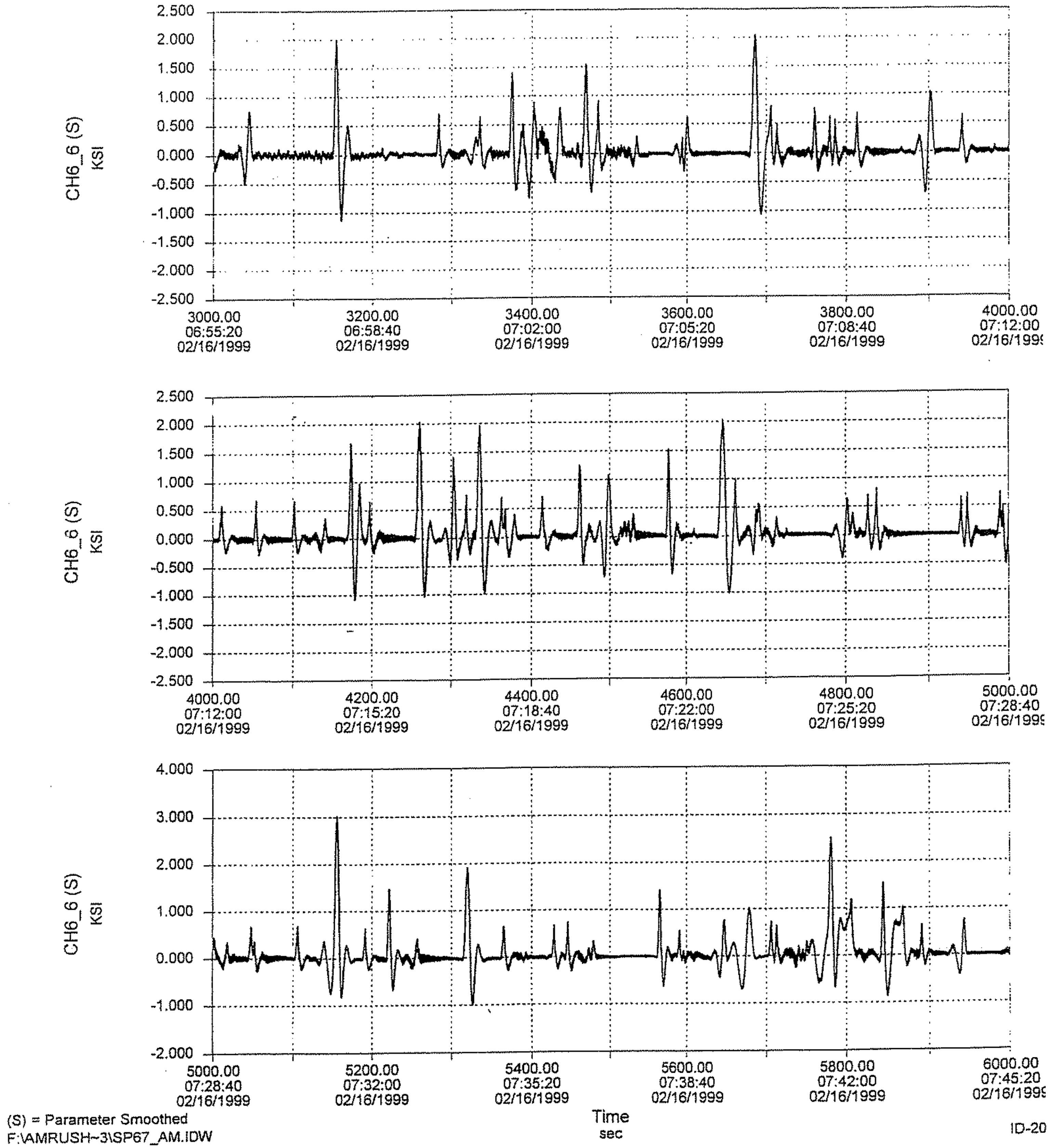
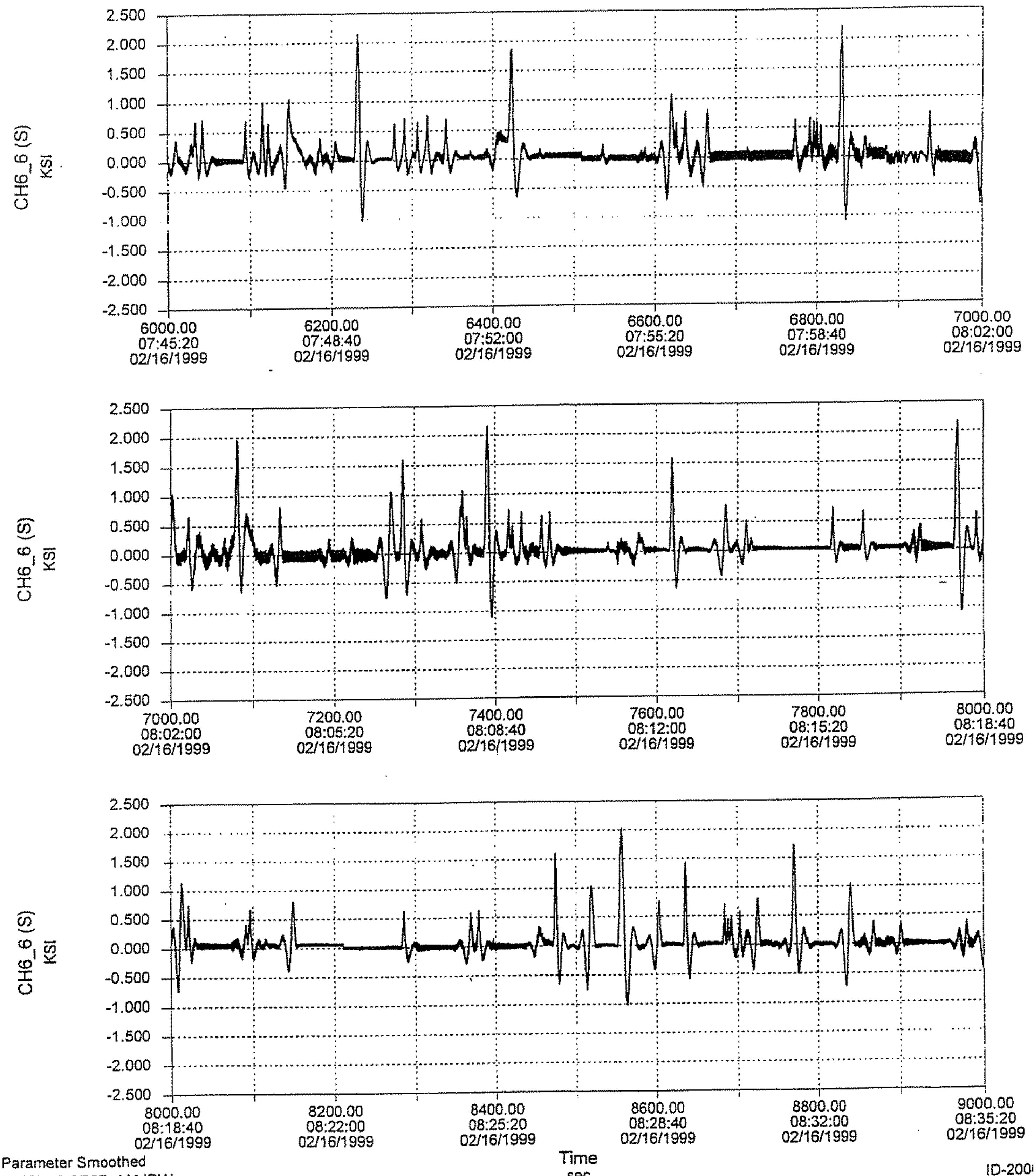


Figure 25. AM Rush-Hour Period Record for Gage 6.6, Span 6
Sheet b: Time = 3000 to 6000 sec



(S) = Parameter Smoothed
F:\AMRUSH~3\SP67_AM.IDW

ID-200

Figure 25. AM Rush-Hour Period Record for Gage 6.6, Span 6
Sheet c: Time = 6000 to 9000 sec

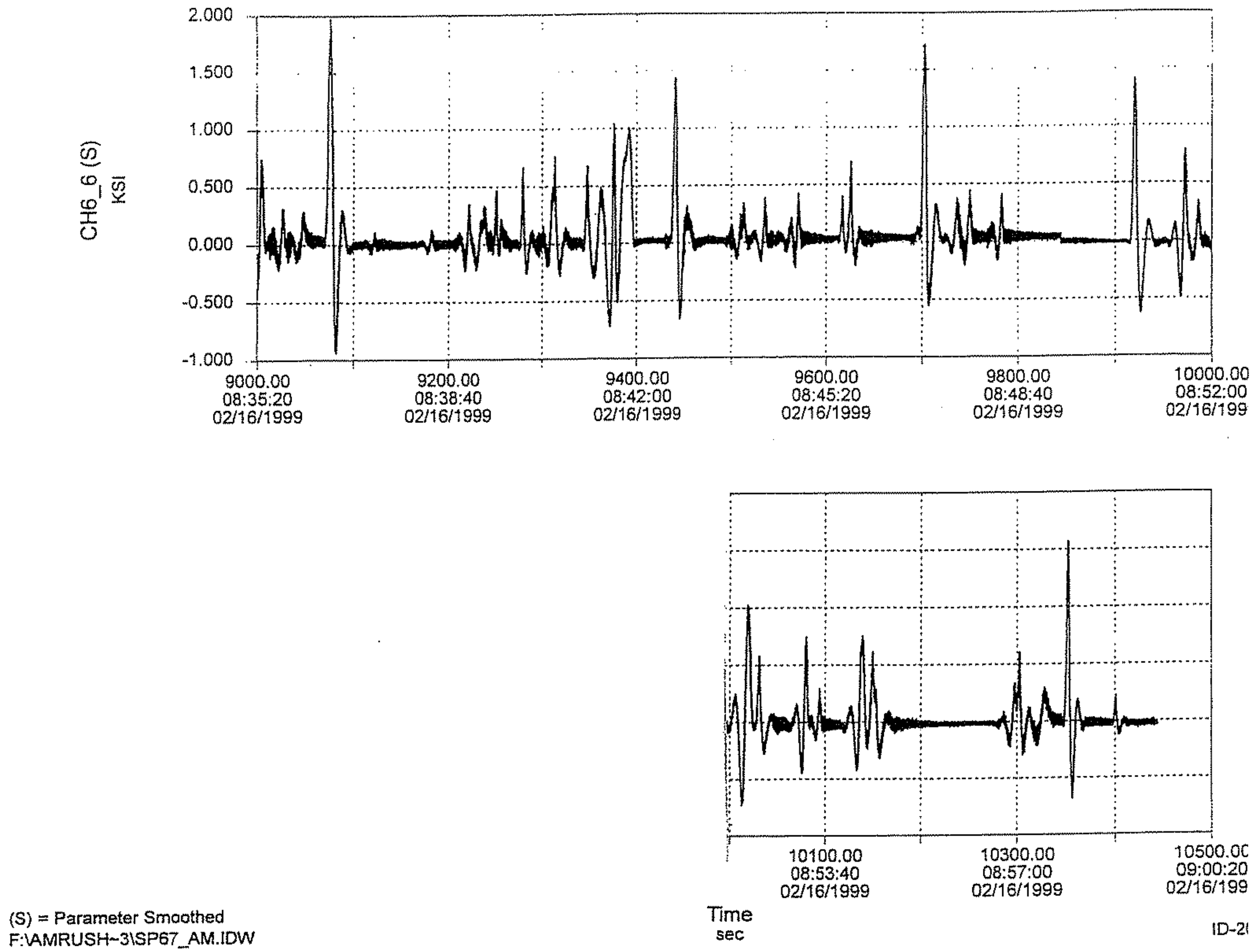


Figure 25. AM Rush-Hour Period Record for Gage 6.6, Span 6
Sheet d: Time = 9000 to 10500 (end) sec

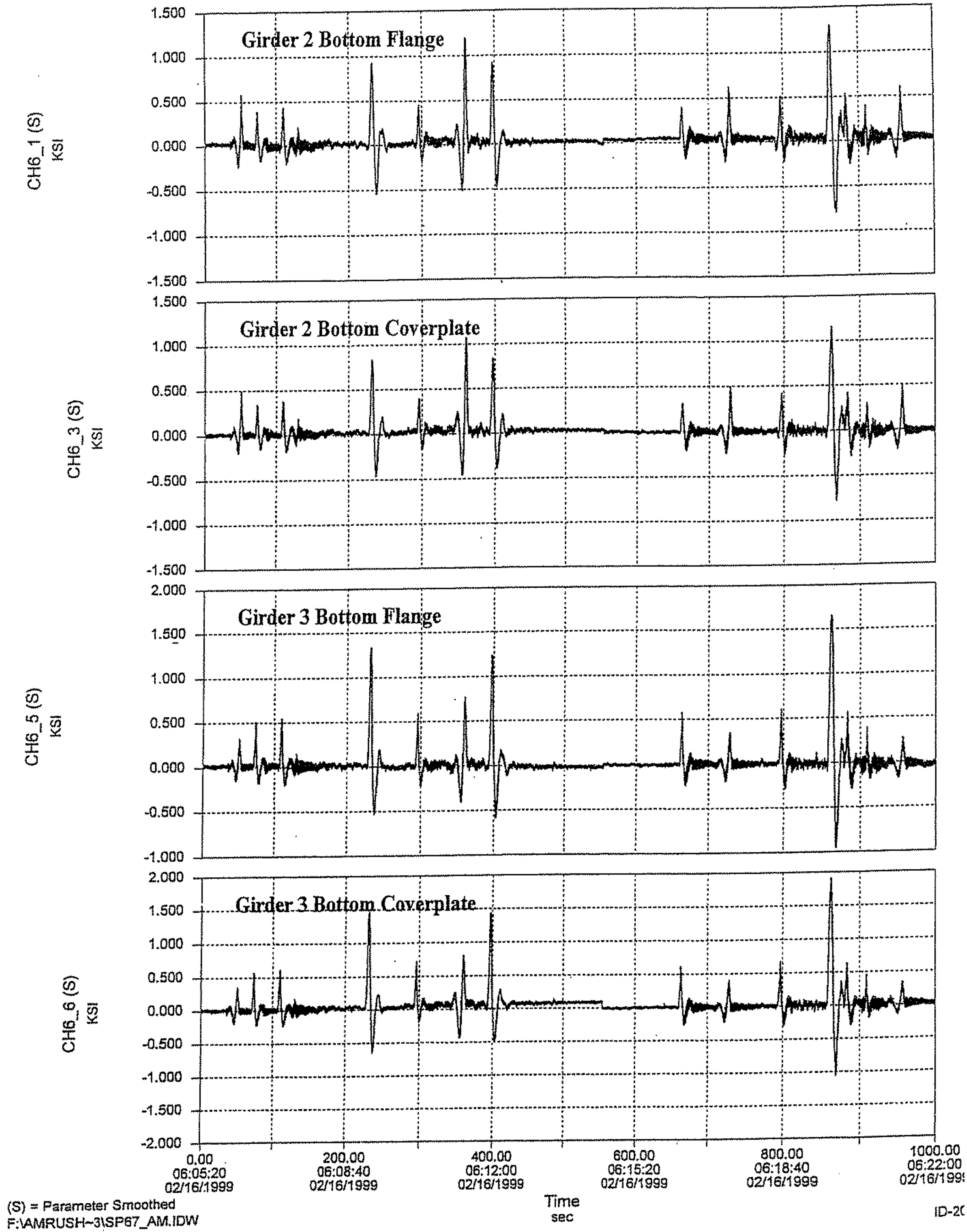


Figure 26. Partial (time = 0 to 1000 sec) AM Rush-Hour Period Records For Girders 2 and 3 in Span 6, Section 4

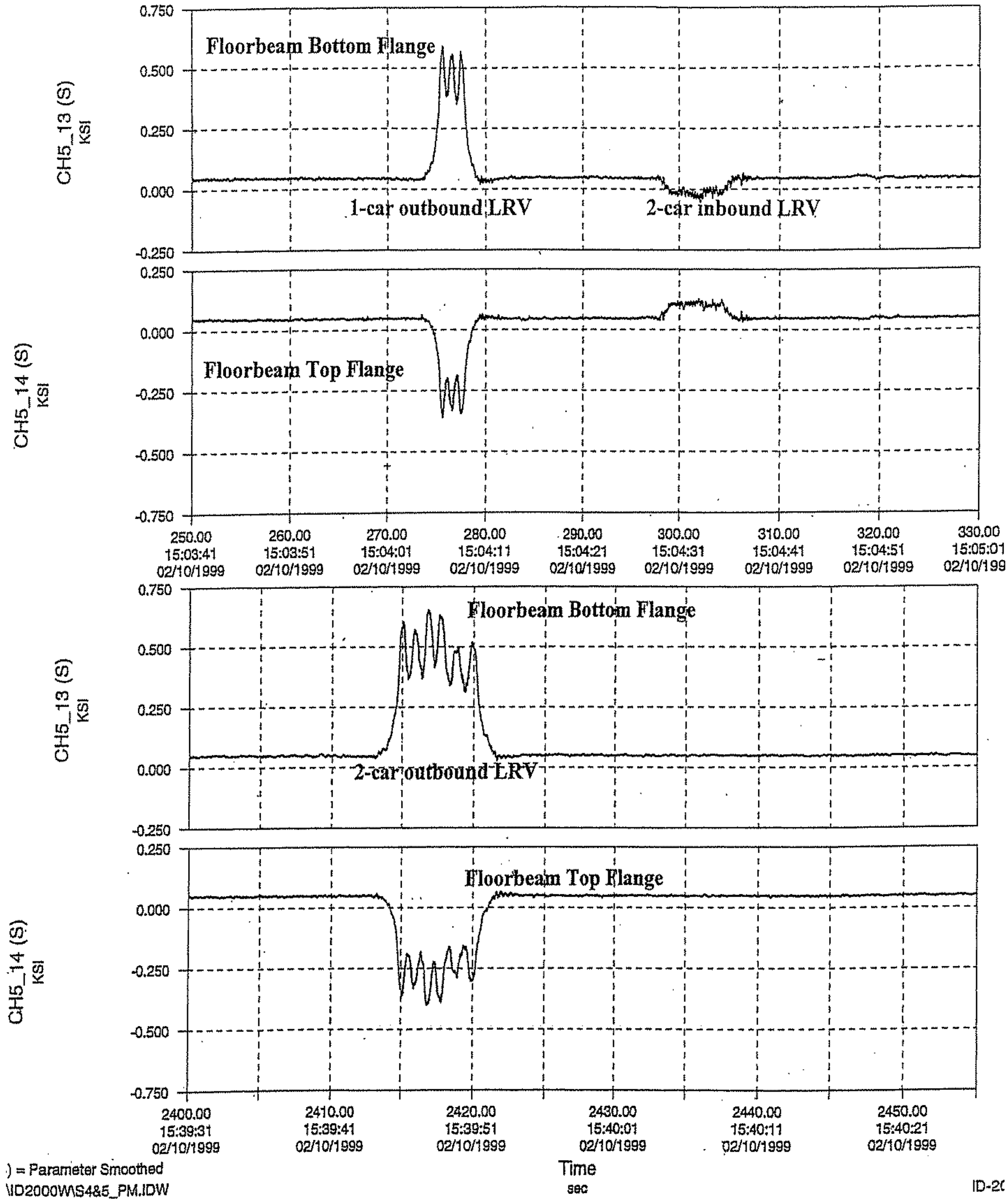


Figure 27. Partial PM Rush-Hour Period Records for a Floorbeam Between Girders 1 and 2 in Span 5, Section bb

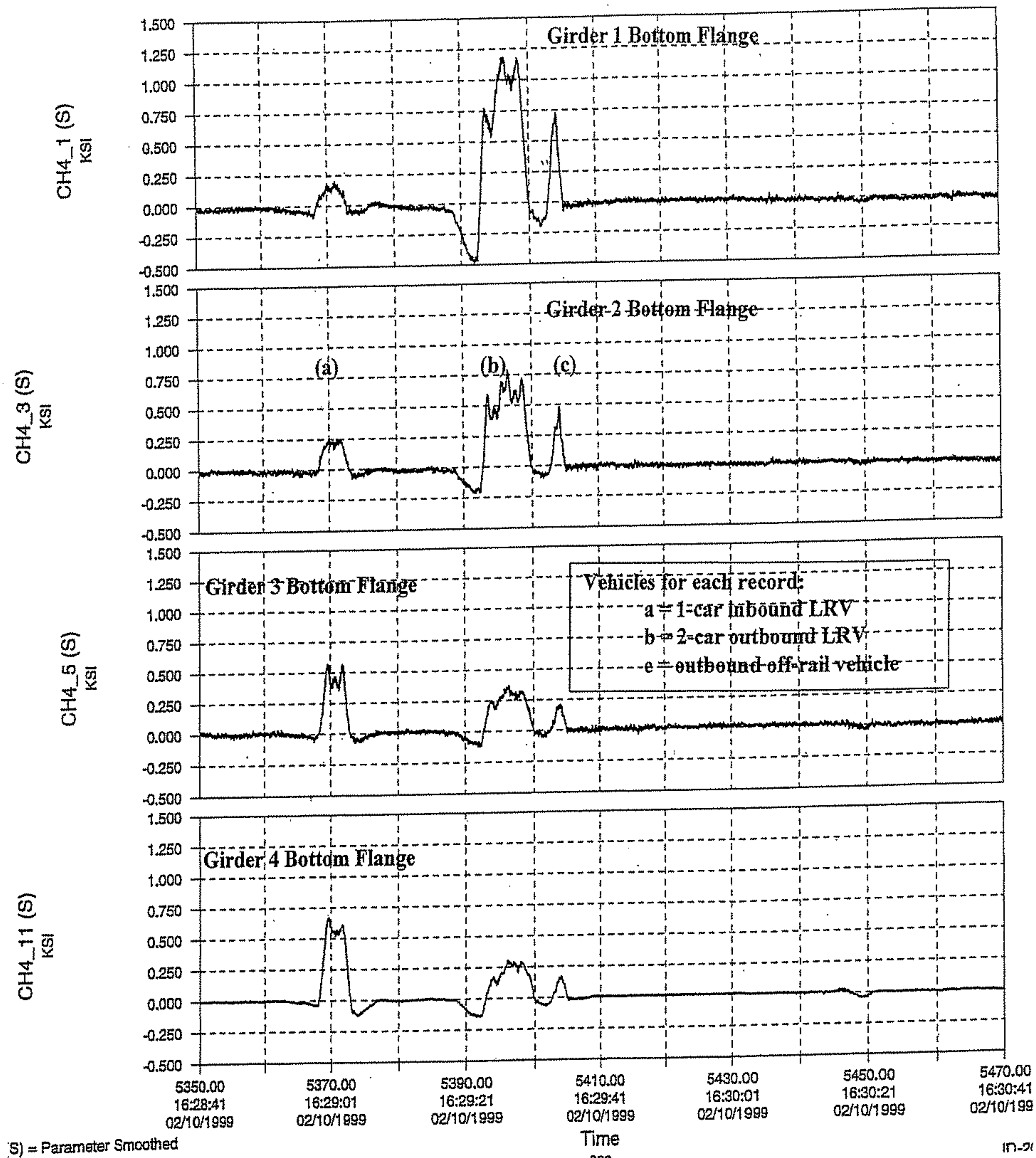
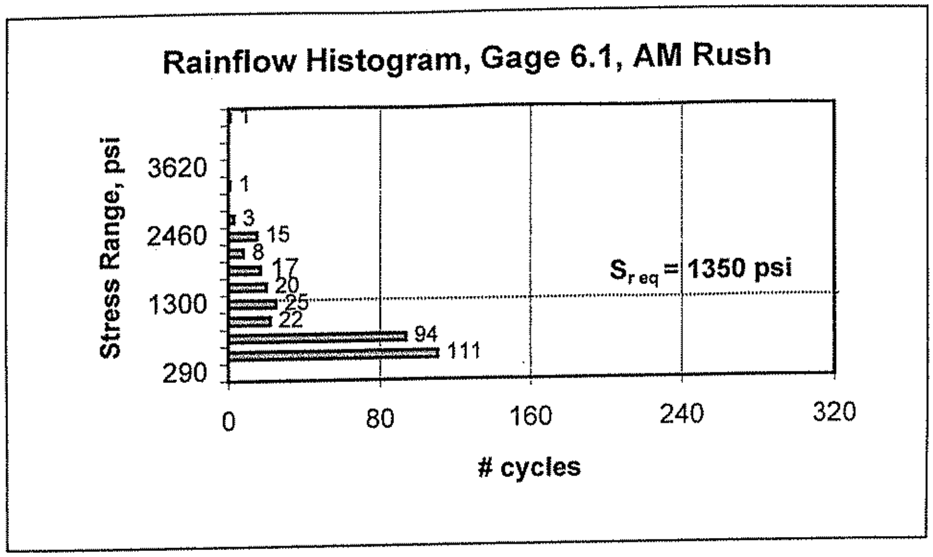
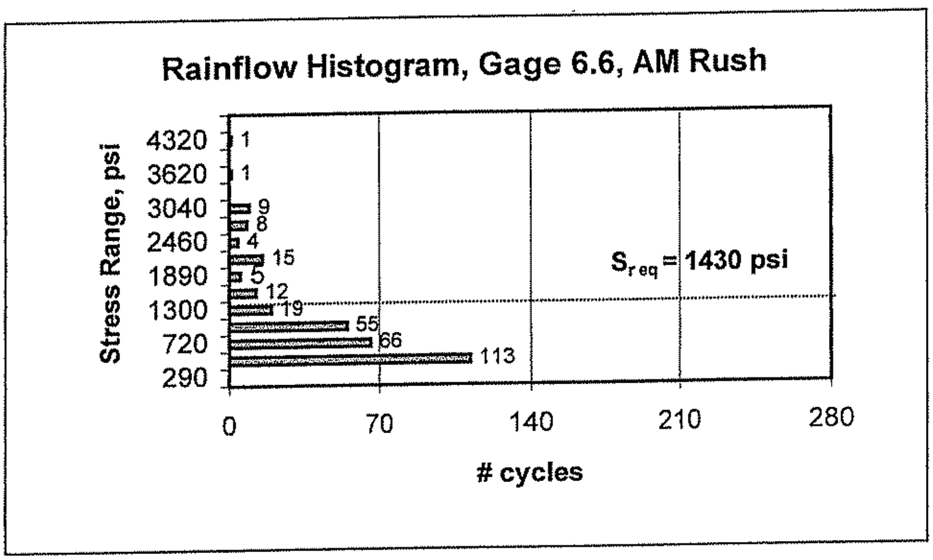


Figure 28. Partial (time = 5350 to 5470 sec) PM Rush-Hour Period Records For Girders 1, 2, 3 and 4 at Span 4, Section a



a) Girder 2



b) Girder 3

Figure 29. Stress Histograms from Rainflow Analysis: Maximum Stress Locations, Girders 2 and 3, Span 6

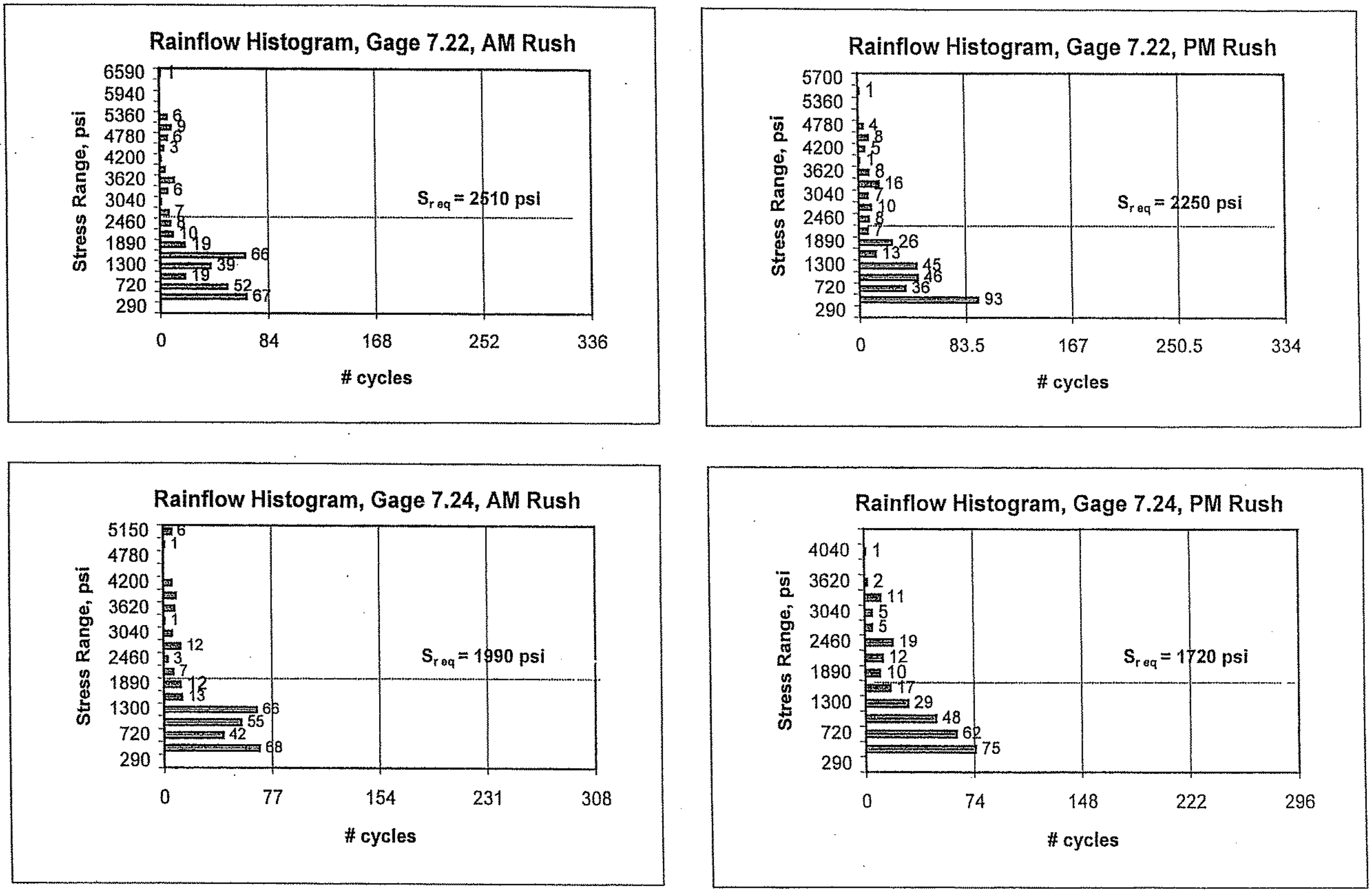
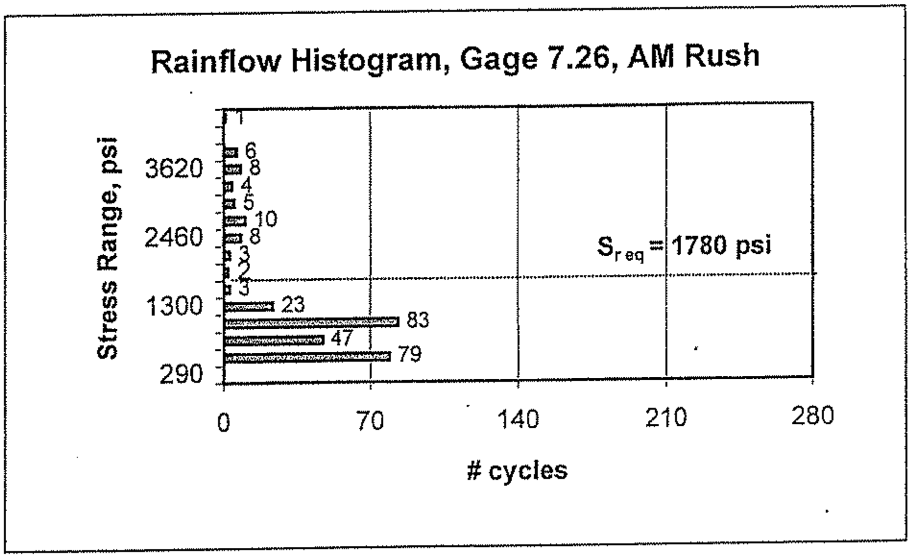
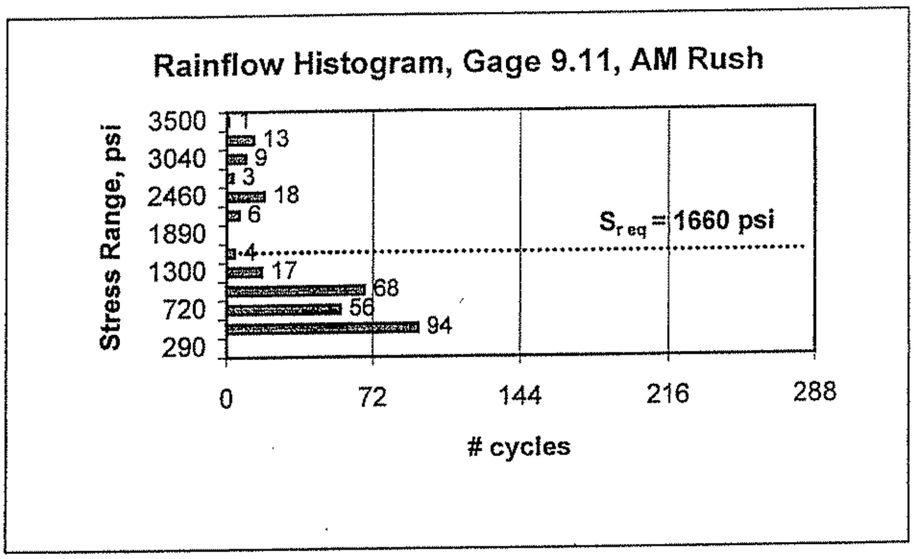


Figure 30. Stress Histograms from Rainflow Analysis: Maximum Stress Locations at Fill Plate Junction, Girder 3, Span 7





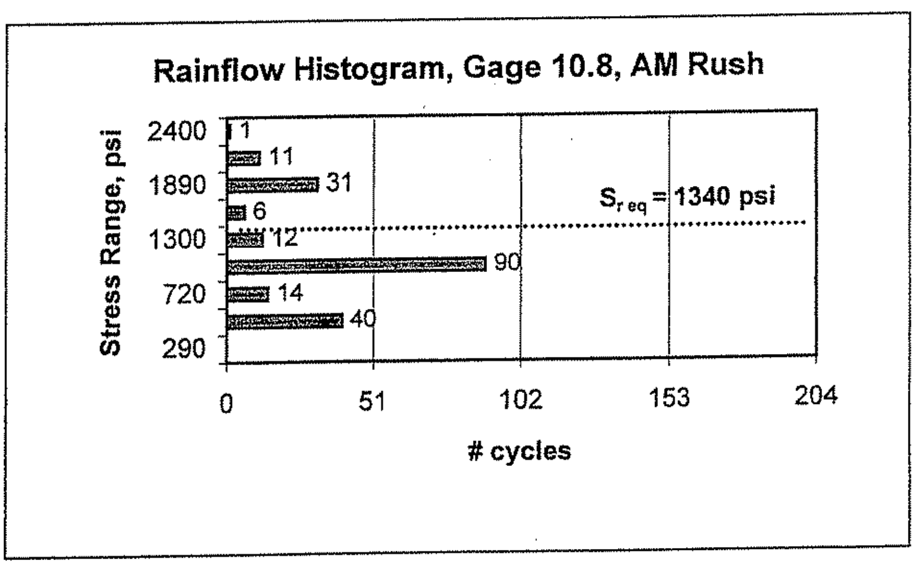


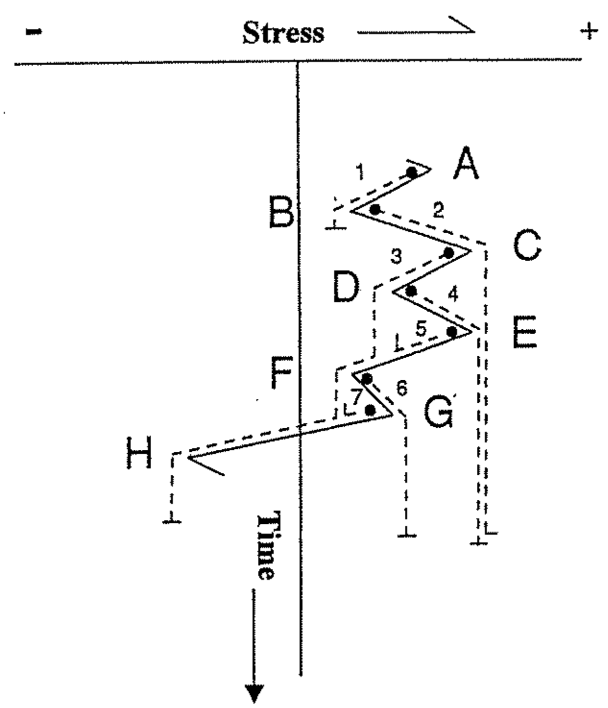
Figure 31. Stress Histograms from Rainflow Analysis: Girder 4, Spans 7, 9 and 10

Appendix

Appendix

A. Rainflow Counting of Stress Cycles

A graphical description is provided below illustrating the use of the rainflow counting method that was employed in the computer algorithm to determine the number of stress cycles caused by the vehicles on the Saw Mill Run Bridge.



Start Inside Each Peak

Minimum - Stop When Opposite Minimum More Negative
Maximum - Stop When Opposite Maximum More Positive
Stop Upon Meeting Rain from Above

1. 1/2 cycle AB
2. 1/2 cycle BC
3. 1/2 cycle CH
4. & 5. 1 cycle DE
6. & 7. 1 cycle FG

Rainflow Method for

CYCLE COUNTING

B. Time-Data Files

Revenue Vehicles. For the recorded rush-hour periods with revenue traffic, a readable CD is provided containing all the collected strain-gage time-data files in ASCII comma-separated format. These records can be imported into Microsoft Excel. There is a README file on the CD, and a copy of it (3 sheets) follows this sheet. Sheet 3 of the README file explains the rows and columns of the data file.

Test Vehicle. Time-data records that were printed from the strain gage data are included in this Appendix for each gage for each run of the test vehicle at each instrumented span. The records are grouped by span number, and each group is initiated with a blue sheet.

SAWMILL RUN DATA FILE INFORMATION
REVENUE TRAINS ONLY

SUMMARY OF DATA FILES COLLECTED DURING MORNING AND EVENING RUSH HOURS AT SPANS 4 & 5.

<u>AM RUSH HOUR – FEBRUARY 10, 1999</u>

1. SAMPLING RATE = 50Hz
2. DATA WERE COLLECTED FROM 6:40AM TO 9:40AM. LATE START DUE TO PROBLEM WITH LAPTOP.

<u>PM RUSH HOUR – FEBRUARY 10, 1999</u>

1 SAMPLING RATE = 50Hz
2 DATA WERE COLLECTED FROM 2:57PM TO 6:00PM.

SUMMARY OF DATA FILES COLLECTED DURING MORNING AND EVENING RUSH HOURS AT SPANS 6 & 7.

<u>AM RUSH HOUR – FEBRUARY 12, 1999</u>

1. SAMPLING RATE = 40Hz
2. DATA WERE COLLECTED FROM 6:10AM TO 9:10AM.

<u>PM RUSH HOUR – FEBRUARY 11, 1999</u>

1. SAMPLING RATE = 40Hz (UNTIL 3:45PM)
2. SAMPLING RATE = 25Hz (3:45PM TO END)
3. CHANNEL 6_11 WOULD NOT BALANCE
4. AN OFFSET OCCURRED APPROX. 4:25 PM DUE TO SHIELDING GETTING DISLODGED.
5. DATA WERE COLLECTED FROM 3:00PM TO 6:00PM.

SUMMARY OF DATA FILES COLLECTED DURING MORNING AND EVENING RUSH HOURS AT SPANS 9 & 10.

AM RUSH HOUR – FEBRUARY 17, 1999

1. SAMPLING RATE = 40Hz
2. CHANNEL 10_4 APPEARS TO BE DRIFTING, CHANNEL 9_7 SEEMS NOISY.
3. DATA WERE COLLECTED FROM 6:01 AM TO 9:04 AM. TEMP = 51F@ 6:00AM. DROPPED TO 48F AT 9:00AM
4. INBOUND TRAINS FULL, OUTBOUND <5 PEOPLE (6:30AM)
5. 8:37 AM, LOGGER WAS BALANCED BY MISTAKE DURING PASSAGE OF OUTBOUND TRAIN. CORRECTED IMMEDIATELY.

PM RUSH HOUR – FEBRUARY 16, 1999

1. SAMPLING RATE = 40Hz
2. TEMPERATURE = 60F
3. APPEARED TO BE SOME "STICK" IN SPAN #10. GAGES IN SPAN 10 DO NOT ALWAYS RETURN TO ZERO AFTER PASSAGE OF TRAIN. POSSIBLE DUE TO FROZEN BEARINGS AT PIER 9.
4. MOST OUTBOUND TRAINS WERE HEAVILY LOADED. INBOUND TRAINS WERE ALMOST EMPTY THROUGHOUT THE 3 HOURS OF MONITORING
5. HEAVY TRAIN WENT BY AT 4:48PM
6. HEAVY TRAIN WENT BY AT 5:19PM
7. OUTBOUND CARS, STANDING ROOM ONLY AT 5:30 PM. INBOUND CARS VERY FEW PEOPLE.

SAWMILL RUN DATA FILE INFORMATION
REVENUE TRAINS ONLY

Col. #1	Col. #2	Col. #3	Col. #4	Col. #5	Col. #6	Col. #7	Col. #8	Col. #9	Col. #10
Type of Data File	Name of Logger	Type of Logger	Misc. Program Information	Logger Software Version	Name of Program in CPU used to Record Data	Misc. Program Information	Name of This Data Table	*Not Used*	*Not Used*
Timestamp of Each Data	Sample or Record Number	Channel Name	Channel Name	Channel Name	Channel Name	Channel Name	Channel Name	Channel Name	Channel Name
Units	Units of Data Below	Units of Data Below	Units of Data Below	Units of Data Below	Units of Data Below	Units of Data Below	Units of Data Below	Units of Data Below	Units of Data Below
Not Used	*Not Used*	Type of Data is a Sample	Type of Data is a Sample	Type of Data is a Sample	Type of Data is a Sample	Type of Data is a Sample	Type of Data is a Sample	Type of Data is a Sample	Type of Data is a Sample
Timestamp	Record #	Data	Data	Data	Data	Data	Data	Data	Data
Timestamp	Record #	Data	Data	Data	Data	Data	Data	Data	Data
Timestamp	Record #	Data	Data	Data	Data	Data	Data	Data	Data

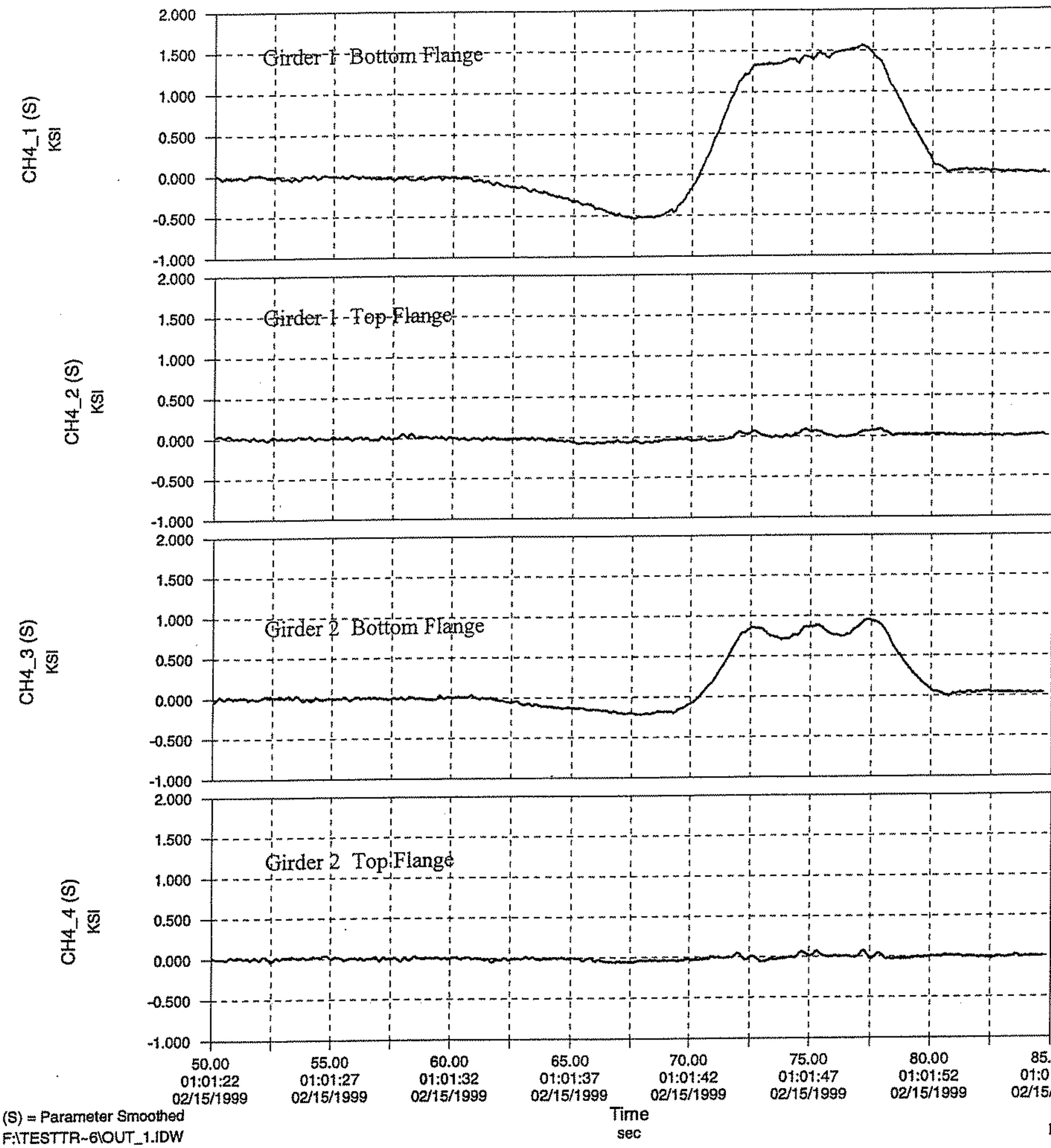
Table 1 – Description of Each Field in a Typical Data File Collected by Data Logger as Imported to Excel

Col. #1	Col. #2	Col. #3	Col. #4	Col. #5	Col. #6	Col. #7	Col. #8	Col. #9	Col. #10
TOA5	logger2	CR9000	1219	2.03	CPU:S9&10_10.DLD	18227	TRAINS		
TIMESTAMP	RECORD	CH9_1	CH9_2	CH9_3	CH9_4	CH9_5	CH9_6	CH9_7	CH9_8
TS	RN	KSI	KSI	KSI	KSI	KSI	KSI	KSI	KSI
		Smp	Smp	Smp	Smp	Smp	Smp	Smp	Smp
1999-02-17 02:09:53.13	0	0.094	-0.071	0.027	0.053	-0.057	0.092	-0.089	0.036
1999-02-17 02:09:53.14	1	-0.098	0.069	-0.069	-0.029	0.04	-0.1	0.125	-0.053
1999-02-17 02:09:53.15	2	0.034	-0.106	0.015	0.013	-0.02	0.049	-0.077	0.074

Table 2 – Typical Data File Collected by Data Logger in Comma Separated Format as Imported to Excel

Notes:
1. Row #1 contains miscellaneous information pertaining to the data logger and data acquisition program.
2. Row #2 contains the name of the respective column.
3. Row #3 contains the unit format of the respective column (e.g., ksi)
4. Row #4 contains the type of data in the column, in this case a data sample.
5. Rows 5 and higher of Columns 3 and higher contain the actual data. The numbers in the columns are in units of ksi.

Strain Gage Records
Test Vehicle, Span 4



(S) = Parameter Smoothed
F:\TESTTR~6\OUT_1.IDW

ID-2000

Test Vehicle at Span 4/Section A: Vehicle Outbound on Outbound Track @ Nominal 10 mph

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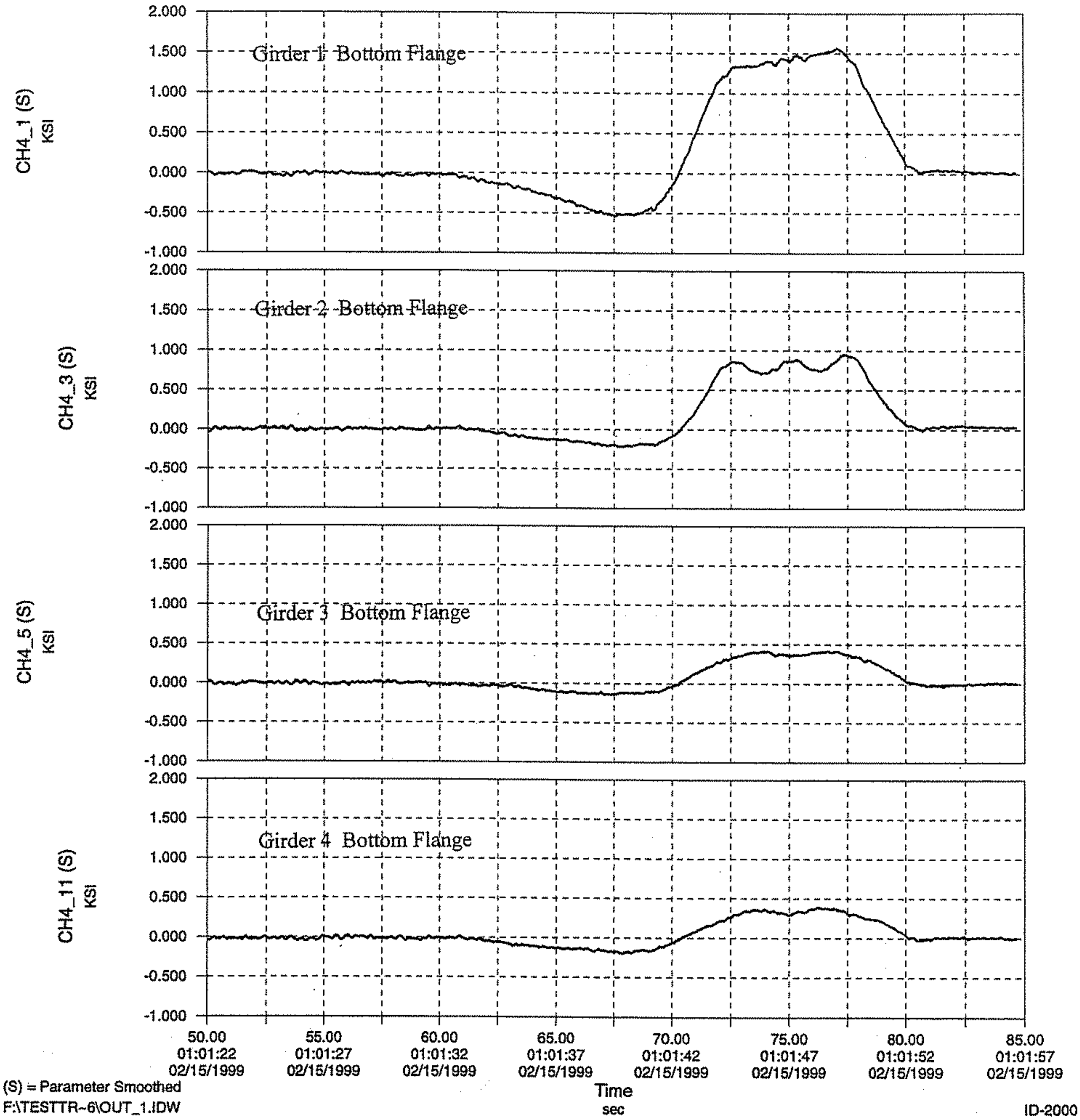
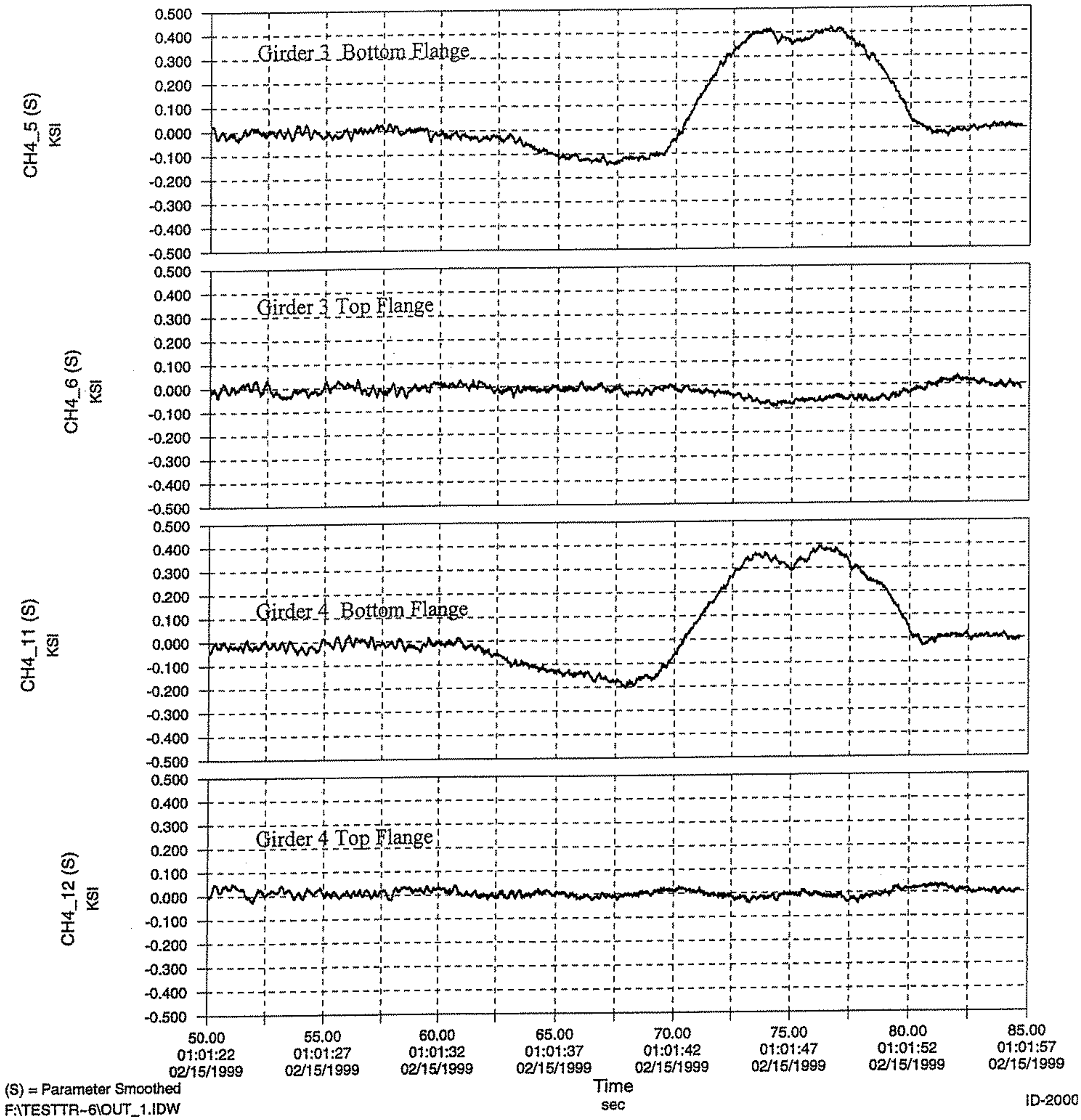
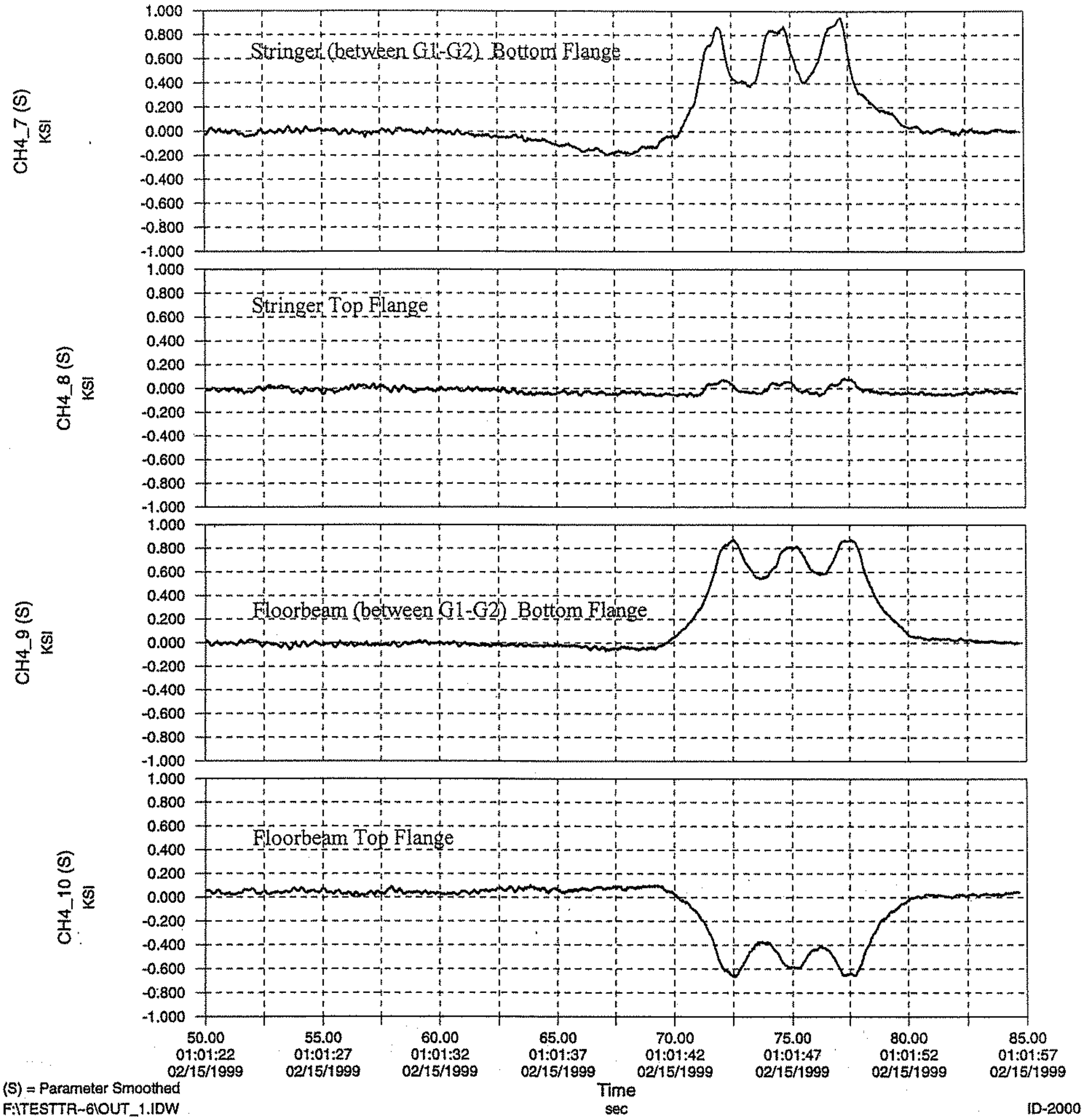


Test Vehicle at Span 4/Section A: Vehicle Outbound on Outbound Track @ Nominal 10 mph

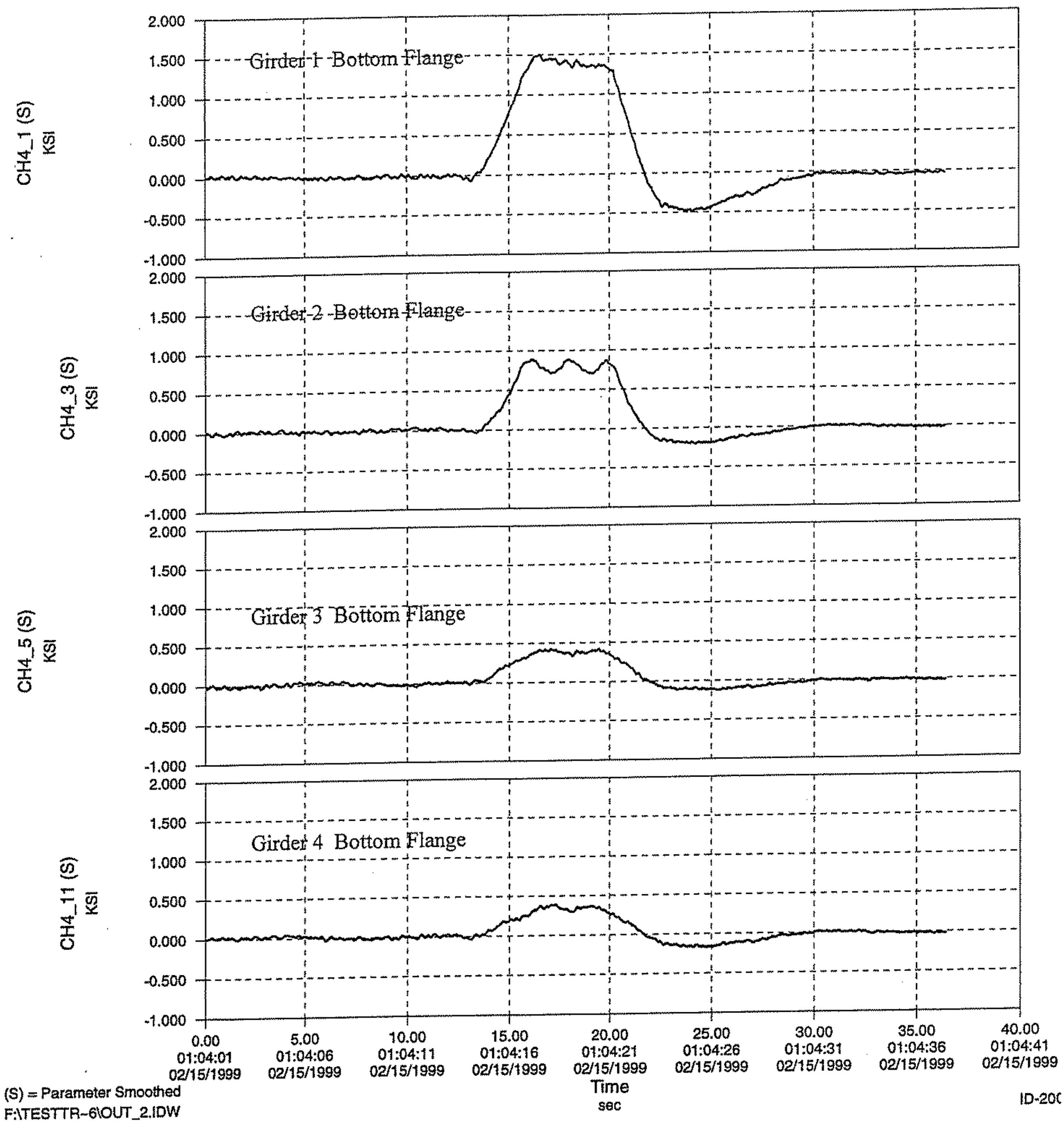


Test Vehicle at Span 4/Section A: Vehicle Outbound on Outbound Track @ Nominal 10 mph



Test Vehicle in Span 4: Vehicle Outbound on Outbound Track @ Nominal 10 mph

- **Top 2 records/Section aa**
- **Bottom 2 records/Section a**



Test Vehicle at Span 4/Section A: Vehicle Inbound on Outbound Track @ Nominal 10 mph

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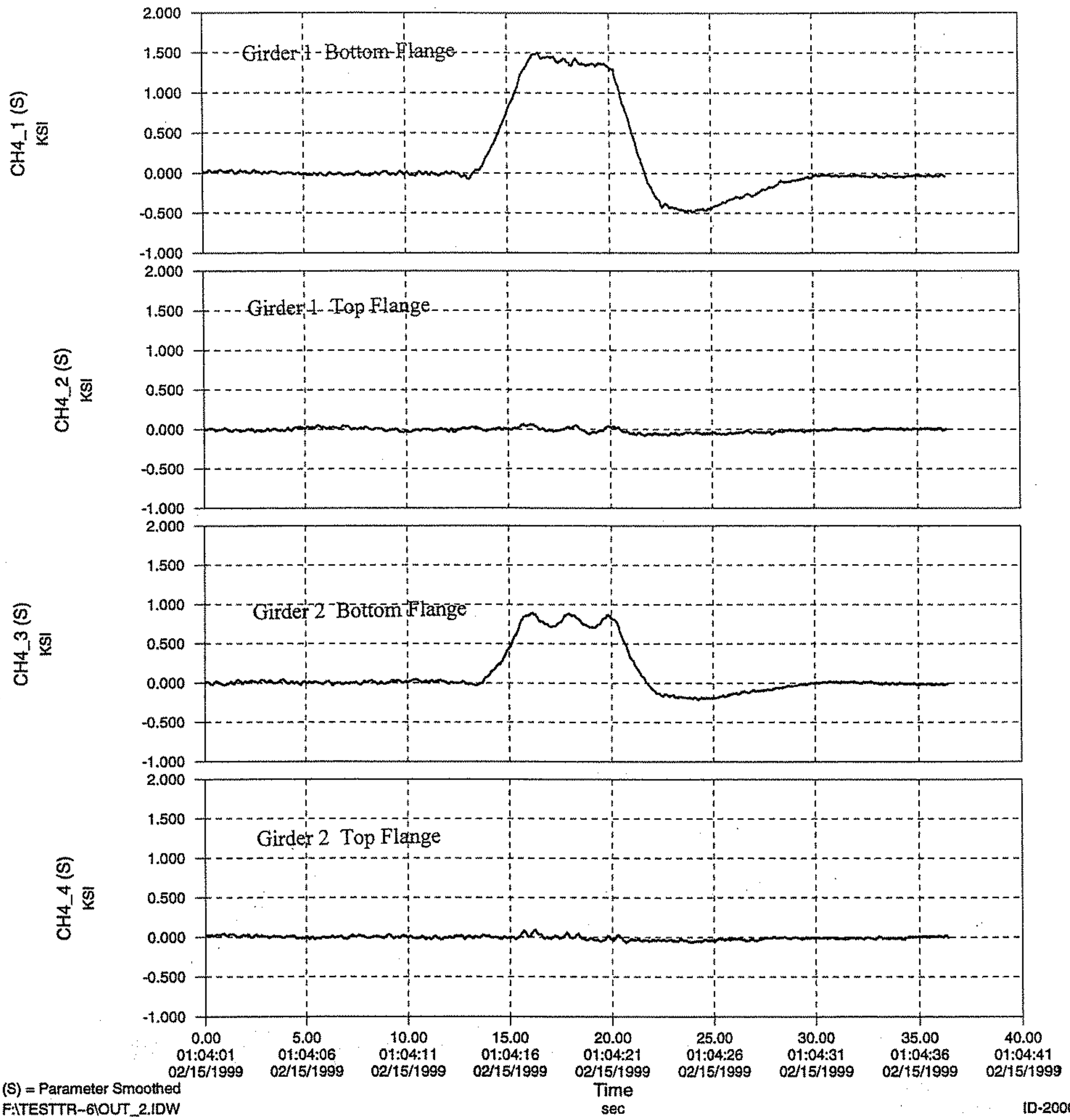

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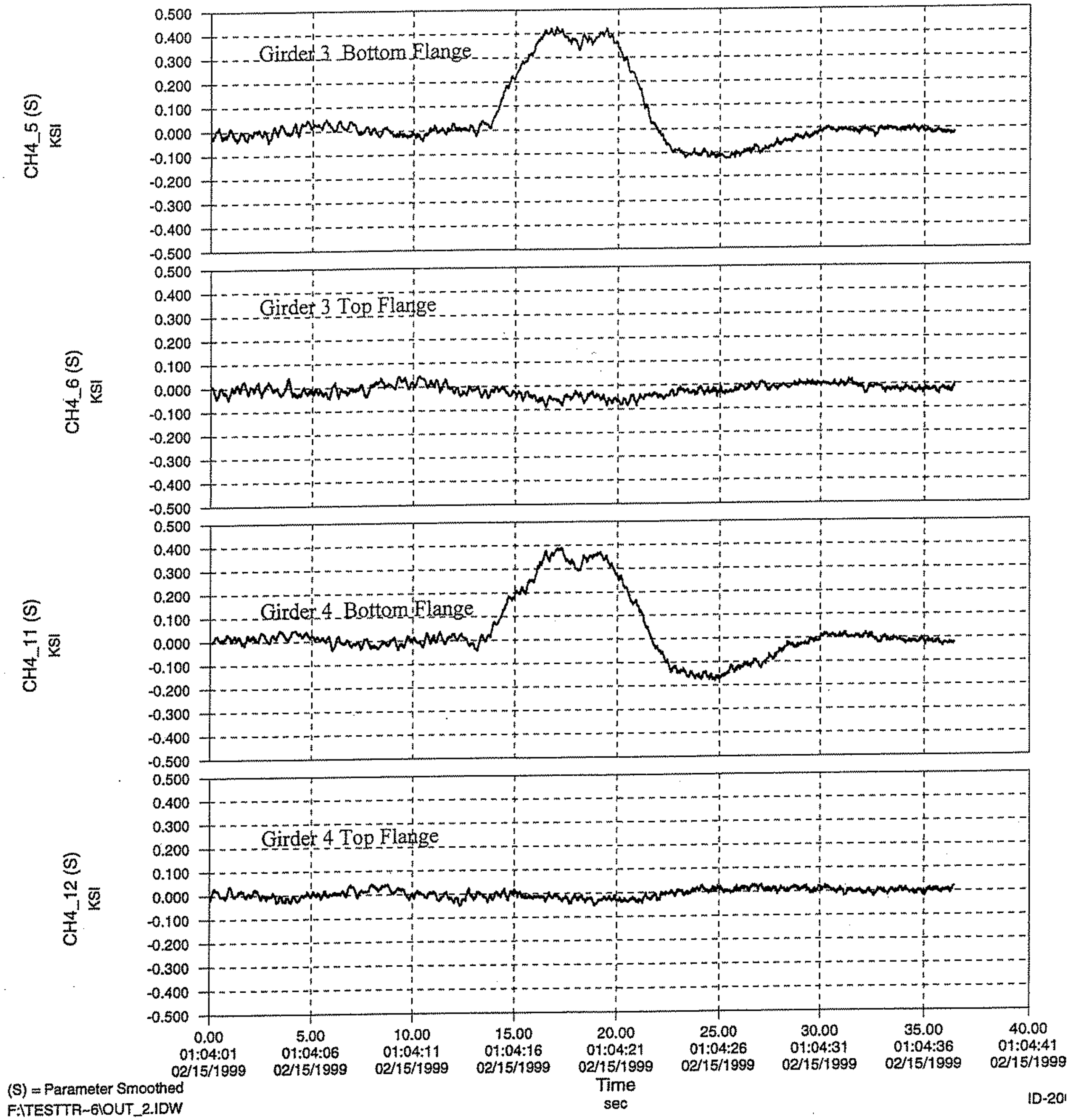
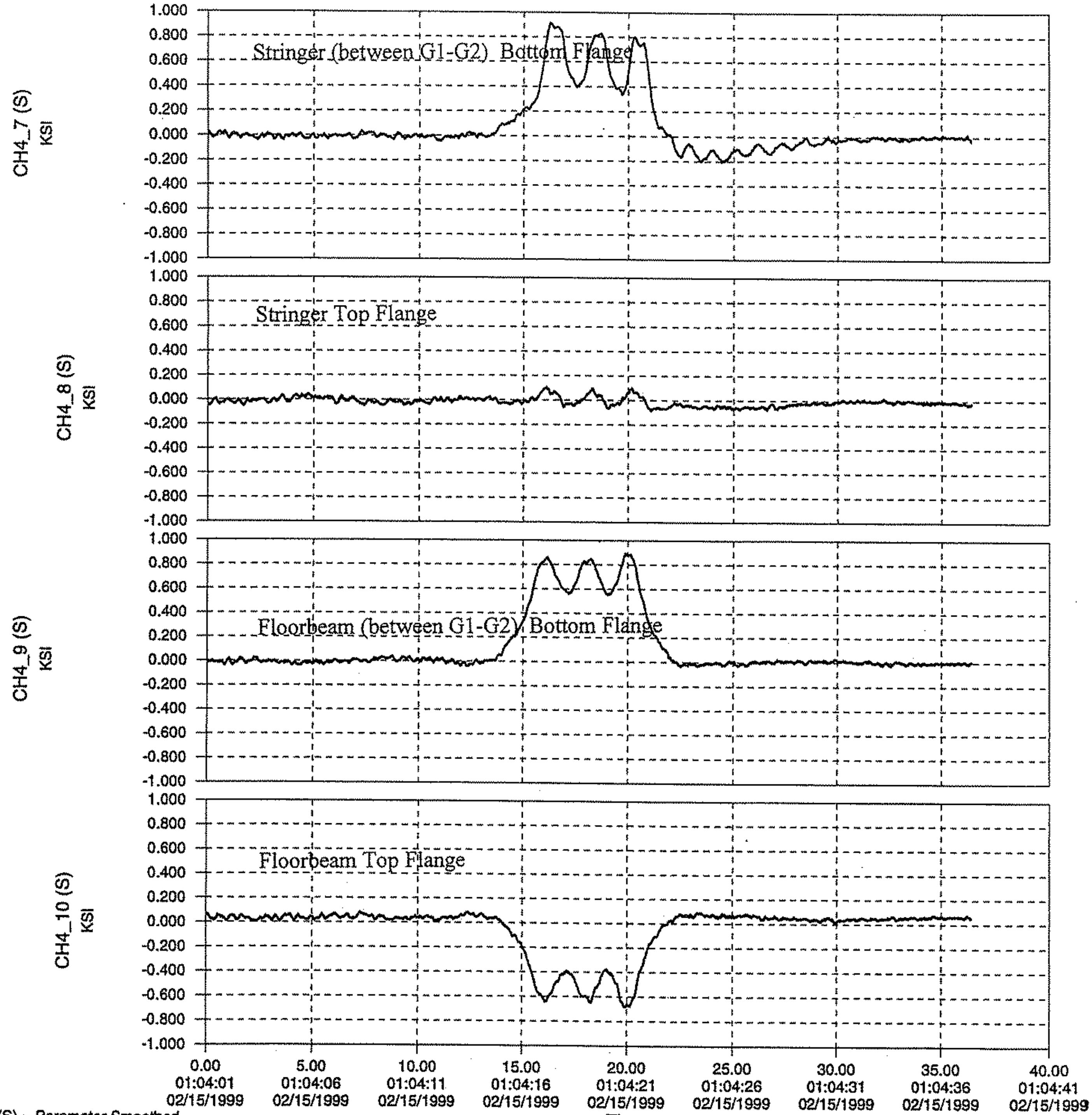
ID-2000

Test Vehicle at Span 4/Section A: Vehicle Inbound on Outbound Track @ Nominal 10 mph



Test Vehicle at Span 4/Section A: Vehicle Inbound on Outbound Track @ Nominal 10 mph

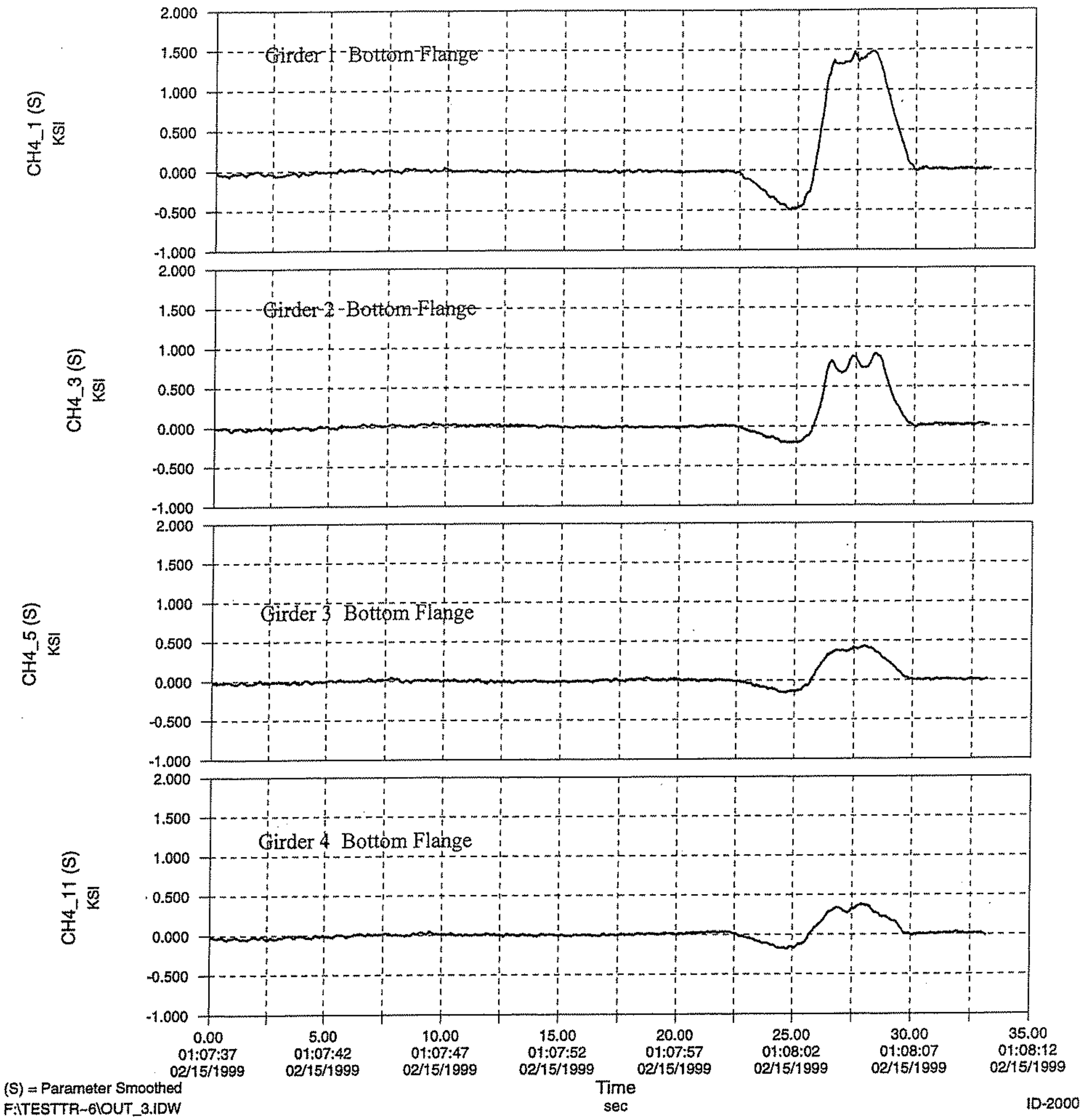


(S) = Parameter Smoothed
F:\TESTTR~6\OUT_2.IDW

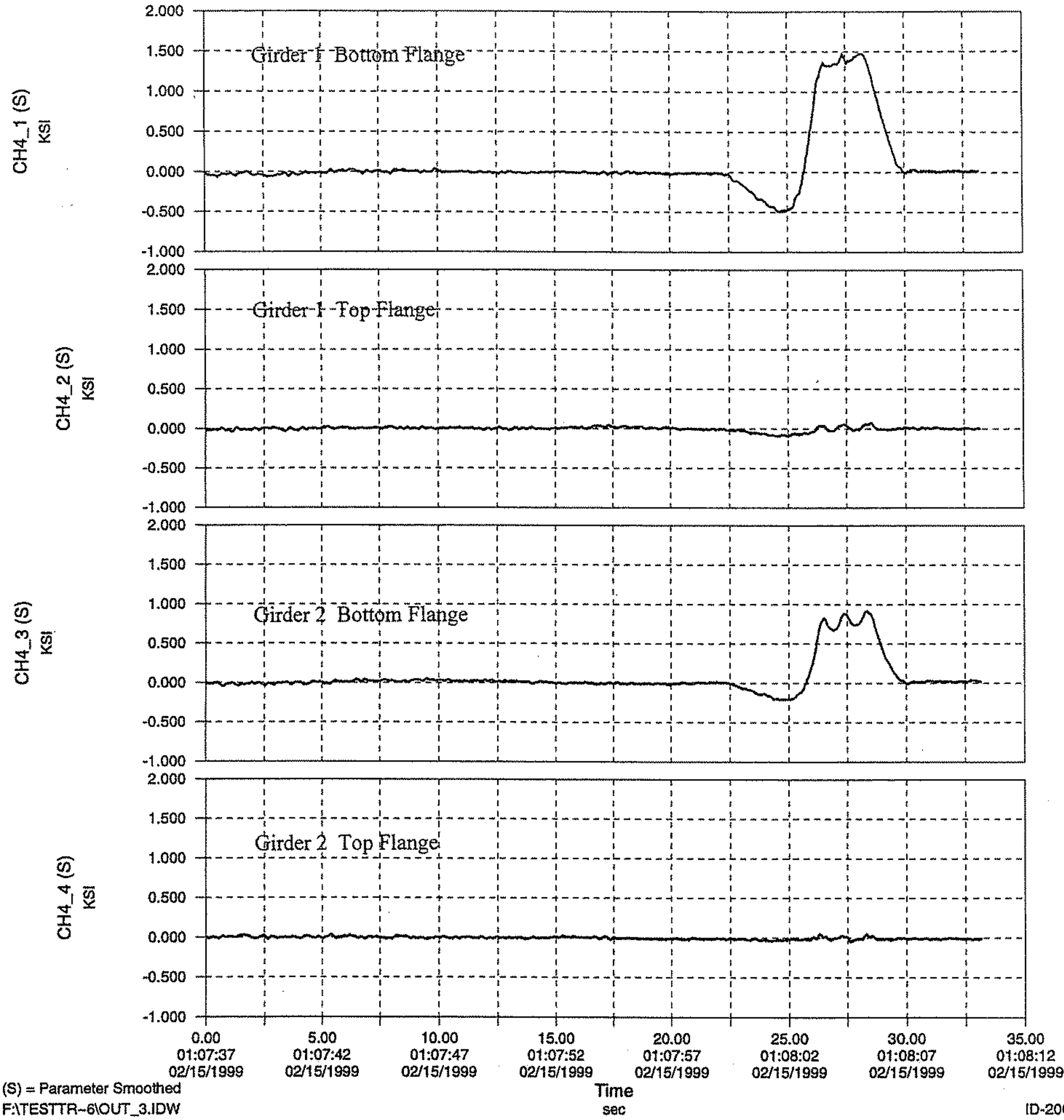
ID-2000

Test Vehicle in Span 4: Vehicle Inbound on Outbound Track @ Nominal 10 mph

- **Top 2 records/Section aa**
- **Bottom 2 records/Section a**



Test Vehicle at Span 4/Section A: Vehicle Outbound on Outbound Track @ Nominal 25 mph



(S) = Parameter Smoothed
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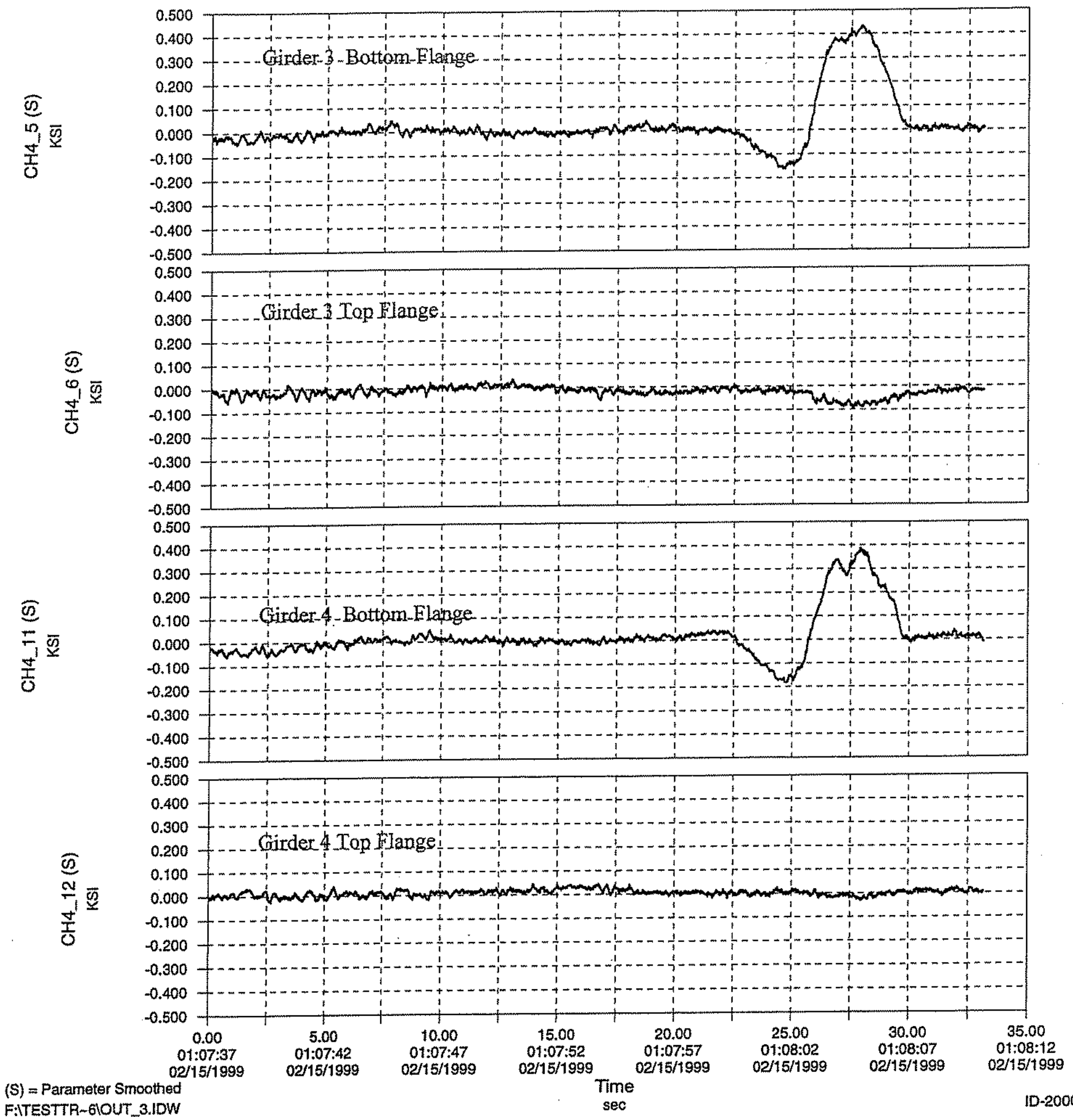
ID-2000

Test Vehicle at Span 4/Section A: Vehicle Outbound on Outbound Track @ Nominal 25 mph



(S) = Parameter Smoothed
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ID-2000

Test Vehicle at Span 4/Section A: Vehicle Outbound on Outbound Track @ Nominal 25 mph

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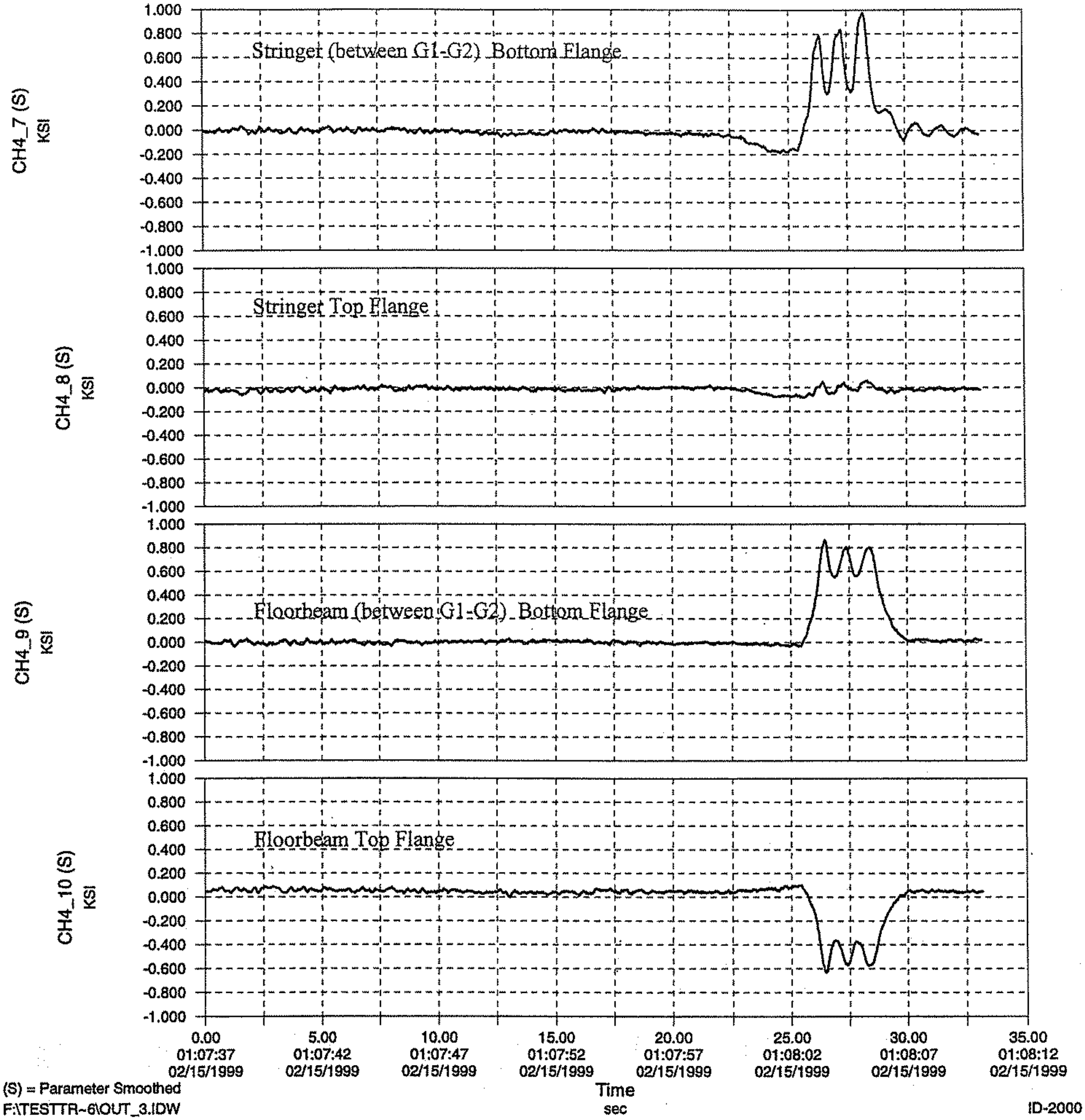
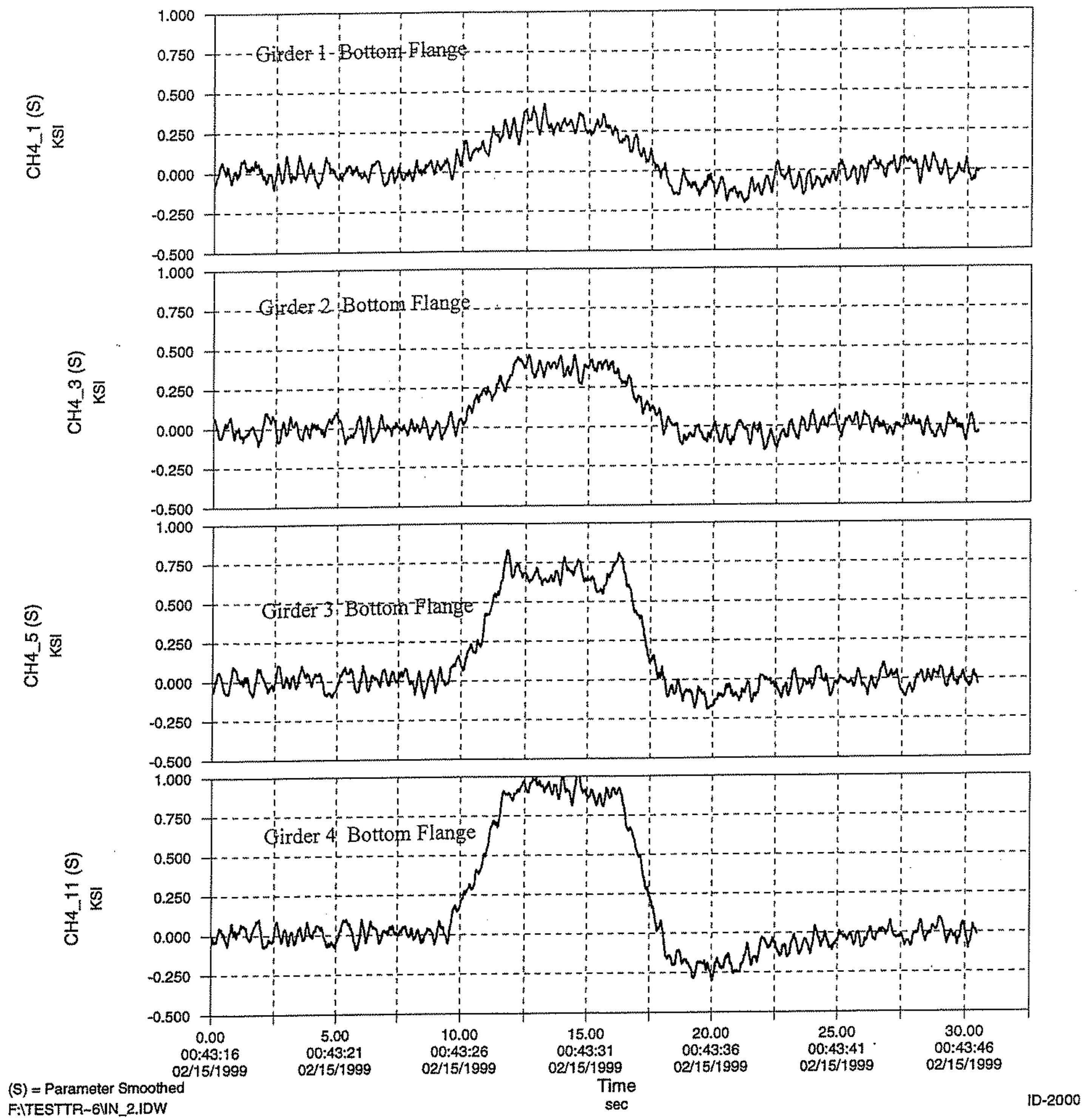
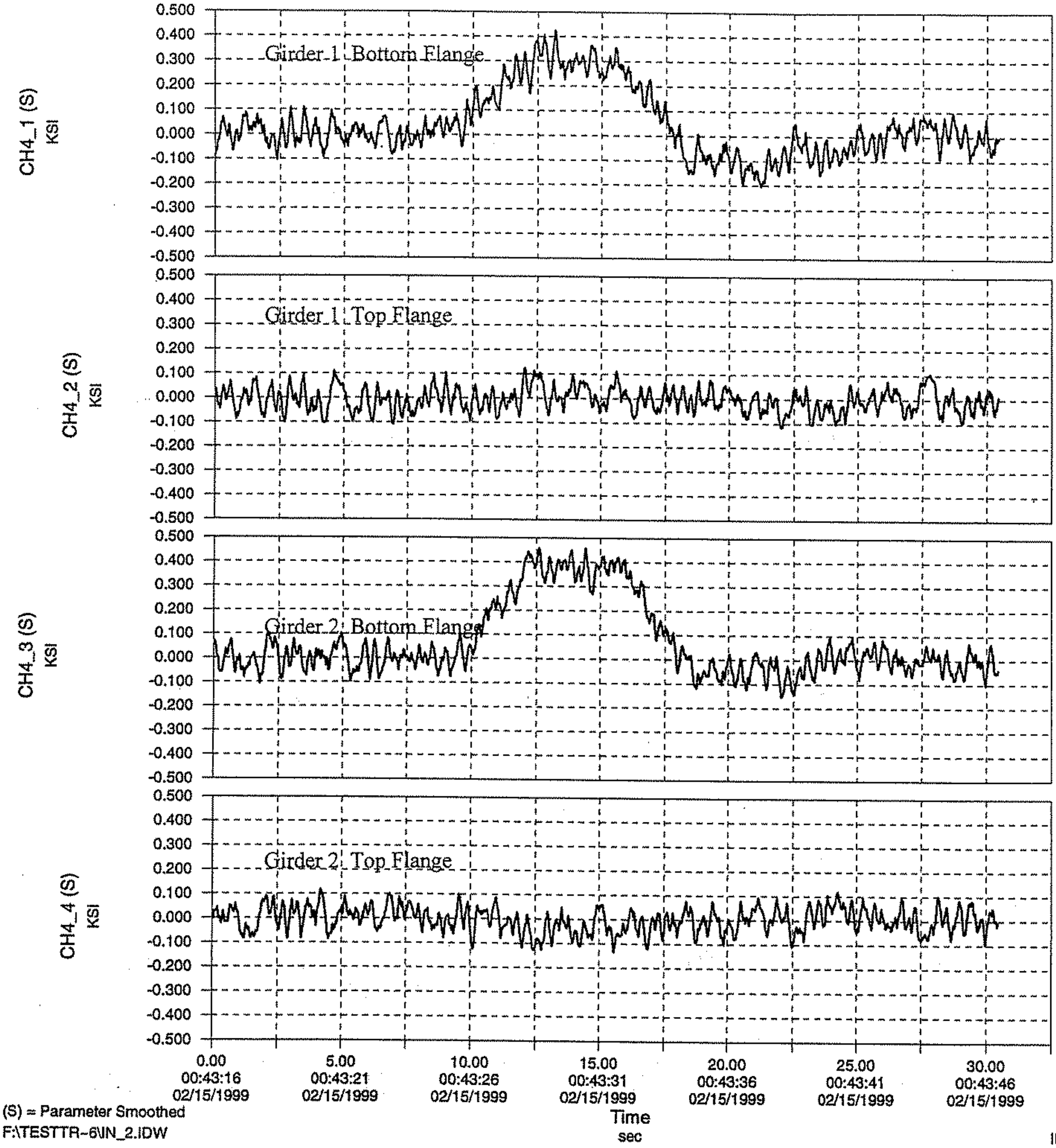


Test Vehicle in Span 4: Vehicle Outbound on Outbound Track @ Nominal 25 mph

- **Top 2 records/Section aa**
- **Bottom 2 records/Section a**



Test Vehicle at Span 4/Section A: Vehicle Inbound on Inbound Track @ Nominal 10 mph



(S) = Parameter Smoothed
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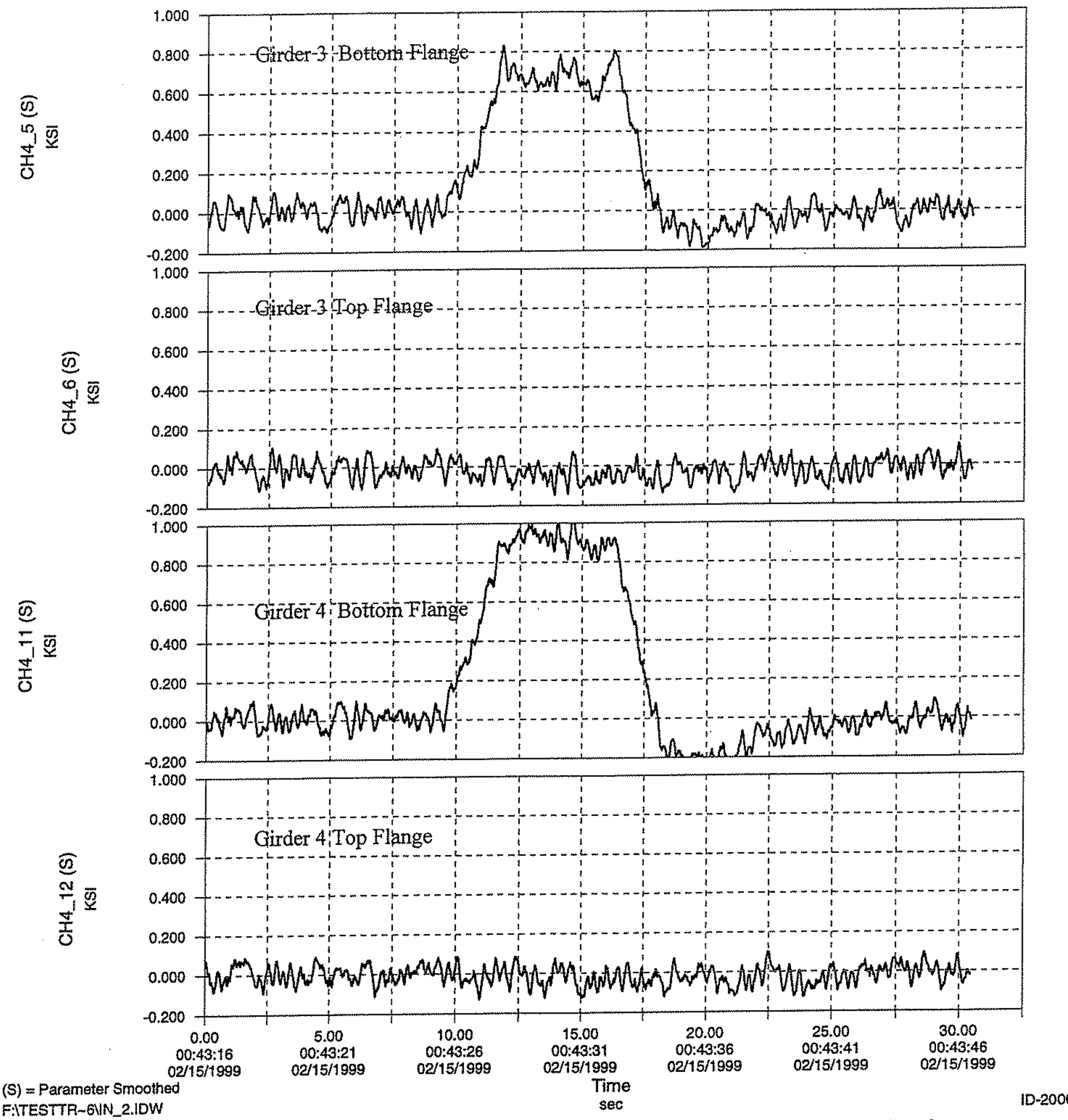
ID-2000

Test Vehicle at Span 4/Section A: Vehicle Inbound on Inbound Track @ Nominal 10 mph



(S) = Parameter Smoothed
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ID-2000

Test Vehicle at Span 4/Section A: Vehicle Inbound on Inbound Track @ Nominal 10 mph

Saw Mill Run Bridge

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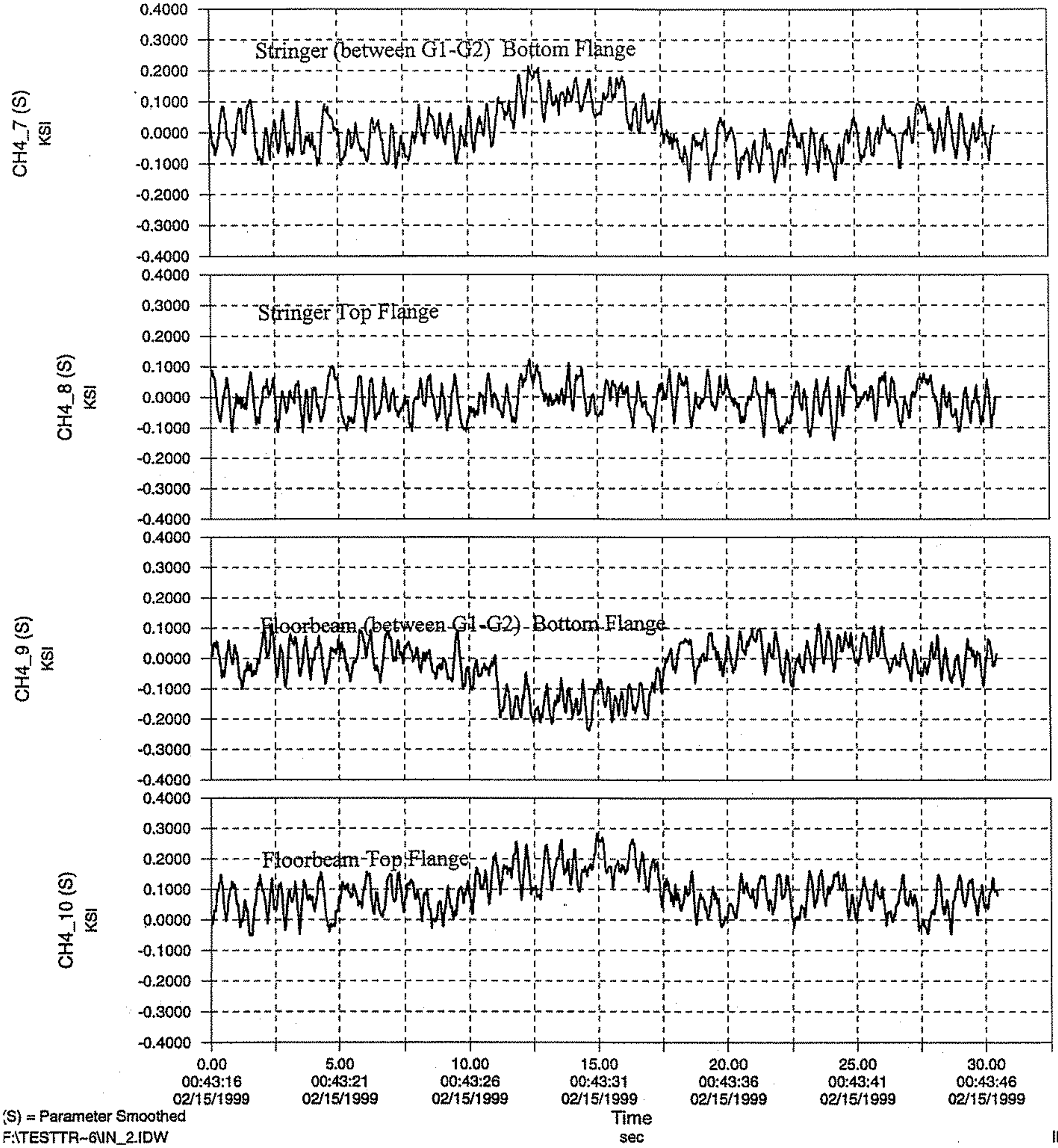
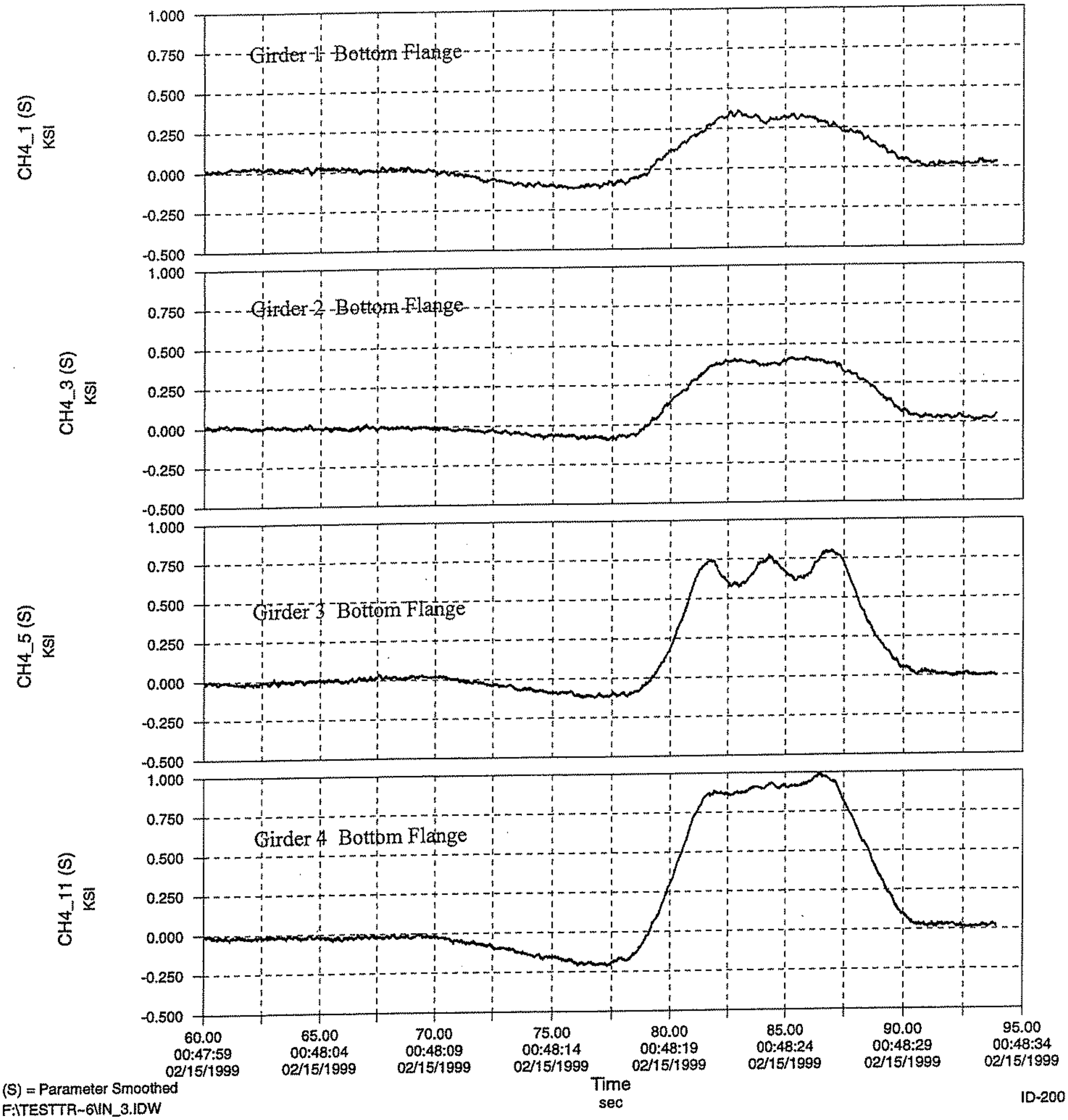


(S) = Parameter Smoothed
F:\TESTTR~6\IN_2.IDW

ID-2000

Test Vehicle in Span 4: Vehicle Inbound on Inbound Track @ Nominal 10 mph

- **Top 2 records/Section aa**
- **Bottom 2 records/Section a**



(S) = Parameter Smoothed
F:\TESTTR~6\IN_3.IDW

ID-200

Test Vehicle at Span 4/Section A: Vehicle Outbound on Inbound Track @ Nominal 10 mph

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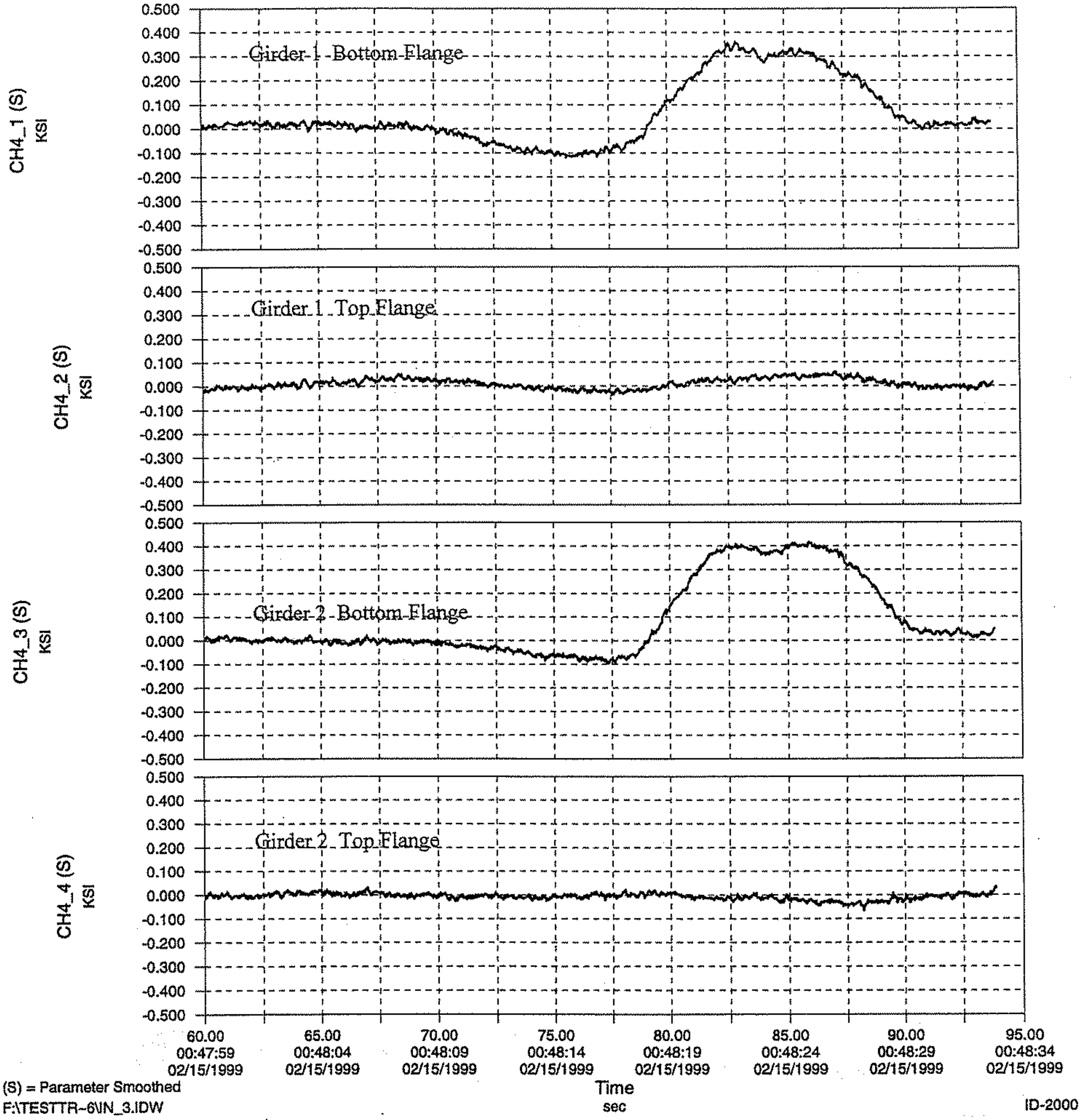
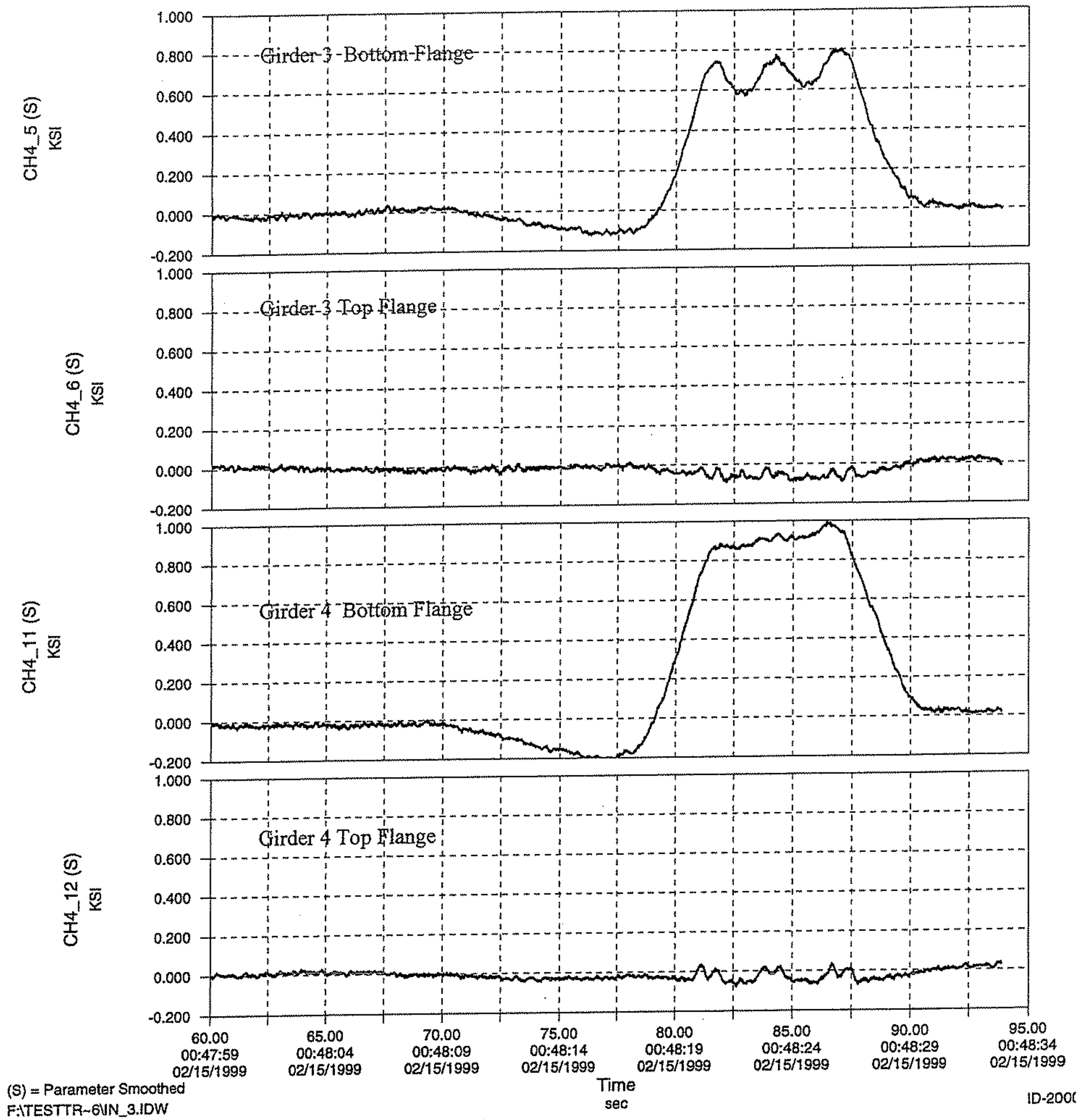
March 23, 1999

Saw Mill Run Bridge



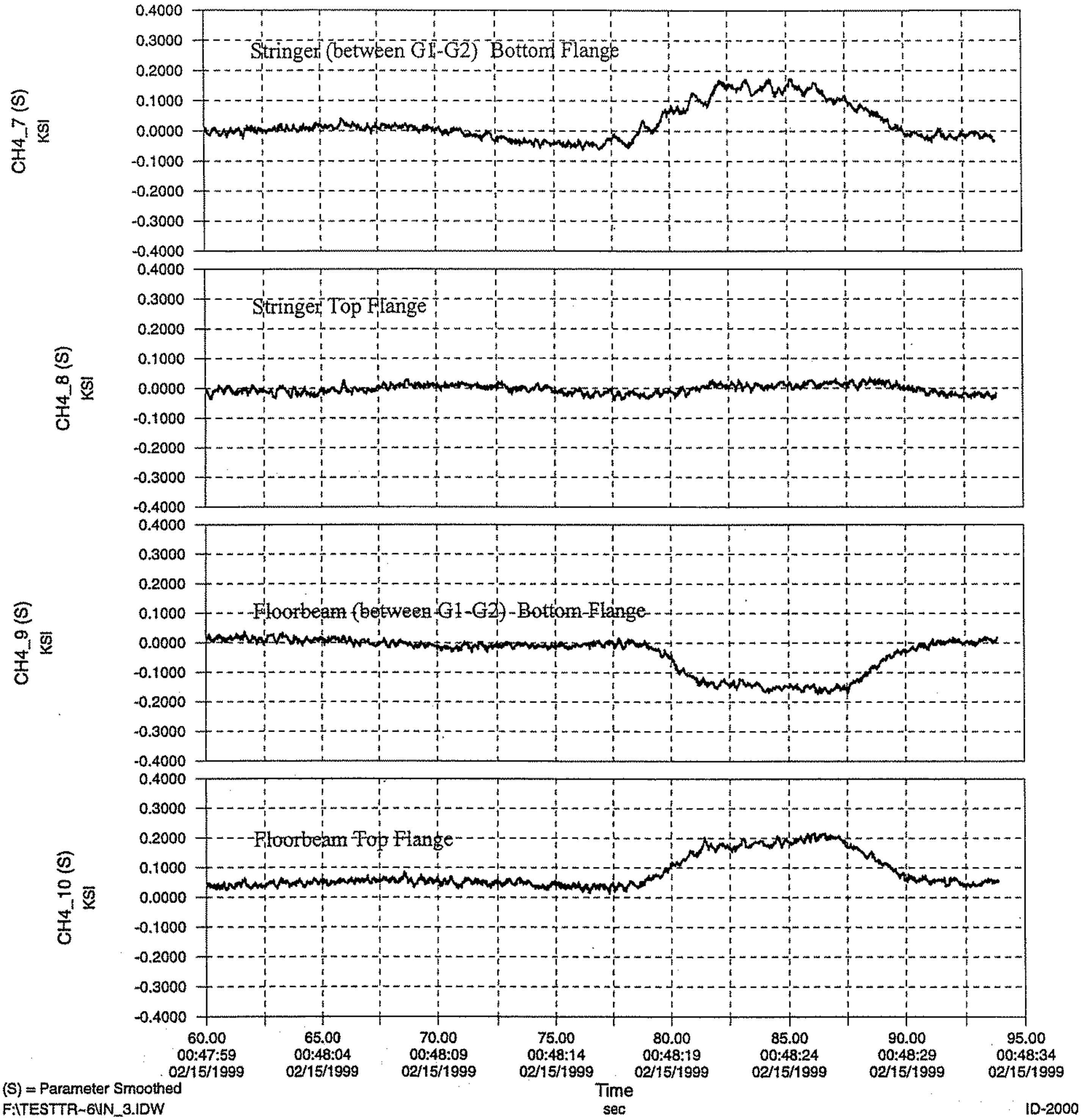
Test Vehicle at Span 4/Section A: Vehicle Outbound on Inbound Track @ Nominal 10 mph



Test Vehicle at Span 4/Section A: Vehicle Outbound on Inbound Track @ Nominal 10 mph

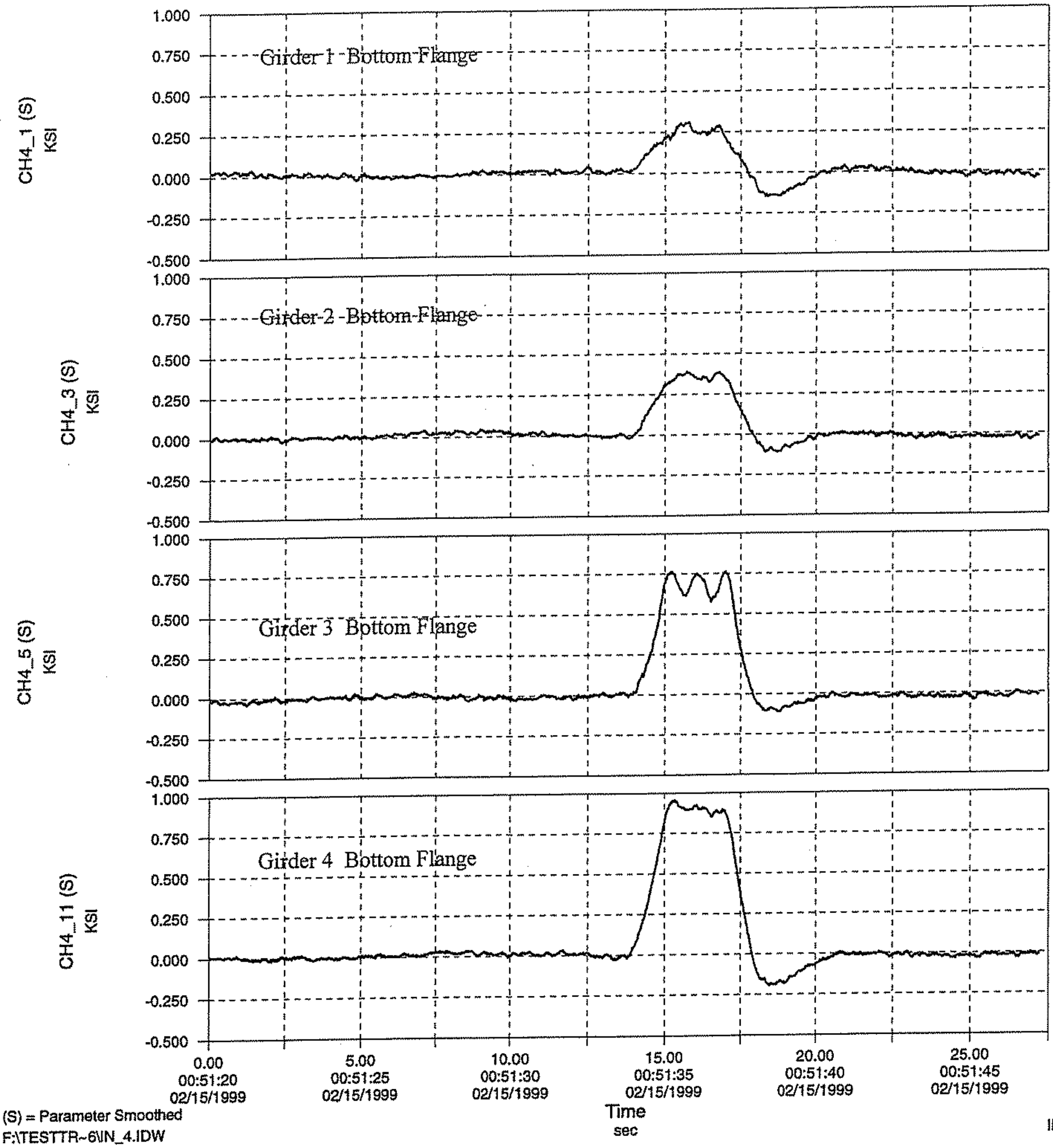
Saw Mill Run Bridge

ATLSS Engineering Research Center
March 23, 1999



Test Vehicle in Span 4: Vehicle Outbound on Inbound Track @ Nominal 10 mph

- **Top 2 records/Section aa**
- **Bottom 2 records/Section a**



(S) = Parameter Smoothed
F:\TESTTR~6\IN_4.IDW

ID-200

Test Vehicle at Span 4/Section A: Vehicle Inbound on Inbound Track @ Nominal 25 mph

Saw Mill Run Bridge

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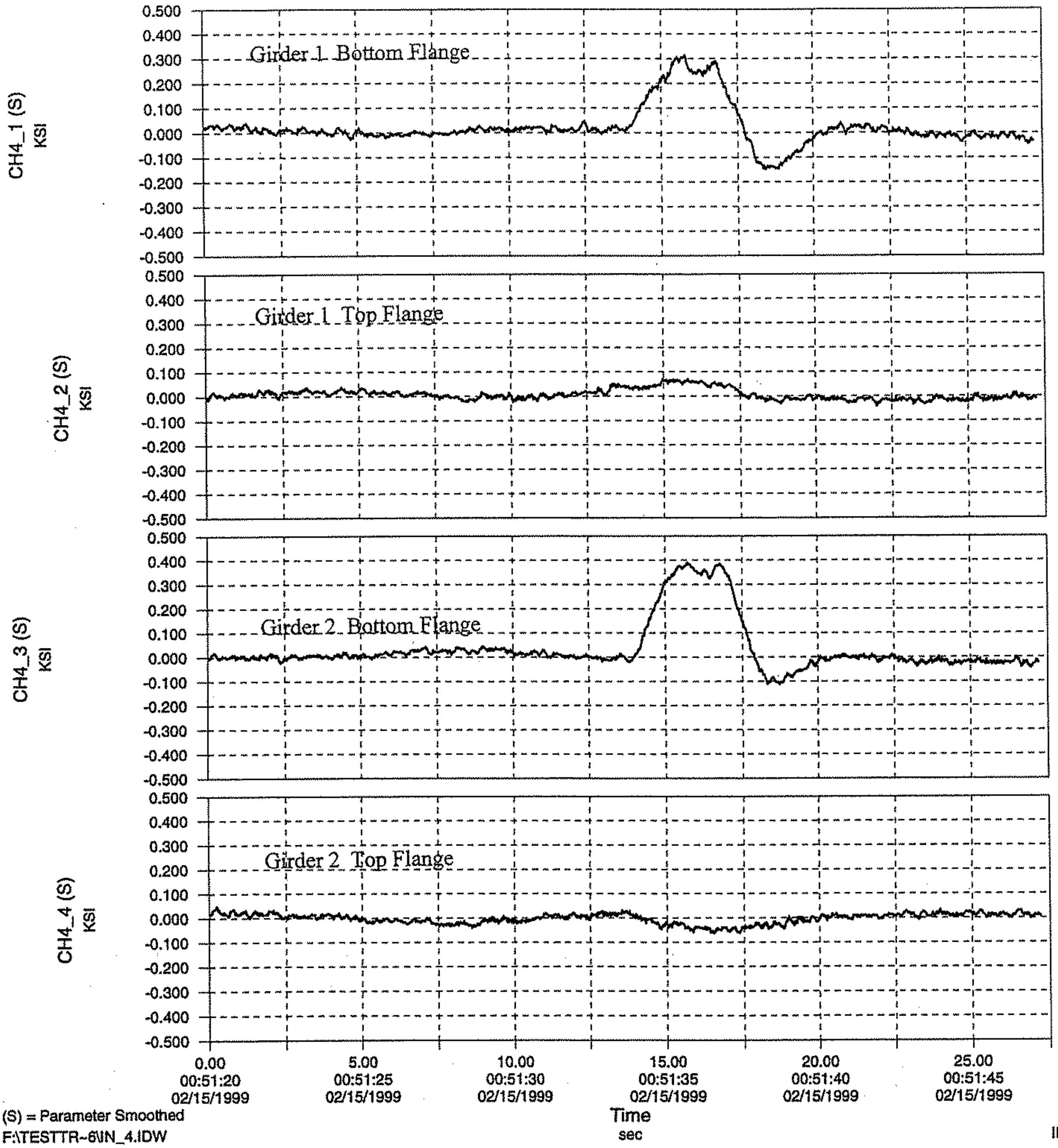
March 23, 1999



(S) = Parameter Smoothed
F:\TESTTR~6\IN_4.IDW

ID-2000

Test Vehicle at Span 4/Section A: Vehicle Inbound on Inbound Track @ Nominal 25 mph

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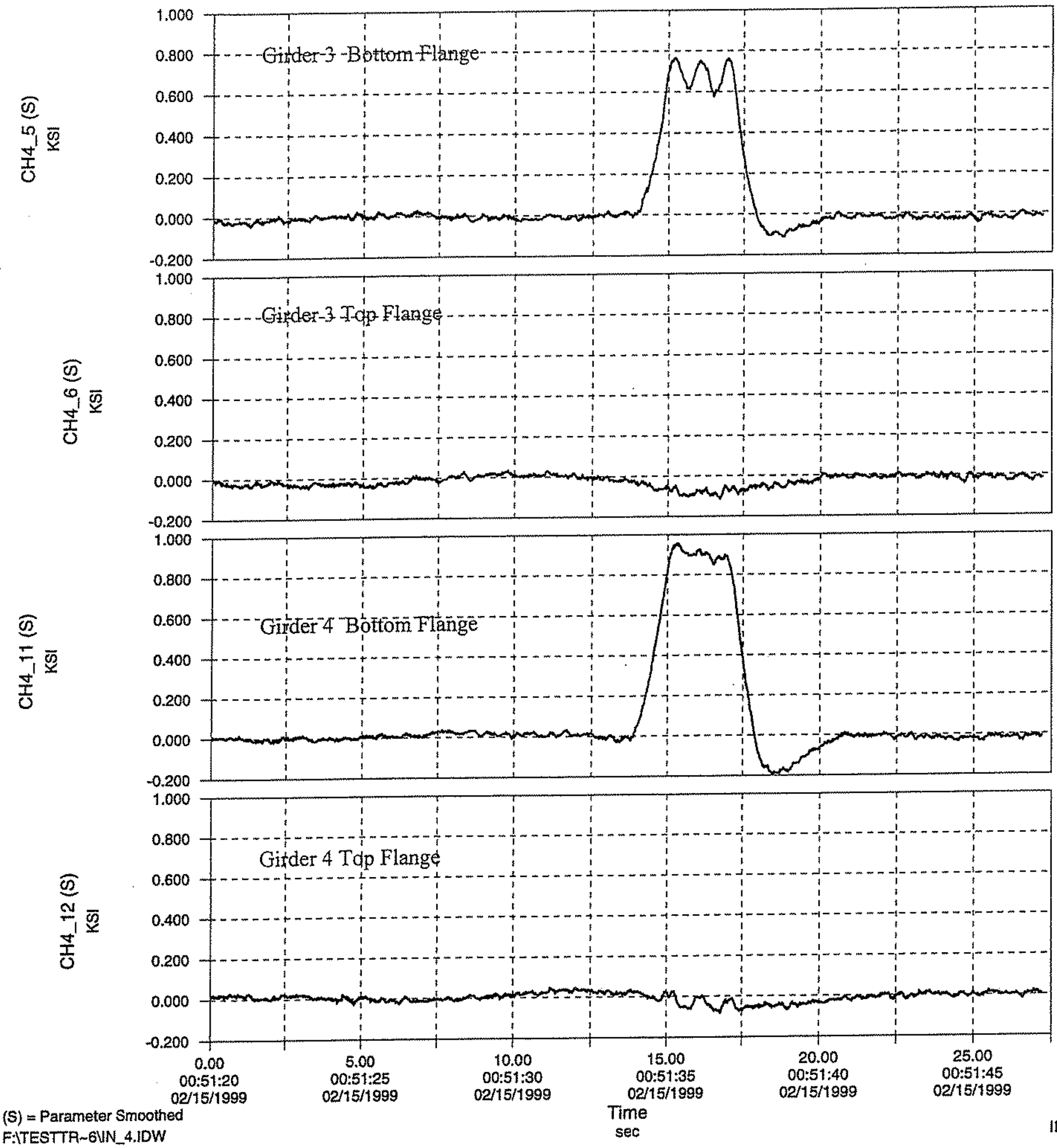
March 23, 1999

Saw Mill Run Bridge



(S) = Parameter Smoothed
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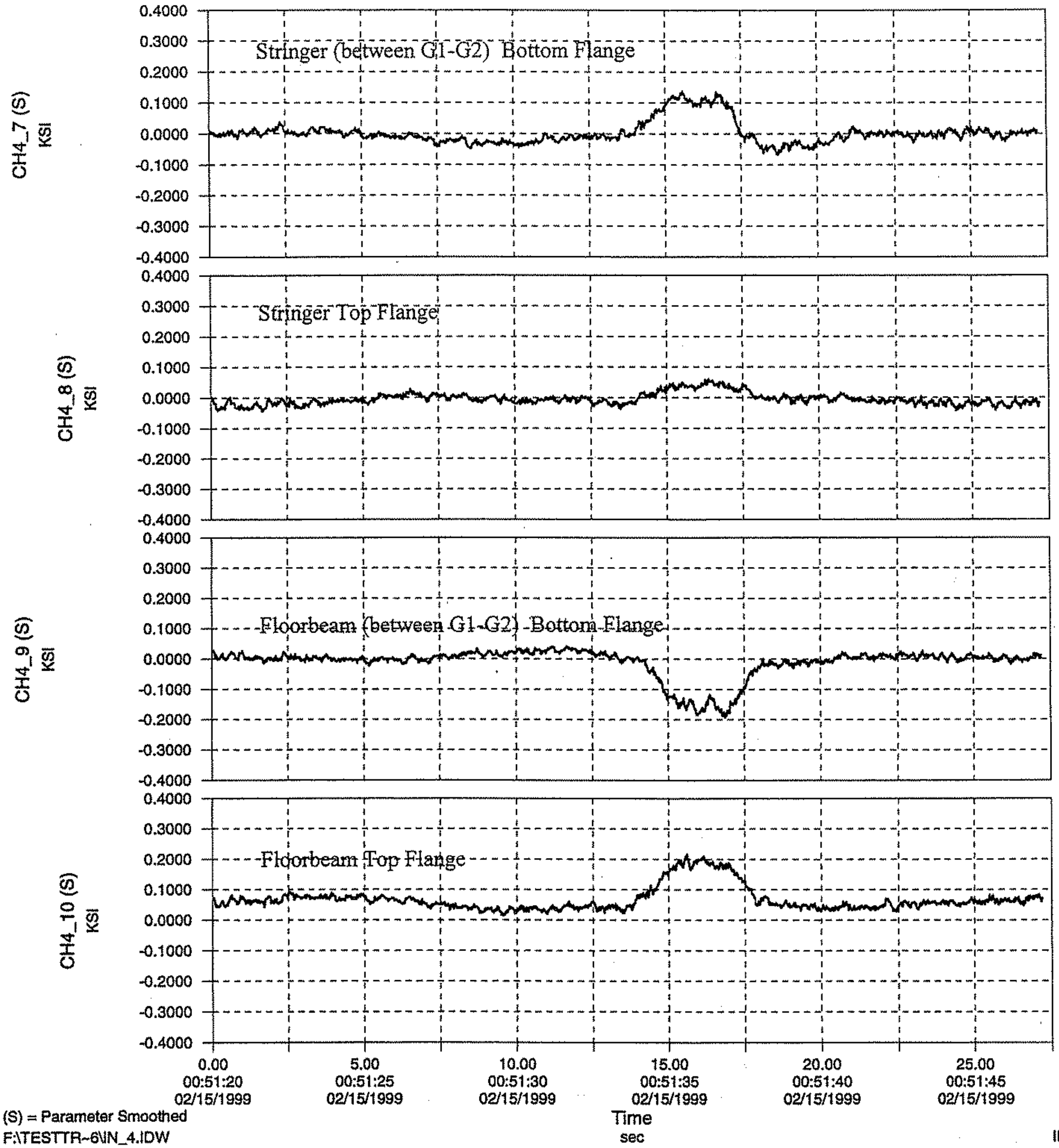
ID-200(

Test Vehicle at Span 4/Section A: Vehicle Inbound on Inbound Track @ Nominal 25 mph

Saw Mill Run Bridge

ATLSS Engineering Research Center
March 23, 1999



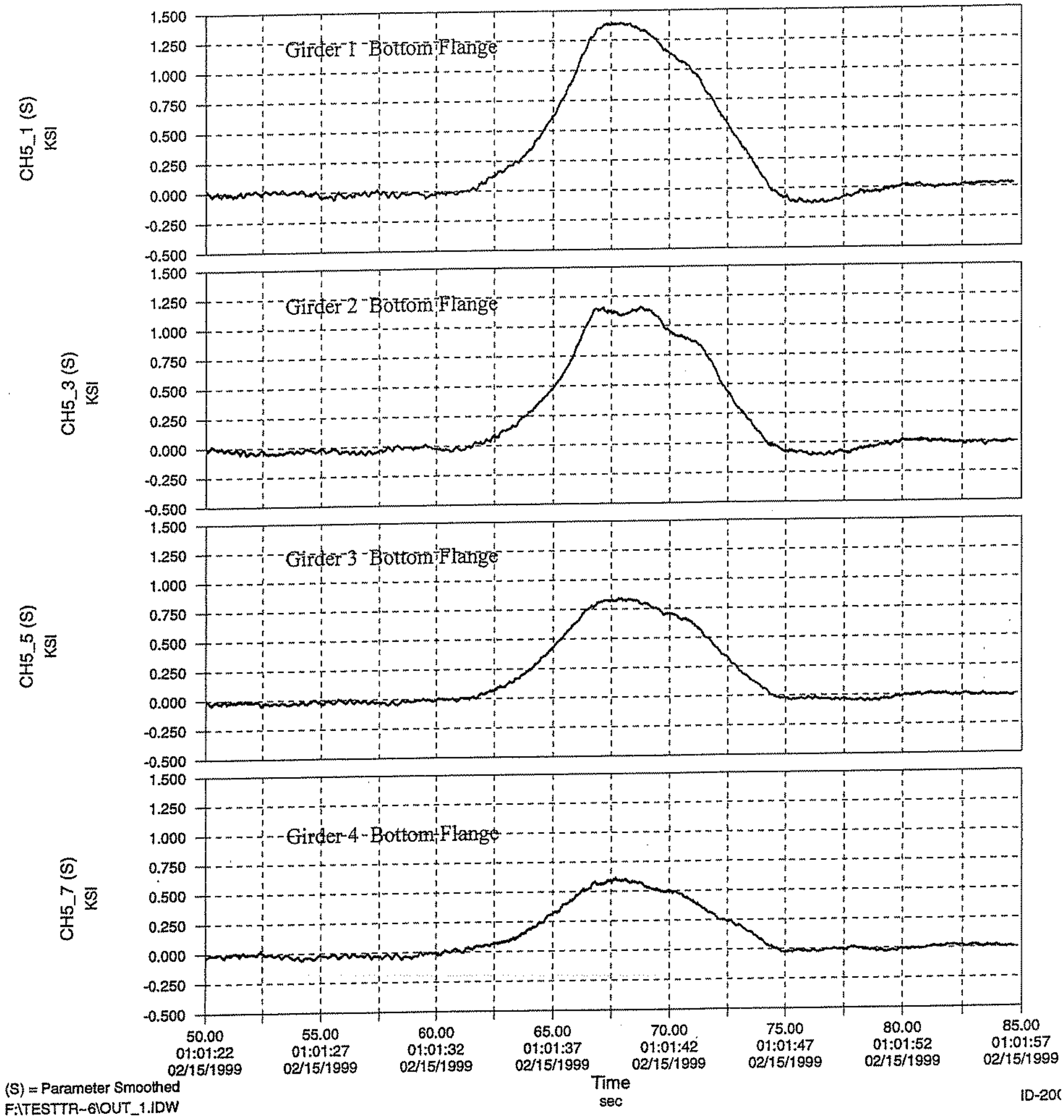
(S) = Parameter Smoothed
F:\TESTTR~6\IN_4.IDW

ID-2000

Test Vehicle in Span 4: Vehicle Inbound on Inbound Track @ Nominal 25 mph

- **Top 2 records/Section aa**
- **Bottom 2 records/Section a**

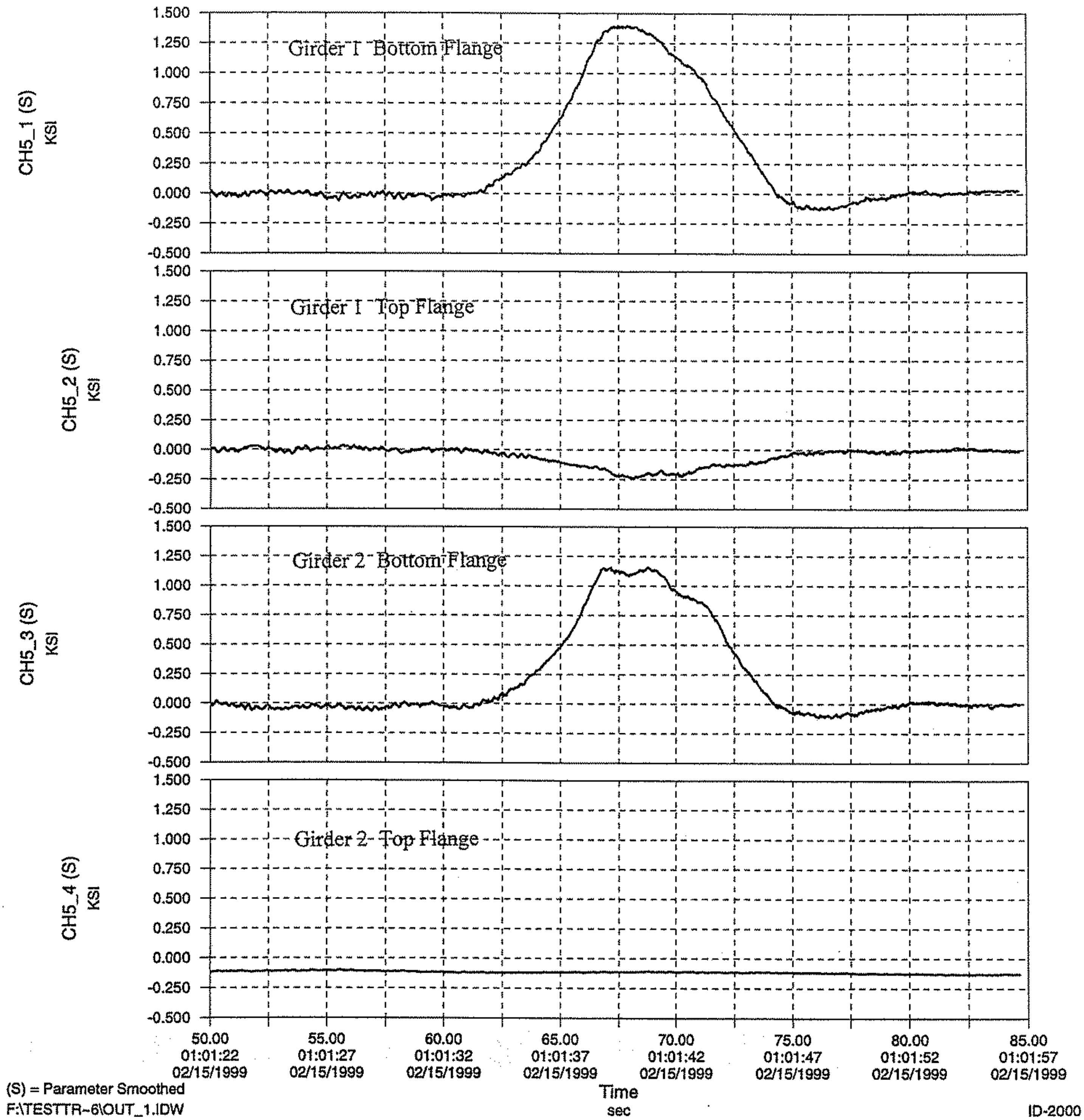
Strain Gage Records
Test Vehicle, Span 5



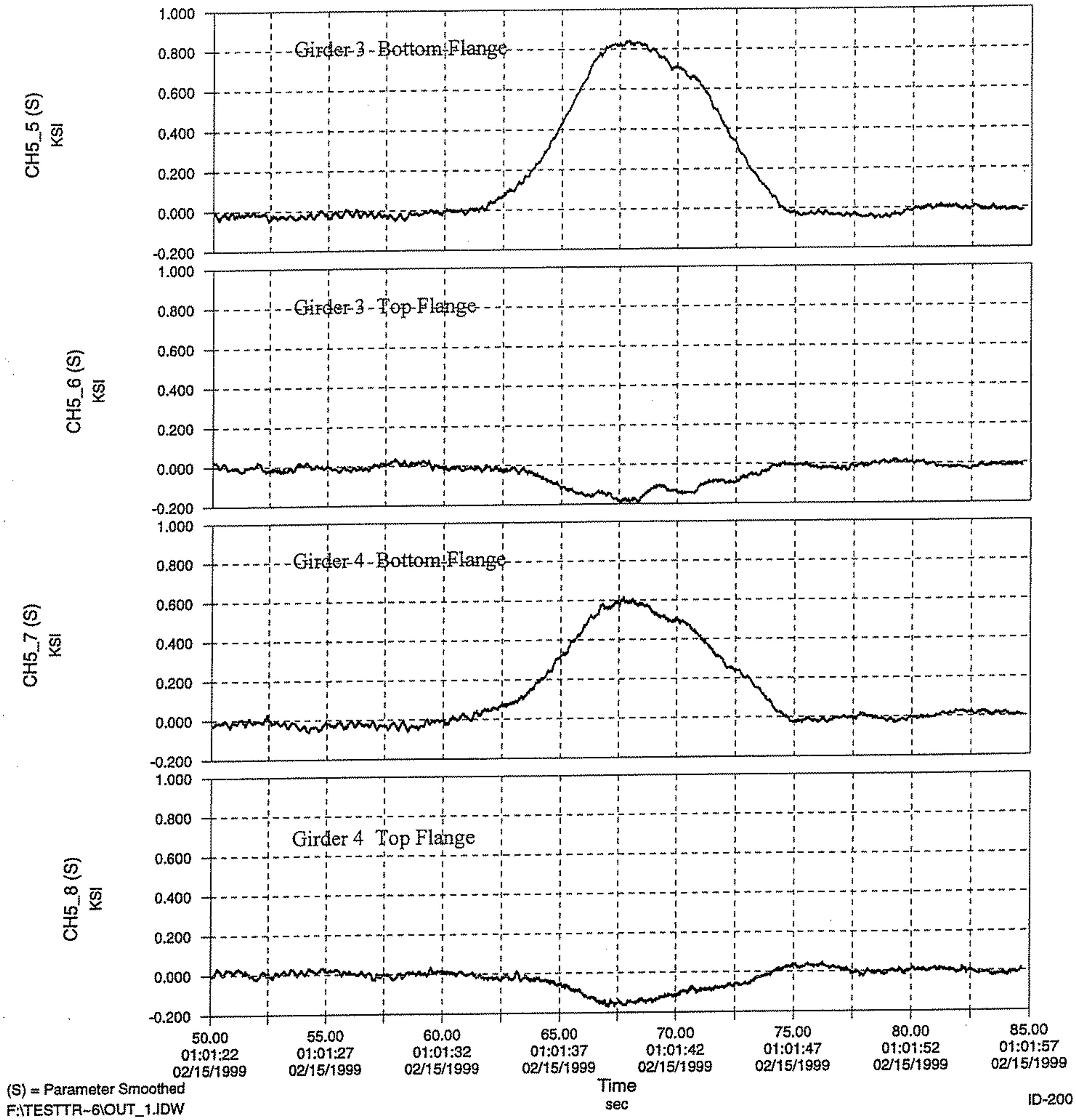
Test Vehicle at Span 5/Section b: Vehicle Outbound on Outbound Track @ Nominal 10 mph

Saw Mill Run Bridge

ATLSS Engineering Research Center
March 24, 1999



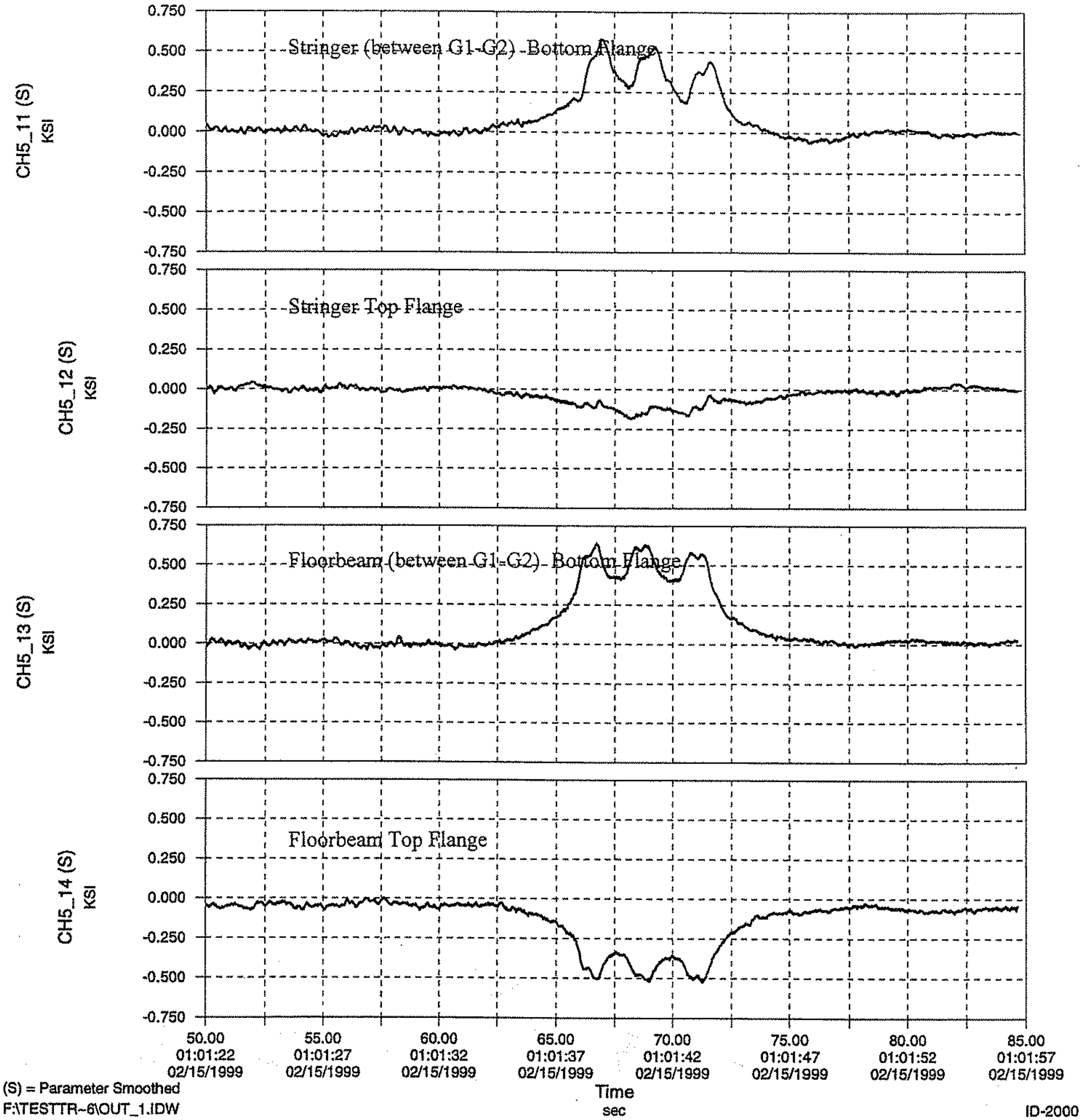
Test Vehicle at Span 5/Section b: Vehicle Outbound on Outbound Track @ Nominal 10 mph



Test Vehicle at Span 5/Section b: Vehicle Outbound on Outbound Track @ Nominal 10 mph

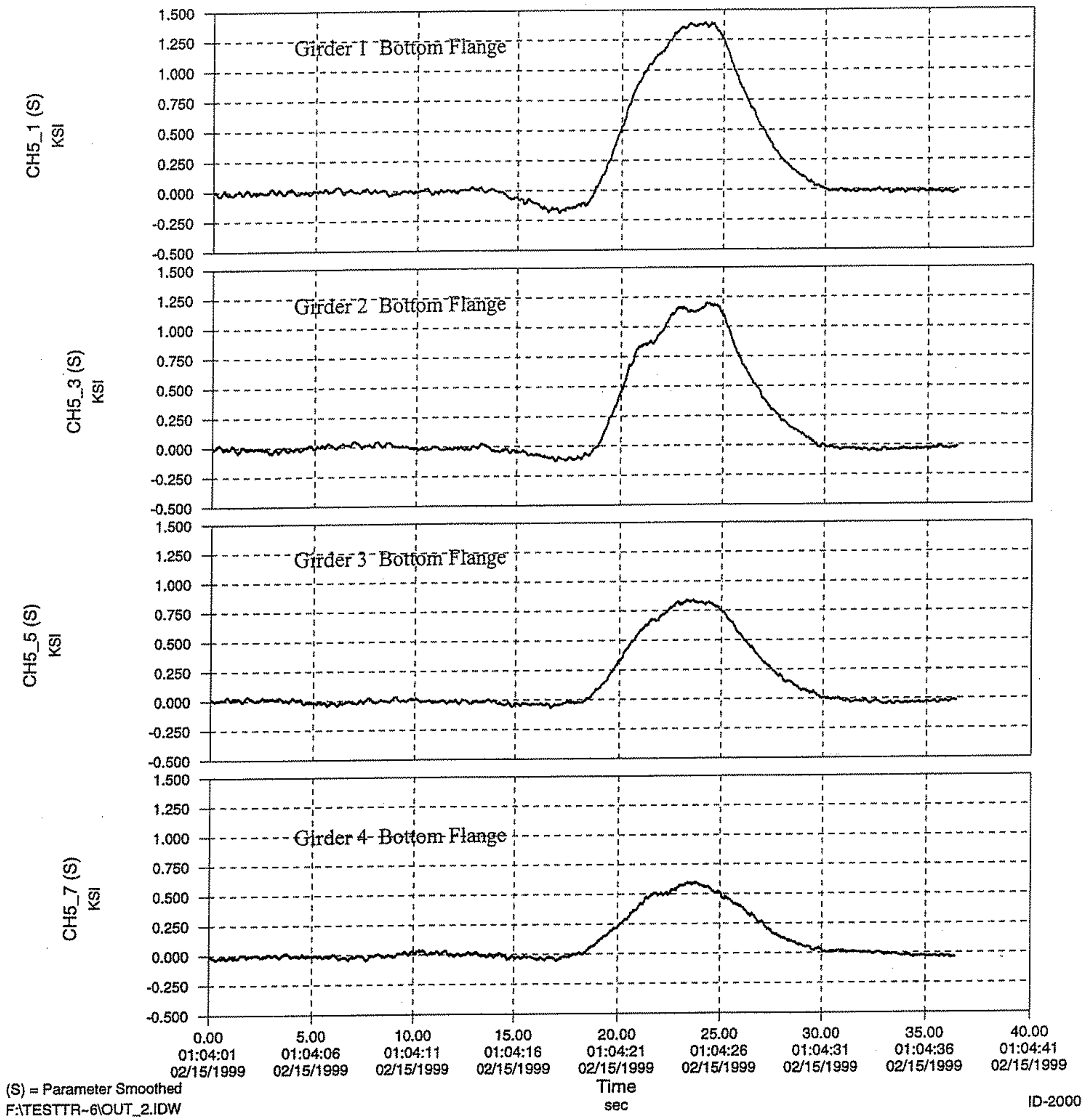
Saw Mill Run Bridge

ATLSS Engineering Research Center
March 24, 1999

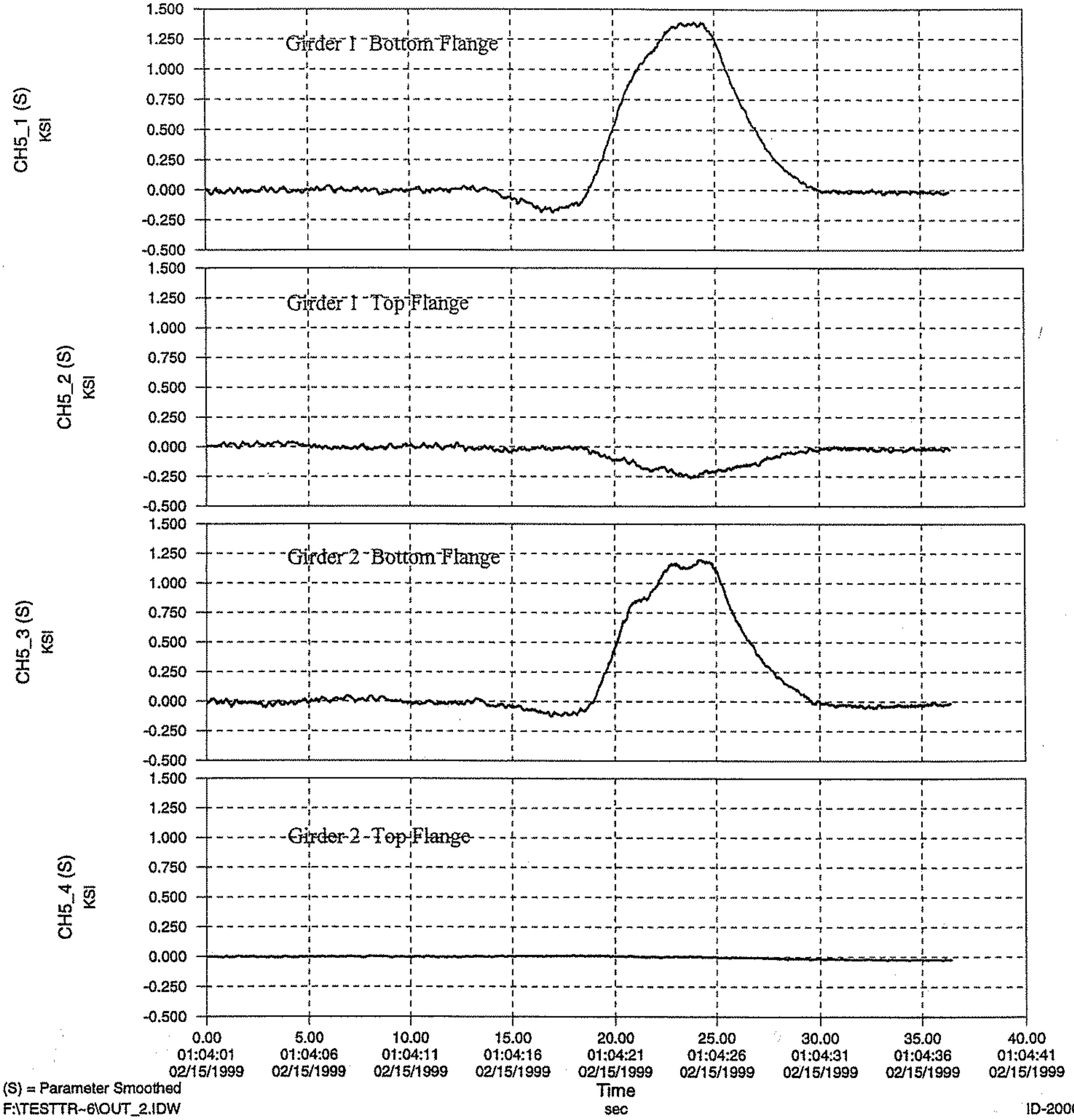


Test Vehicle in Span 5: Vehicle Outbound on Outbound Track @ Nominal 10 mph

- **Top 2 records/Section b**
- **Bottom 2 records/Section bb**



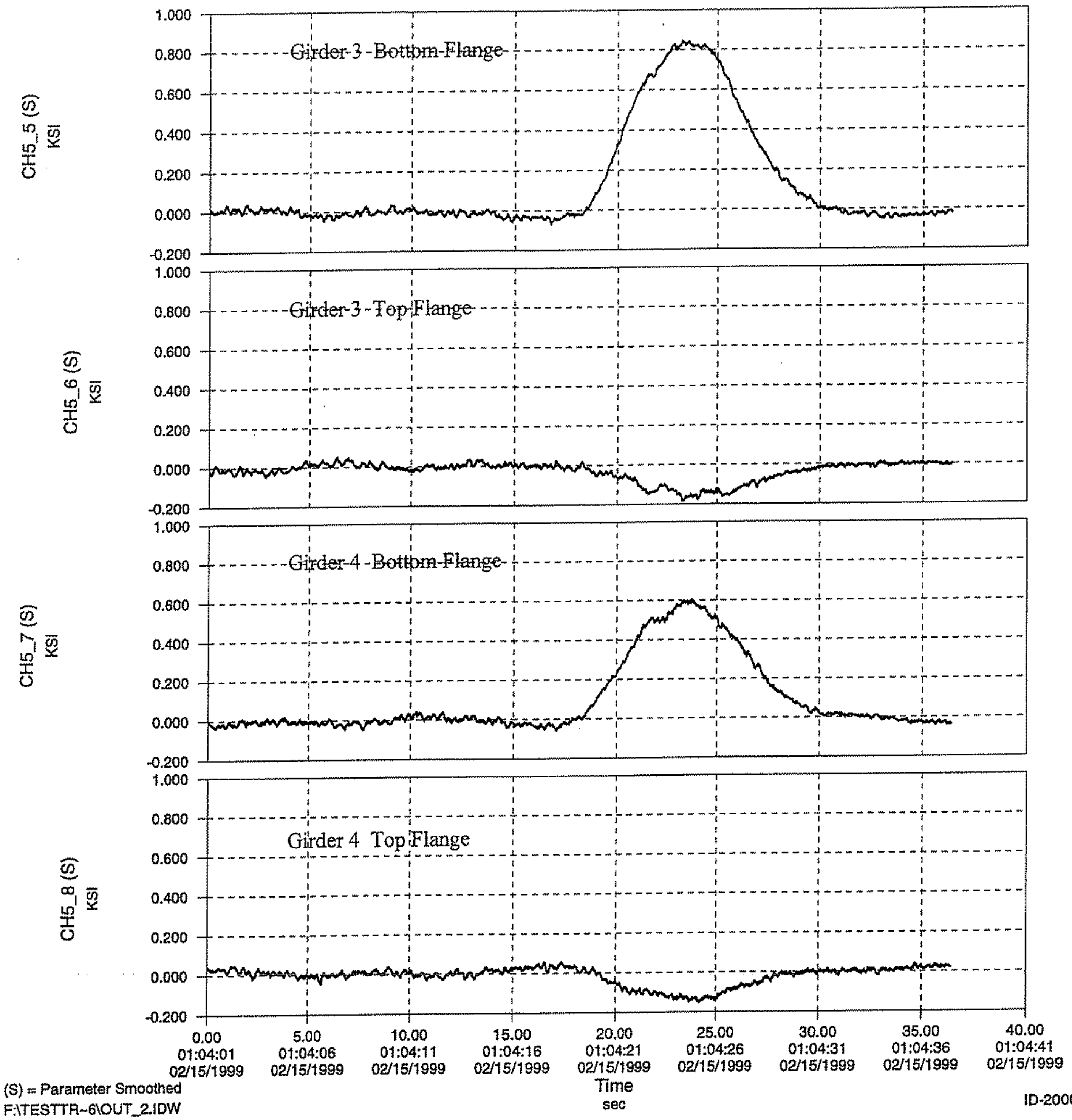
Test Vehicle at Span 5/Section b: Vehicle Inbound on Outbound Track @ Nominal 10 mph



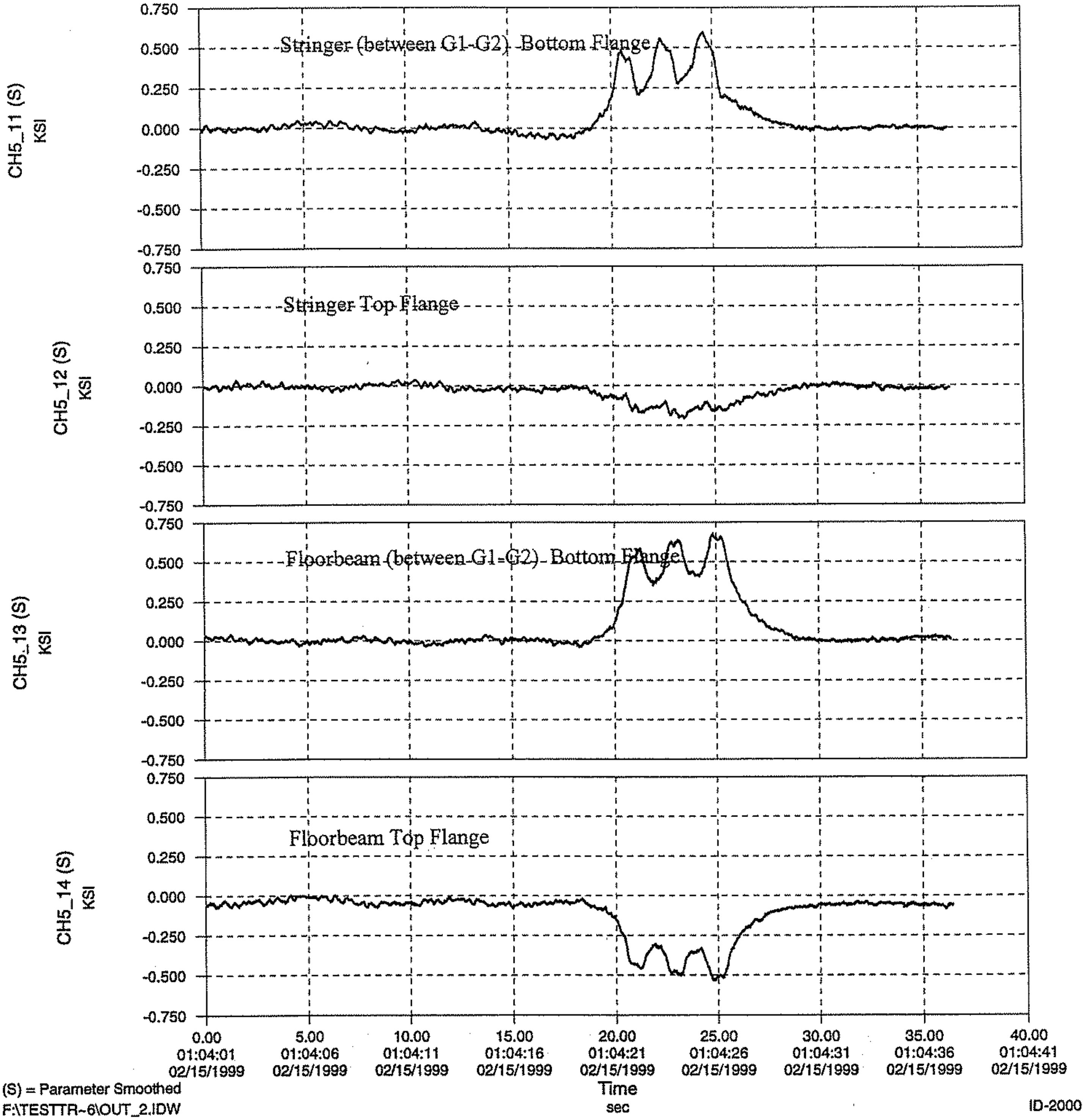
(S) = Parameter Smoothed
F:\TESTTR~6\OUT_2.IDW

ID-2000

Test Vehicle at Span 5/Section b: Vehicle Inbound on Outbound Track @ Nominal 10 mph

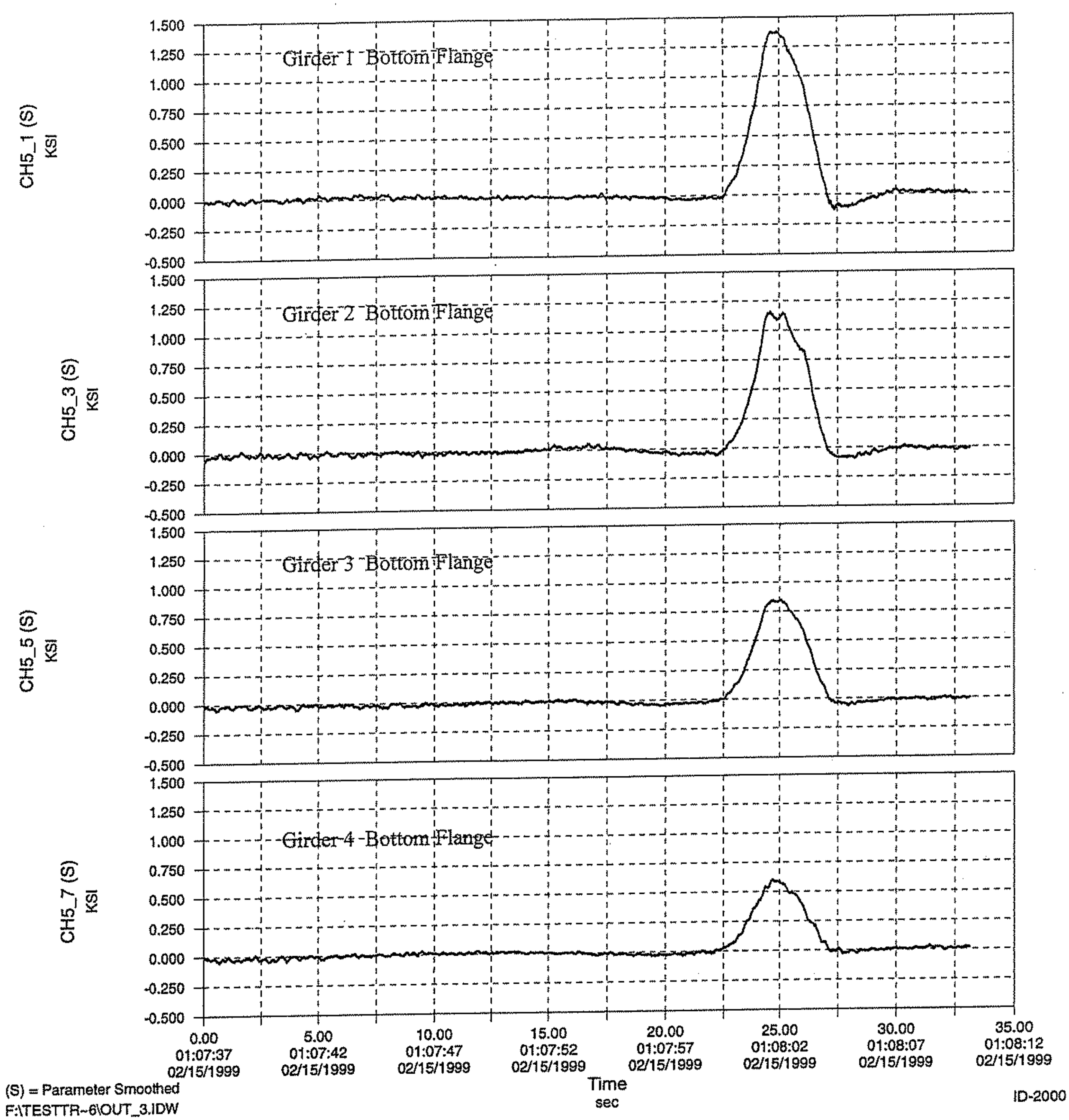


Test Vehicle at Span 5/Section b: Vehicle Inbound on Outbound Track @ Nominal 10 mph



Test Vehicle in Span 5: Vehicle Inbound on Outbound Track @ Nominal 10 mph

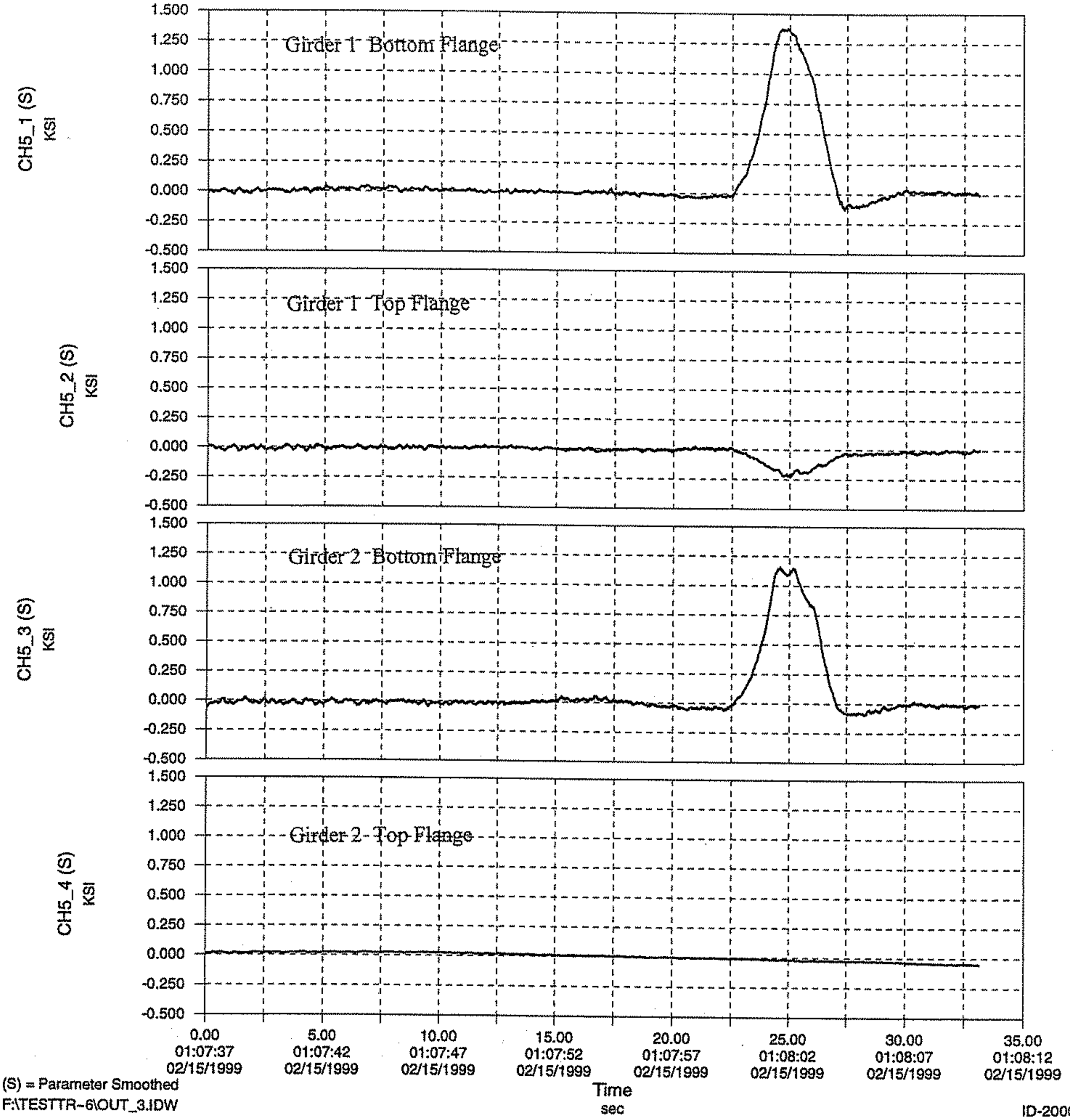
- **Top 2 records/Section b**
- **Bottom 2 records/Section bb**



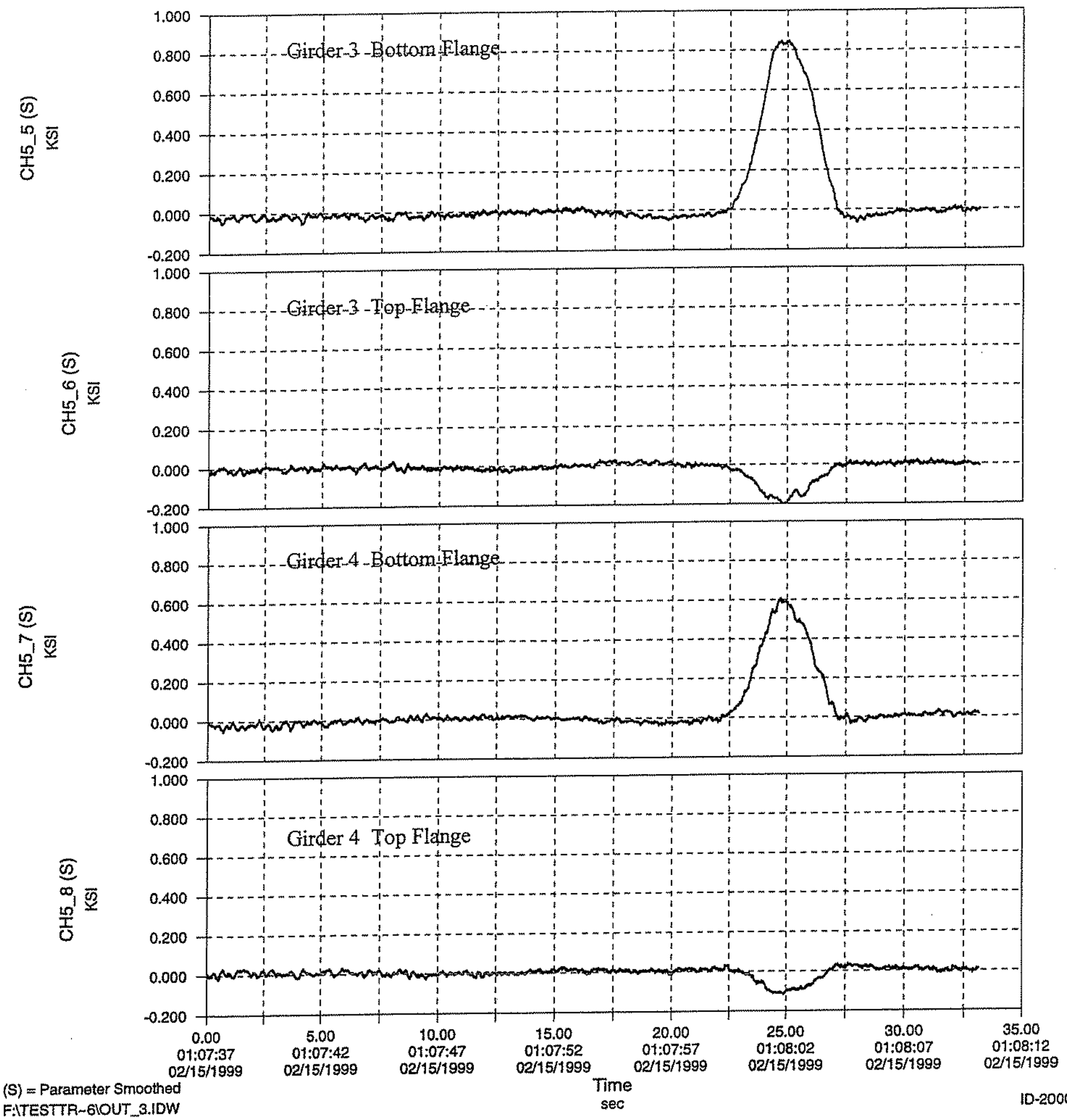
Test Vehicle at Span 5/Section b: Vehicle Outbound on Outbound Track @ Nominal 25 mph

ATLSS Engineering Research Center
March 24, 1999

Saw Mill Run Bridge



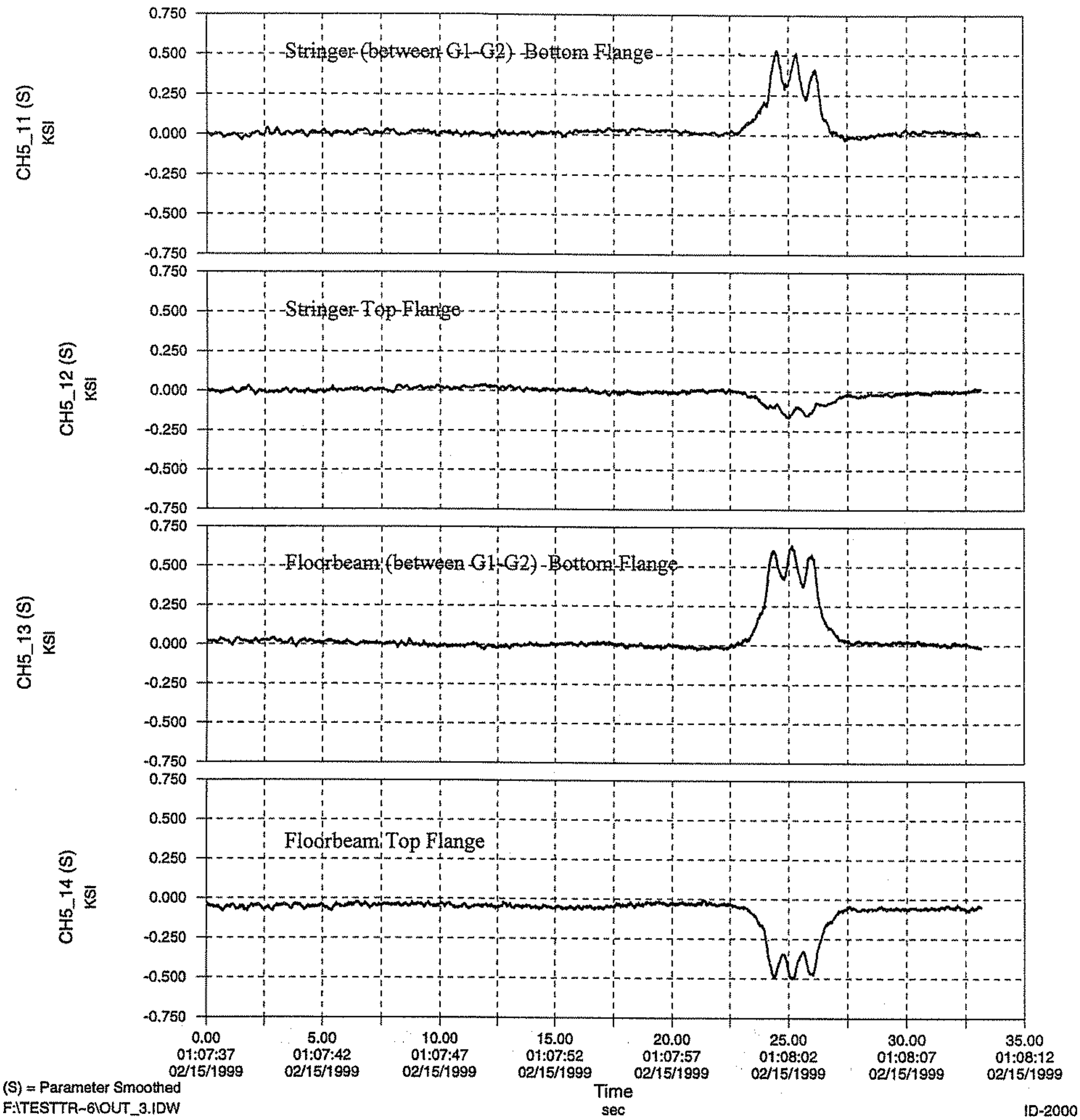
Test Vehicle at Span 5/Section b: Vehicle Outbound on Outbound Track @ Nominal 25 mph



Test Vehicle at Span 5/Section b: Vehicle Outbound on Outbound Track @ Nominal 25 mph

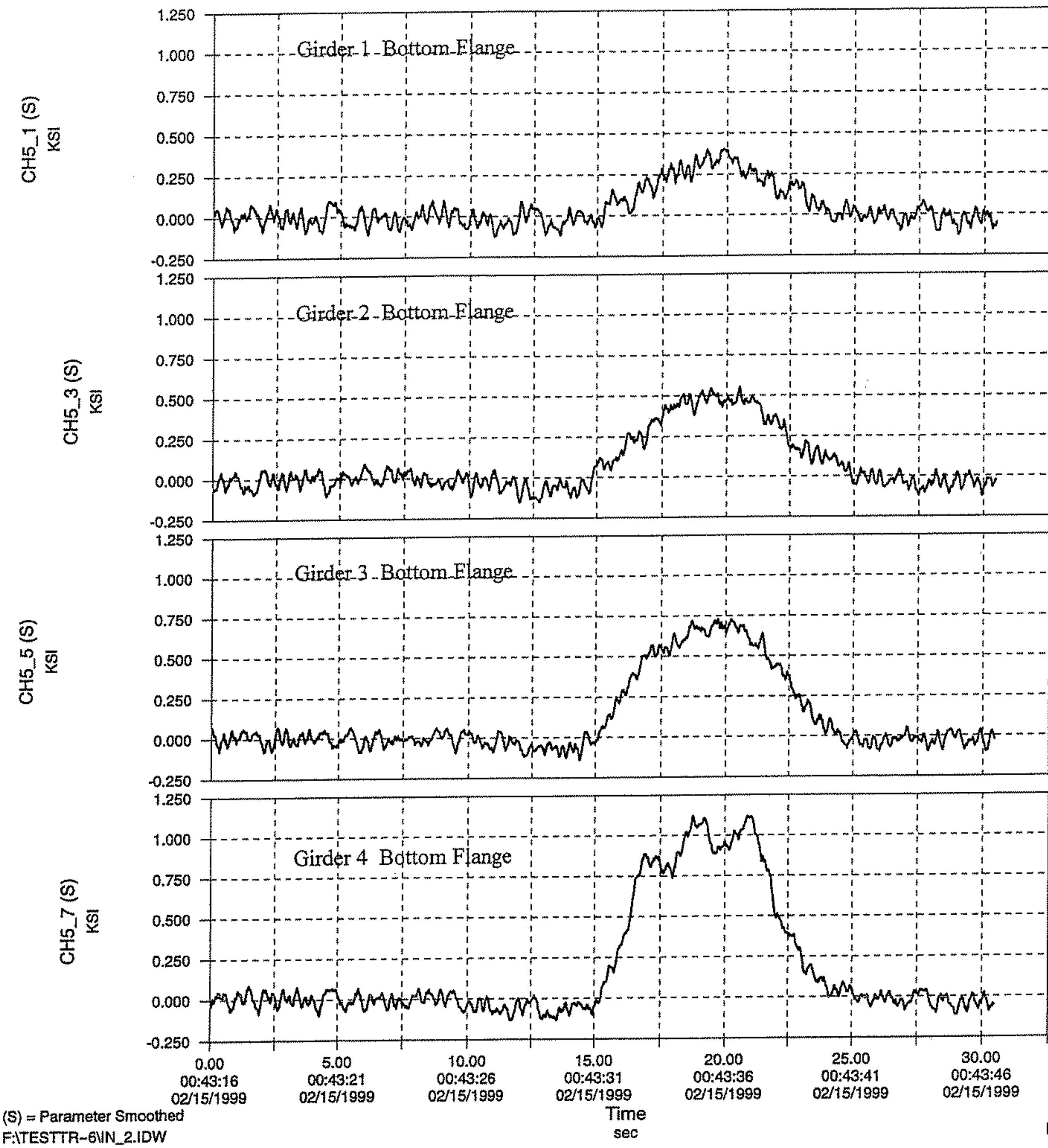
Saw Mill Run Bridge

ATLSS Engineering Research Center
March 24, 1999



Test Vehicle in Span 5: Vehicle Outbound on Outbound Track @ Nominal 25 mph

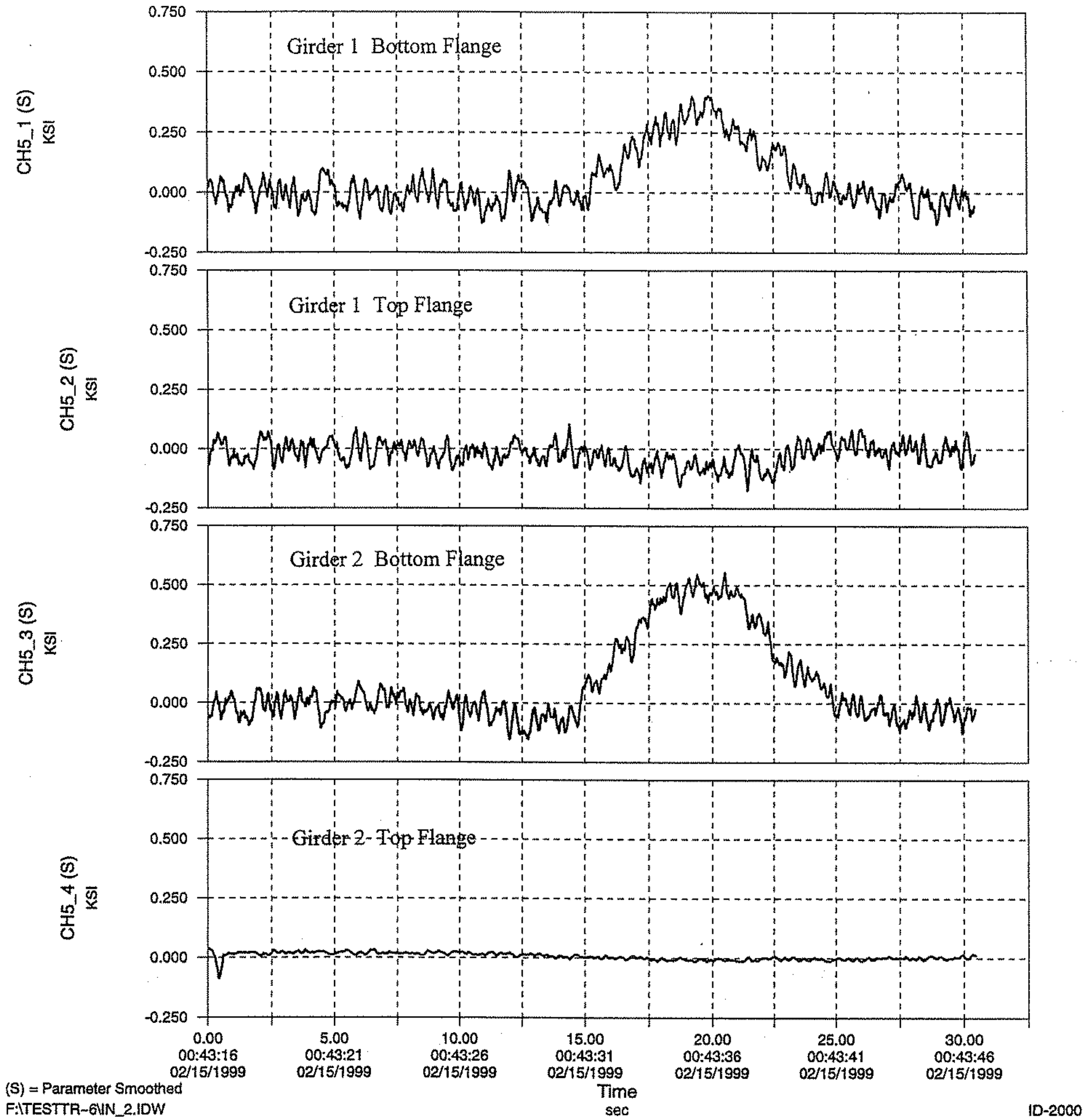
- **Top 2 records/Section b**
- **Bottom 2 records/Section bb**



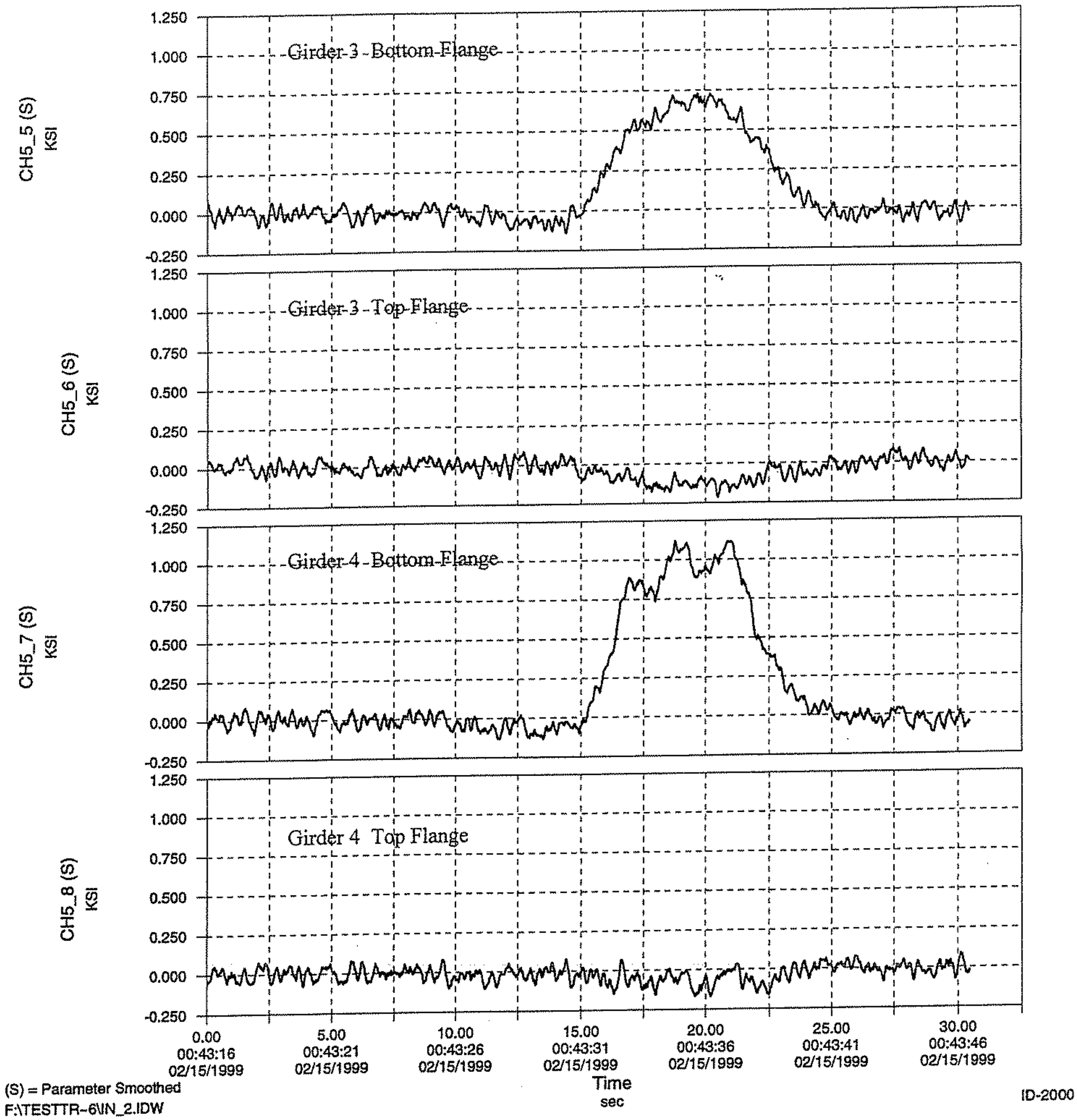
(S) = Parameter Smoothed
F:\TESTTR-6\IN_2.IDW

ID-200(

Test Vehicle at Span 5/Section b: Vehicle Inbound on Inbound Track @ Nominal 10 mph



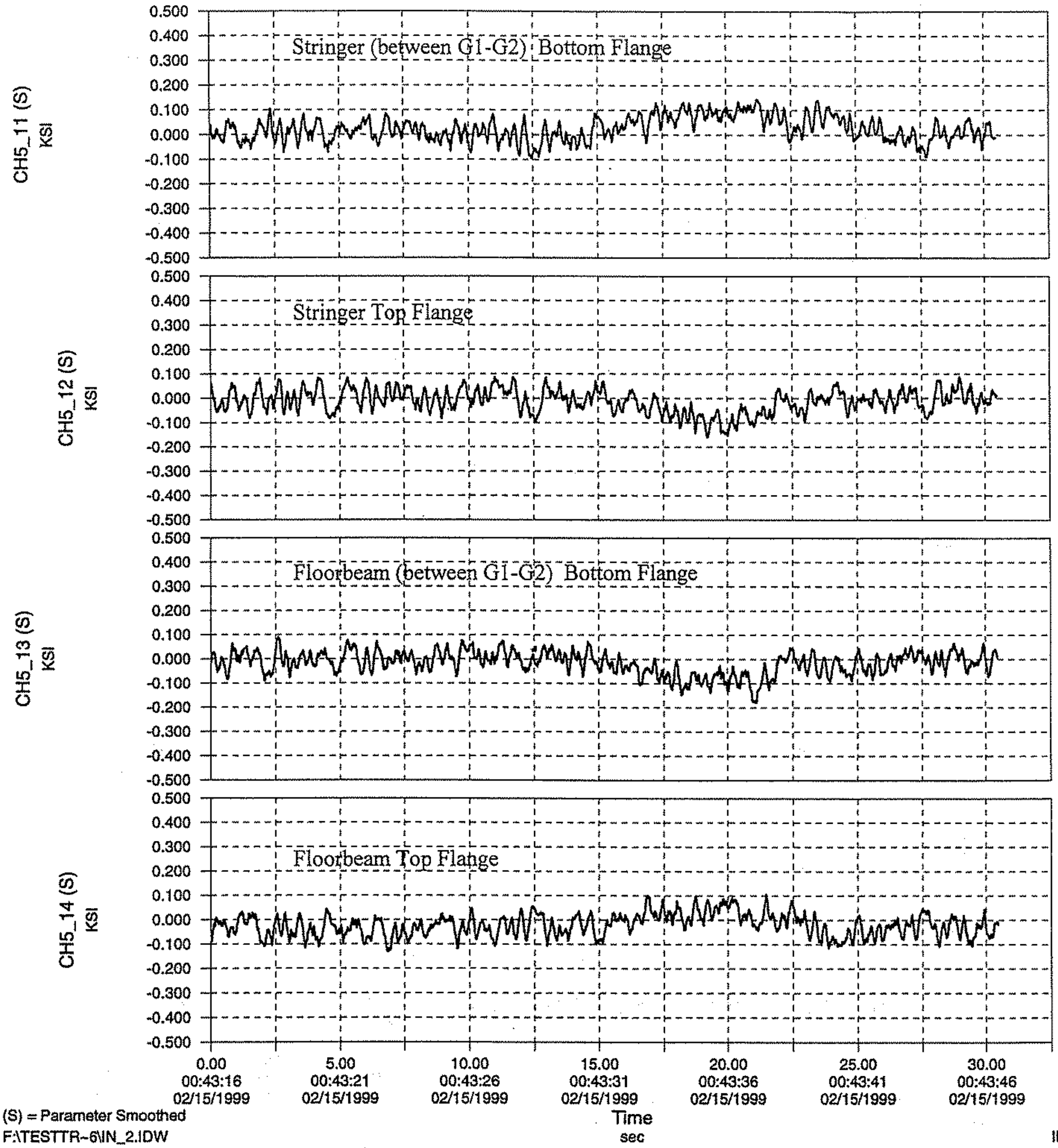
Test Vehicle at Span 5/Section b: Vehicle Inbound on Inbound Track @ Nominal 10 mph



Test Vehicle at Span 5/Section b: Vehicle Inbound on Inbound Track @ Nominal 10 mph

Saw Mill Run Bridge

ATLSS Engineering Research Center
March 24, 1999



(S) = Parameter Smoothed
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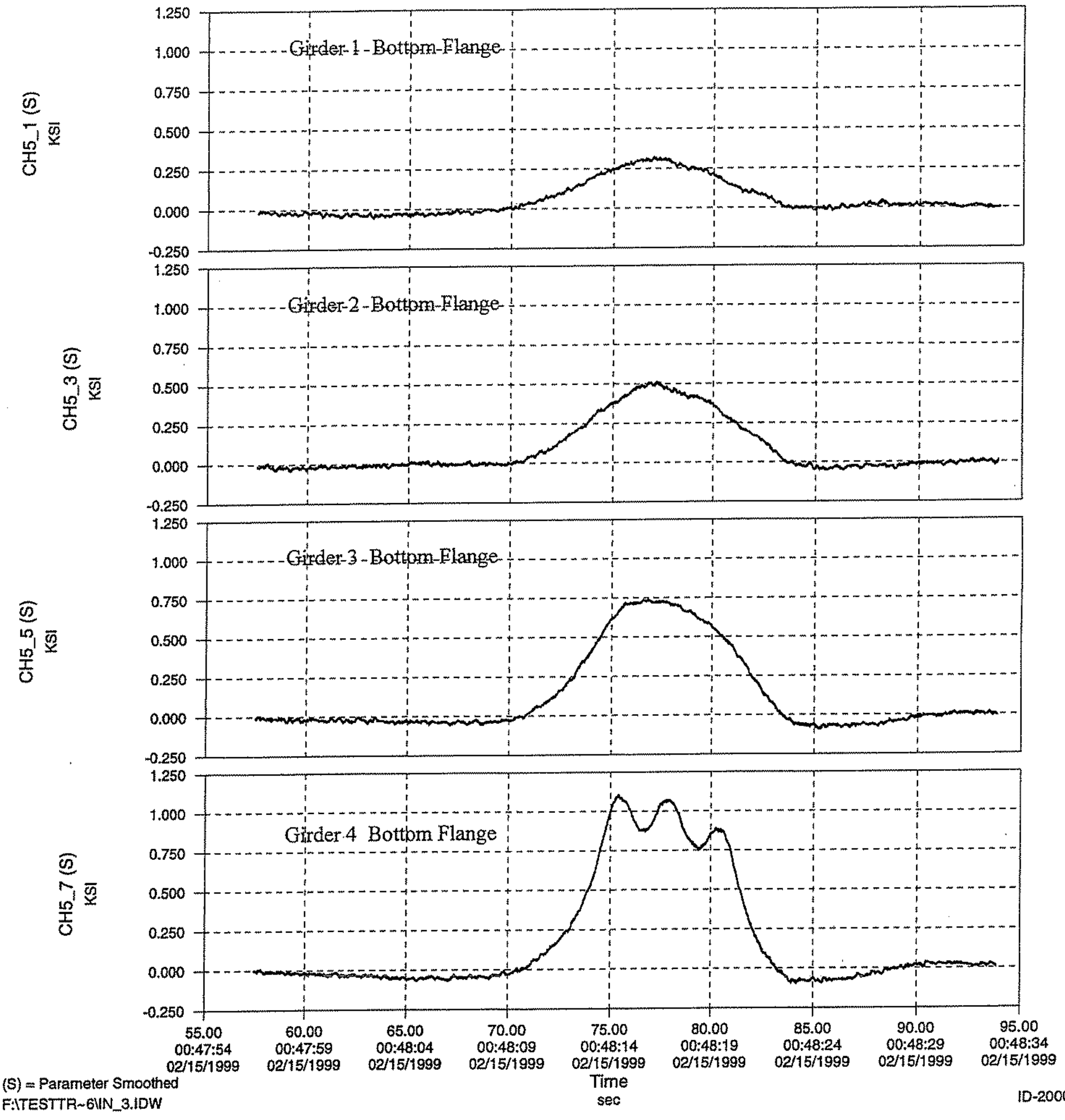
ID-2000

Test Vehicle in Span 5: Vehicle Inbound on Inbound Track @ Nominal 10 mph

- **Top 2 records/Section b**
- **Bottom 2 records/Section bb**



(S) = Parameter Smoothed
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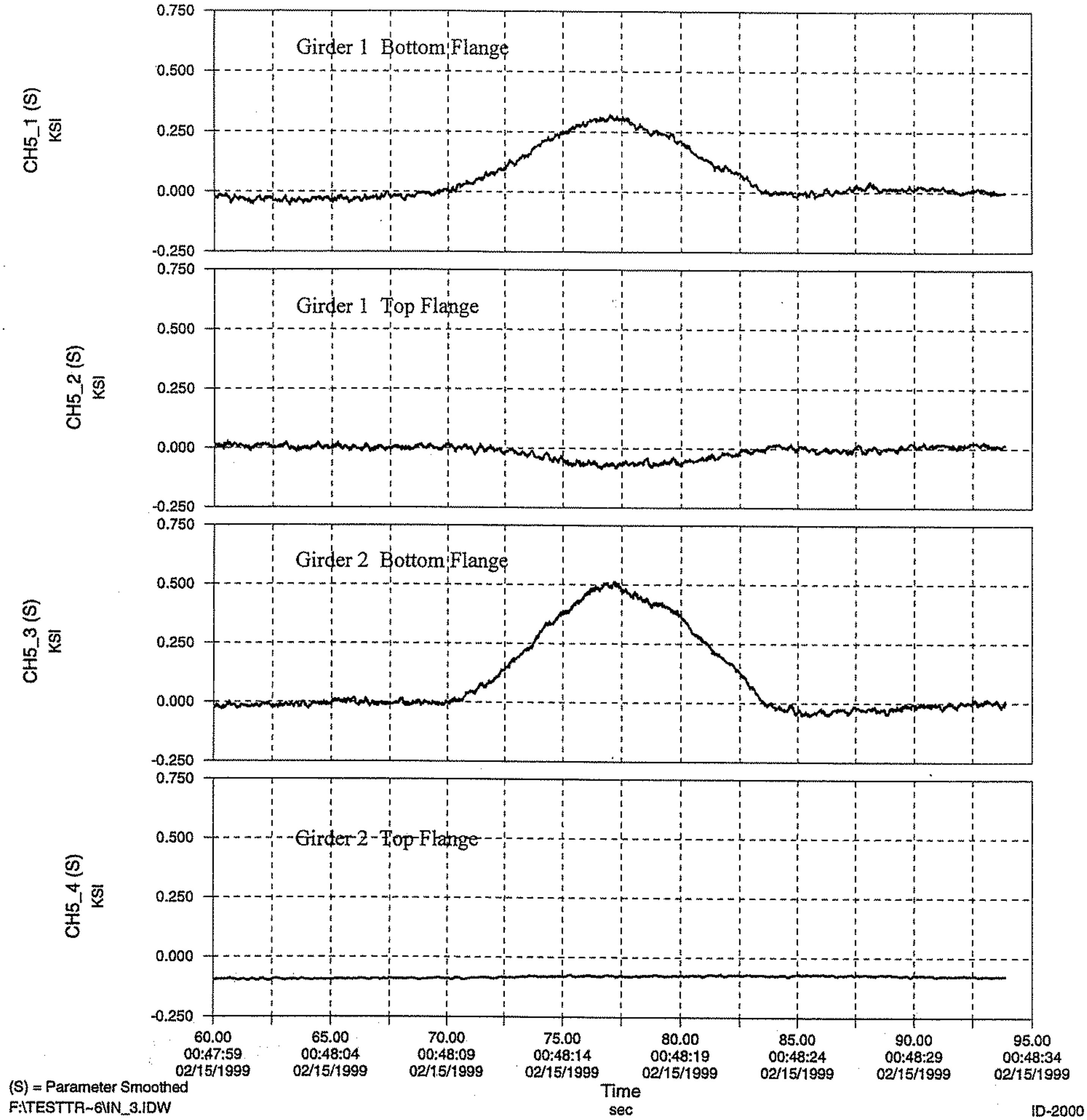
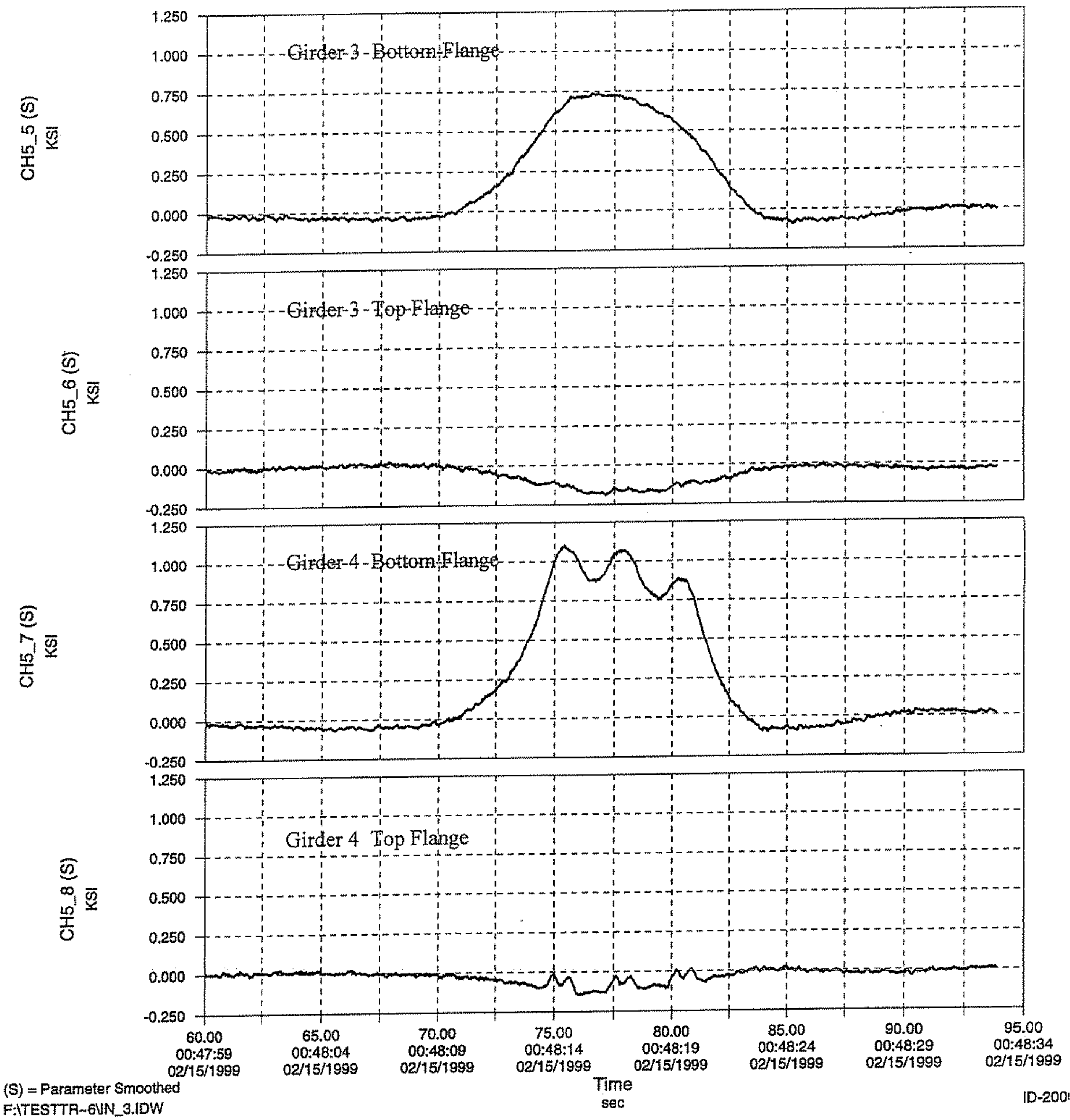
ID-2000

Test Vehicle at Span 5/Section b: Vehicle Outbound on Inbound Track @ Nominal 10 mph



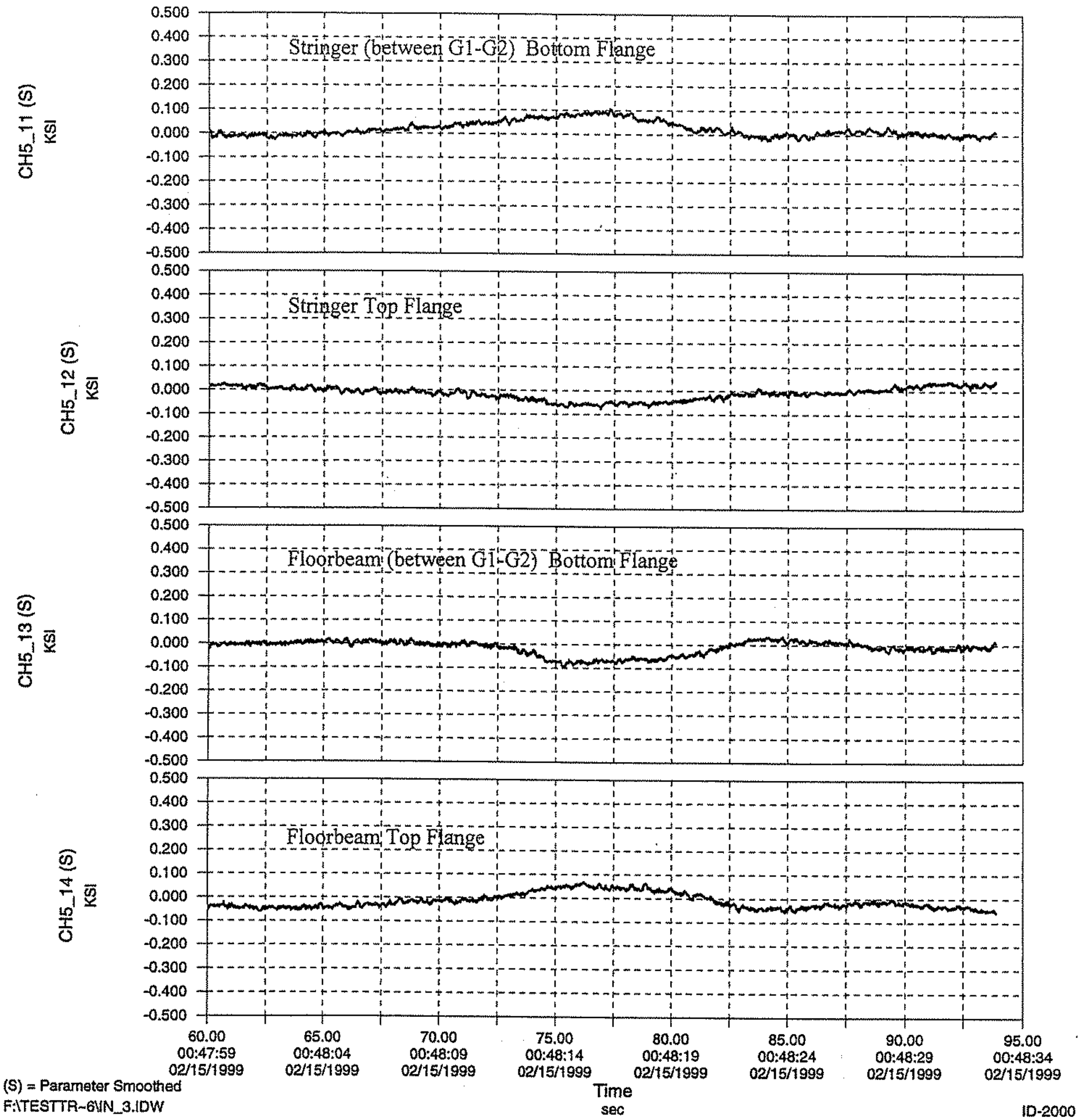
Test Vehicle at Span 5/Section b: Vehicle Outbound on Inbound Track @ Nominal 10 mph



Test Vehicle at Span 5/Section b: Vehicle Outbound on Inbound Track @ Nominal 10 mph

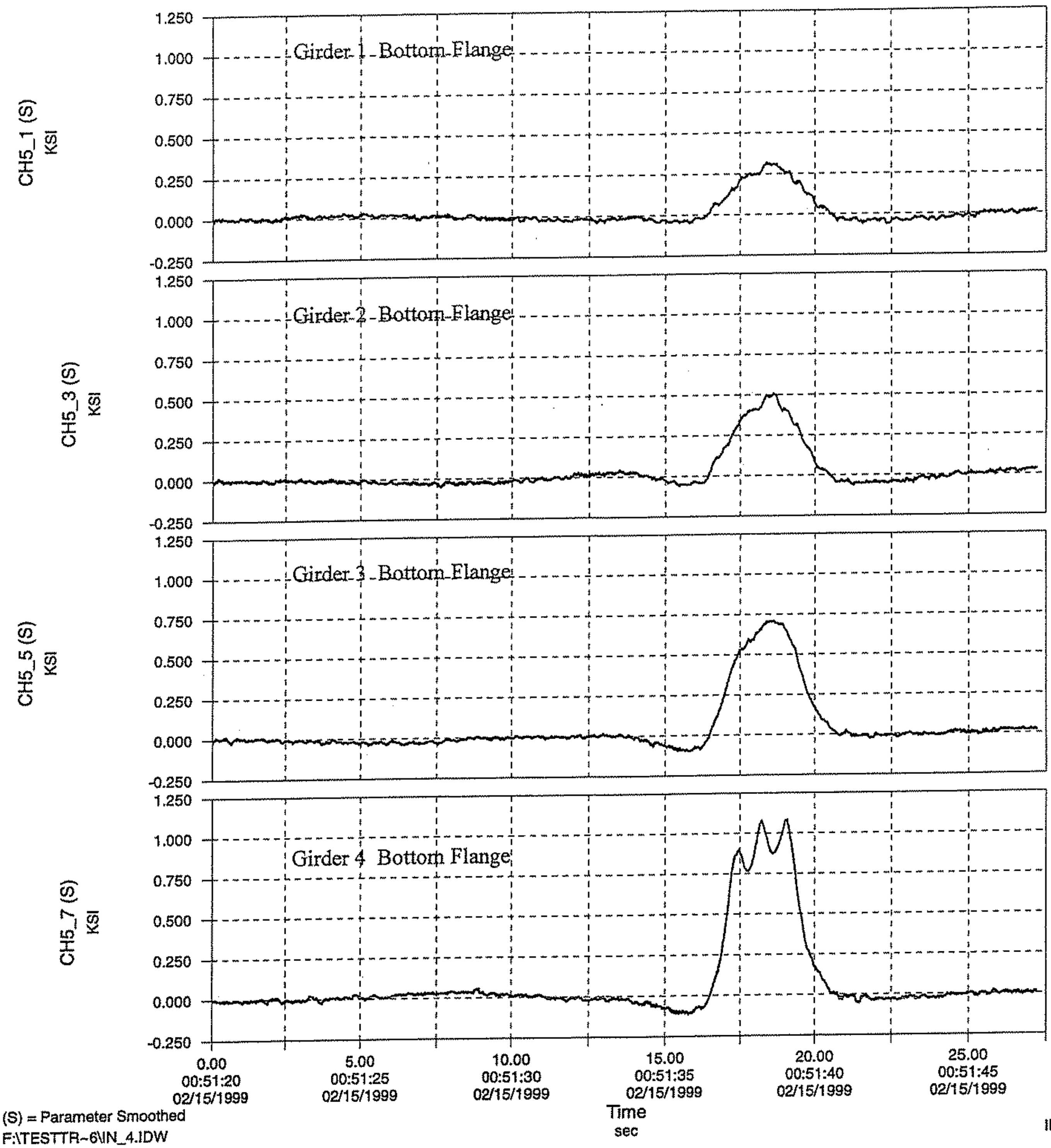
Saw Mill Run Bridge

ATLSS Engineering Research Center
March 24, 1999



Test Vehicle in Span 5: Vehicle Outbound on Inbound Track @ Nominal 10 mph

- **Top 2 records/Section b**
- **Bottom 2 records/Section bb**



(S) = Parameter Smoothed
F:\TESTTR~6\IN_4.IDW

ID-200C

Test Vehicle at Span 5/Section b: Vehicle Inbound on Inbound Track @ Nominal 25 mph

ATLSS Engineering Research Center
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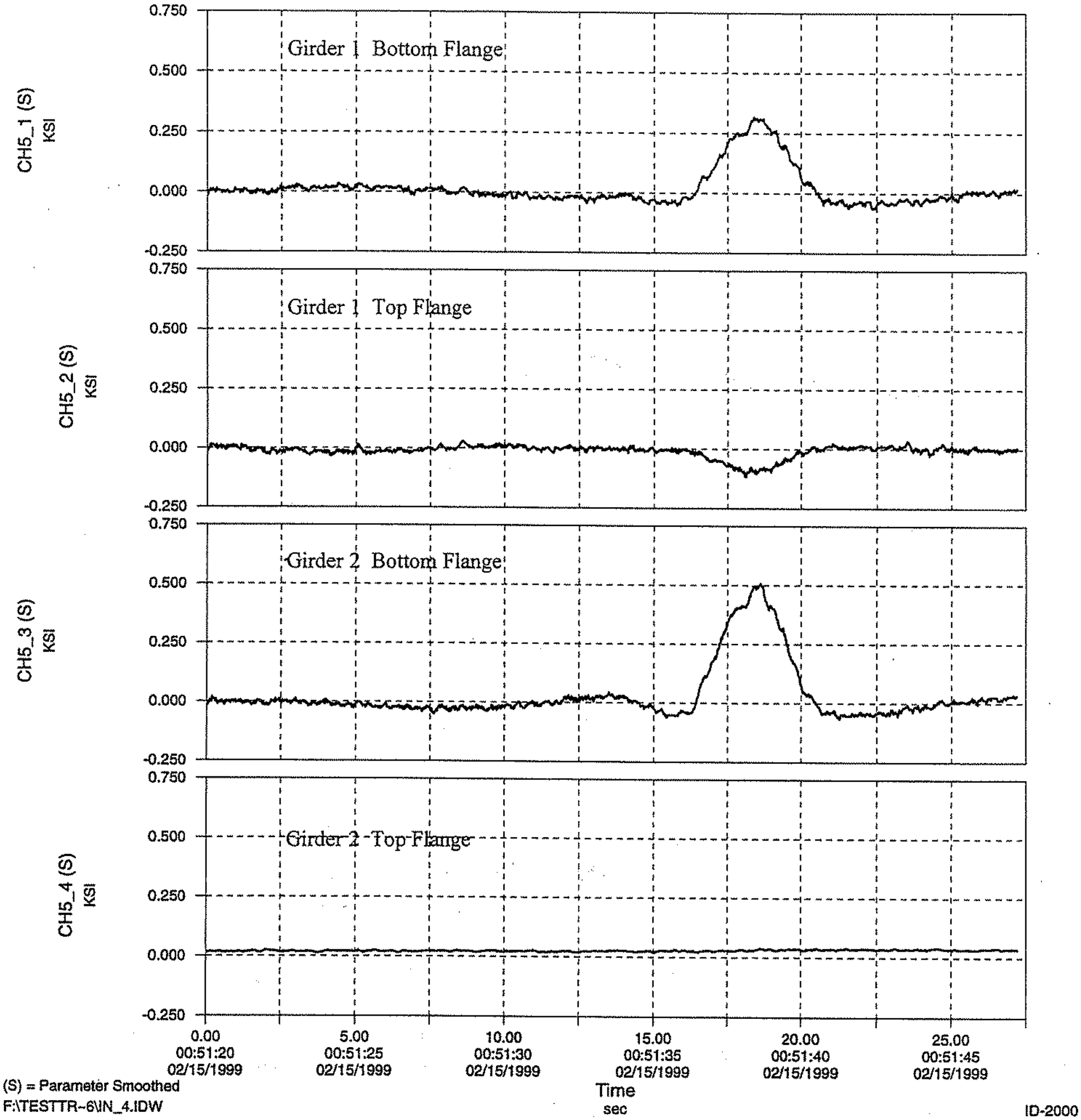
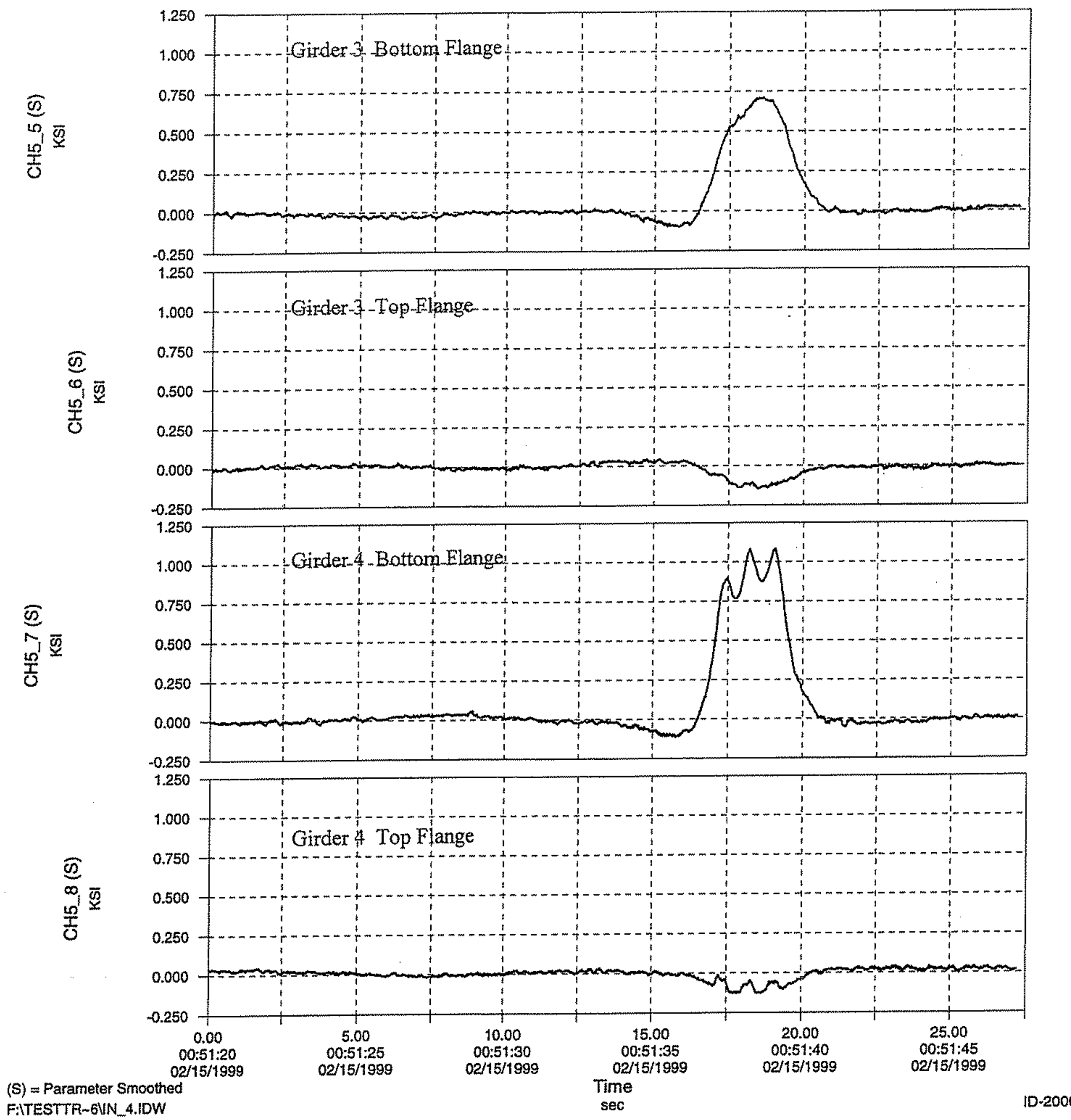
Saw Mill Run Bridge



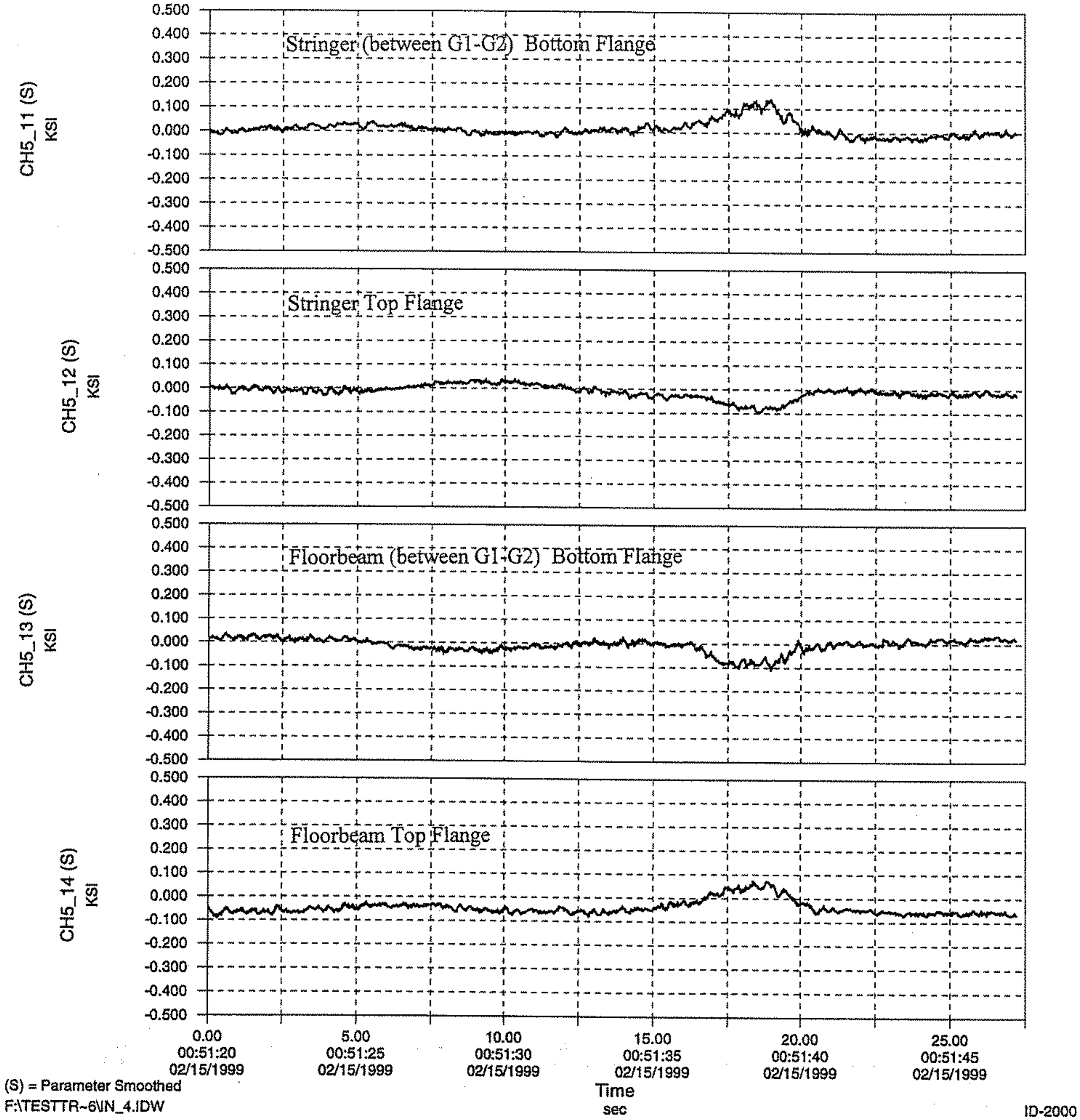
Test Vehicle at Span 5/Section b: Vehicle Inbound on Inbound Track @ Nominal 25 mph



Test Vehicle at Span 5/Section b: Vehicle Inbound on Inbound Track @ Nominal 25 mph

ATLSS Engineering Research Center
March 24, 1999

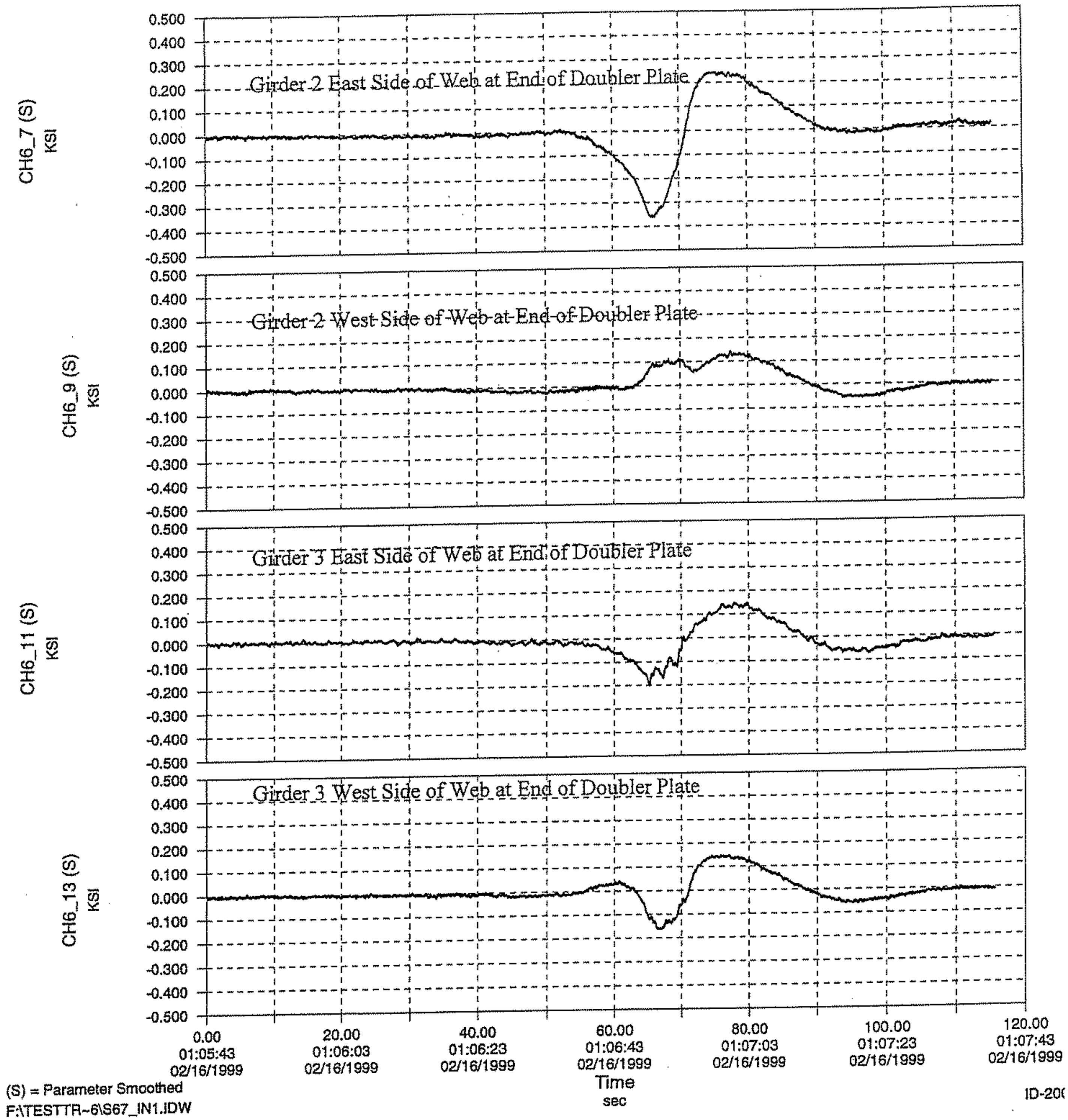
Saw Mill Run Bridge



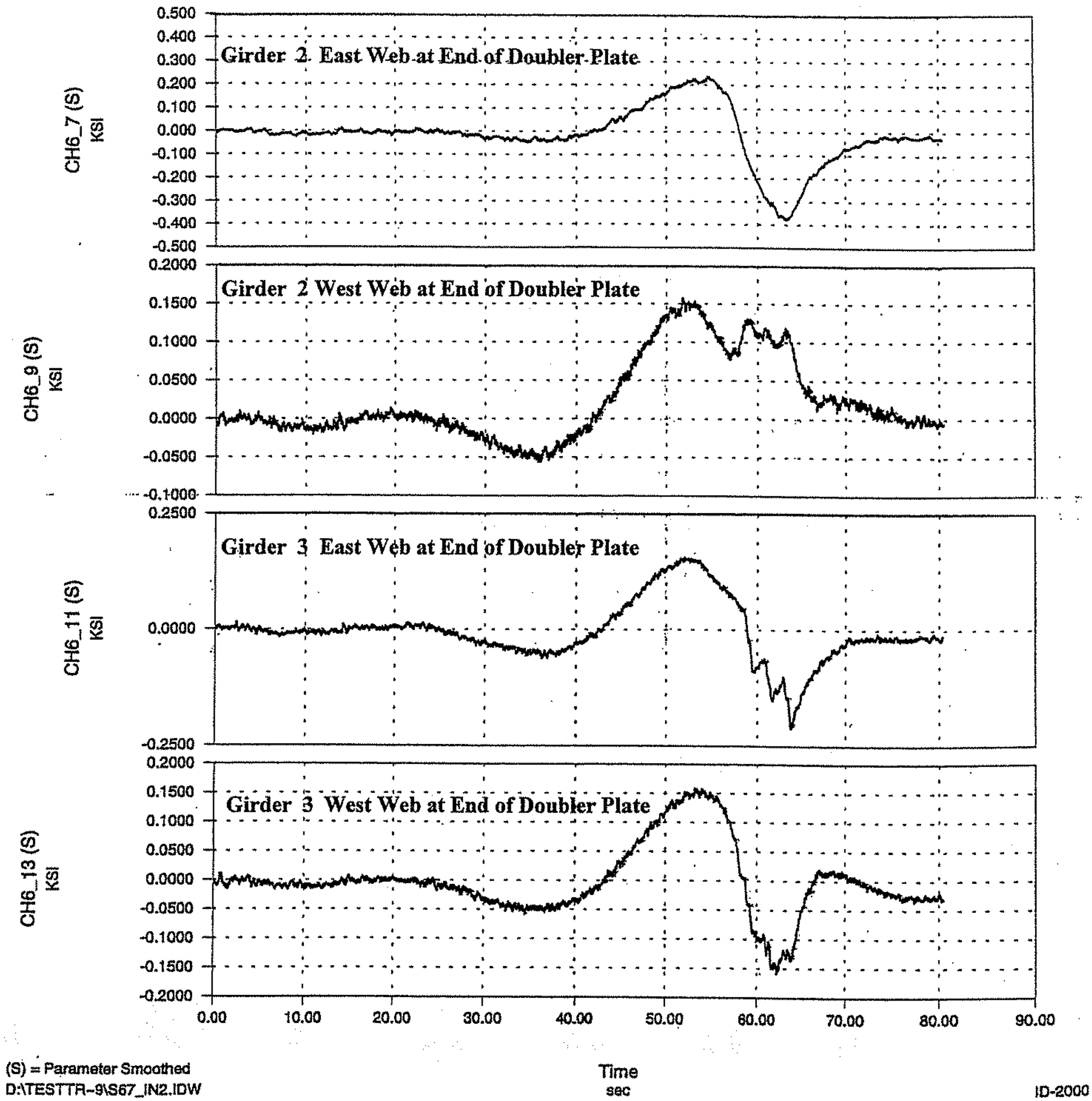
Test Vehicle in Span 5: Vehicle Inbound on Inbound Track @ Nominal 25 mph

- **Top 2 records/Section b**
- **Bottom 2 records/Section bb**

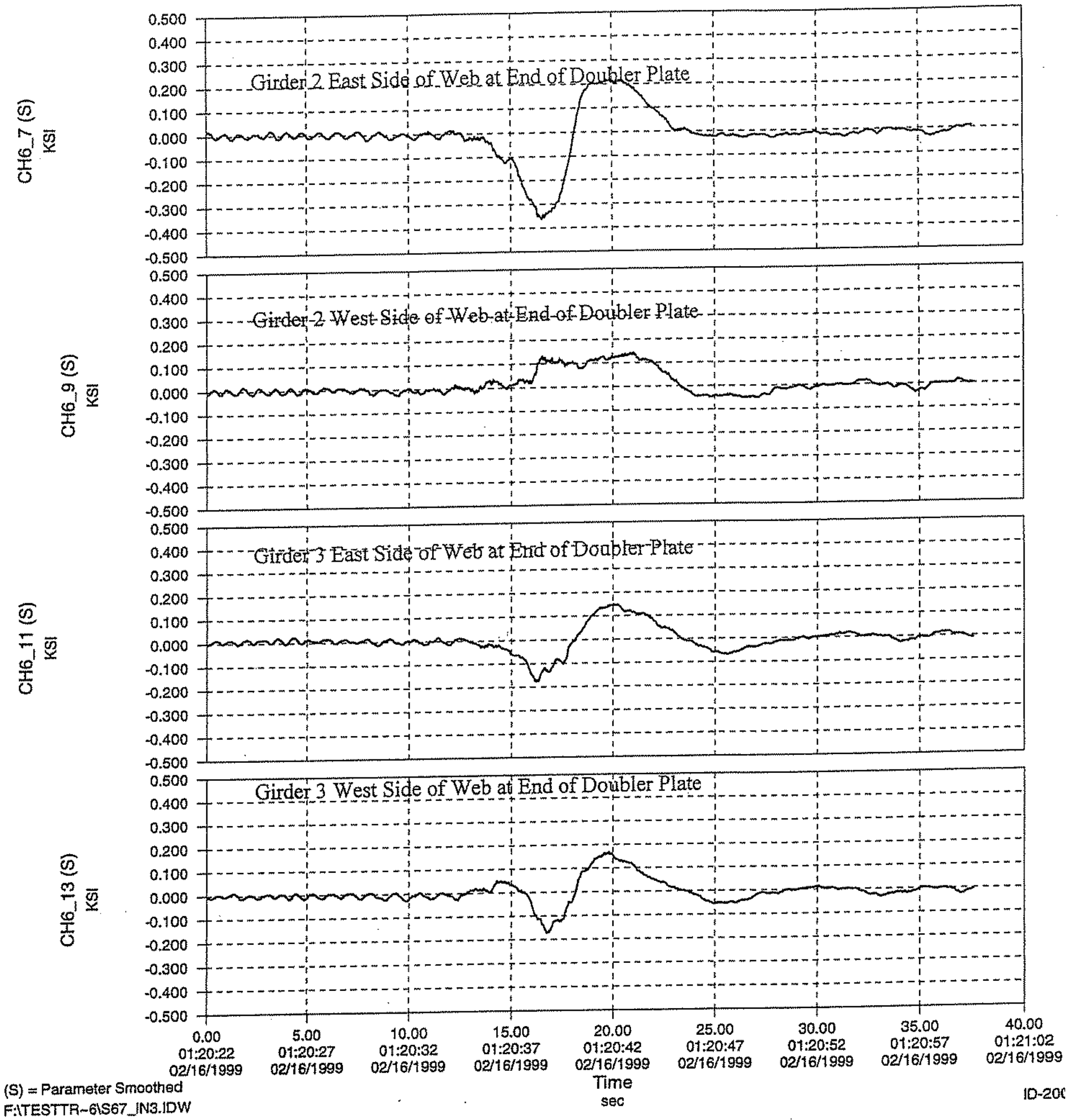
Strain Gage Records
Test Vehicle, Span 6



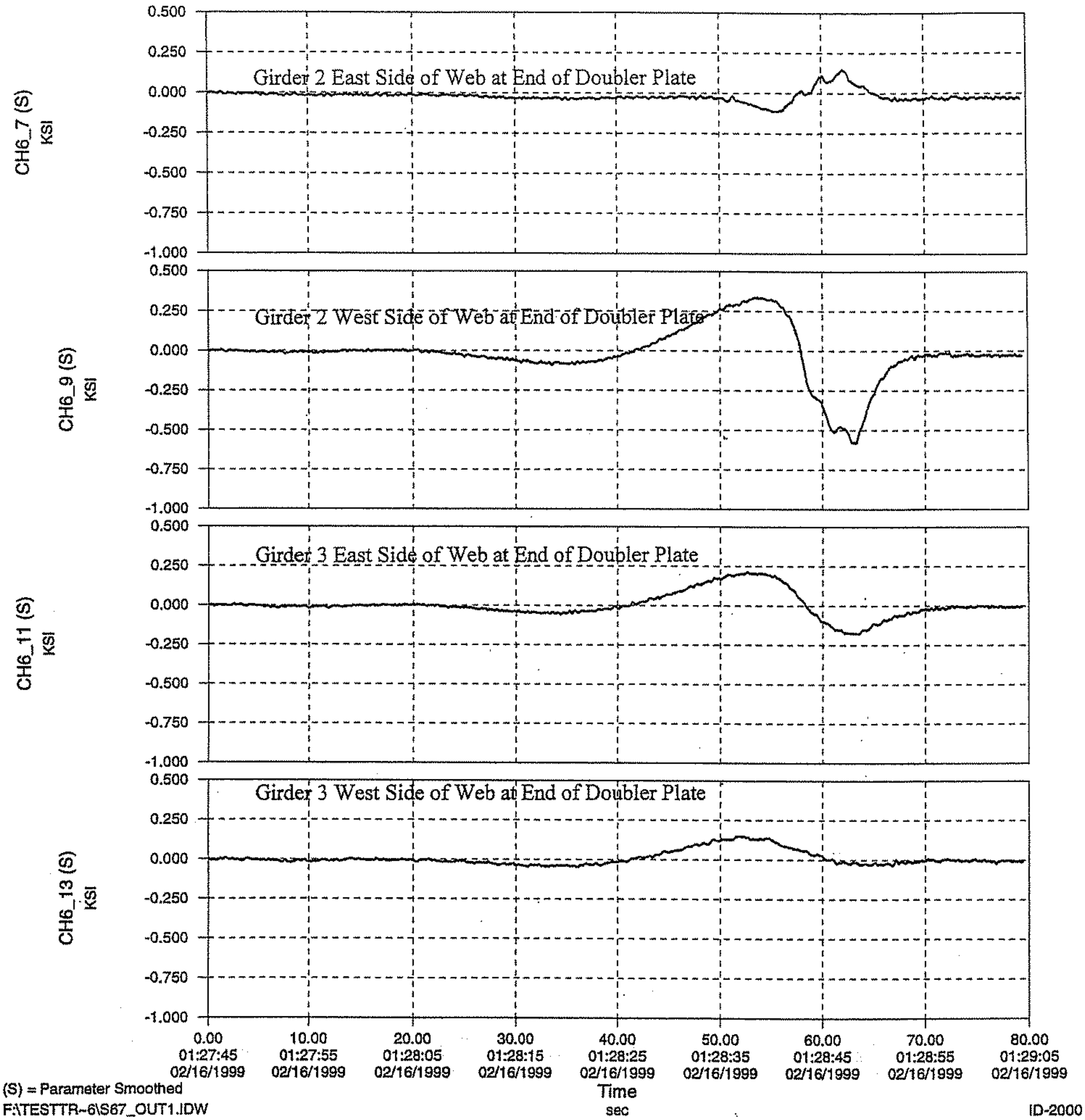
Test Vehicle at Span 6 / Section 3; Vehicle Inbound on Inbound Track @ Nominal 10 mph



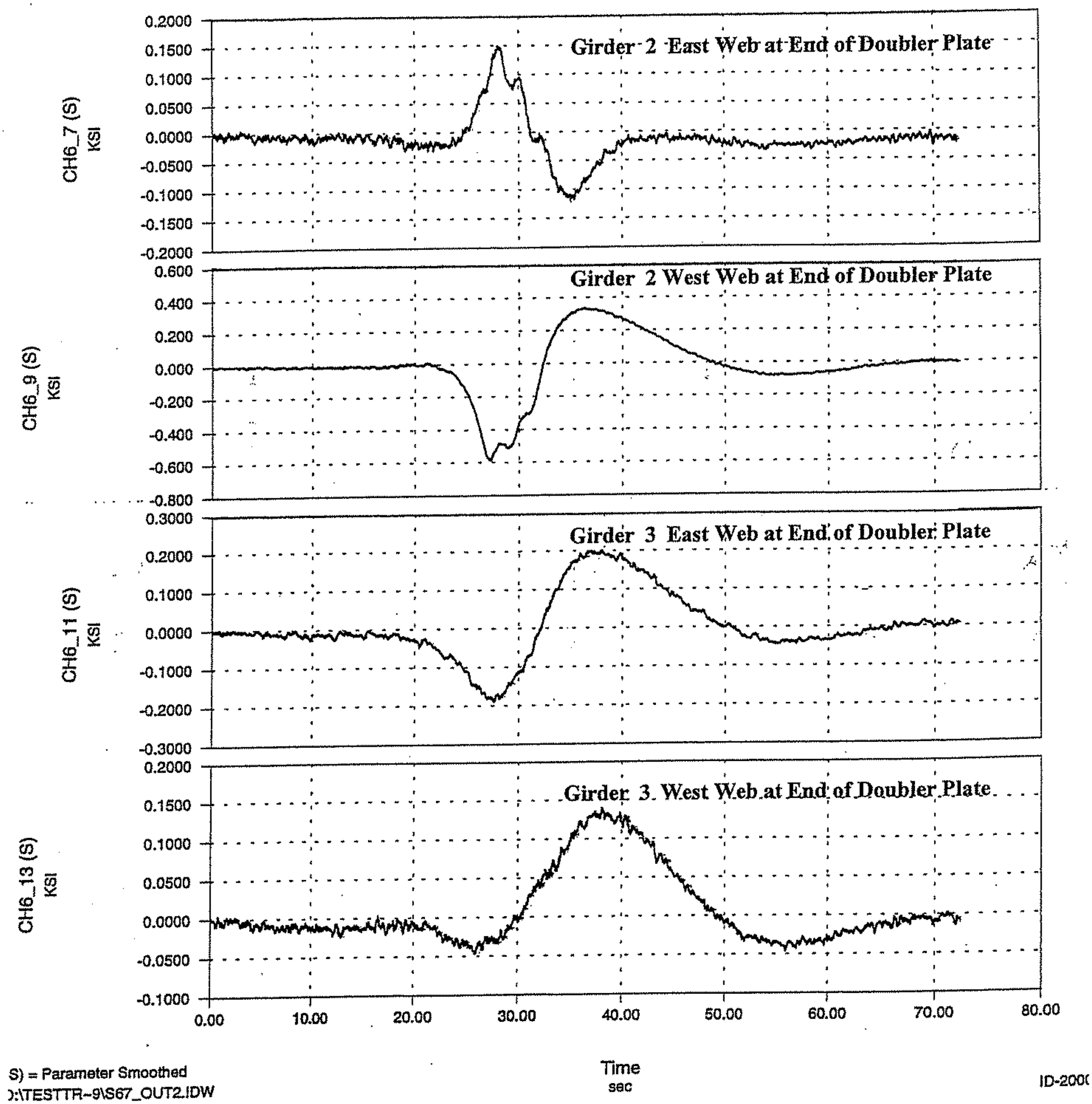
Test Vehicle at Span 6 / Section 3; Vehicle Outbound on Inbound Track @ Nominal 10 mph



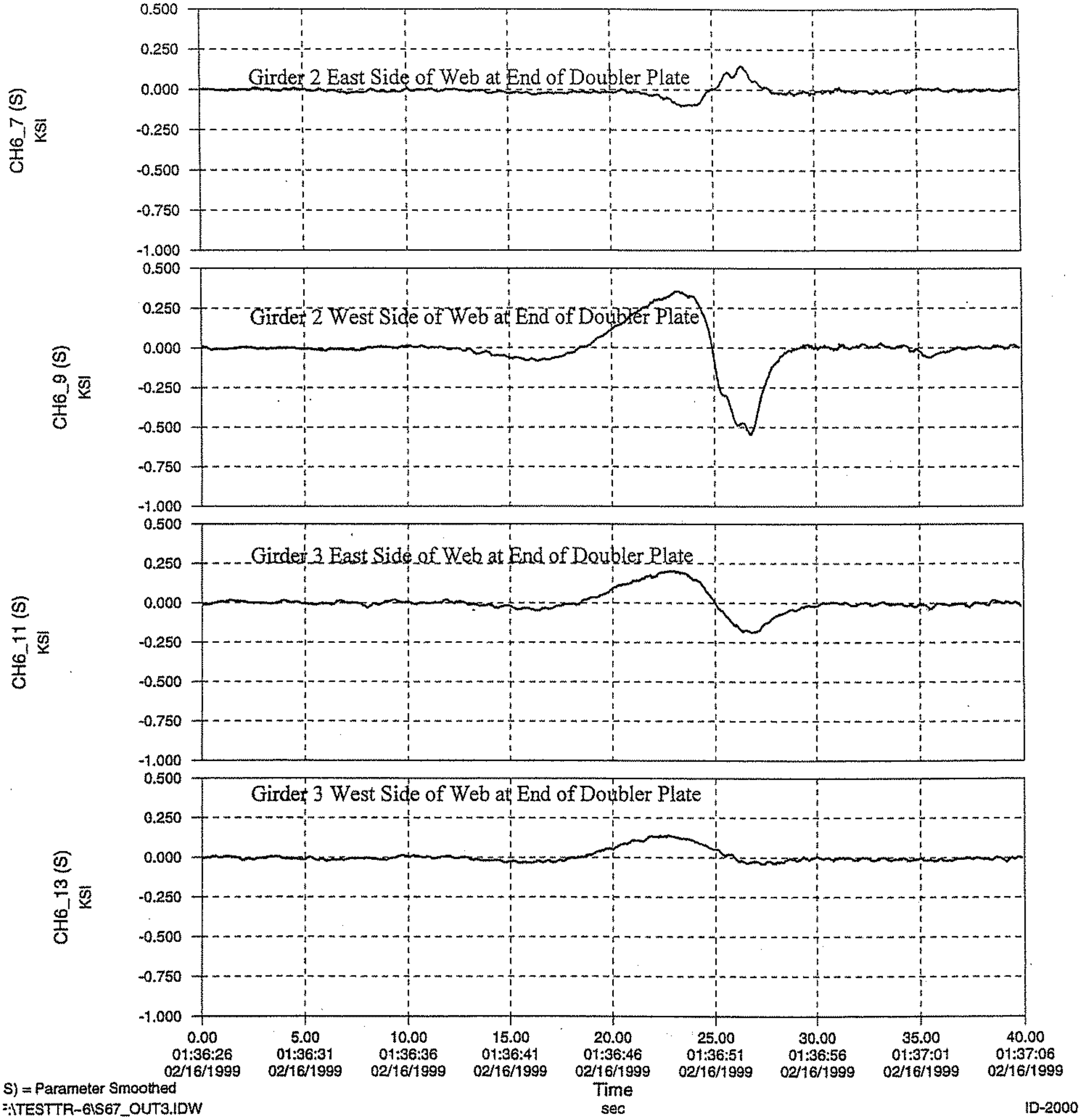
Test Vehicle at Span 6 / Section 3; Vehicle Inbound on Inbound Track @ Nominal 25 mph



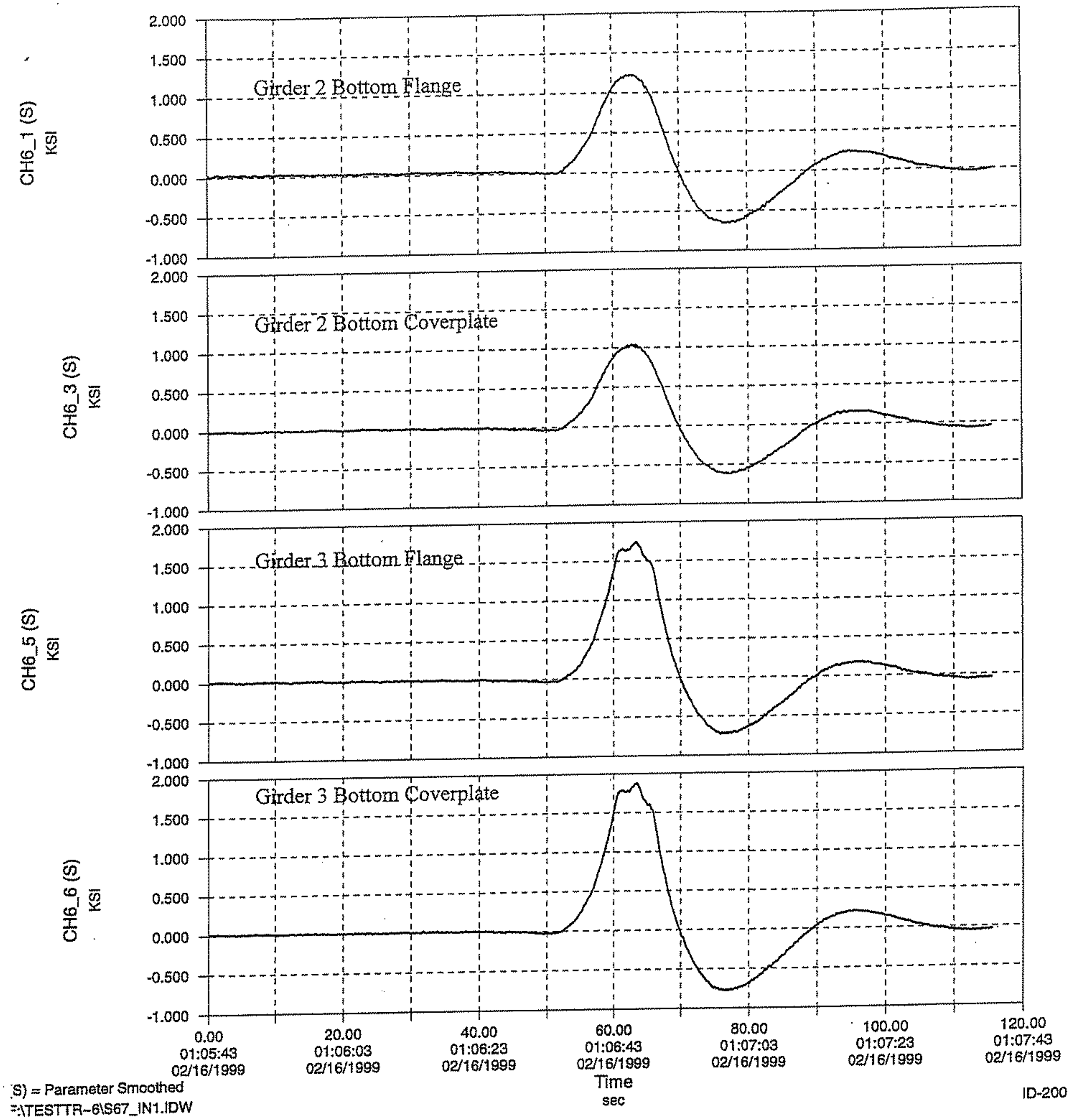
Test Vehicle at Span 6 / Section 3; Vehicle Outbound on Outbound Track @ Nominal 10 mph



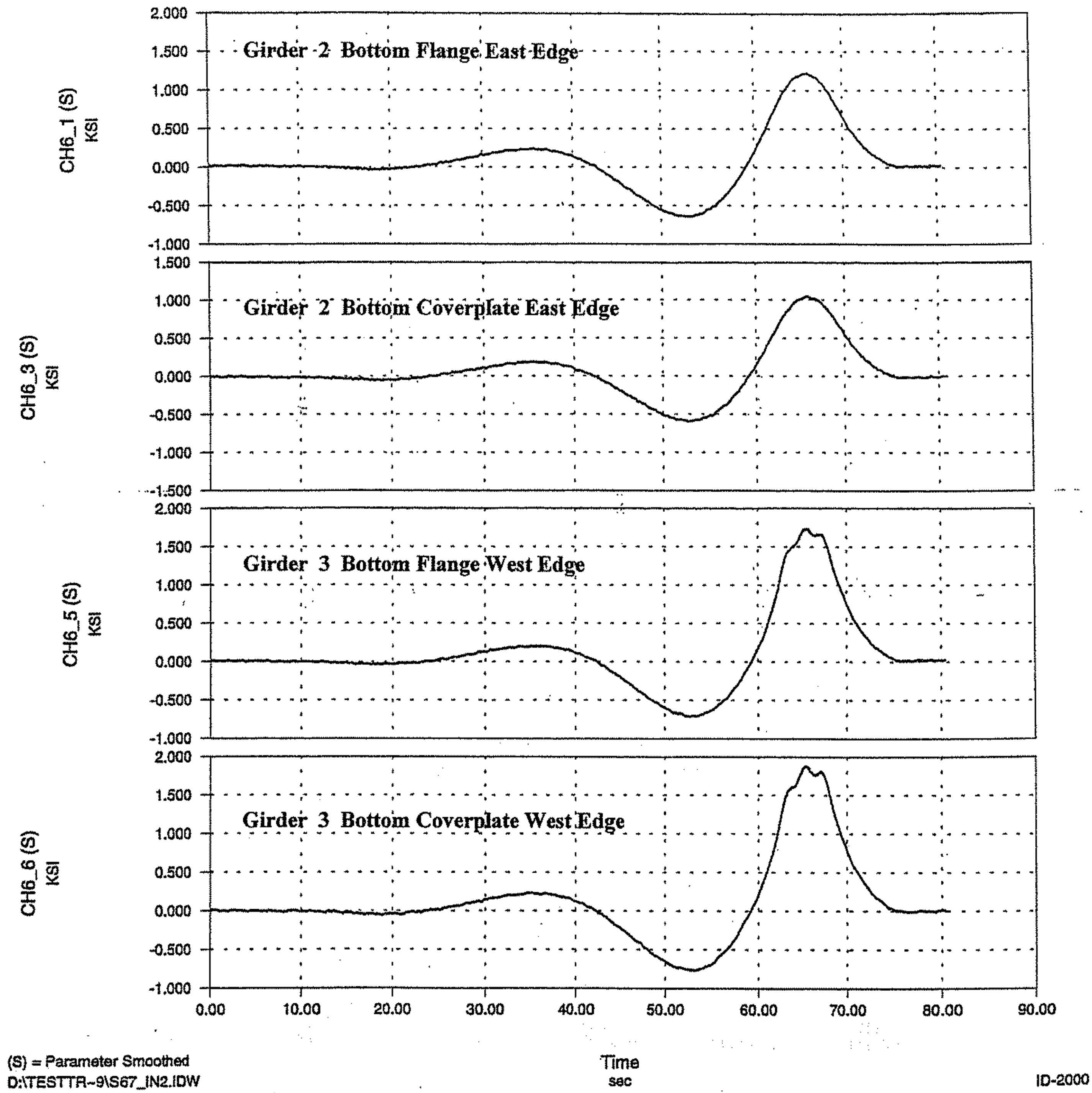
Test Vehicle at Span 6 / Section 3; Vehicle Inbound on Outbound Track @ Nominal 10 mph



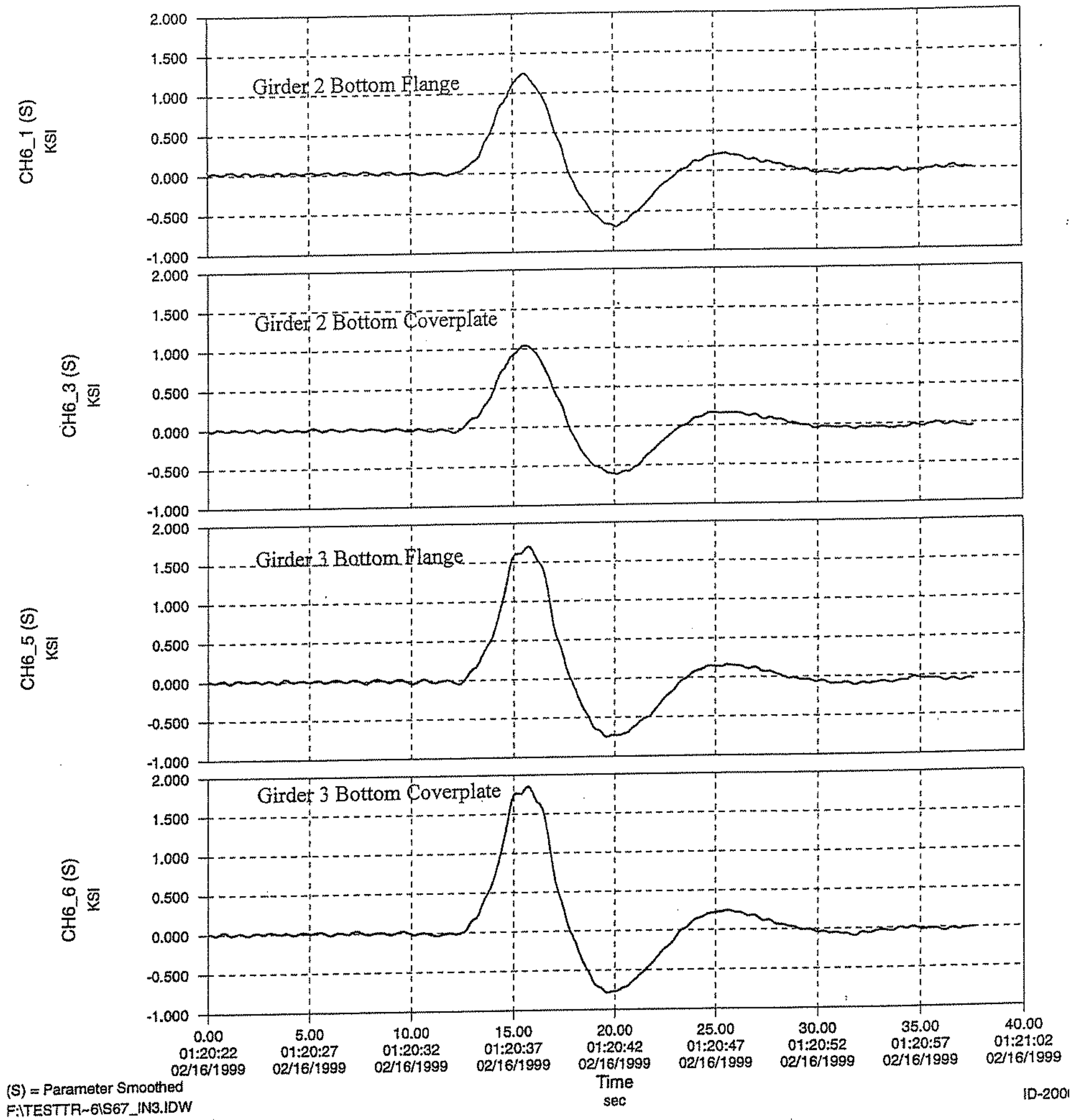
Test Vehicle at Span 6 / Section 3; Vehicle Outbound on Outbound Track @ Nominal 25 mph



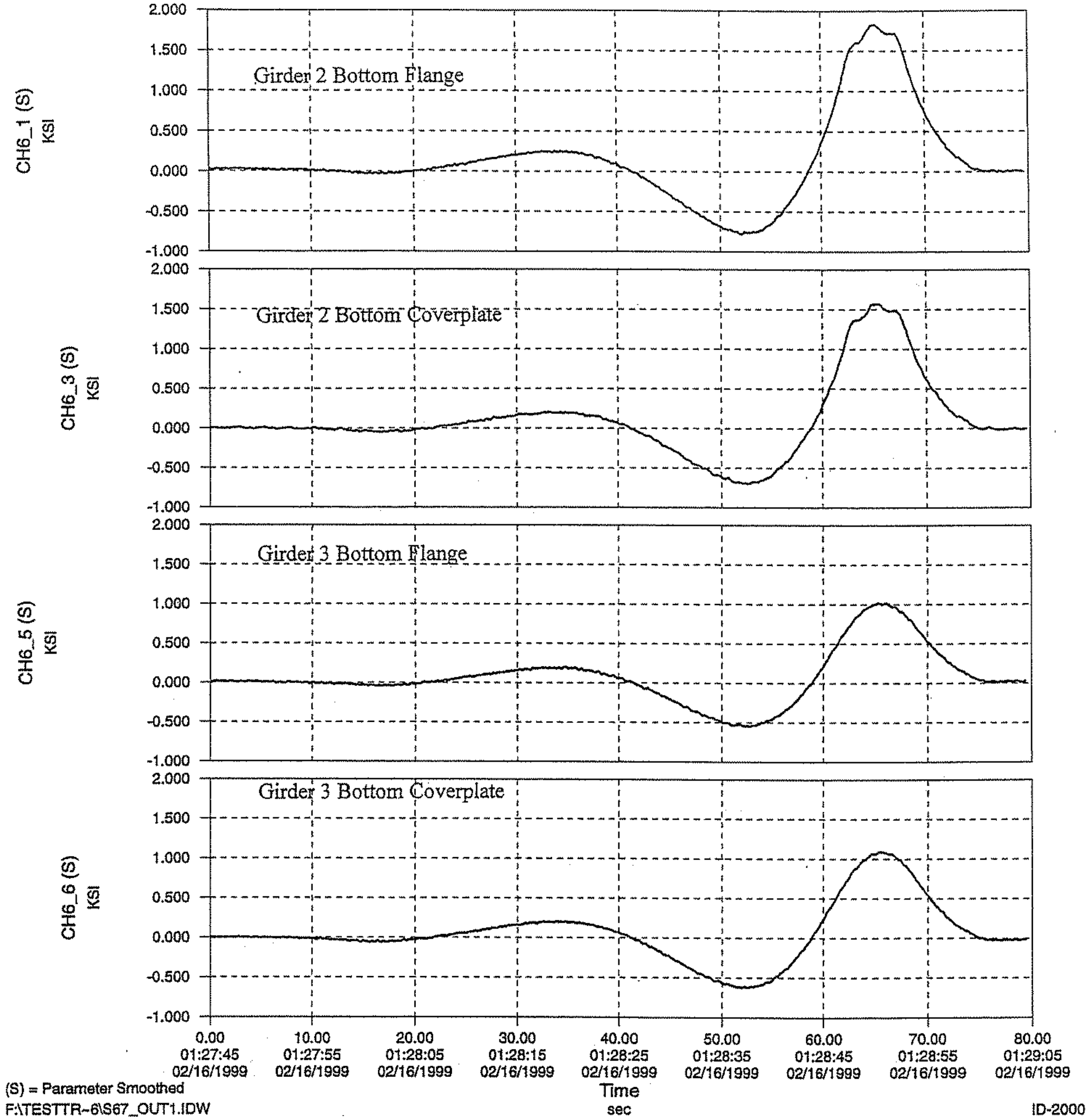
Test Vehicle at Span 6 / Section 4; Vehicle Inbound on Inbound Track @ Nominal 10 mph



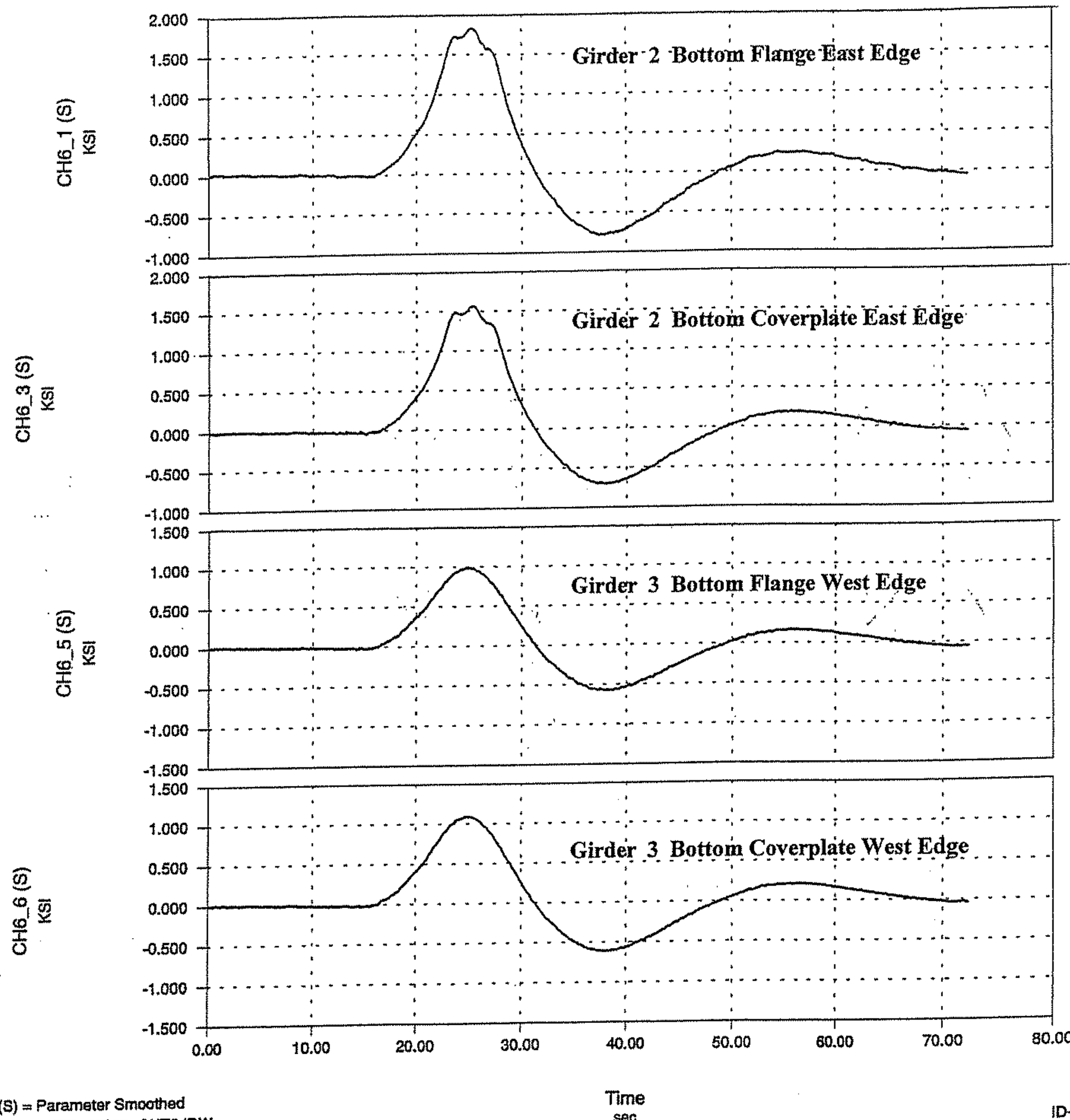
Test Vehicle at Span 6 / Section 4; Vehicle Outbound on Inbound Track @ Nominal 10 mph



Test Vehicle at Span 6 / Section 4; Vehicle Inbound on Inbound Track @ Nominal 25 mph



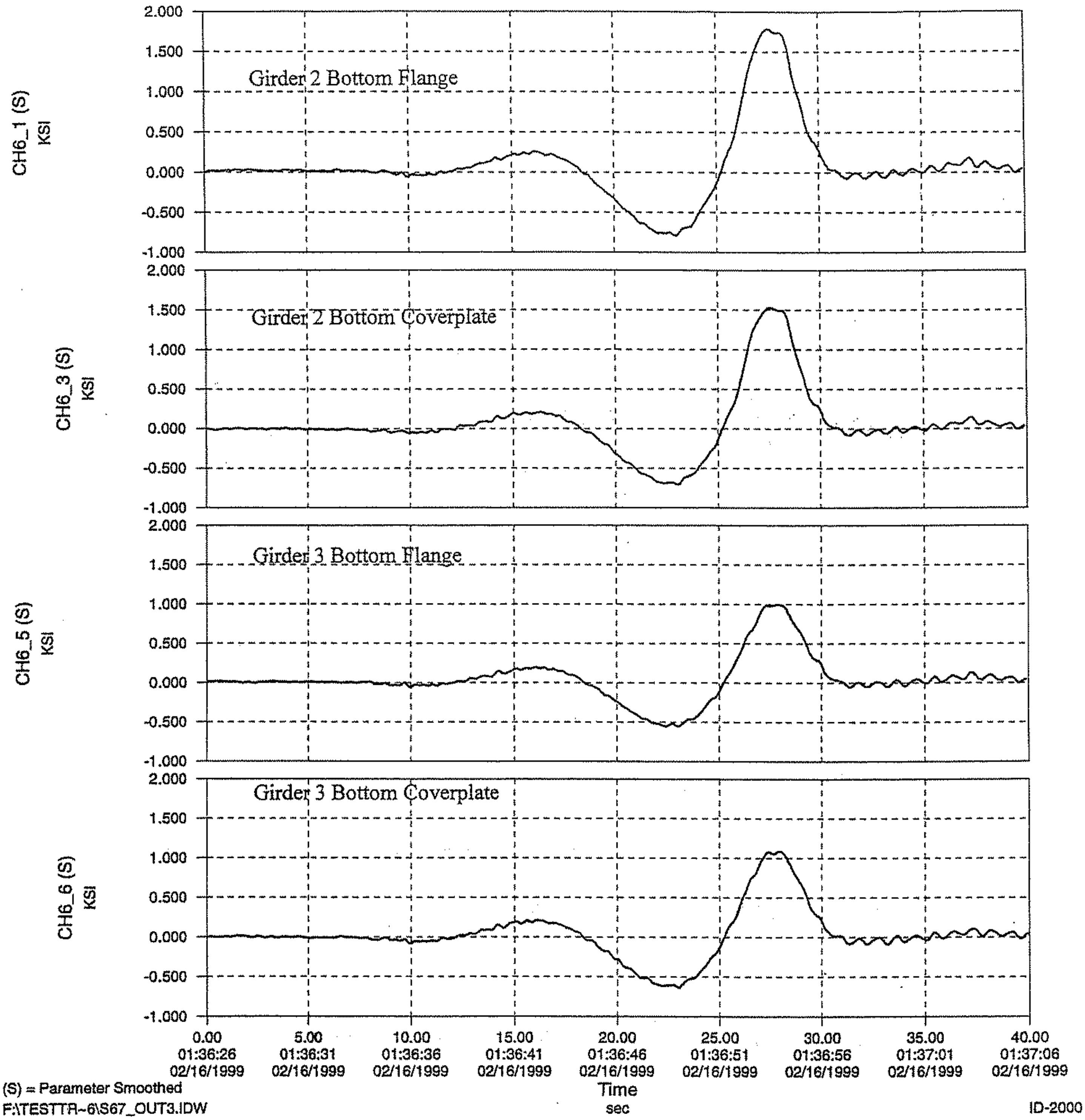
Test Vehicle at Span 6 / Section 4; Vehicle Outbound on Outbound Track @ Nominal 10 mph



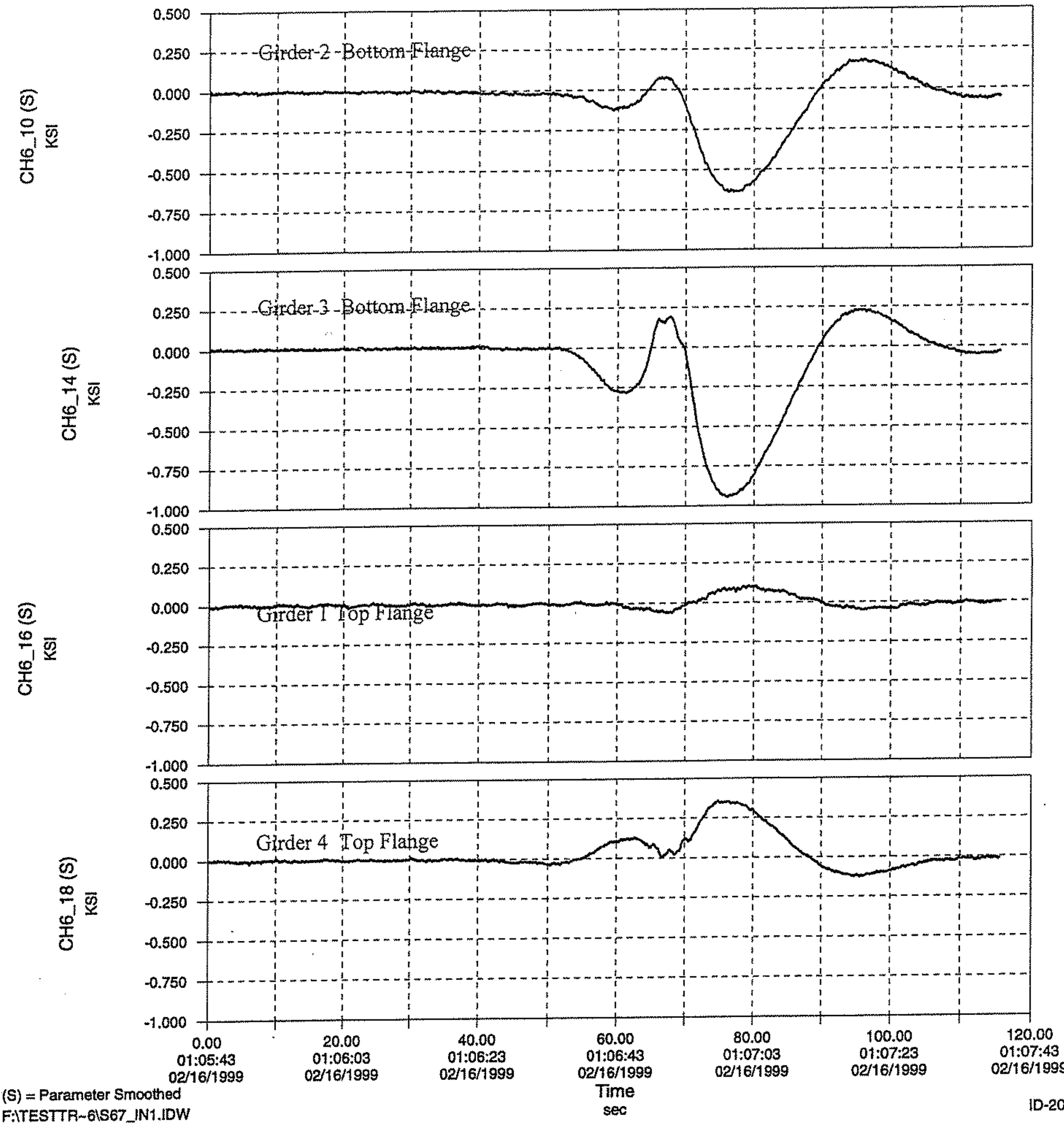
(S) = Parameter Smoothed
D:\TESTTR~9\S67_OUT2.IDW

ID-2

Test Vehicle at Span 6 / Section 4; Vehicle Inbound on Outbound Track @ Nominal 10 mph



Test Vehicle at Span 6 / Section 4; Vehicle Outbound on Outbound Track @ Nominal 25 mph



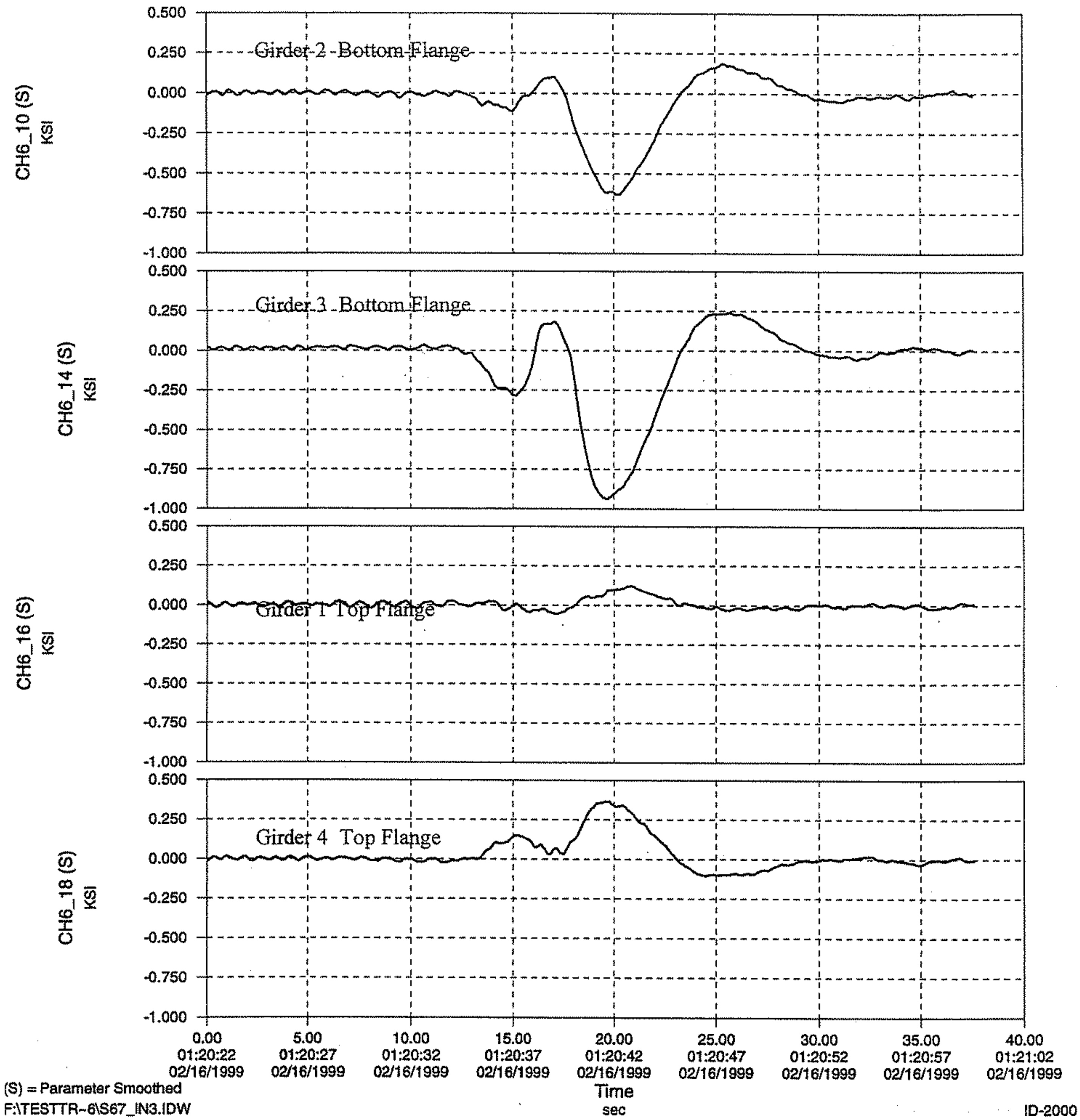
(S) = Parameter Smoothed
F:\TESTTR~6\S67_IN1.IDW

ID-200(

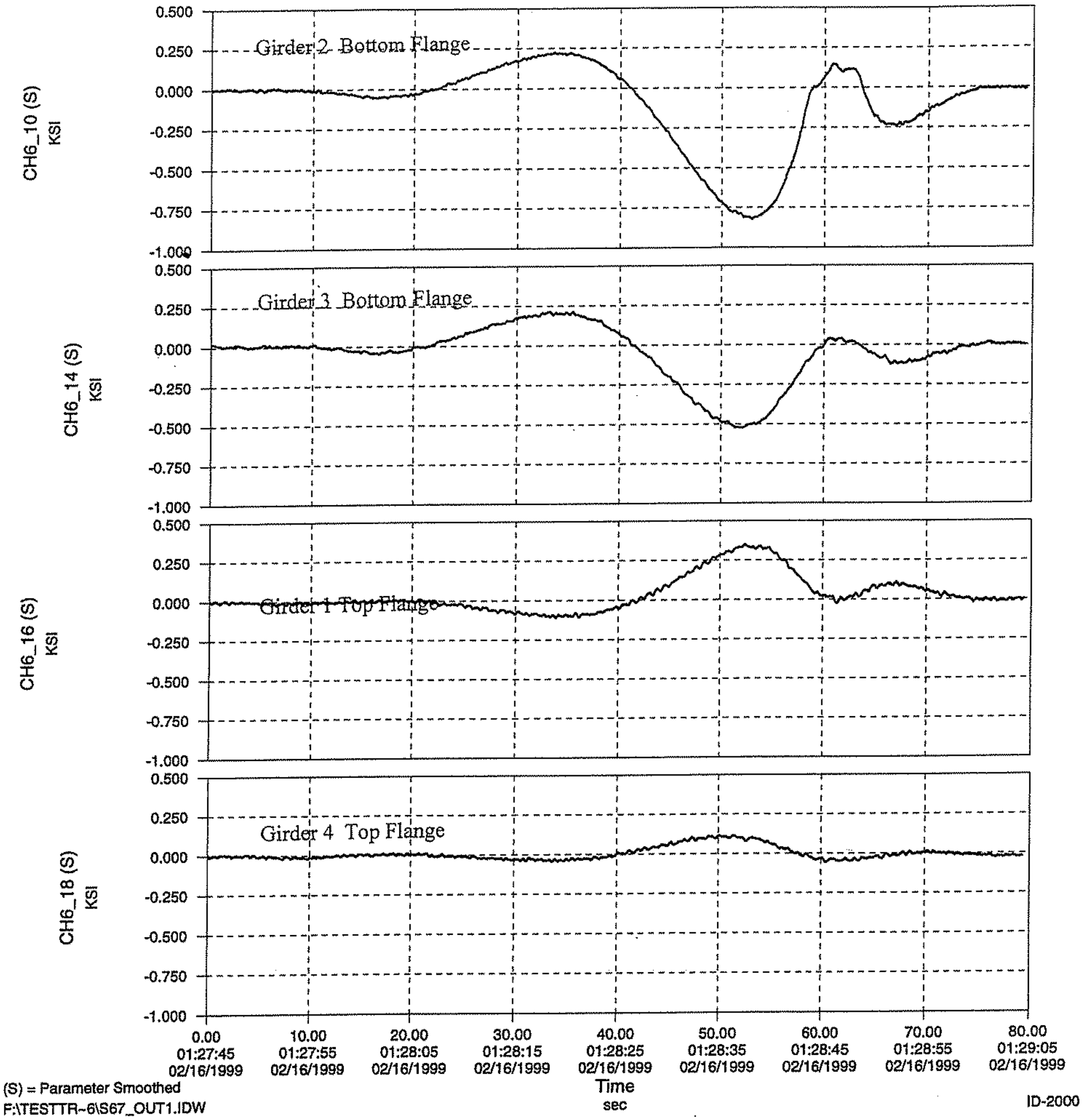
Test Vehicle at Span 6/Section 3: Vehicle Inbound on Inbound Track @ Nominal 10 mph

Saw Mill Run Bridge

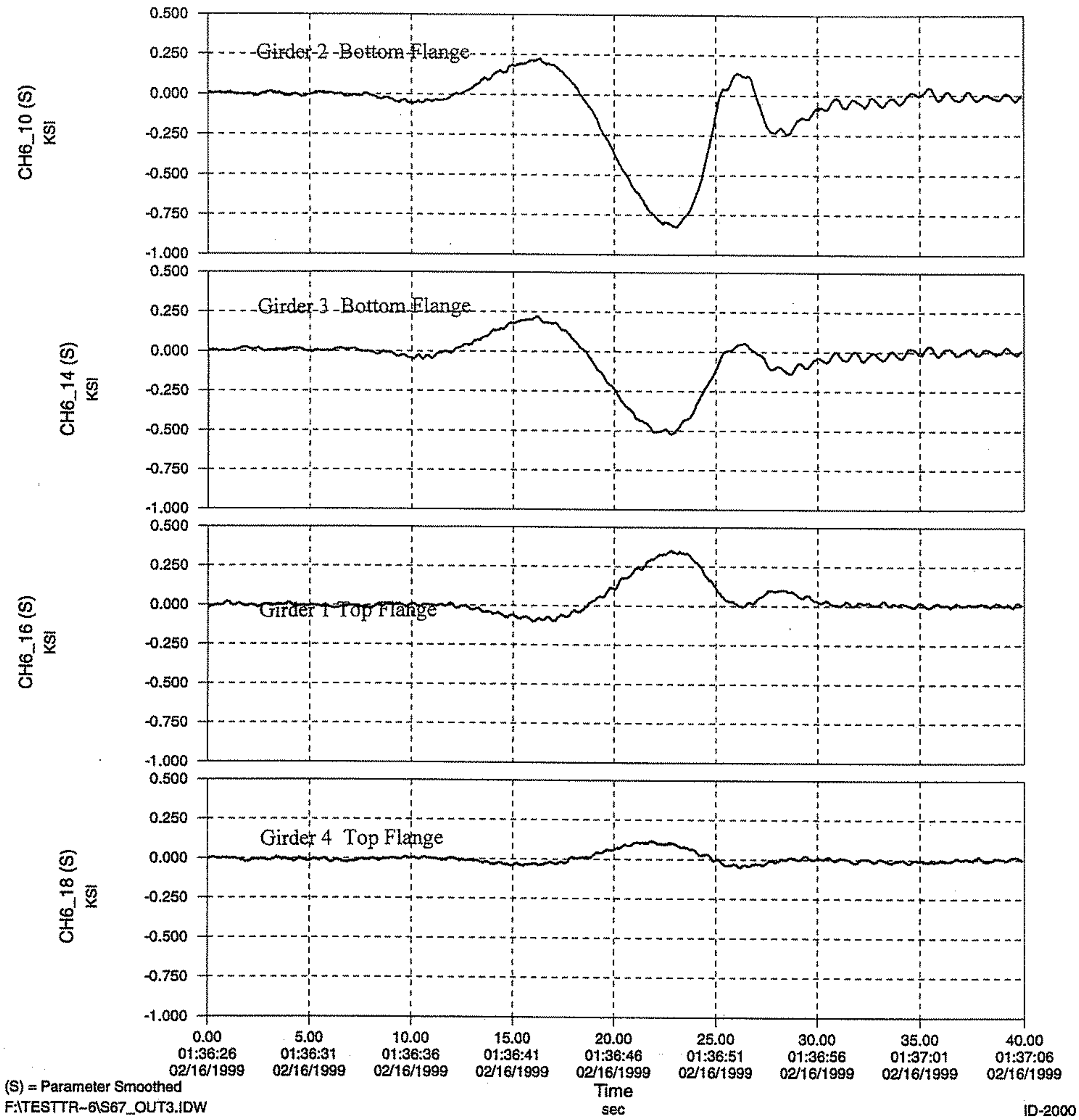
ATLSS Engineering Research Center
March 26, 1999



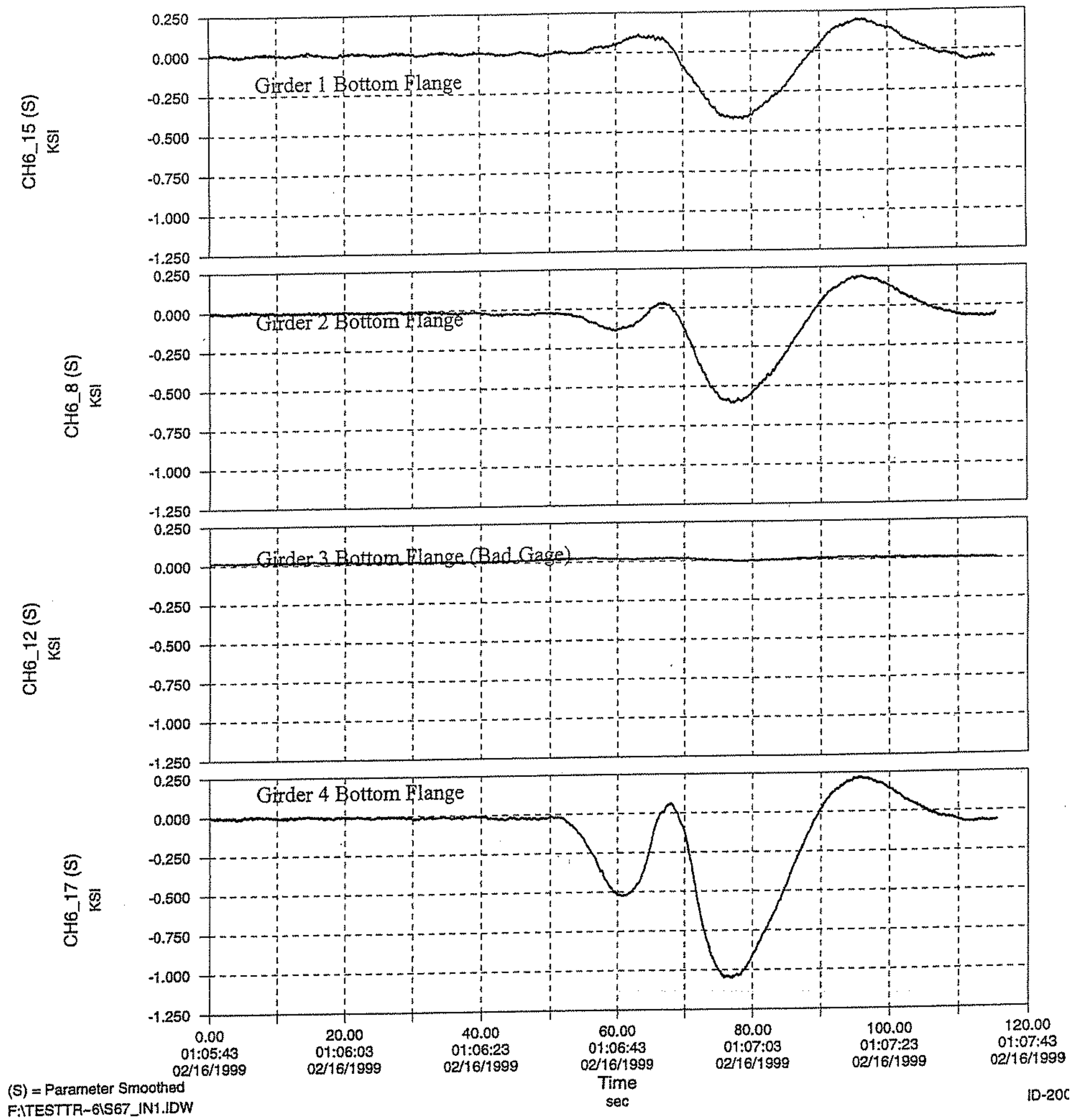
Test Vehicle at Span 6/Section 3: Vehicle Inbound on Inbound Track @ Nominal 25 mph



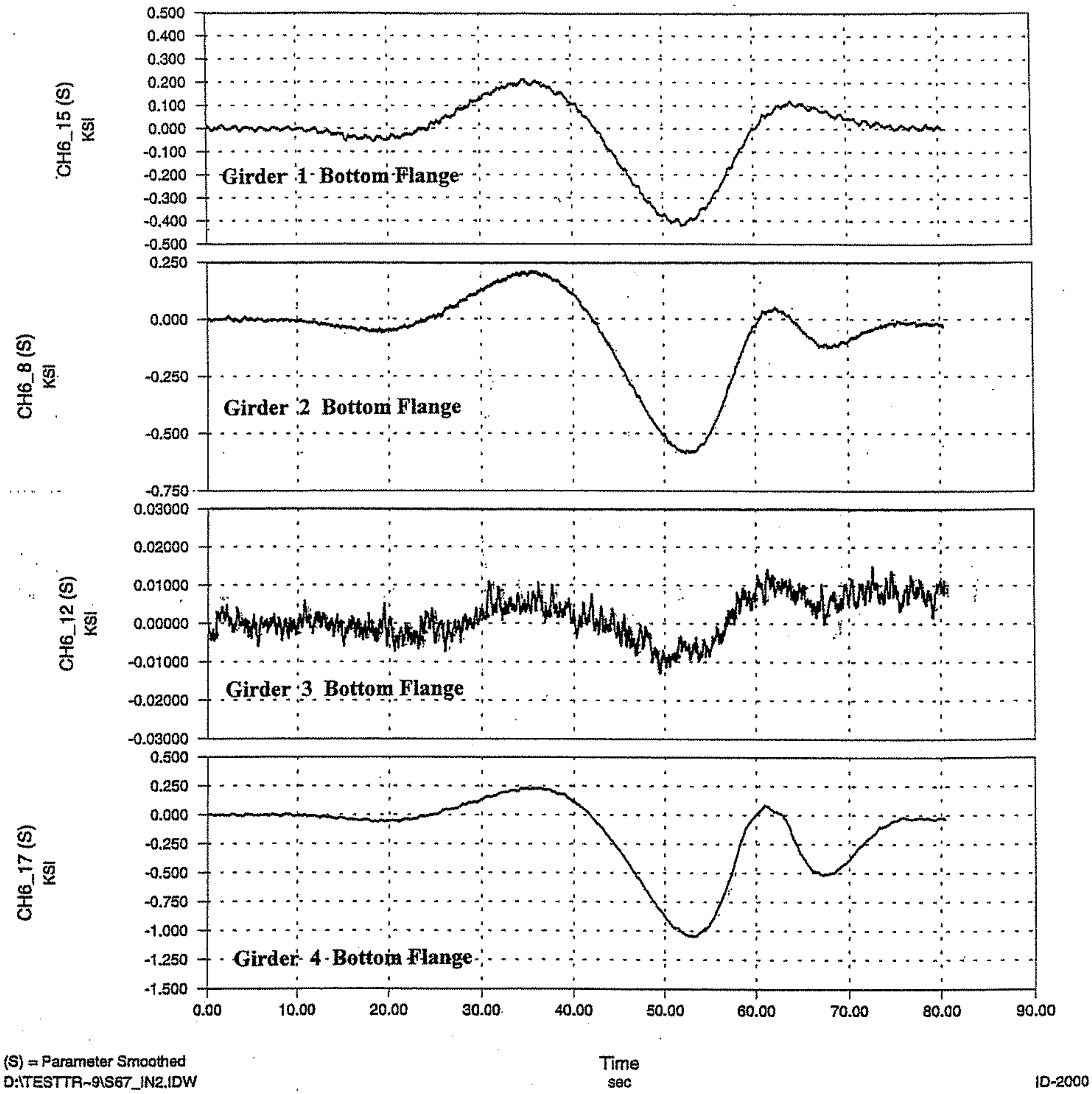
Test Vehicle at Span 6/Section 3: Vehicle Outbound on Outbound Track @ Nominal 10 mph



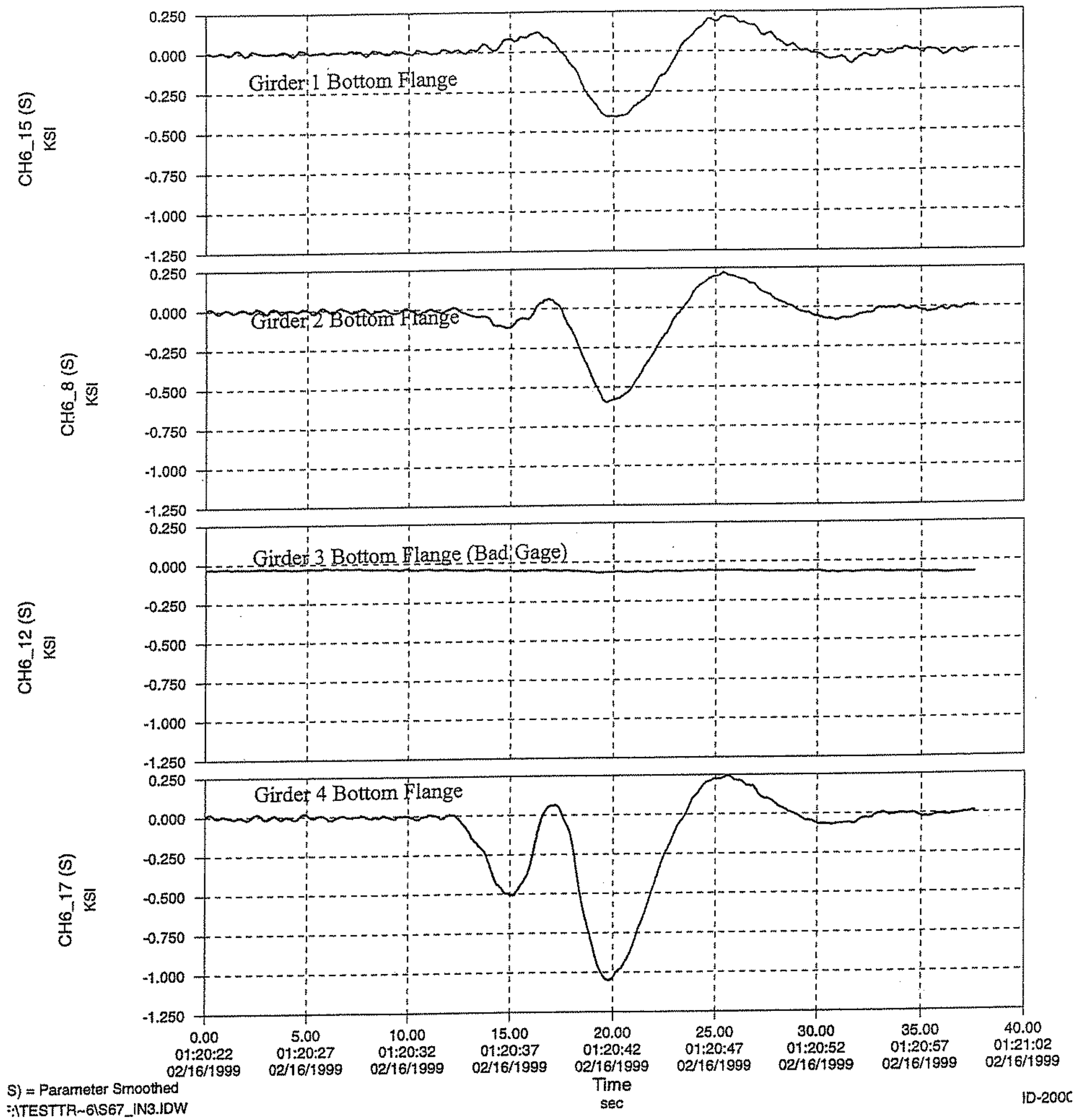
Test Vehicle at Span 6/Section 3: Vehicle Outbound on Outbound Track @ Nominal 25 mph



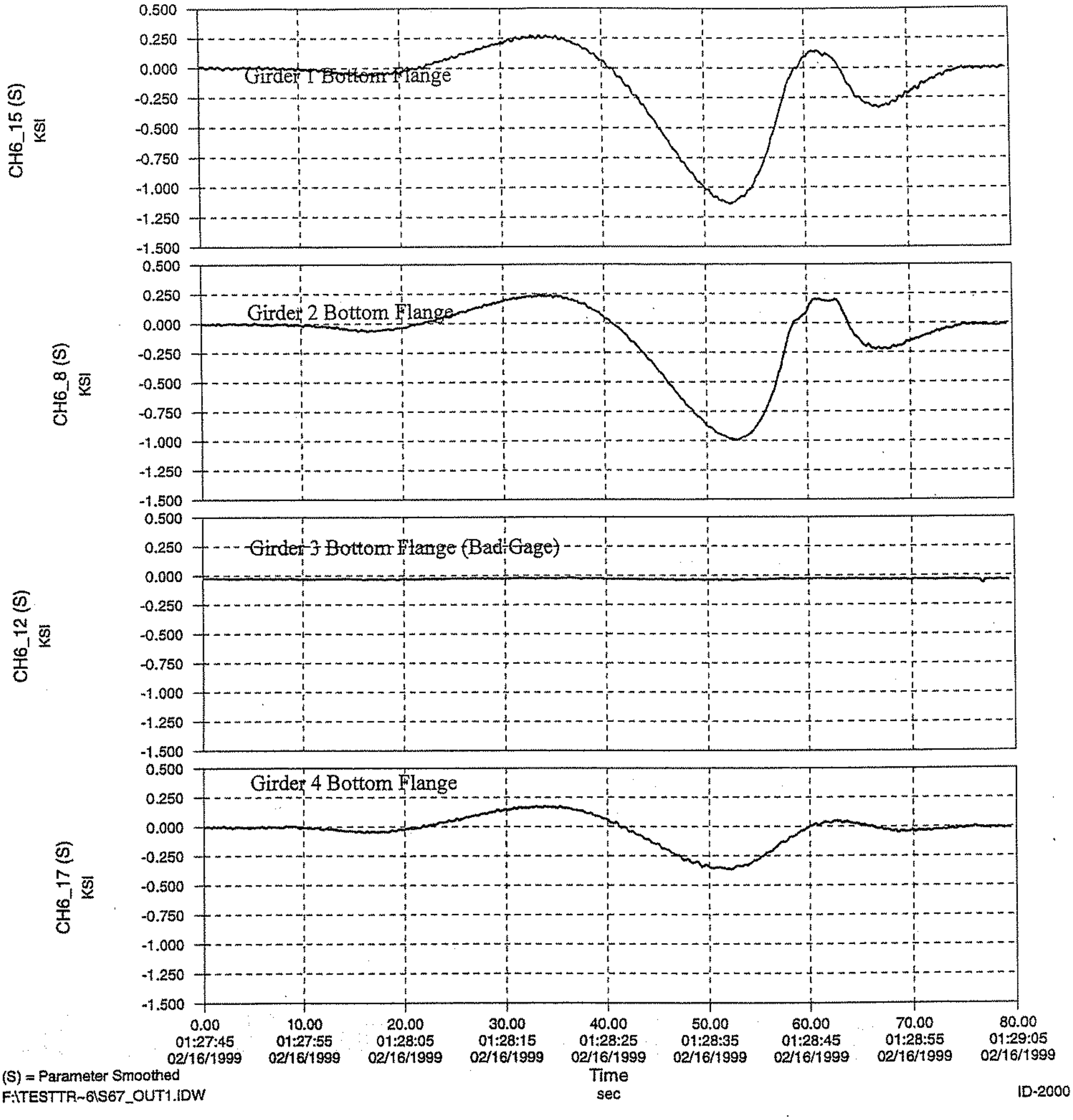
Test Vehicle at Span 6 / Section 3; Vehicle Inbound on Inbound Track @ Nominal 10 mph



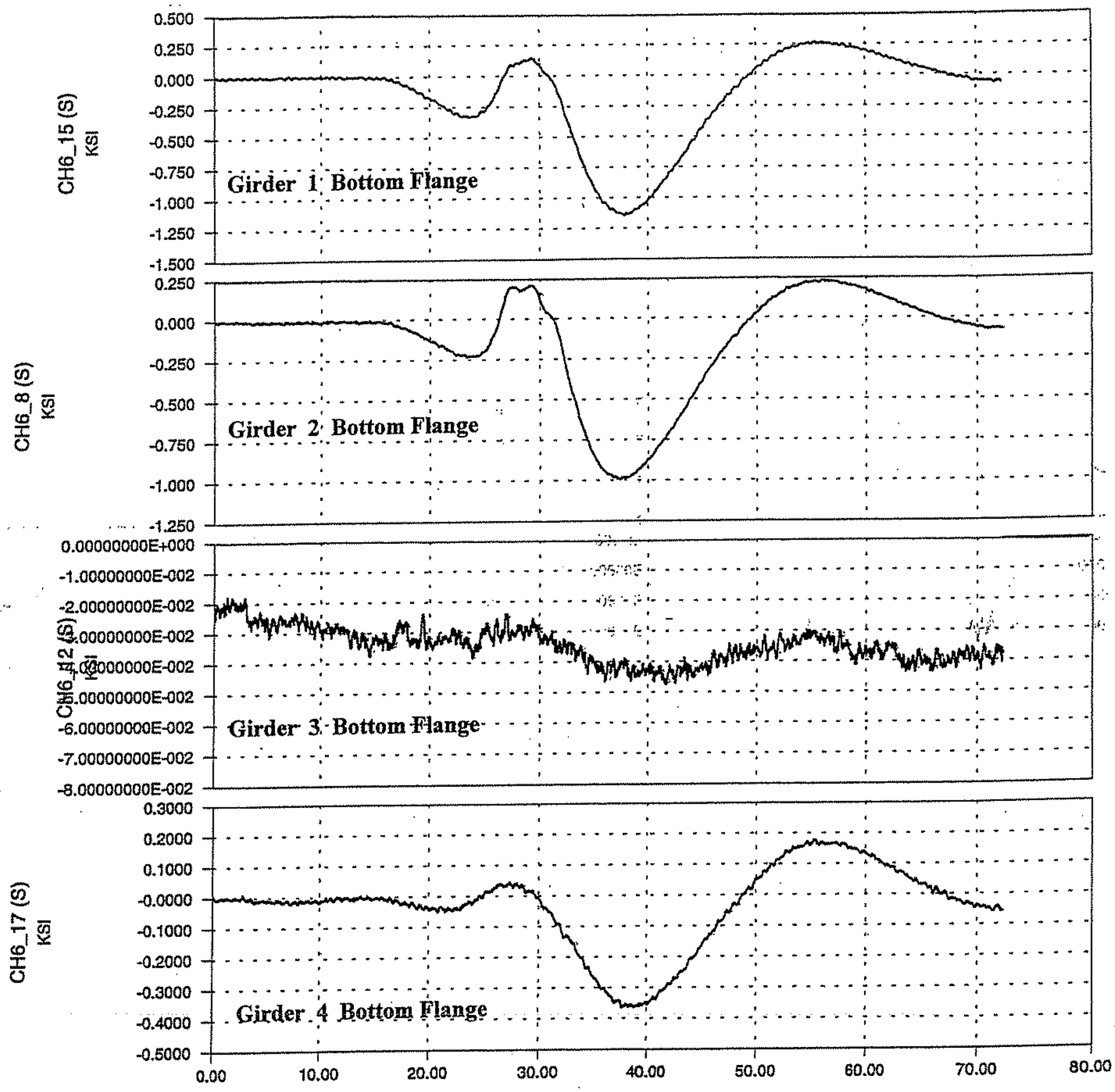
Test Vehicle at Span 6 / Section 3; Vehicle Outbound on Inbound Track @ Nominal 10 mph



Test Vehicle at Span 6 / Section 3; Vehicle Inbound on Inbound Track @ Nominal 25 mph



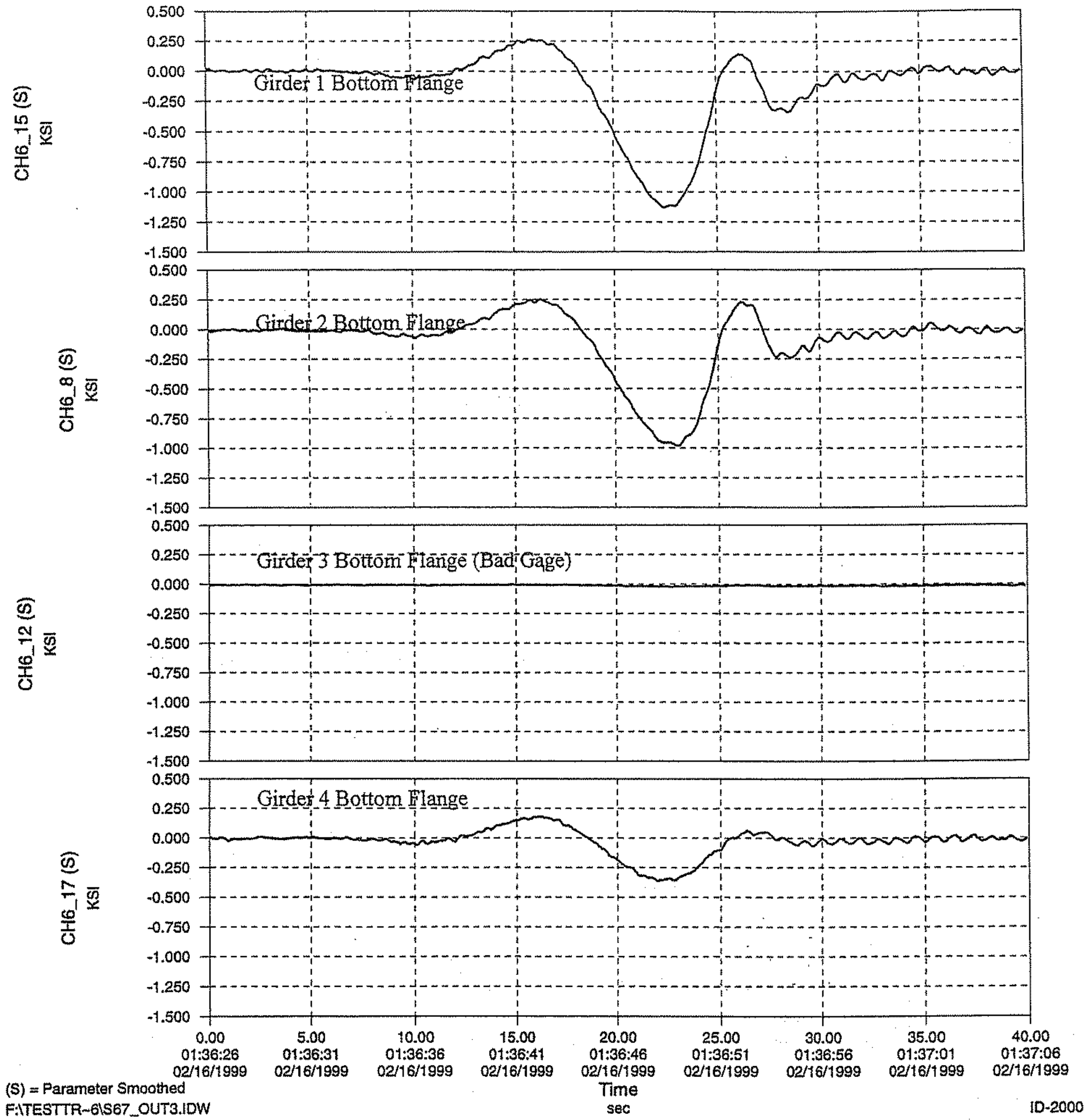
Test Vehicle at Span 6 / Section 3; Vehicle Outbound on Outbound Track @ Nominal 10 mph



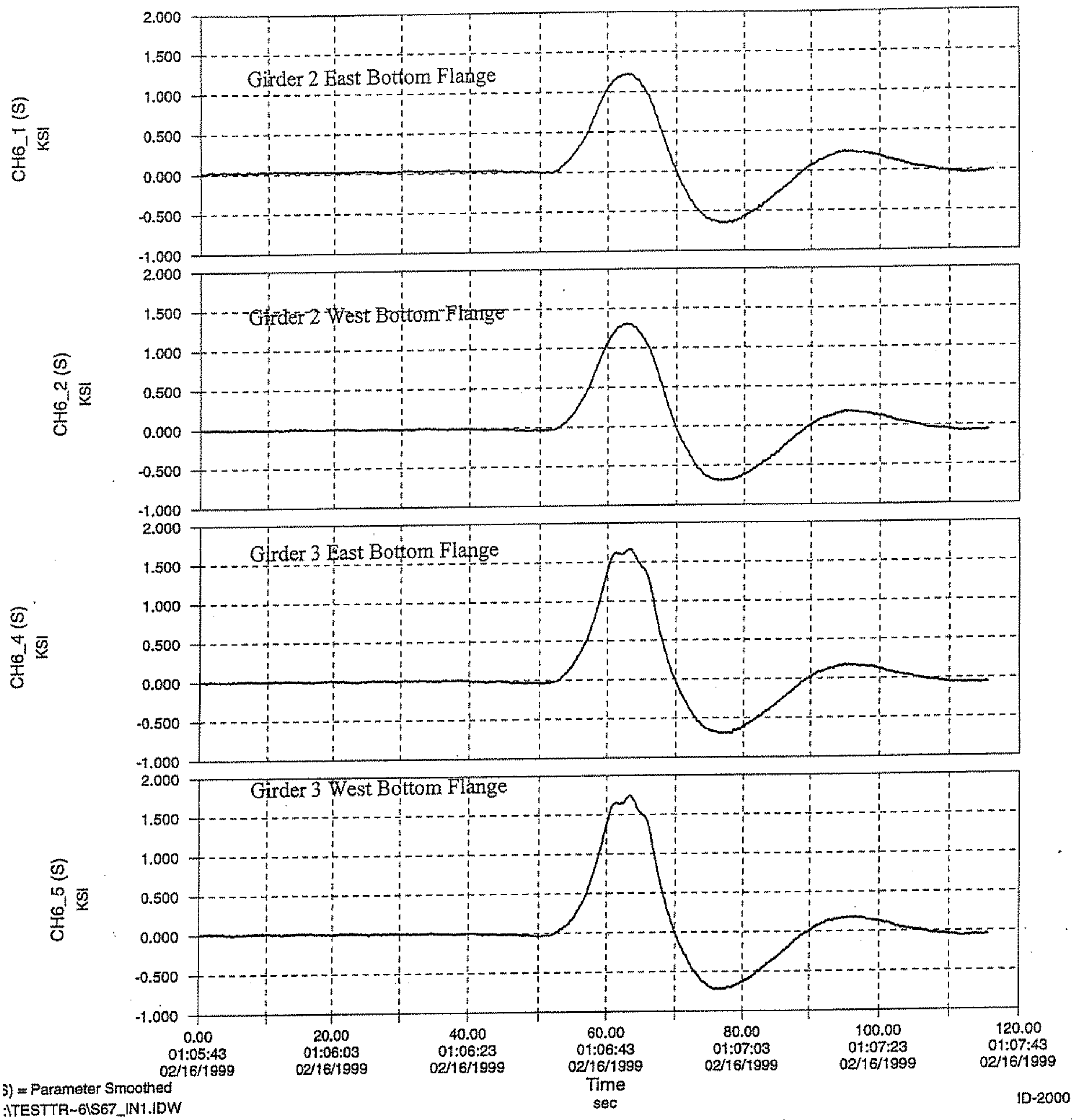
(S) = Parameter Smoothed
D:\TESTTR~9\S67_OUT2.IDW

ID-200

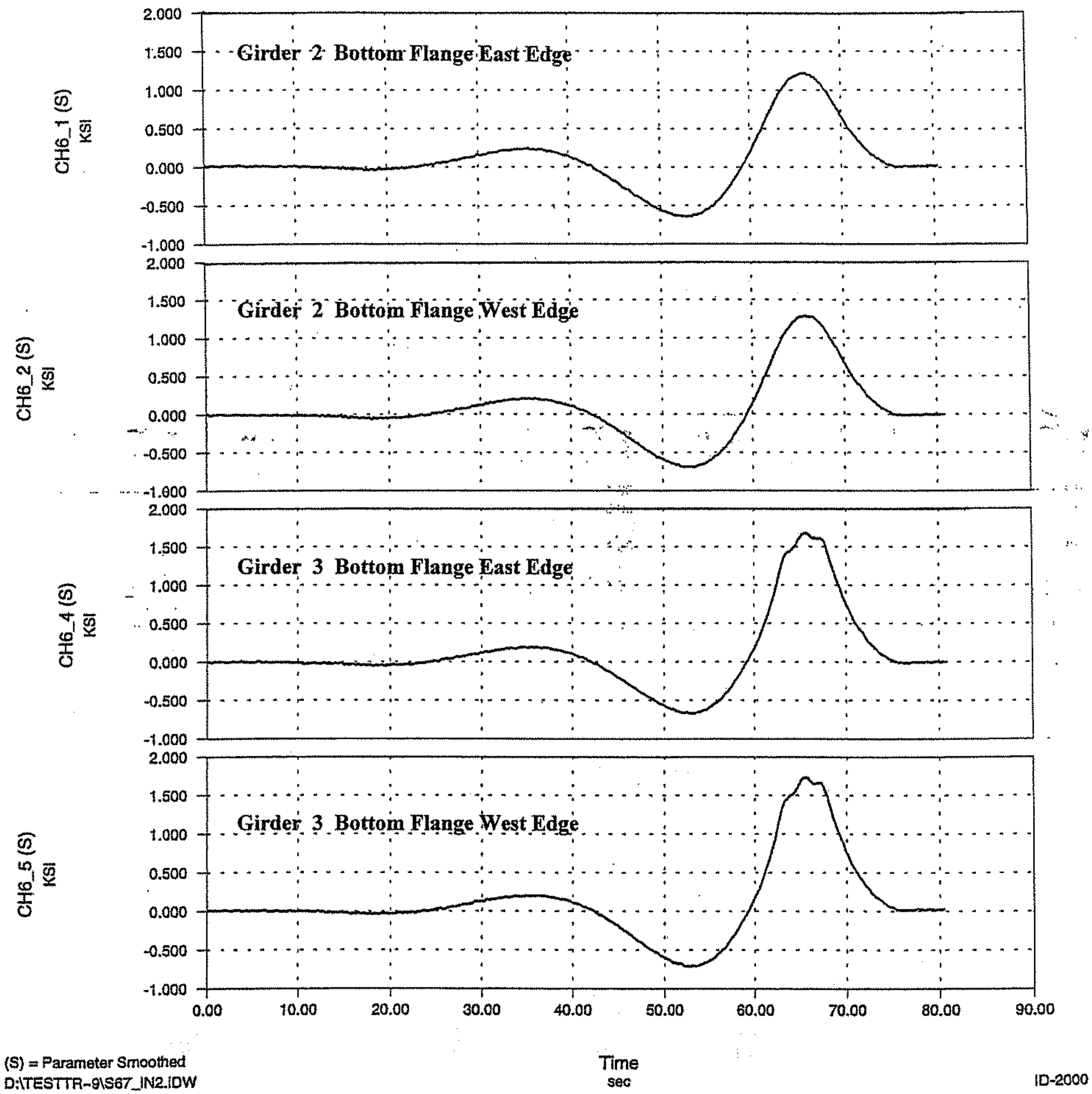
Test Vehicle at Span 6 / Section 3; Vehicle Inbound on Outbound Track @ Nominal 10 mph



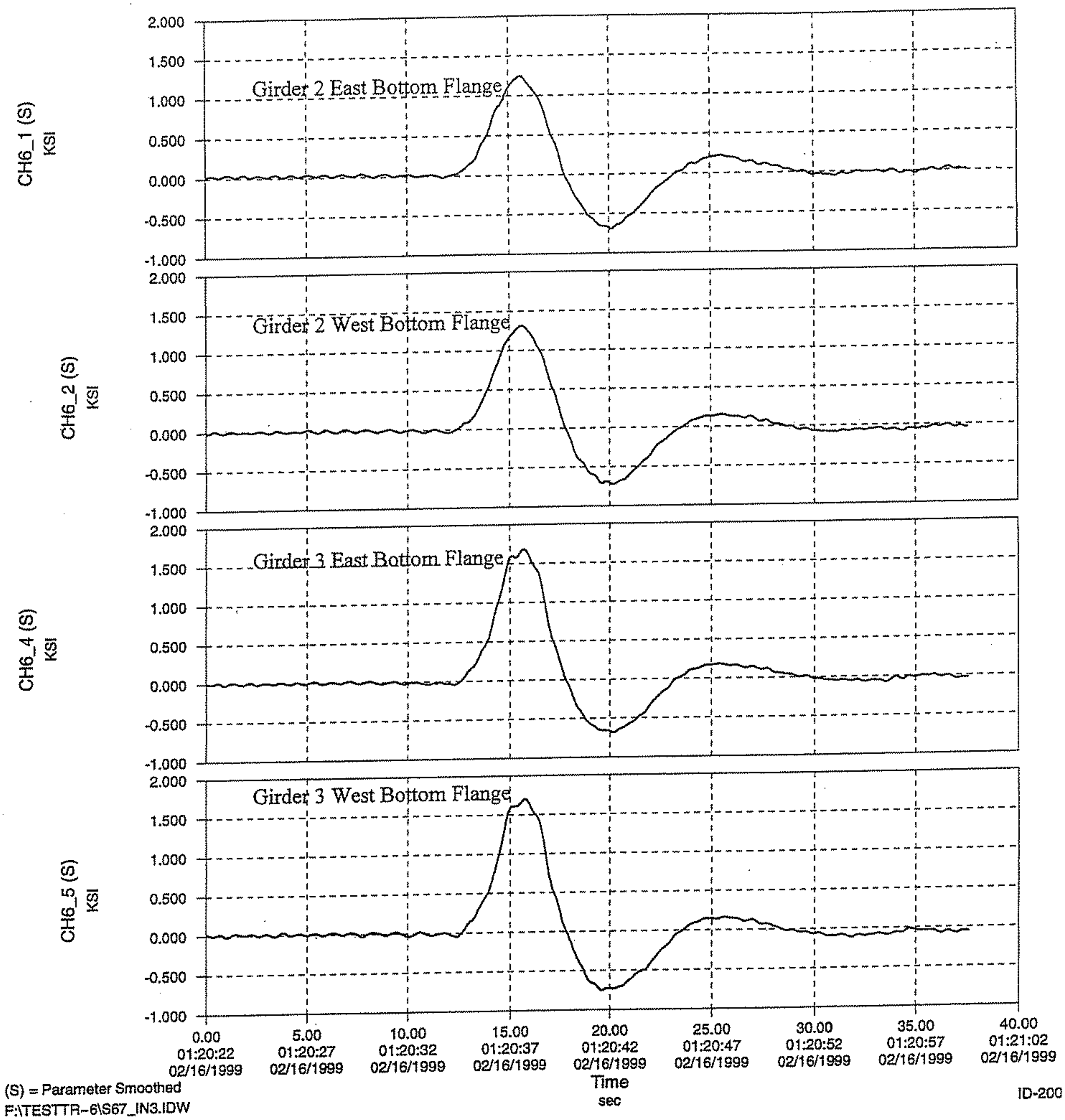
Test Vehicle at Span 6 / Section 3; Vehicle Outbound on Outbound Track @ Nominal 25 mph



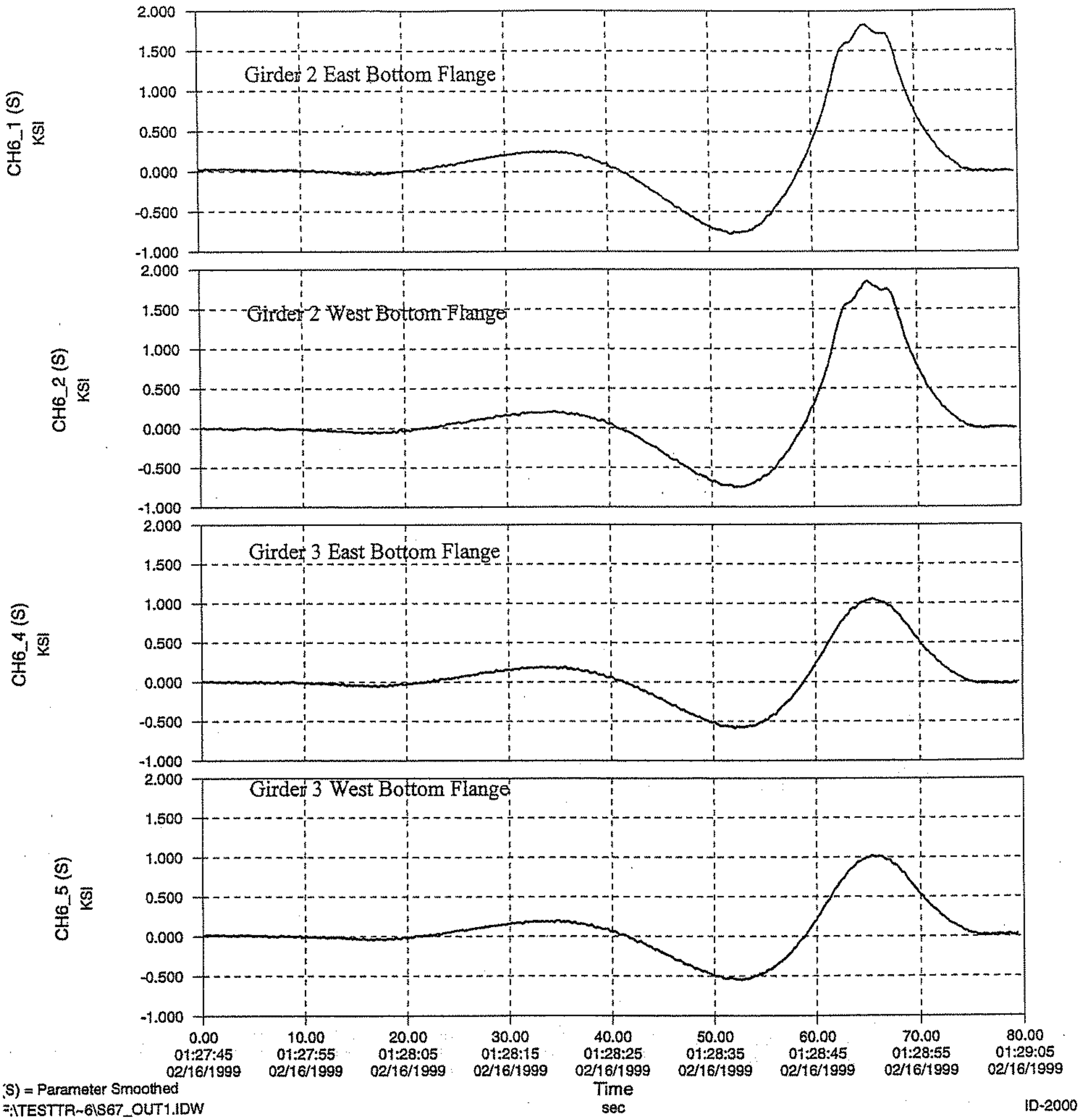
Test Vehicle at Span 6 / Section 4; Vehicle Inbound on Inbound Track @ Nominal 10 mph



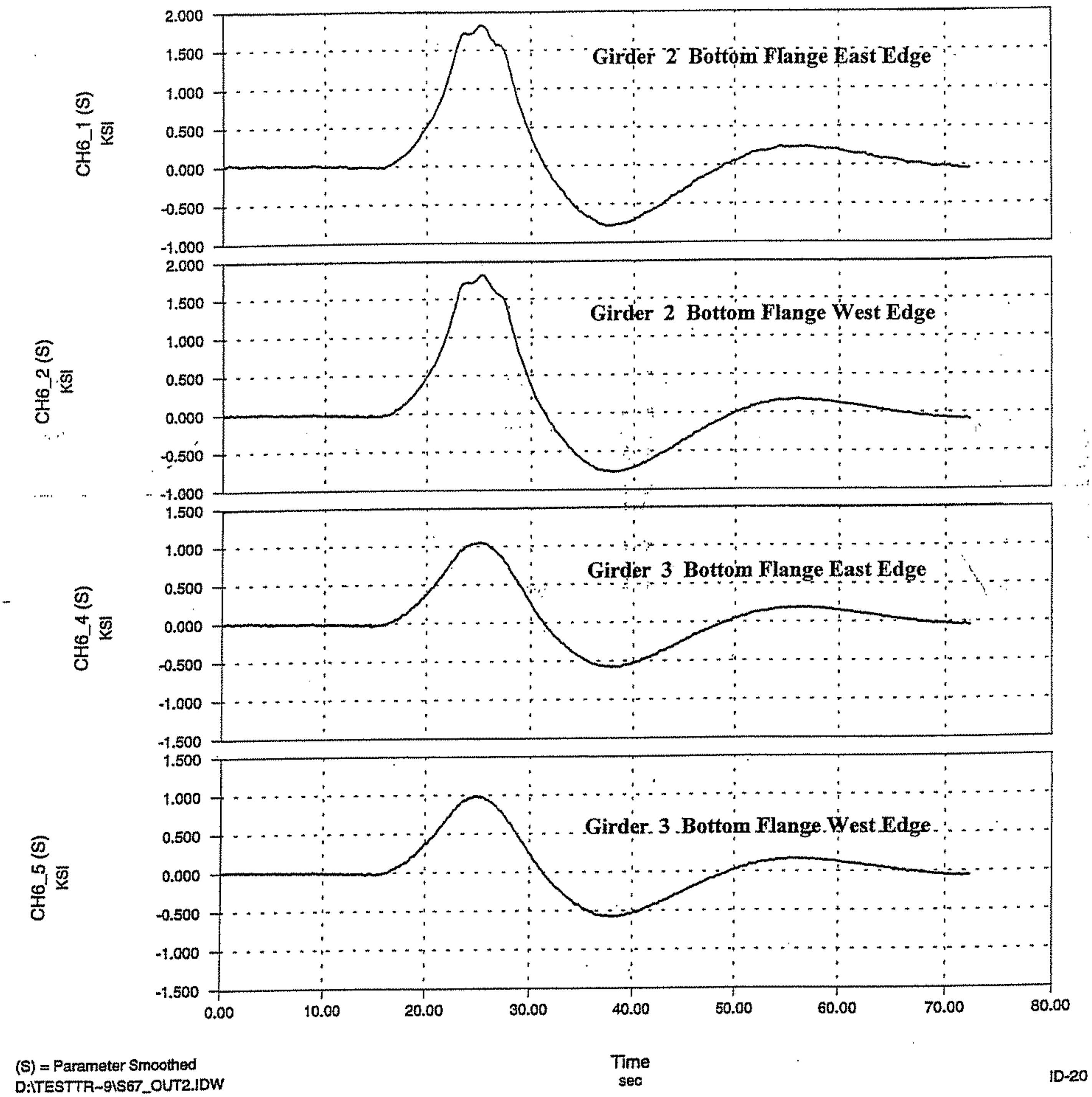
Test Vehicle at Span 6 / Section 4; Vehicle Outbound on Inbound Track @ Nominal 10 mph



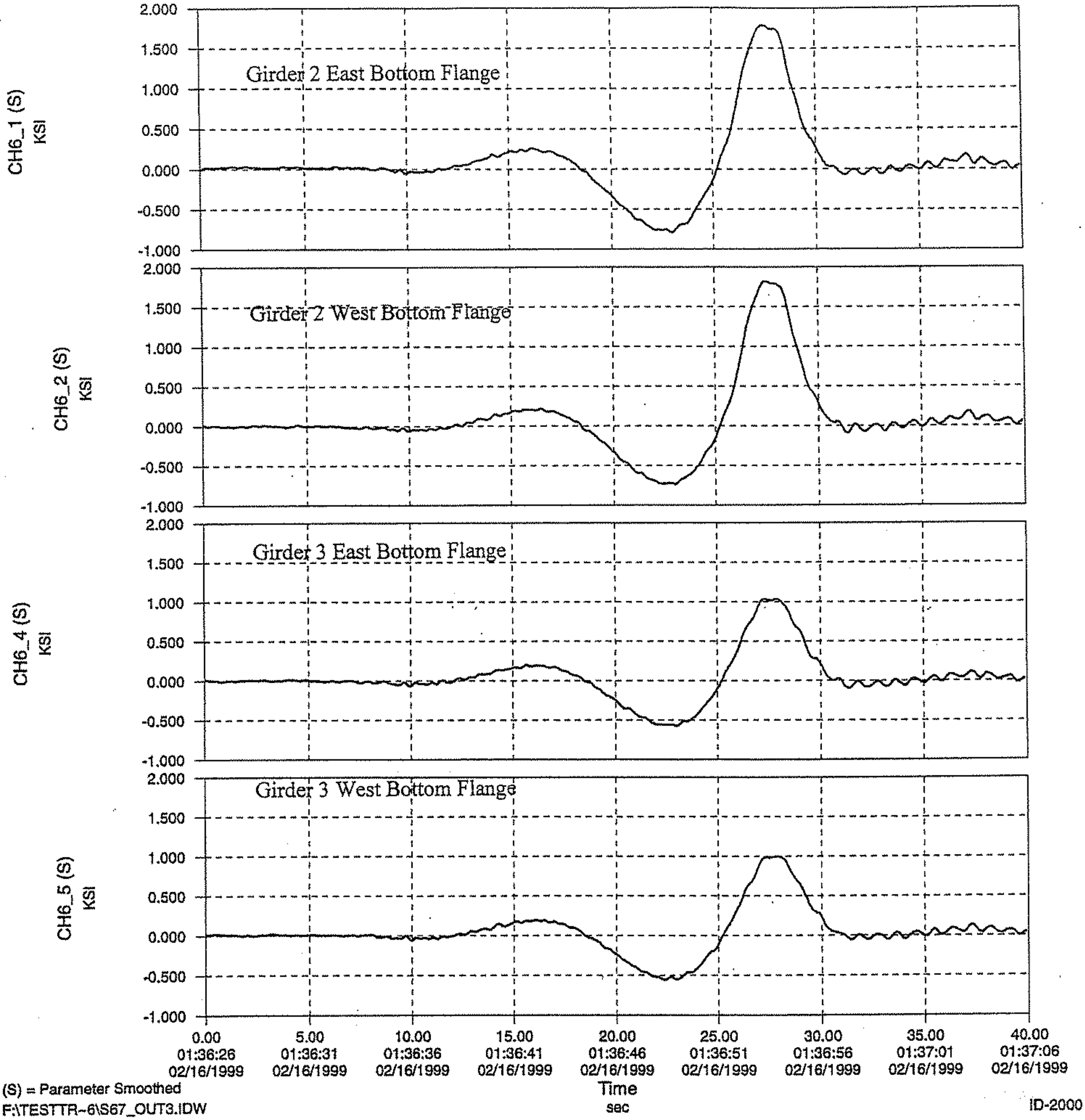
Test Vehicle at Span 6 / Section 4; Vehicle Inbound on Inbound Track @ Nominal 25 mph



Test Vehicle at Span 6 / Section 4; Vehicle Outbound on Outbound Track @ Nominal 10 mph

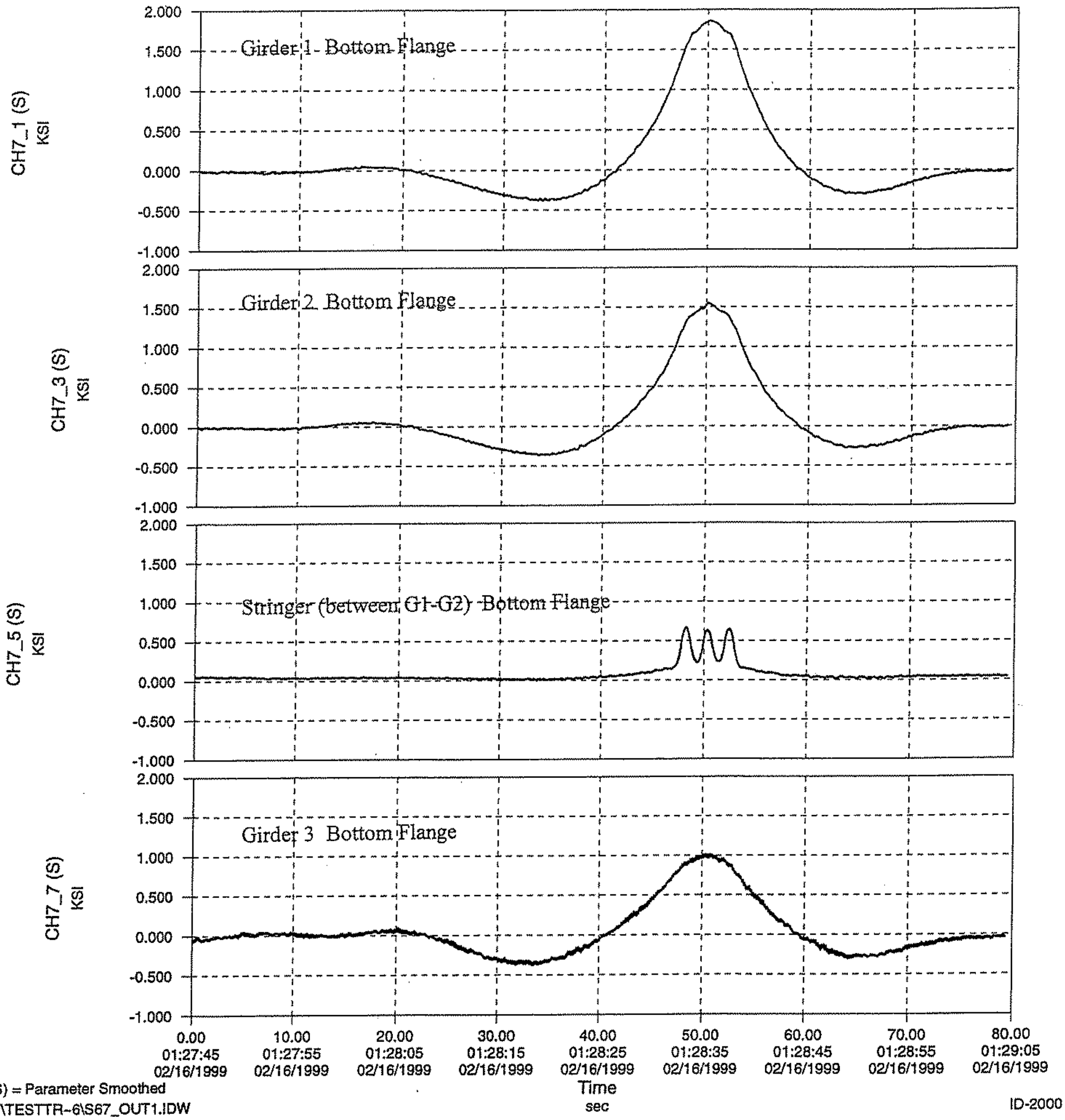


Test Vehicle at Span 6 / Section 4; Vehicle Inbound on Outbound Track @ Nominal 10 mph



Test Vehicle at Span 6 / Section 4; Vehicle Outbound on Outbound Track @ Nominal 25 mph

Strain Gage Records
Test Vehicle, Span 7



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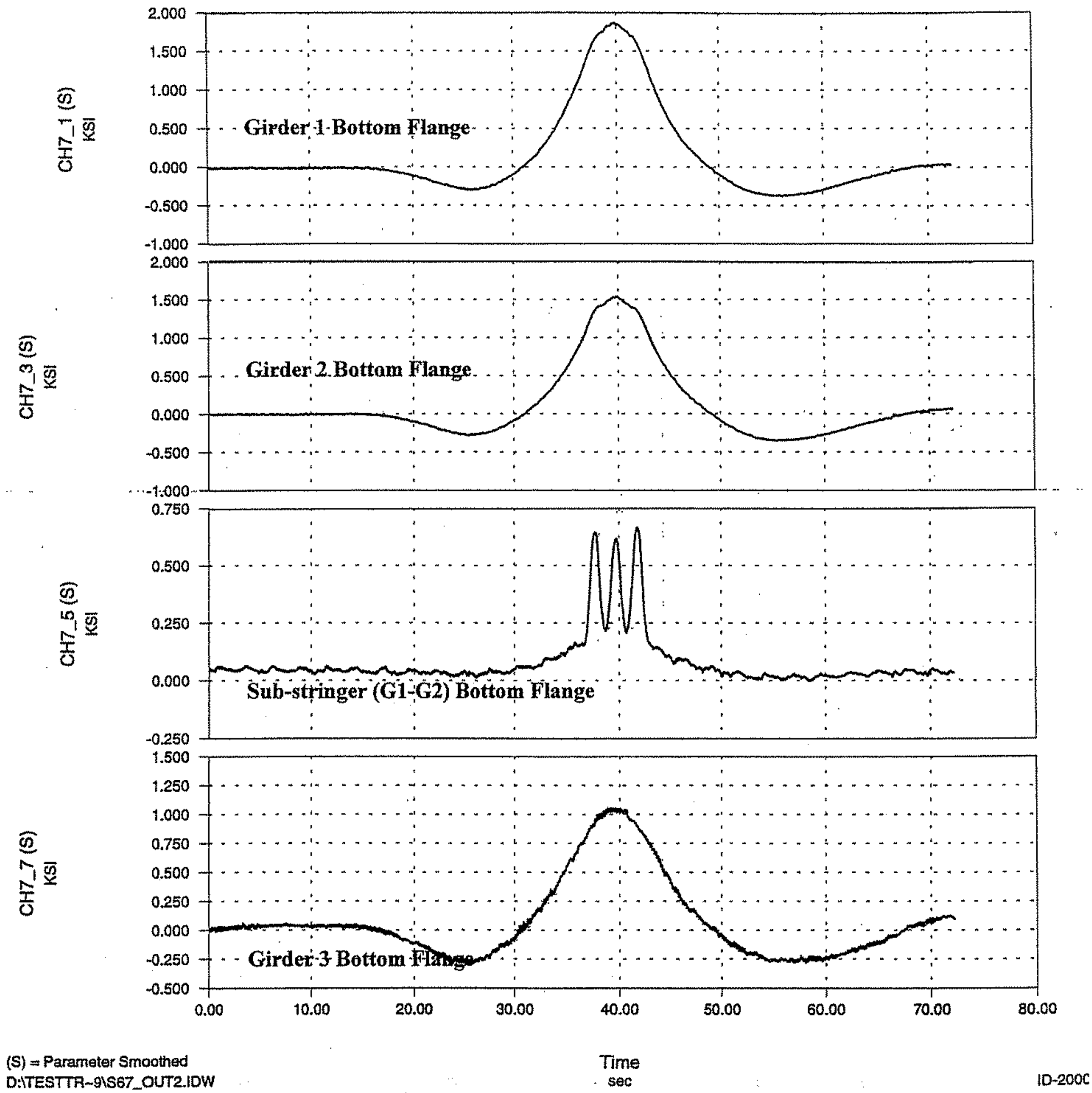
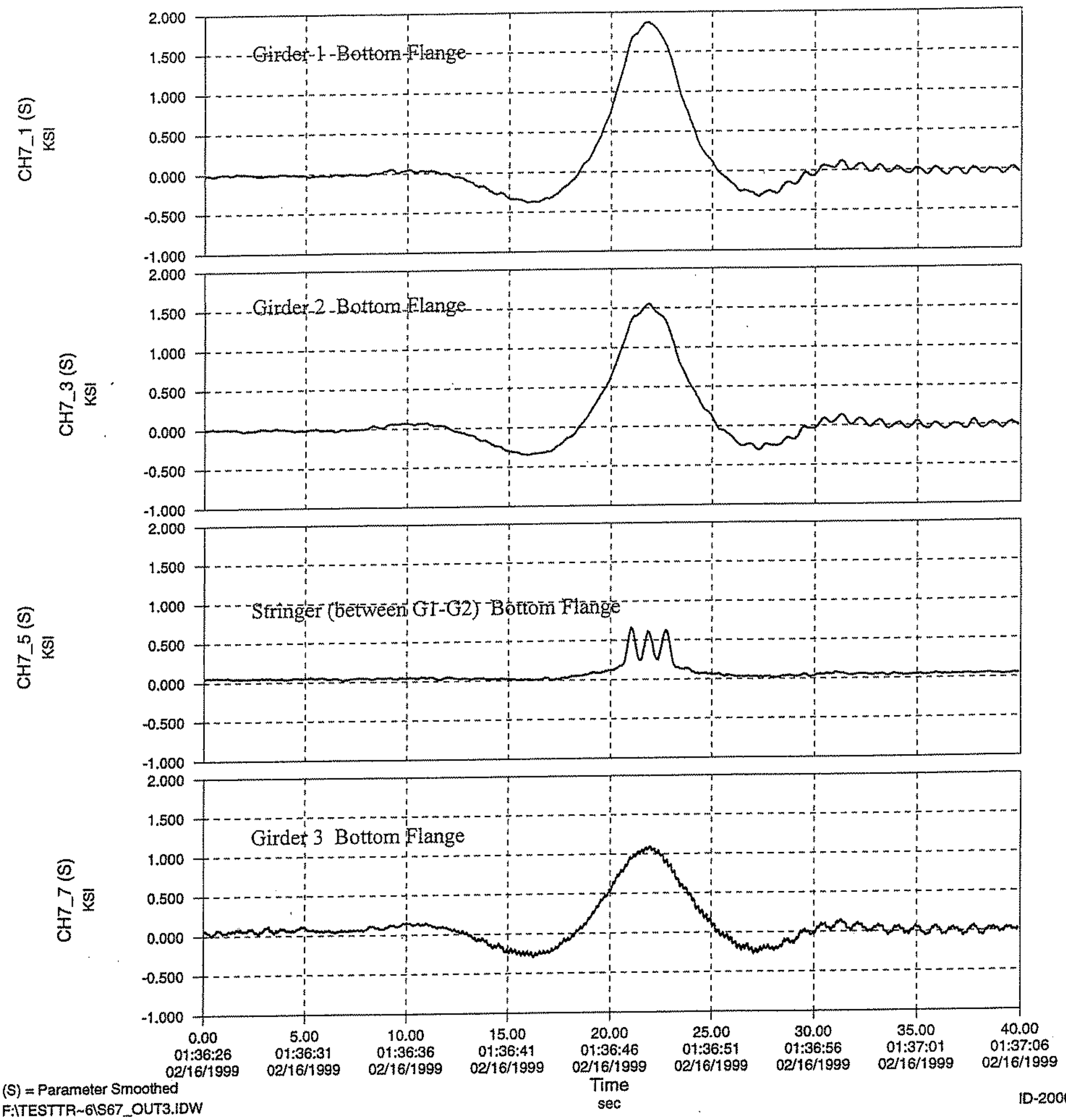
ID-2000

Test Vehicle at Span 7/Section 1: Vehicle Outbound on Outbound Track @ Nominal 10 mph



Test Vehicle at Span 7/Section 1; Vehicle Inbound on Outbound Track @ Nominal 10 mph



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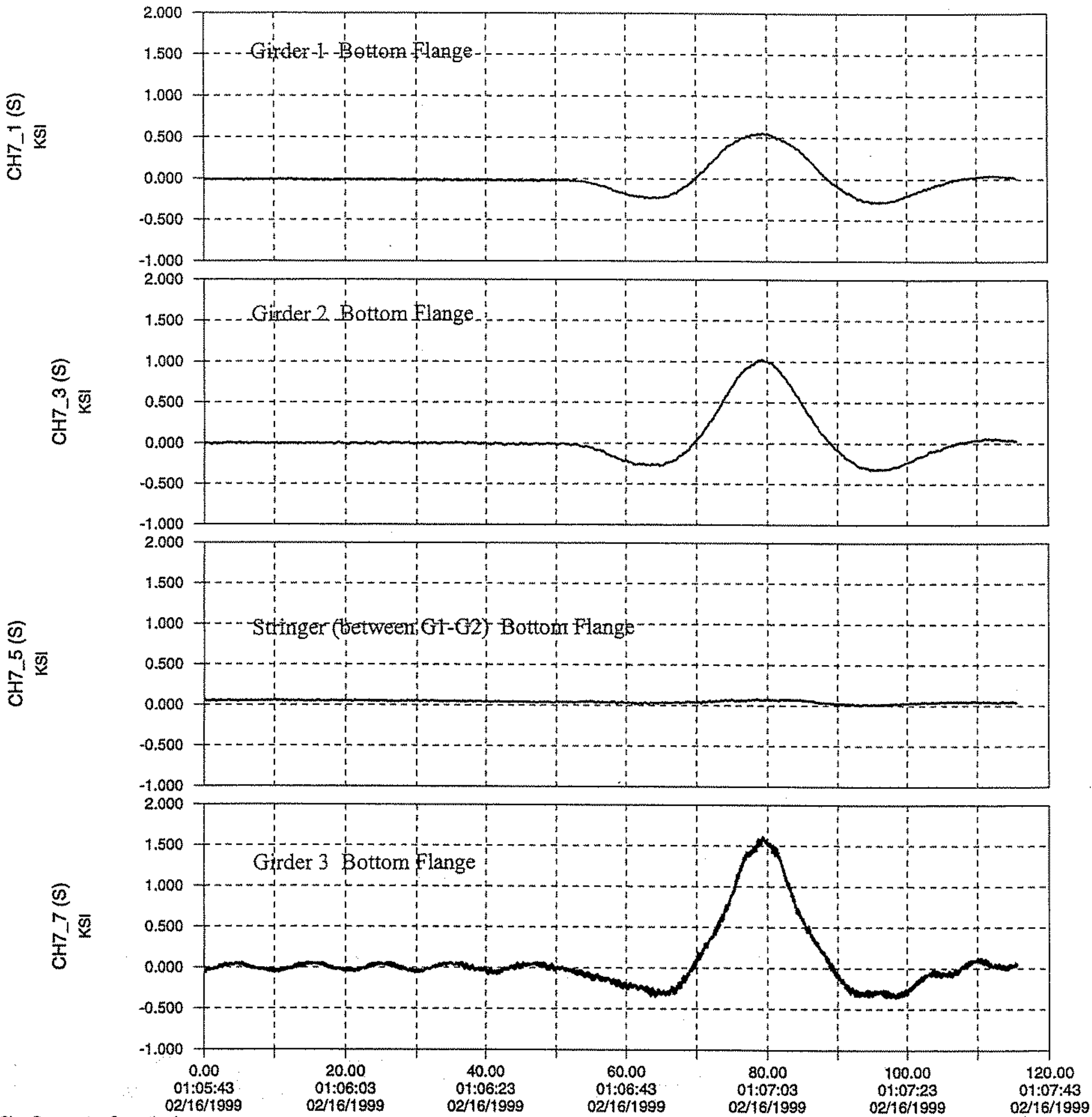
ID-200

Test Vehicle at Span 7/Section 1: Vehicle Outbound on Outbound Track @ Nominal 25 mph

ATLSS Engineering Research Center
March 25, 1999

Saw Mill Run Bridge



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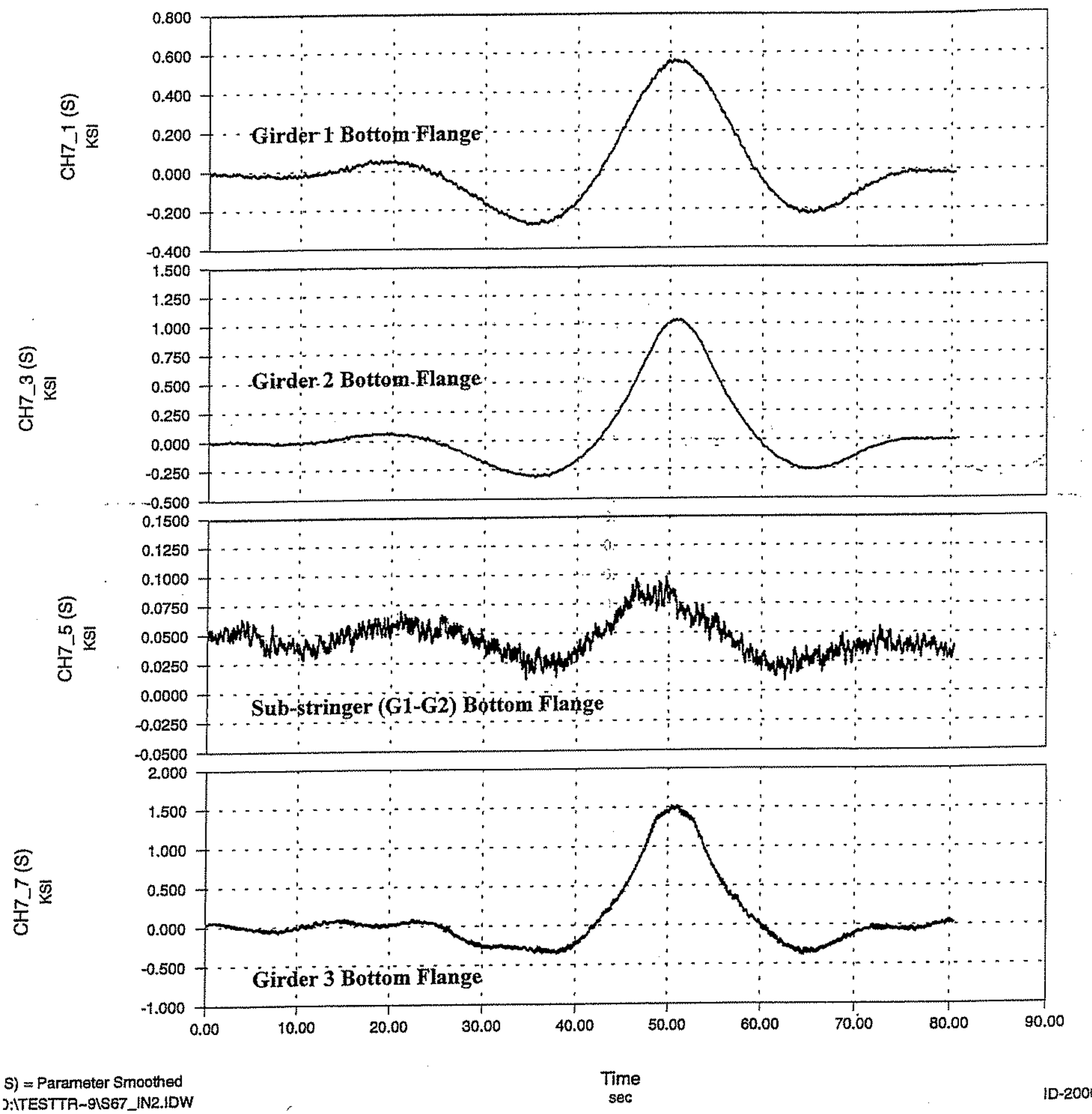
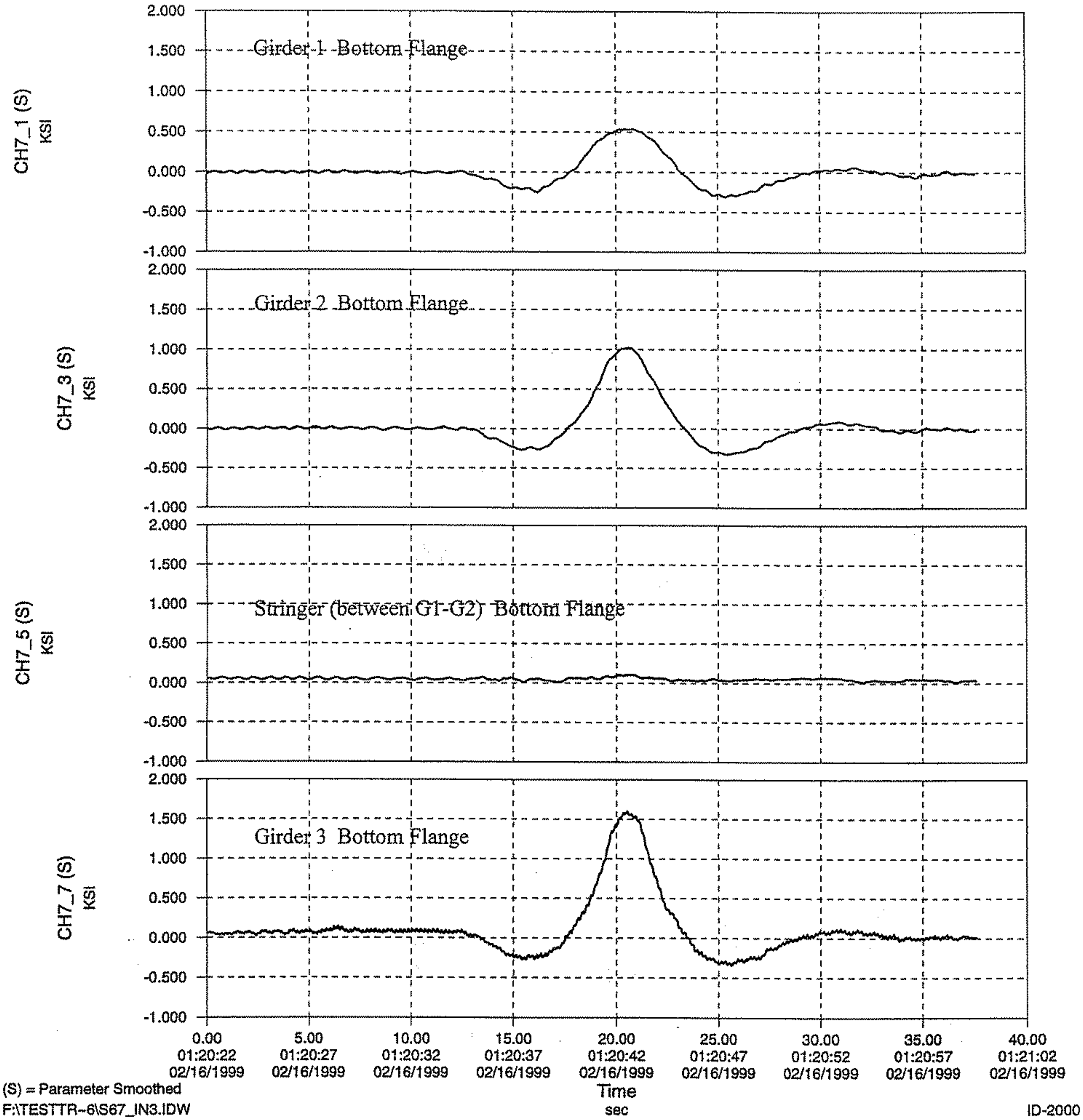
ID-2000

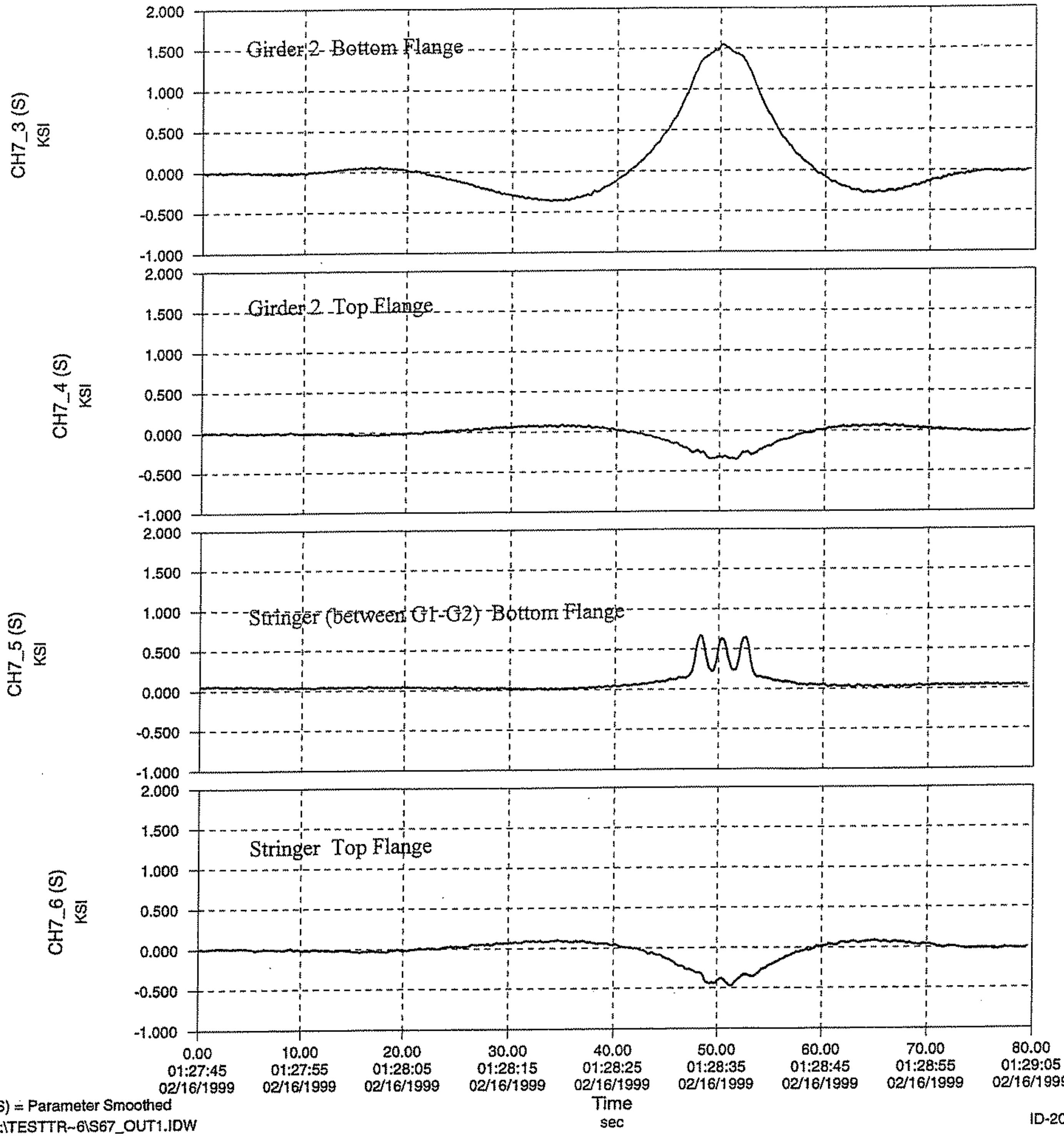
Test Vehicle at Span 7/Section 1: Vehicle Inbound on Inbound Track @ Nominal 10 mph



Test Vehicle at Span 7/Section 1; Vehicle Outbound on Inbound Track @ Nominal 10 mph



Test Vehicle at Span 7/Section 1: Vehicle Inbound on Inbound Track @ Nominal 25 mph



(S) = Parameter Smoothed
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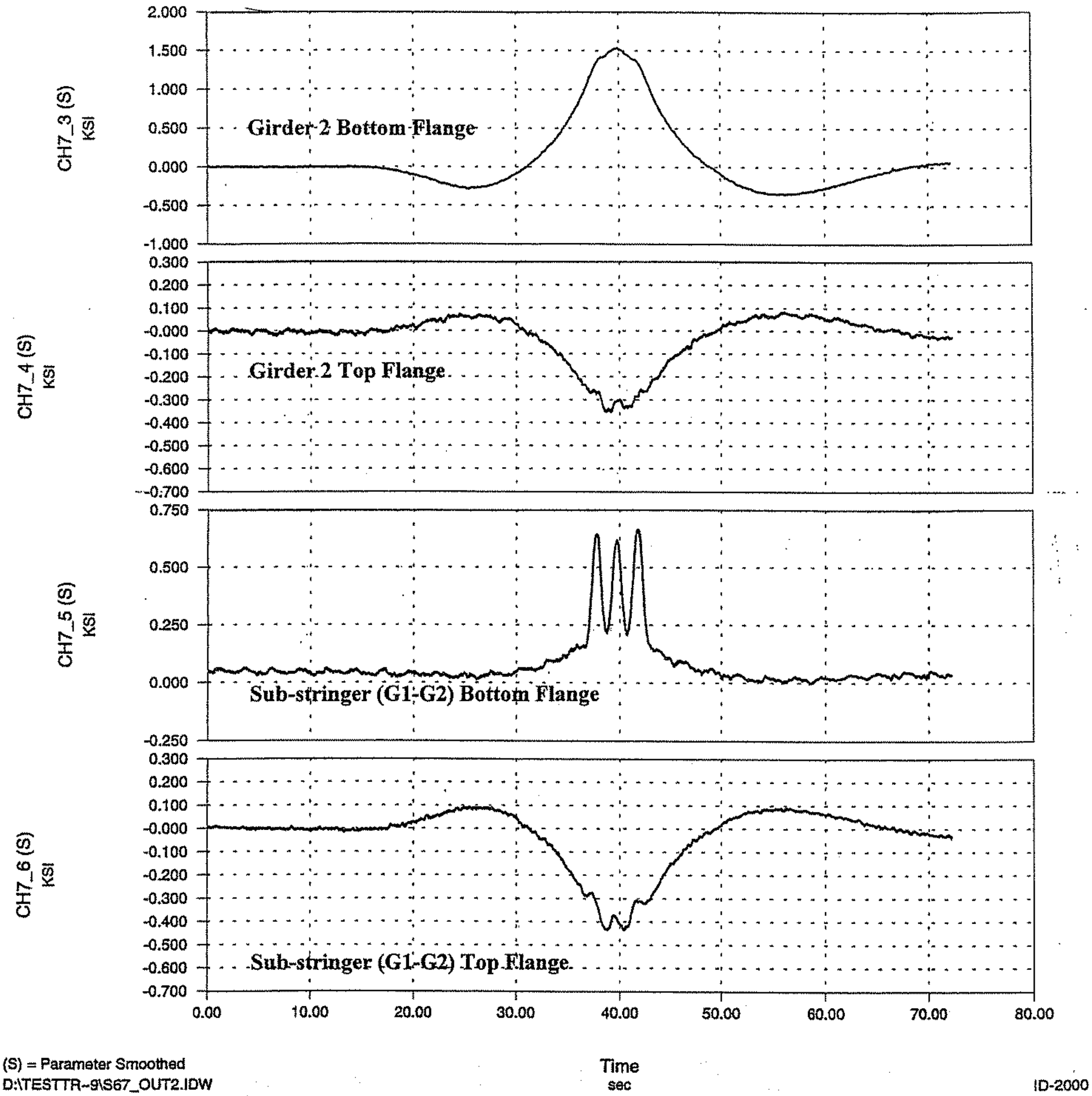
ID-2000

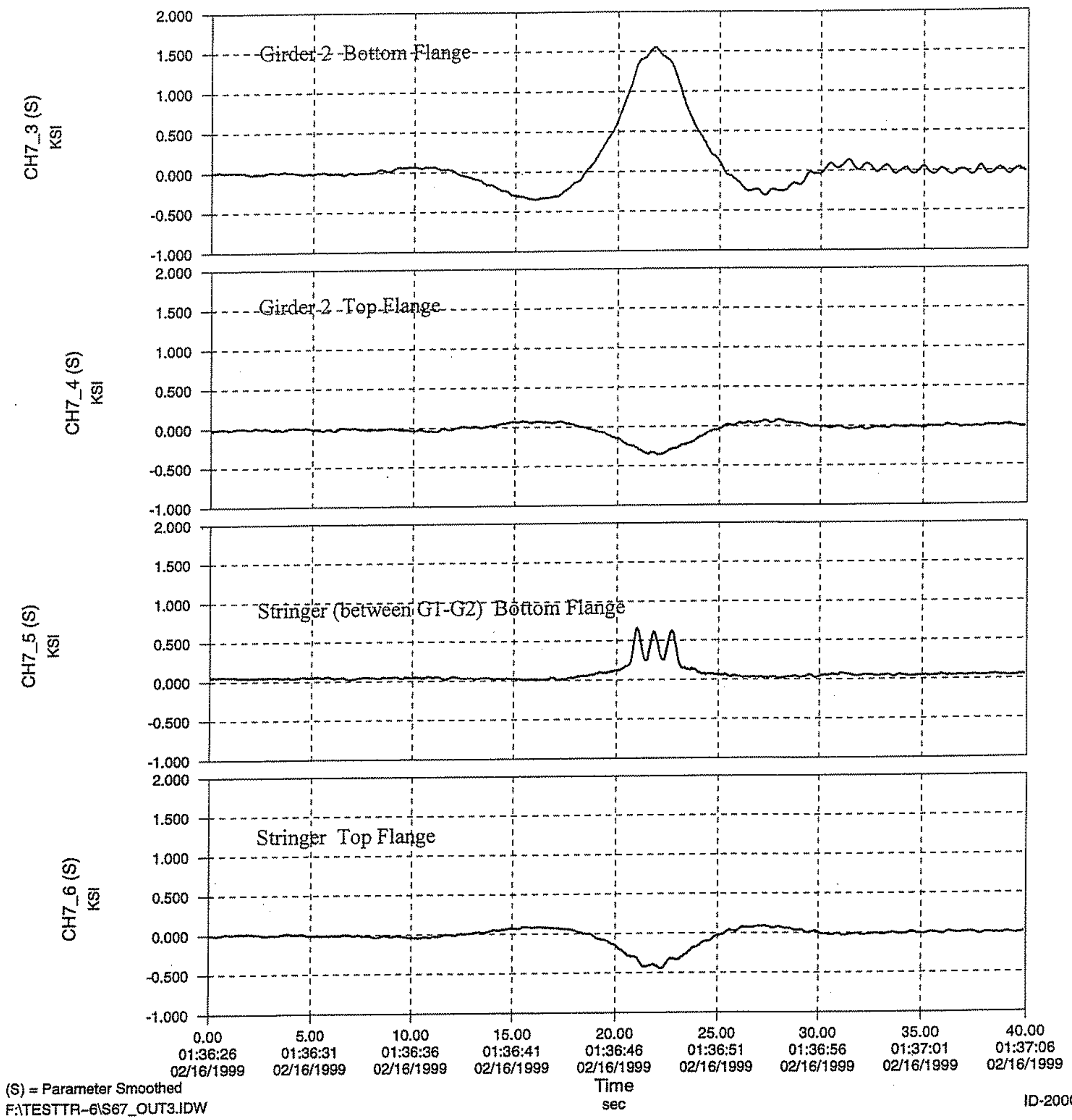
Test Vehicle at Span 7/Section 1: Vehicle Outbound on Outbound Track @ Nominal 10 mph

ATLSS Engineering Research Center
March 25, 1999

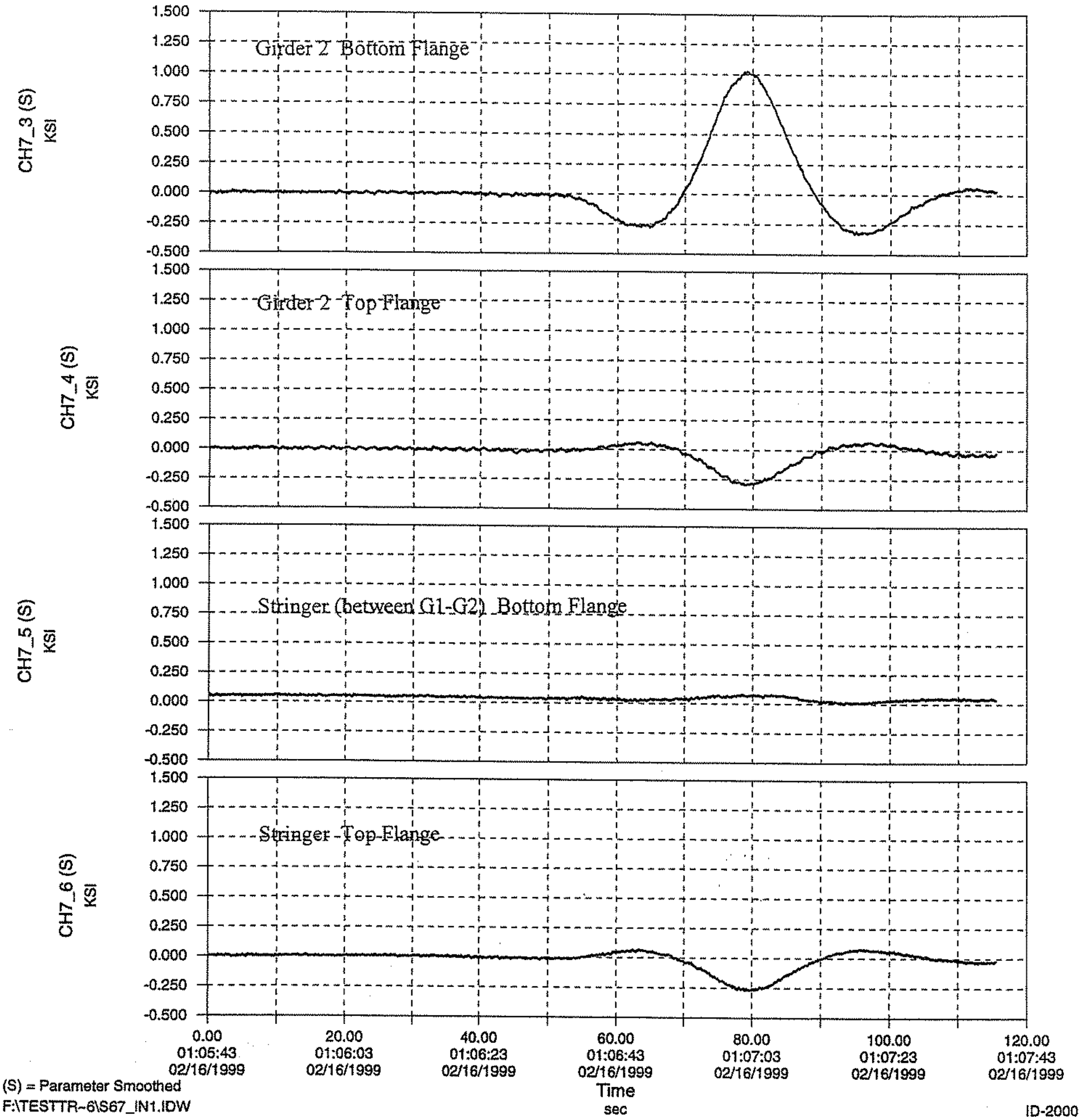
Saw Mill Run Bridge



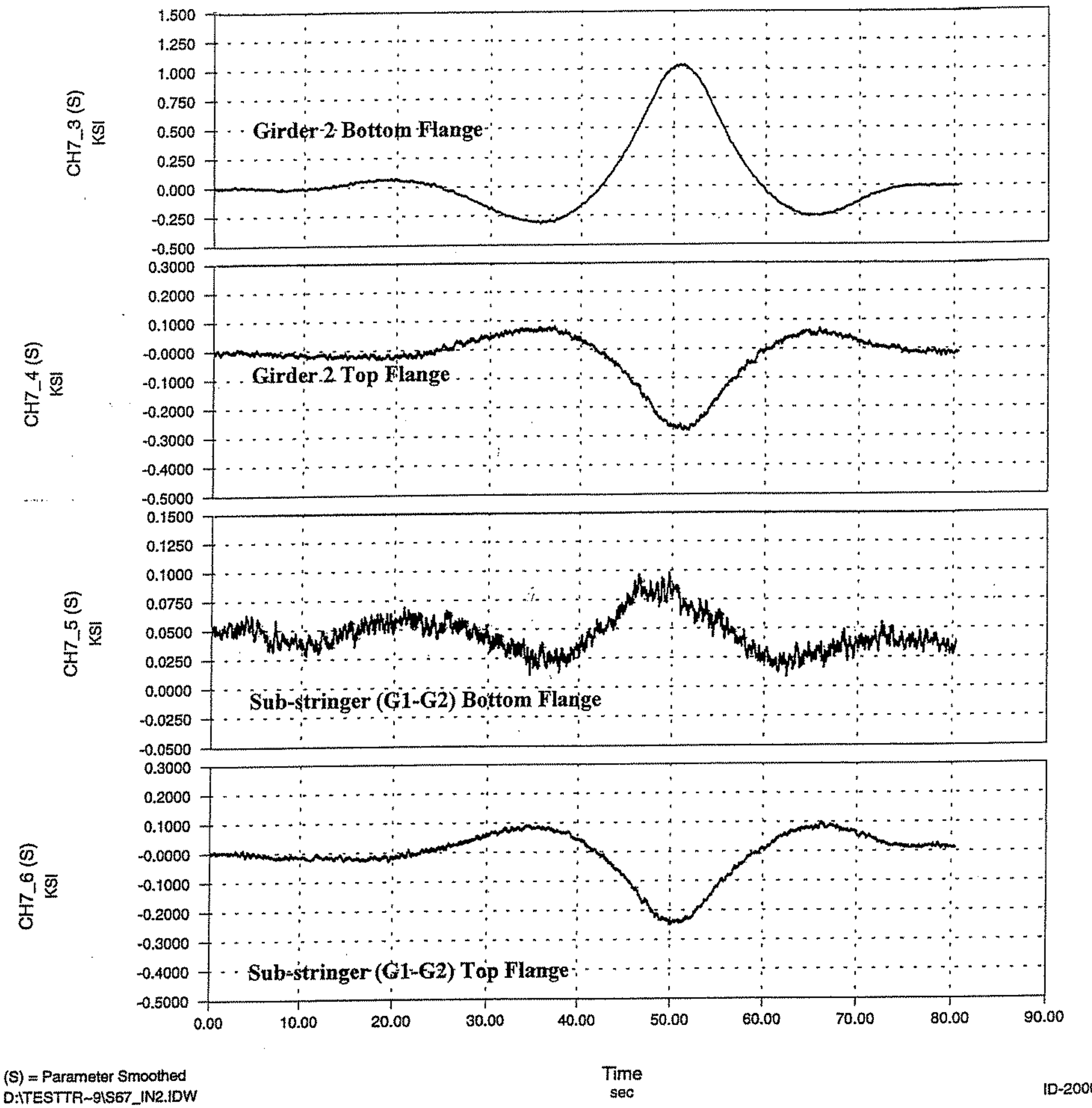
Test Vehicle at Span 7/Section 1; Vehicle Inbound on Outbound Track @ Nominal 10 mph



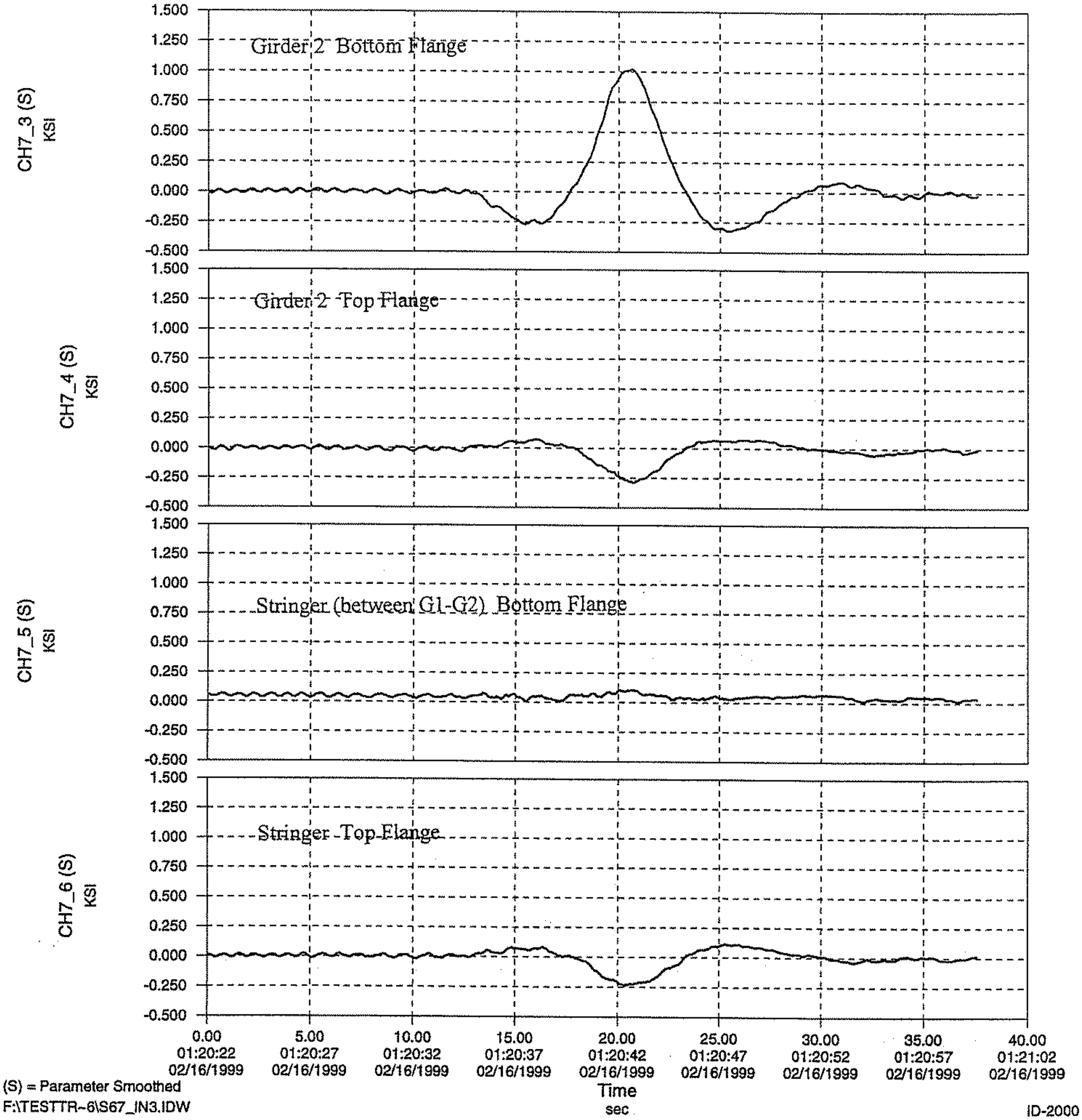
Test Vehicle at Span 7/Section 1: Vehicle Outbound on Outbound Track @ Nominal 25 mph



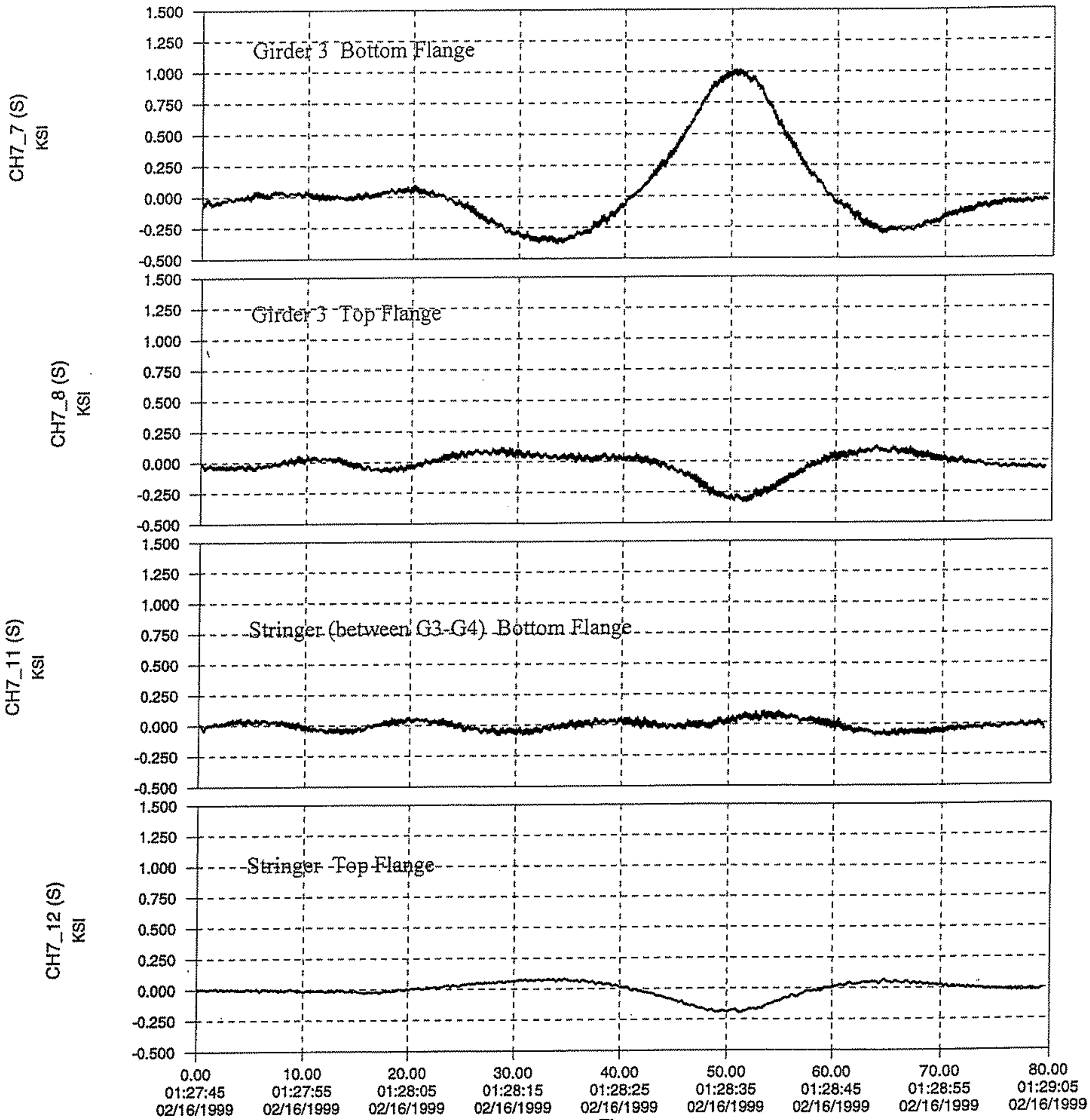
Test Vehicle at Span 7/Section 1: Vehicle Inbound on Inbound Track @ Nominal 10 mph



Test Vehicle at Span 7/Section 1; Vehicle Outbound on Inbound Track @ Nominal 10 mph



Test Vehicle at Span 7/Section 1: Vehicle Inbound on Inbound Track @ Nominal 25 mph



(S) = Parameter Smoothed
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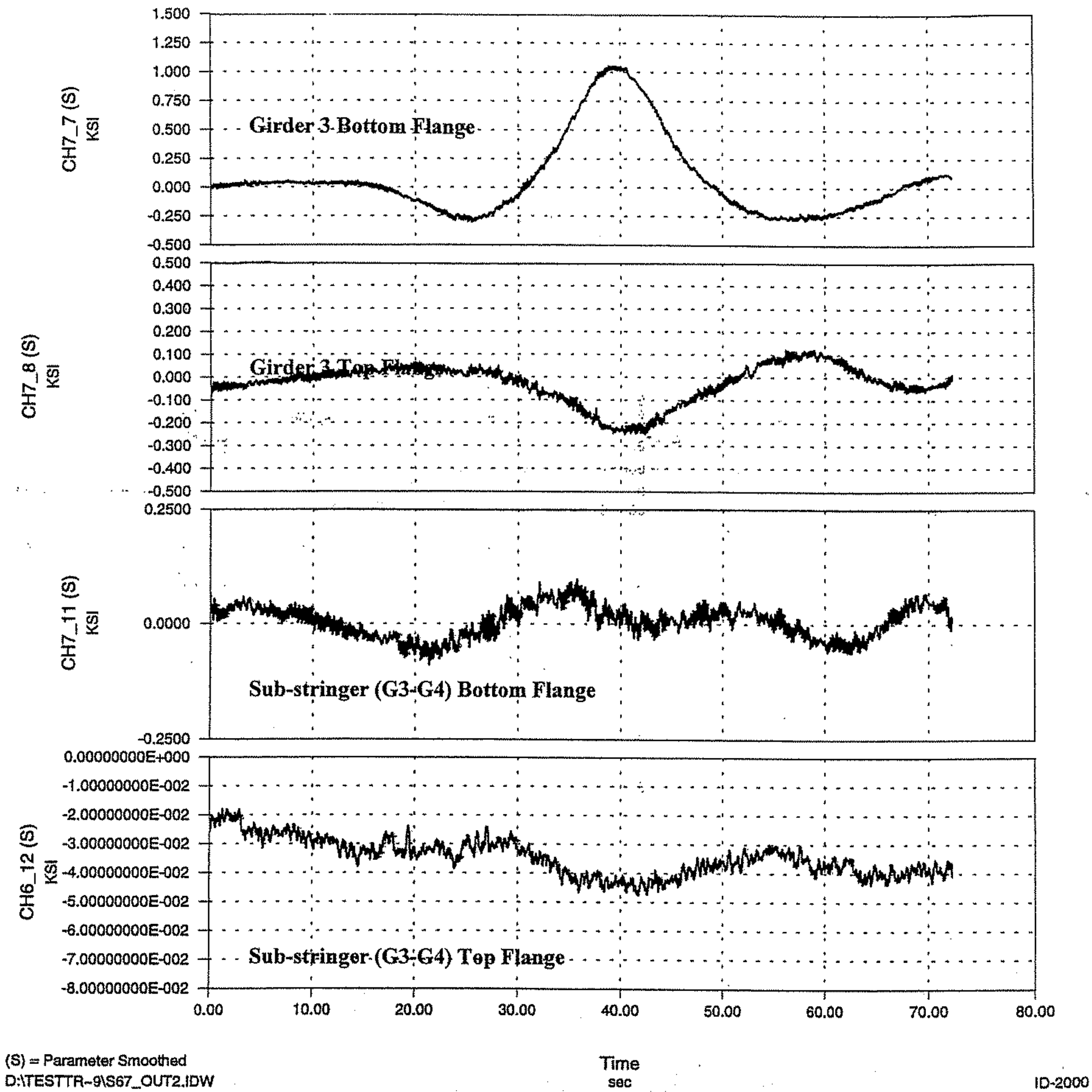
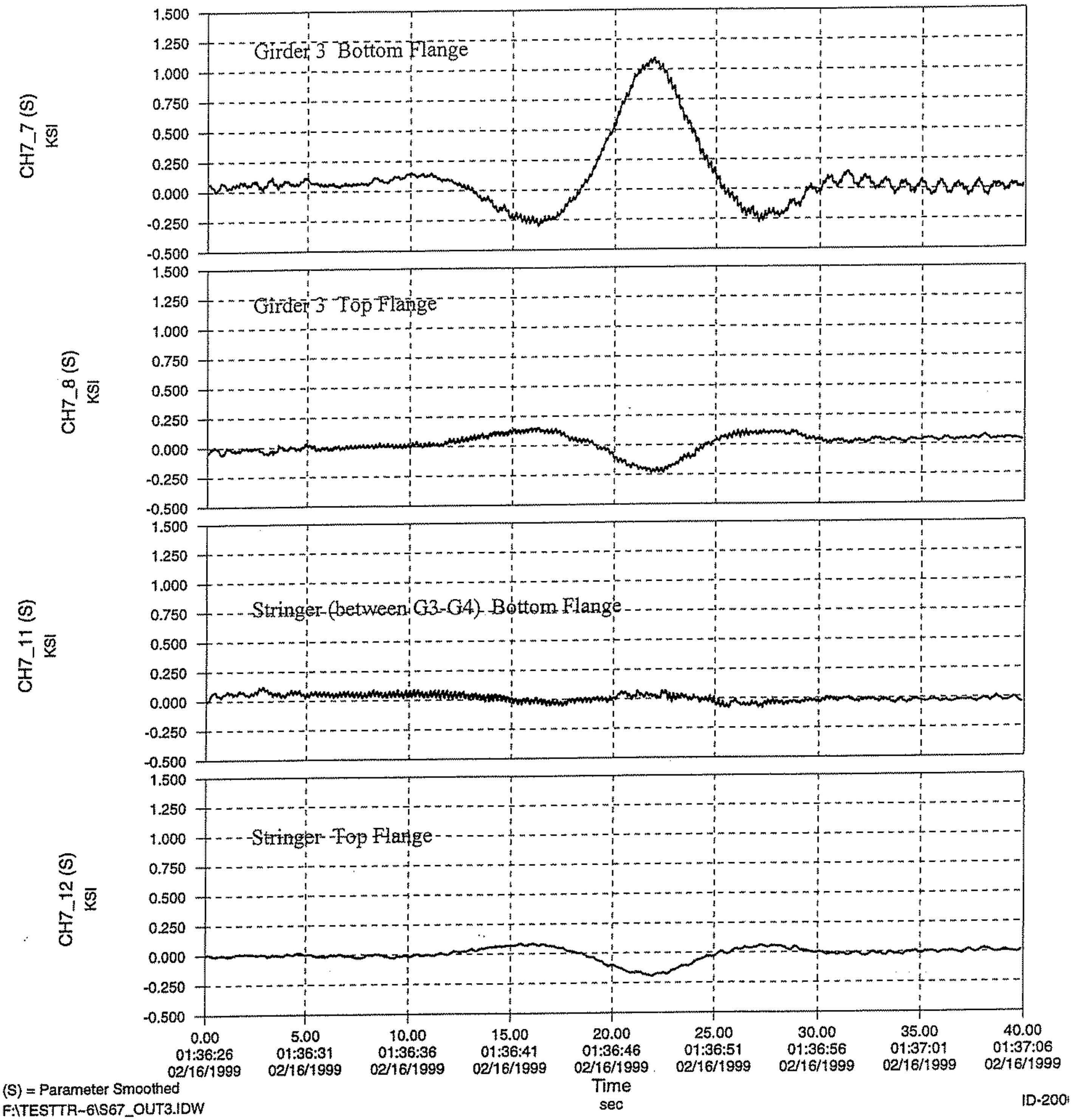
ID-200C

Test Vehicle at Span 7/Section 1: Vehicle Outbound on Outbound Track @ Nominal 10 mph



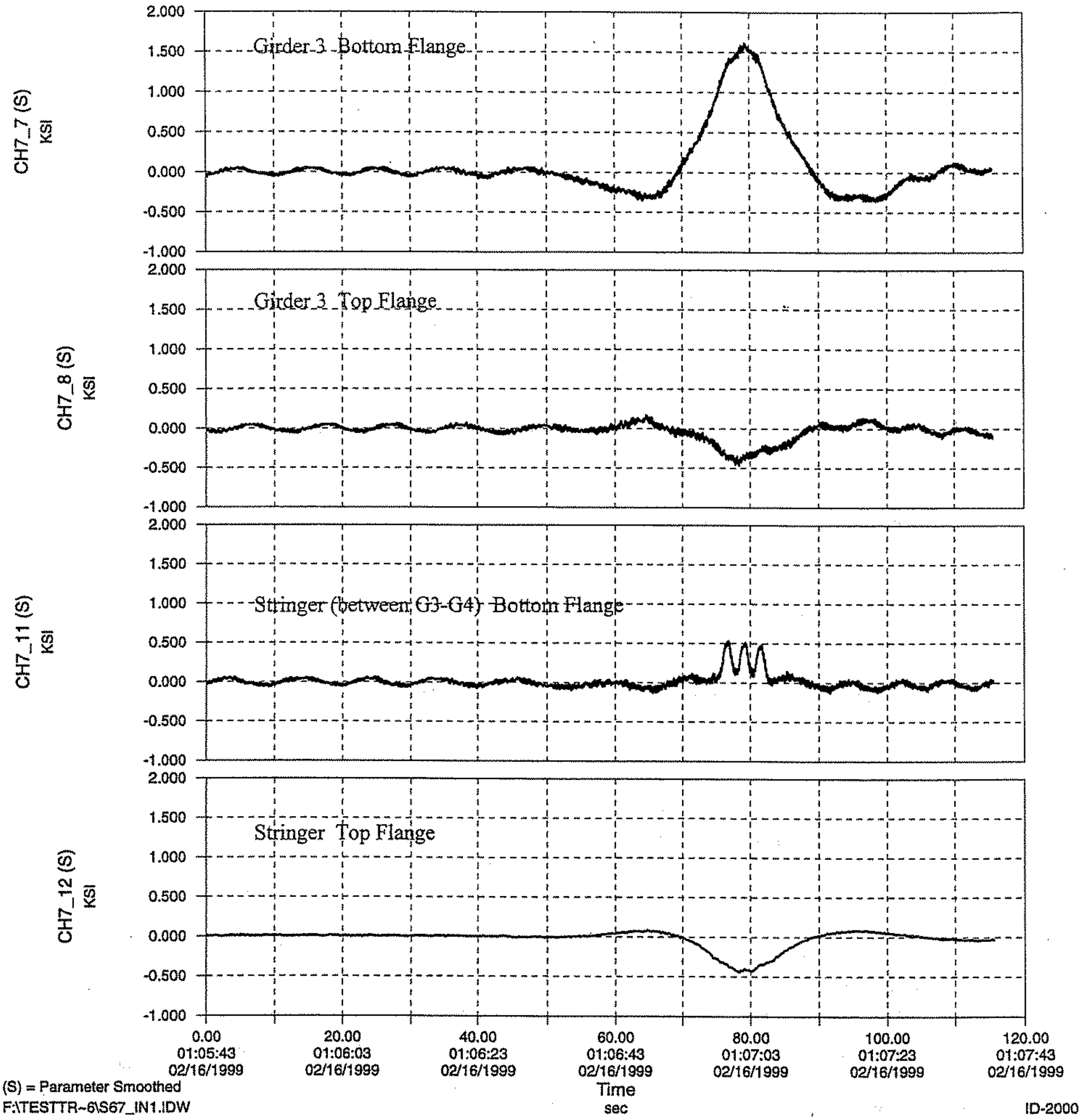
Test Vehicle at Span 7/Section 1; Vehicle Inbound on Outbound Track @ Nominal 10 mph



(S) = Parameter Smoothed
F:\TESTTR~6\S67_OUT3.IDW

ID-200

Test Vehicle at Span 7/Section 1: Vehicle Outbound on Outbound Track @ Nominal 25 mph



(S) = Parameter Smoothed
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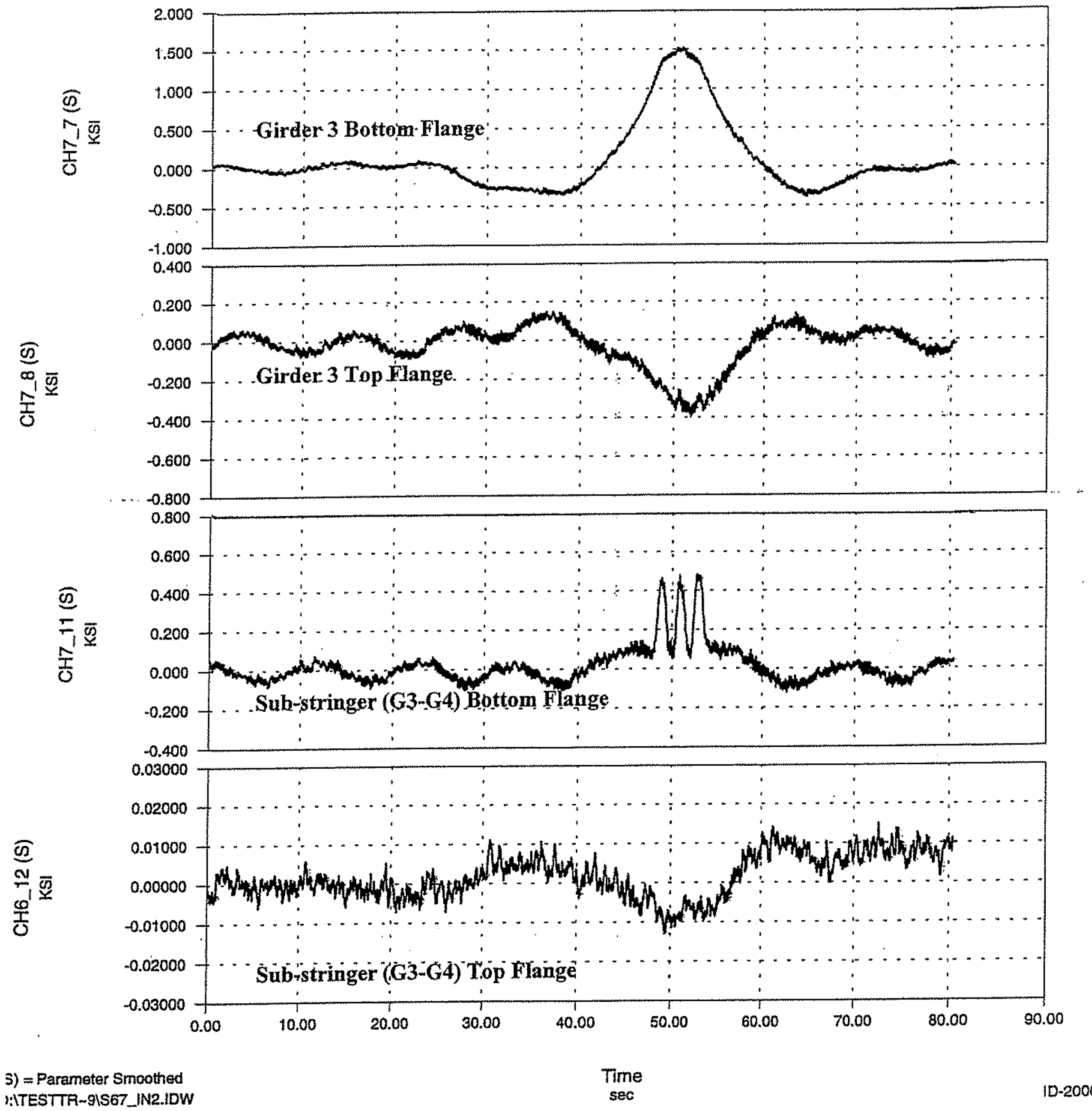
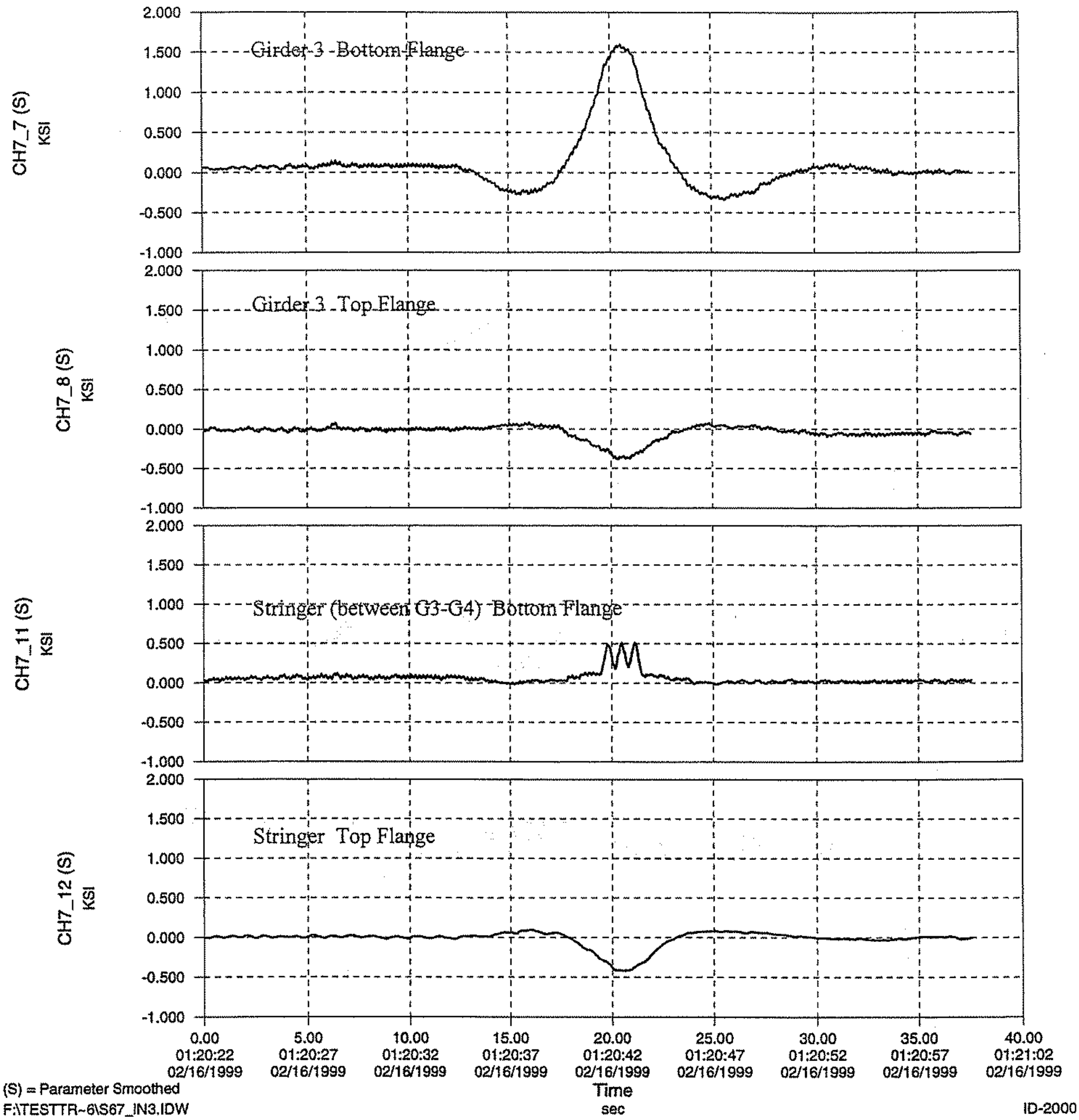
ID-2000

Test Vehicle at Span 7/Section 1: Vehicle Inbound on Inbound Track @ Nominal 10 mph



Test Vehicle at Span 7/Section 1; Vehicle Outbound on Inbound Track @ Nominal 10 mph



(S) = Parameter Smoothed
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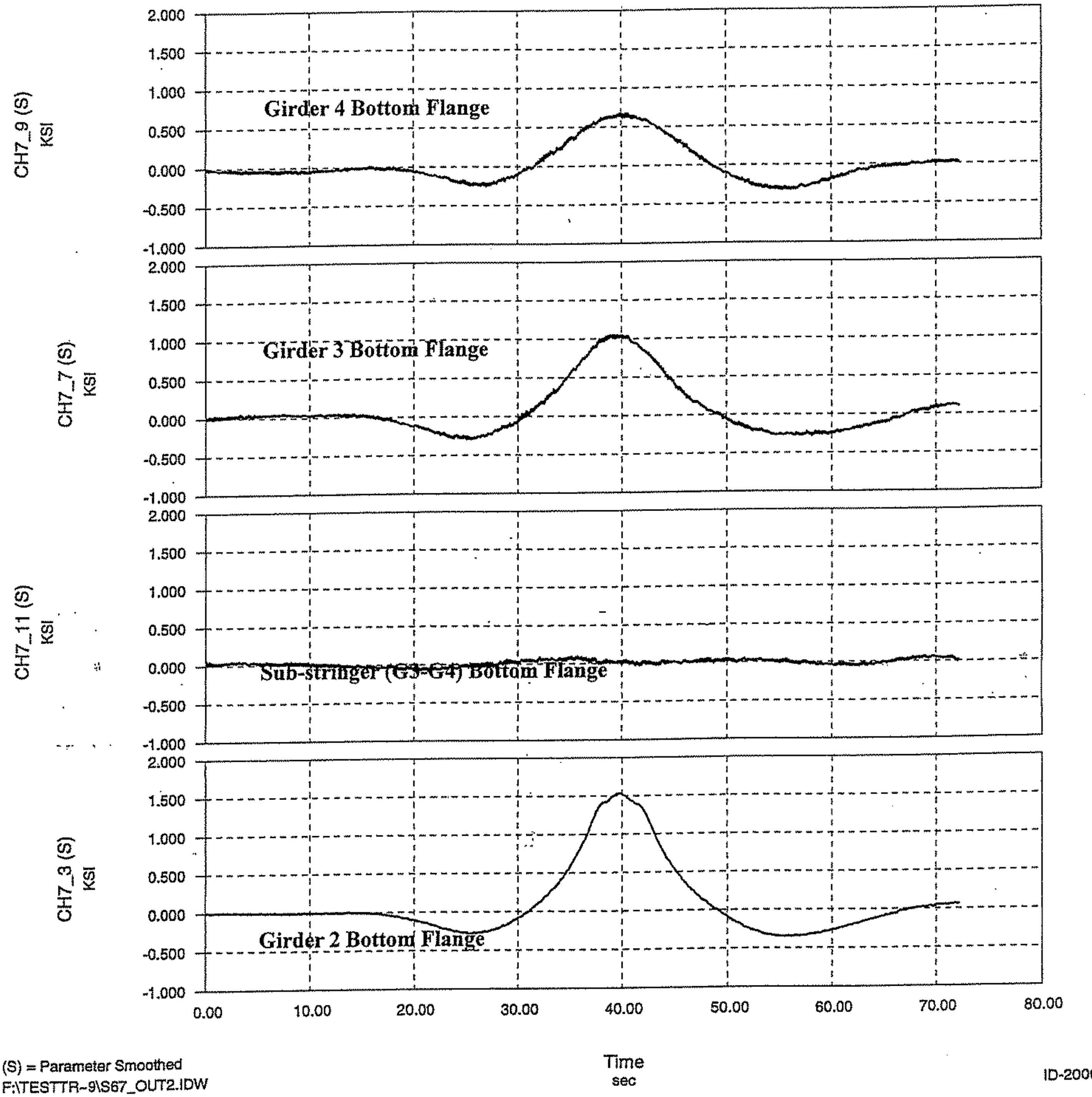
ID-2000

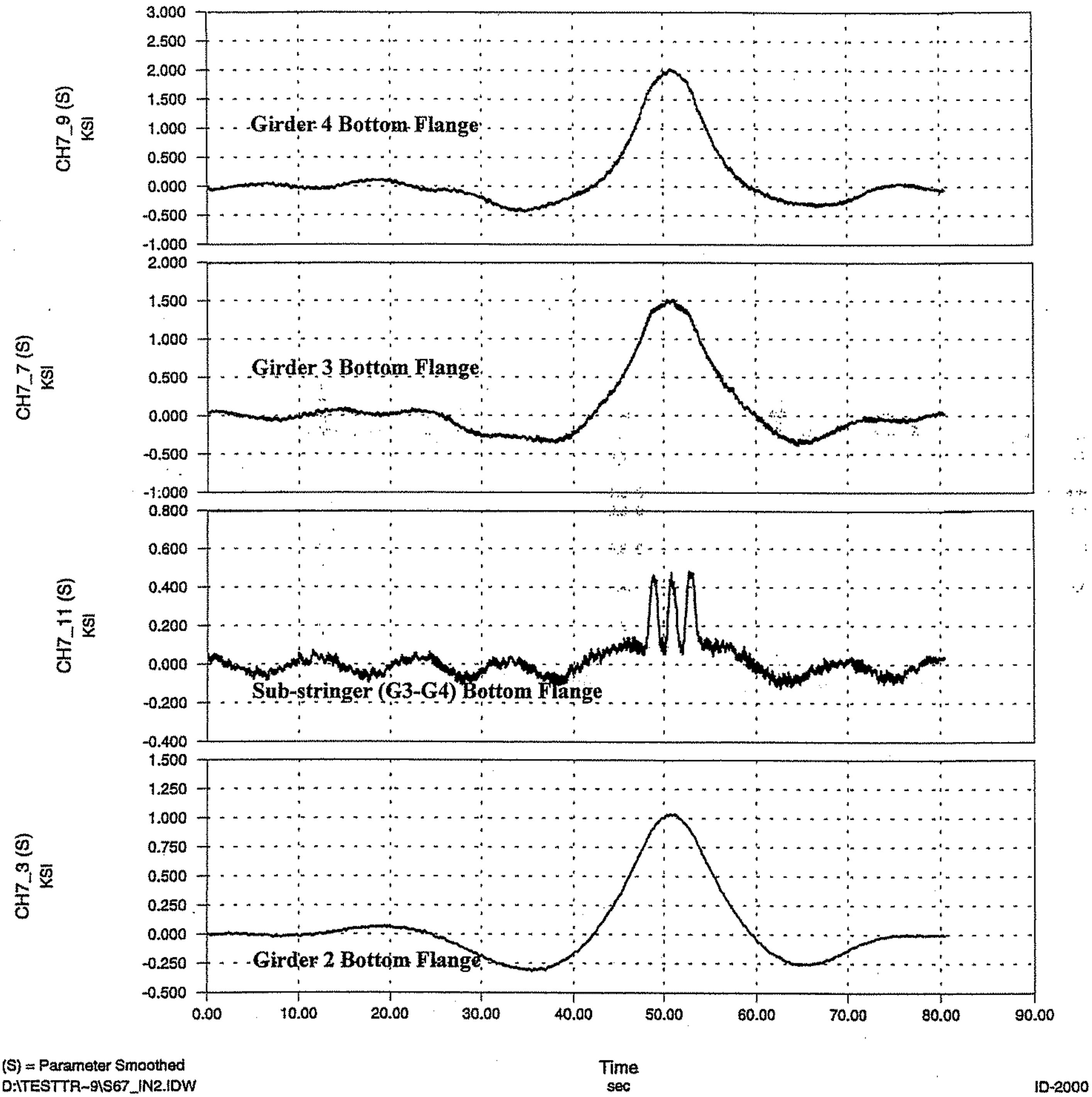
Test Vehicle at Span 7/Section 1: Vehicle Inbound on Inbound Track @ Nominal 25 mph

ATLSS Engineering Research Center
March 25, 1999

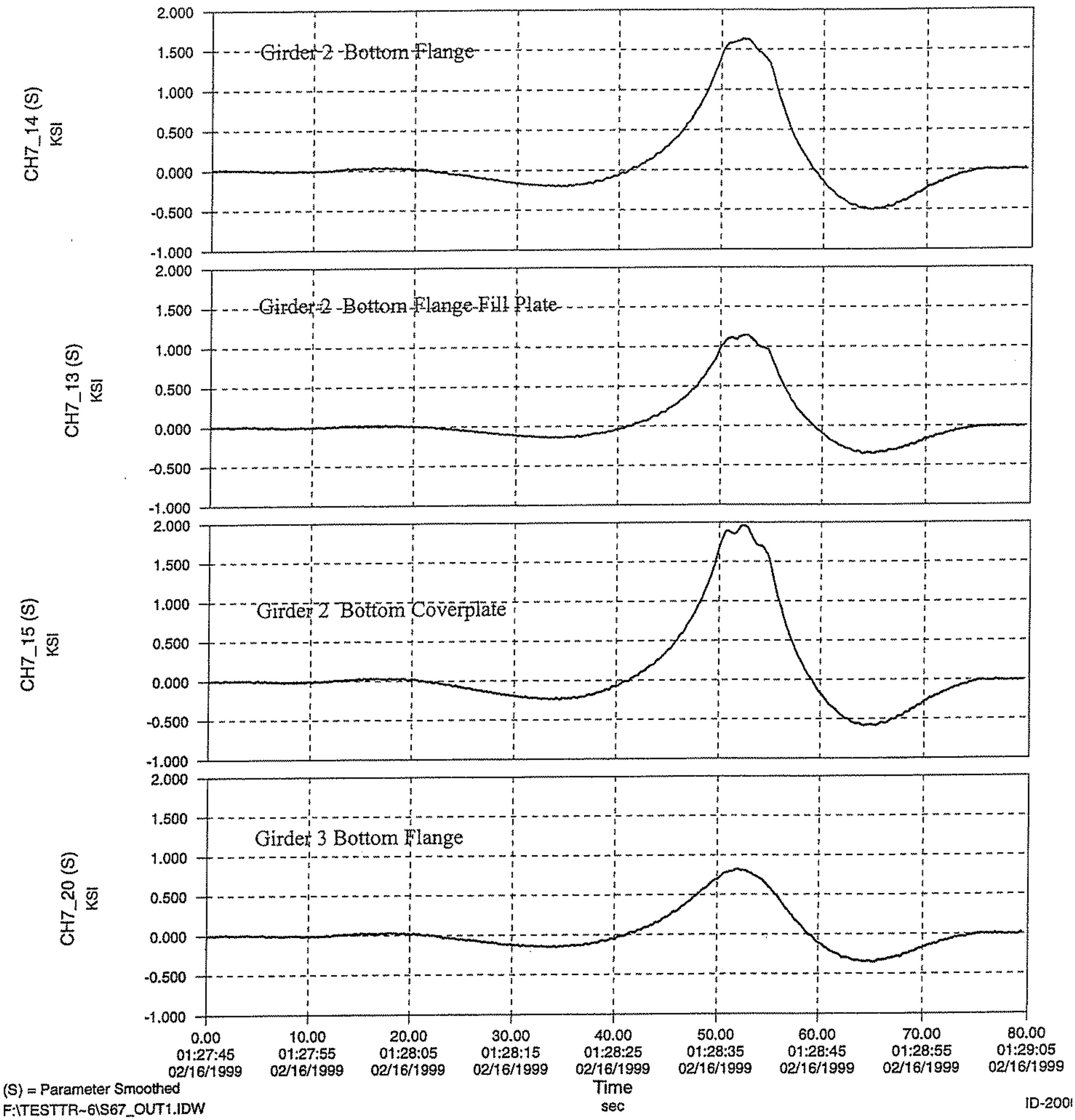
Saw Mill Run Bridge



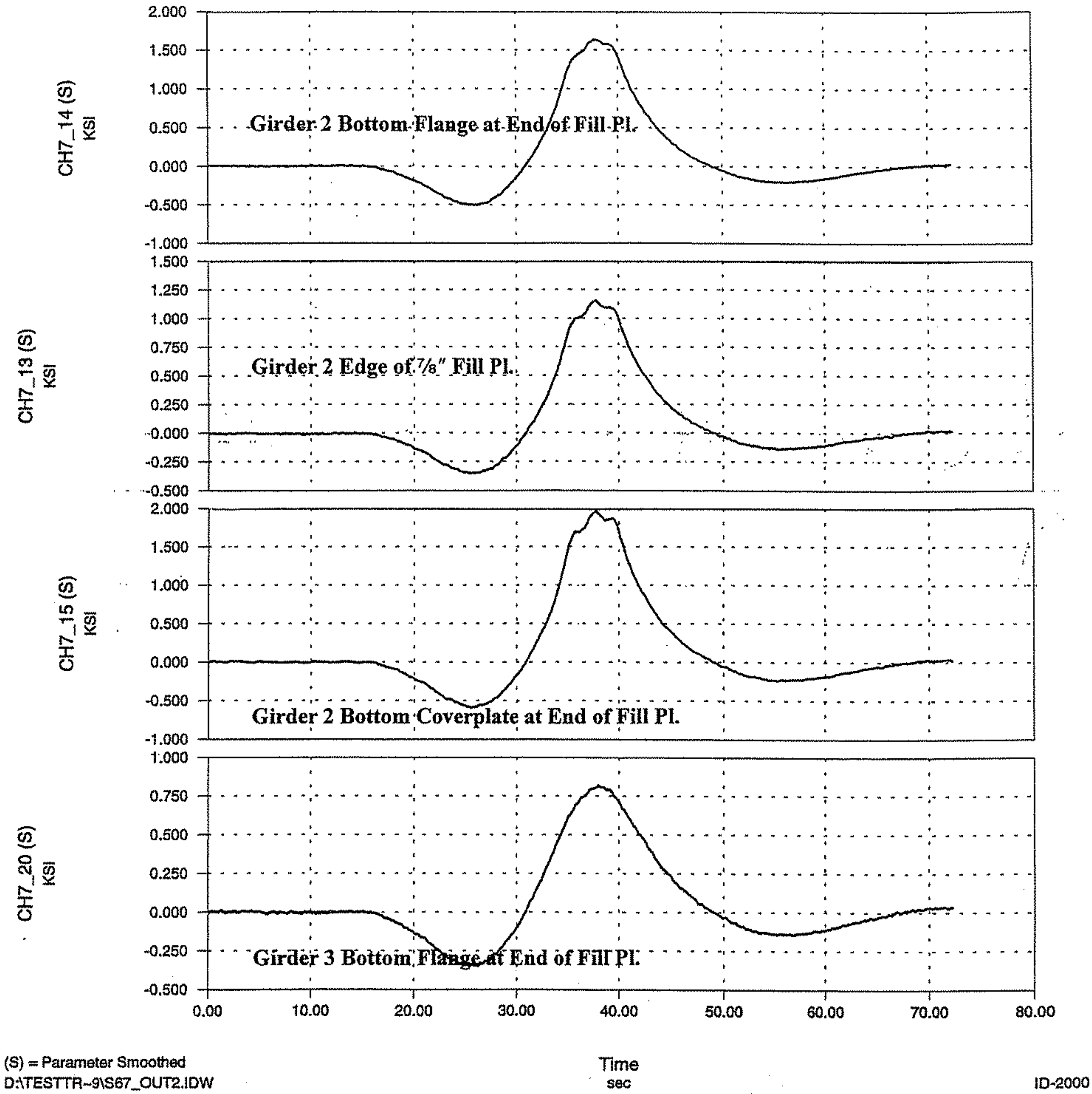
Test Vehicle at Span 7/Section 1; Vehicle Inbound on Outbound Track @ Nominal 10 mph



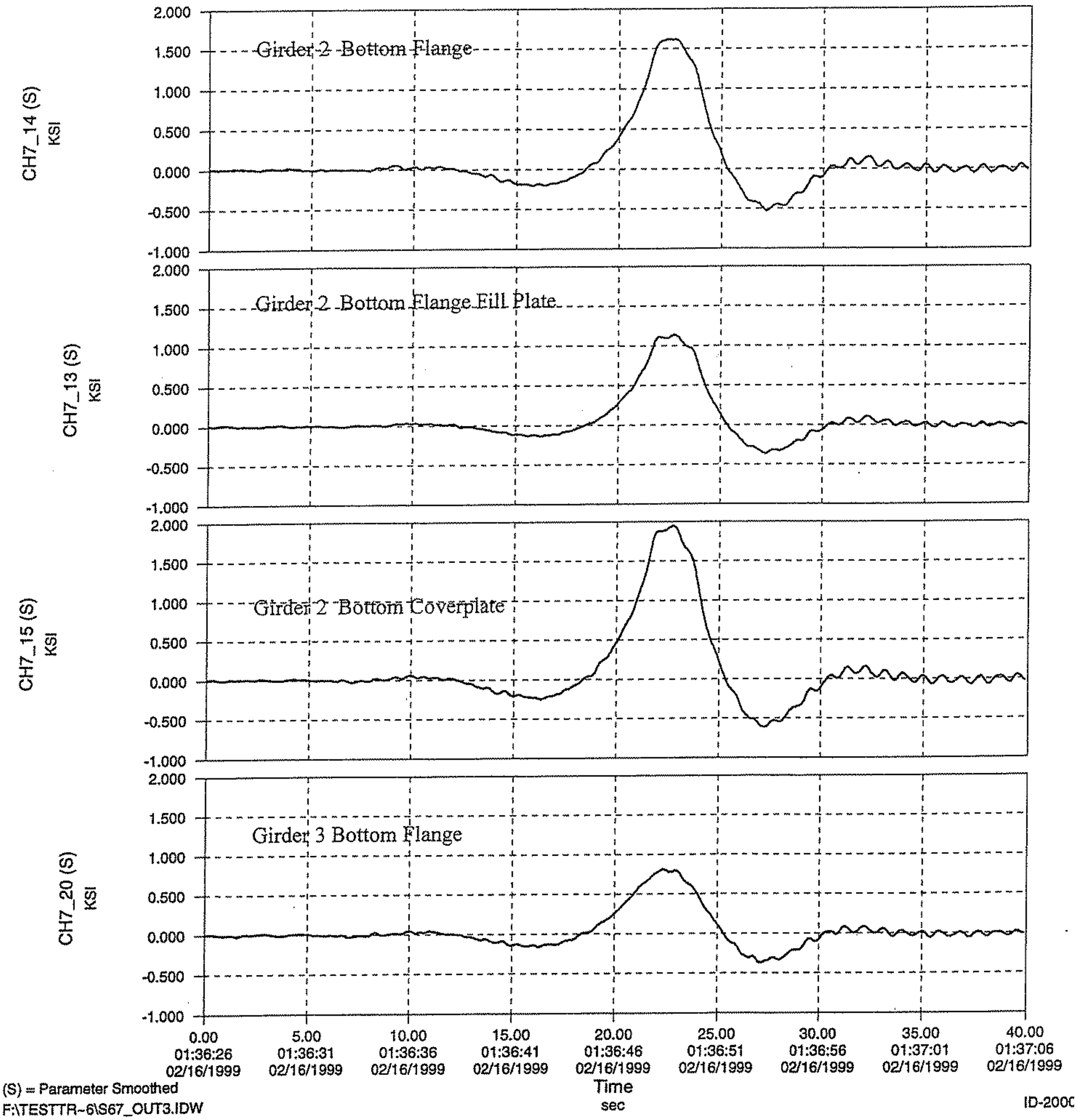
Test Vehicle at Span 7/Section 1; Vehicle Outbound on Inbound Track @ Nominal 10 mph



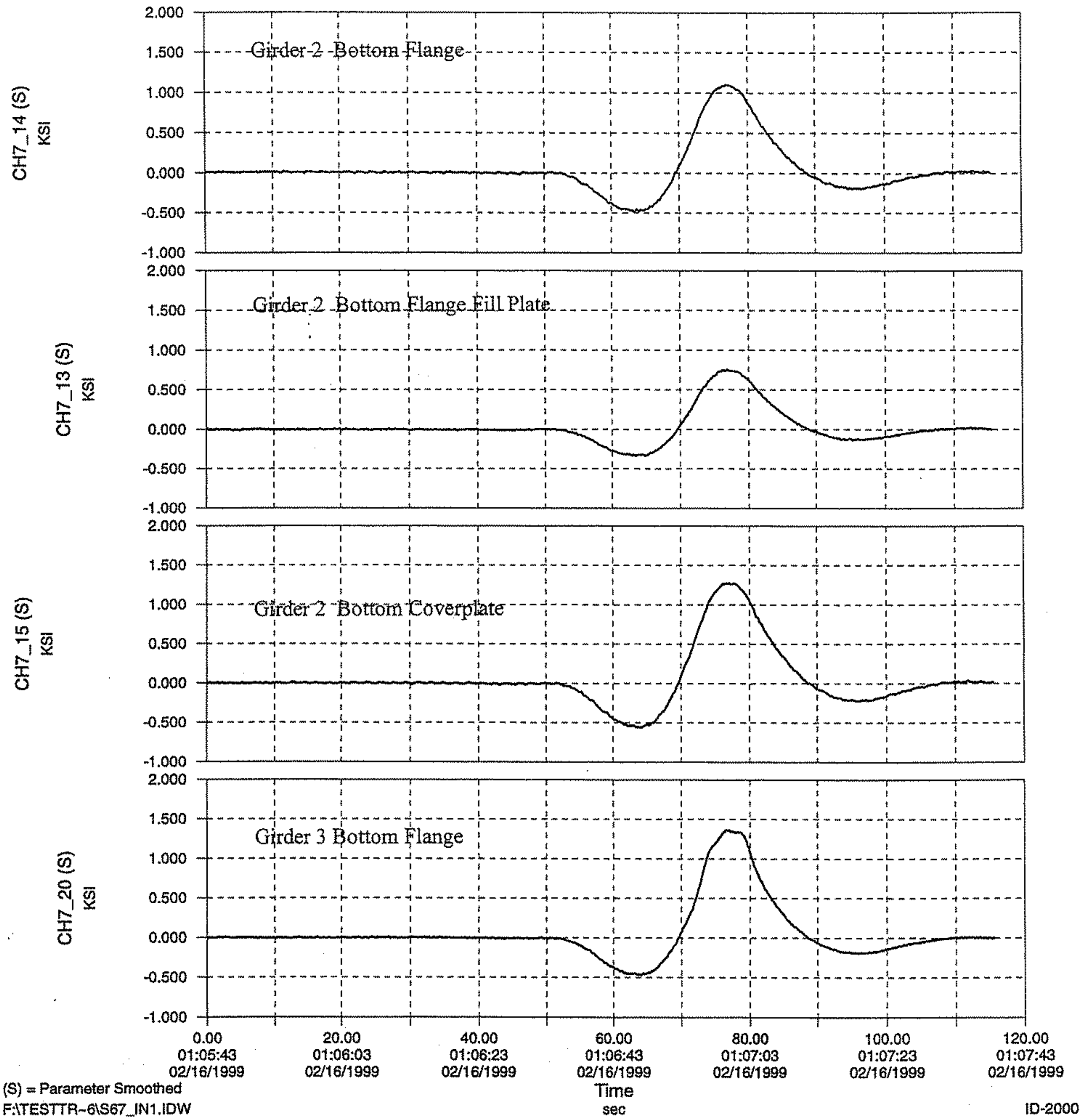
Test Vehicle at Span 7/Section 2: Vehicle Outbound on Outbound Track @ Nominal 10 mph



Test Vehicle at Span 7/Section 2; Vehicle Inbound on Outbound Track @ Nominal 10 mph



Test Vehicle at Span 7/Section 2: Vehicle Outbound on Outbound Track @ Nominal 25 mph



(S) = Parameter Smoothed
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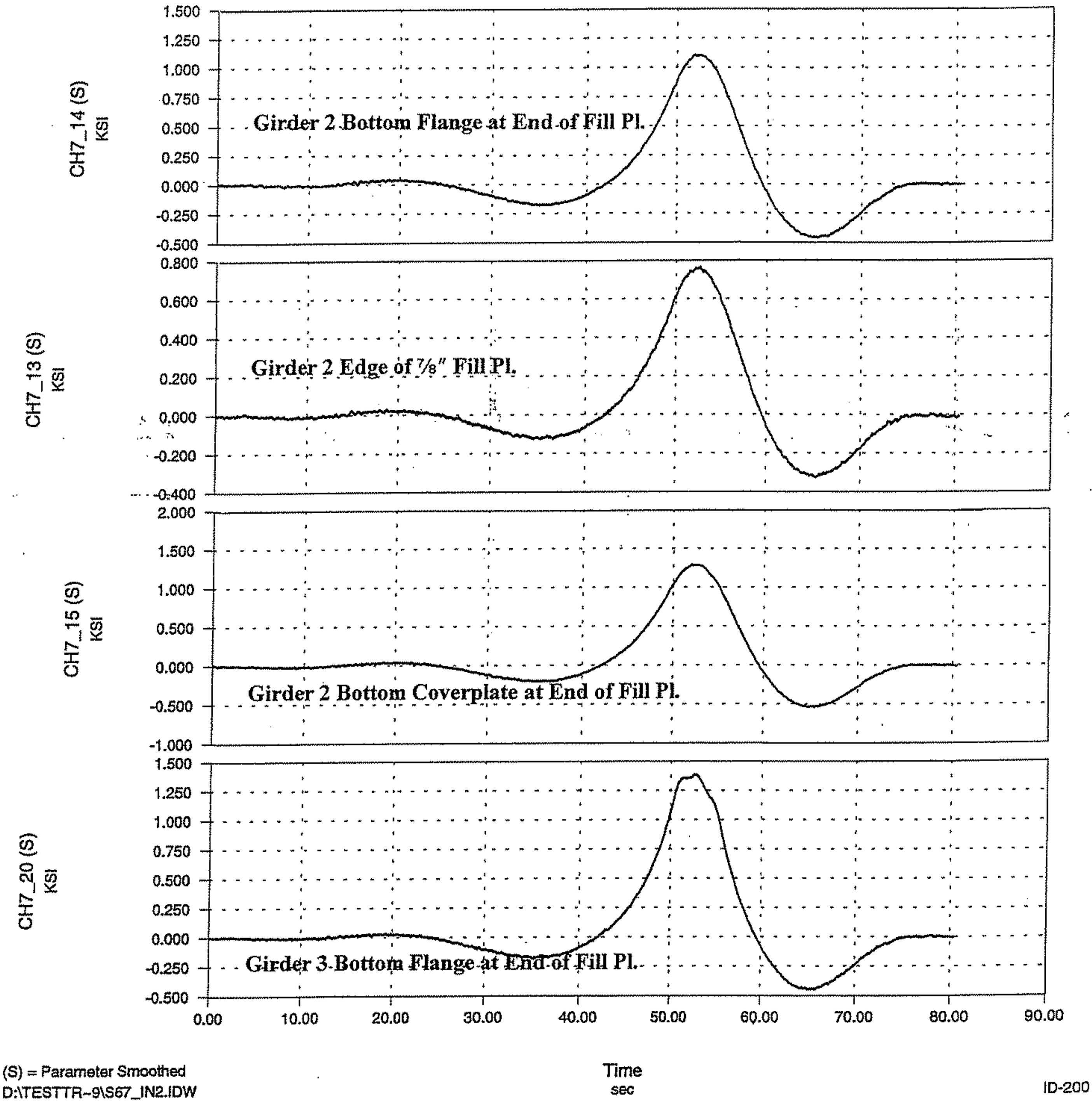
ID-2000

Test Vehicle at Span 7/Section 2: Vehicle Inbound on Inbound Track @ Nominal 10 mph



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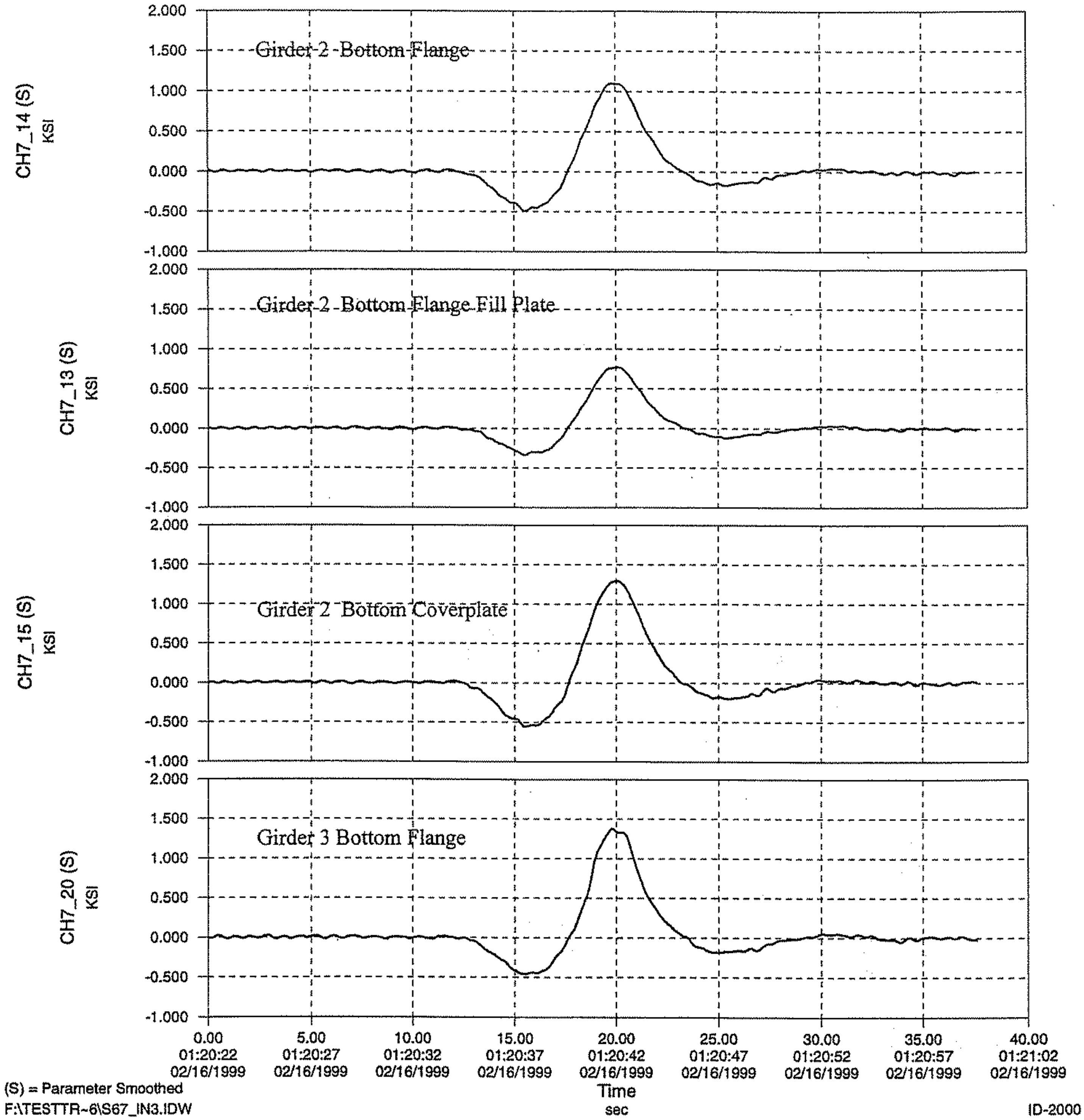
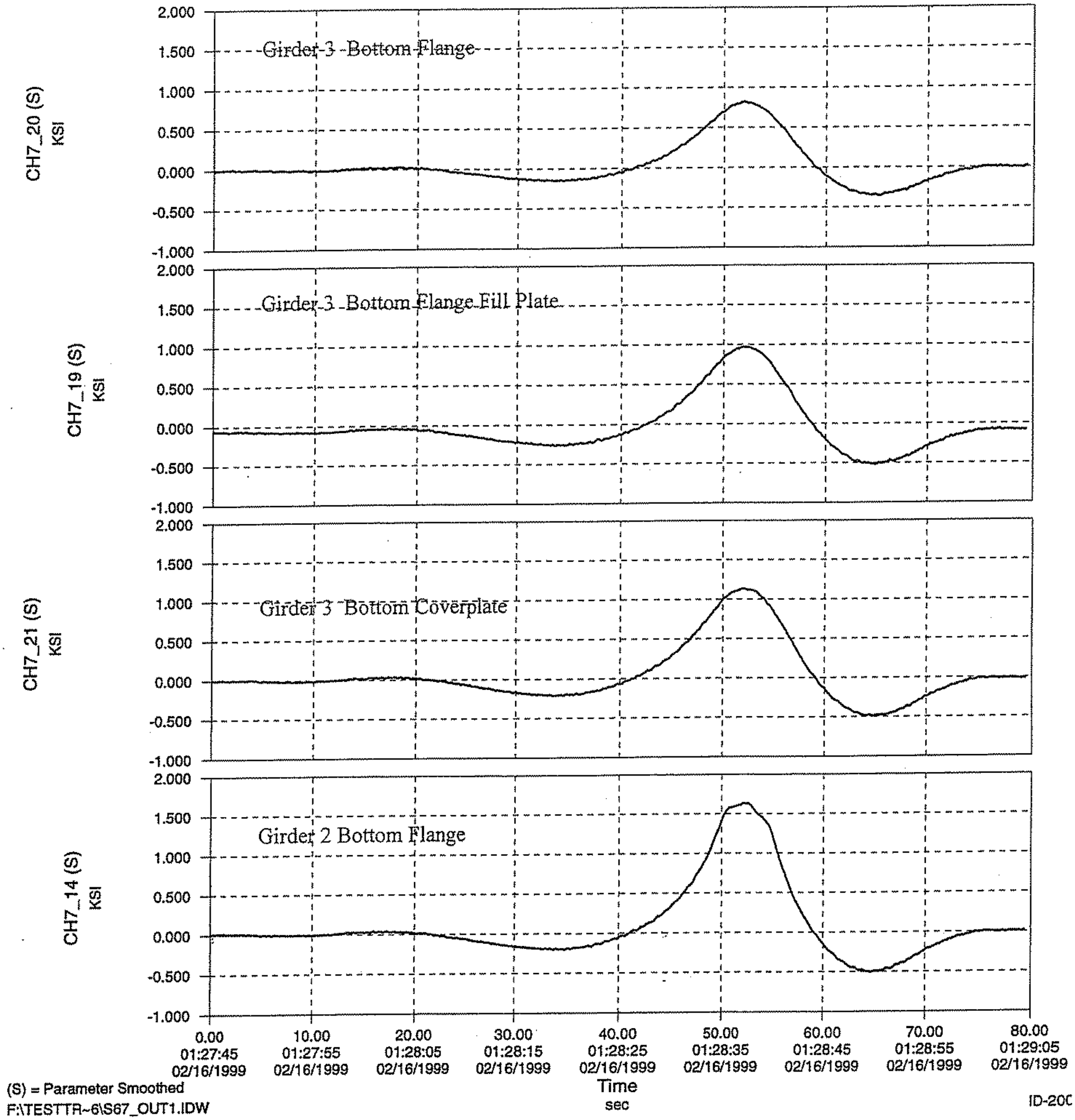
ID-200

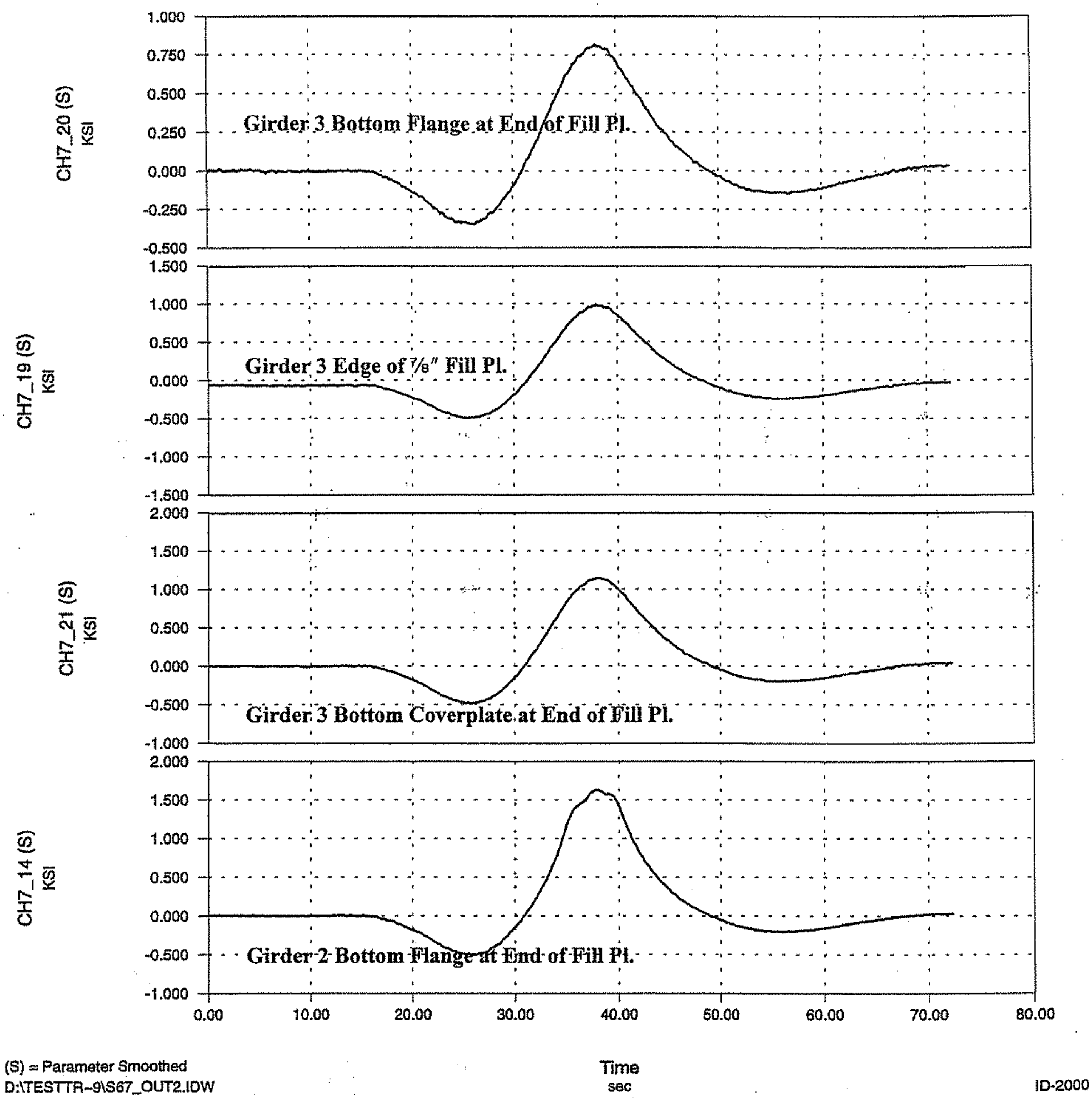
Test Vehicle at Span 7/Section 2; Vehicle Outbound on Inbound Track @ Nominal 10 mph



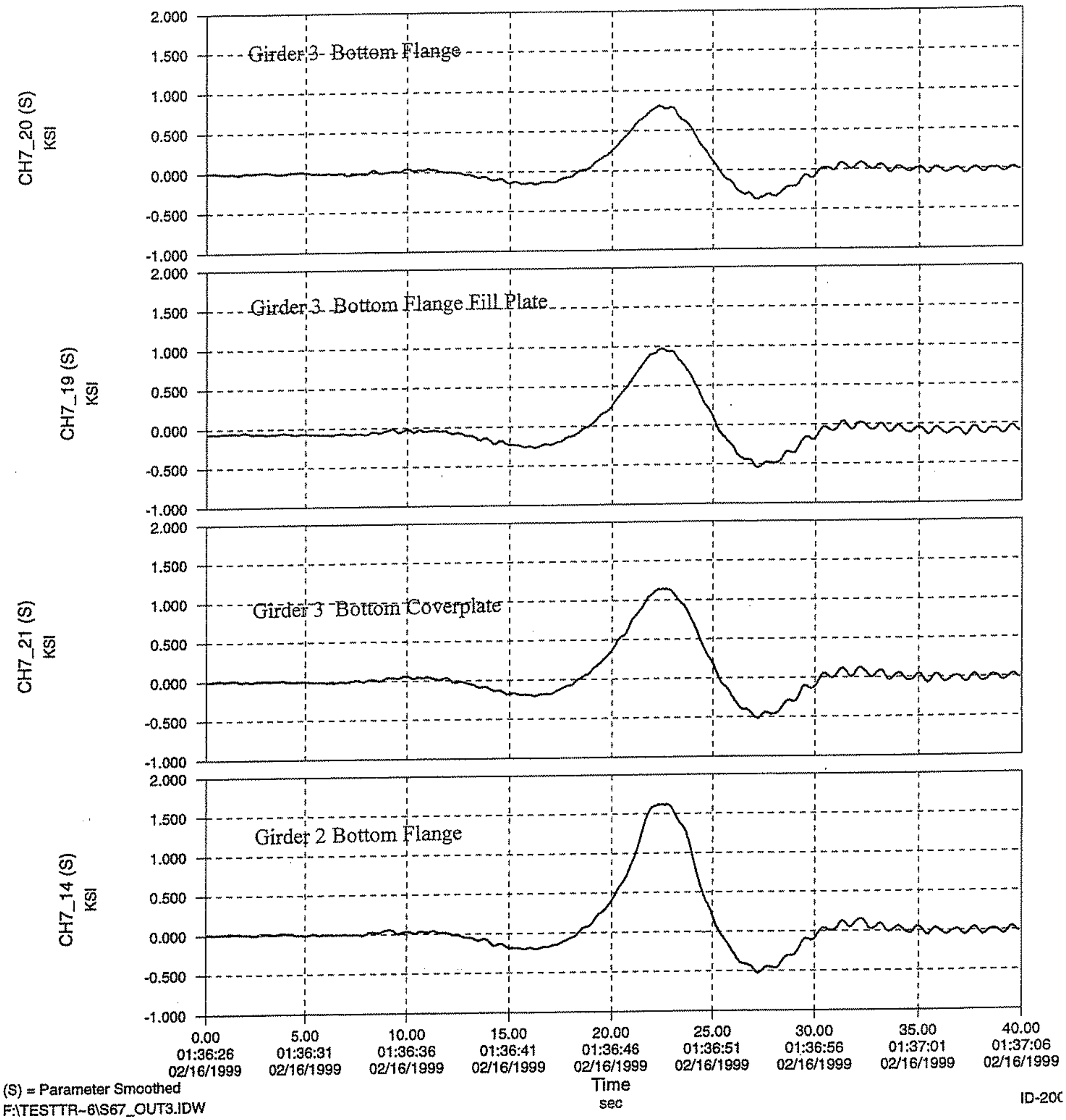
Test Vehicle at Span 7/Section 2: Vehicle Inbound on Inbound Track @ Nominal 25 mph



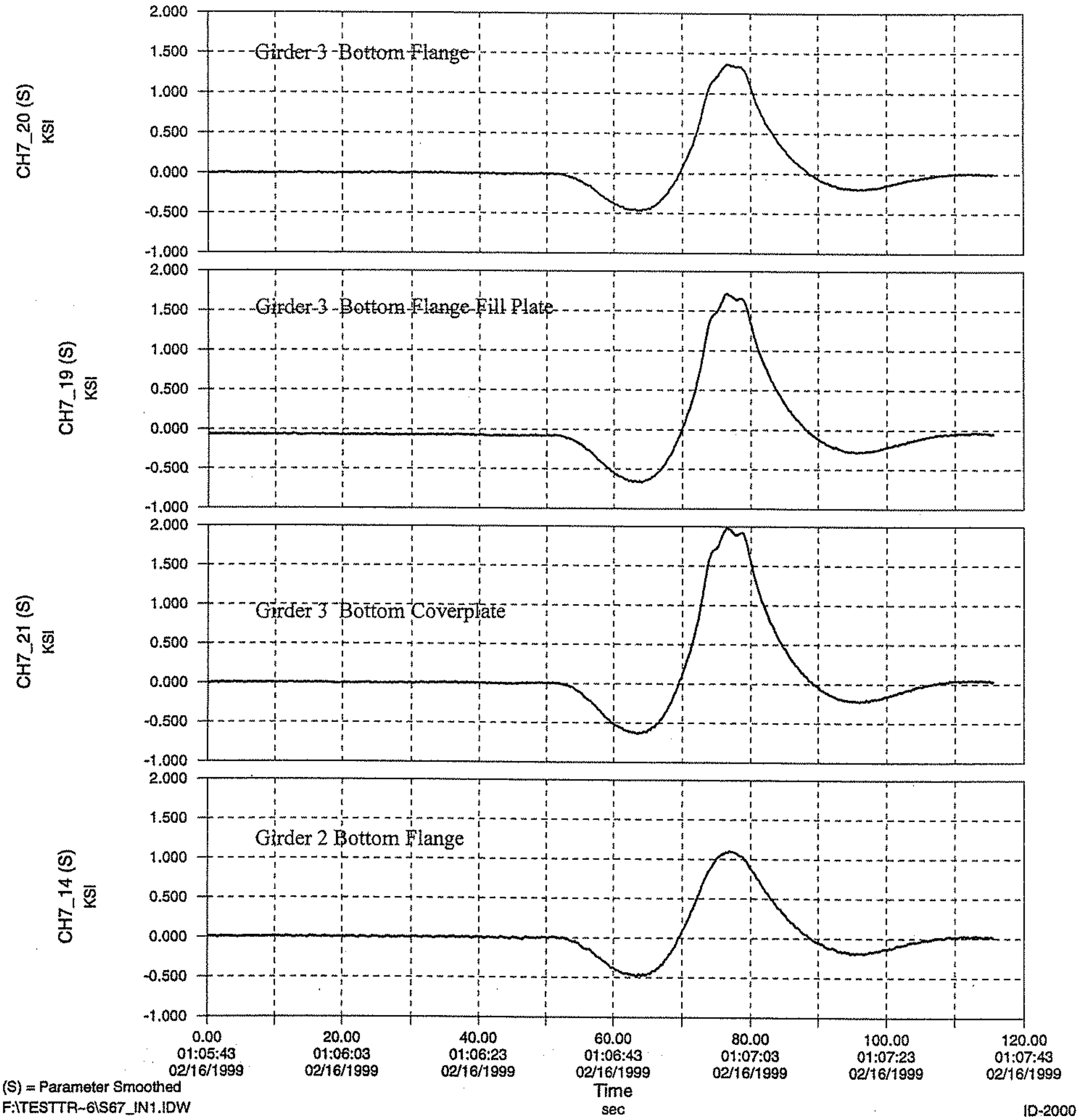
Test Vehicle at Span 7/Section 2: Vehicle Outbound on Outbound Track @ Nominal 10 mph



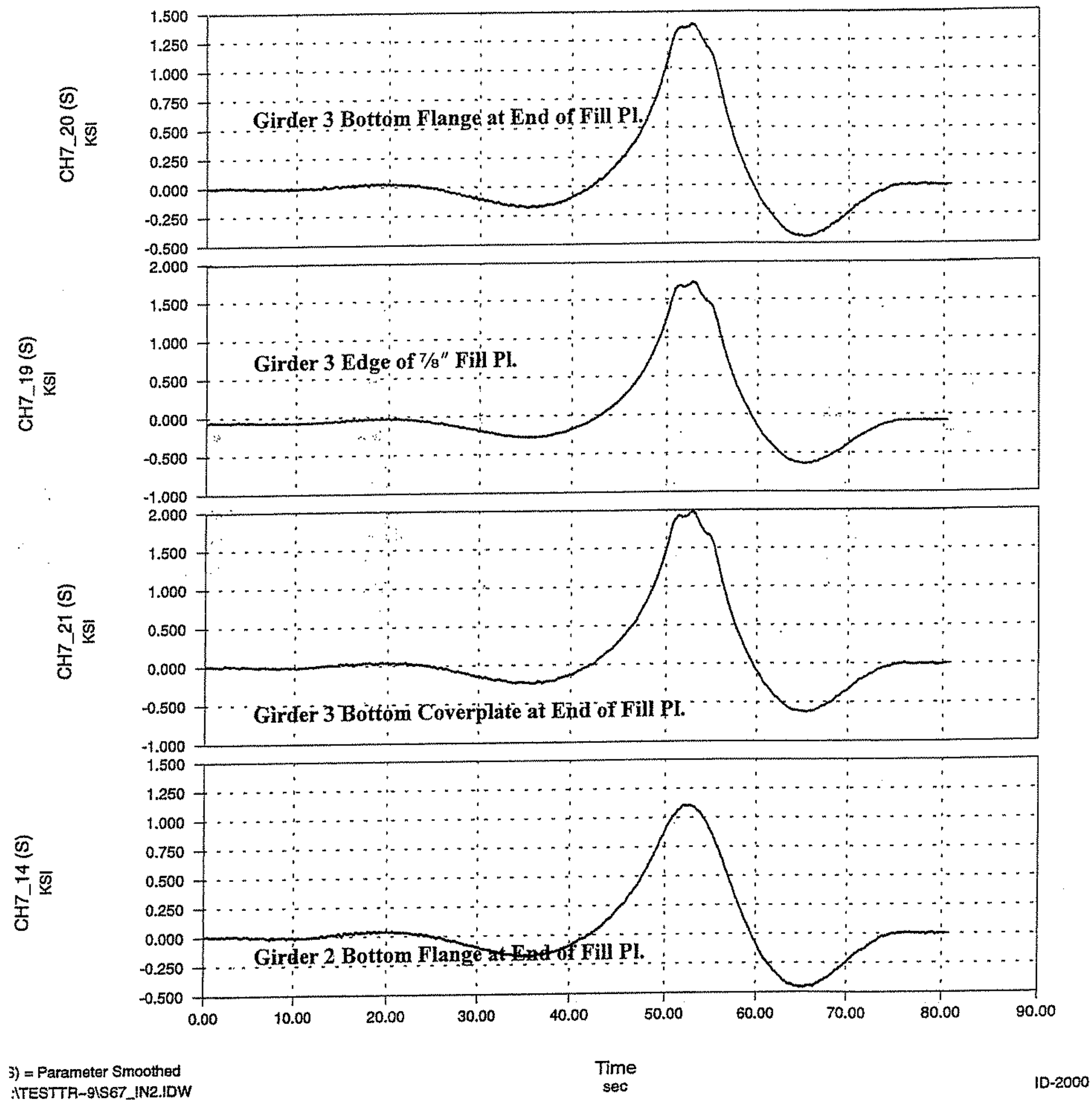
Test Vehicle at Span 7/Section 2; Vehicle Inbound on Outbound Track @ Nominal 10 mph



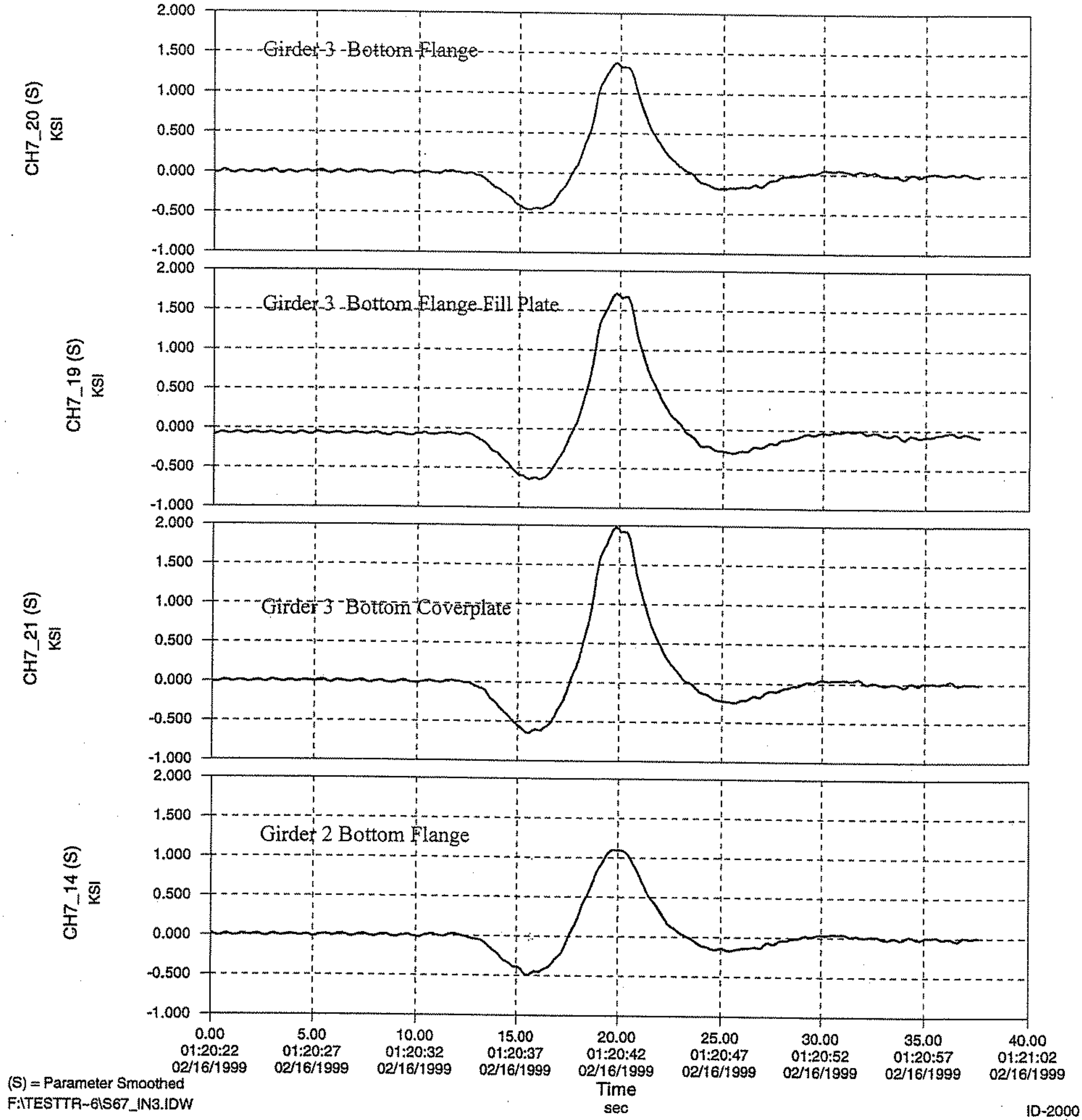
Test Vehicle at Span 7/Section 2: Vehicle Outbound on Outbound Track @ Nominal 25 mph



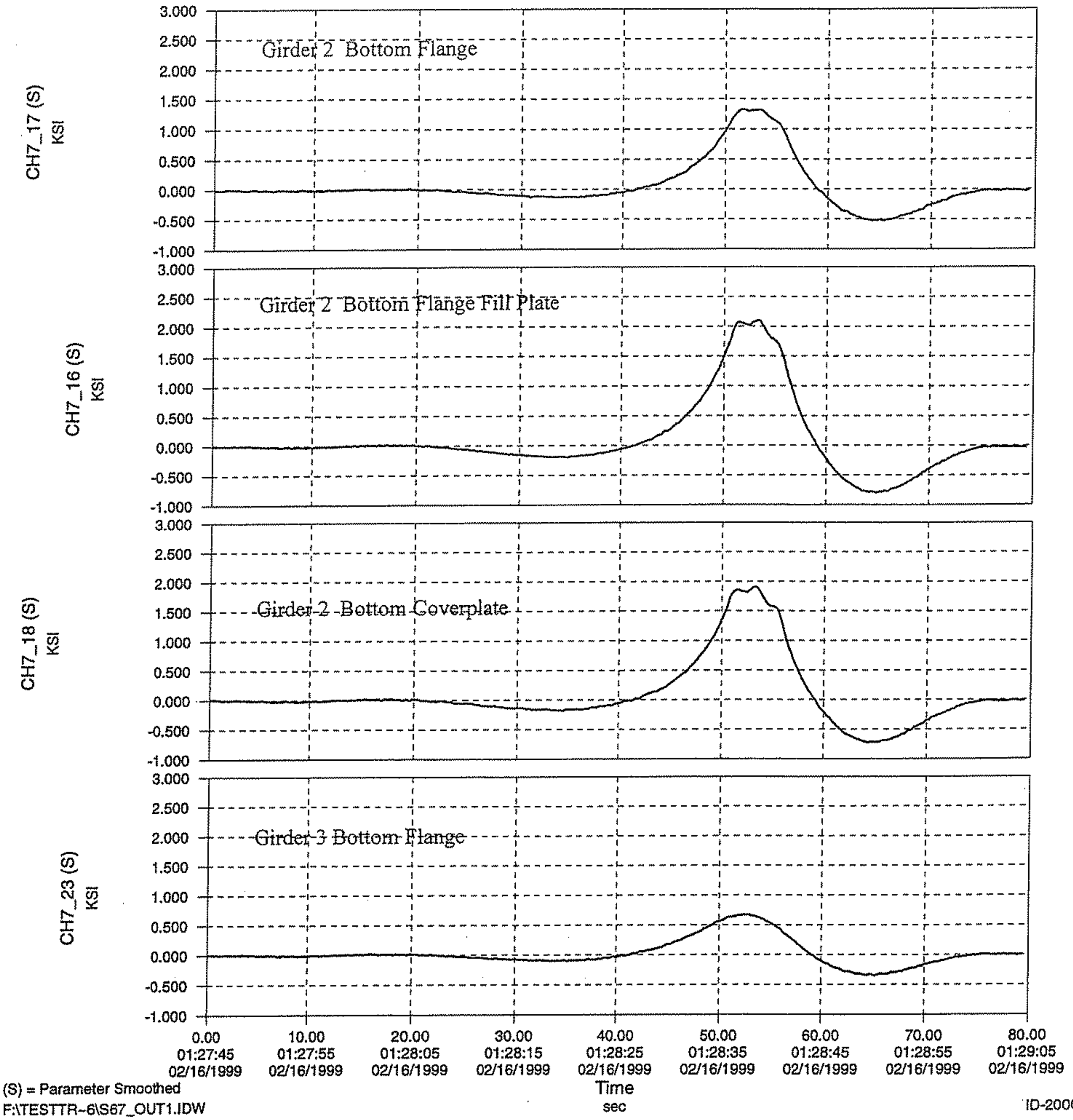
Test Vehicle at Span 7/Section 2: Vehicle Inbound on Inbound Track @ Nominal 10 mph



Test Vehicle at Span 7/Section 2; Vehicle Outbound on Inbound Track @ Nominal 10 mph



Test Vehicle at Span 7/Section 2: Vehicle Inbound on Inbound Track @ Nominal 25 mph



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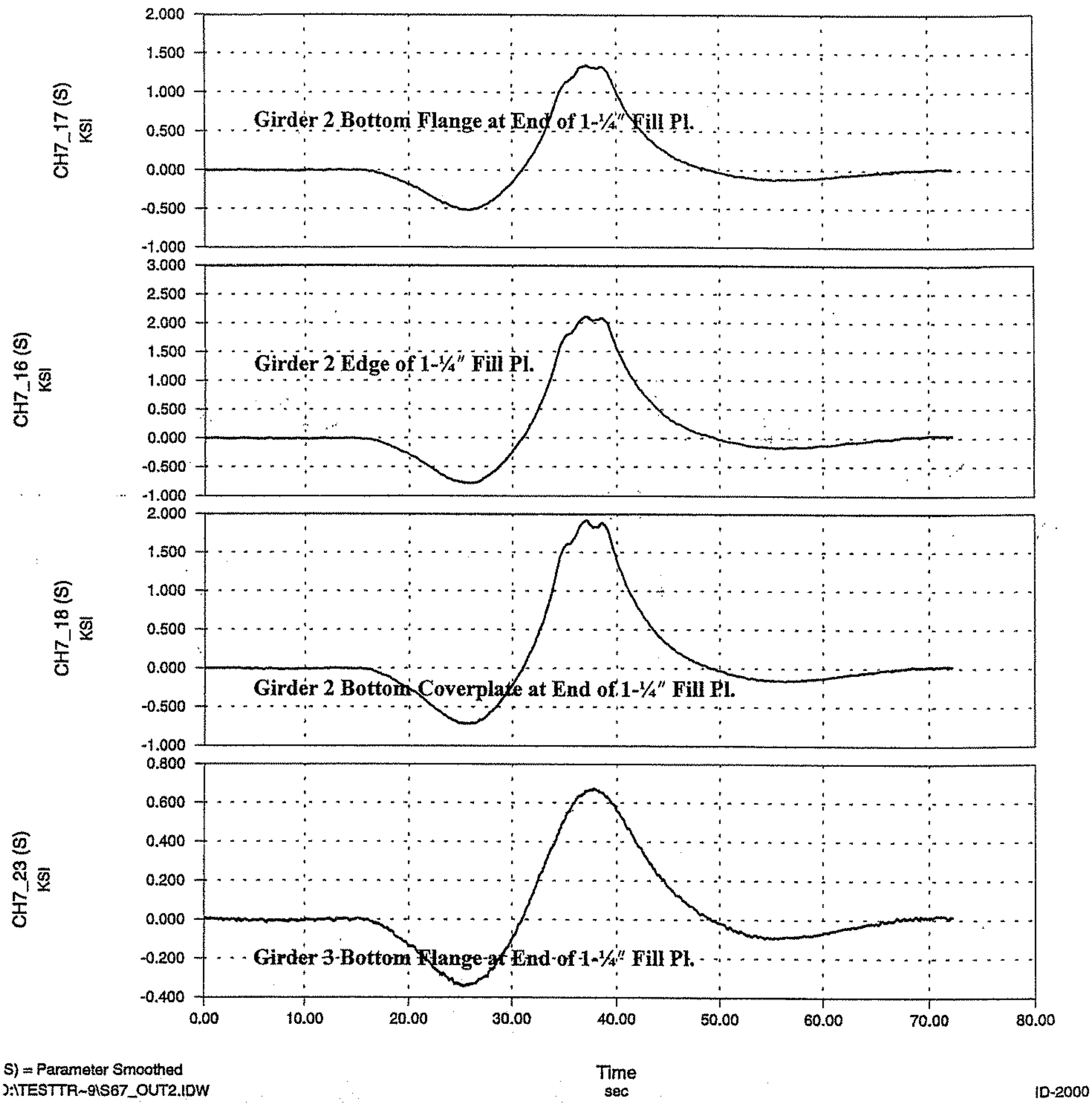
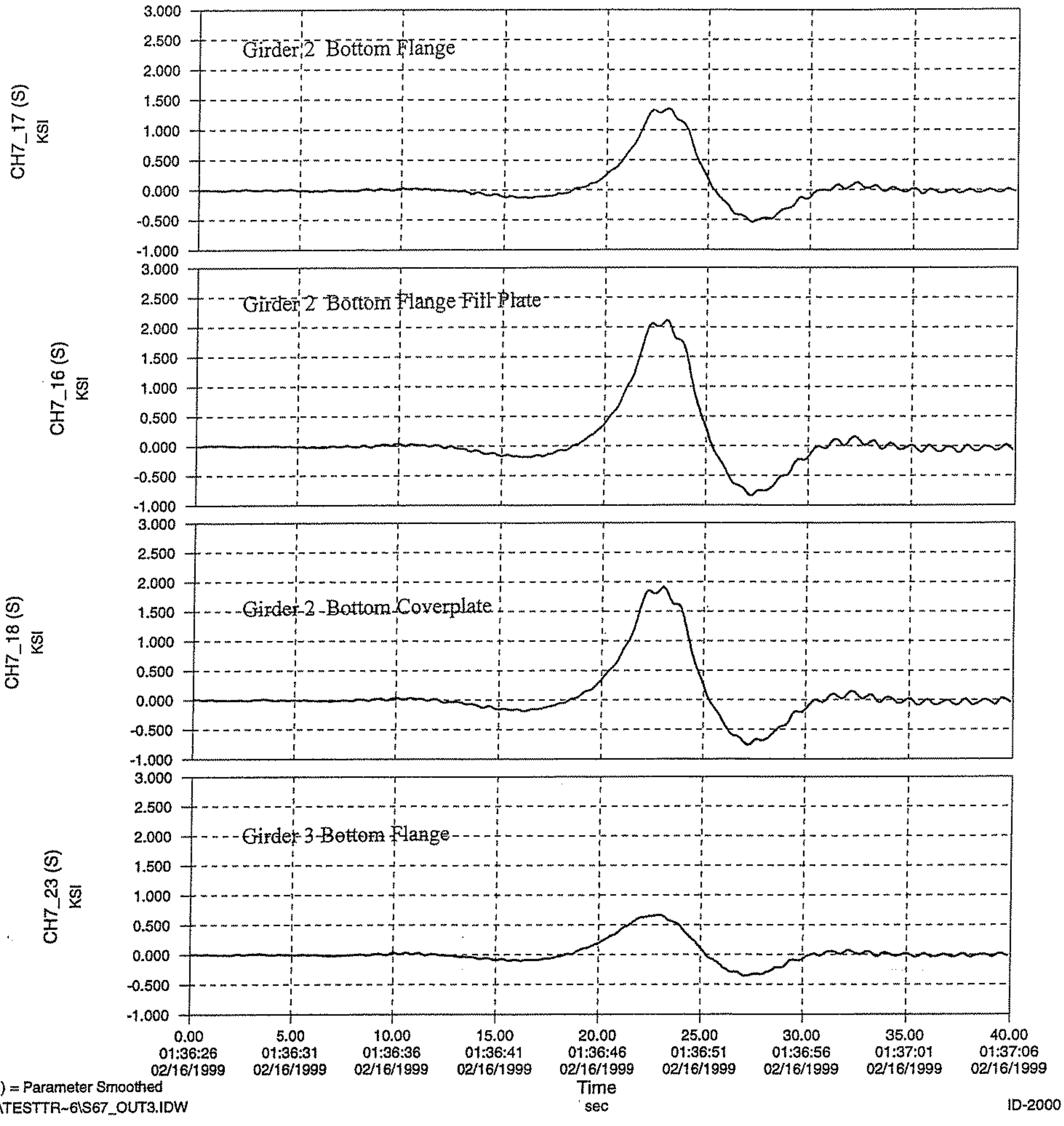
ID-2000

Test Vehicle at Span 7/Section 22: Vehicle Outbound on Outbound Track @ Nominal 10 mph



Test Vehicle at Span 7/Section 22; Vehicle Inbound on Outbound Track @ Nominal 10 mph



(S) = Parameter Smoothed
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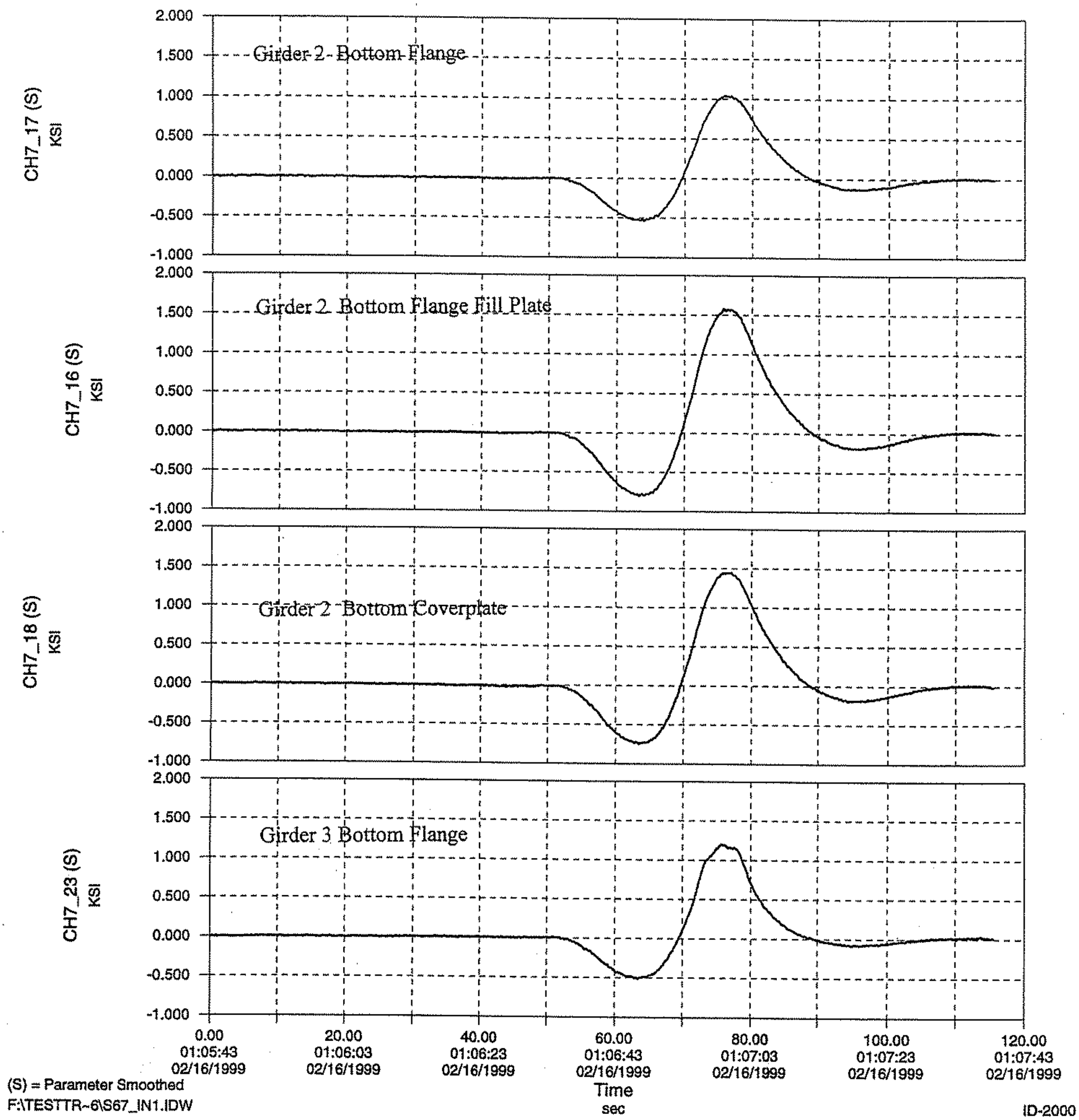
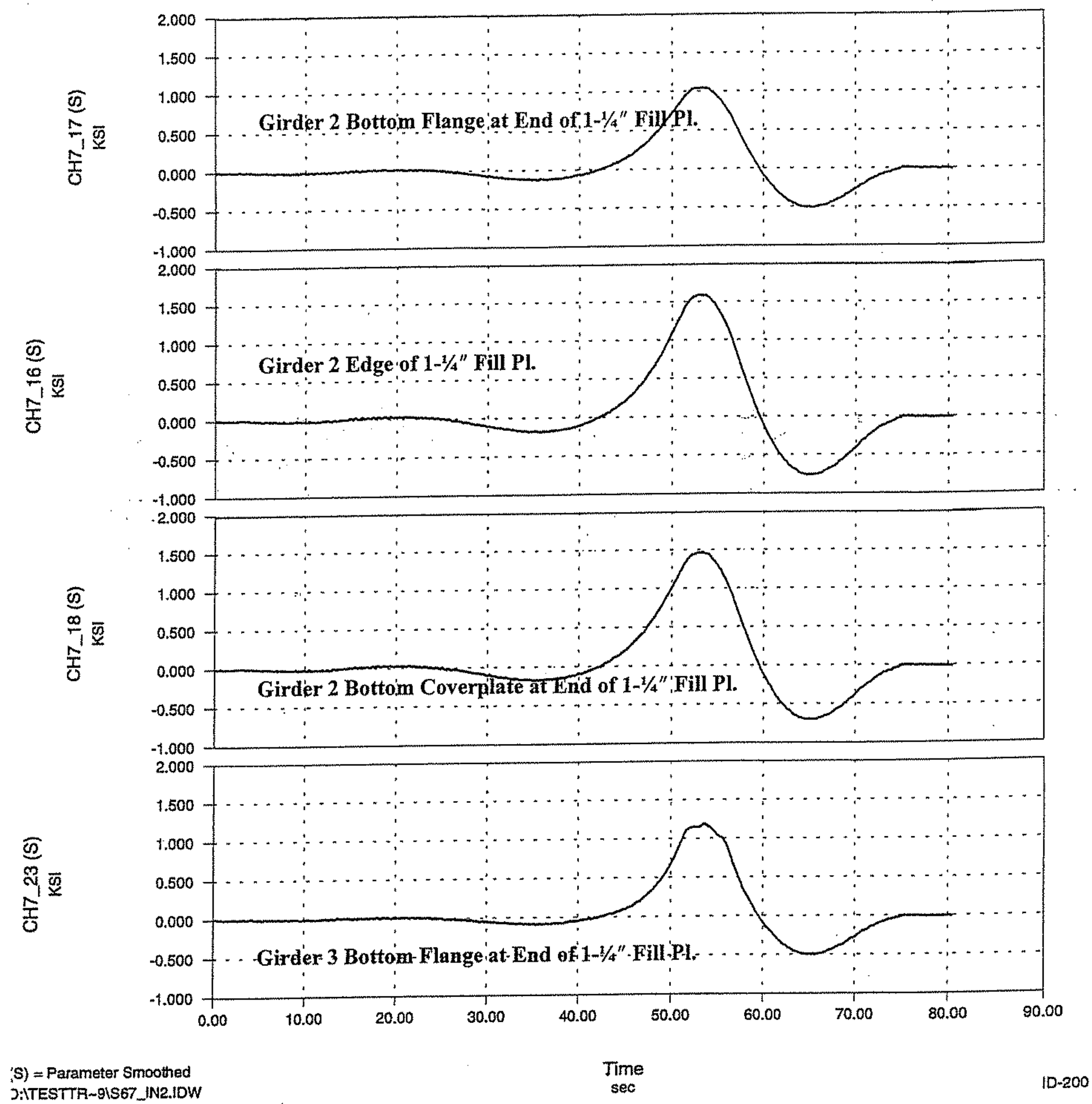
ID-2000

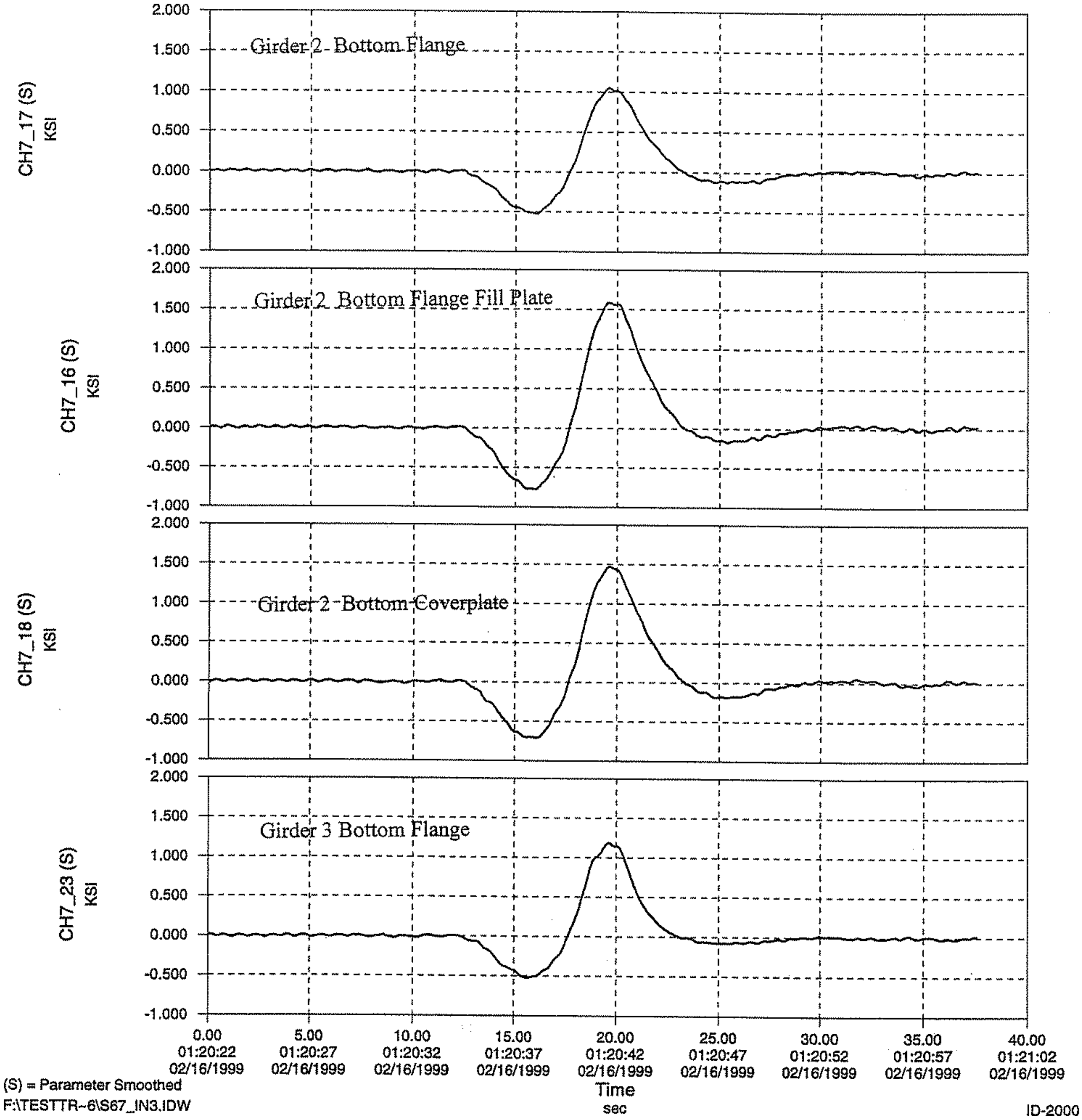
Test Vehicle at Span 7/Section 22: Vehicle Outbound on Outbound Track @ Nominal 25 mph



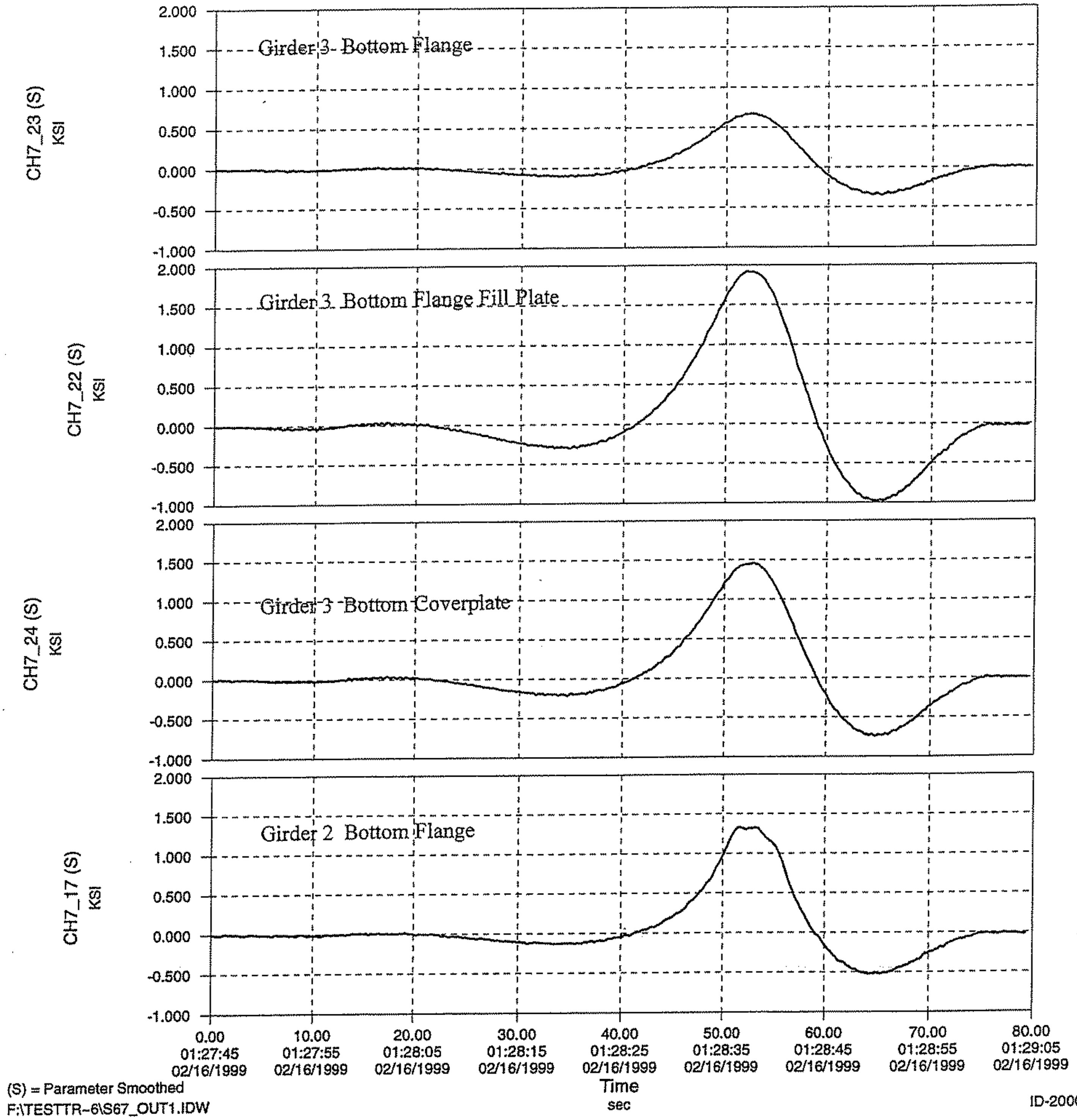
Test Vehicle at Span 7/Section 22: Vehicle Inbound on Inbound Track @ Nominal 10 mph



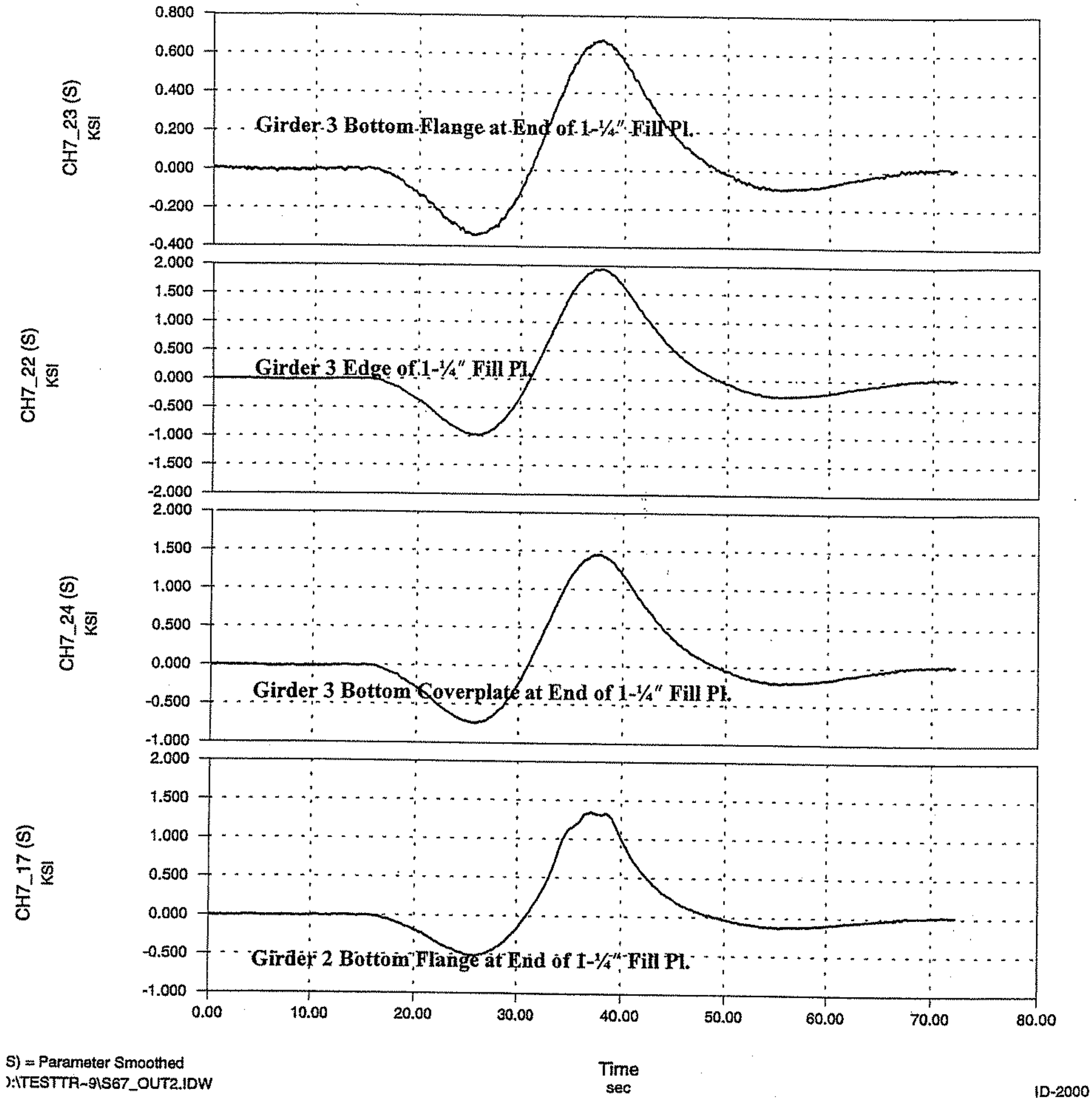
Test Vehicle at Span 7/Section 22; Vehicle Outbound on Inbound Track @ Nominal 10 mph



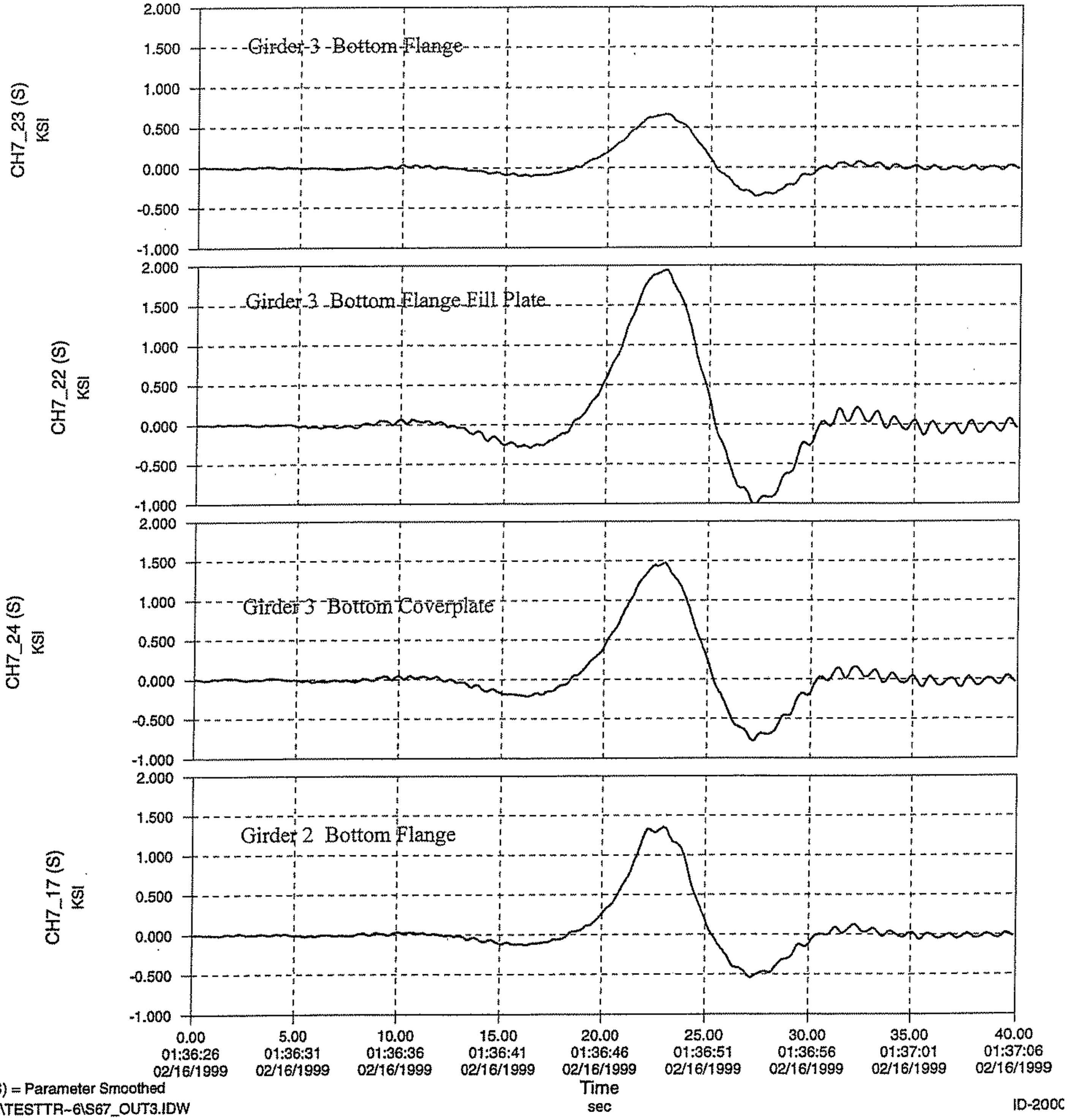
Test Vehicle at Span 7/Section 22: Vehicle Inbound on Inbound Track @ Nominal 25 mph



Test Vehicle at Span 7/Section 22: Vehicle Outbound on Outbound Track @ Nominal 10 mph



Test Vehicle at Span 7/Section 22; Vehicle Inbound on Outbound Track @ Nominal 10 mph



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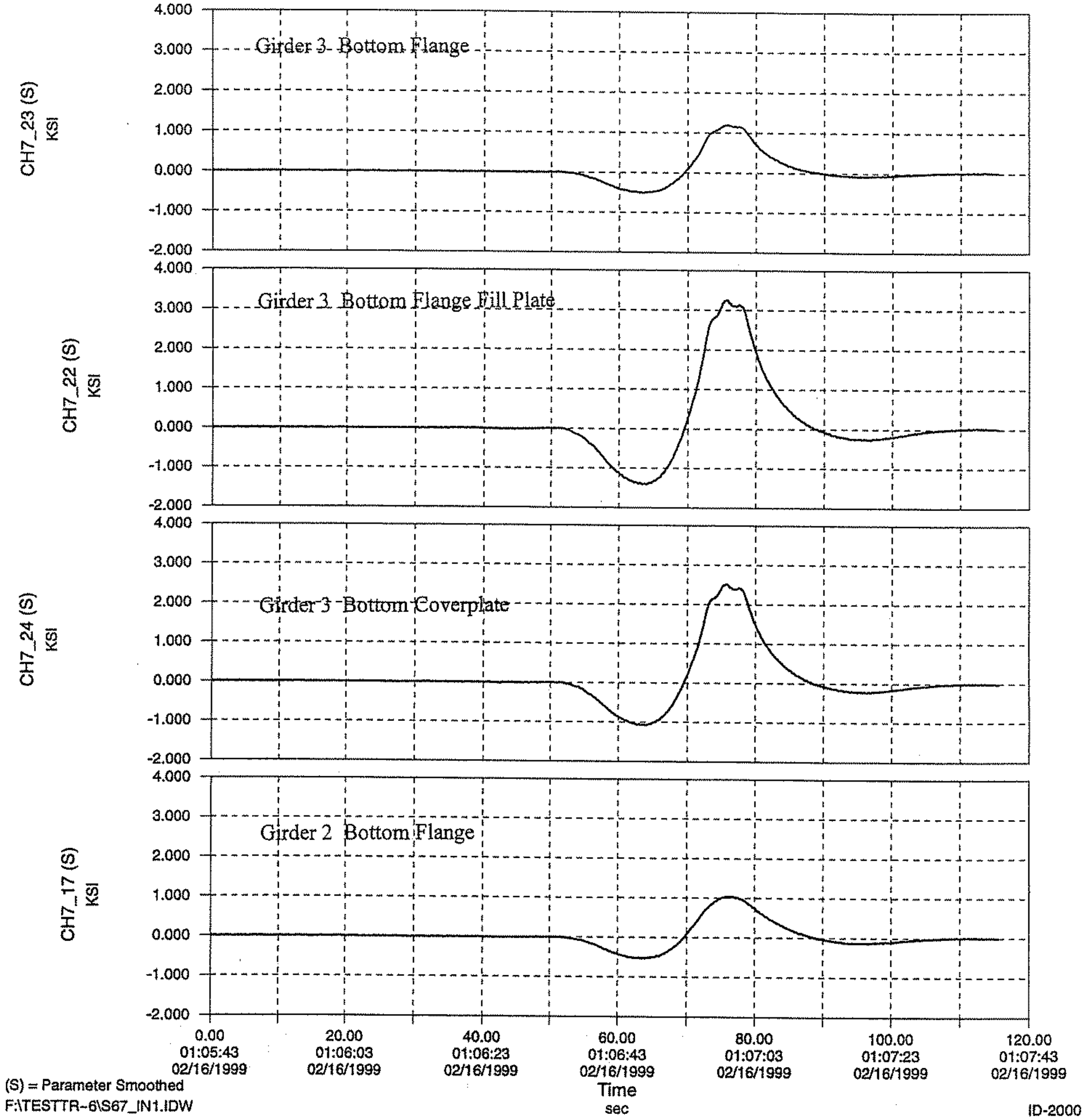
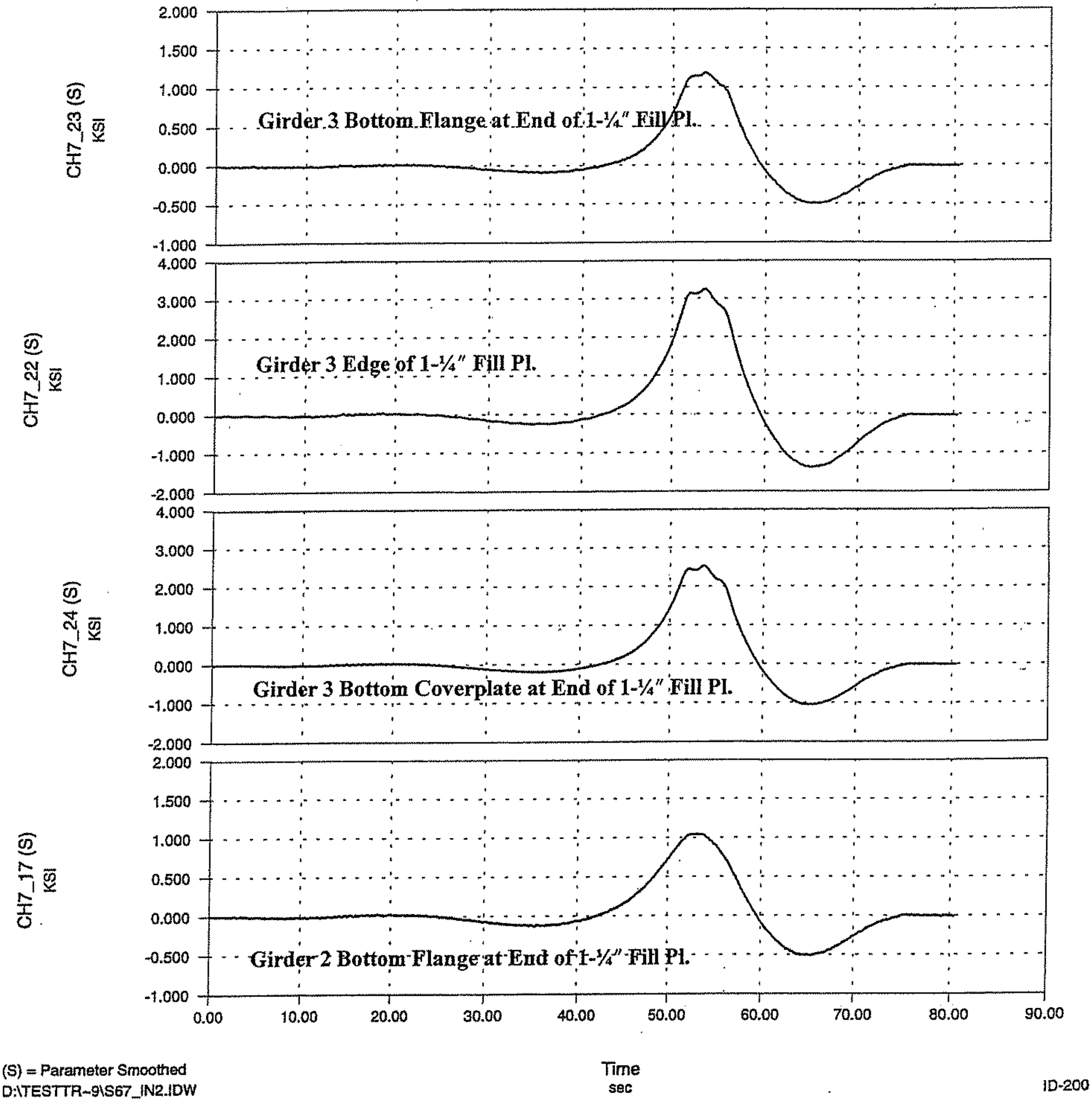
ID-200C

Test Vehicle at Span 7/Section 22: Vehicle Outbound on Outbound Track @ Nominal 25 mph



Test Vehicle at Span 7/Section 22: Vehicle Inbound on Inbound Track @ Nominal 10 mph



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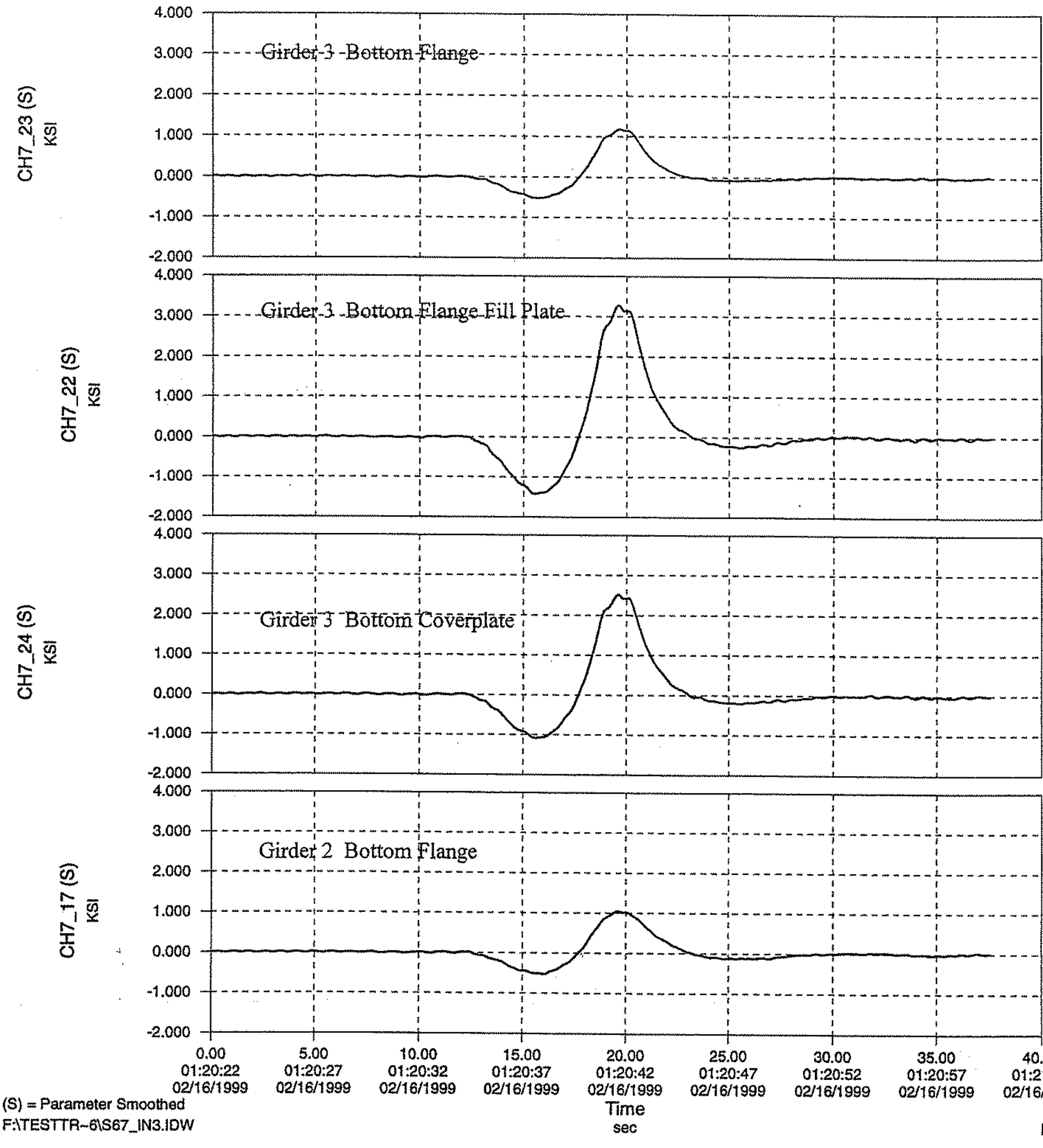
ID-200

Test Vehicle at Span 7/Section 22; Vehicle Outbound on Inbound Track @ Nominal 10 mph



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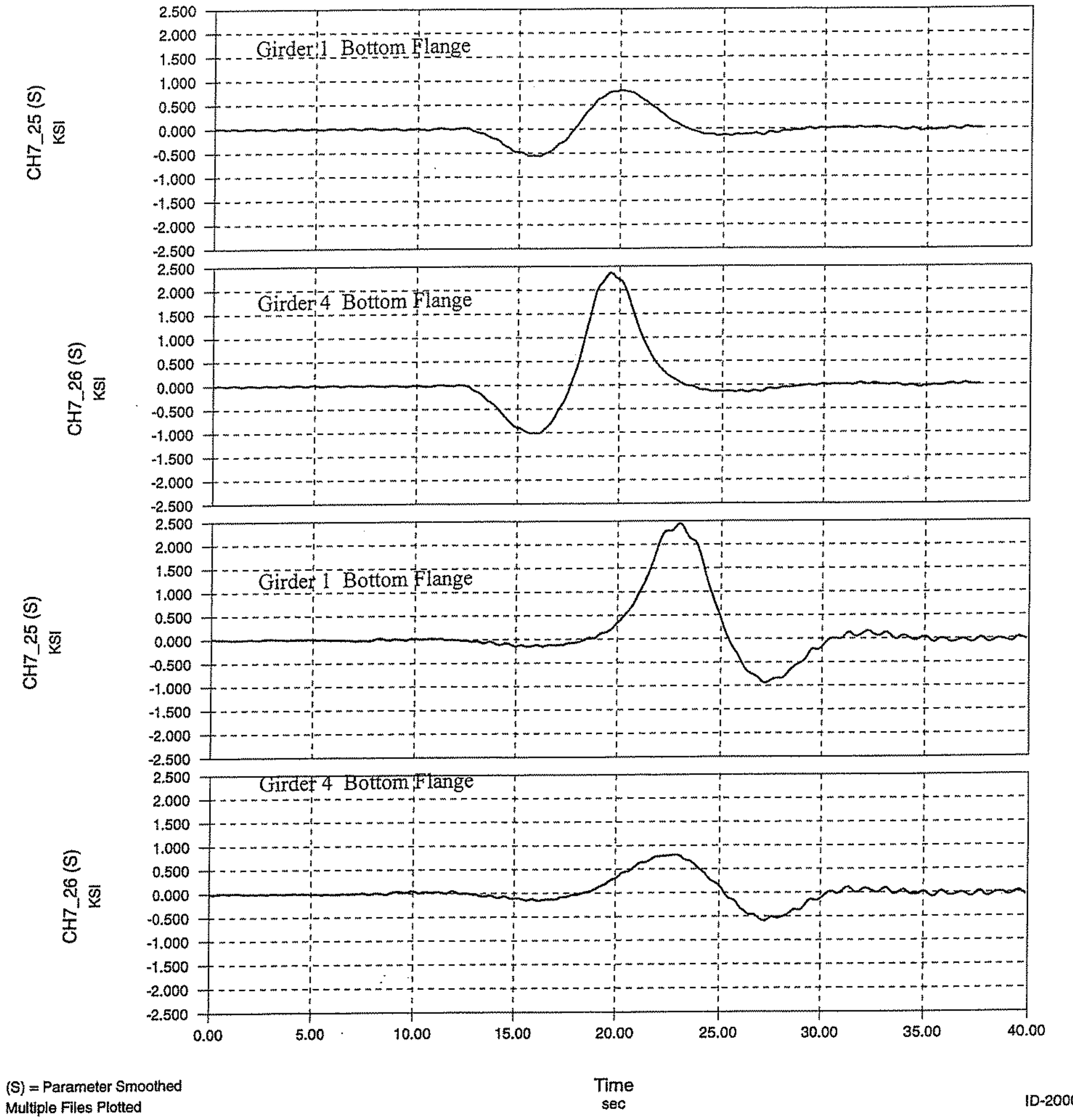
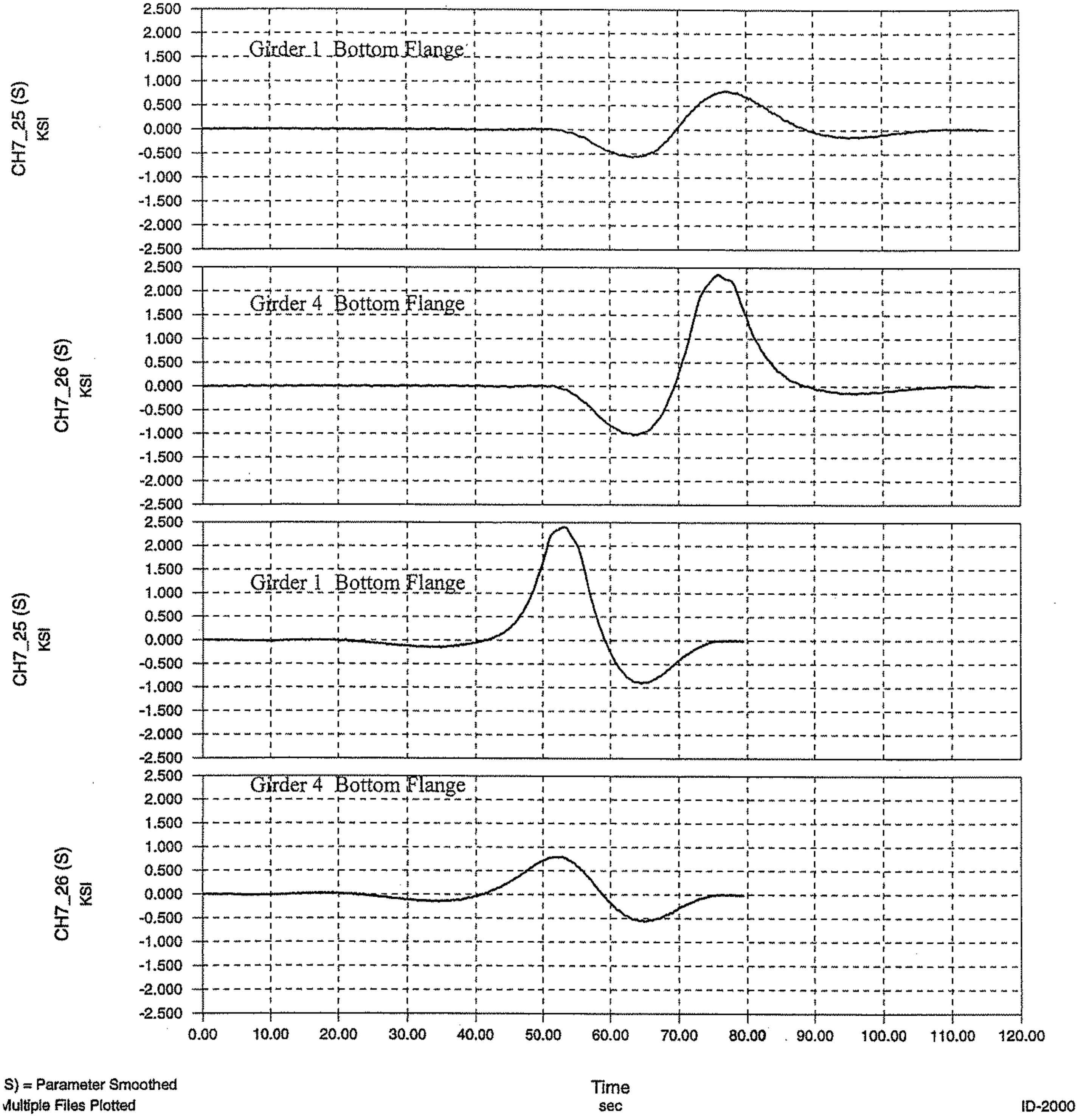
ID-2000

Test Vehicle at Span 7/Section 22: Vehicle Inbound on Inbound Track @ Nominal 25 mph



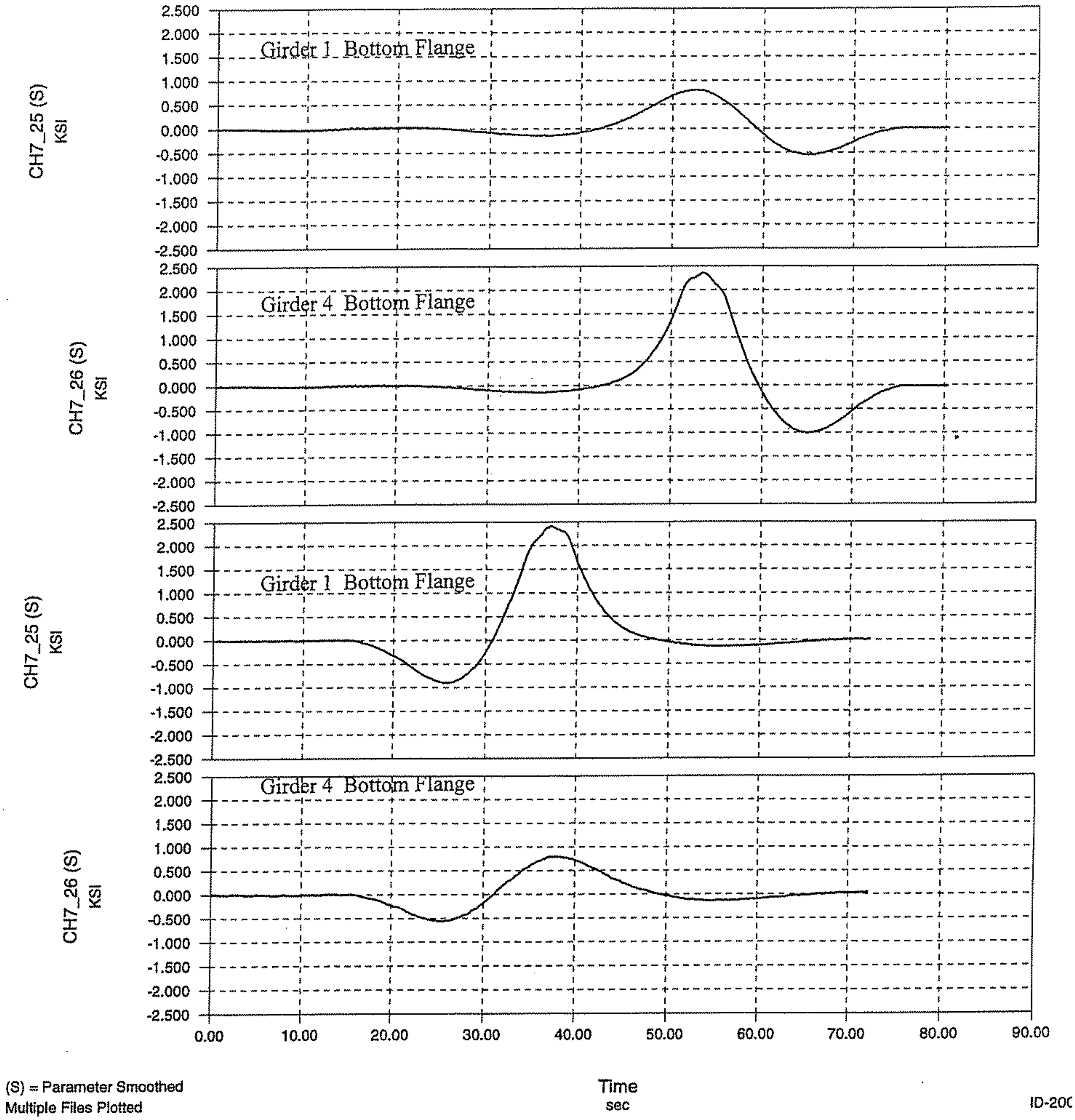
Test Vehicle at Span 7/Section 22: @ Nominal 25 mph:

- **Top 2 Records; Vehicle Inbound on Inbound Track**
- **Bottom 2 Records; Vehicle Outbound on Outbound Track**



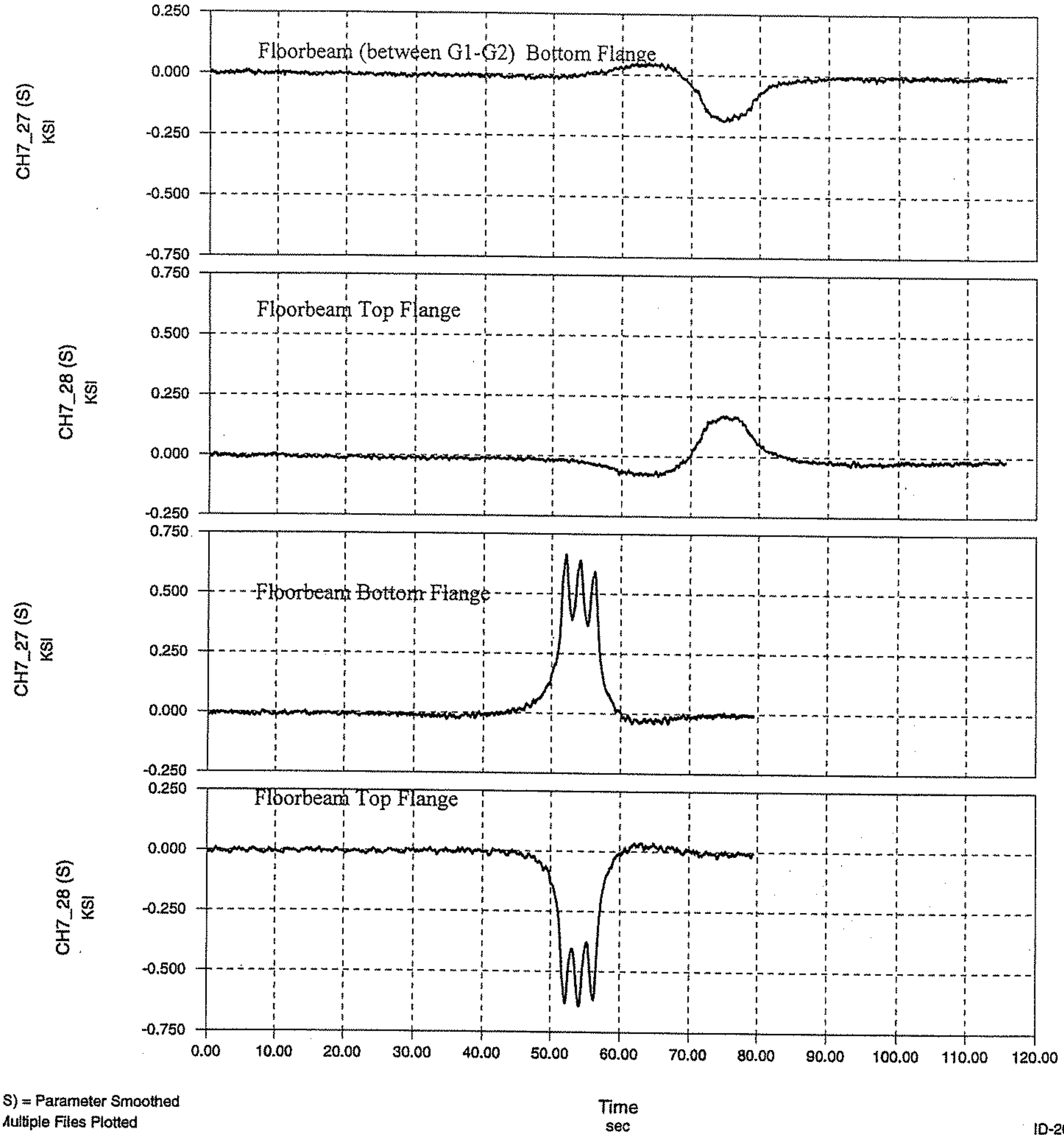
Test Vehicle at Span 7/Section 22: @ Nominal 10 mph:

- **Top 2 Records; Vehicle Inbound on Inbound Track**
- **Bottom 2 Records; Vehicle Outbound on Outbound Track**



Test Vehicle at Span 7/Section 22: @ Nominal 10 mph:

- **Top 2 Records; Vehicle Outbound on Inbound Track**
- **Bottom 2 Records; Vehicle Inbound on Outbound Track**

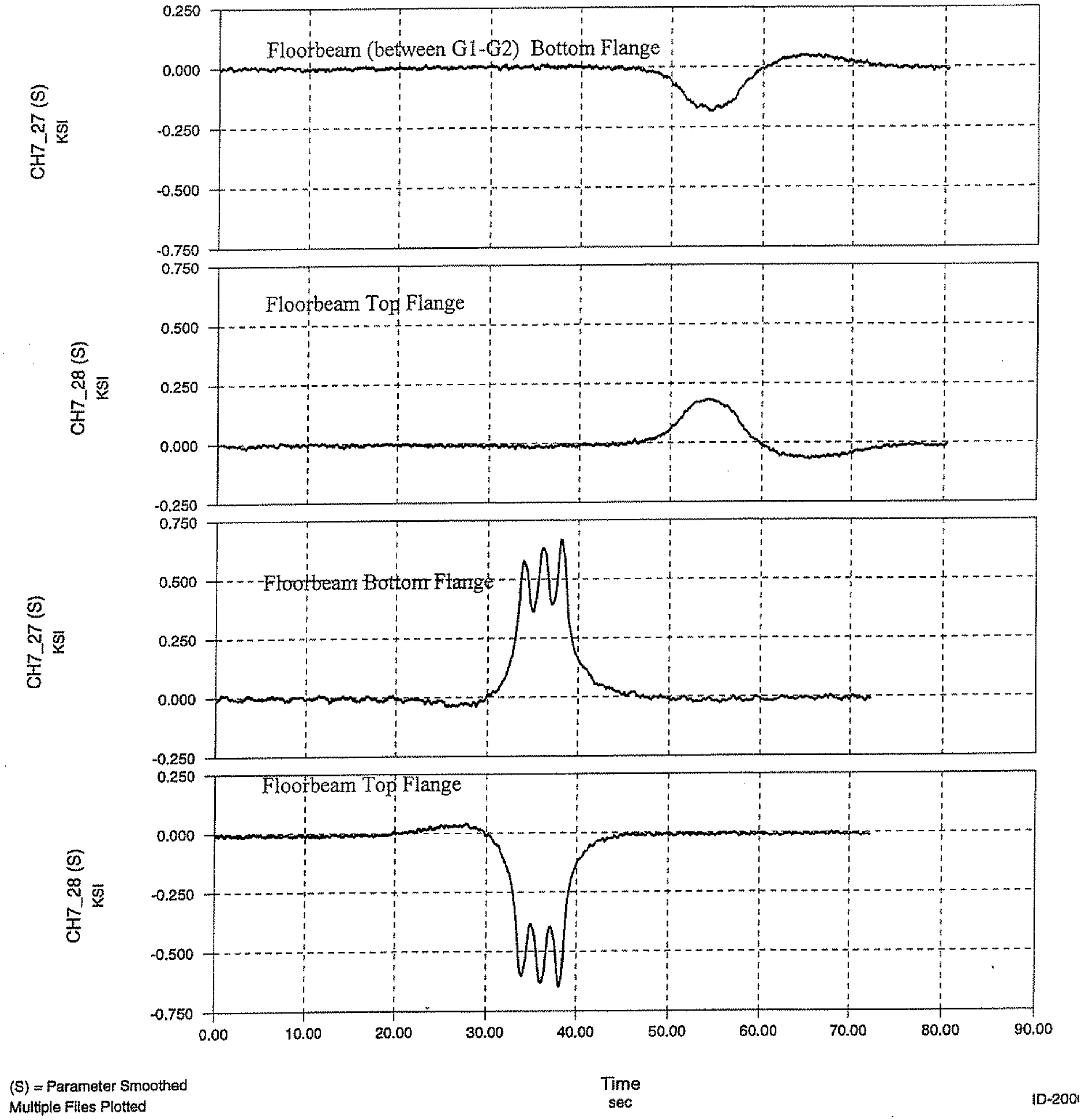


S) = Parameter Smoothed
/Iultiple Files Plotted

ID-2000

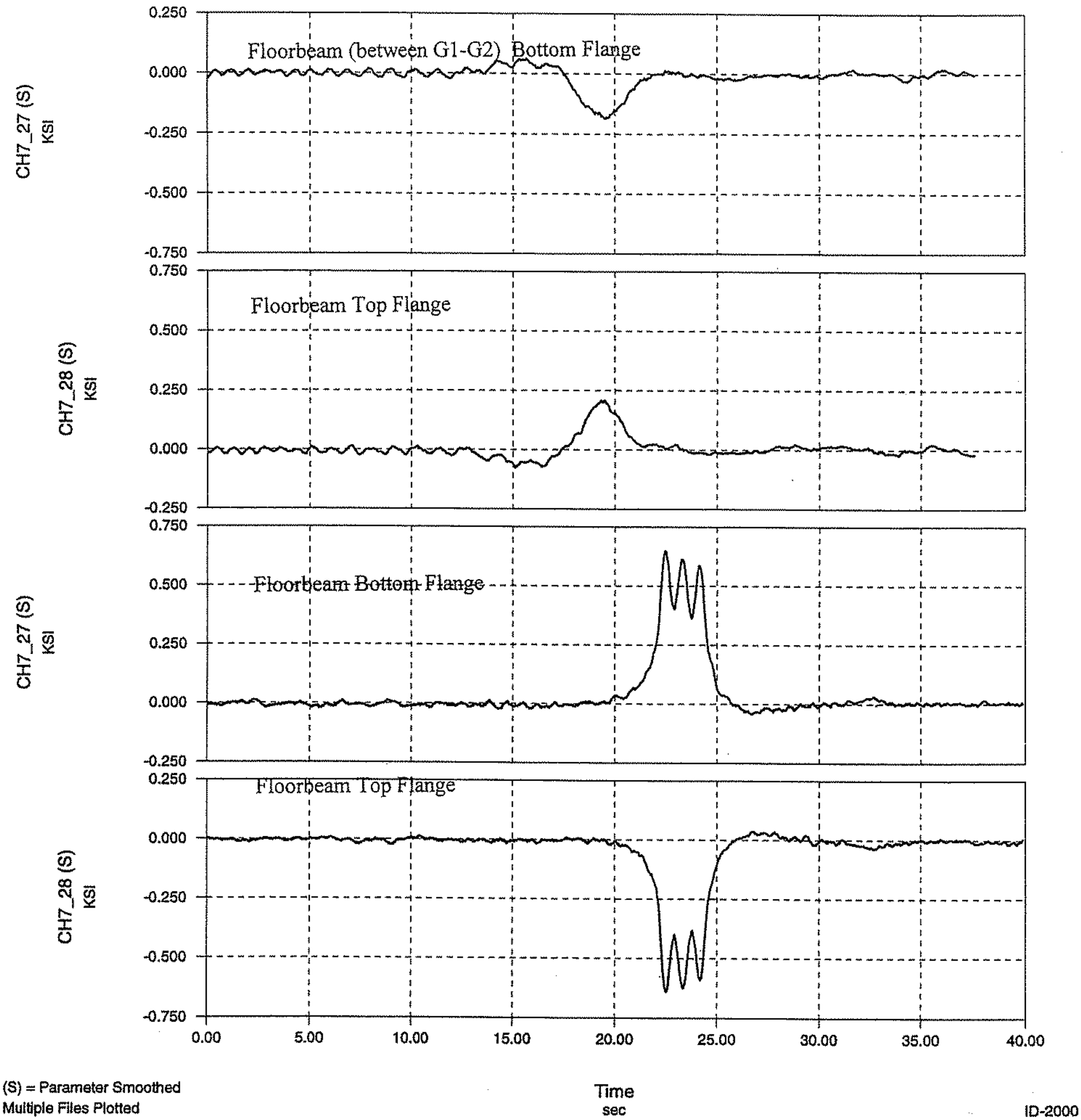
Test Vehicle at Span 7/Section 222: @ Nominal 10 mph:

- **Top 2 Records; Vehicle Inbound on Inbound Track**
- **Bottom 2 Records; Vehicle Outbound on Outbound Track**



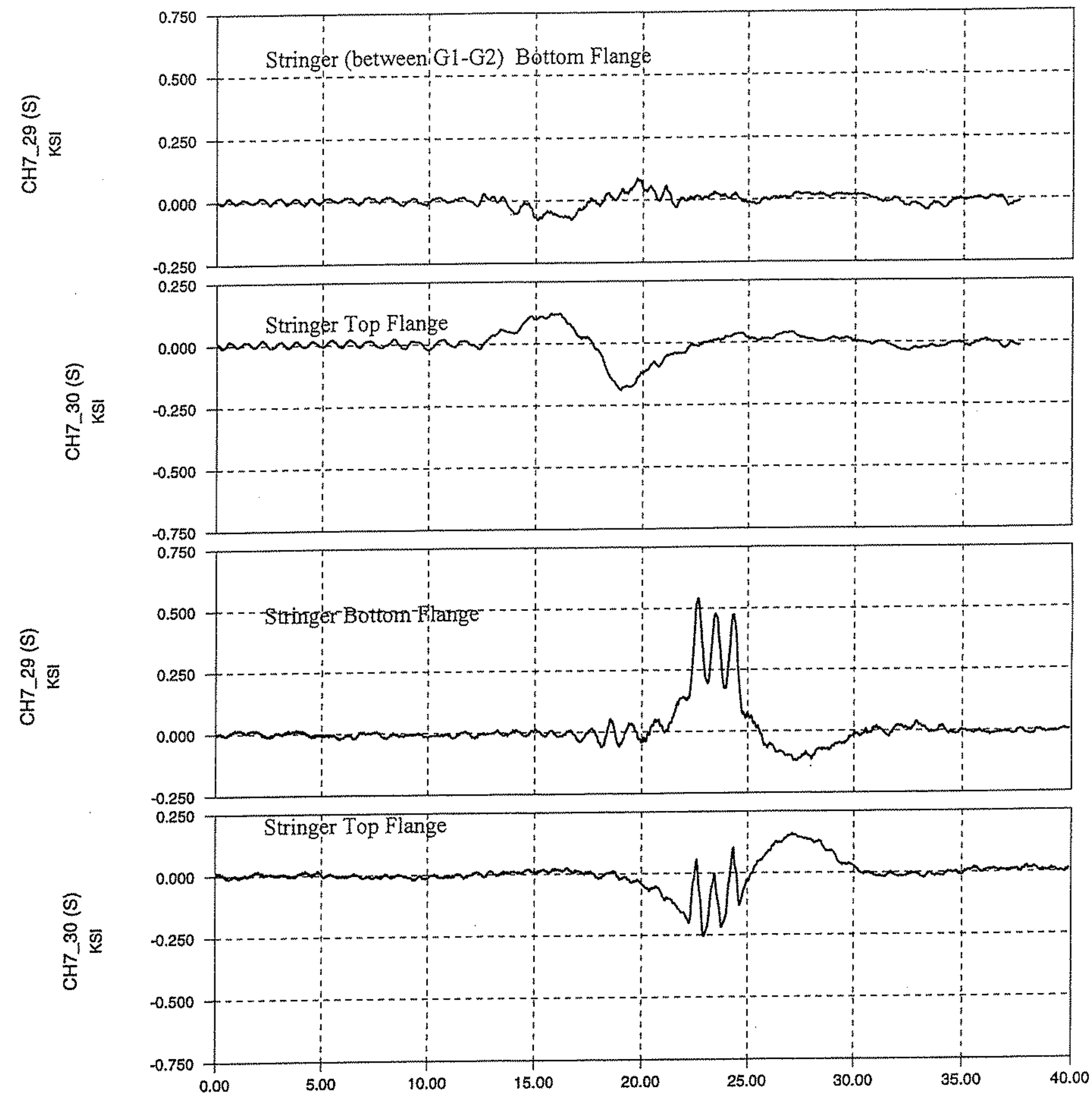
Test Vehicle at Span 7/Section 222: @ Nominal 10 mph:

- **Top 2 Records; Vehicle Outbound on Inbound Track**
- **Bottom 2 Records; Vehicle Inbound on Outbound Track**



Test Vehicle at Span 7/Section 222: @ Nominal 25 mph:

- **Top 2 Records; Vehicle Inbound on Inbound Track**
- **Bottom 2 Records; Vehicle Outbound on Outbound Track**

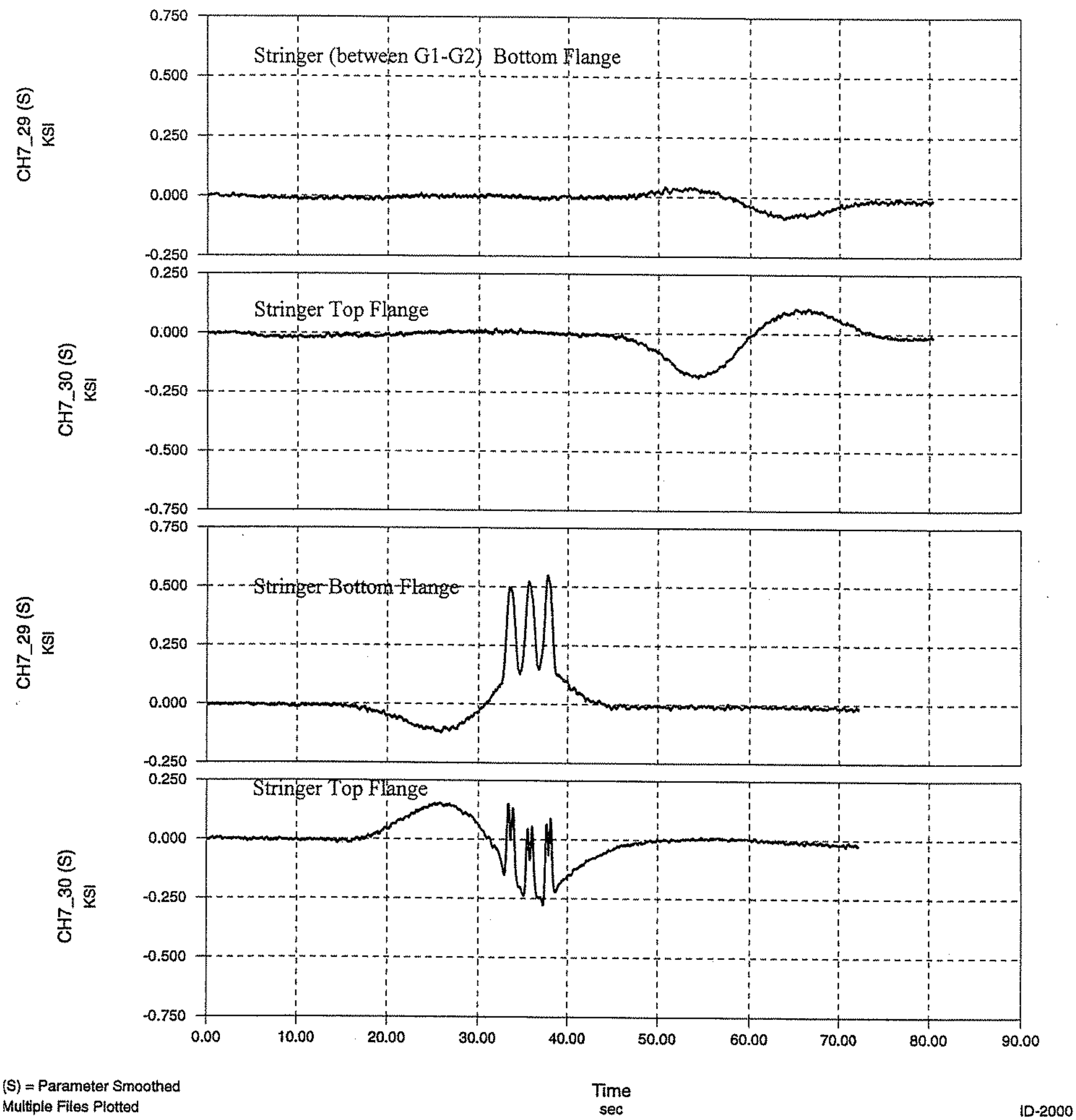


(S) = Parameter Smoothed
Multiple Files Plotted

ID-20

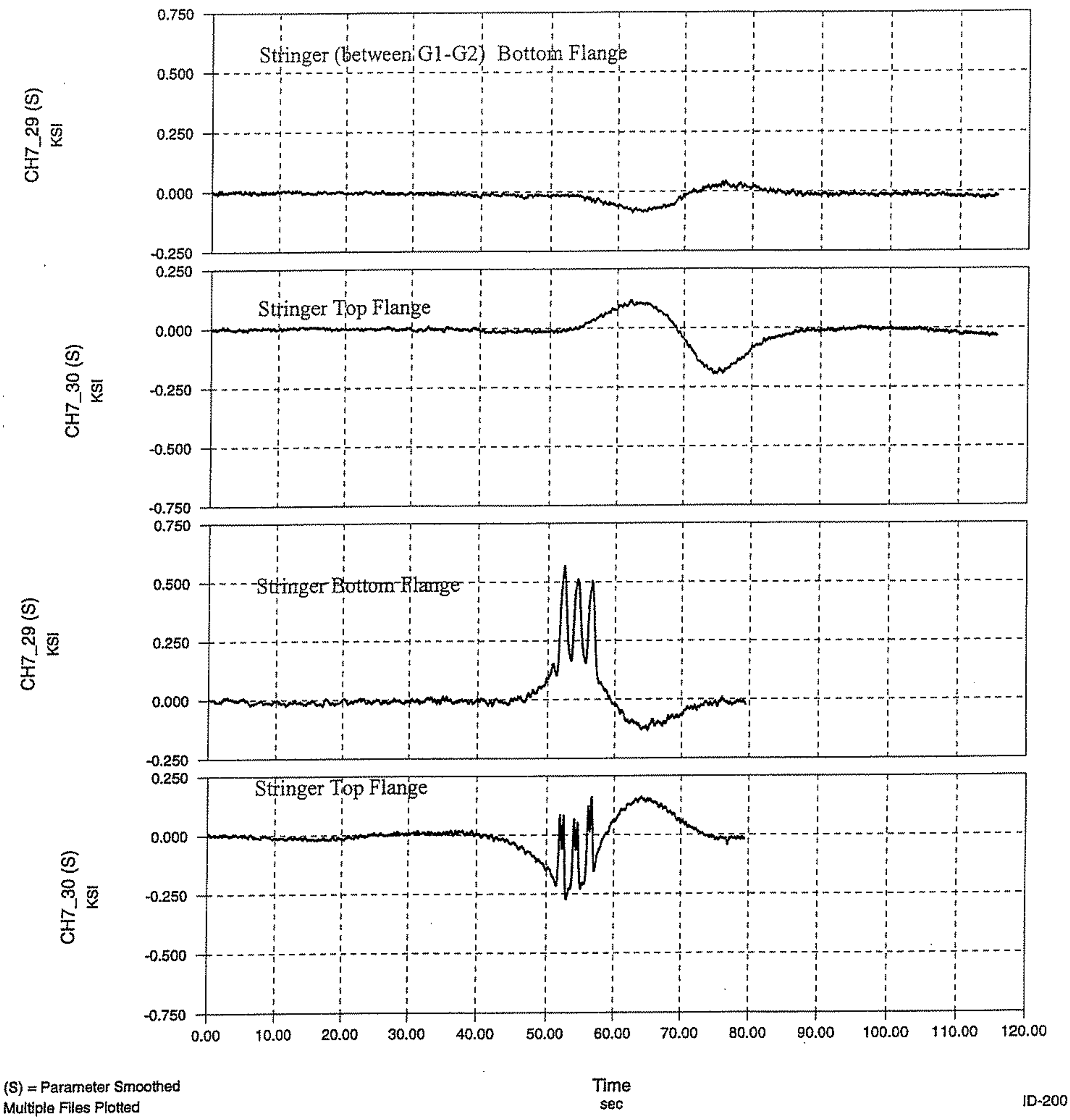
Test Vehicle at Span 7/Section 2222: @ Nominal 25 mph:

- **Top 2 Records; Vehicle Inbound on Inbound Track**
- **Bottom 2 Records; Vehicle Outbound on Outbound Track**



Test Vehicle at Span 7/Section 2222: @ Nominal 10 mph:

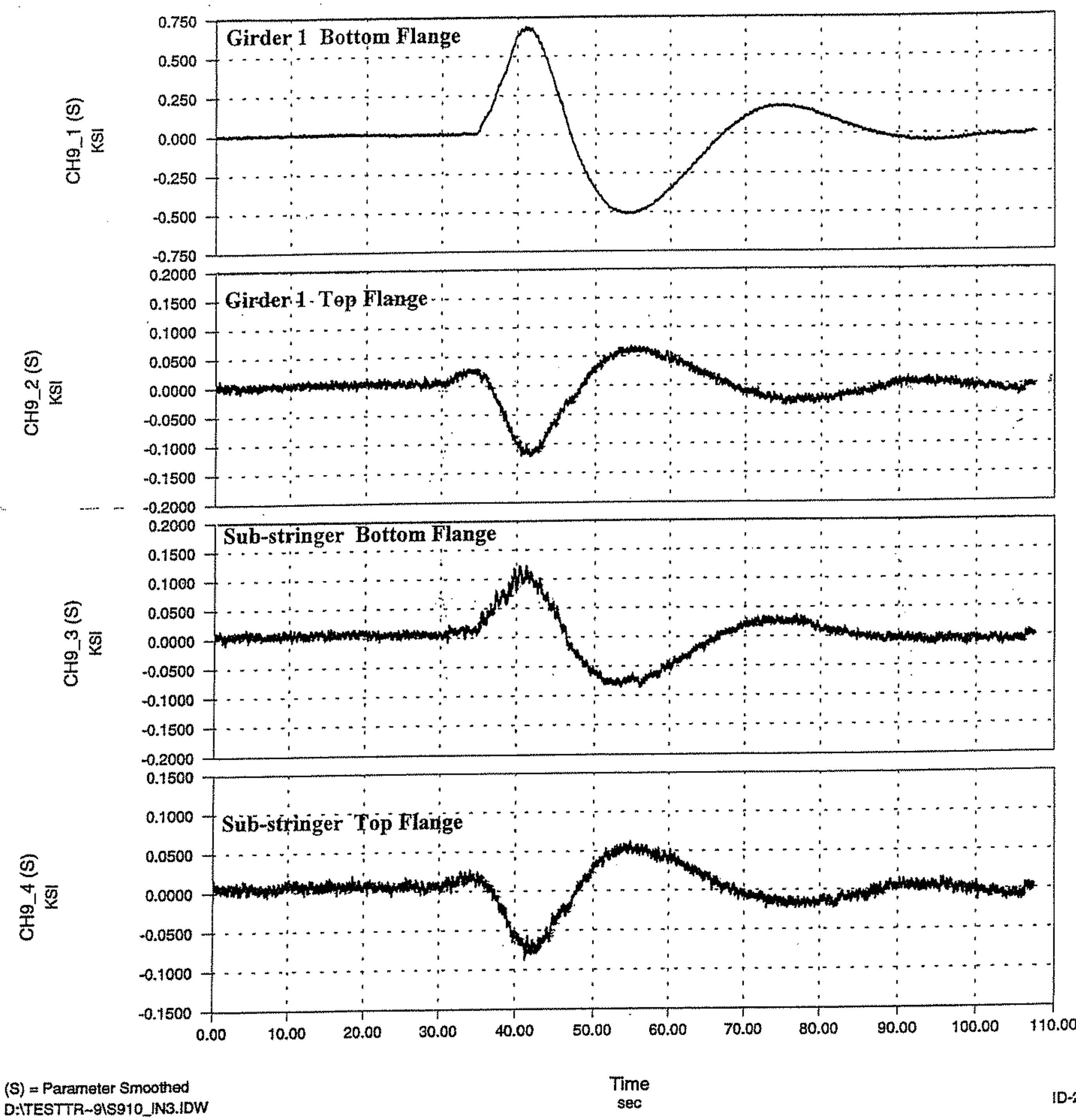
- **Top 2 Records; Vehicle Outbound on Inbound Track**
- **Bottom 2 Records; Vehicle Inbound on Outbound Track**



Test Vehicle at Span 7/Section 2222: @ Nominal 10 mph:

- **Top 2 Records; Vehicle Inbound on Inbound Track**
- **Bottom 2 Records; Vehicle Outbound on Outbound Track**

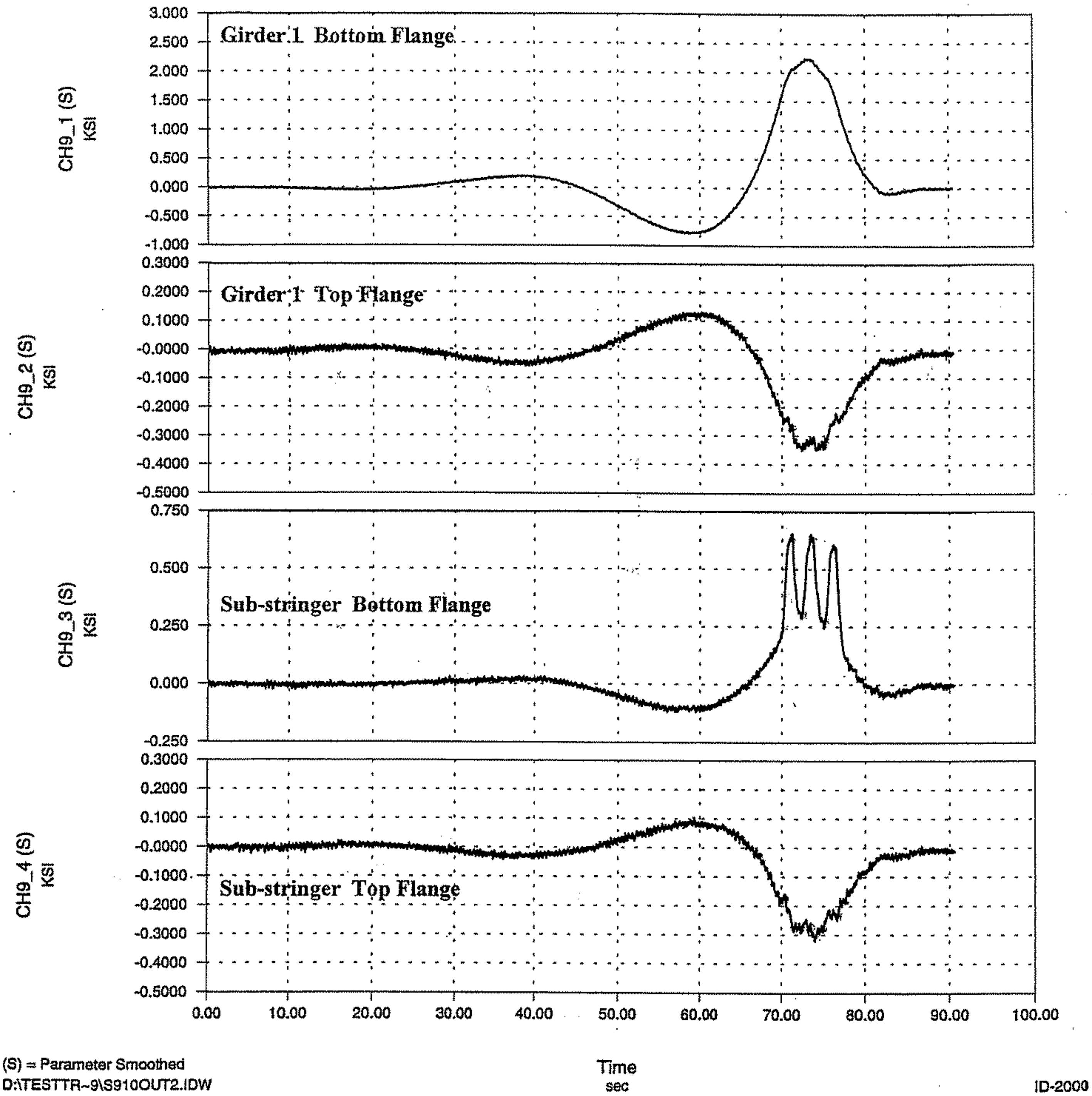
Strain Gage Records
Test Vehicle, Span 9



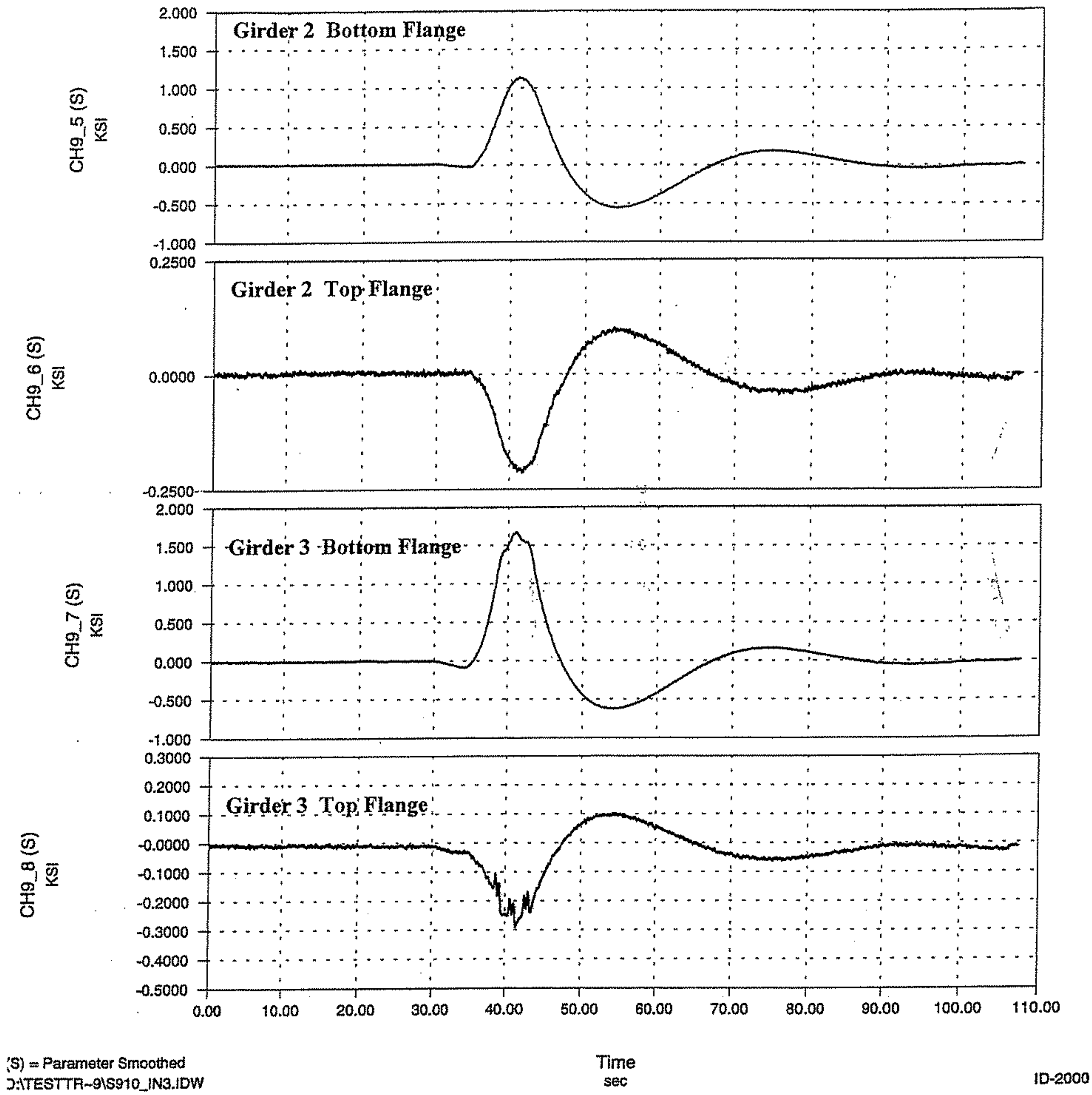
(S) = Parameter Smoothed
D:\TESTTR~9\S910_IN3.IDW

ID-20

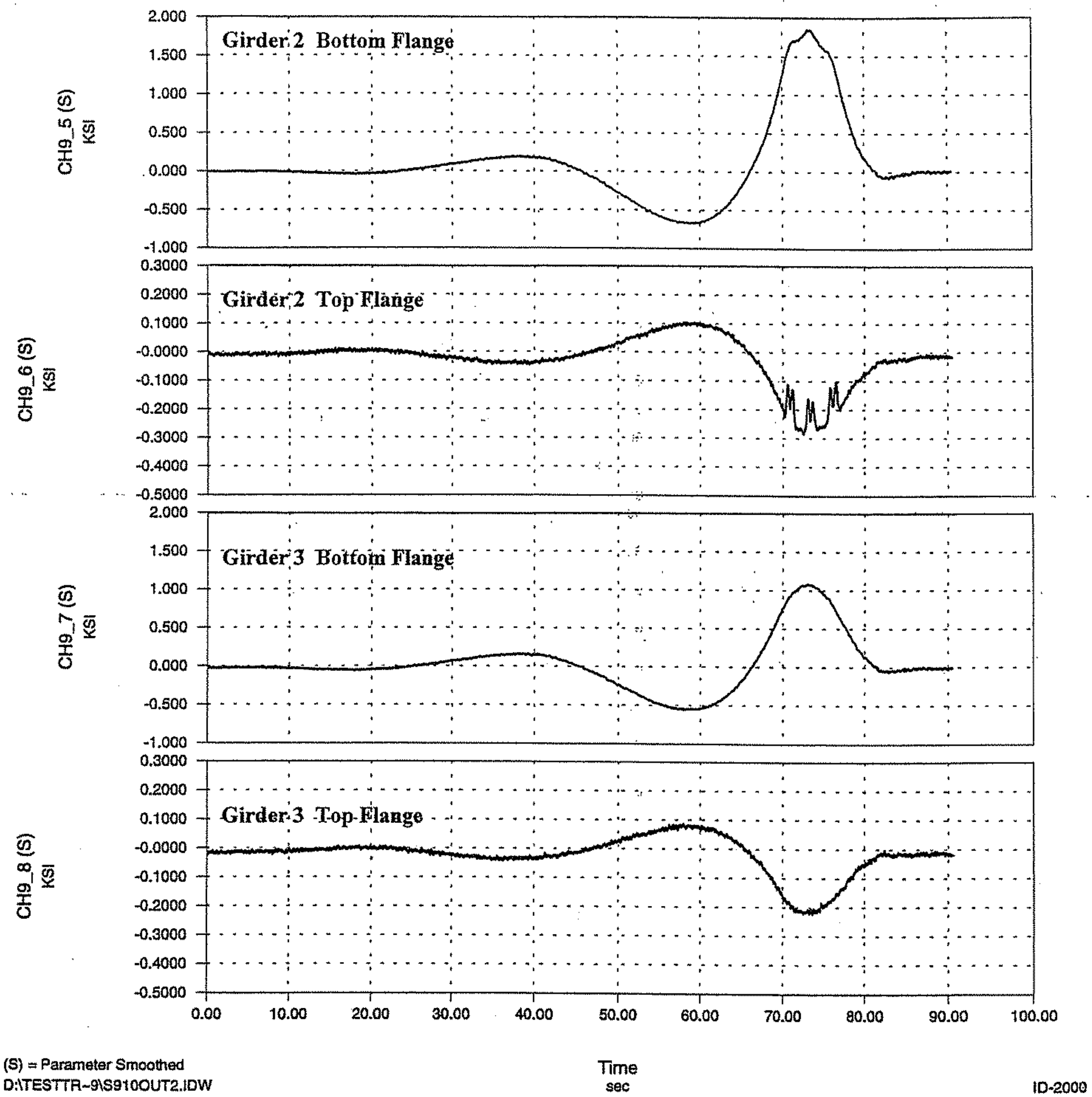
Test Vehicle at Span 9 / Section c; Vehicle Outbound on Inbound Track @ Nominal 10 mph



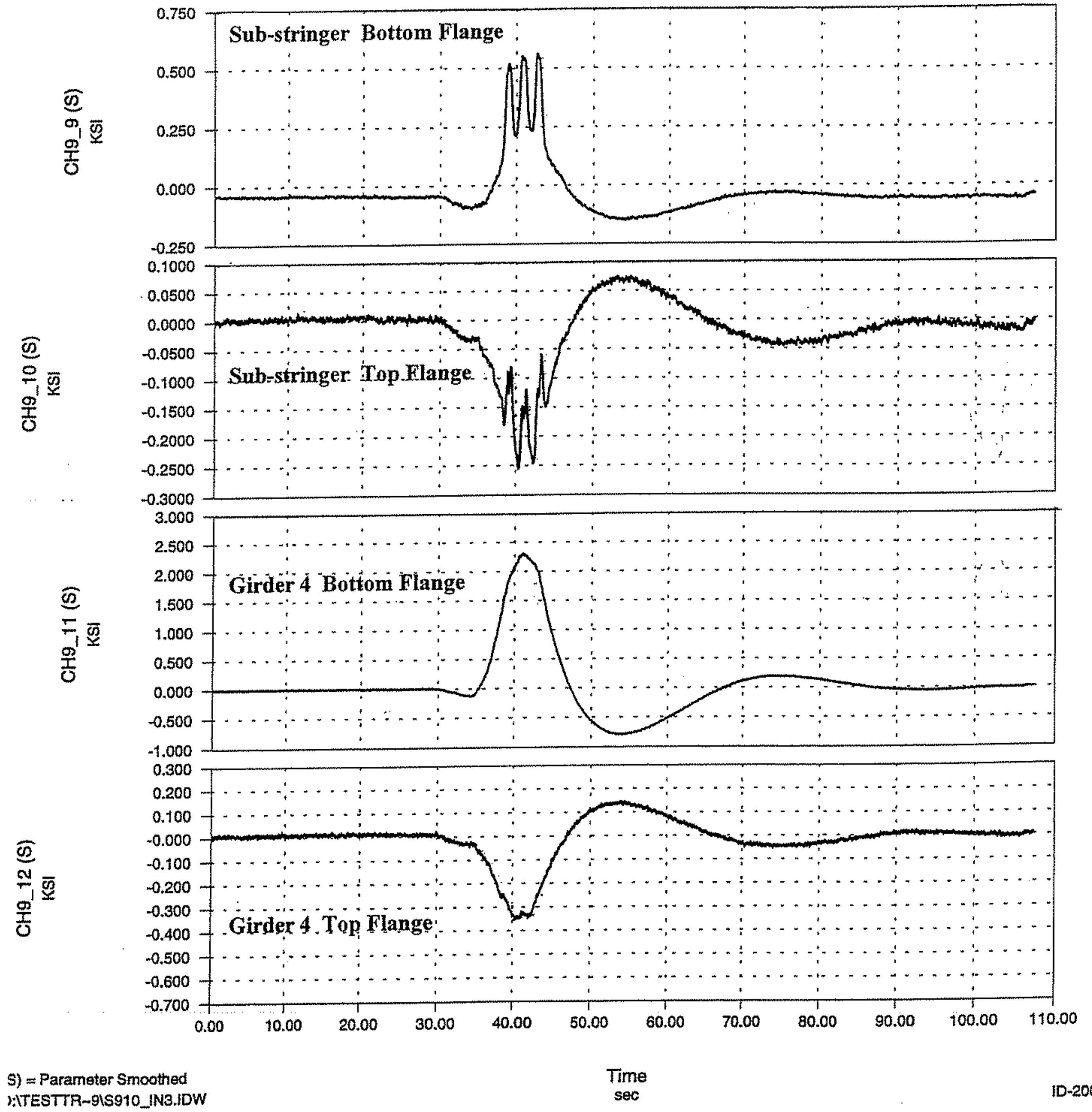
Test Vehicle at Span 9 / Section c; Vehicle Inbound on Outbound Track @ Nominal 10 mph



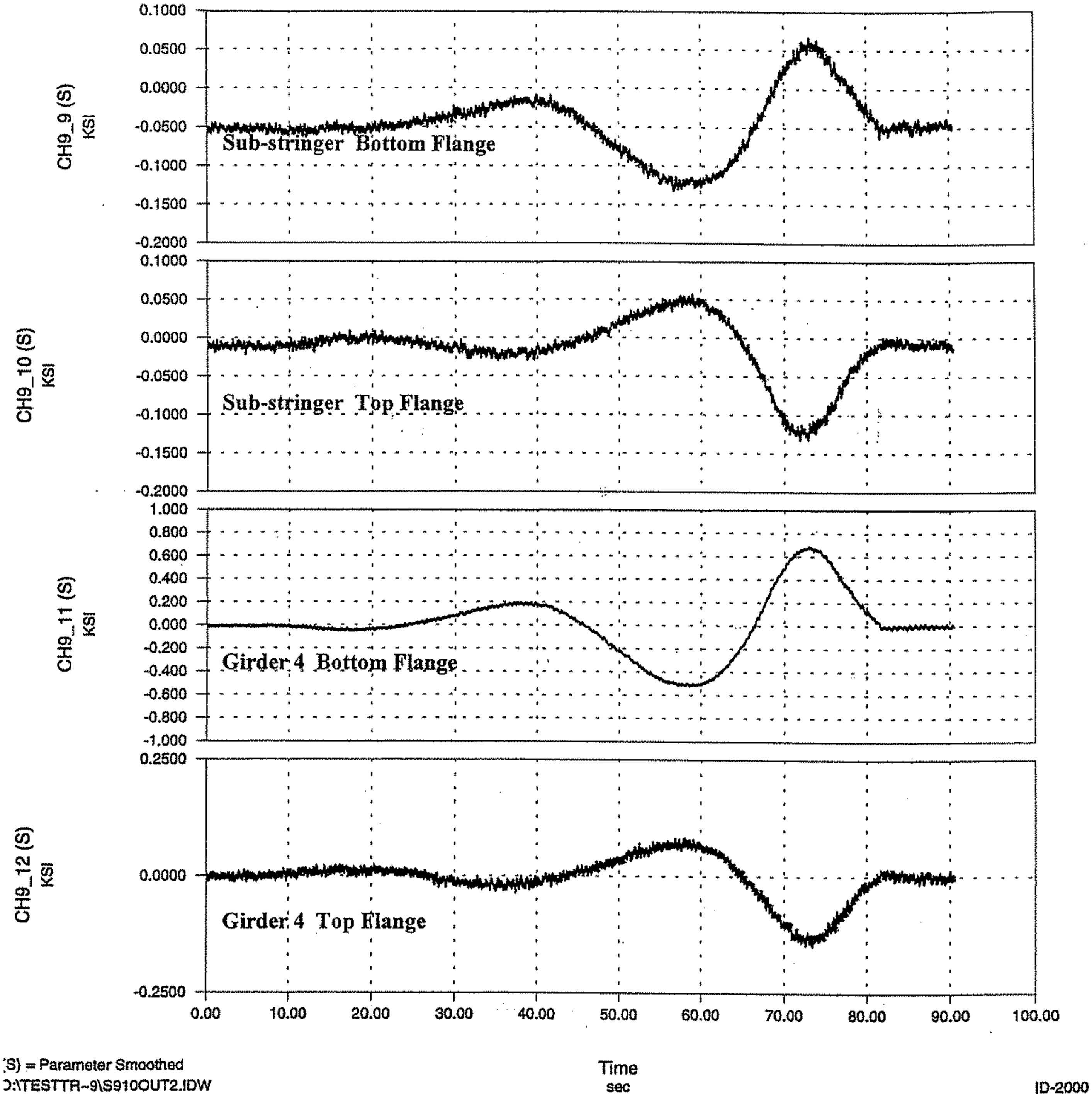
Test Vehicle at Span 9 / Section c; Vehicle Outbound on Inbound Track @ Nominal 10 mph



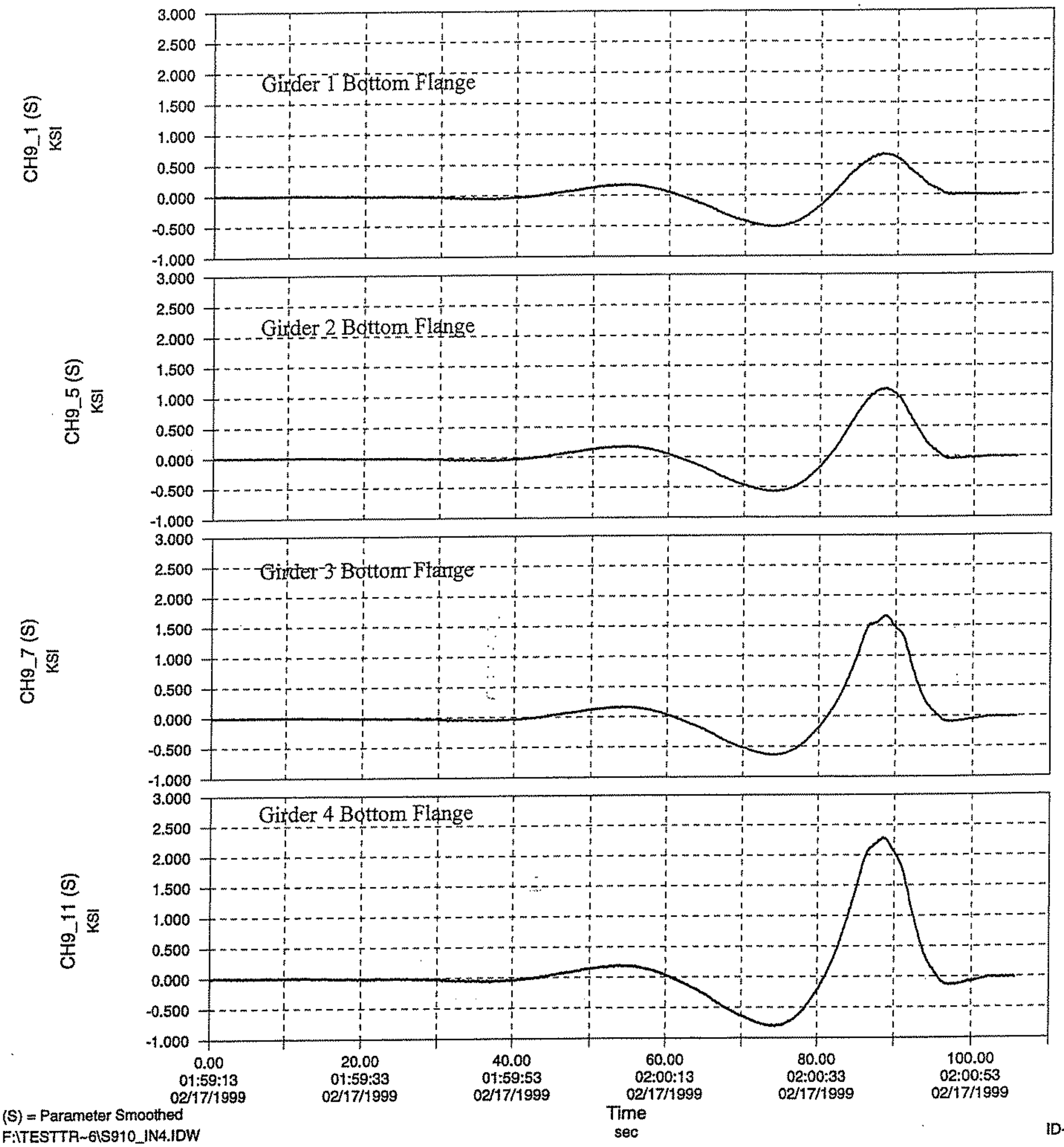
Test Vehicle at Span 9 / Section c; Vehicle Inbound on Outbound Track @ Nominal 10 mph



Test Vehicle at Span 9 / Section c; Vehicle Outbound on Inbound Track @ Nominal 10 mph



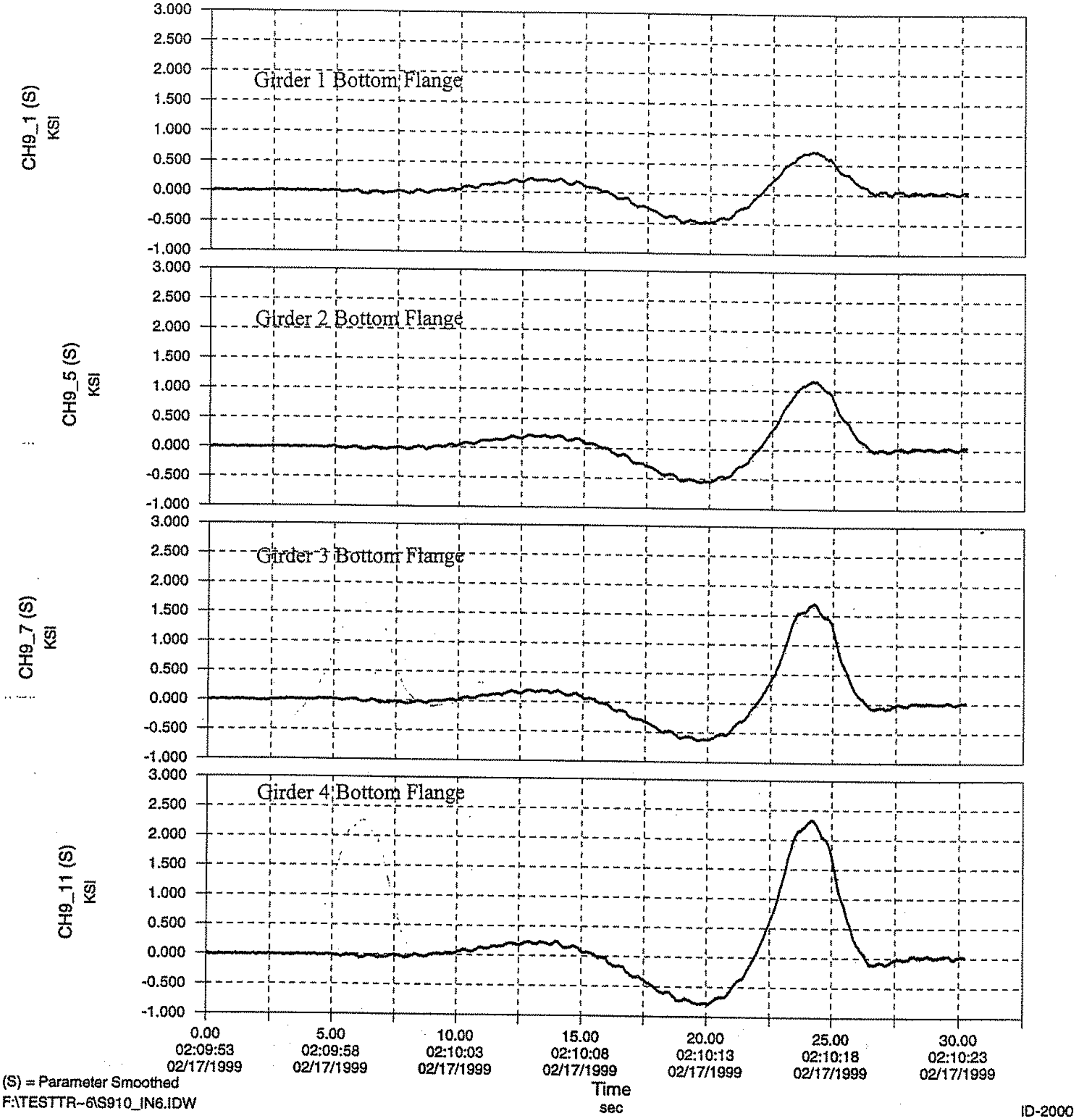
Test Vehicle at Span 9 / Section c; Vehicle Inbound on Outbound Track @ Nominal 10 mph



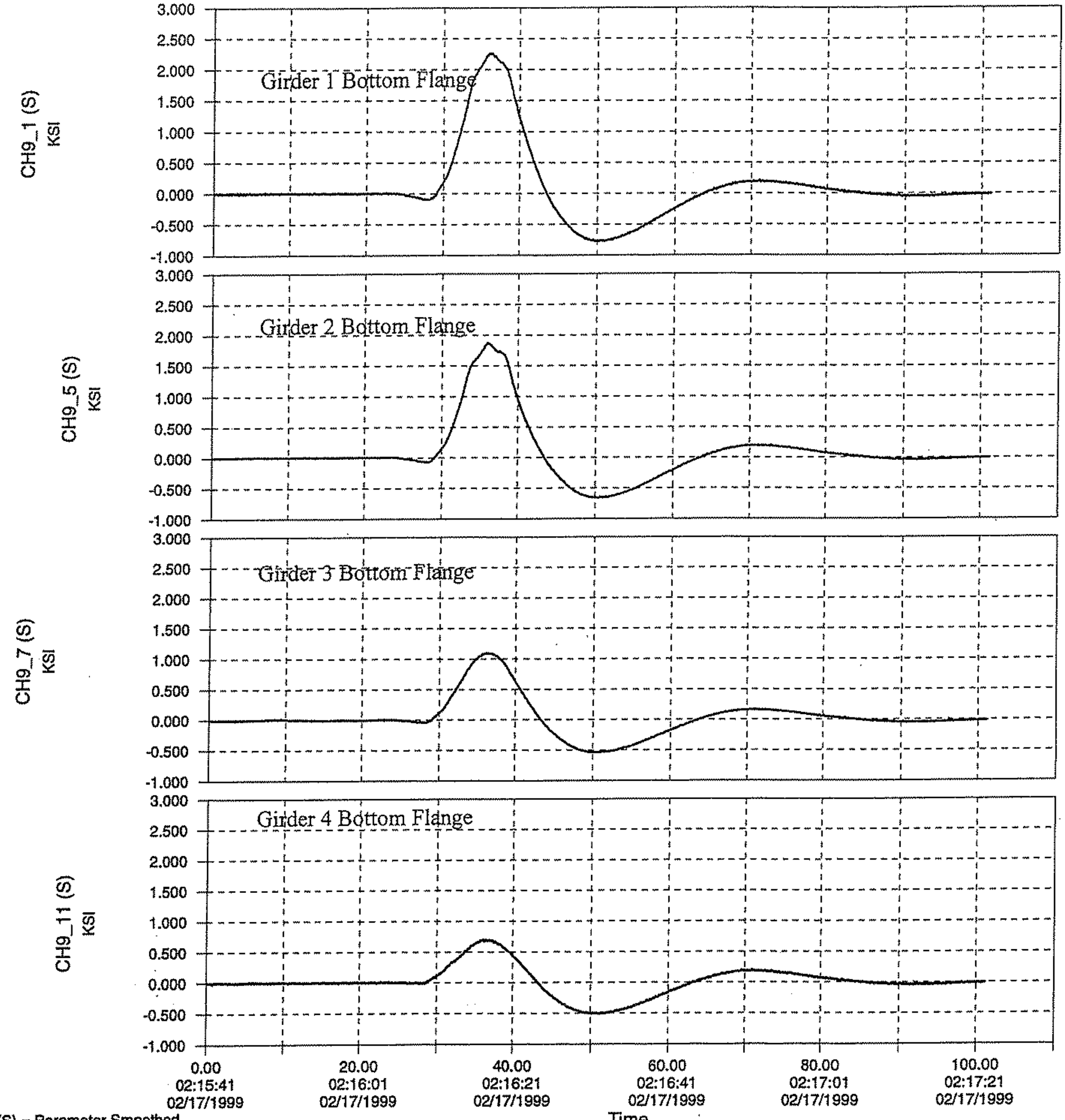
(S) = Parameter Smoothed
F:\TESTTR~6\S910_IN4.IDW

ID-200(

Test Vehicle at Span 9 / Section C; Vehicle Inbound on Inbound Track @ Nominal 10 mph



Test Vehicle at Span 9 / Section C; Vehicle Inbound on Inbound Track @ Nominal 25 mph



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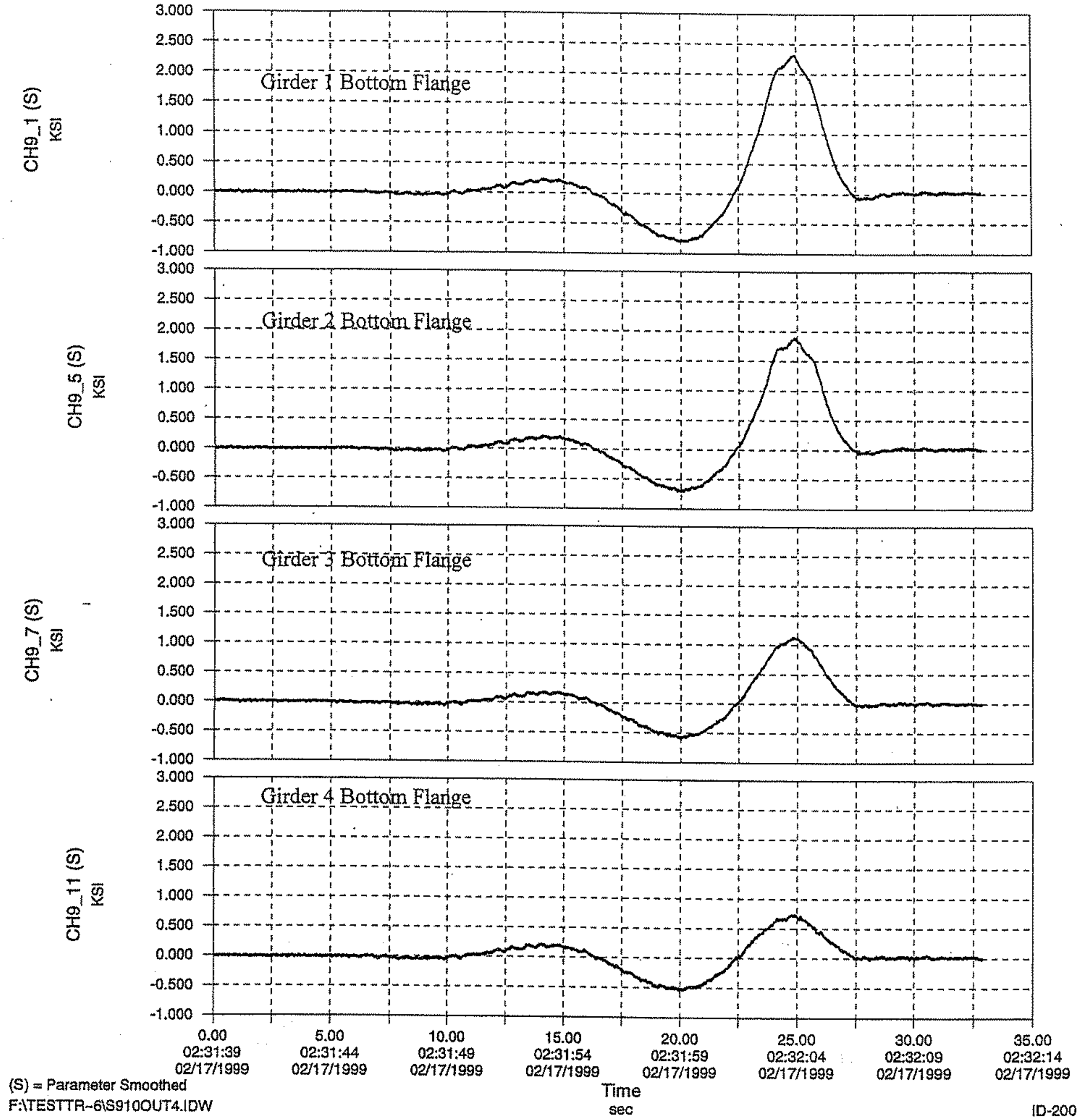
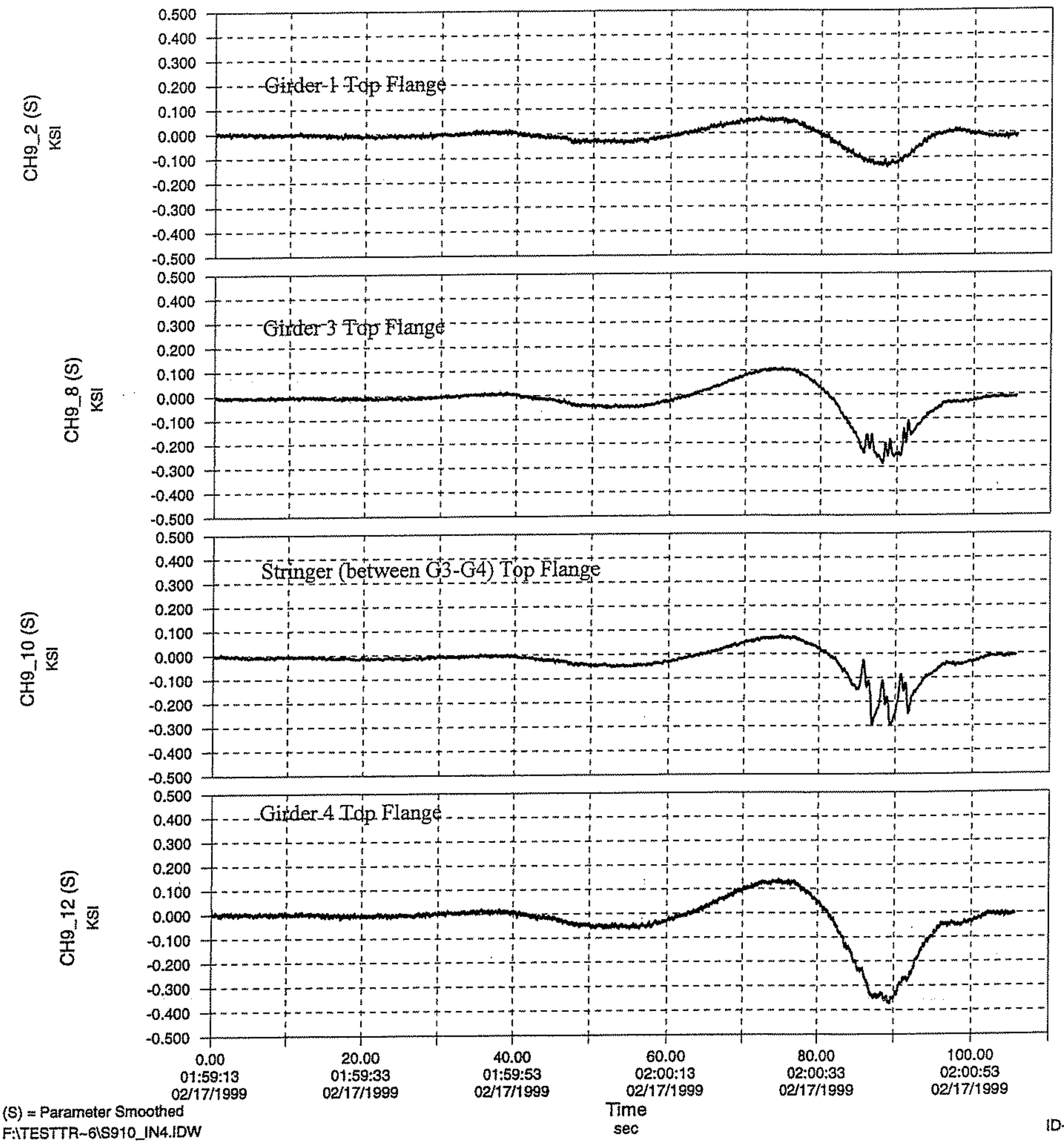
Test Vehicle at Span 9 / Section C; Vehicle Outbound on Outbound Track @ Nominal 10 mph



Test Vehicle at Span 9 / Section C; Vehicle Inbound on Outbound Track @ Nominal 25 mph



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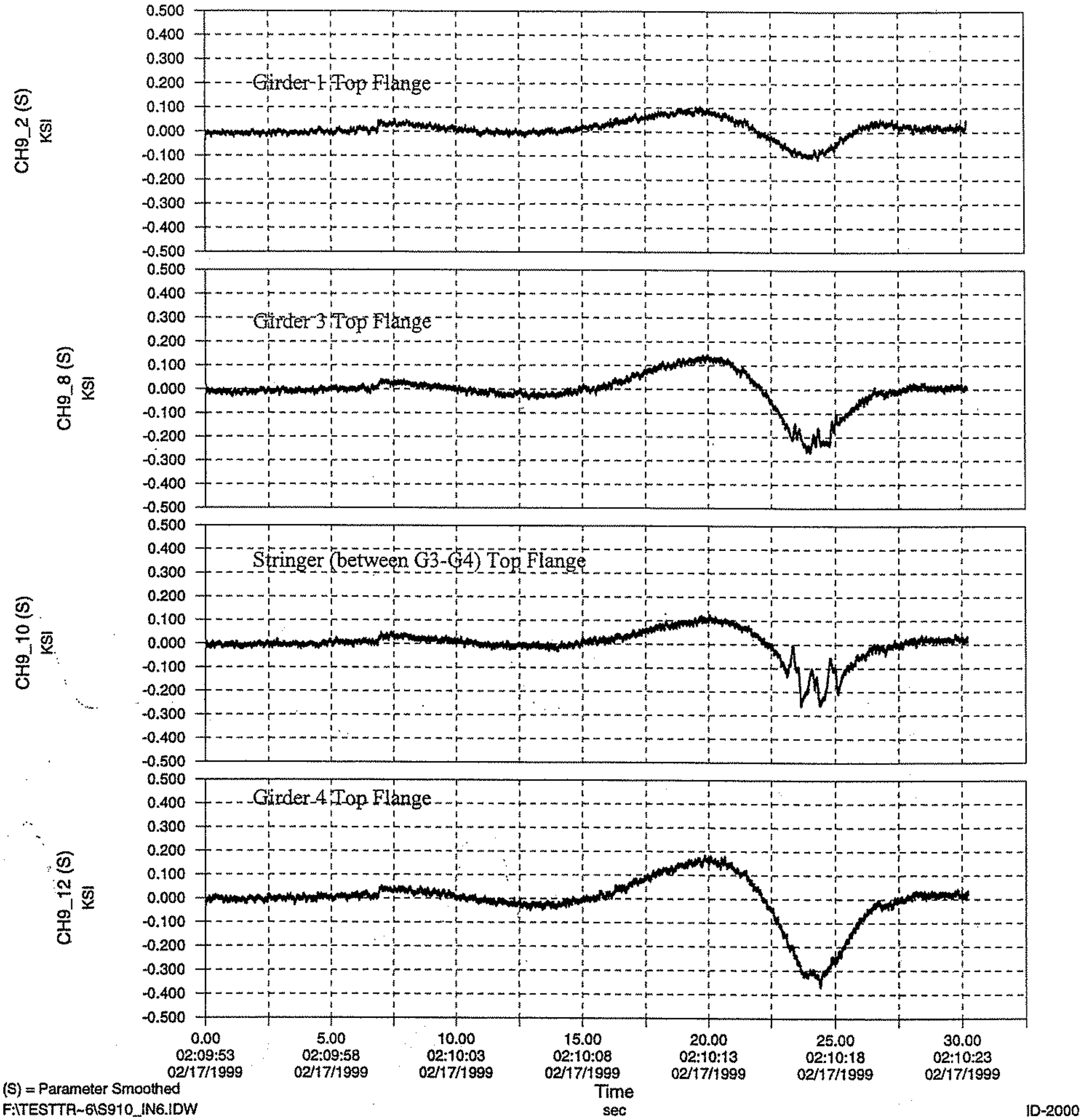
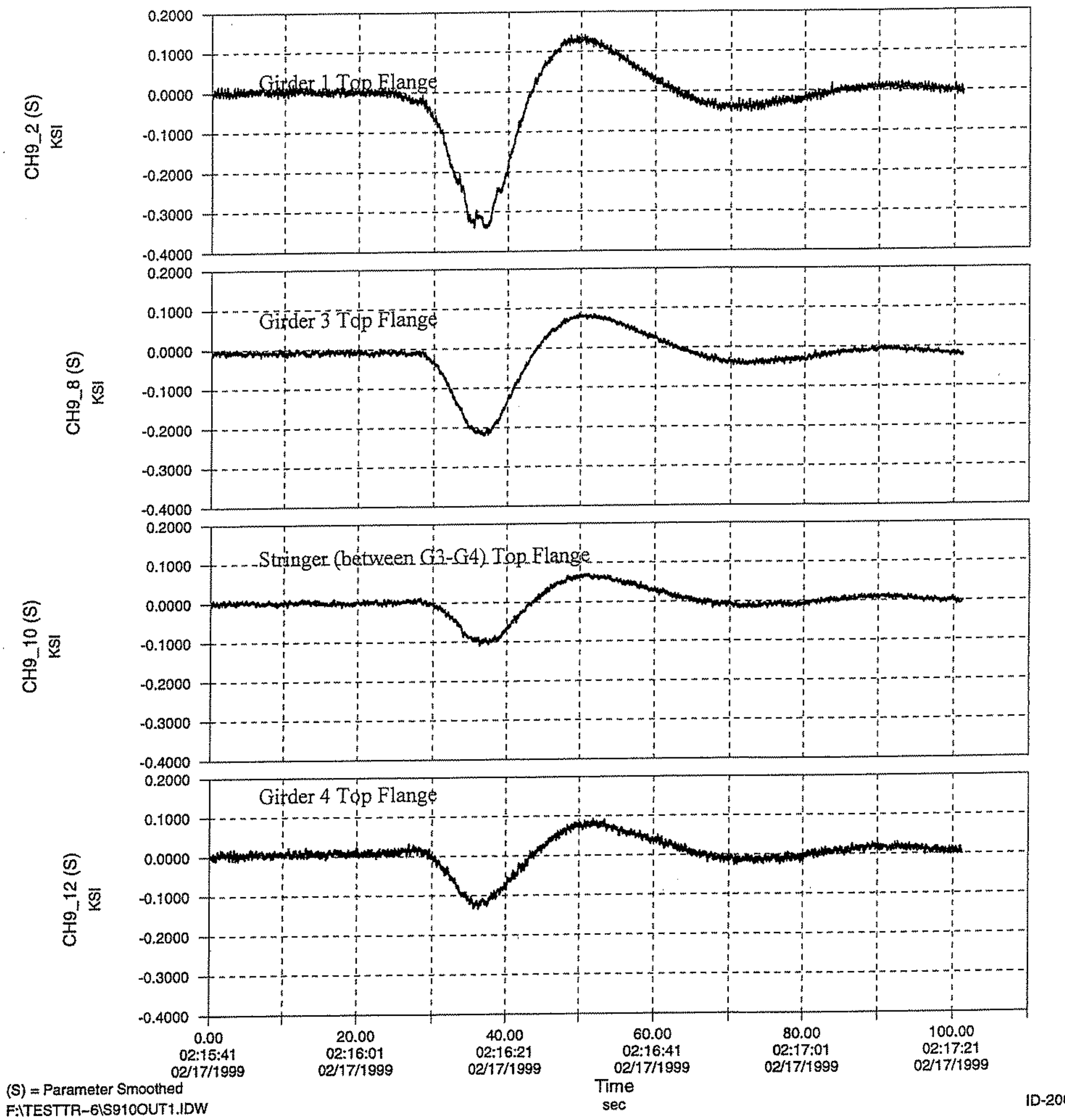
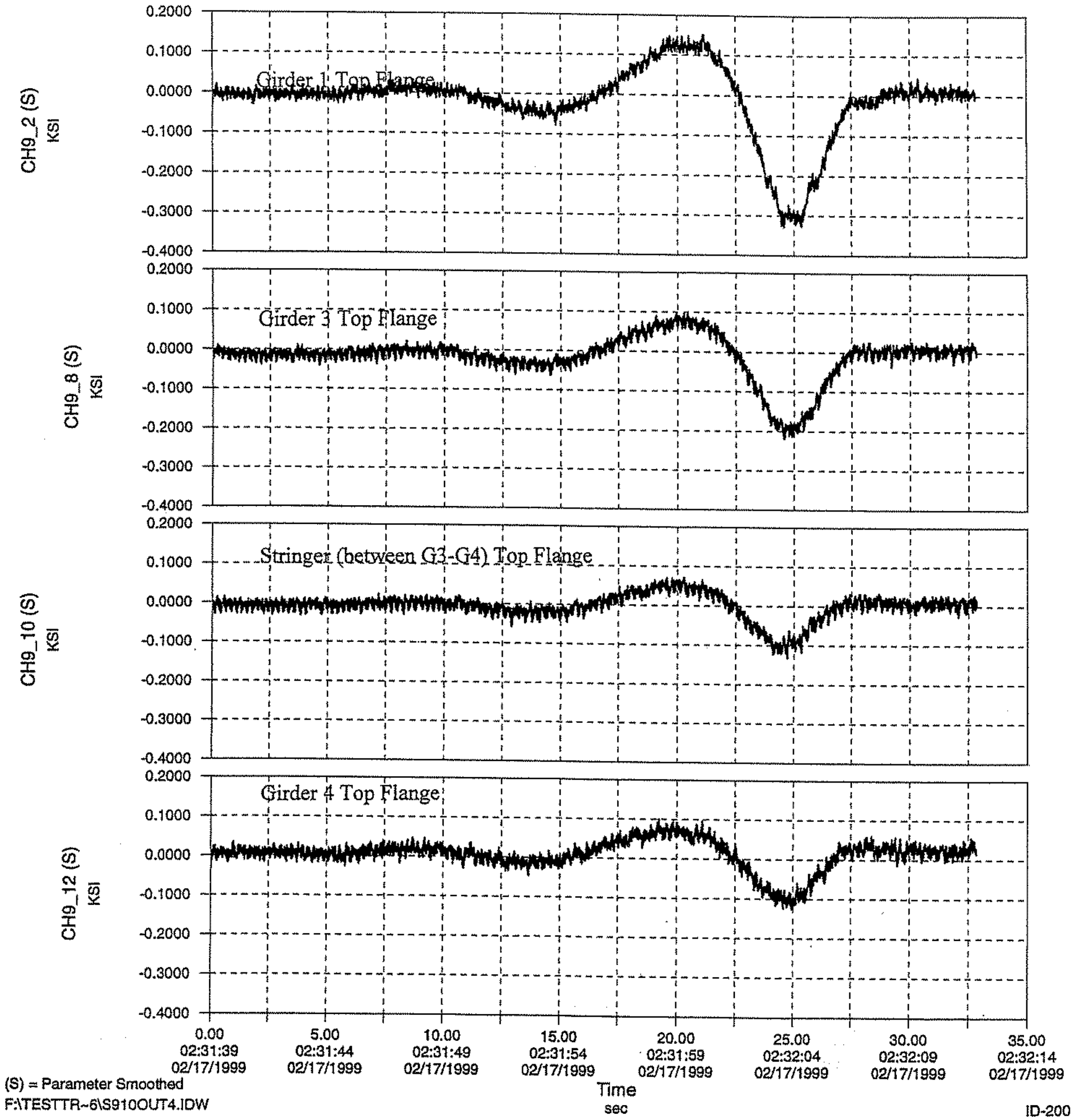
Test Vehicle at Span 9 / Section C; Vehicle Inbound on Inbound Track @ Nominal 10 mph



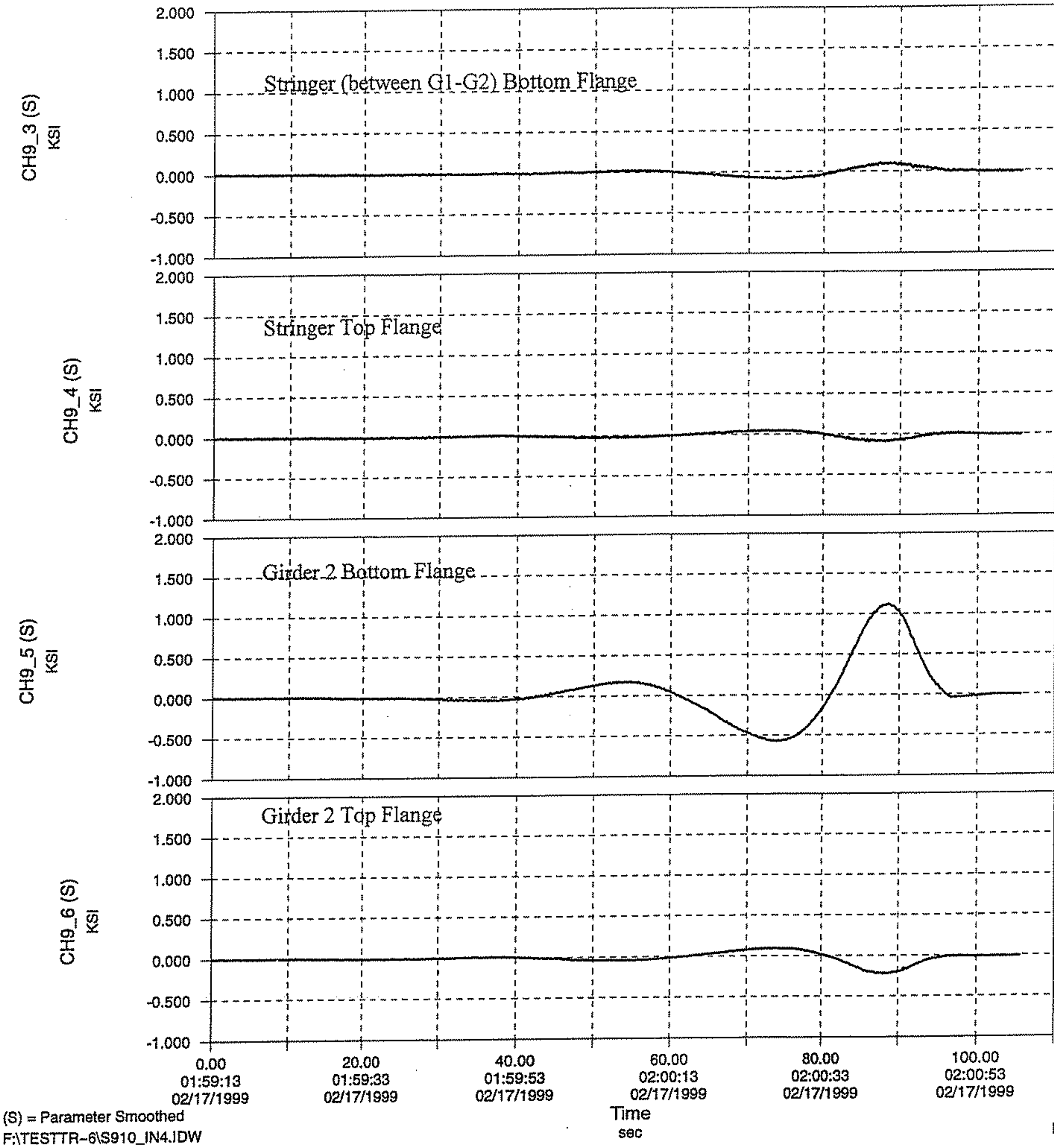
Test Vehicle at Span 9 / Section C; Vehicle Inbound on Inbound Track @ Nominal 25 mph



Test Vehicle at Span 9 / Section C; Vehicle Outbound on Outbound Track @ Nominal 10 mph



Test Vehicle at Span 9 / Section C; Vehicle Inbound on Outbound Track @ Nominal 25 mph



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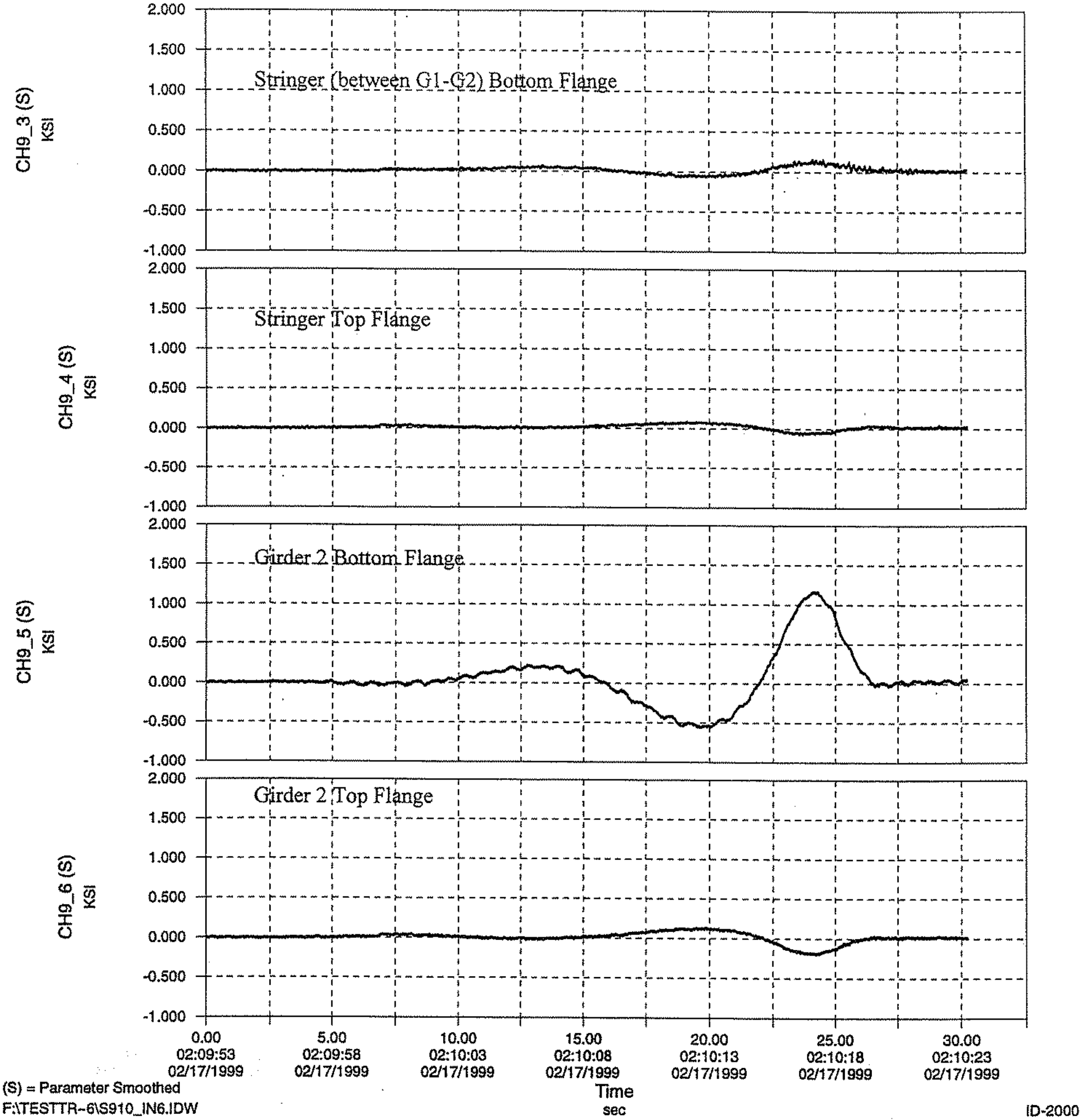
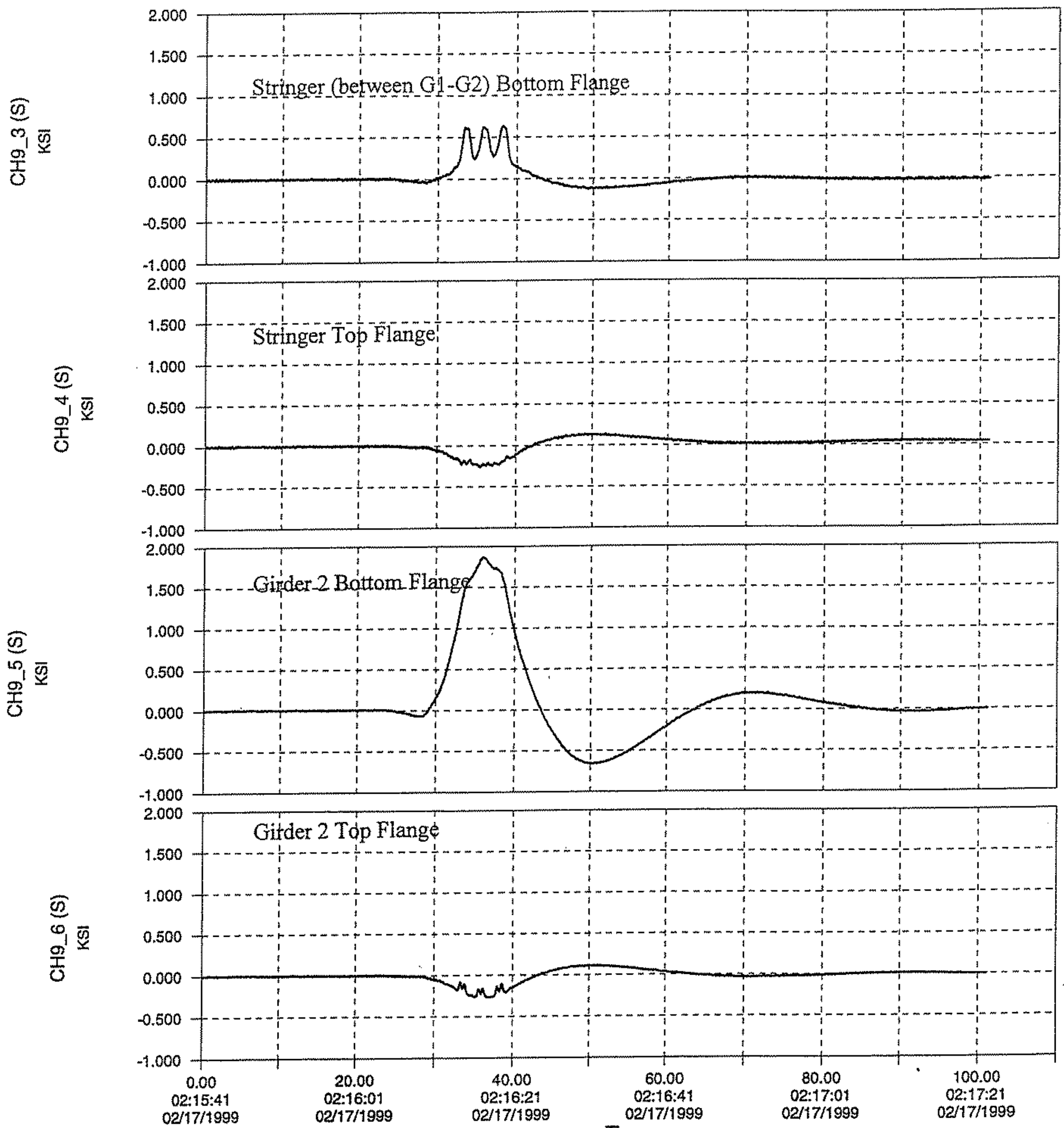
Test Vehicle at Span 9 / Section C; Vehicle Inbound on Inbound Track @ Nominal 10 mph



Test Vehicle at Span 9 / Section C; Vehicle Inbound on Inbound Track @ Nominal 25 mph



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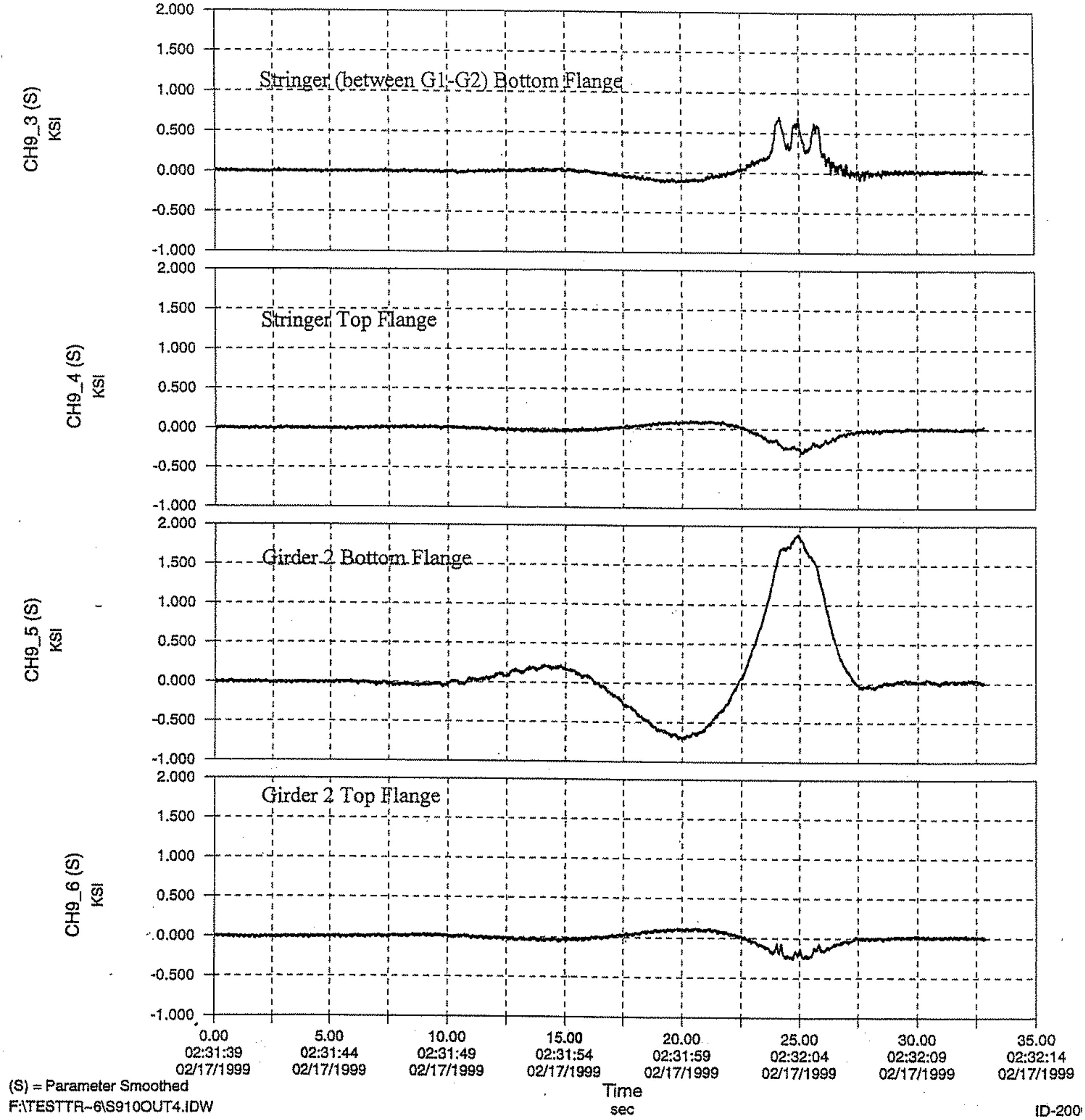
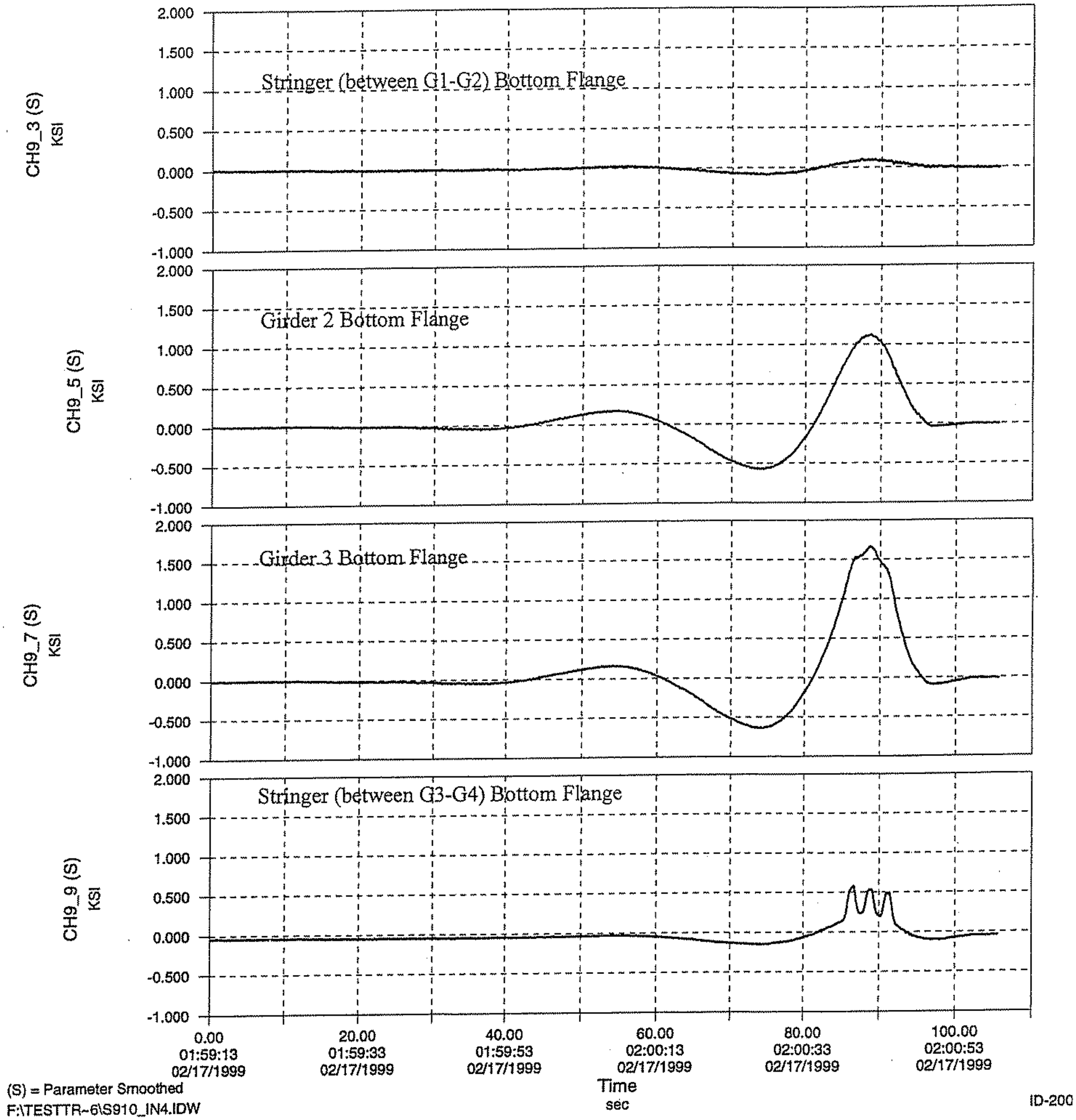
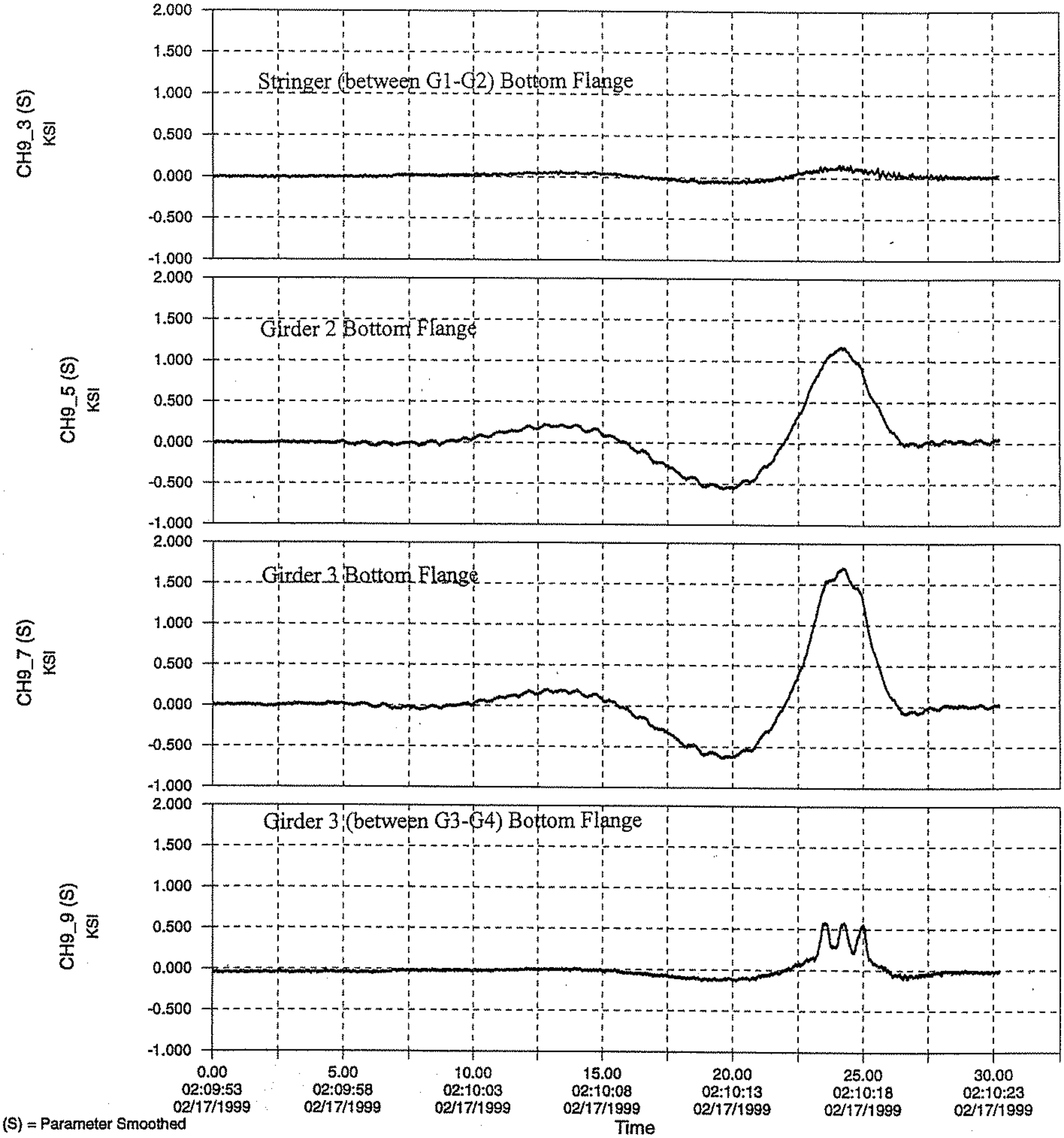
Test Vehicle at Span 9 / Section C; Vehicle Outbound on Outbound Track @ Nominal 10 mph



Test Vehicle at Span 9 / Section C; Vehicle Inbound on Outbound Track @ Nominal 25 mph



Test Vehicle at Span 9 / Section C; Vehicle Inbound on Inbound Track @ Nominal 10 mph



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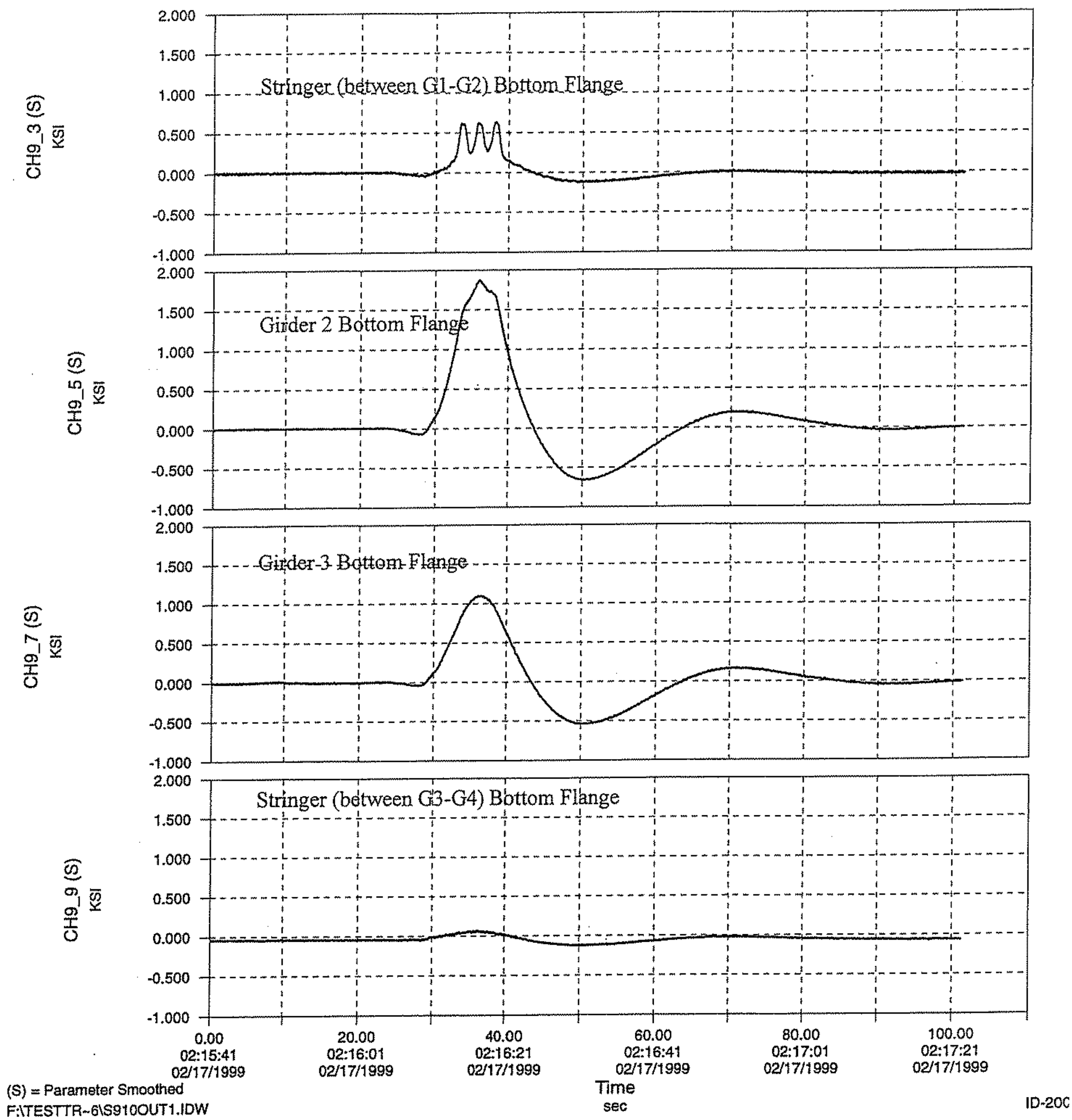
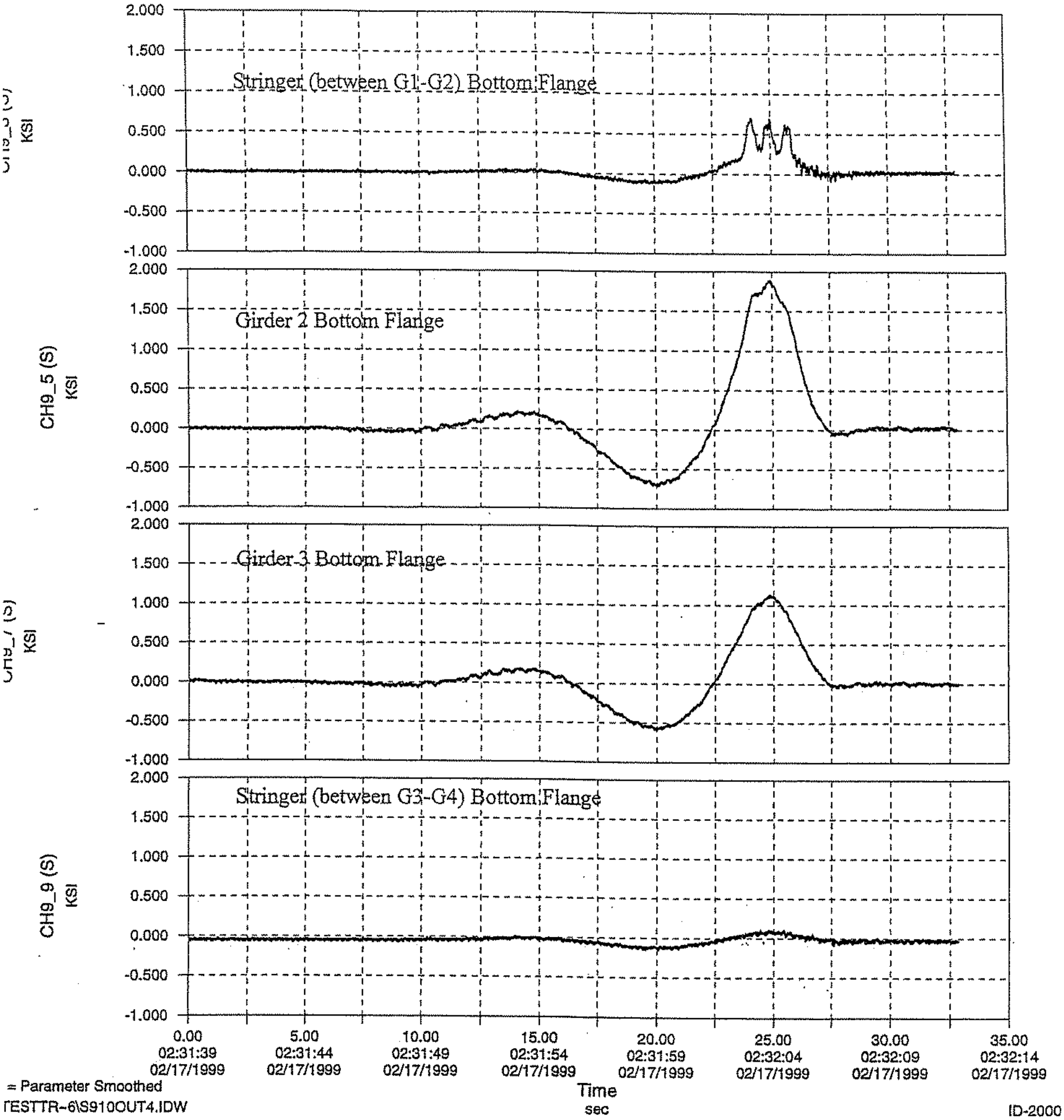
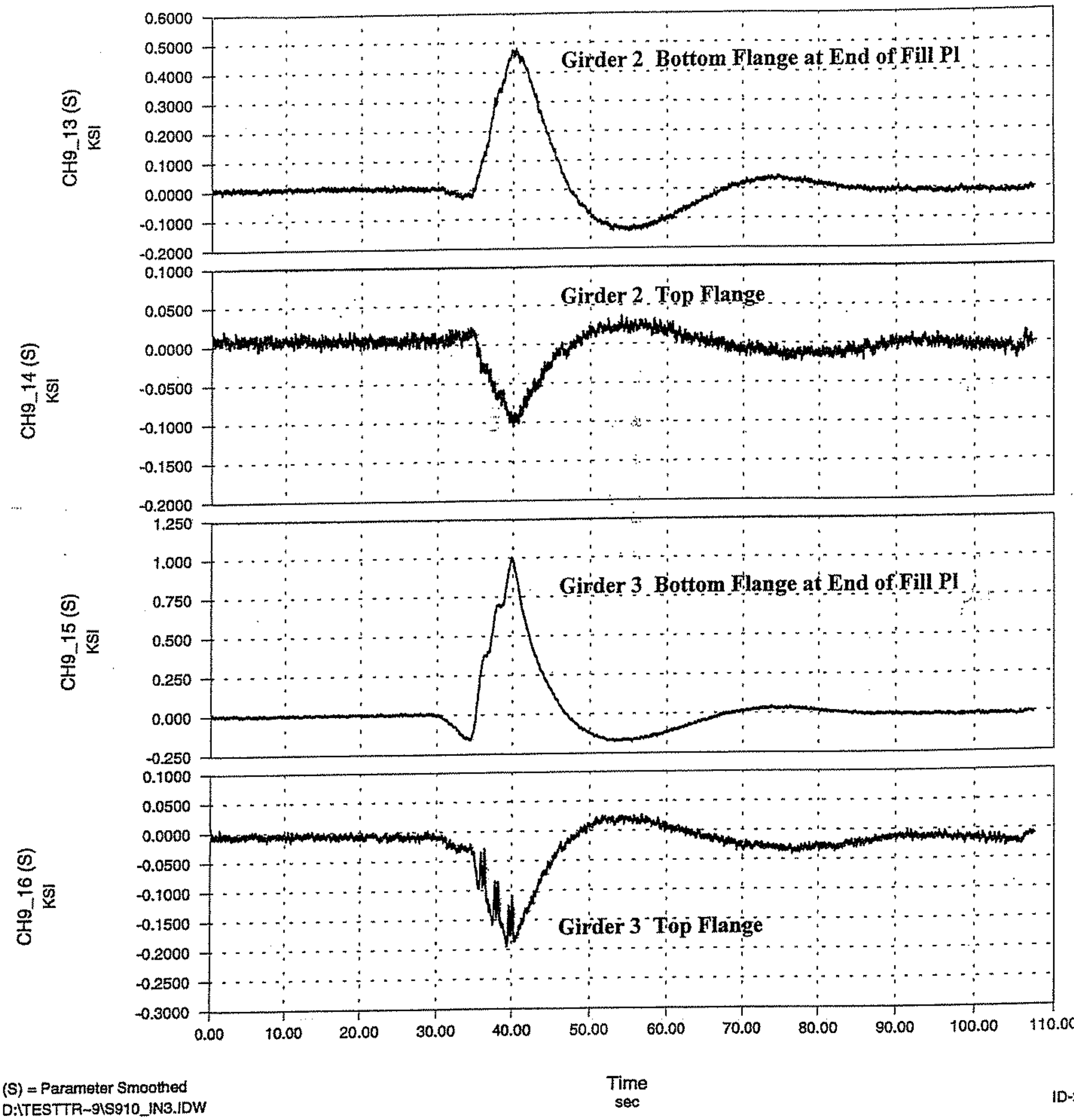
Test Vehicle at Span 9 / Section C; Vehicle Inbound on Inbound Track @ Nominal 25 mph



Test Vehicle at Span 9 / Section C; Vehicle Outbound on Outbound Track @ Nominal 10 mph



Test Vehicle at Span 9 / Section C; Vehicle Inbound on Outbound Track @ Nominal 25 mph



(S) = Parameter Smoothed
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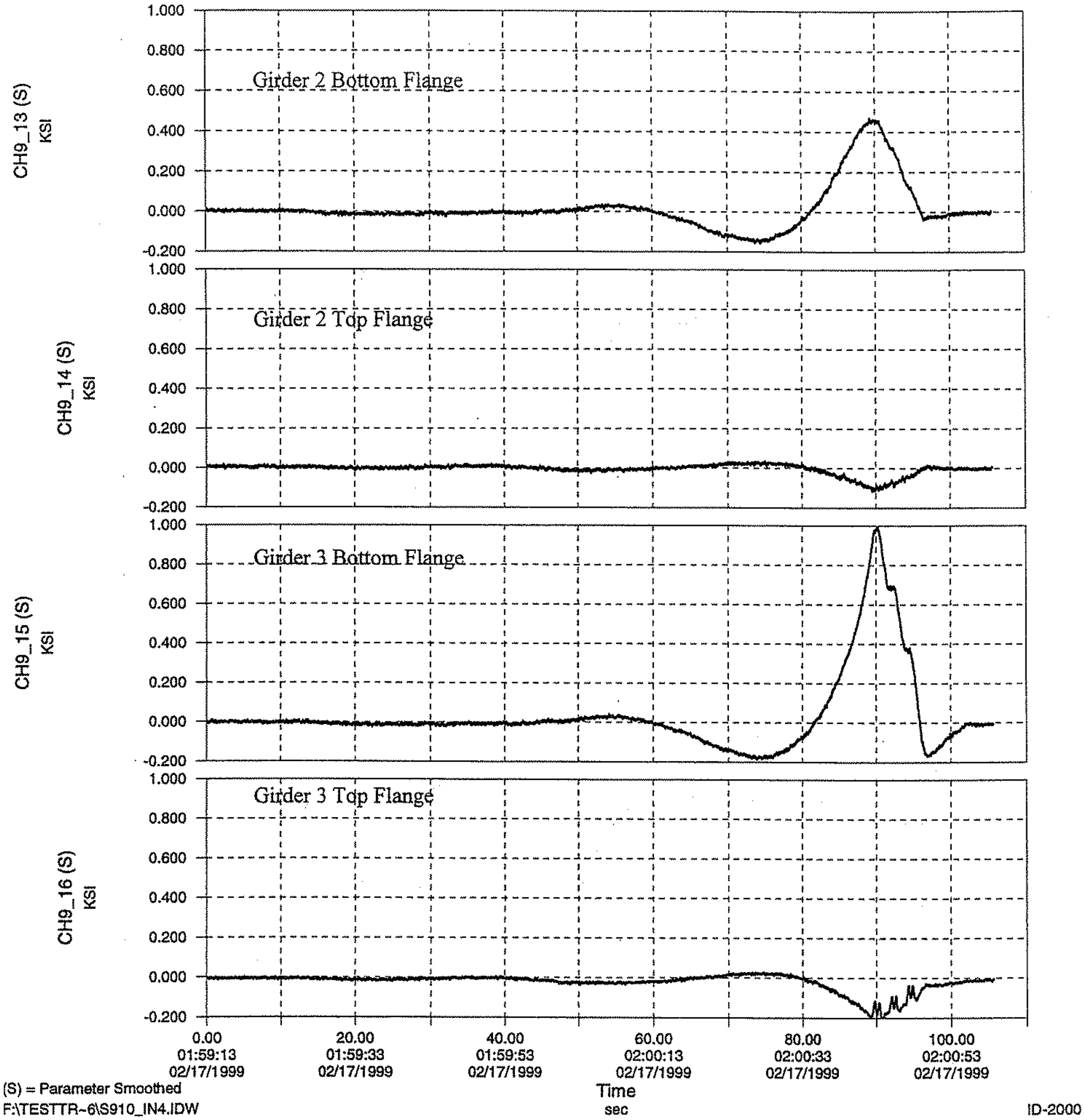
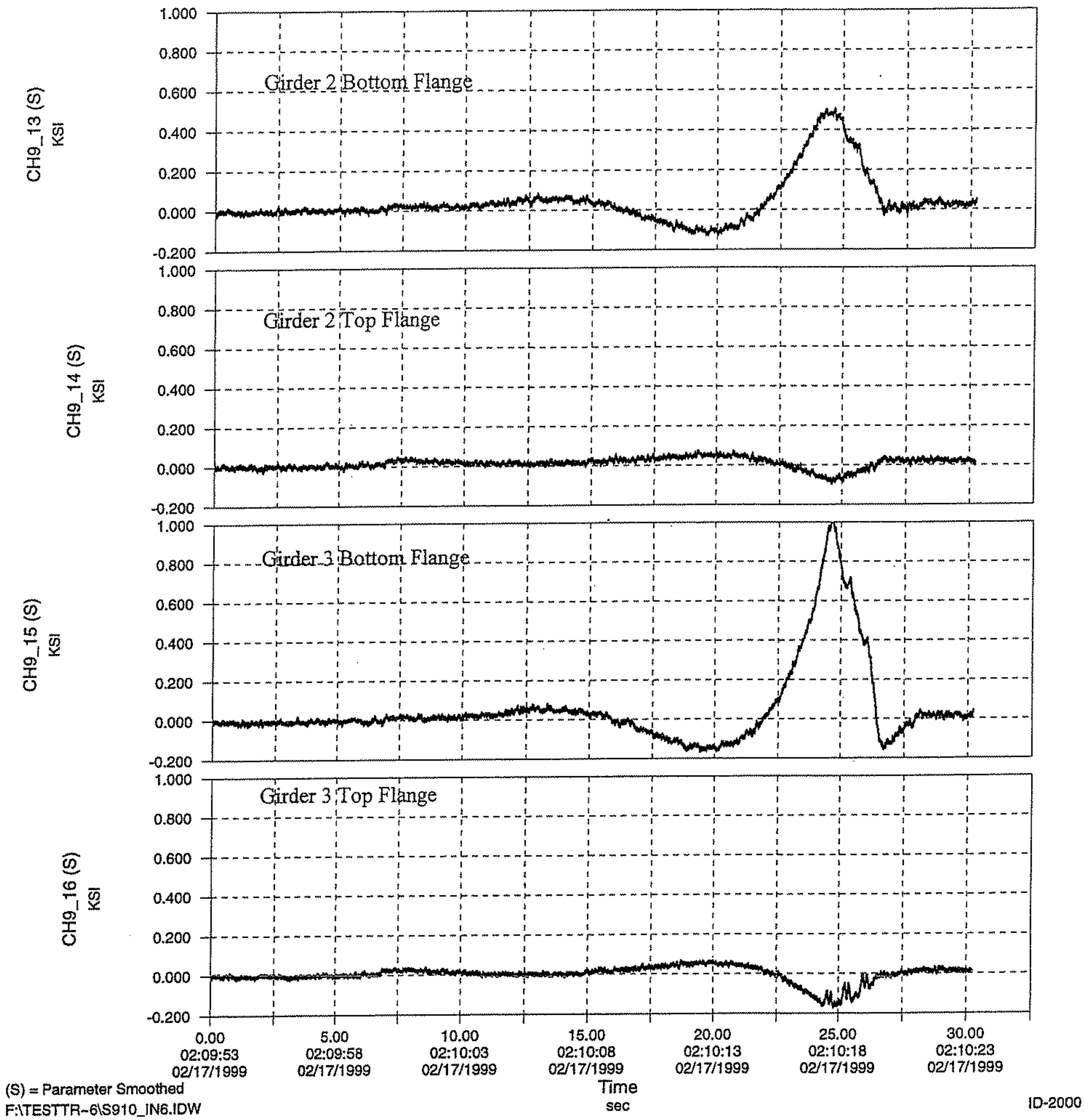
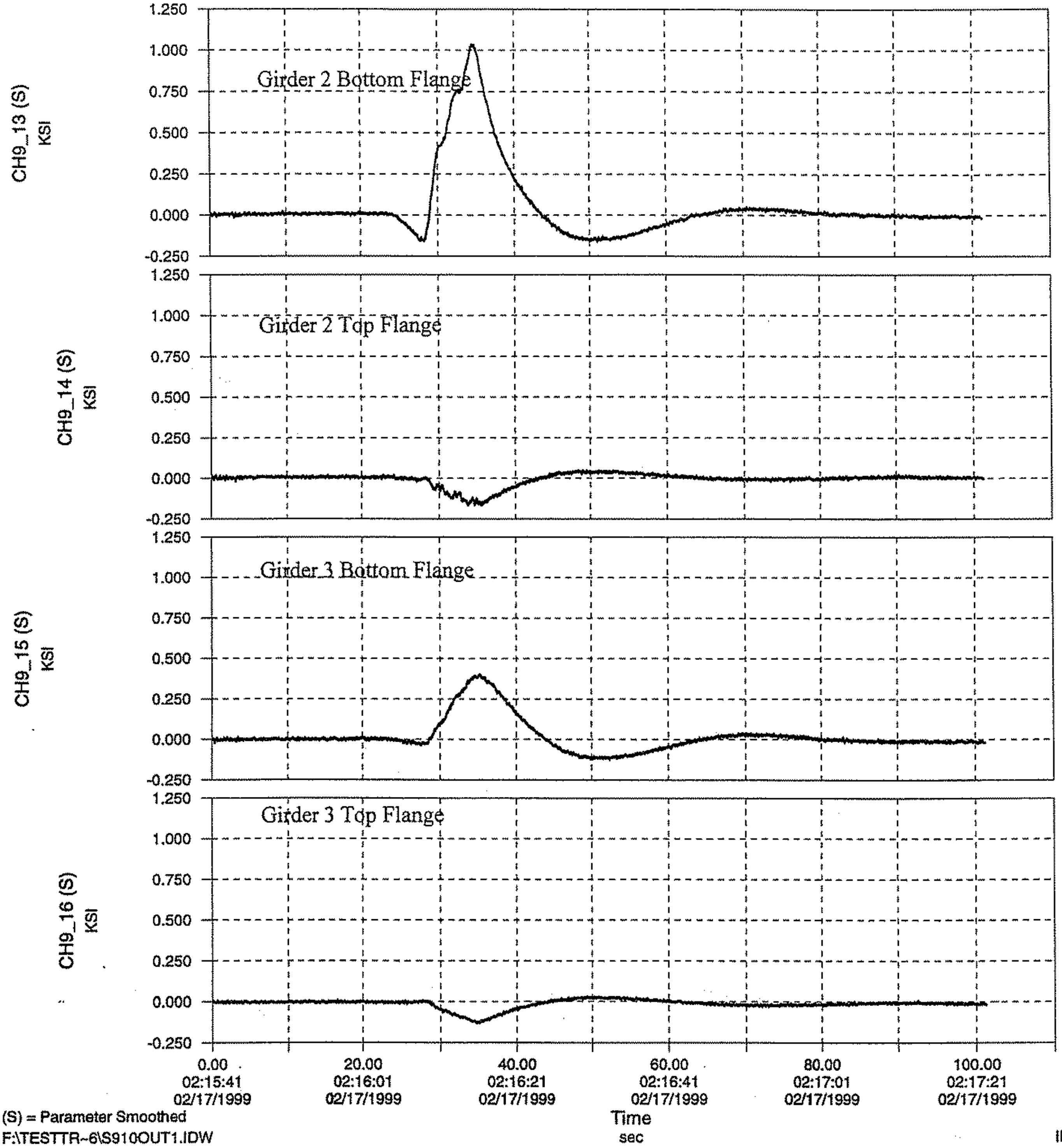
Test Vehicle at Span 9 / Section 5; Vehicle Outbound on Inbound Track @ Nominal 10 mph



Test Vehicle at Span 9 / Section 5; Vehicle Inbound on Inbound Track @ Nominal 10 mph



Test Vehicle at Span 9 / Section 5; Vehicle Inbound on Inbound Track @ Nominal 25 mph



(S) = Parameter Smoothed
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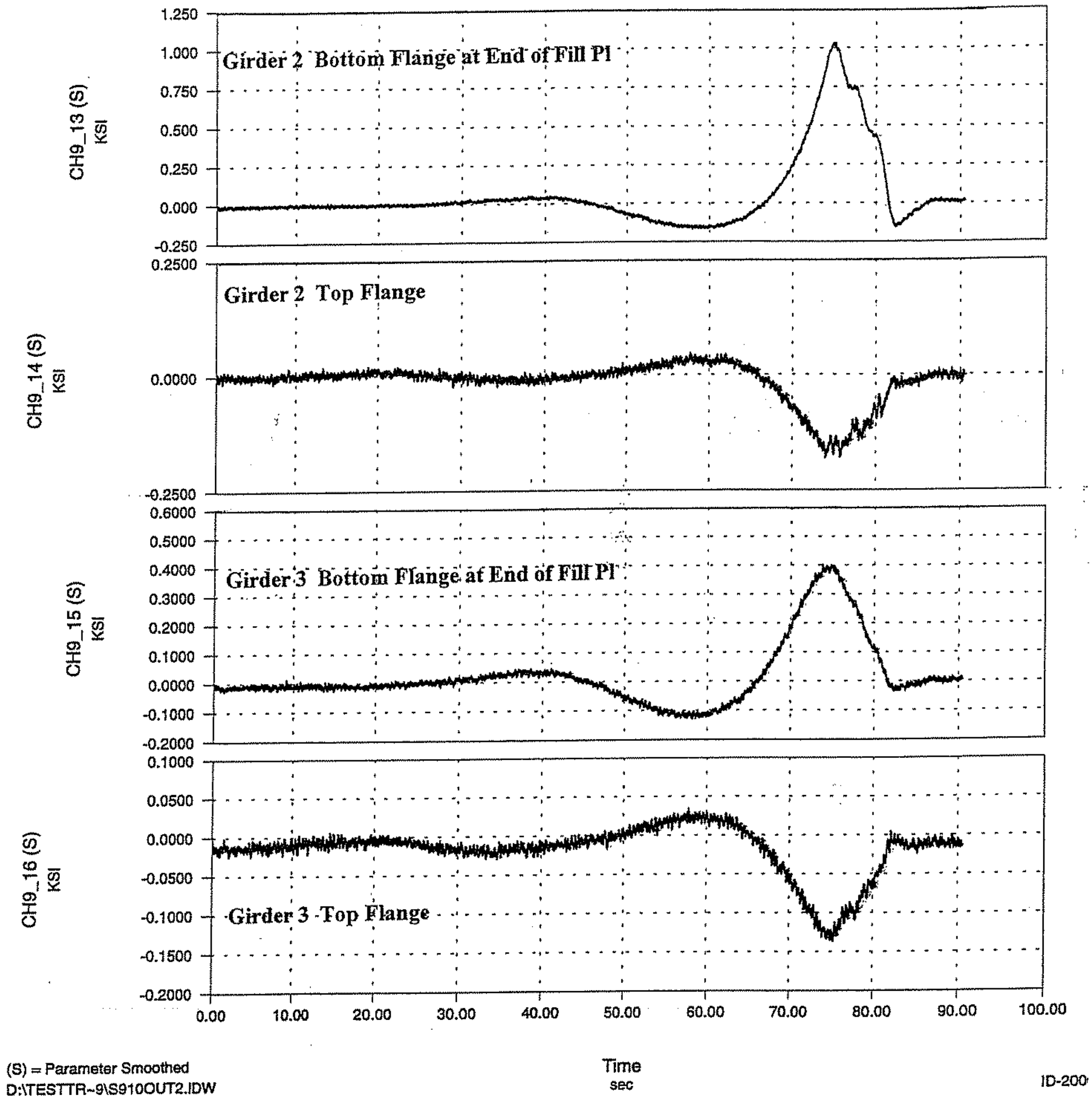
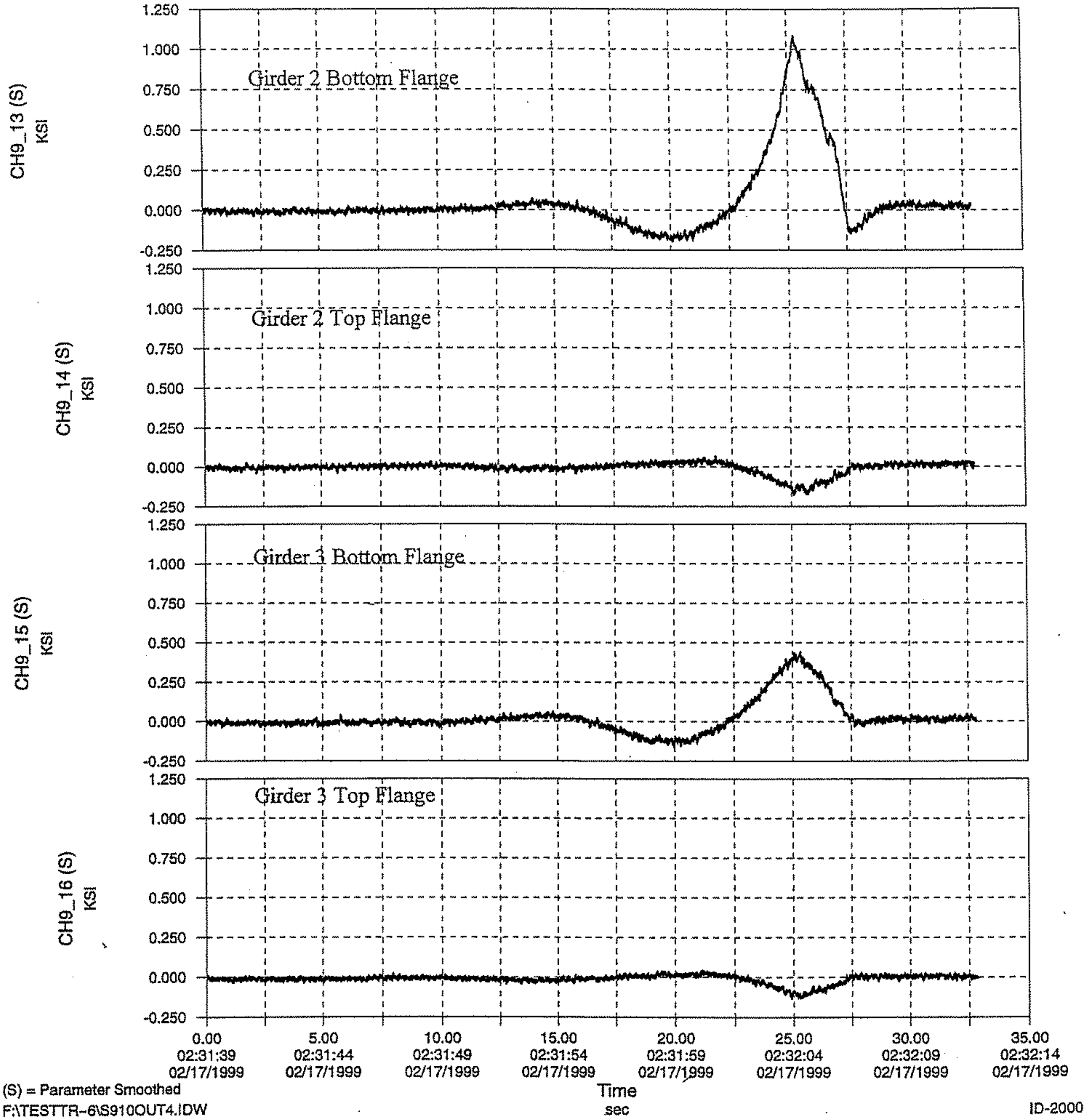
Test Vehicle at Span 9 / Section 5; Vehicle Outbound on Outbound Track @ Nominal 10 mph



Test Vehicle at Span 9 / Section 5; Vehicle Inbound on Outbound Track @ Nominal 10 mph



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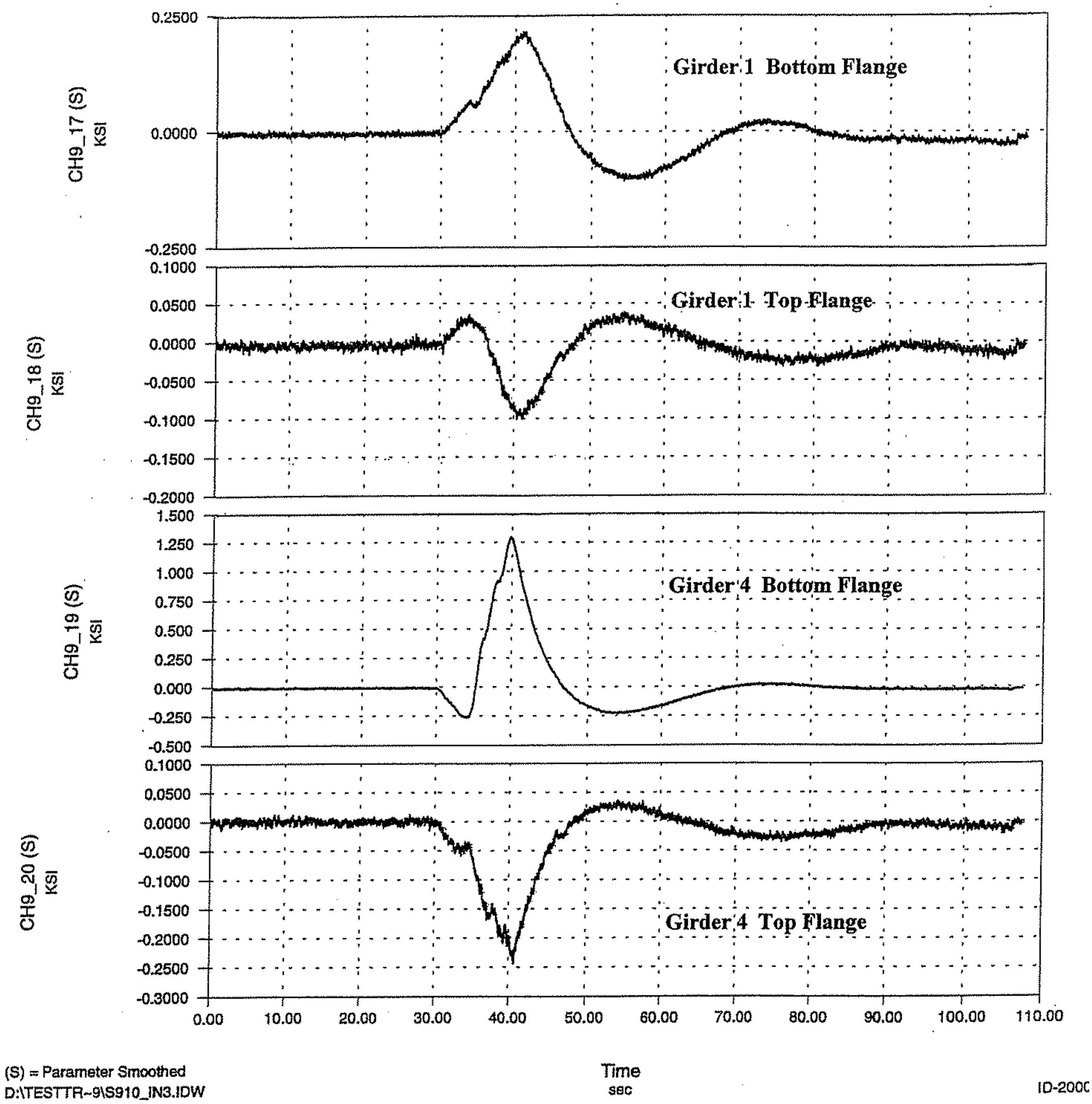
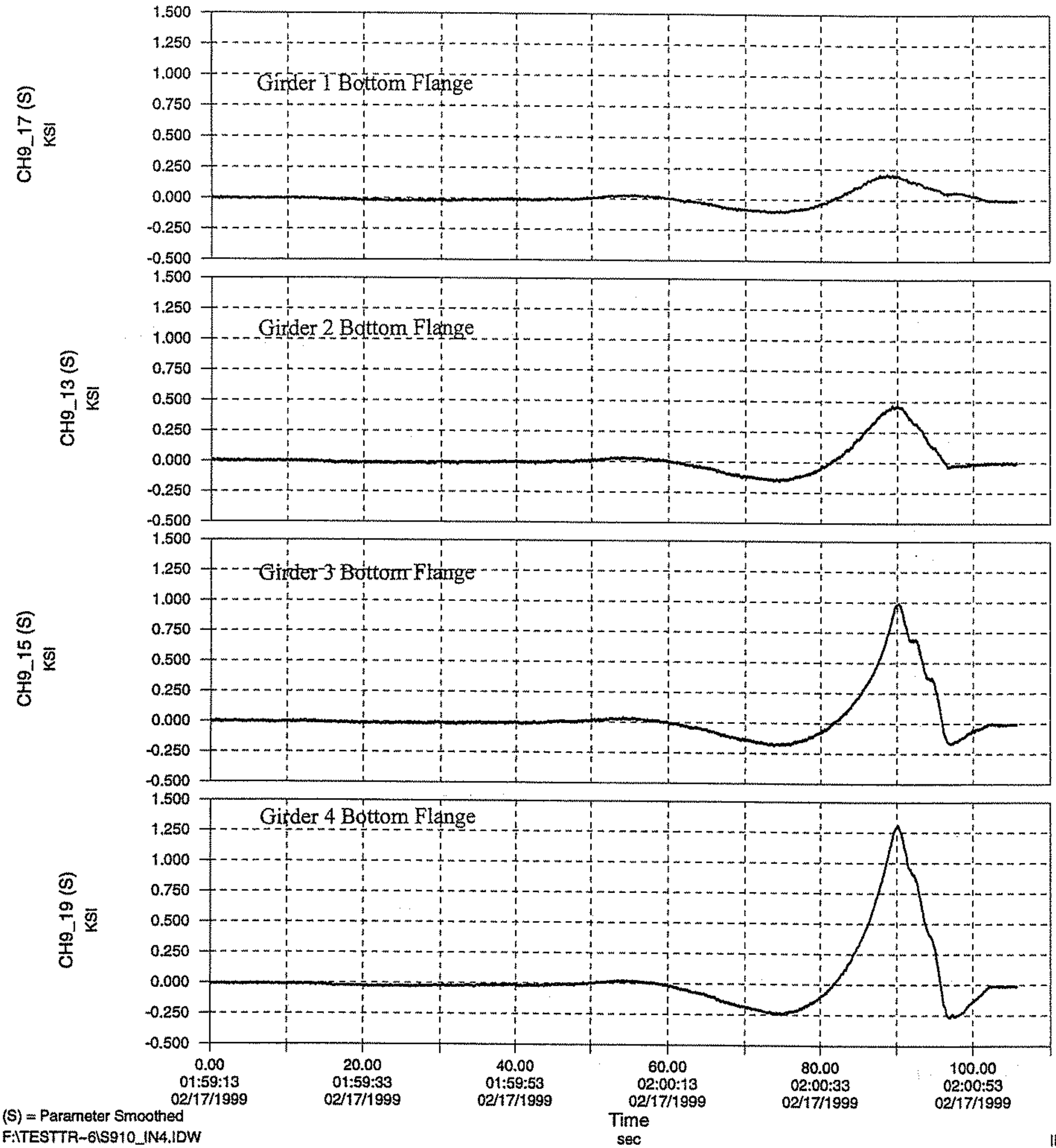
Test Vehicle at Span 9 / Section 5; Vehicle Inbound on Outbound Track @ Nominal 25 mph



Test Vehicle at Span 9 / Section 5; Vehicle Outbound on Inbound Track @ Nominal 10 mph



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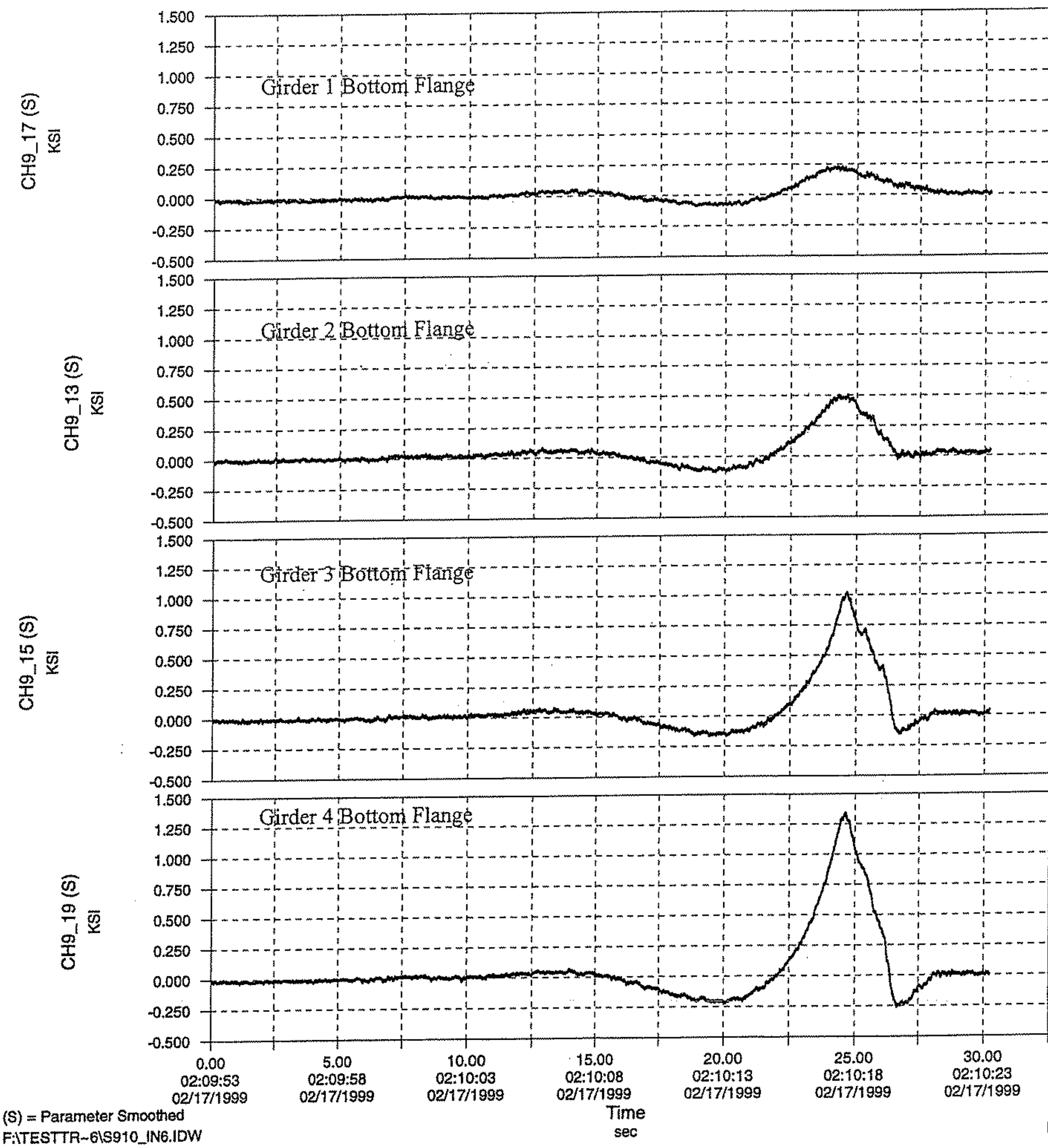
Test Vehicle at Span 9 / Section 5; Vehicle Inbound on Inbound Track @ Nominal 10 mph



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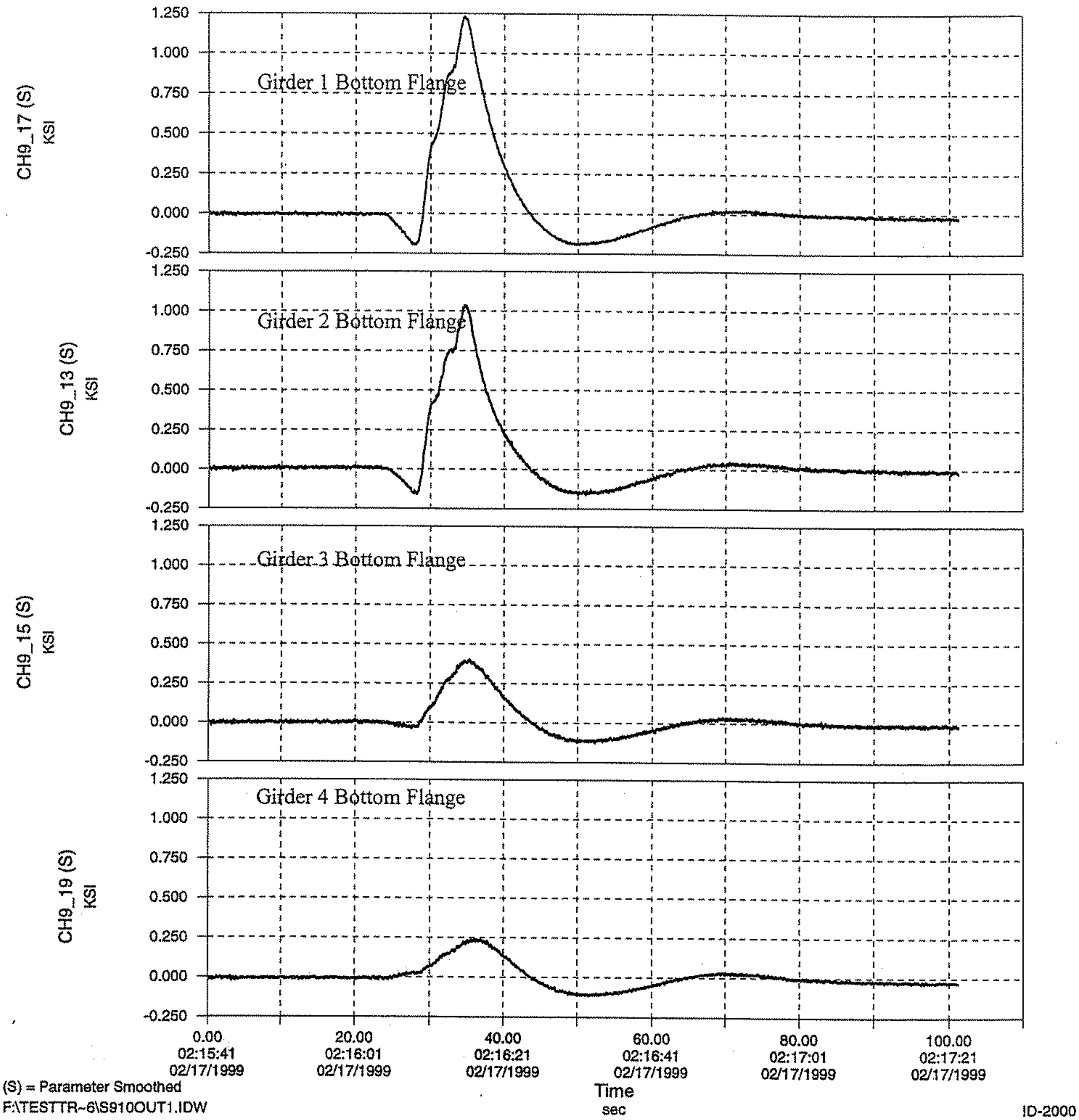
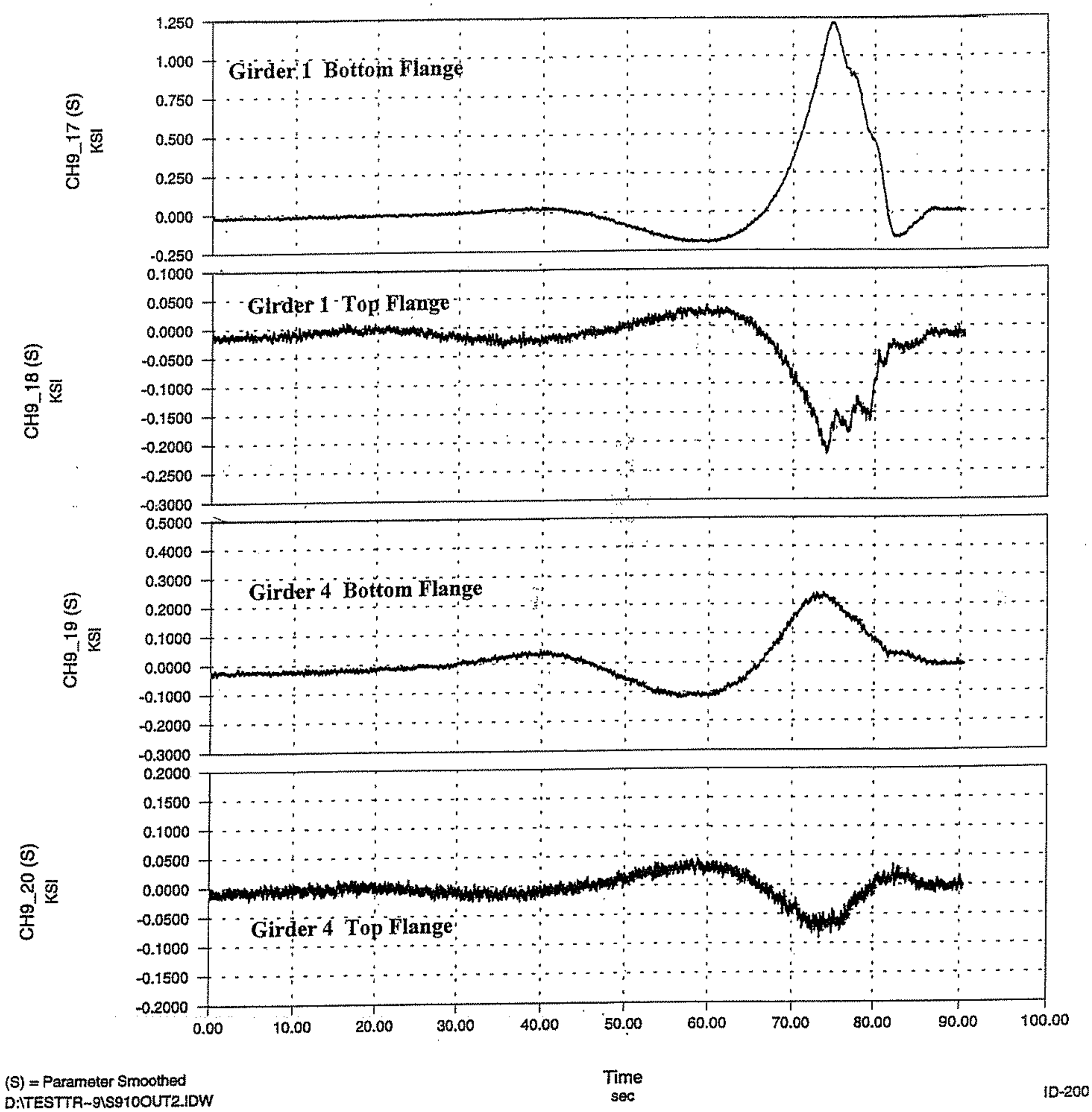
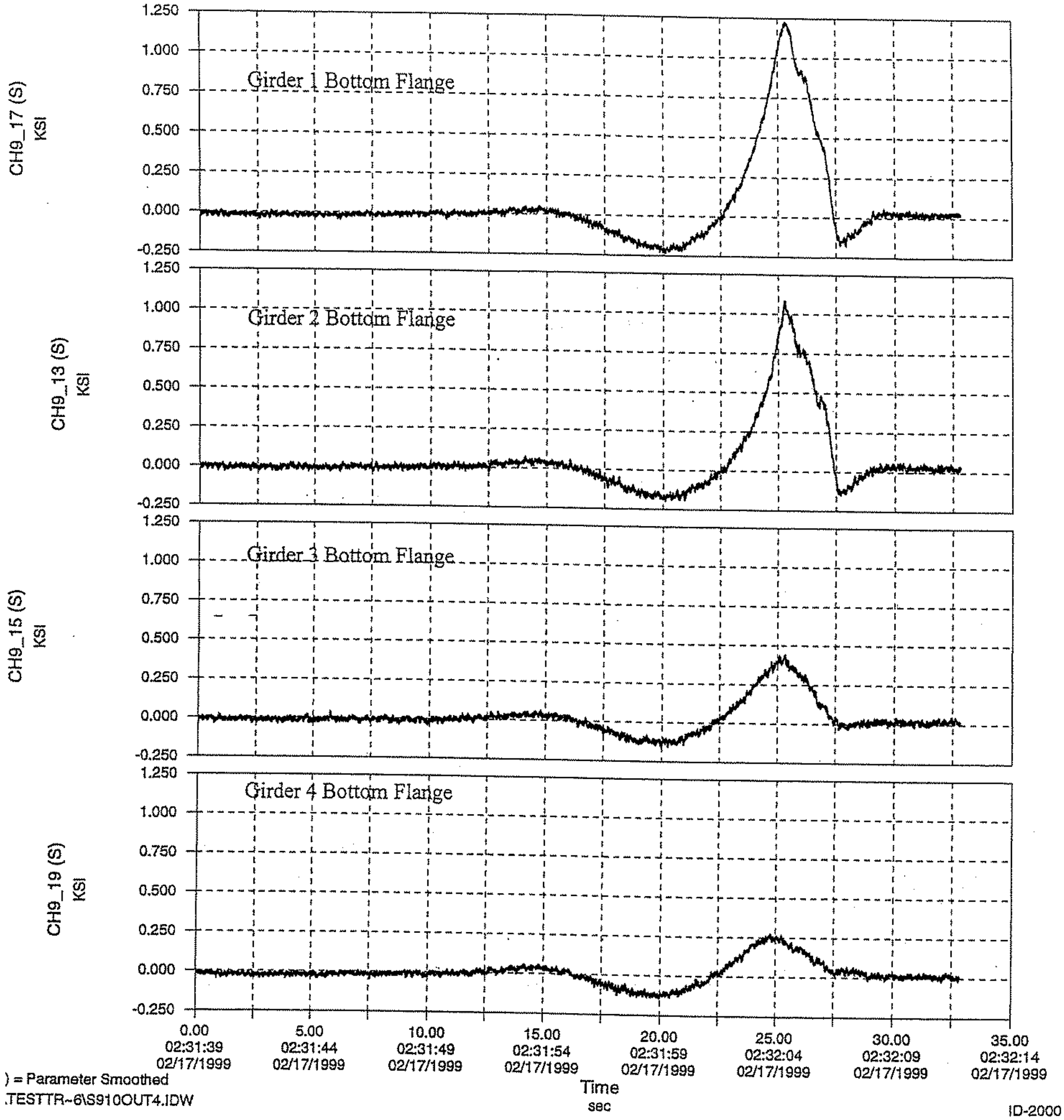
Test Vehicle at Span 9 / Section 5; Vehicle Inbound on Inbound Track @ Nominal 25 mph



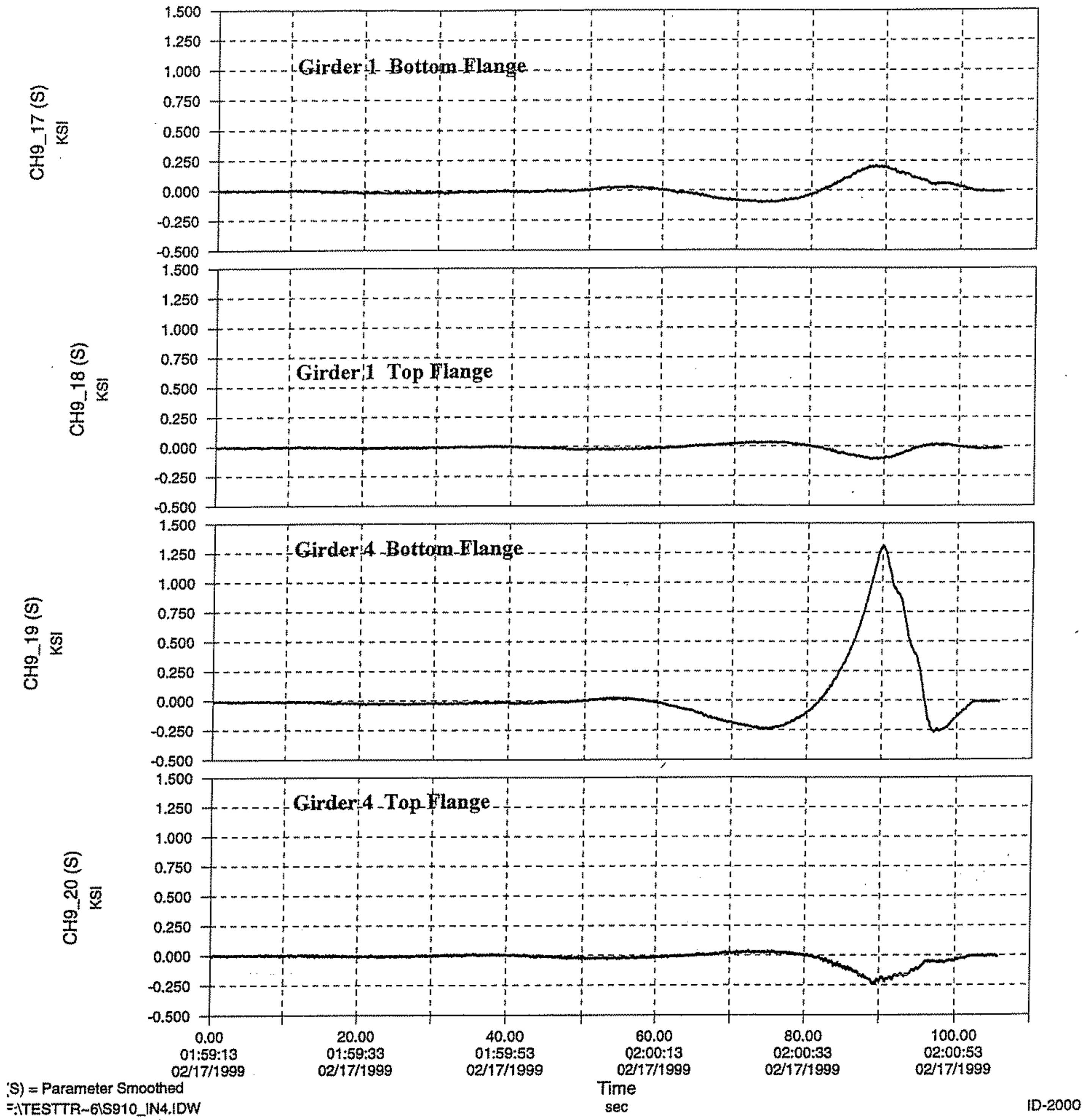
Test Vehicle at Span 9 / Section 5; Vehicle Outbound on Outbound Track @ Nominal 10 mph



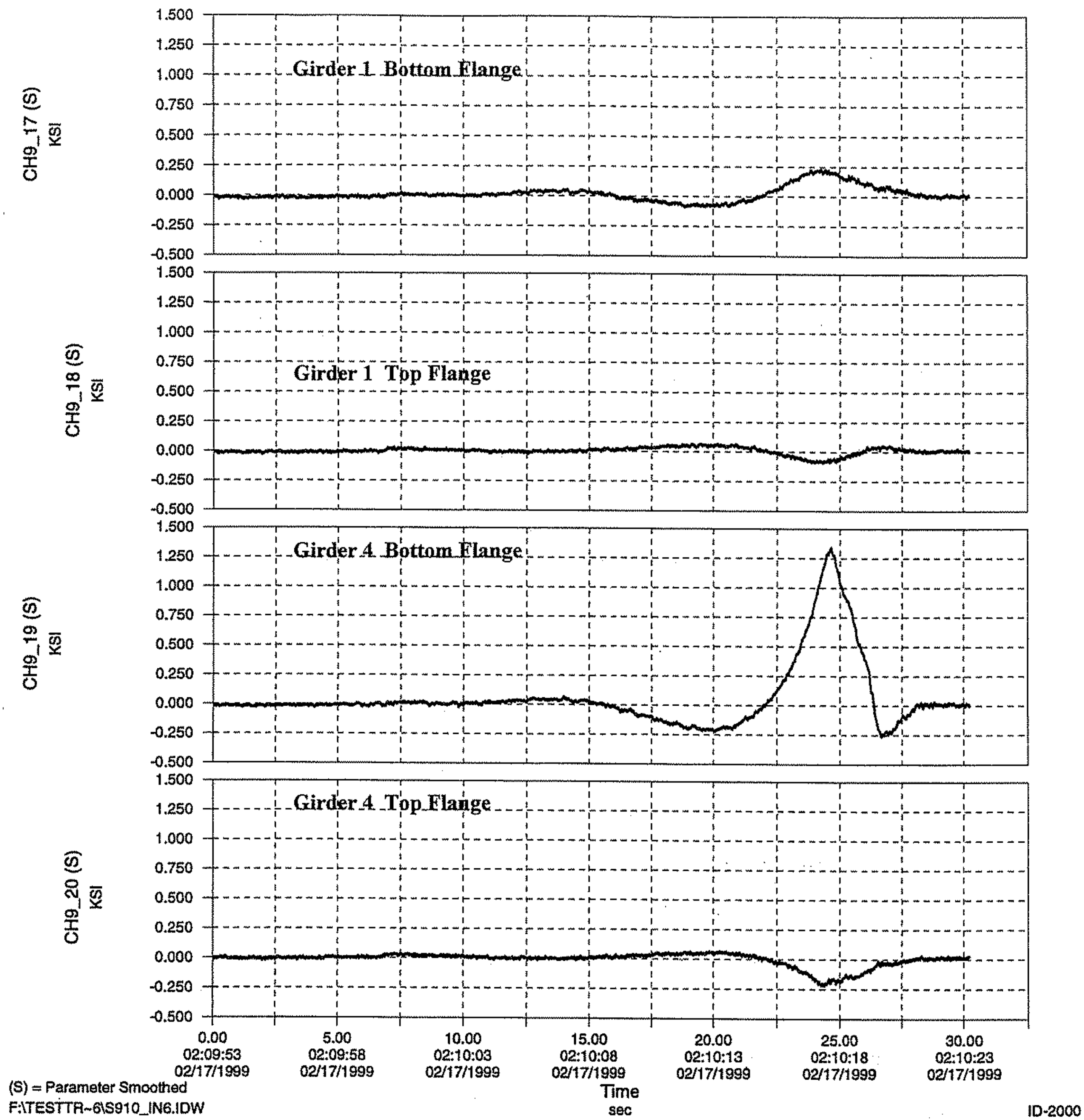
Test Vehicle at Span 9 / Section 5; Vehicle Inbound on Outbound Track @ Nominal 10 mph



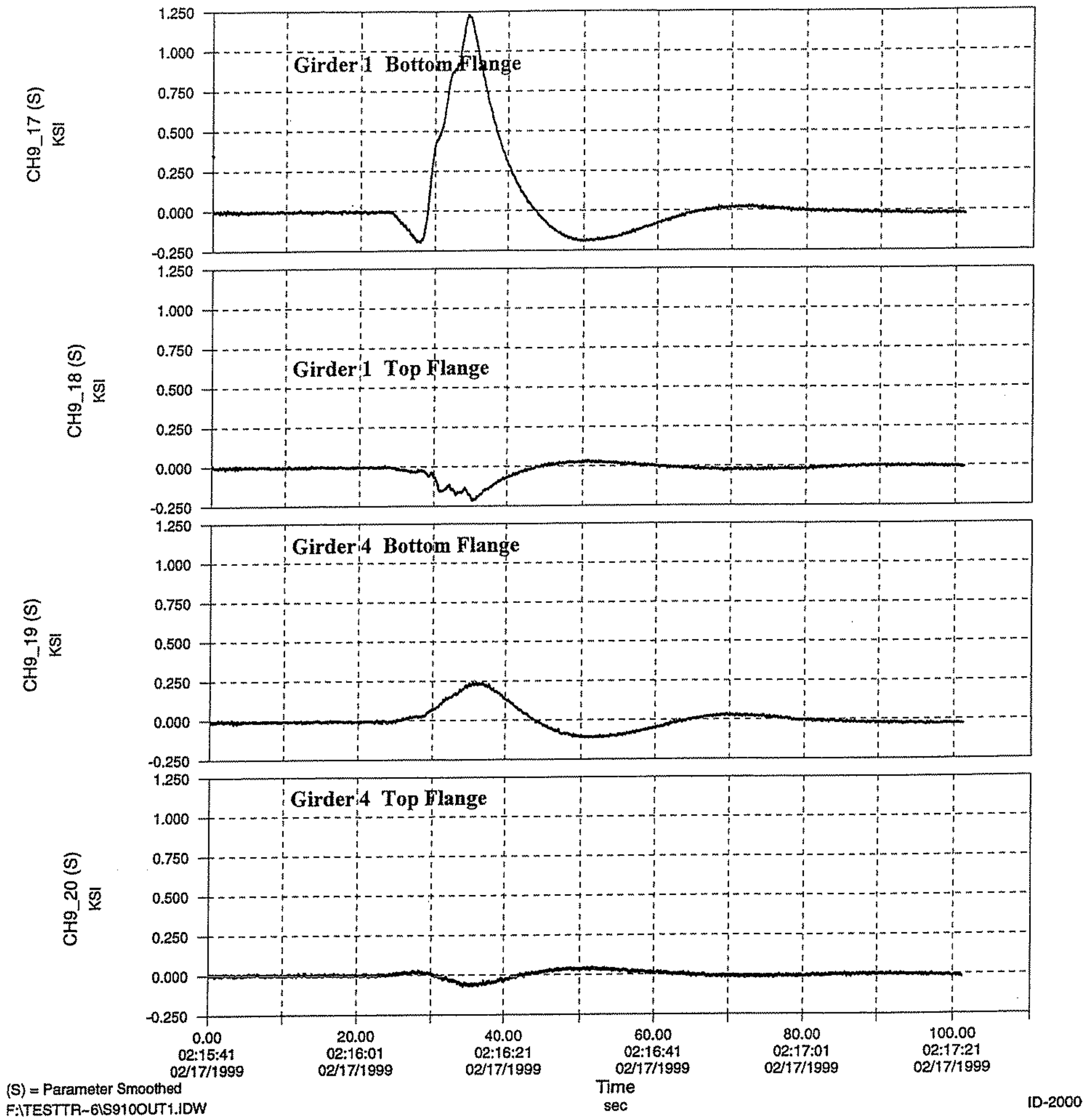
Test Vehicle at Span 9 / Section 5; Vehicle Inbound on Outbound Track @ Nominal 25 mph



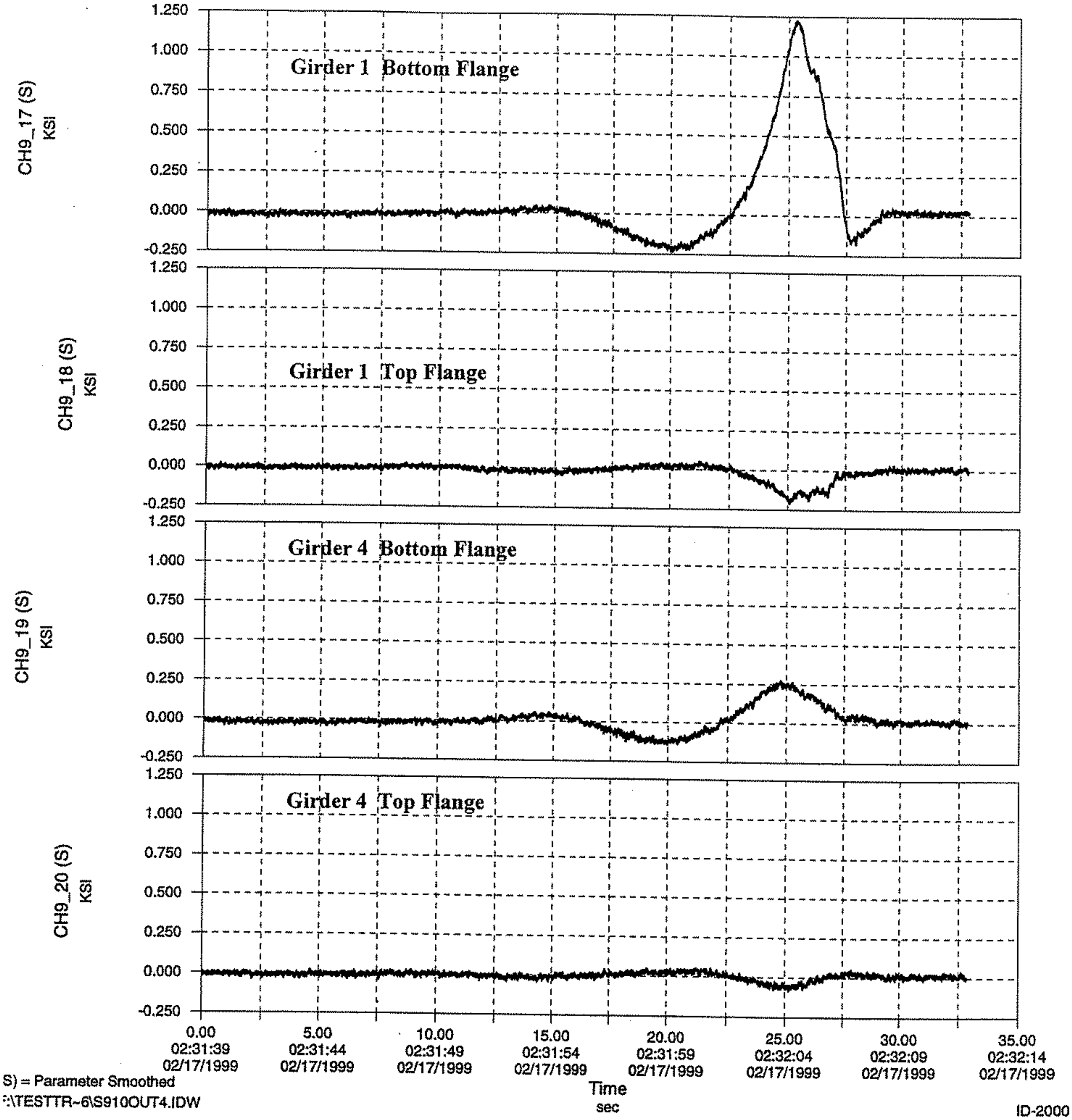
Test Vehicle at Span 9 / Section 5; Vehicle Inbound on Inbound Track @ Nominal 10 mph



Test Vehicle at Span 9 / Section 5; Vehicle Inbound on Inbound Track @ Nominal 25 mph

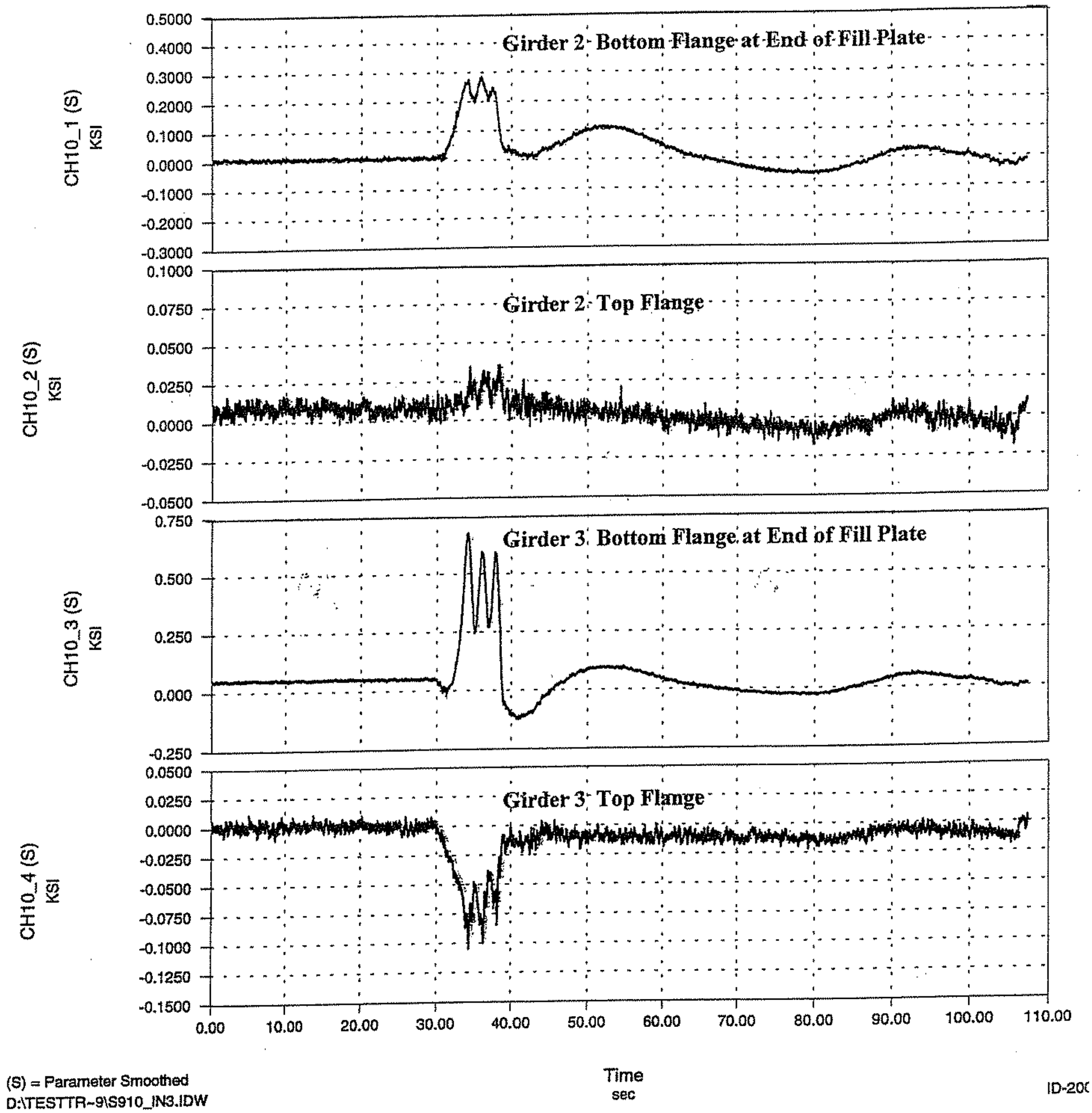


Test Vehicle at Span 9 / Section 5; Vehicle Outbound on Outbound Track @ Nominal 10 mph

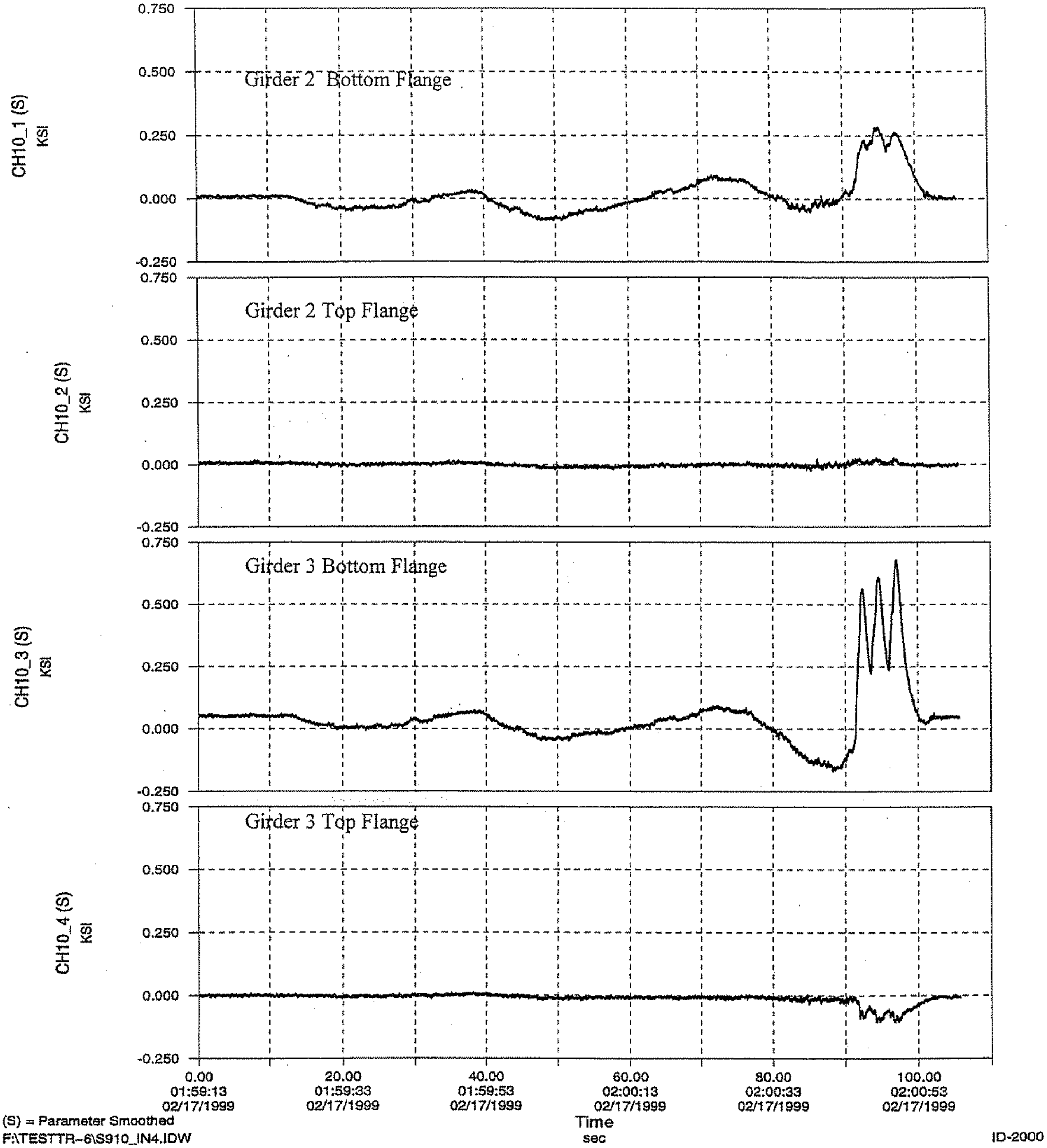


Test Vehicle at Span 9 / Section 5; Vehicle Inbound on Outbound Track @ Nominal 25 mph

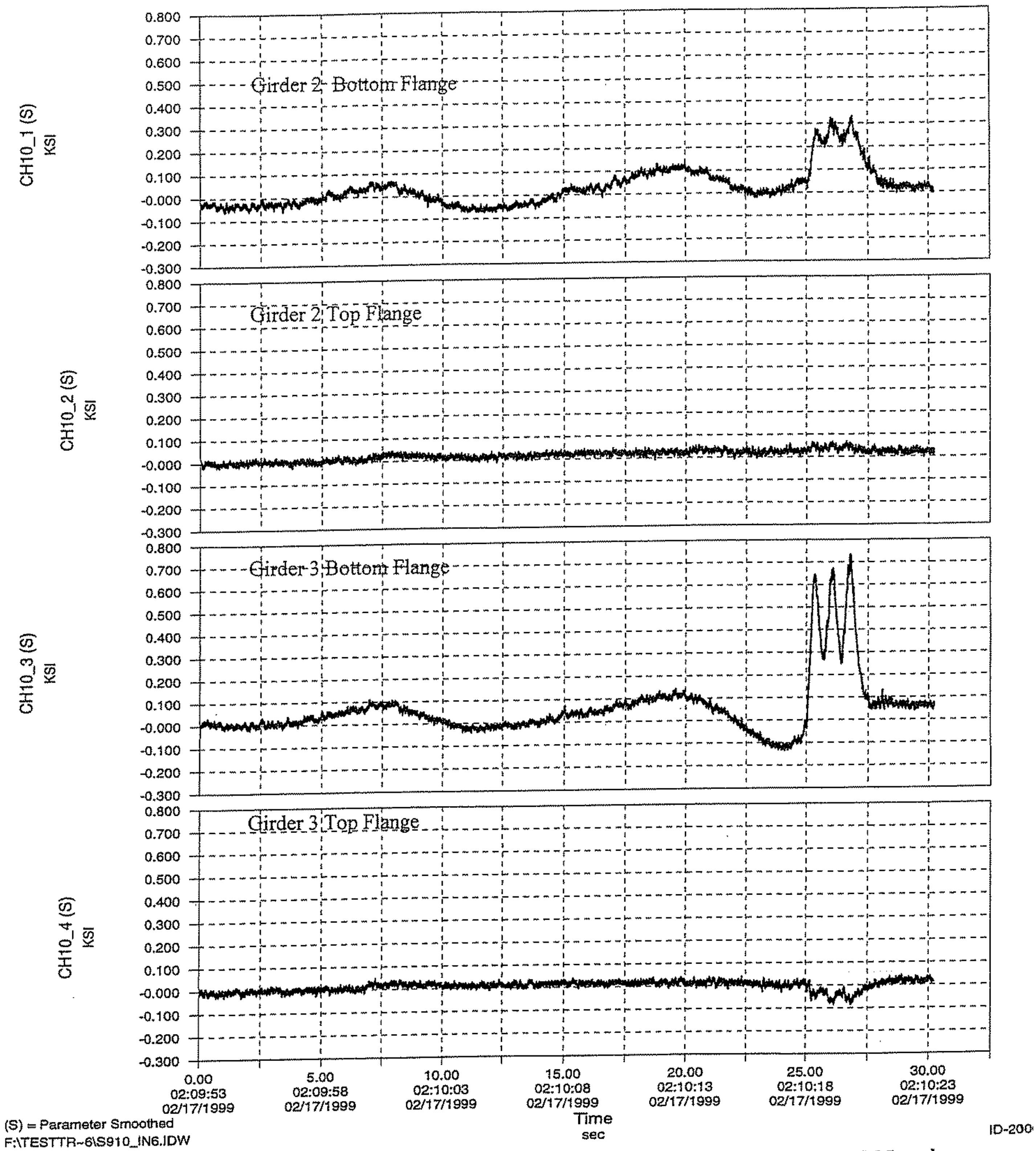
Strain Gage Records
Test Vehicle, Span 10



Test Vehicle at Span 10 / Section 6; Vehicle Outbound on Inbound Track @ Nominal 10 mph



Test Vehicle at Span 10/Section 6; Vehicle Inbound on Inbound Track @Nominal 10 mph

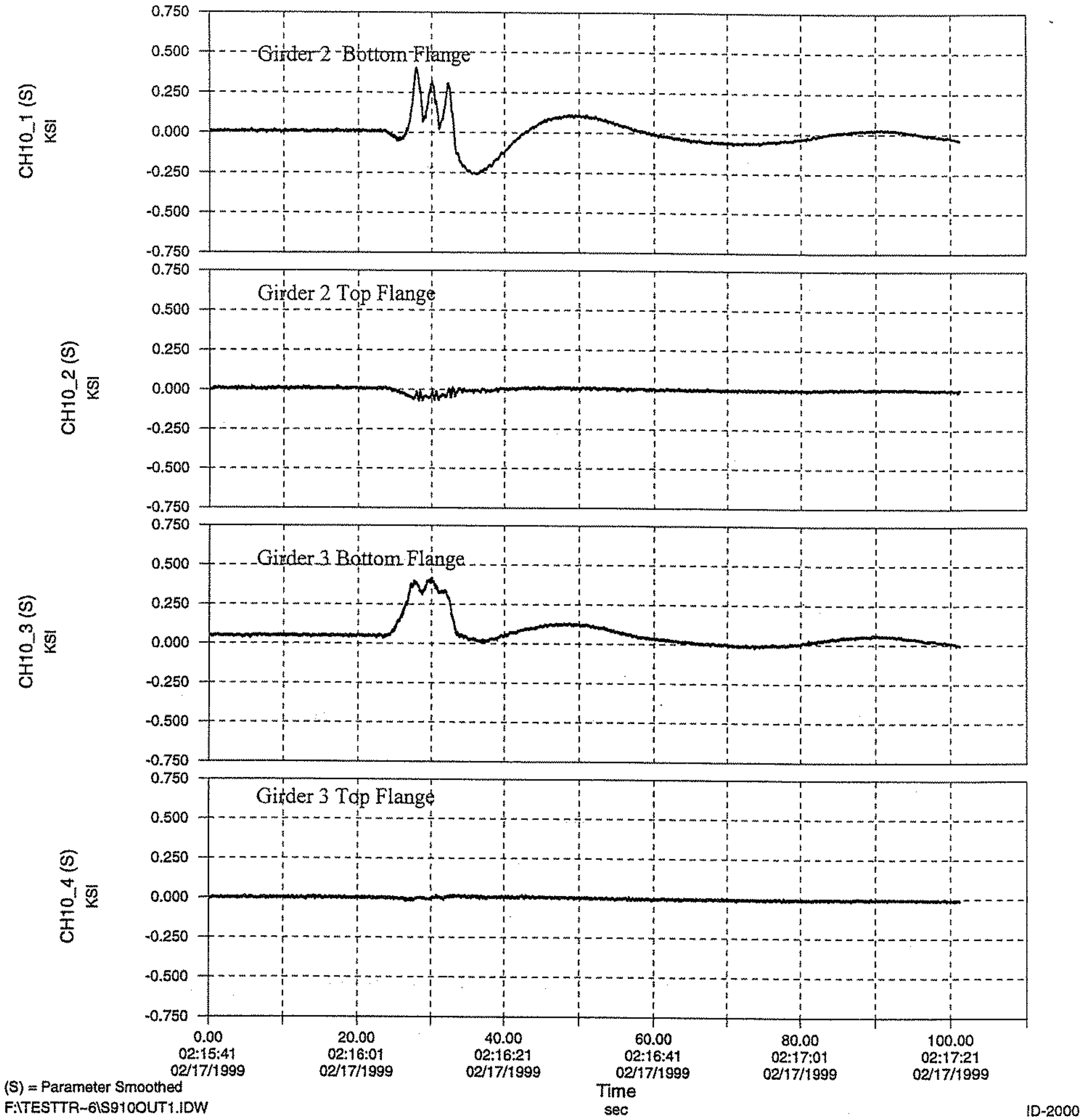


Test Vehicle at Span 10/Section 6; Vehicle Inbound on Inbound Track @Nominal 25 mph

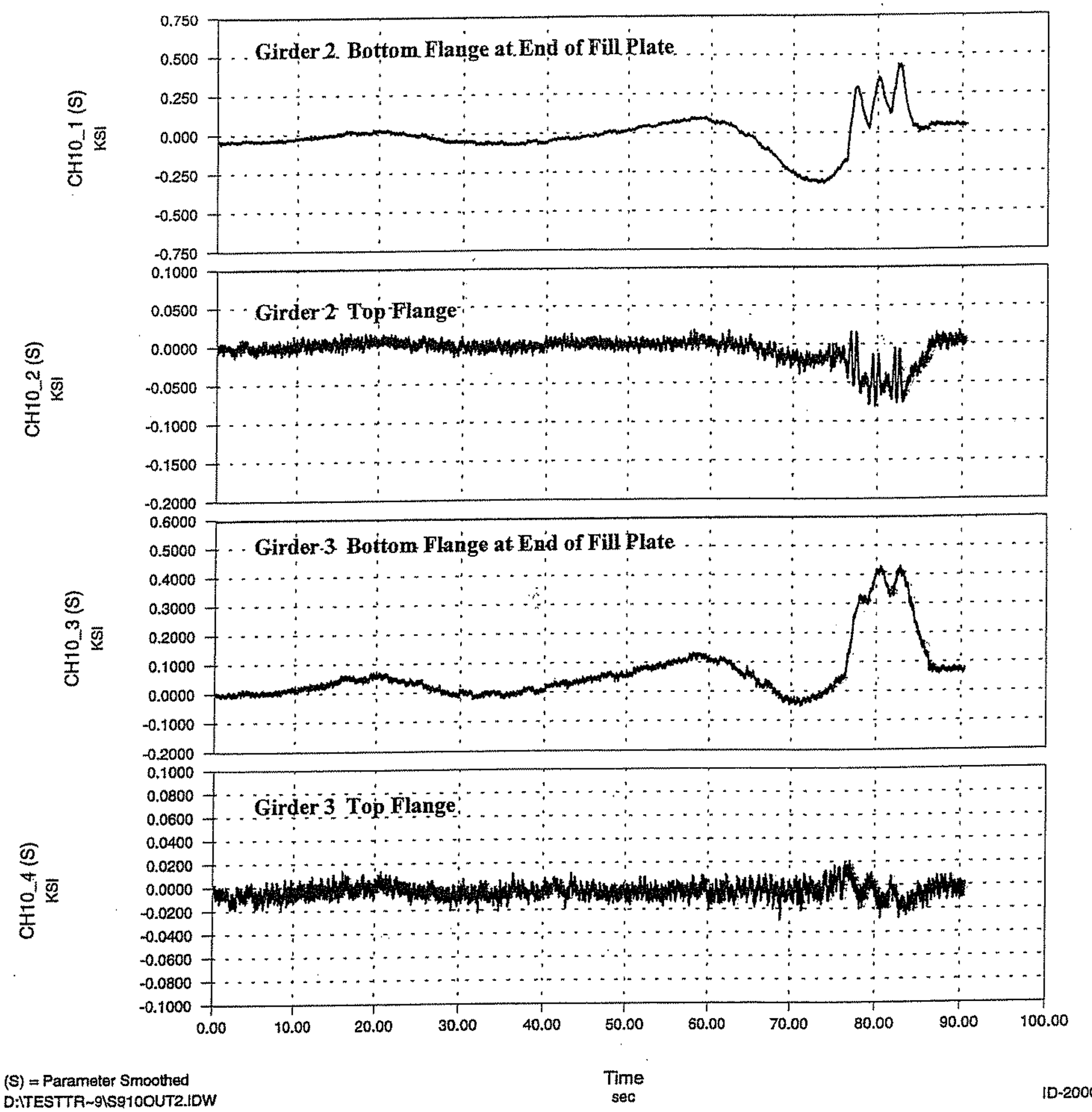
Saw Mill Run Bridge

ATLSS Engineering Research Center

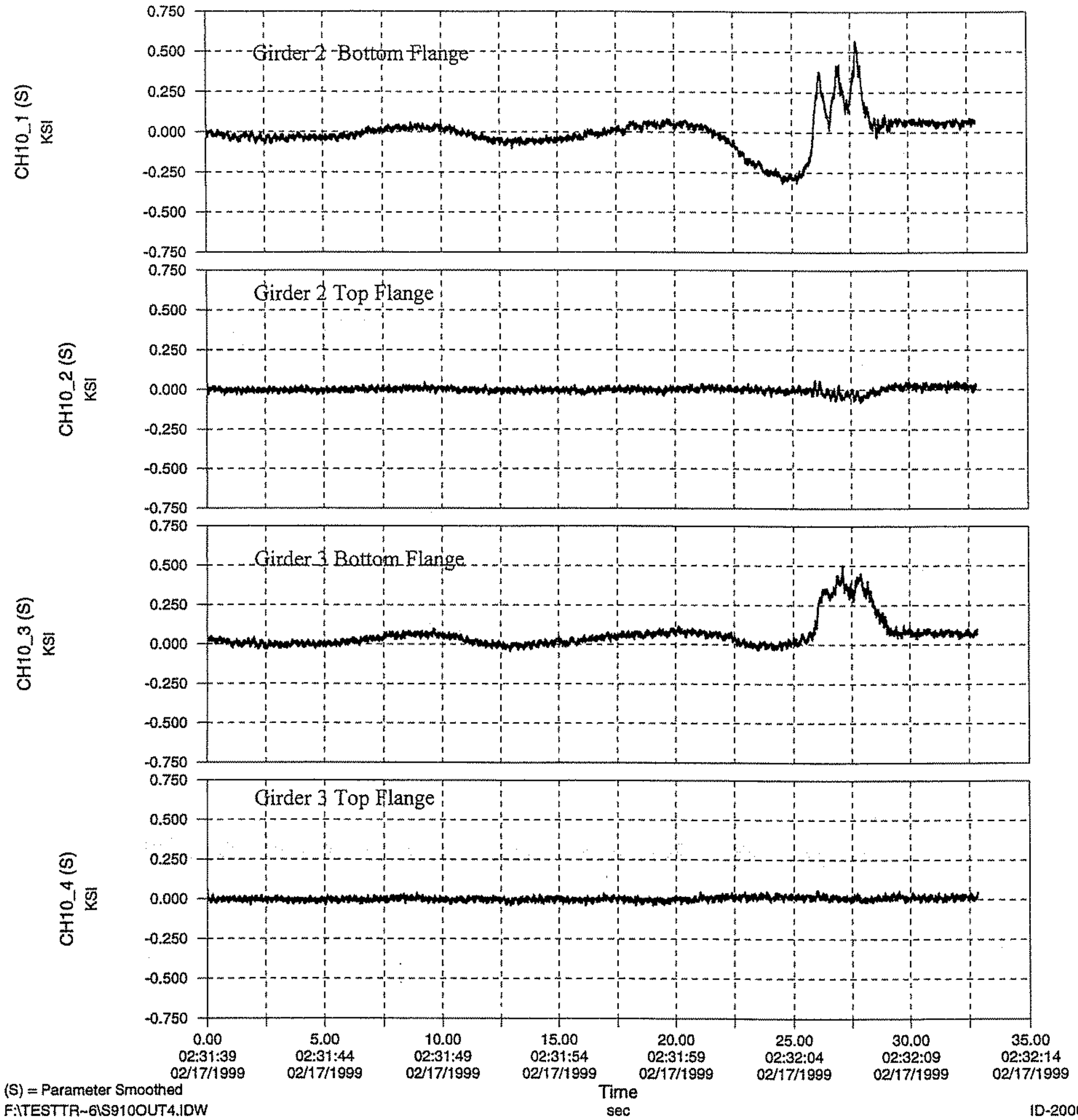
March 8, 1999



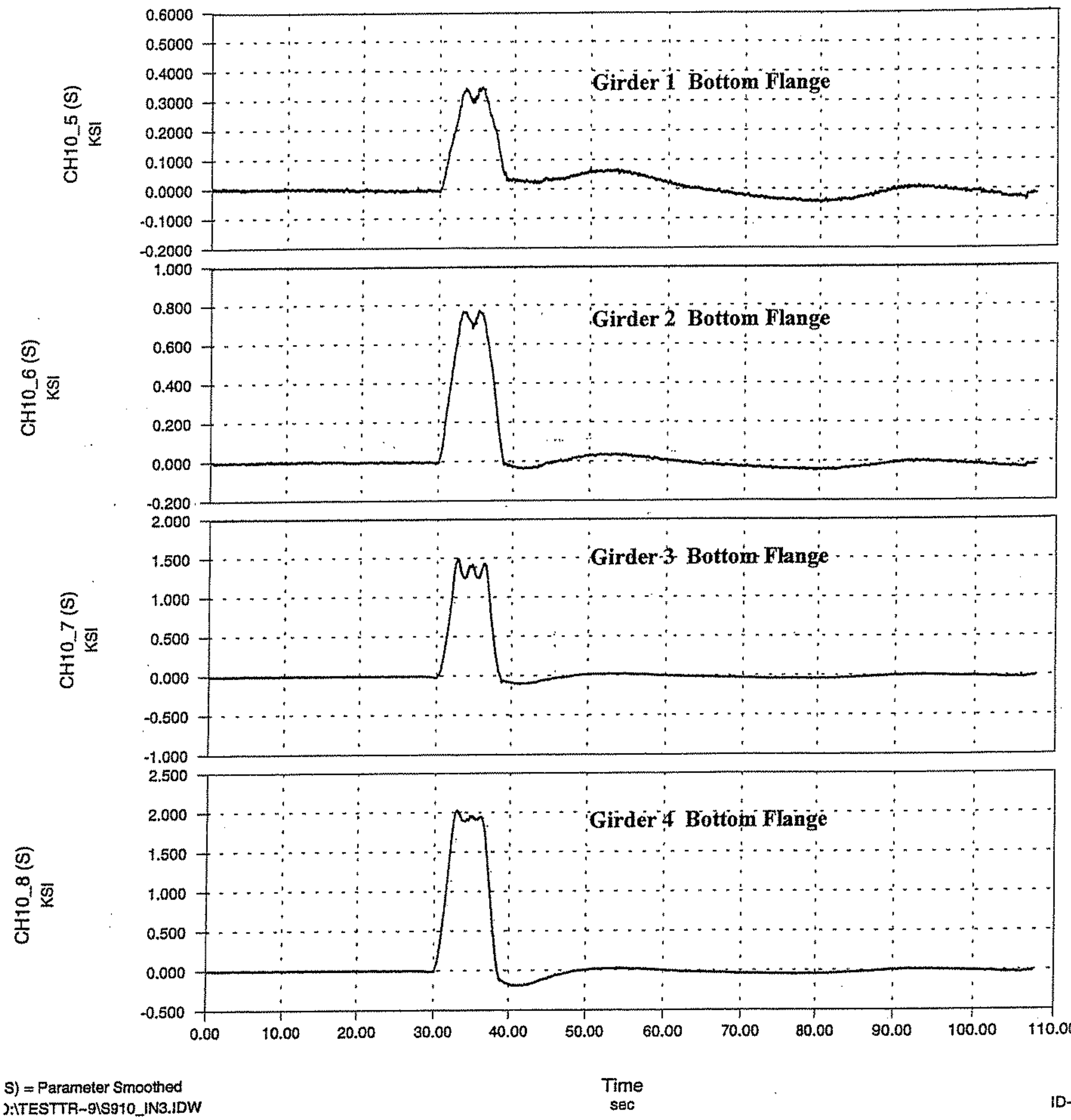
Test Vehicle at Span 10/Section 6; Vehicle Outbound on Outbound Track @Nominal **10 mph**



Test Vehicle at Span 10 / Section 6; Vehicle Inbound on Outbound Track @ Nominal 10 mph



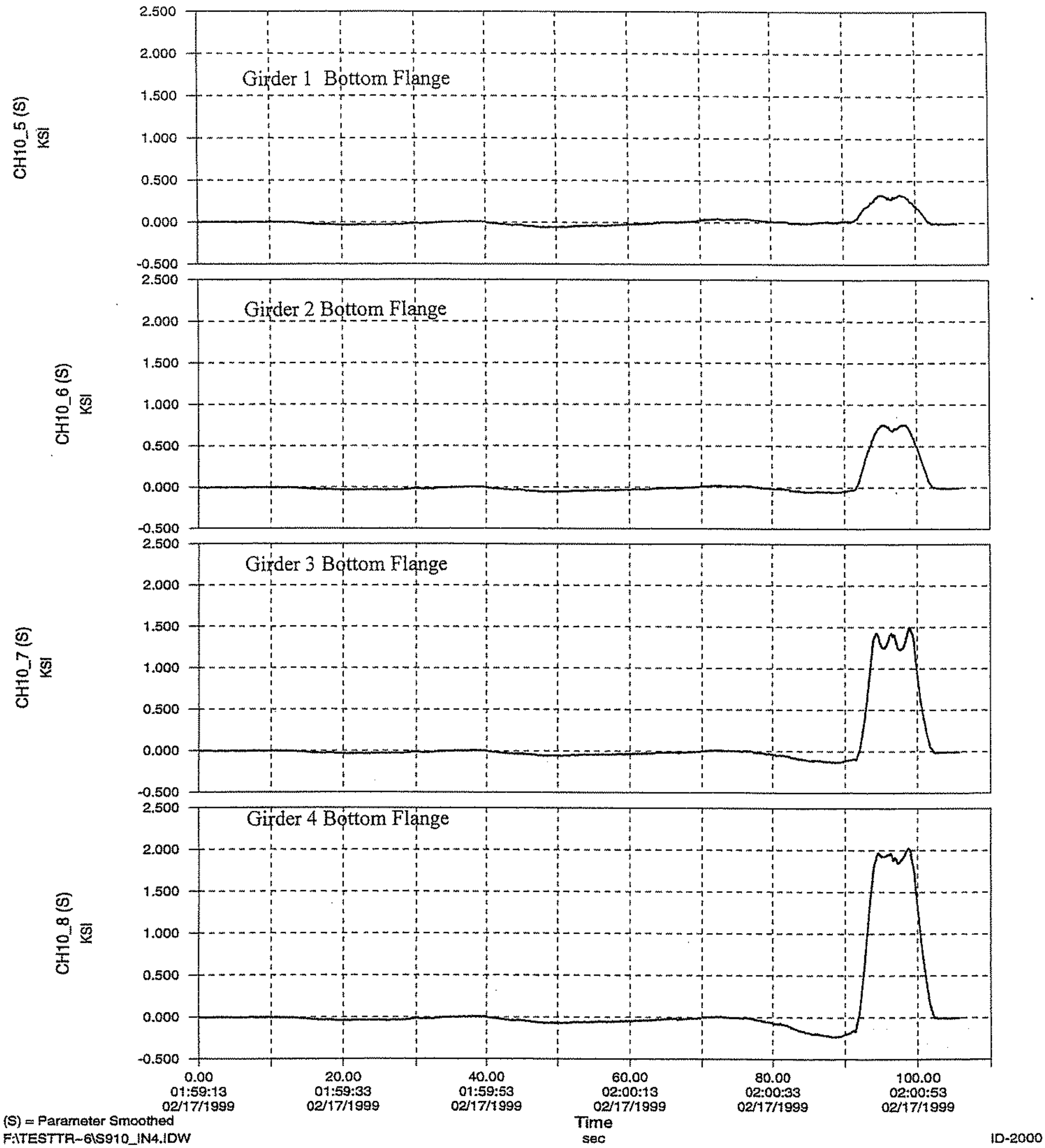
Test Vehicle at Span 10/Section 6; Vehicle Inbound on Outbound Track @Nominal 25 mph



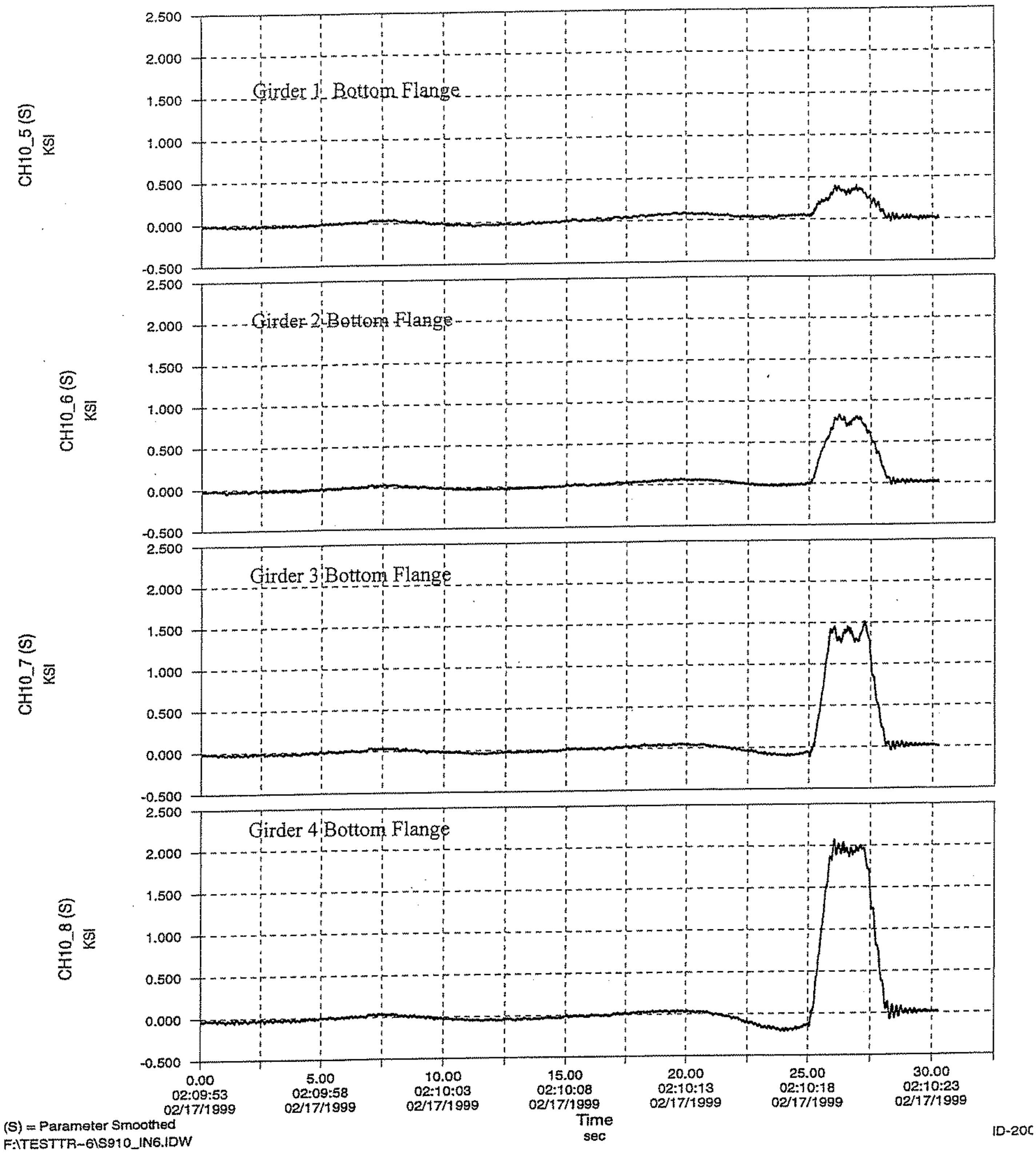
S) = Parameter Smoothed
):\TESTTR~9\S910_IN3.IDW

ID-20(

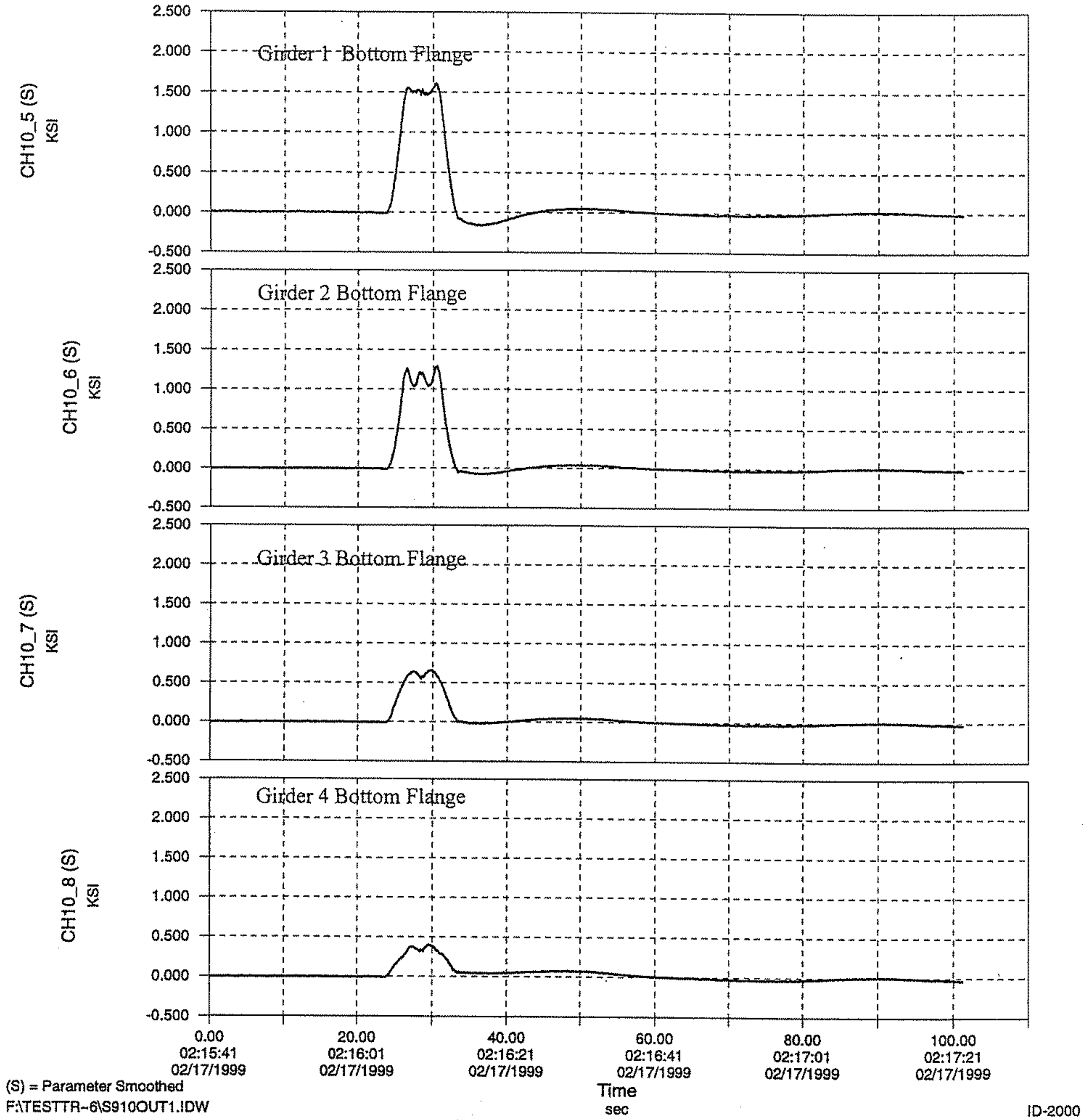
Test Vehicle at Span 10 / Section 7; Vehicle Outbound on Inbound Track @ Nominal 10 mph



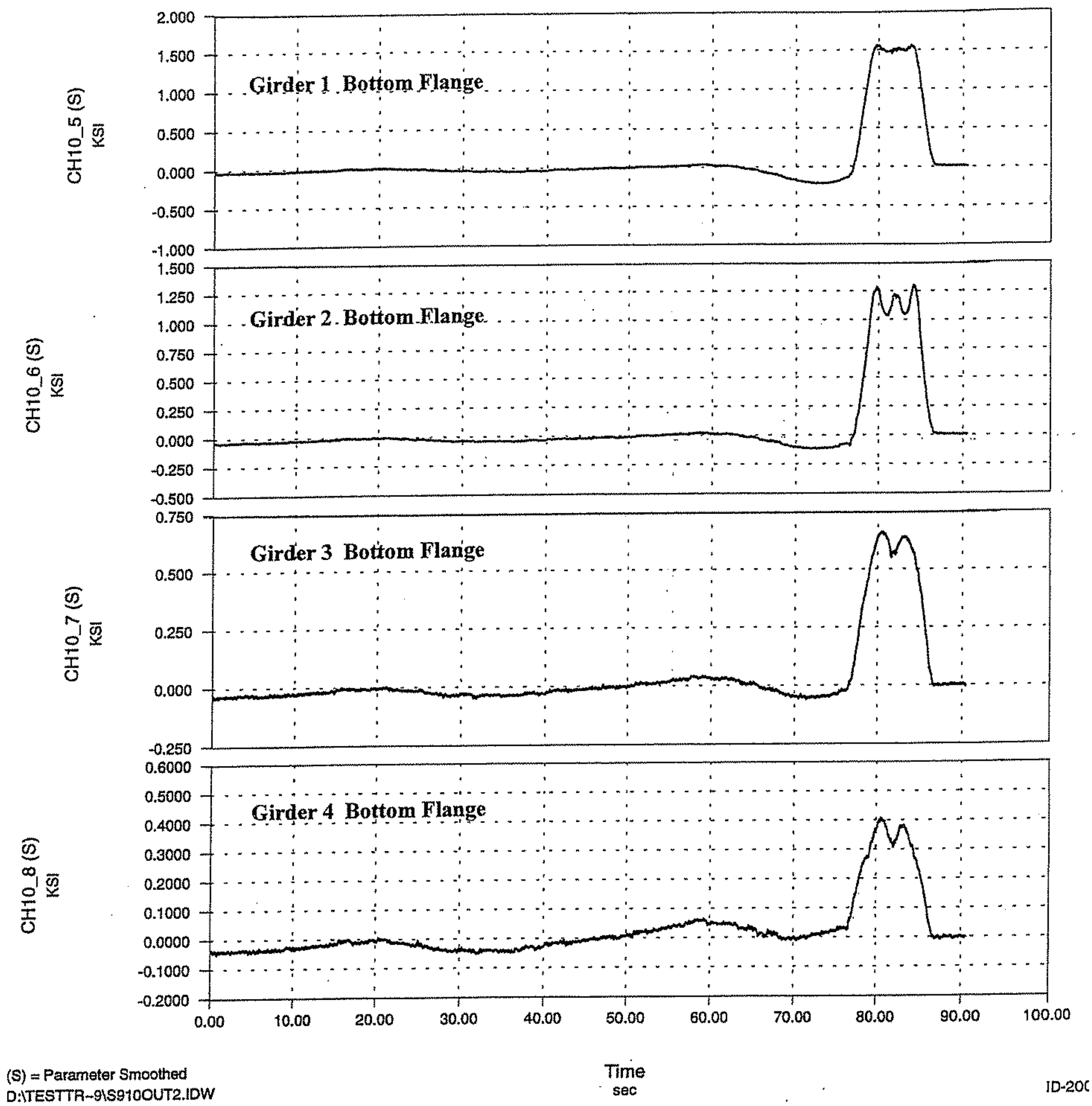
Test Vehicle at Span 10/Section 7; Vehicle Inbound on Inbound Track @Nominal 10 mph



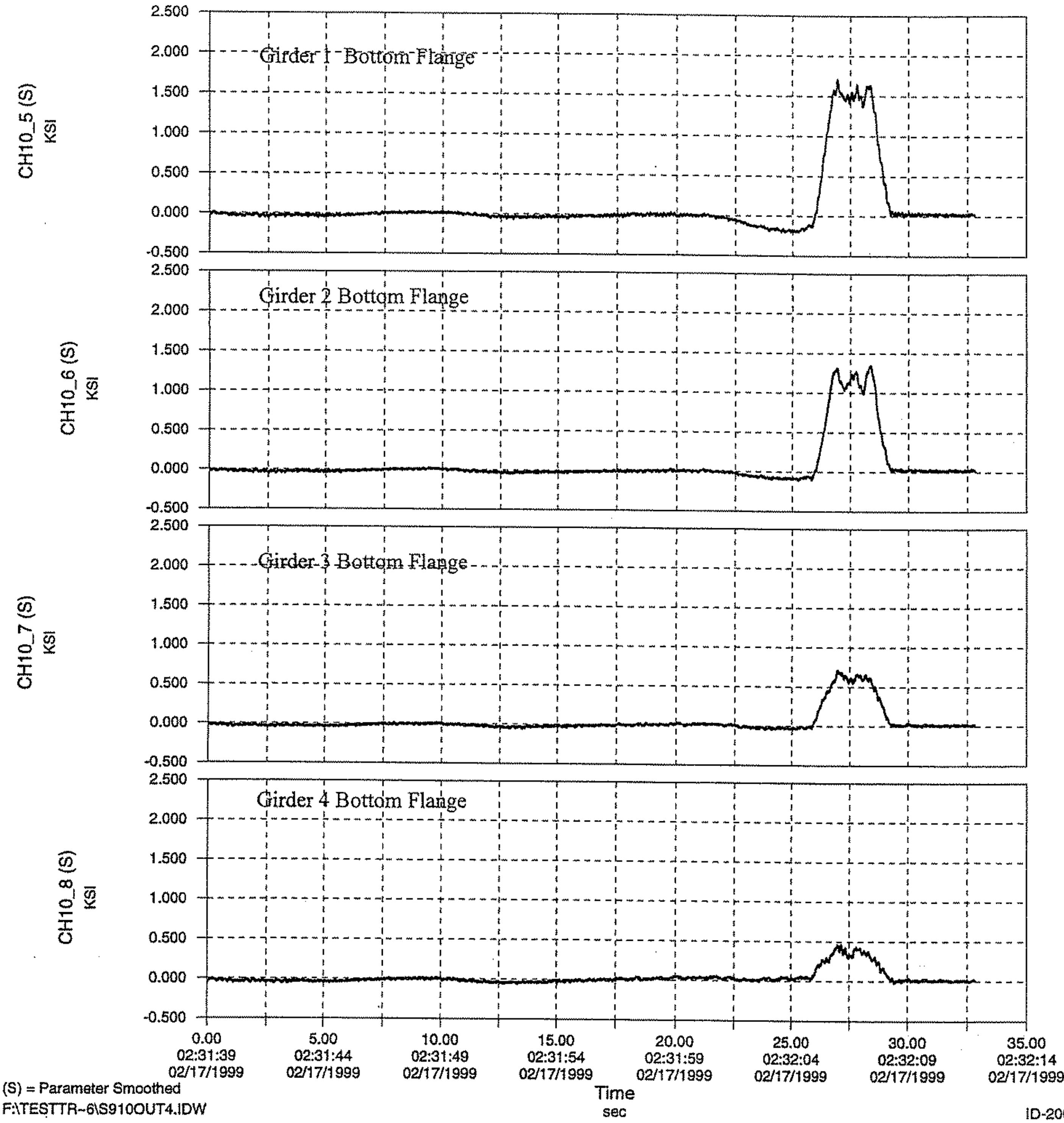
Test Vehicle at Span 10/Section 7; Vehicle Inbound on Inbound Track @Nominal 25 mph



Test Vehicle at Span 10/Section 7; Vehicle Outbound on Outbound Track @Nominal **10 mph**



Test Vehicle at Span 10 / Section 7; Vehicle Inbound on Outbound Track @ Nominal 10 mph



(S) = Parameter Smoothed
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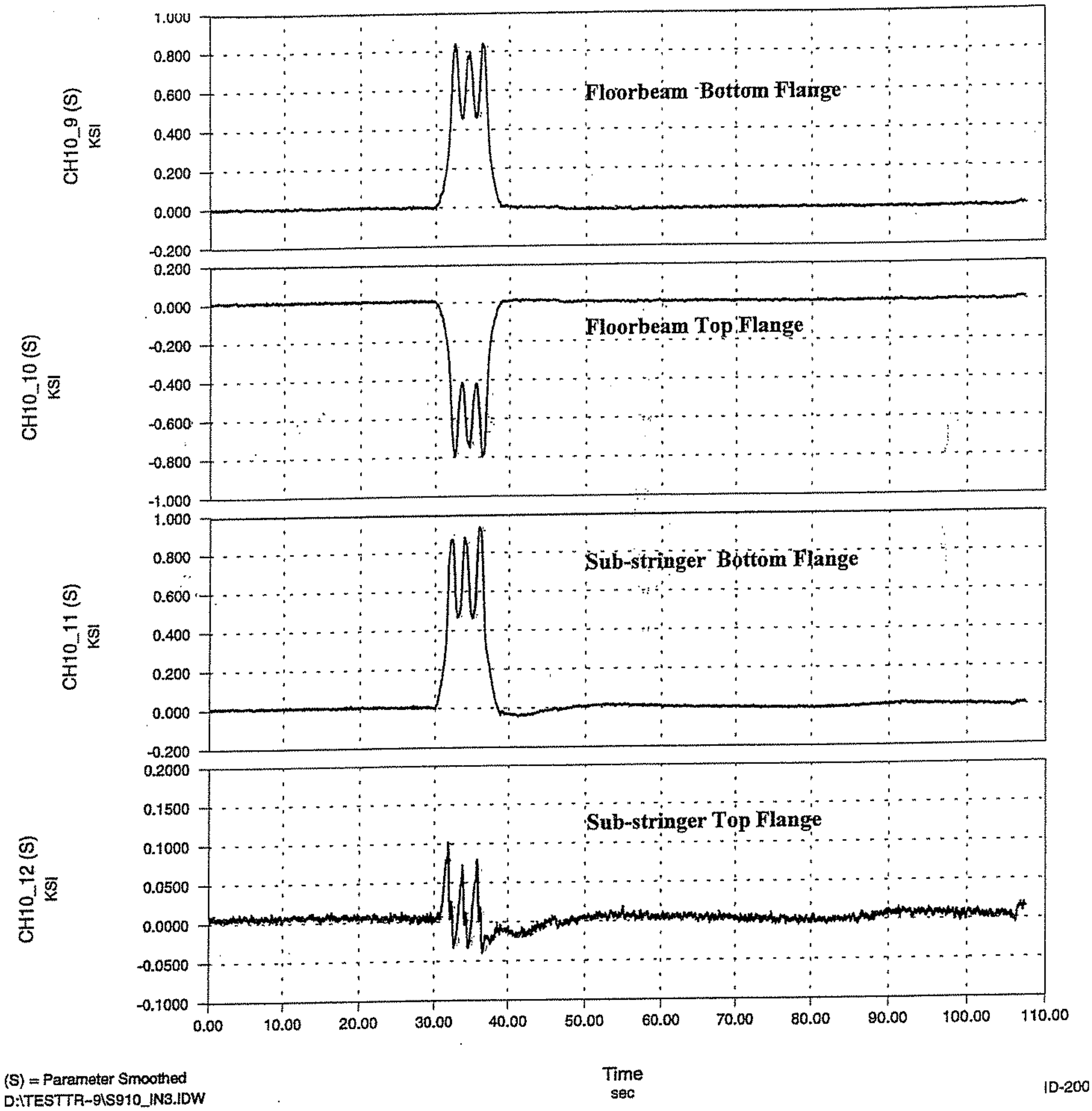
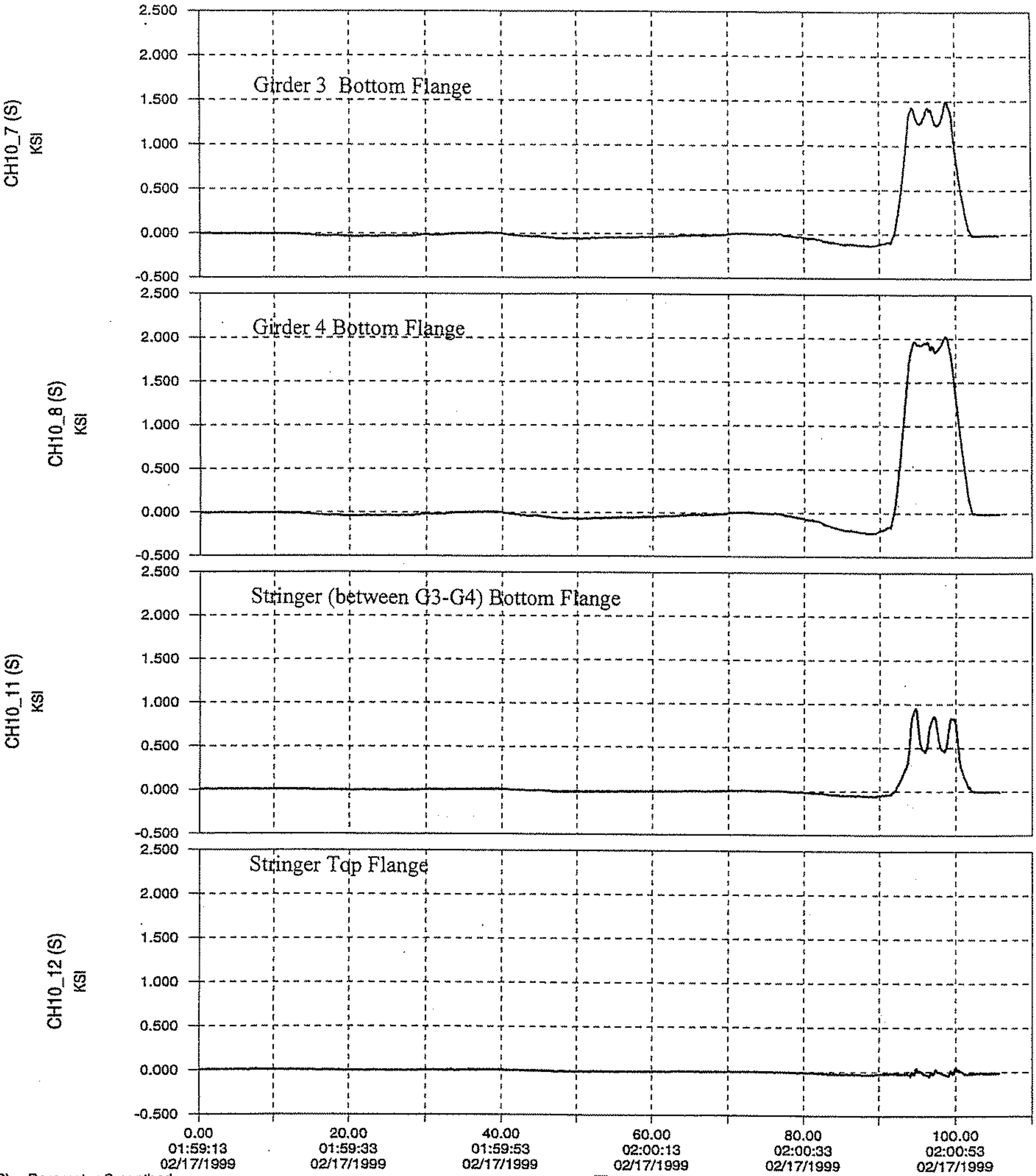
ID-2000

Test Vehicle at Span 10/Section 7; Vehicle Inbound on Outbound Track @Nominal 25 mph



Test Vehicle at Span 10 / Section 7; Vehicle Outbound on Inbound Track @ Nominal 10 mph



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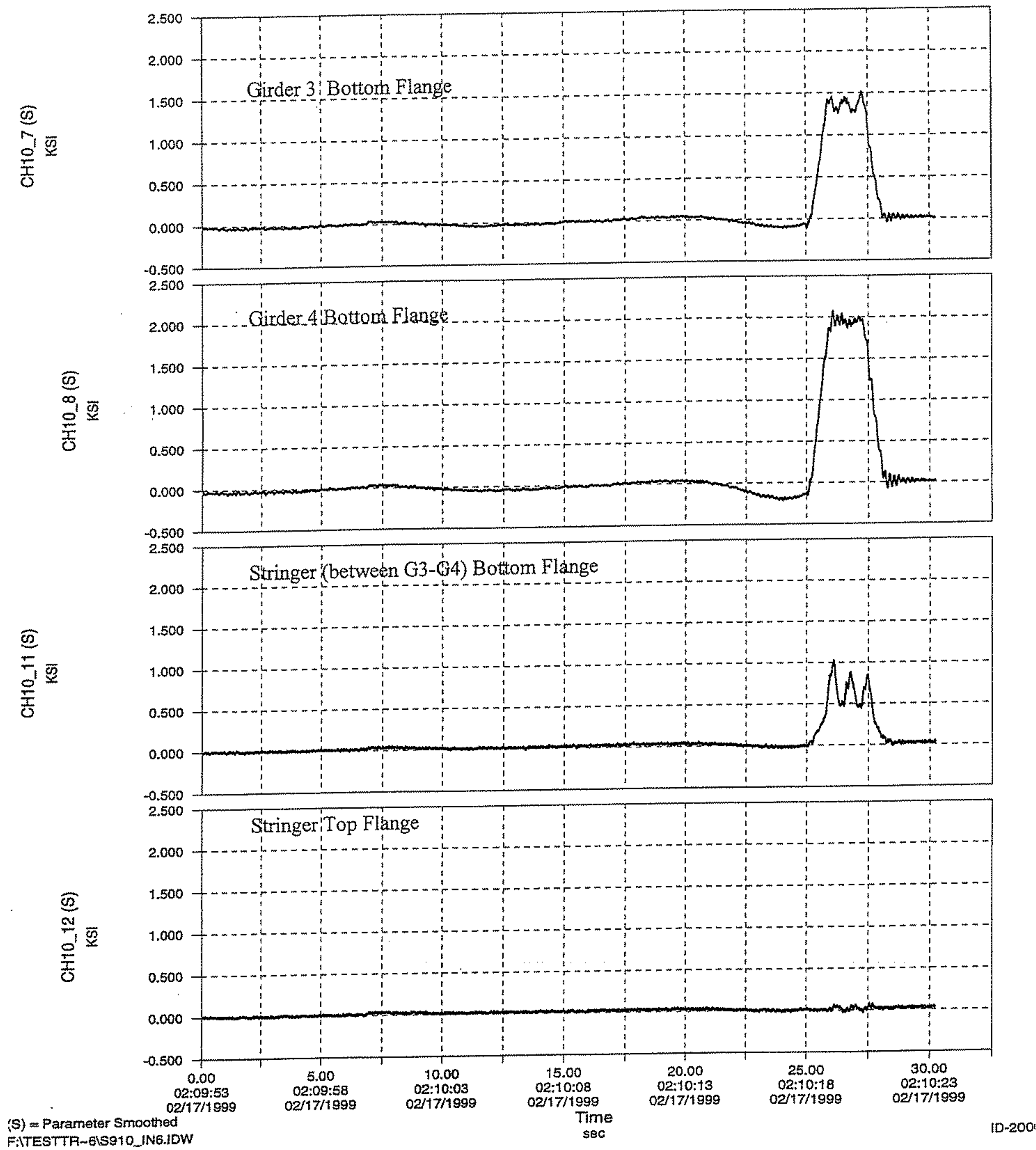
ID-2000

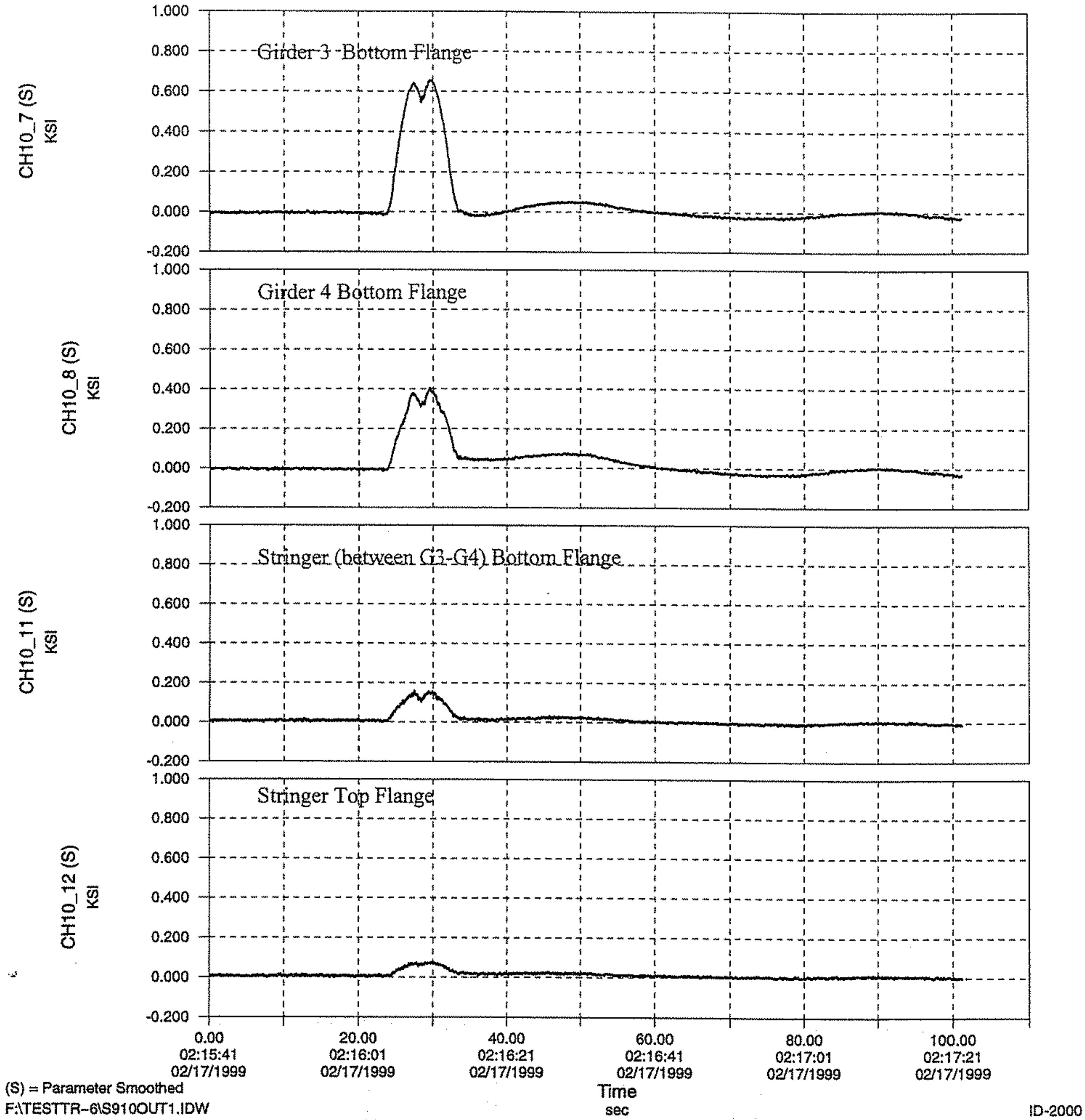
Test Vehicle at Span 10/Section 7; Vehicle Inbound on Inbound Track @Nominal 10 mph



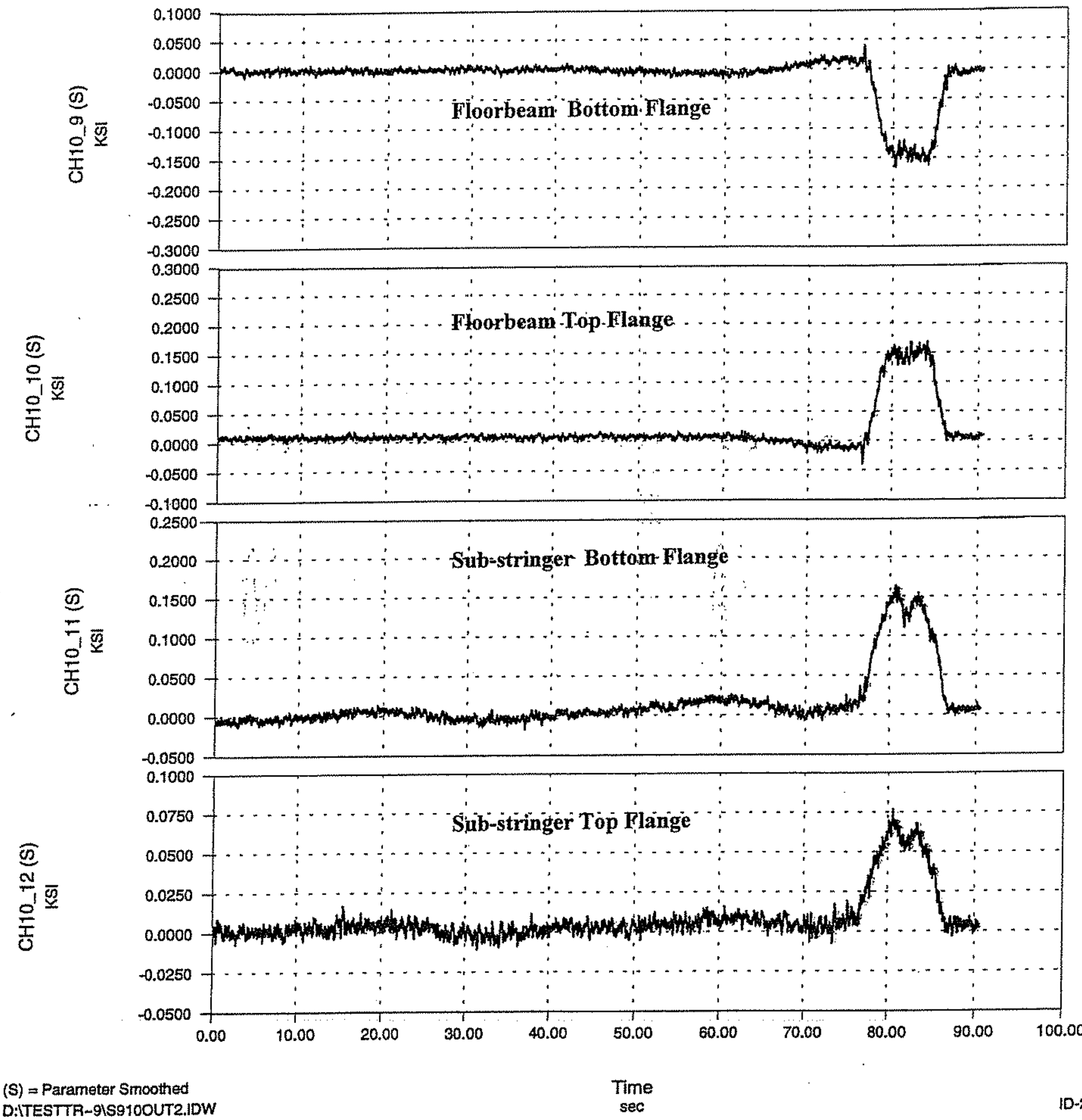
Test Vehicle at Span 10/Section 7; Vehicle Inbound on Inbound Track @Nominal 25 mph

ATLSS Engineering Research Center
March 8, 1999

Saw Mill Run Bridge



Test Vehicle at Span 10/Section 7; Vehicle Outbound on Outbound Track @Nominal **10 mph**



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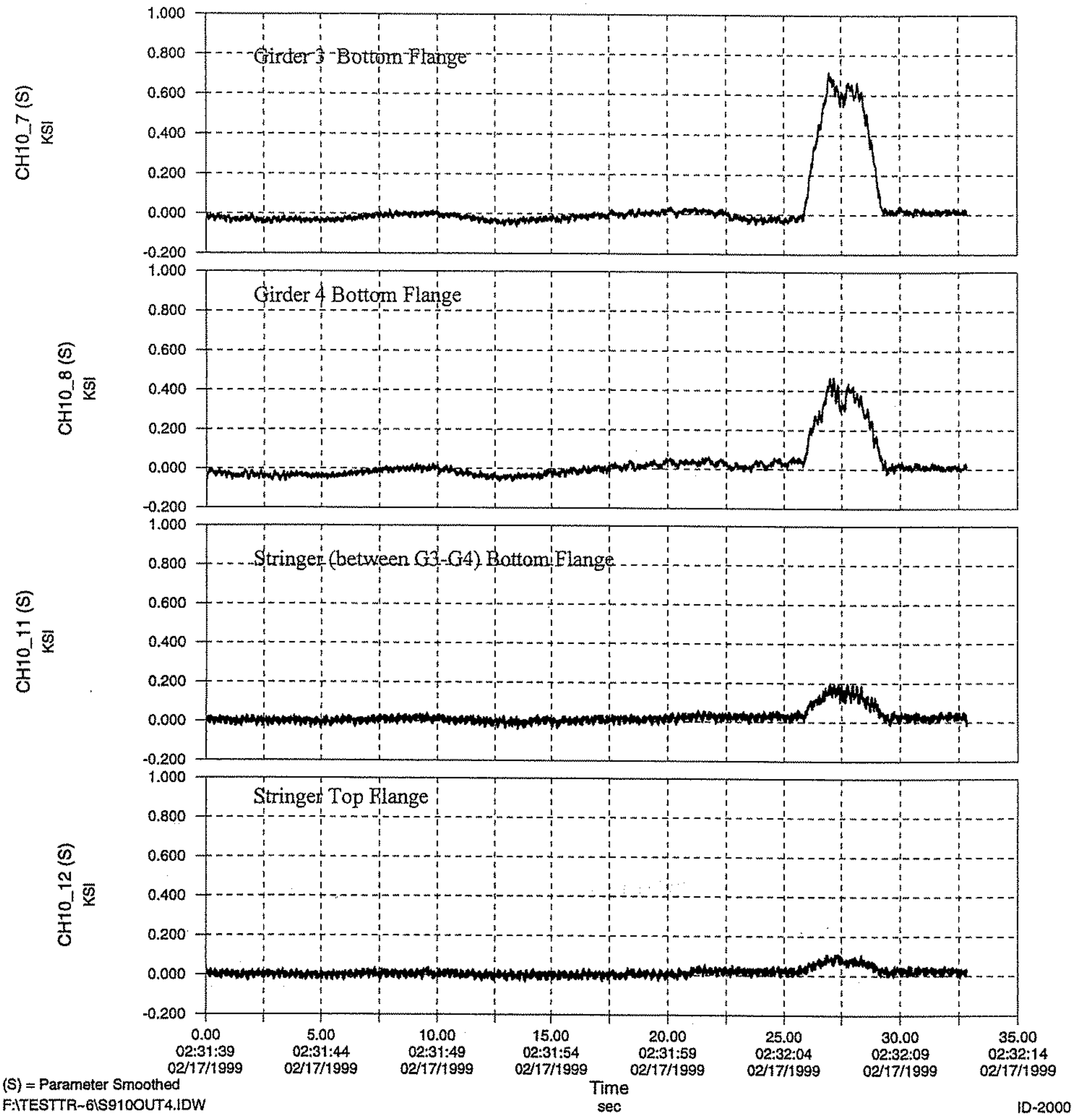
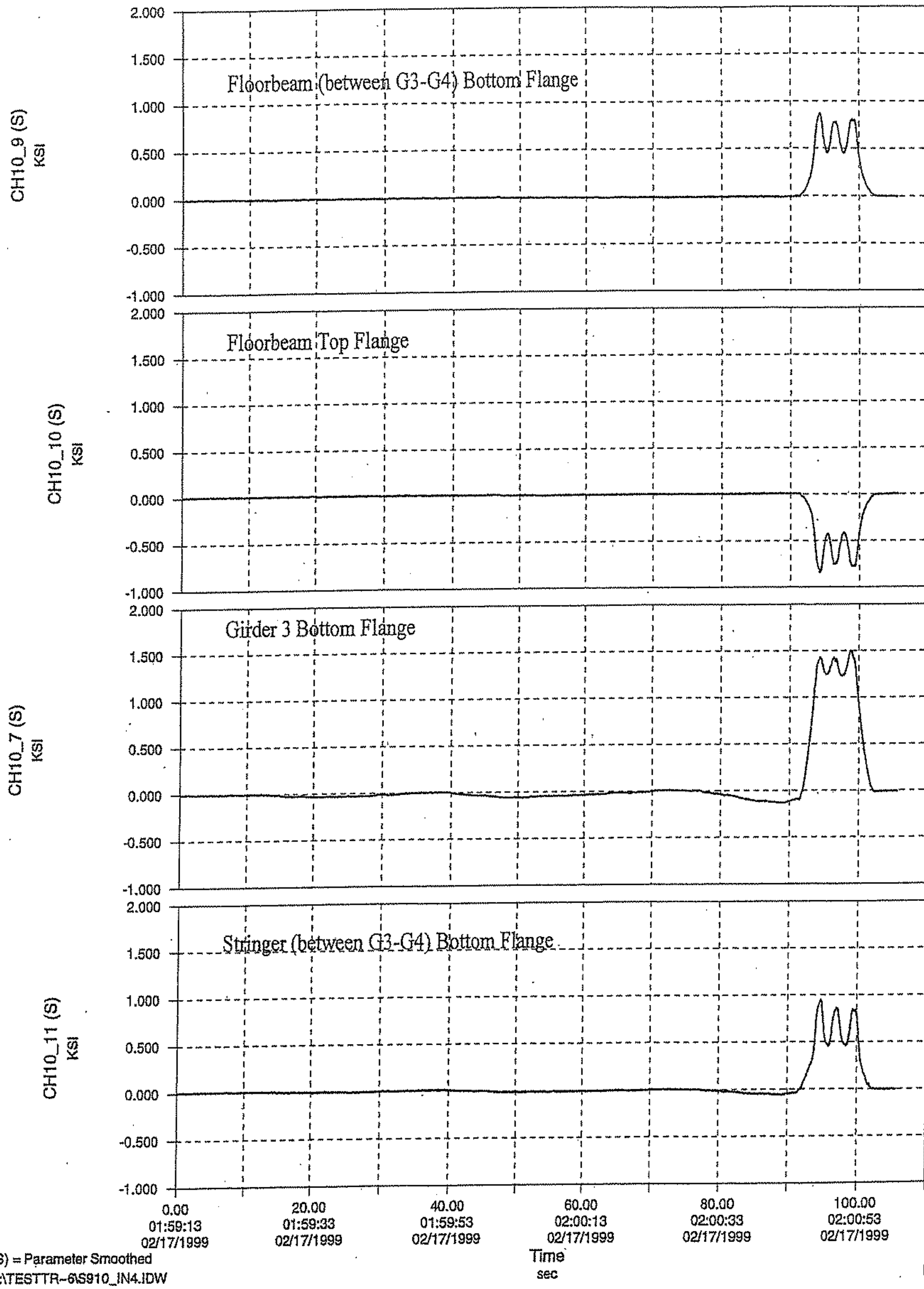
ID-20

Test Vehicle at Span 10 / Section 7; Vehicle Inbound on Outbound Track @ Nominal 10 mph



Test Vehicle at Span 10/Section 7; Vehicle Inbound on Outbound Track @Nominal 25 mph



(S) = Parameter Smoothed
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ID-2000

Test Vehicle at Span 10/Section 7; Vehicle Inbound on Inbound Track @Nominal 10 mph

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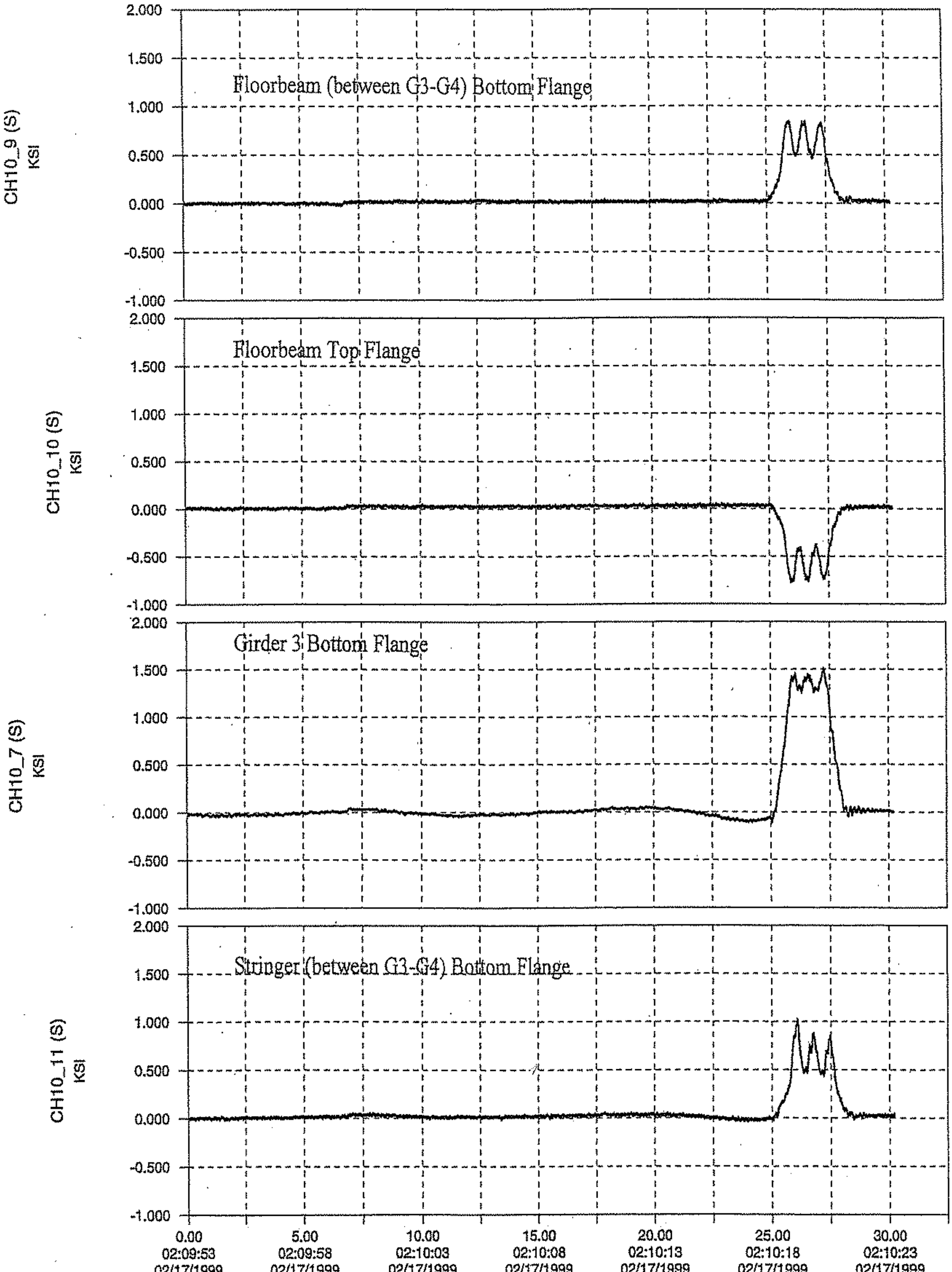
Saw Mill Run Bridge



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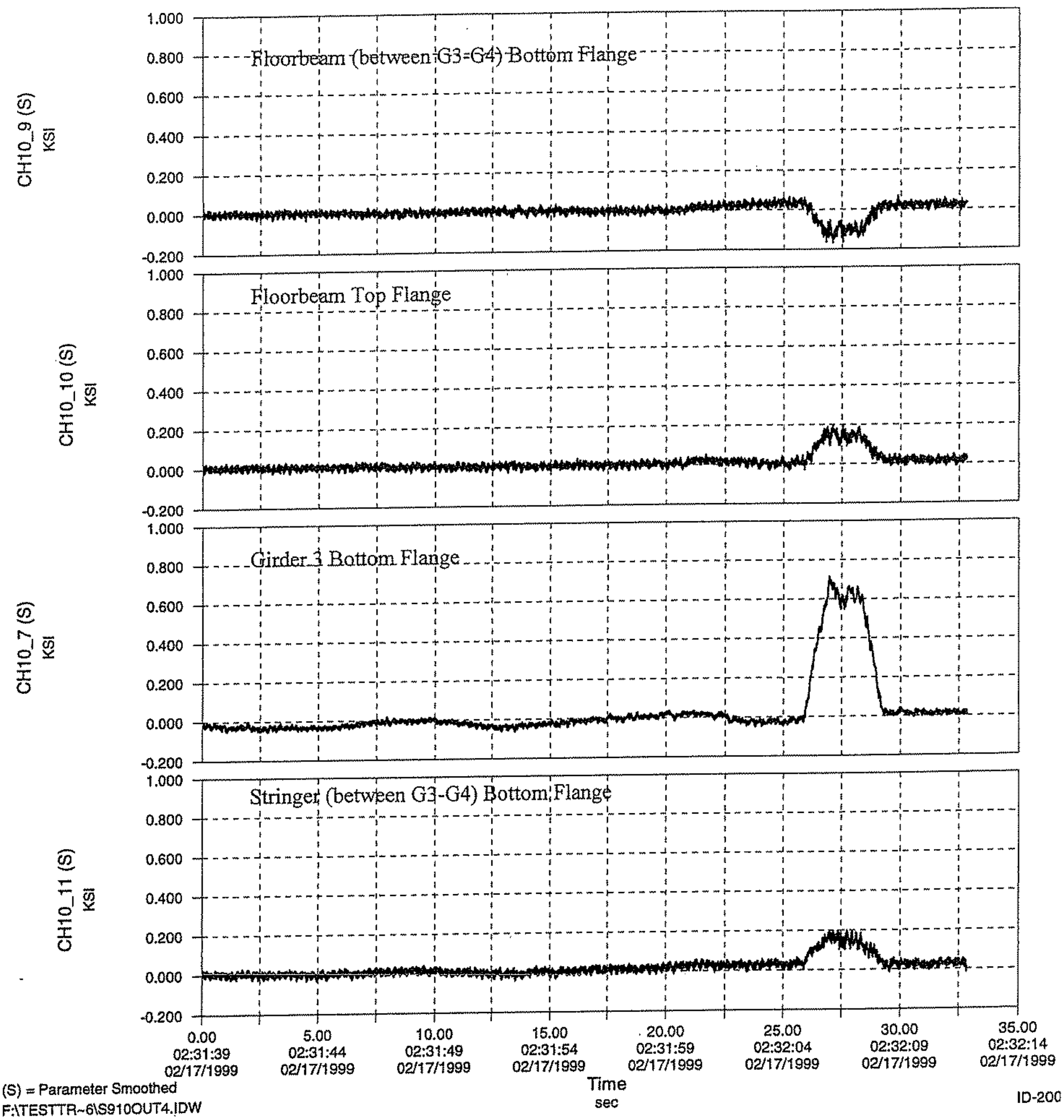
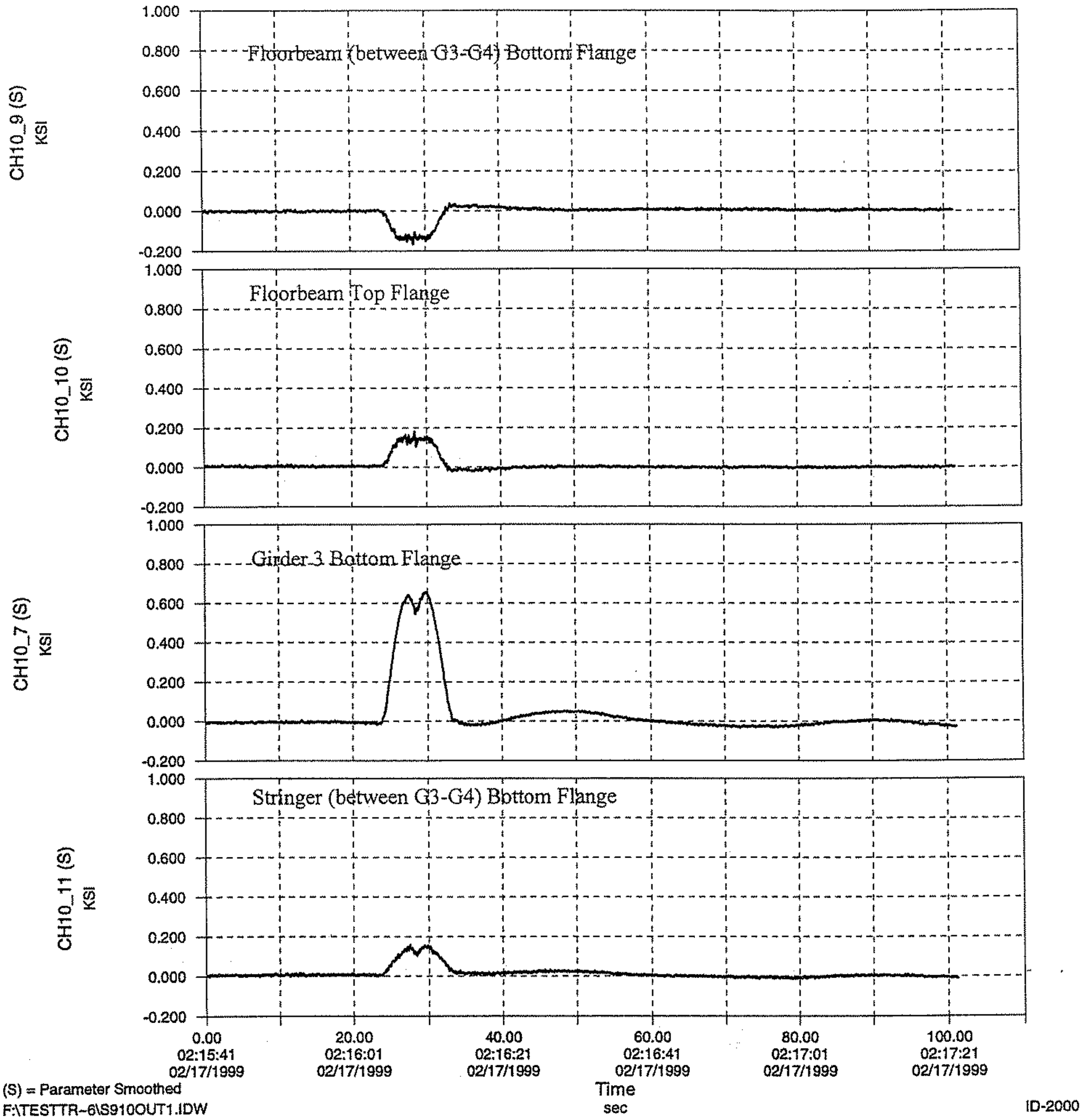
Test Vehicle at Span 10/Section 7; Vehicle Inbound on Inbound Track @Nominal 25 mph



Test Vehicle at Span 10/Section 7; Vehicle Inbound on Outbound Track @Nominal 25 mph



Test Vehicle at Span 10/Section 7; Vehicle Outbound on Outbound Track @Nominal **10 mph**