ASSESSMENT METHODOLOGY FOR DIAGONALLY CRACKED REINFORCED CONCRETE DECK GIRDERS

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2.0 FIELD TESTING

Four bridges were investigated during the field testing portion of the research program. These bridges were: Willamette River Bridge on OR 219 near Newberg, OR; Spores Bridge on northbound I-5 over the McKenzie River; Jasper Bridge over the Middle Fork of the Willamette River near Jasper, OR; and 15 Mile Creek Bridge consisting of both east and westbound I-84 east of The Dalles, OR. Data and results from the Willamette River Bridge are detailed in a separate report (*Higgins, et al. 2004*). Spores Bridge, Jasper Bridge, and 15 Mile Creek Bridge are described below.

2.1 SPORES BRIDGE, I-5 NORTHBOUND OVER MCKENZIE RIVER (BRIDGE NUMBER 08175N)

Spores Bridge crosses the McKenzie River on Interstate 5 in Lane County at the Linn County line. The bridge consists of 11 spans (Figures 2.1a-c): four (4) reinforced concrete deck girder approach spans at each end, and three (3) reinforced concrete box-girder main spans. The bridge was constructed in 1960. The south approach spans of the northbound lane of Spores Bridge, shown in Figure 2.2, were selected for testing due to ease of accessibility and no need for traffic control. The names McKenzie River Bridge and Spores Bridge are used interchangeably in this report.

The south approach spans are each 50 ft long from centerline of supports. The south-most span is a simple span, followed by a 3-span continuous portion. The spans support a roadway width of 30 ft, and have a total width of 35 ft - 2 in.. There are four girder lines in each of the spans, with diaphragms 9 in. x 46 in. located at the quarter points. The girders are 14.5 in. x 48 in. uniform and prismatic along the simple span. In the continuous spans, the girders are 13 in. x 48 in. over the middle half of the spans, but the web widths taper to become wider 20 in. x 48 in. at continuous support locations. Bent caps are 16.5 in. x 75 in. and supported on 20 in. square columns. The reinforced concrete deck is 6 in. thick. The specified concrete compression strength was 3300 psi and the reinforcing steel consisted of intermediate grade (nominally 40 ksi yield stress) deformed round bars.

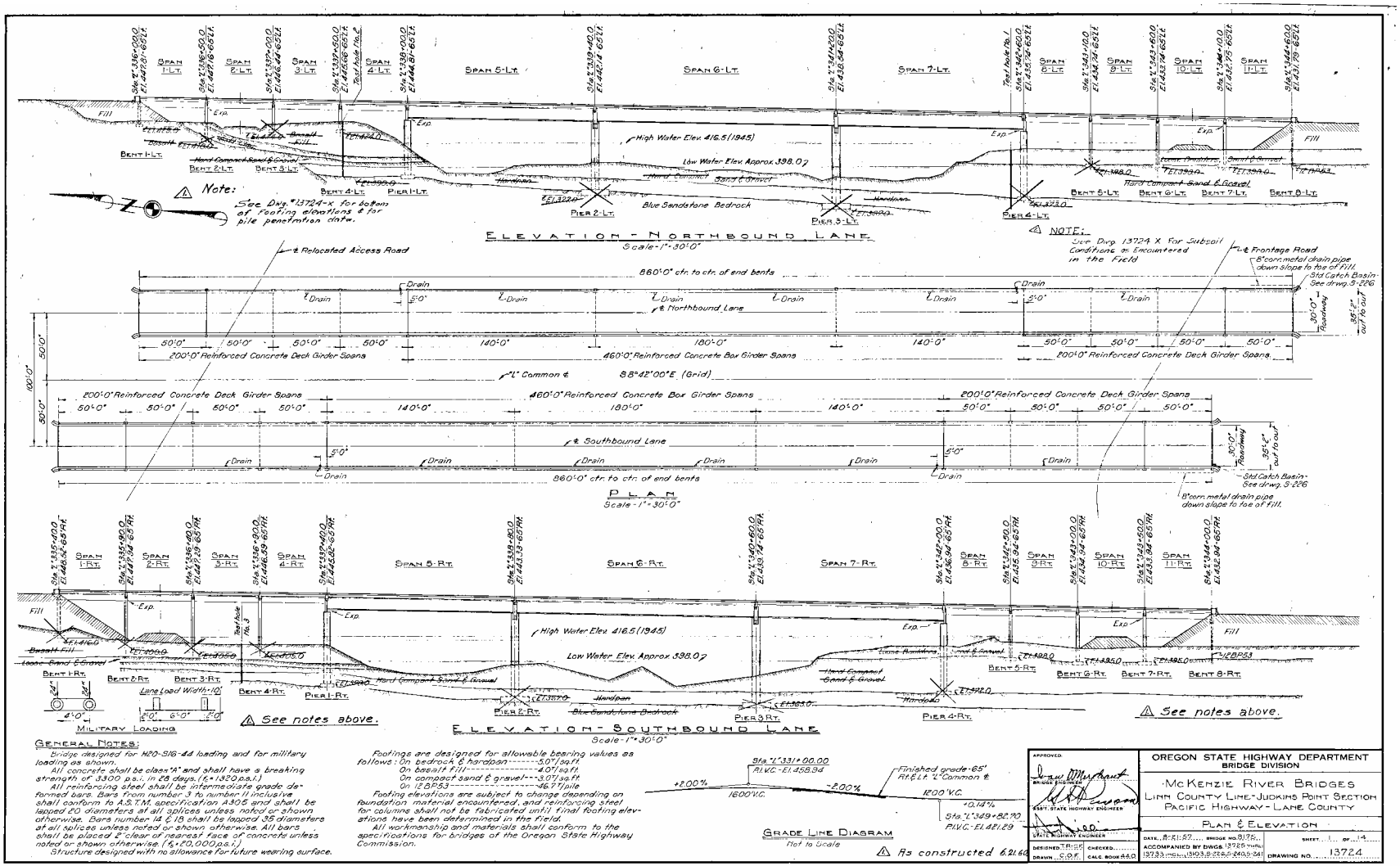

Figure 2.1a: Design drawing for McKenzie River Bridge

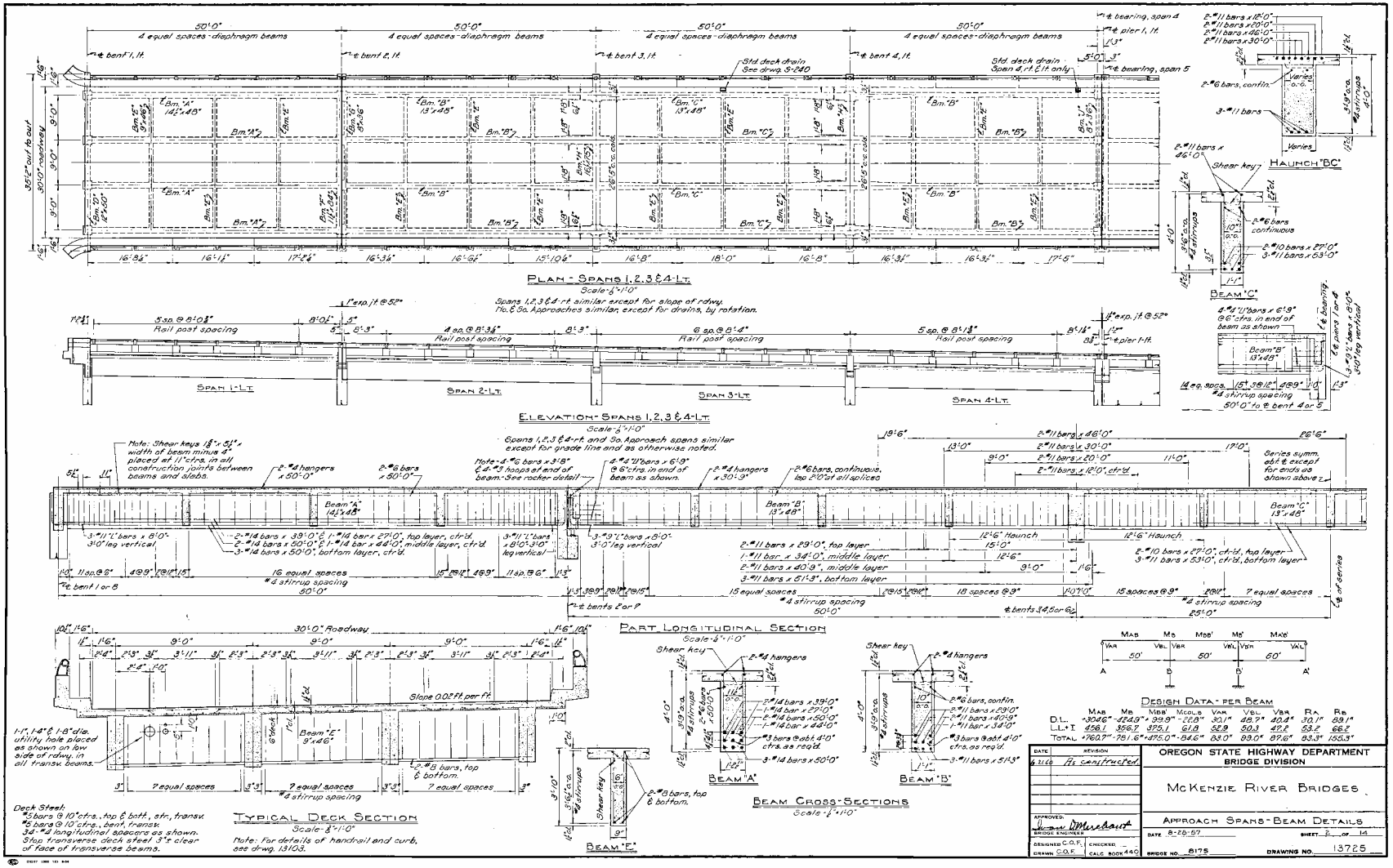

Figure 2.1b: Design drawing for McKenzie River Bridge

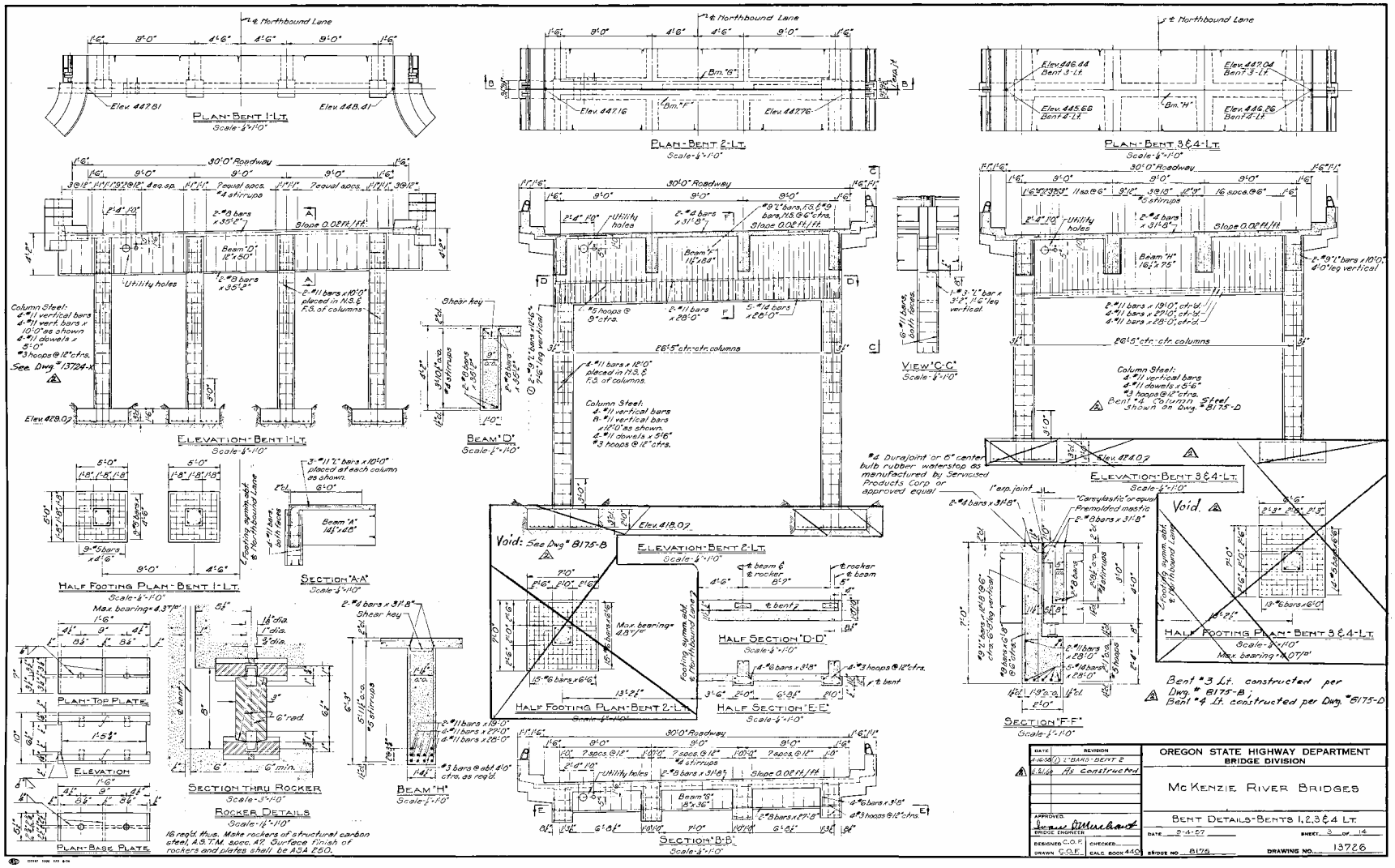

Figure 2.1c: Design drawing for McKenzie River Bridge

Figure 2.2: Portion of McKenzie River Bridge selected for field investigation

2.1.1 Crack Identification and Mapping

All bent caps and longitudinal deck girders were inspected to determine the extent of diagonal tension and flexural cracking. Crack widths were measured using an ODOT crack comparator, as shown in Figure 2.3. The location of each crack having a width of 0.008 in. or larger was measured and recorded using a Leica Disto Pro[4] hand-held laser distance meter, as shown in Figure 2.4.

Locations of stirrups were identified using a Proceq Profometer 3 rebar locator, as shown in Figure 2.5, and recorded using the laser distance meter. Stirrup locations and the extents and widths of existing diagonal cracks on the face of each structural element are shown in Figures 2.6a-e.

Diagonal tension cracks were observed in bent caps, interior girders and exterior girders. In general, cracking of the exterior girders was found to be more severe than cracking of the interior girders, with wider and more numerous cracks in the exterior girders compared to adjacent interior girders.

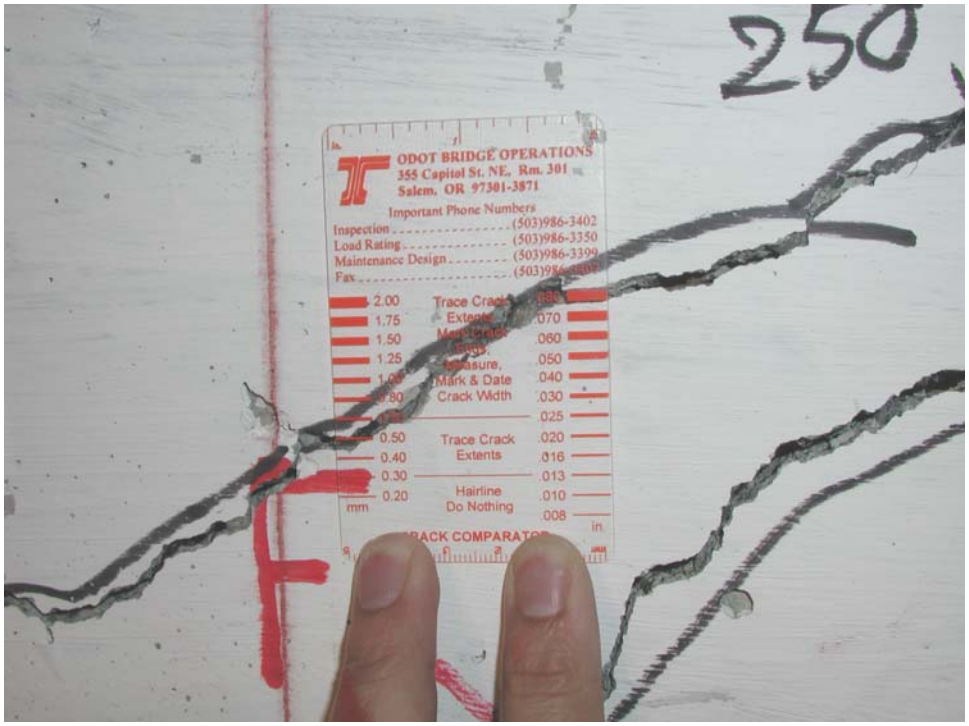

Figure 2.3: ODOT crack comparator used to measure crack widths

Figure 2.4: Laser distance meter used to locate cracks and stirrups relative to support locations

Figure 2.5: Rebar locator used to identify embedded stirrups

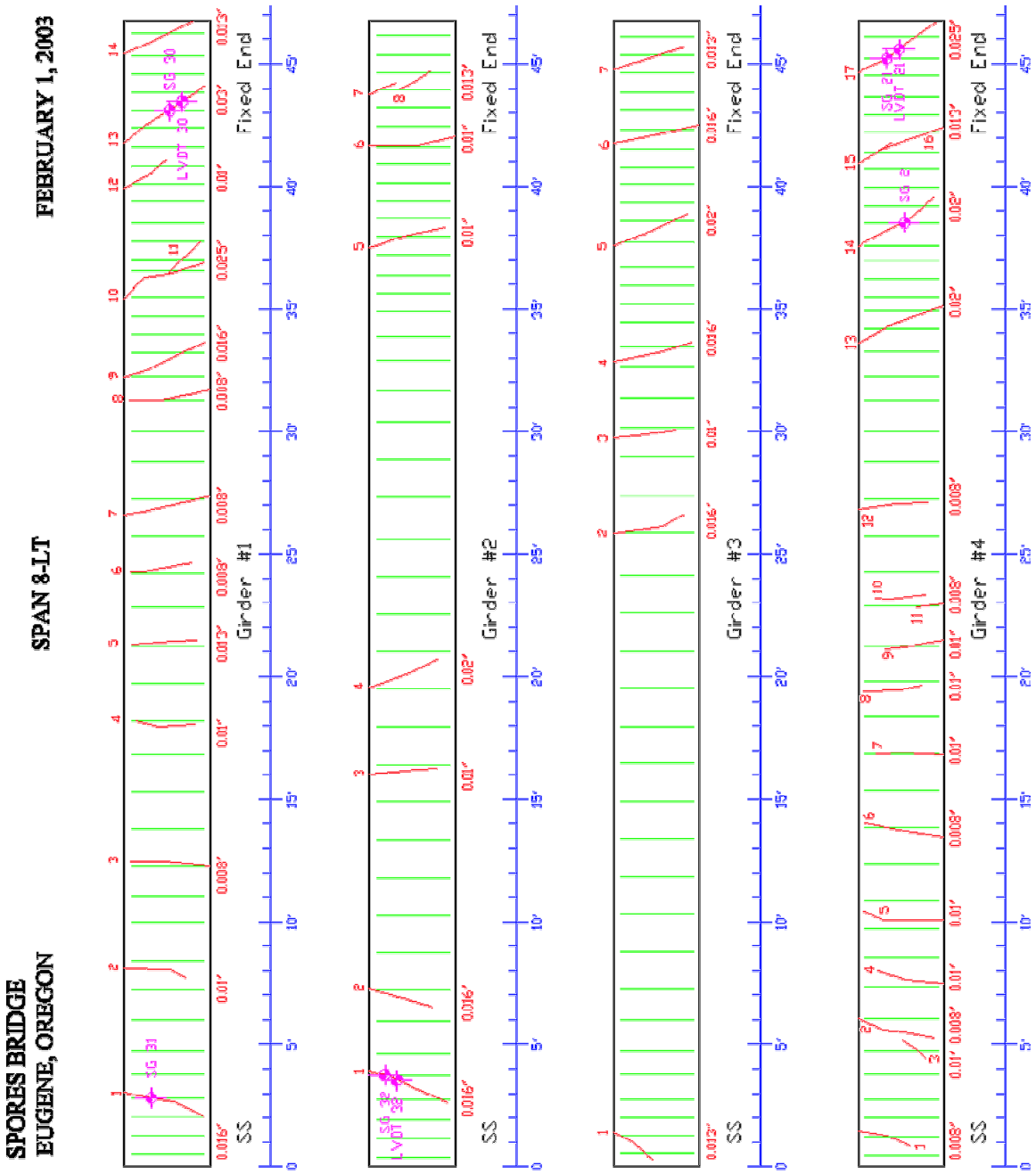

Figure 2.6a: McKenzie bridge crack and instrument locations on span 8

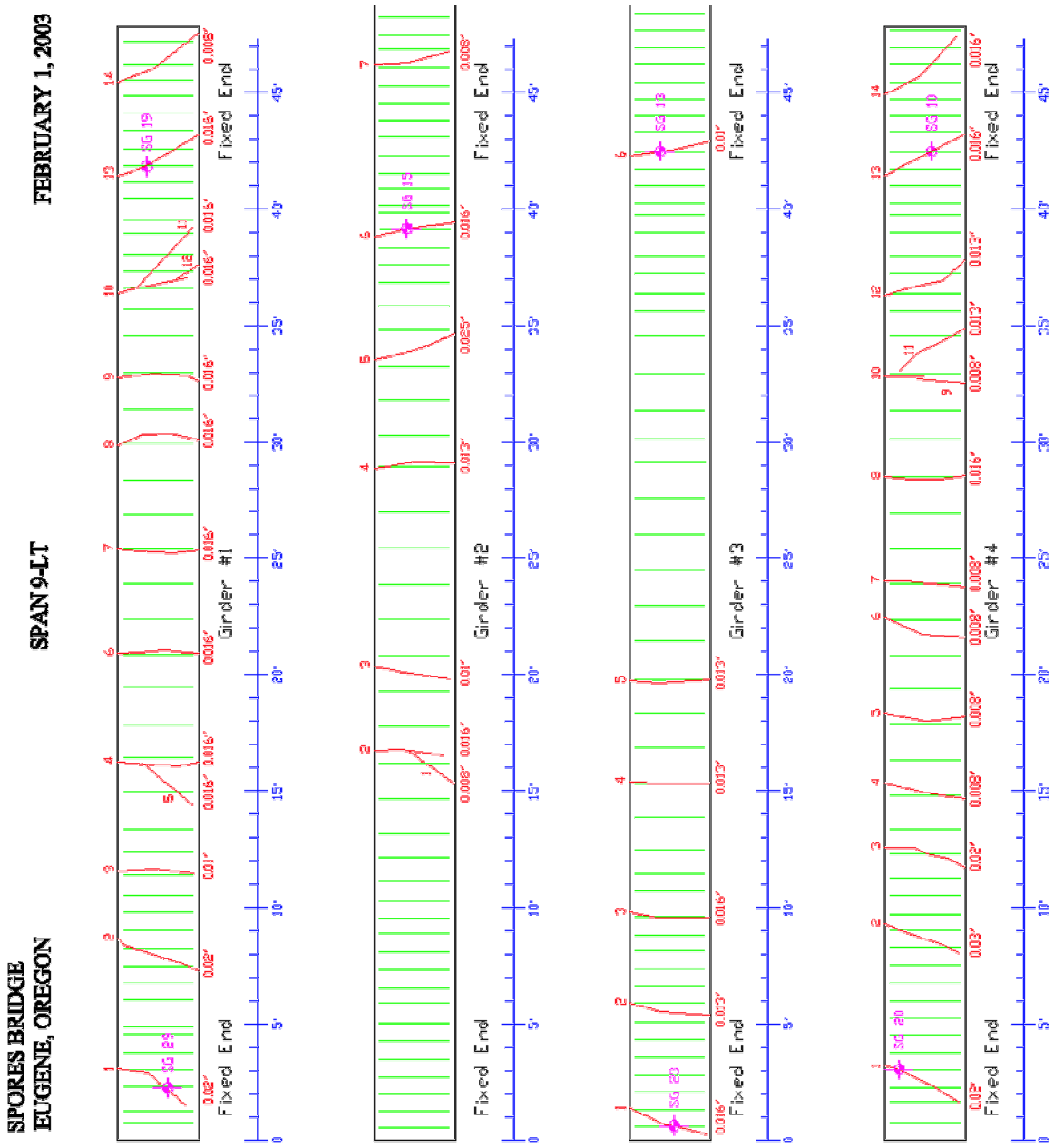

Figure 2.6b: McKenzie bridge crack and instrument locations on span 9

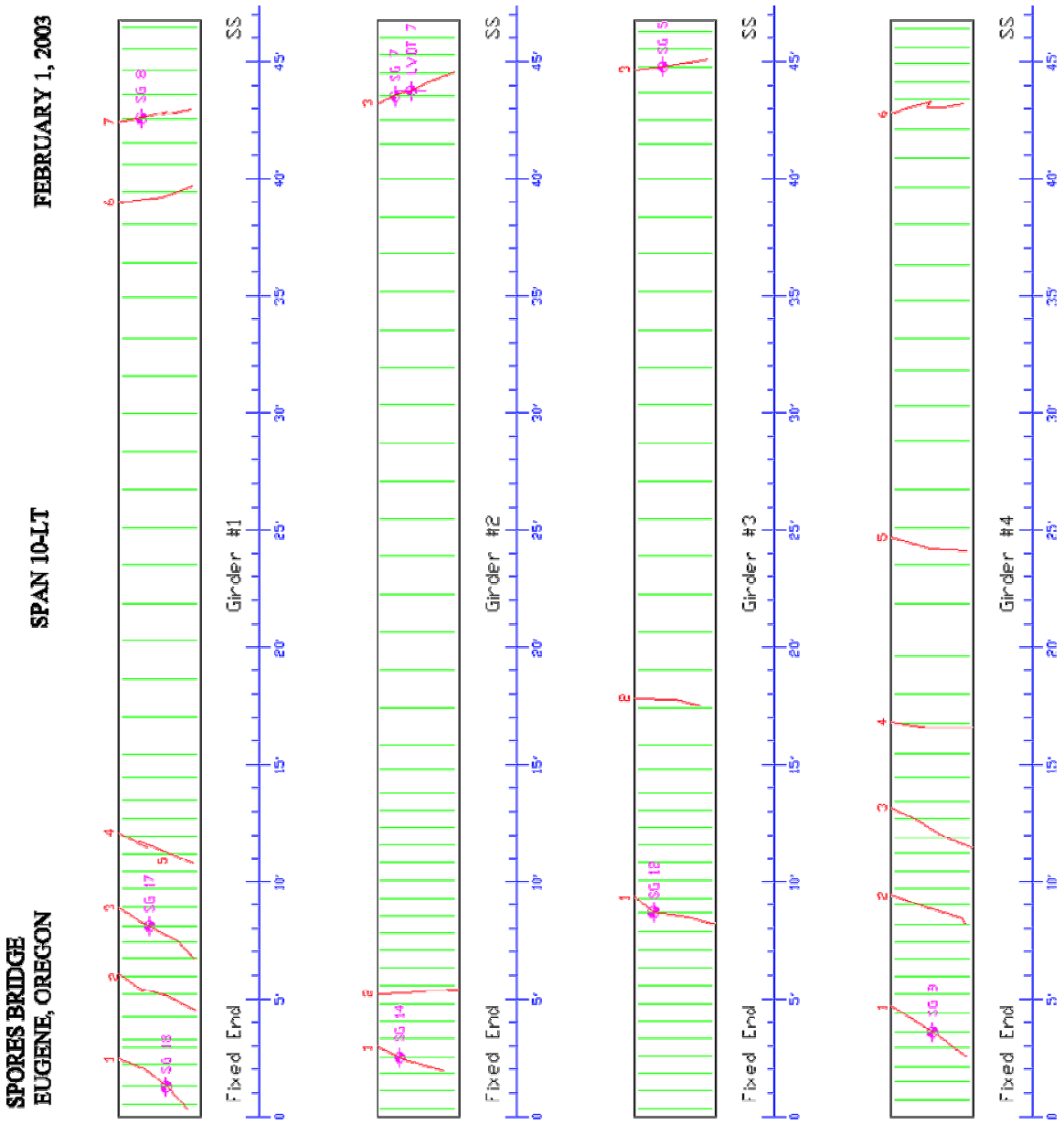

Figure 2.6c: McKenzie bridge crack and instrument locations on span 10

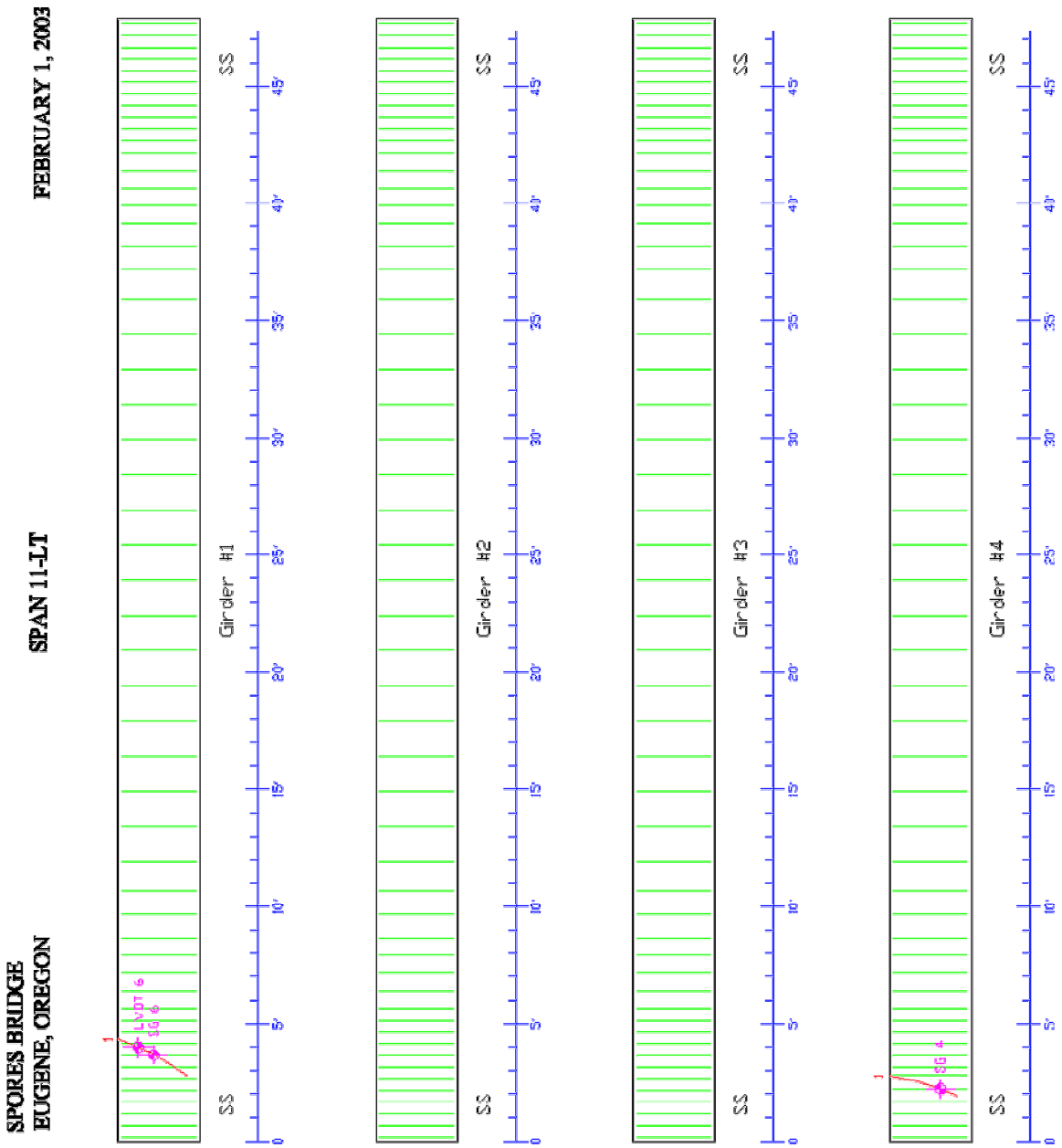

Figure 2.6d: McKenzie bridge crack and instrument locations on span 11

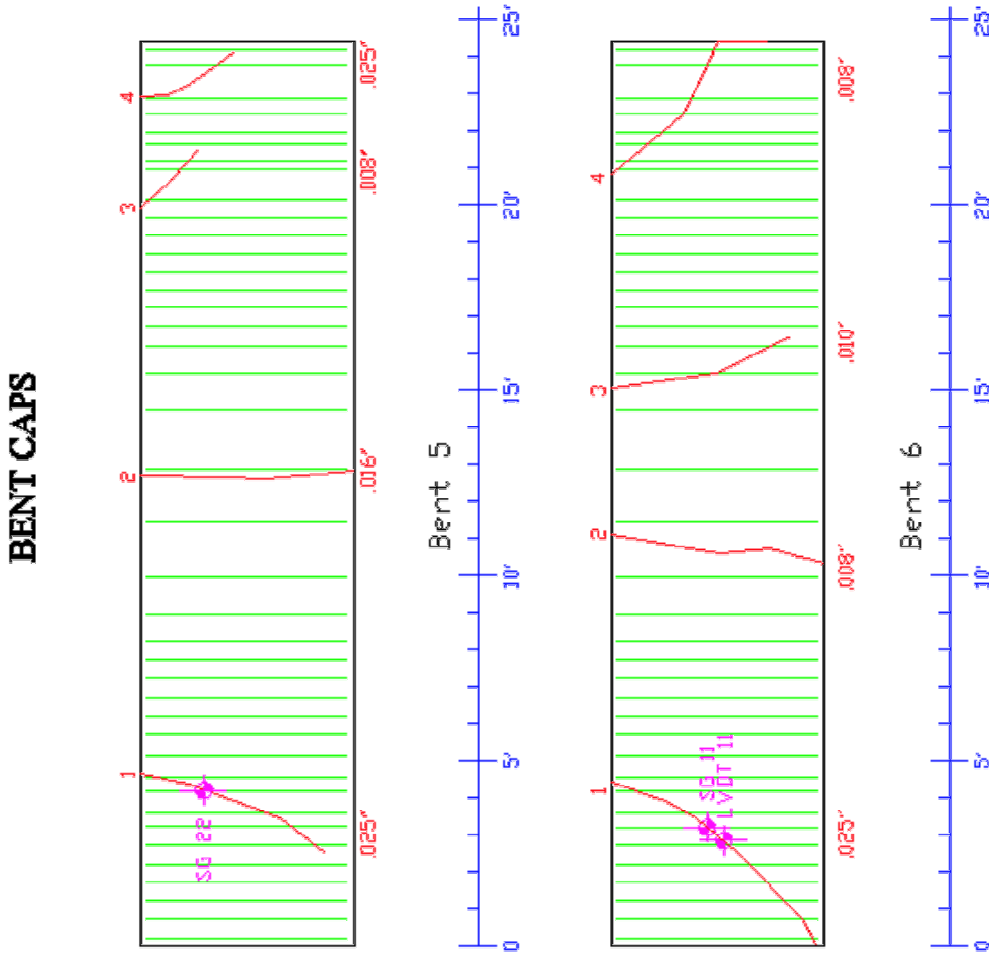

Figure 2.6e: McKenzie bridge crack and instrument locations on bent caps

2.1.2 Instrumentation

After inspection, strain gages and displacement transducers were installed at selected diagonal crack locations. Instrumentation locations were chosen for regions that experience relatively high live-load shear forces and for relatively wide diagonal cracks. Preference was given to diagonal cracks that crossed stirrups at approximately mid-height of the girder web. Strain gages were used to measure the stress carried by stirrups across diagonal cracks and linear position sensors were used to measure crack displacement during traffic loading. Strain gages were installed by chipping into the concrete and exposing the embedded stirrup at the crack location. The actual amount of concrete removed depended on the concrete cover, but typical concrete removal provided an exposed stirrup length of approximately 4 in. overall, centered about the crack, as shown in Figure 2.7.

Figure 2.7: Concrete removed to expose stirrup and attach strain gage

The width of the excavation was approximately 3 in. permitting preparation of the rebar surface for bonding strain gages on the stirrup leg. The deformation pattern was generally not removed to install the strain gage unless the vertical rib was located on the outside face. The chosen strain gage size (Measurements Group strain gage EA-06-062AQ-350, with a gage length of 1/16 in.) permitted installation within the deformation pattern of the stirrups. This strain gage is a bondable type gage with a 350 ohm resistance.

Position sensors were surface mounted at selected strain gage locations across a diagonal crack. A typical installation of a strain gage and position sensor is shown in Figure 2.8. Strain gages were installed in 24 different locations on the bridge. Crack displacement sensors were also installed at six (6) of these locations. Instrumented locations are illustrated schematically in Figure 2.9 and precise locations are shown in Figures 2.6a-e.

Figure 2.8: Example instrumented location with strain gage and LVDT on McKenzie River Bridge

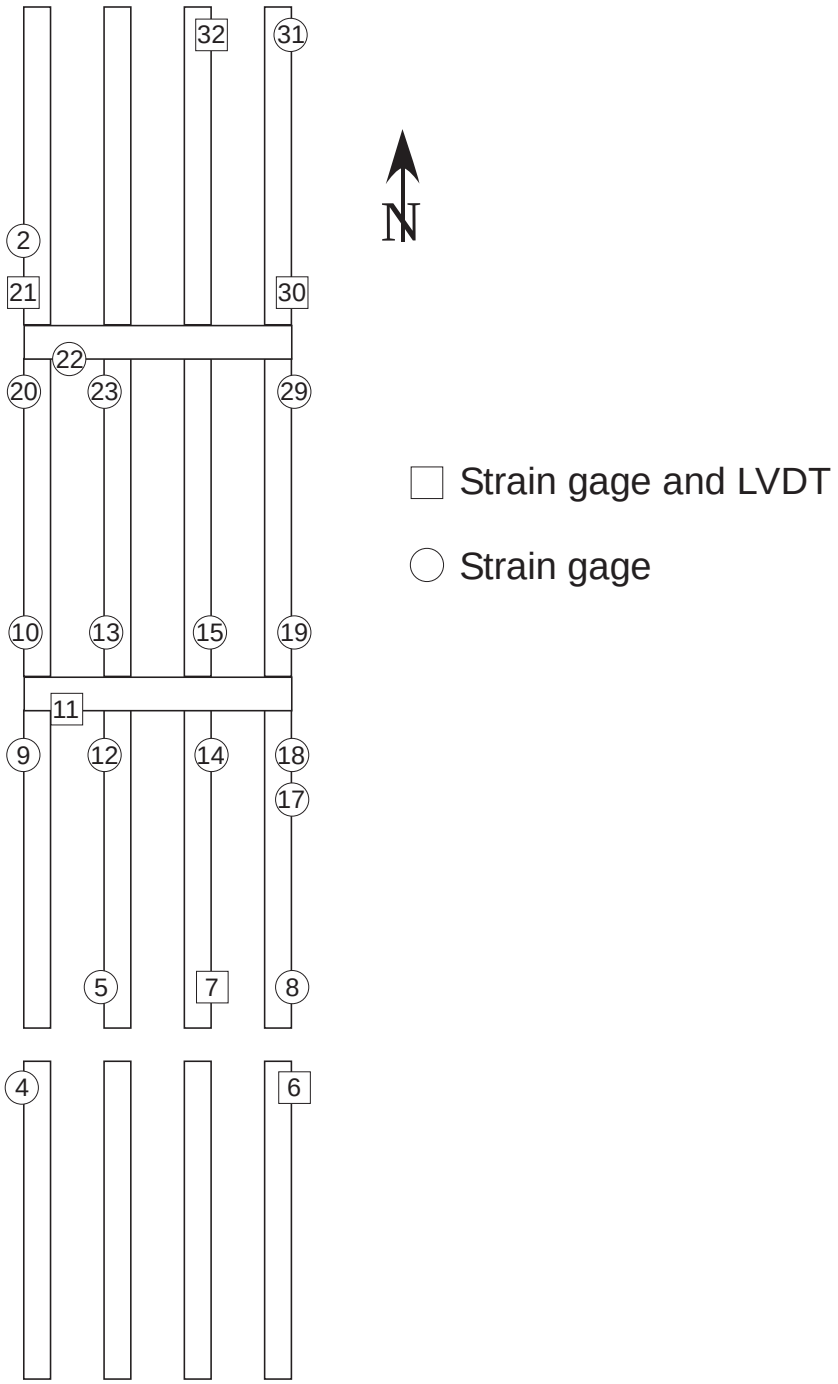

Figure 2.9: Schematic of sensor locations on McKenzie River Bridge

The strain gages and position sensors were connected to a Campbell Scientific CR9000 data logger. This is a high-speed, multi-channel, 16-bit digital data acquisition system. In order to reduce noise and prevent aliasing in the data, both analog and digital filters were employed. During the ambient monitoring period, data were sampled at 100 Hz. A digital high-pass filter

was utilized with a cut-off frequency of 40 Hz. The system recorded sensor readings and converted signals into corresponding rebar stresses and crack displacements.

Data from sensors were archived for retrieval and post-processing. The data acquisition system also included a digital video camera capable of capturing high-resolution images of traffic crossing the bridge.

2.1.3 Testing Method

Two series of live load data were collected: response under ambient traffic loading and response under controlled truck loading. The stirrup reinforcing stresses and crack displacements generated by normal traffic flow were recorded over a period of 8 calendar days in February and March, 2003.

The system also recorded individual event histories when stress thresholds exceeded 5.5 ksi at sensor location CH_7 or 2.0 ksi at location CH_21. For each trigger event, data were recorded for three seconds prior to and following the trigger. During these events, a video image of the corresponding vehicle was produced. These video images, taken during daylight hours (which enabled identification of the vehicle configurations) were used to determine a vehicle type and the axle configurations during larger stress events.

The observed vehicle configurations are summarized in Figure 2.10 according to ODOT vehicle classification charts and in Figure 2.11 according to the type of cargo carried by the vehicle. The most common axle configuration observed was the 3S2 and the most frequently observed cargo type was approximately evenly divided between carrier box and forest products (including log and chip trucks as well as those caring finished wood products).

Controlled truck tests were conducted using a heavily loaded ODOT maintenance truck, as shown in Figure 2.12a. Tests were conducted using the truck with trailer combination, as well as with the truck alone. The axle weights and spacing were determined before the test and are shown in Figure 2.12b. Traffic was temporarily slowed with the use of a rolling roadblock so that the control truck would be the only vehicle on the bridge during data collection.

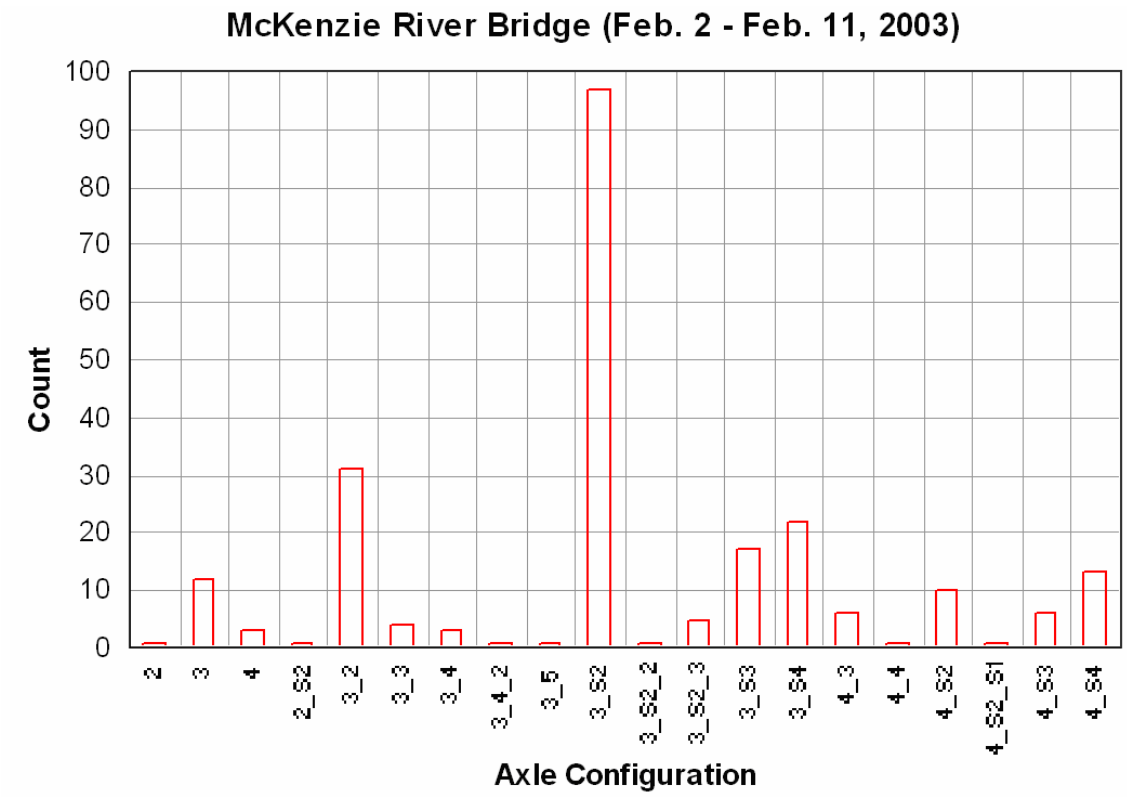

Figure 2.10: Truck classification based on triggered video at McKenzie River Bridge

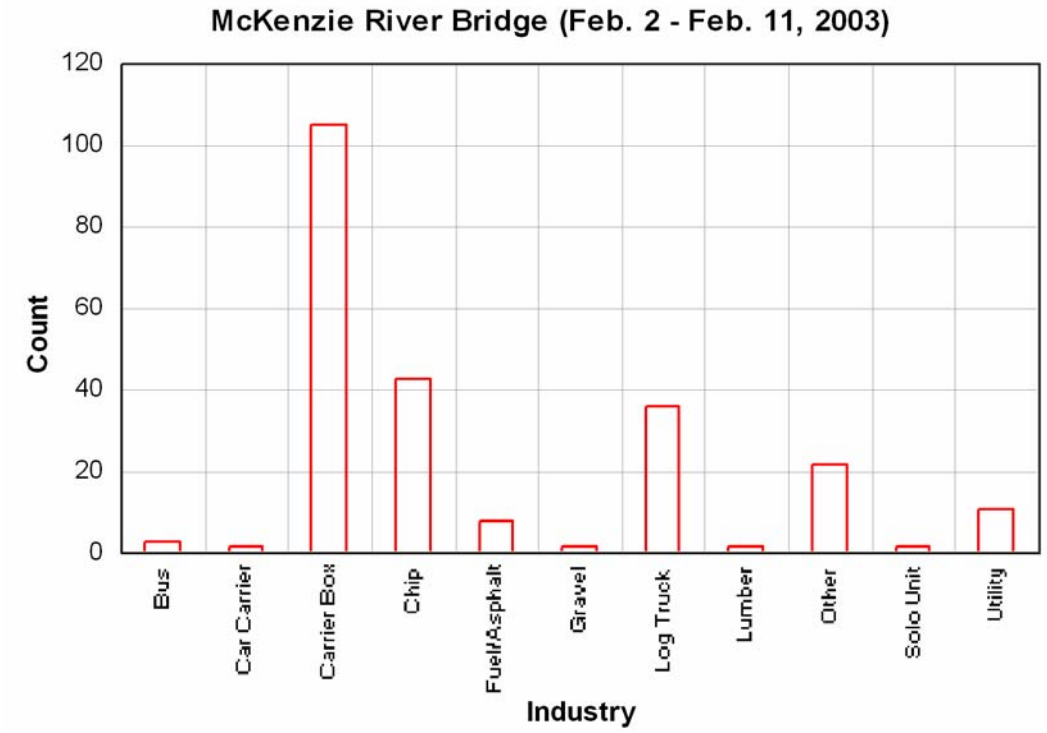

Figure 2.11: Cargo type based on triggered video at McKenzie River Bridge

Figure 2.12a: Test truck with trailer for McKenzie River Bridge

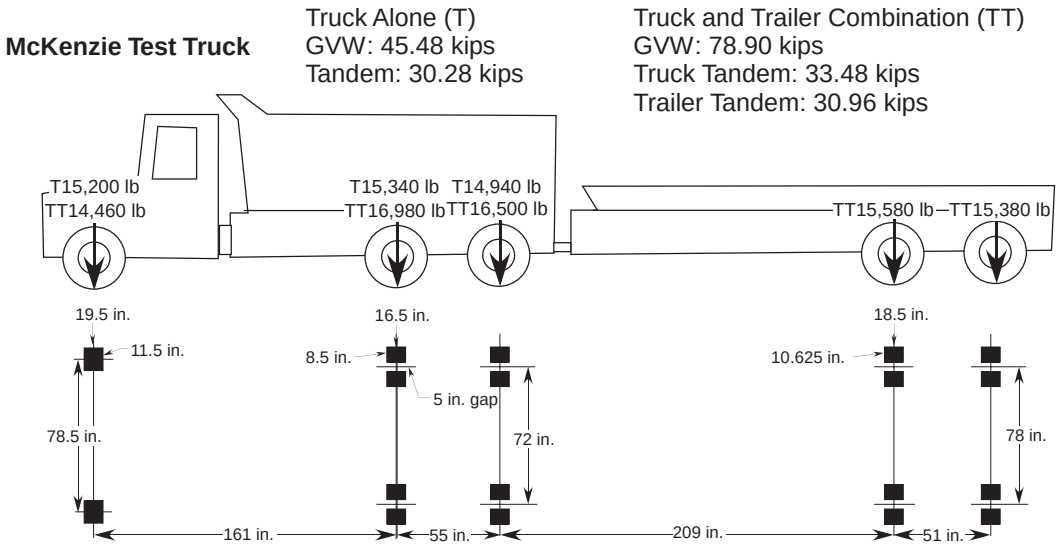

Figure 2.12b: Truck with trailer axle spacing and weights for tests on McKenzie River Bridge

The control truck passed over the bridge at several designated speeds and lane positions. Test speeds varied from 5 mph to 65 mph. Lane locations included placing the truck in the truck lane, in the passing lane, and the passenger side tires located on the fog line. Lane positions and the corresponding truck positions relative to the girder locations are illustrated in Figure 2.13.

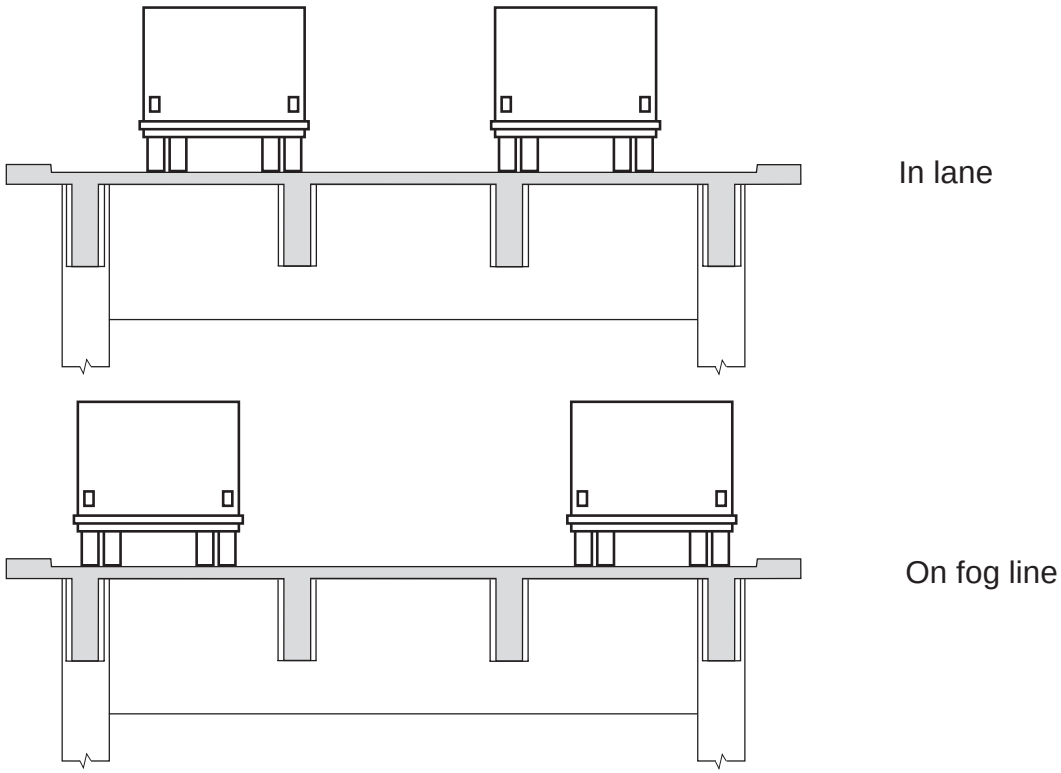

Figure 2.13: Truck lane positions on McKenzie River Bridge

During each pass of the control truck, stirrup stresses and crack deflections were recorded for each instrumented location. Stirrup stress histories for each of the test runs are shown in Figures 2.14a-l and the crack motions are shown in Figures 2.15a-f. Peak values and stress ranges are summarized in Table 2.1.

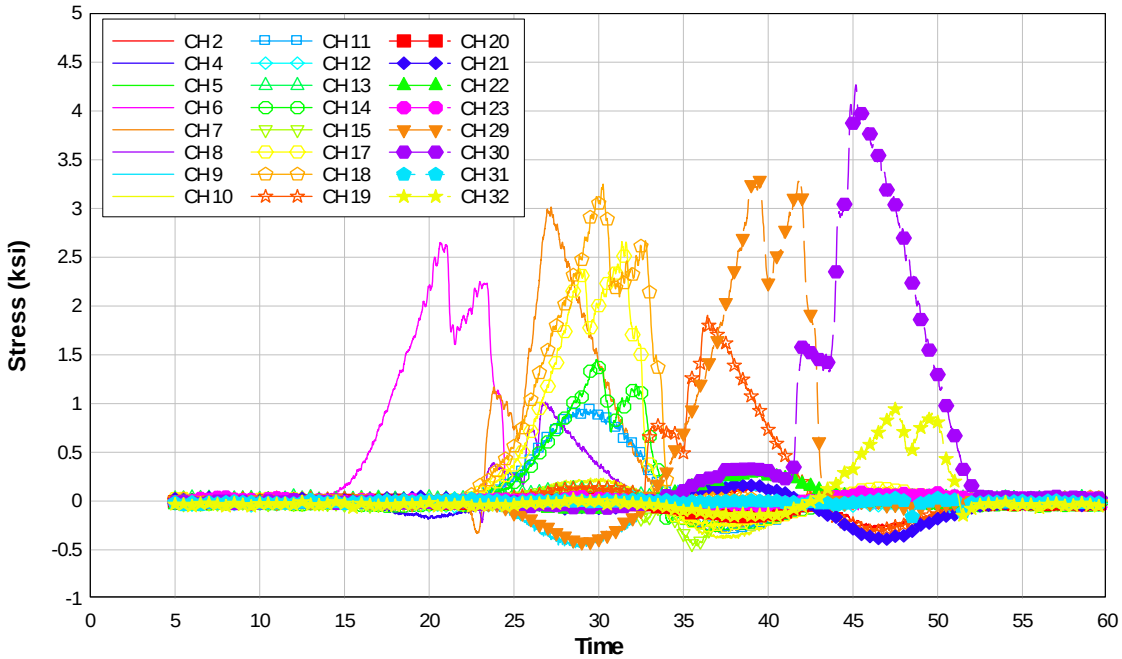

Figure 2.14a: Stirrup stress response for test truck on north-bound fog line at 5 mph

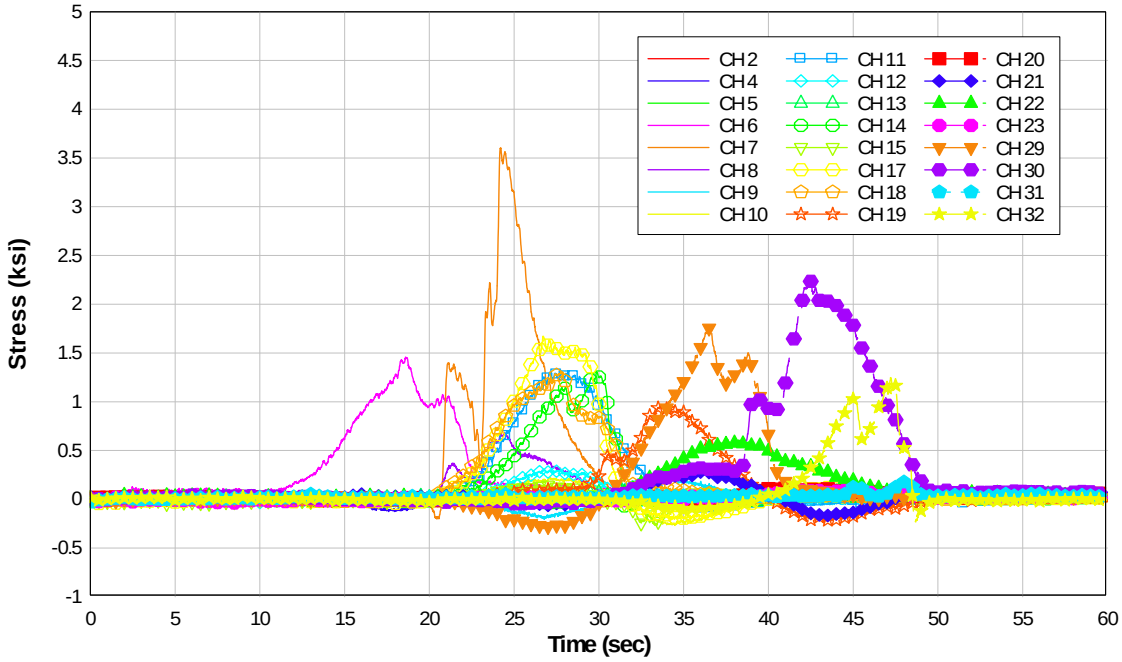

Figure 2.14b: Stirrup stress response for test truck in north-bound truck lane at 5 mph

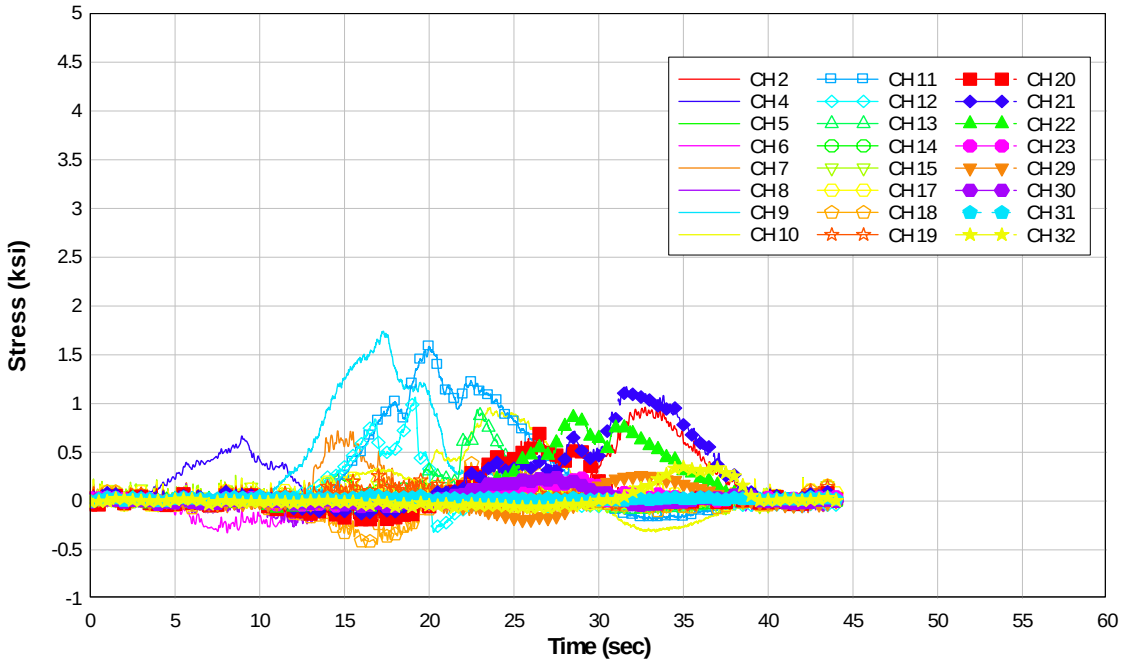

Figure 2.14c: Stirrup stress response for test truck in north-bound passing lane at 5 mph

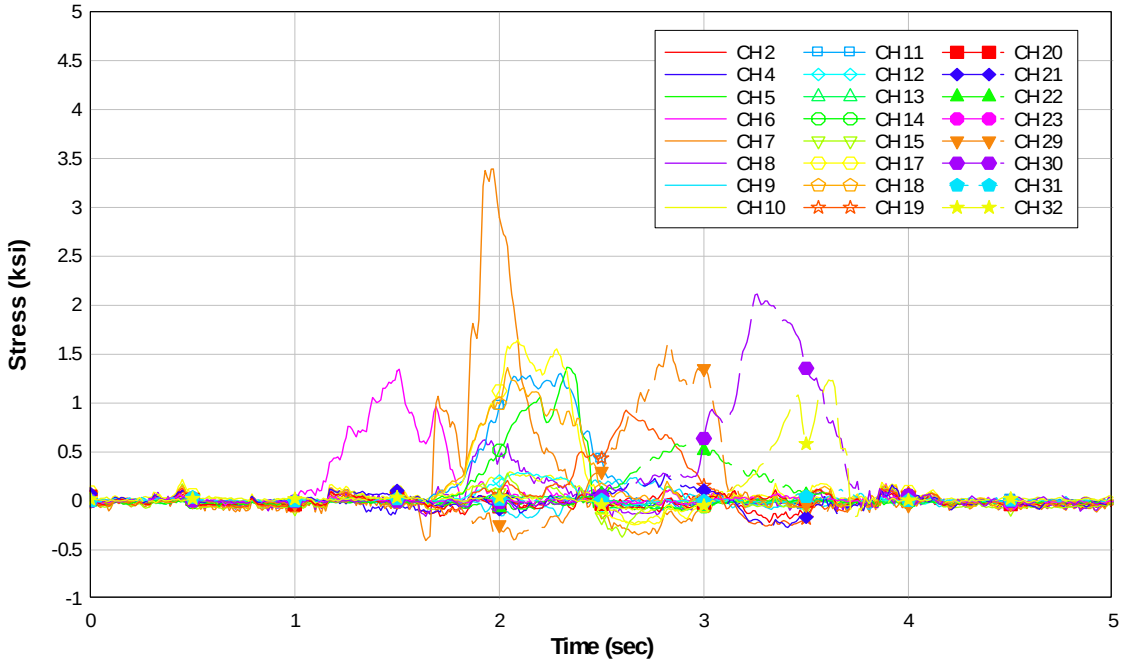

Figure 2.14d: Stirrup stress response for test truck in north-bound truck lane at 55 mph

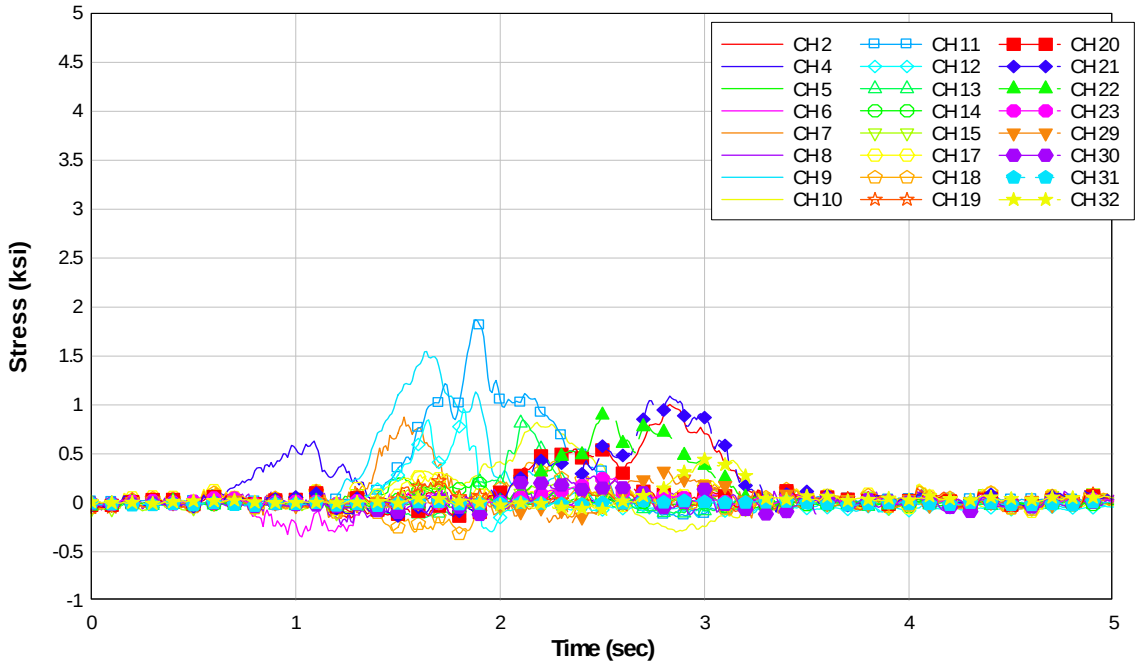

Figure 2.14e: Stirrup stress response for test truck in north-bound passing lane at 55 mph

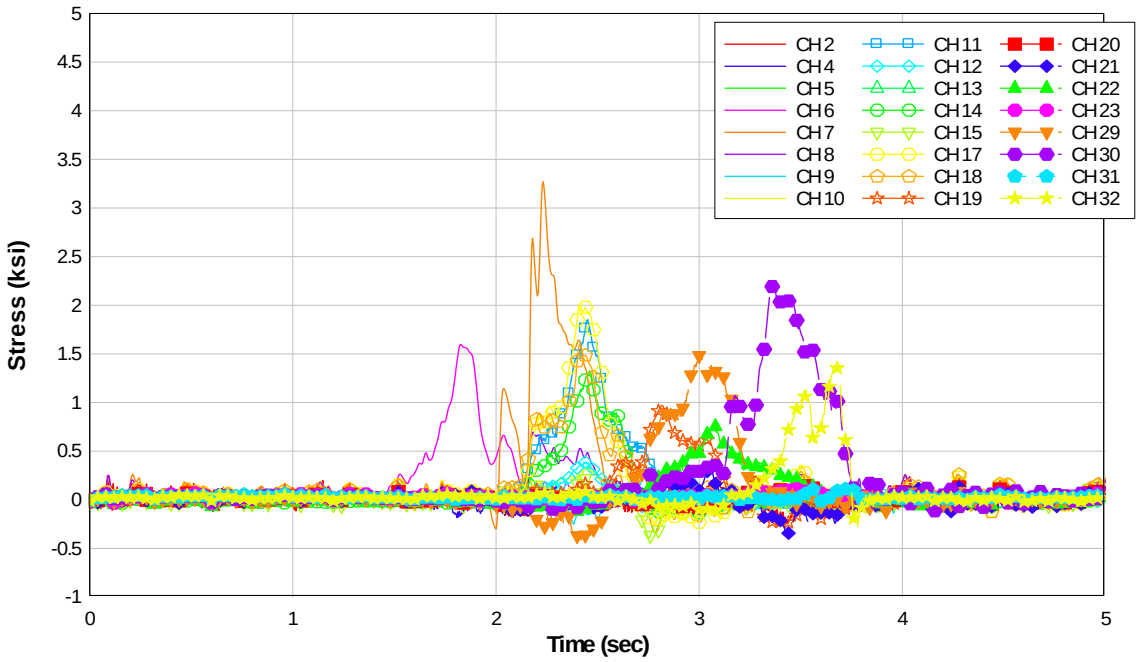

Figure 2.14f: Stirrup stress response for test truck in north-bound truck lane at 64 mph

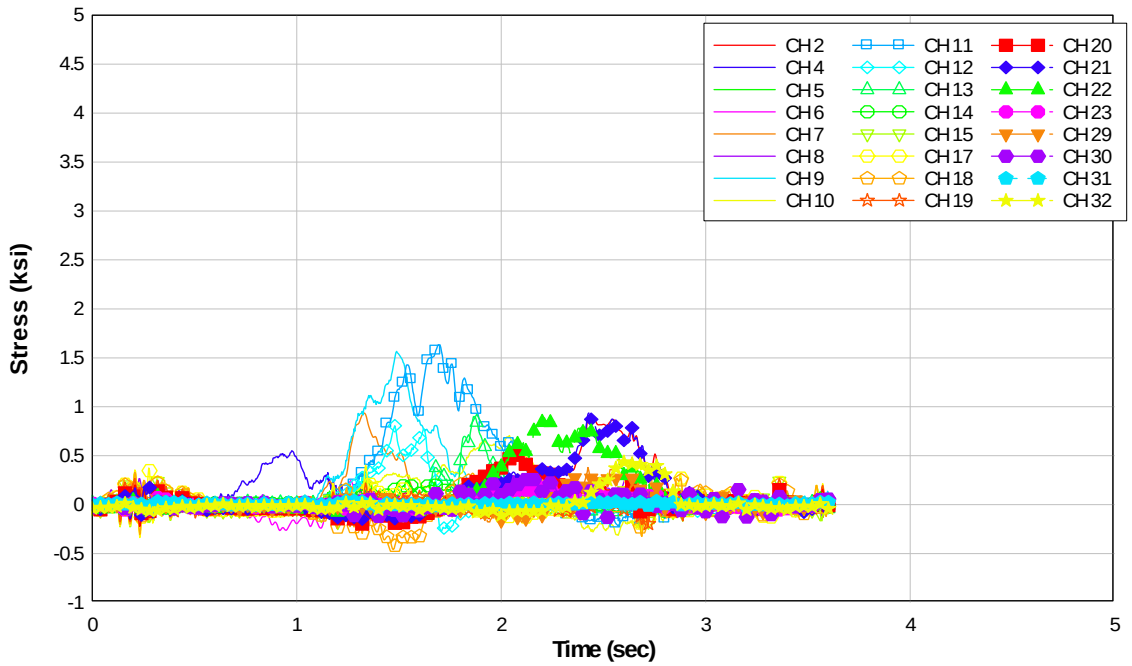

Figure 2.14g: Stirrup stress response for test truck in north-bound passing lane at 60 mph

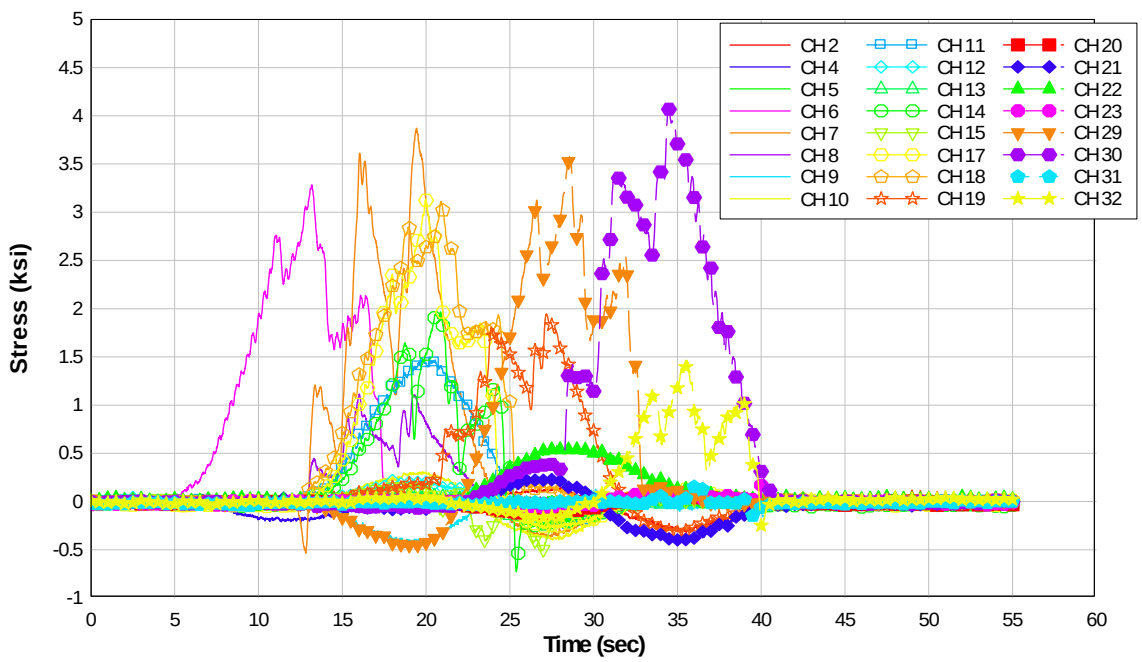

Figure 2.14h: Stirrup stress response test truck with trailer on north-bound fog lane at 5 mph

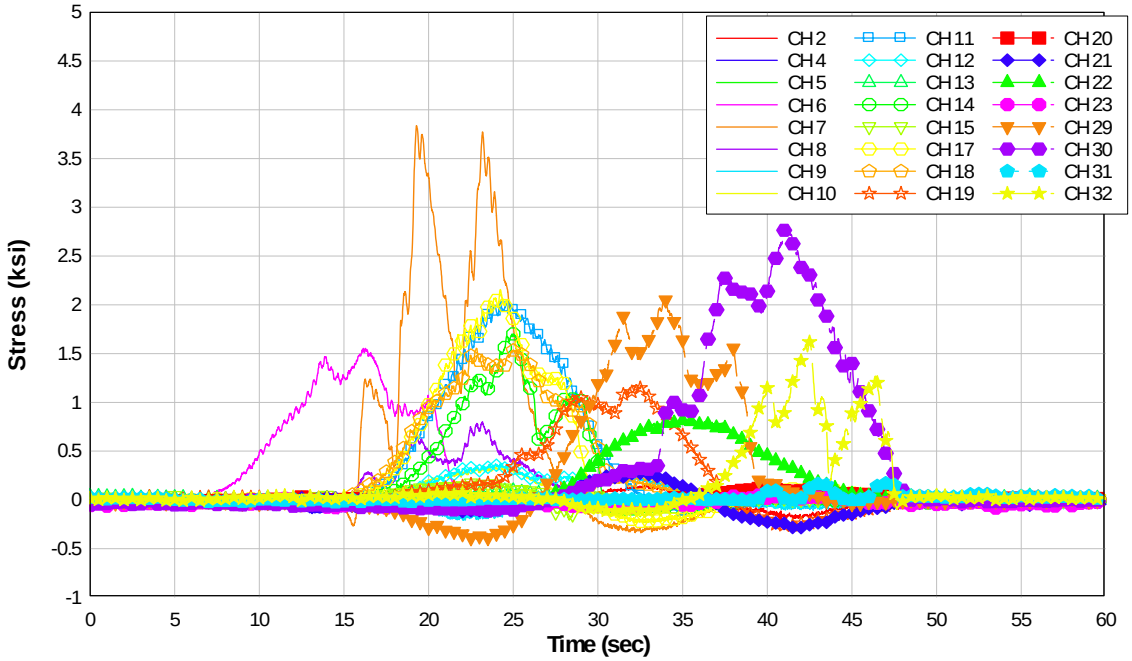

Figure 2.14i: Stirrup stress response for test truck with trailer in north-bound truck lane at 5 mph

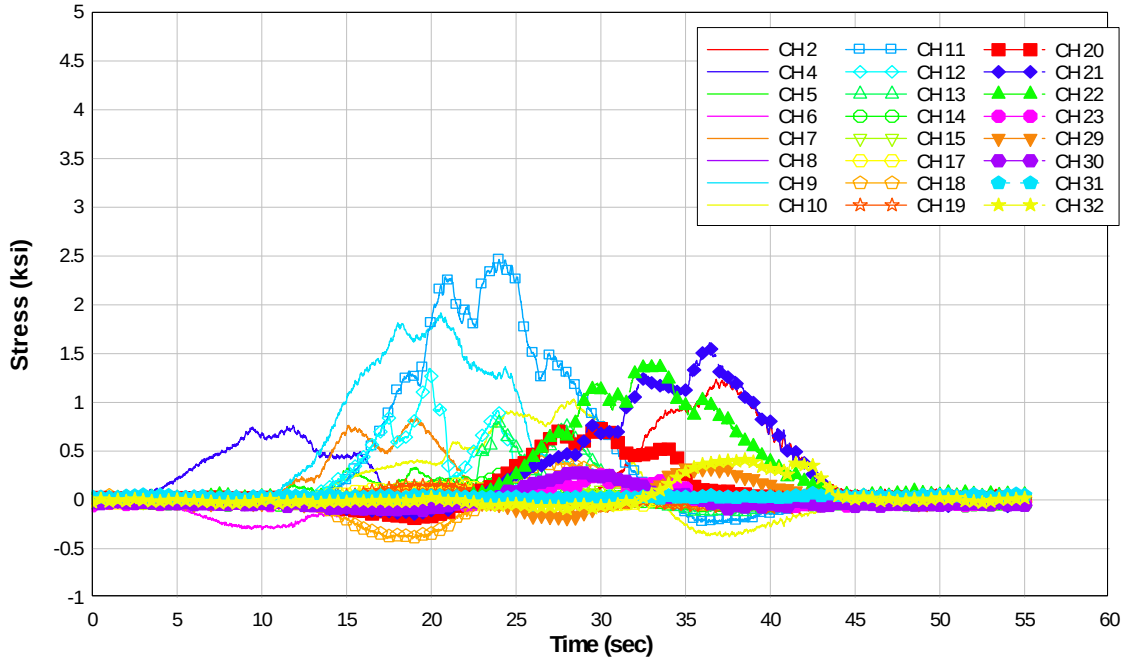

Figure 2.14j: Stirrup stress response for test truck with trailer in north-bound passing lane at 5 mph

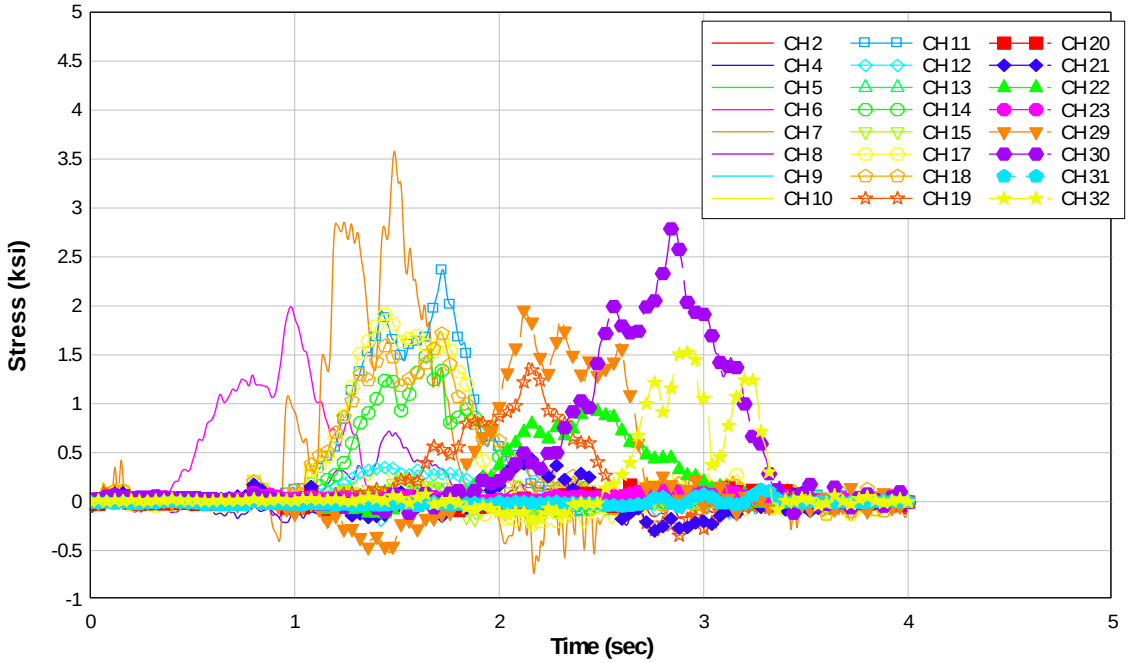

Figure 2.14k: Stirrup stress response for test truck with trailer in north-bound truck lane at 54 mph

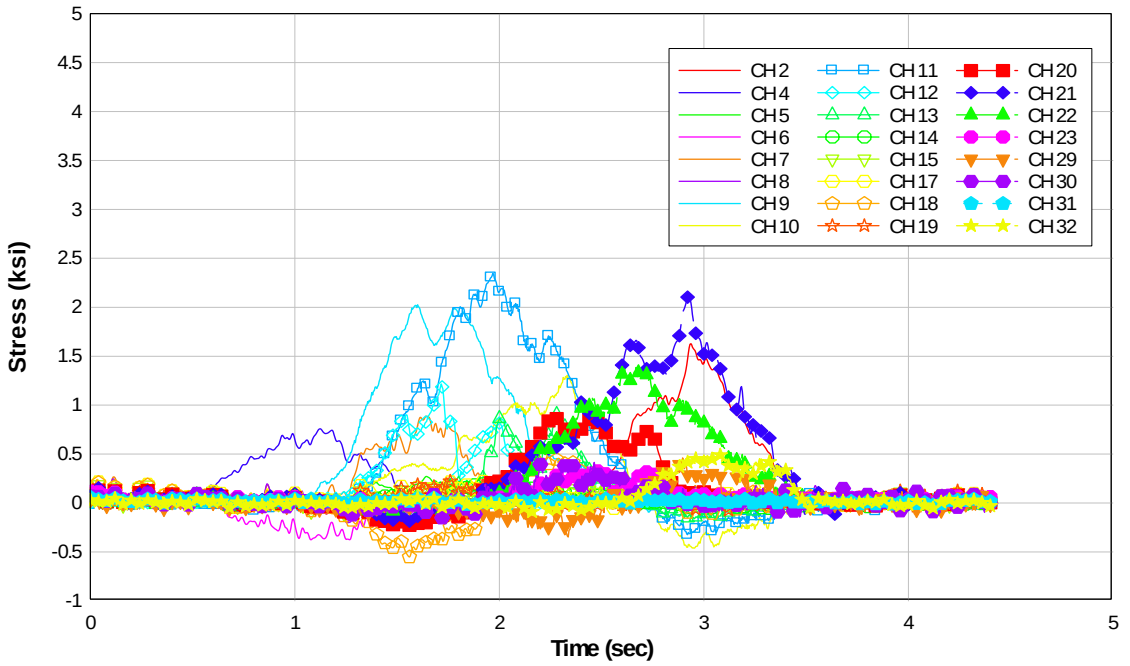

Figure 2.14l: Stirrup stress response test truck with trailer in north-bound passing lane at 55 mph

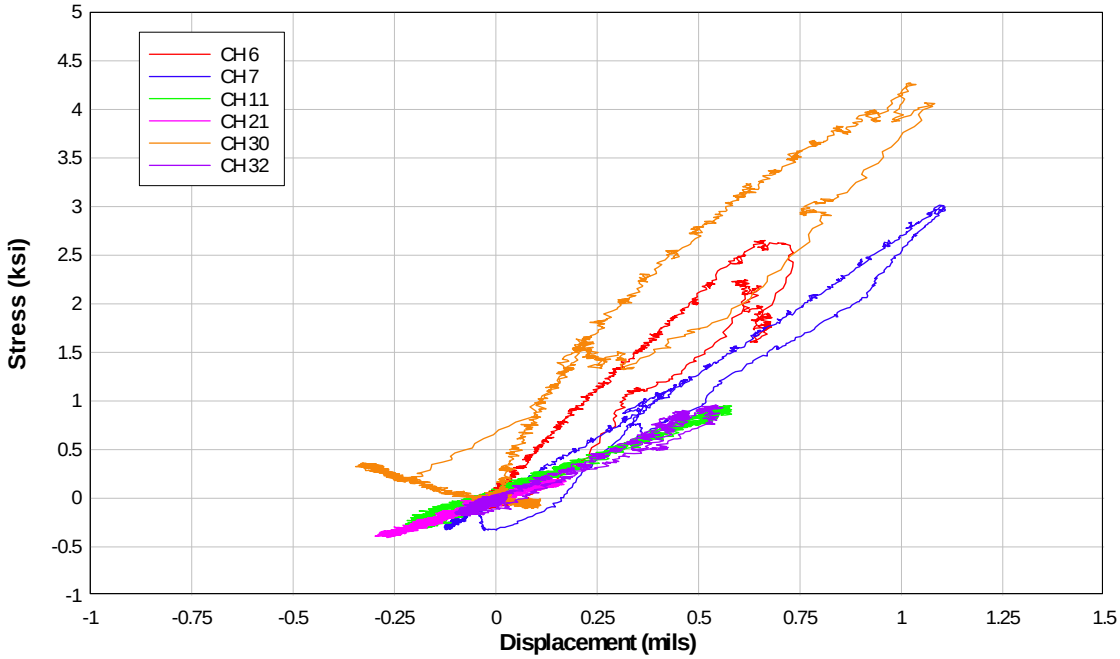

Figure 2.15a: Crack displacement-Stirrup stress response for test truck on north-bound fog line at 5 mph

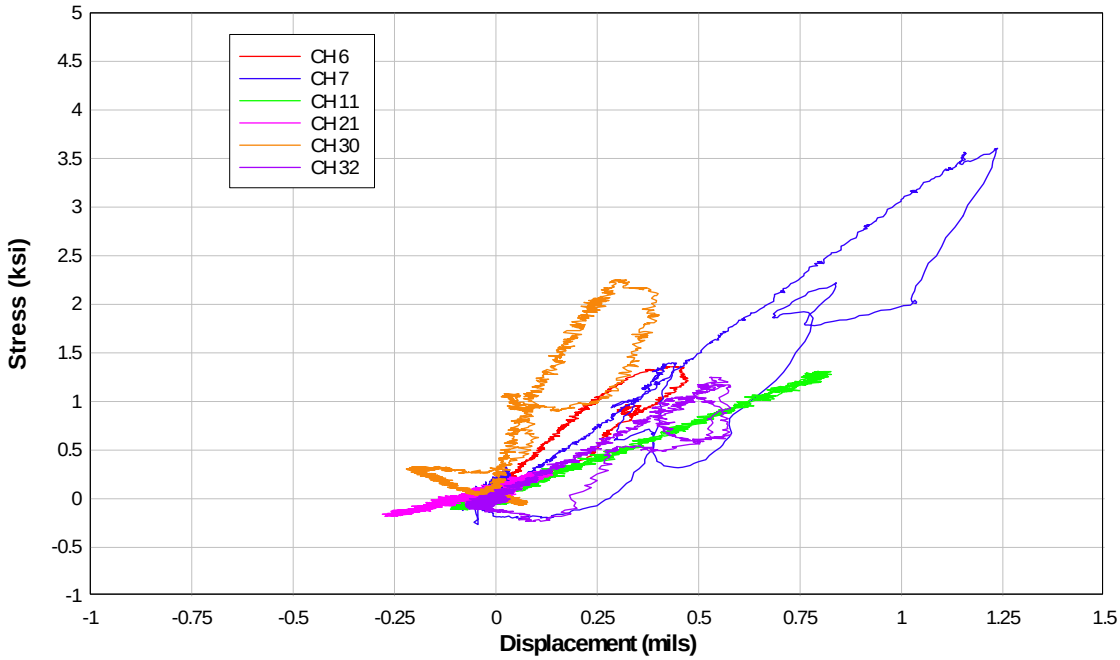

Figure 2.15b: Crack displacement-Stirrup stress response for test truck in north-bound truck lane at 5 mph

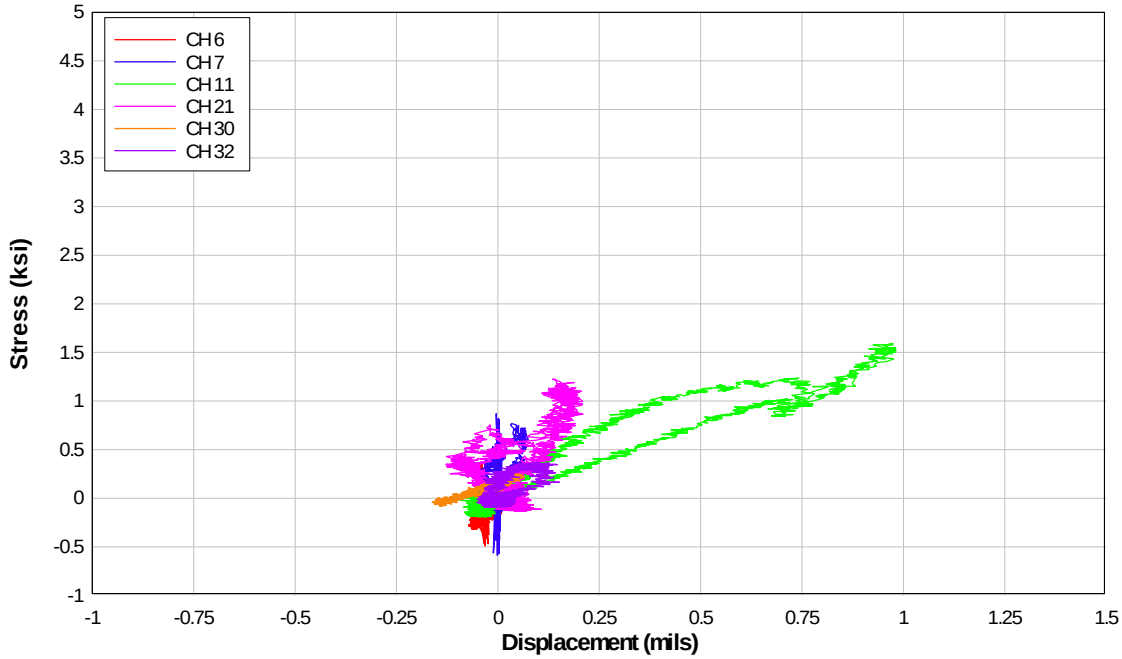

Figure 2.15c: Crack displacement-Stirrup stress response for test truck in north-bound passing lane at 5 mph

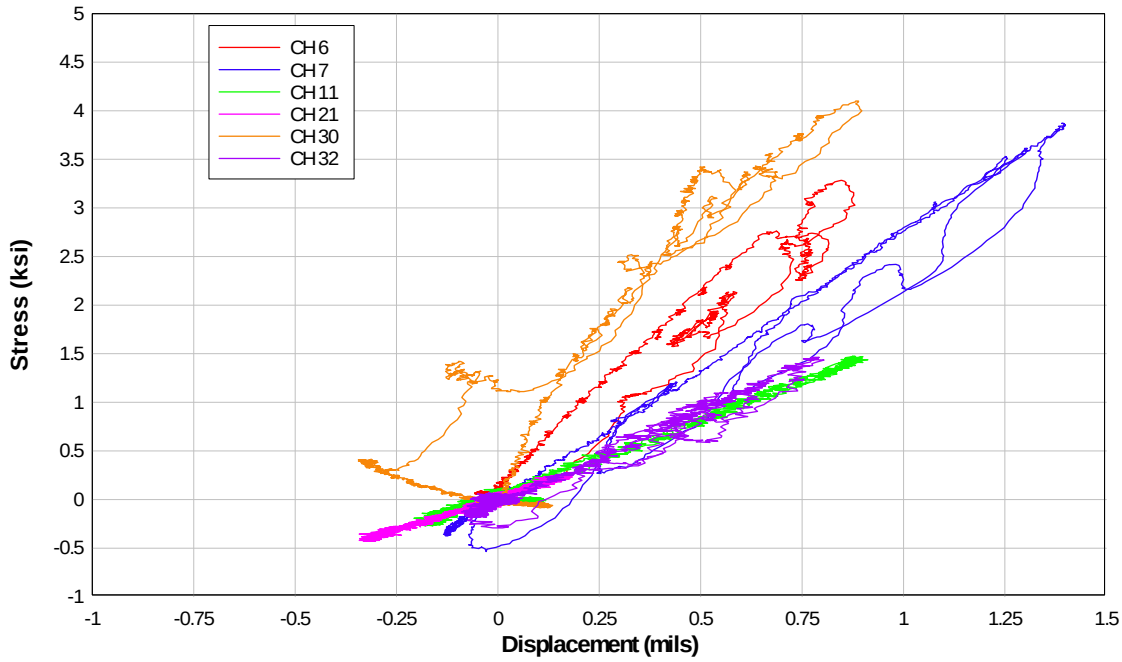

Figure 2.15d: Crack displacement-Stirrup stress response for test truck with trailer on north-bound fog line at 5 mph

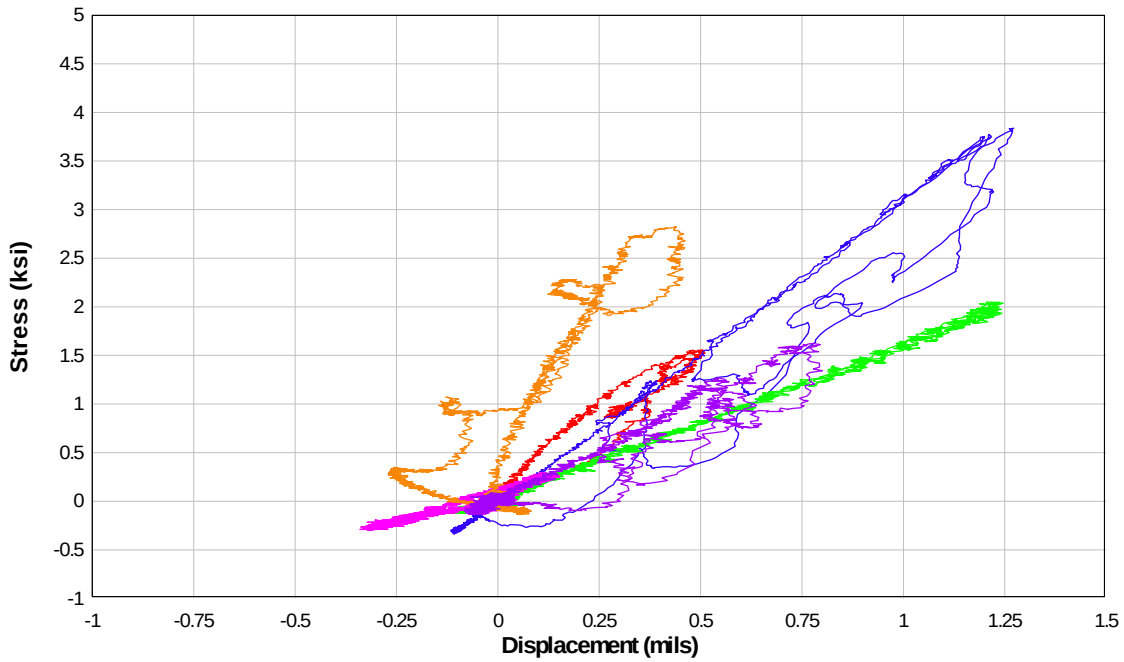

Figure 2.15e: Crack displacement-Stirrup stress response for test truck with trailer in north-bound truck lane at 5 mph

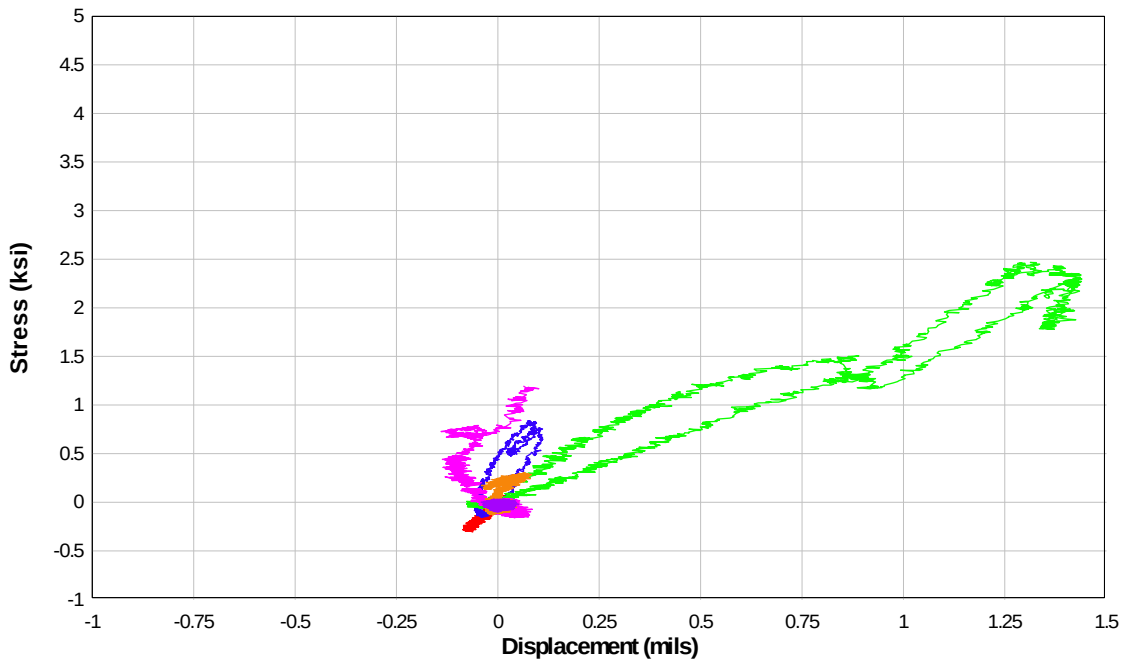

Figure 2.15f: Crack displacement-Stirrup stress response for test truck with trailer in north-bound passing lane at 5 mph

Table 2.1: Maximum and minimum stresses and stress ranges at instrumented locations for test truck (with and without trailer) on McKenzie River Bridge

Maximum Stress

Test Truck Configuration	Speed (mph)	Lane Position	CH_2 (ksi)	CH_4 (ksi)	CH_5 (ksi)	CH_6 (ksi)	CH_7 (ksi)	CH_8 (ksi)	CH_9 (ksi)	CH_10 (ksi)	CH_11 (ksi)	CH_12 (ksi)	CH_13 (ksi)	CH_14 (ksi)	CH_15 (ksi)	CH_17 (ksi)	CH_18 (ksi)	CH_19 (ksi)	CH_20 (ksi)	CH_21 (ksi)	CH_22 (ksi)	CH_23 (ksi)	CH_29 (ksi)	CH_30 (ksi)	CH_31 (ksi)	CH_32 (ksi)
Truck	5	Fog	0.15	0.07	0.01	2.65	3.01	1.02	0.23	0.24	0.95	0.11	0.14	1.45	0.14	2.66	3.25	1.90	0.05	0.19	0.31	0.10	3.30	4.27	0.06	0.96
Truck	5	Truck	0.04	0.07	0.05	1.46	3.60	0.68	0.23	0.22	1.31	0.31	0.08	1.30	0.15	1.67	1.31	0.97	0.13	0.28	0.61	0.11	1.77	2.25	0.18	1.25
Truck	5	Passing	0.96	0.67	0.28	0.18	0.72	0.18	1.74	0.96	1.59	1.07	0.94	0.15	0.27	0.29	0.41	0.30	0.73	1.19	0.88	0.28	0.27	0.25	0.06	0.37
Truck and Trailer	5	Fog	0.15	0.04	0.08	3.28	3.87	1.12	0.26	0.31	1.47	0.23	0.11	1.97	0.17	3.14	3.11	1.95	0.09	0.25	0.58	0.17	3.58	4.10	0.18	1.46
Truck and Trailer	5	Truck	0.15	0.06	0.05	1.55	3.84	0.80	0.28	0.35	2.05	0.37	0.11	1.70	0.18	2.16	1.56	1.18	0.12	0.29	0.83	0.07	2.10	2.82	0.21	1.62
Truck and Trailer	5	Passing	1.24	0.76	0.33	0.07	0.84	0.05	1.92	1.03	2.47	1.35	0.81	0.27	0.15	0.18	0.40	0.18	0.75	1.61	1.40	0.29	0.36	0.30	0.08	0.43
Truck	55	Truck	0.12	0.07	0.05	1.35	3.39	0.63	0.24	0.30	1.30	0.29	0.06	1.37	0.29	1.65	1.36	0.93	0.14	0.27	0.58	0.08	1.63	2.12	0.12	1.24
Truck	64	Truck	0.25	0.18	0.12	1.60	3.27	0.70	0.35	0.35	1.85	0.39	0.09	1.33	0.25	2.01	1.60	0.97	0.19	0.32	0.76	0.16	1.49	2.20	0.13	1.37
Truck	55	Passing	1.01	0.63	0.26	0.17	0.88	0.15	1.55	0.82	1.87	0.97	0.85	0.22	0.19	0.29	0.42	0.22	0.60	1.09	0.92	0.26	0.35	0.29	0.02	0.45
Truck	60	Passing	0.91	0.55	0.32	0.25	0.94	0.28	1.57	0.71	1.64	0.81	0.90	0.25	0.33	0.40	0.33	0.27	0.51	0.94	0.89	0.22	0.38	0.30	0.06	0.46
Truck and Trailer	54	Truck	0.20	0.13	0.02	1.99	3.58	0.72	0.38	0.33	2.37	0.37	0.12	1.50	0.27	1.93	1.74	1.42	0.21	0.47	0.96	0.14	1.97	2.87	0.13	1.54
Truck and Trailer	55	Passing	1.63	0.76	0.27	0.16	0.89	0.27	2.02	1.30	2.35	1.22	0.91	0.24	0.21	0.25	0.51	0.26	0.92	2.12	1.39	0.38	0.46	0.42	0.07	0.50

Minimum Stress

Test Truck Configuration	Speed (mph)	Lane Position	CH_2 (ksi)	CH_4 (ksi)	CH_5 (ksi)	CH_6 (ksi)	CH_7 (ksi)	CH_8 (ksi)	CH_9 (ksi)	CH_10 (ksi)	CH_11 (ksi)	CH_12 (ksi)	CH_13 (ksi)	CH_14 (ksi)	CH_15 (ksi)	CH_17 (ksi)	CH_18 (ksi)	CH_19 (ksi)	CH_20 (ksi)	CH_21 (ksi)	CH_22 (ksi)	CH_23 (ksi)	CH_29 (ksi)	CH_30 (ksi)	CH_31 (ksi)	CH_32 (ksi)
Truck	5	Fog	-0.27	-0.19	-0.08	-0.10	-0.33	-0.22	-0.48	-0.38	-0.31	-0.11	-0.15	-0.26	-0.46	-0.27	-0.04	-0.32	-0.19	-0.40	-0.10	-0.07	-0.44	-0.10	-0.20	-0.18
Truck	5	Truck	-0.03	-0.13	-0.04	-0.03	-0.20	-0.02	-0.21	-0.27	-0.11	-0.05	-0.05	-0.07	-0.27	-0.21	-0.04	-0.22	-0.04	-0.18	-0.07	-0.06	-0.30	-0.07	-0.04	-0.23
Truck	5	Passing	-0.18	-0.05	-0.13	-0.33	-0.18	-0.26	-0.08	-0.32	-0.19	-0.32	-0.15	-0.05	-0.11	-0.08	-0.44	-0.08	-0.21	-0.13	-0.09	-0.06	-0.20	-0.08	-0.01	-0.09
Truck and Trailer	5	Fog	-0.32	-0.21	-0.02	-0.01	-0.53	-0.13	-0.44	-0.40	-0.27	-0.07	-0.20	-0.73	-0.51	-0.28	-0.05	-0.33	-0.14	-0.43	-0.07	-0.09	-0.50	-0.09	-0.17	-0.29
Truck and Trailer	5	Truck	-0.21	-0.14	-0.05	-0.04	-0.34	-0.10	-0.21	-0.23	-0.13	-0.07	-0.08	-0.11	-0.21	-0.23	-0.04	-0.27	-0.06	-0.30	-0.11	-0.10	-0.41	-0.14	-0.03	-0.14
Truck and Trailer	5	Passing	-0.04	-0.02	-0.04	-0.30	-0.15	-0.09	-0.08	-0.38	-0.24	-0.07	-0.18	-0.08	-0.04	-0.07	-0.40	-0.09	-0.20	-0.16	-0.04	-0.09	-0.20	-0.13	-0.02	-0.10
Truck	55	Truck	-0.22	-0.14	-0.04	-0.07	-0.40	-0.16	-0.17	-0.23	-0.09	-0.07	-0.09	-0.10	-0.37	-0.24	-0.08	-0.25	-0.11	-0.30	-0.09	-0.05	-0.40	-0.11	-0.02	-0.17
Truck	64	Truck	-0.24	-0.18	-0.06	-0.07	-0.34	-0.13	-0.25	-0.24	-0.12	-0.11	-0.10	-0.13	-0.40	-0.24	-0.16	-0.25	-0.09	-0.35	-0.14	-0.05	-0.41	-0.15	-0.04	-0.29
Truck	55	Passing	-0.16	-0.05	-0.09	-0.35	-0.16	-0.22	-0.15	-0.30	-0.14	-0.29	-0.15	-0.06	-0.12	-0.13	-0.32	-0.09	-0.15	-0.14	-0.06	-0.04	-0.22	-0.14	-0.03	-0.07
Truck	60	Passing	-0.13	-0.09	-0.14	-0.26	-0.15	-0.19	-0.10	-0.31	-0.22	-0.27	-0.12	-0.09	-0.26	-0.34	-0.46	-0.22	-0.23	-0.20	-0.10	-0.08	-0.18	-0.13	-0.03	-0.11
Truck and Trailer	54	Truck	-0.17	-0.21	-0.07	-0.05	-0.74	-0.18	-0.25	-0.30	-0.14	-0.07	-0.12	-0.17	-0.18	-0.26	-0.17	-0.35	-0.14	-0.30	-0.12	-0.01	-0.52	-0.14	-0.05	-0.20
Truck and Trailer	55	Passing	-0.16	-0.02	-0.09	-0.38	-0.09	-0.20	-0.14	-0.46	-0.32	-0.04	-0.18	-0.08	-0.11	-0.08	-0.55	-0.09	-0.26	-0.19	-0.11	-0.08	-0.35	-0.15	-0.04	-0.12

Stress Range

Test Truck Configuration	Speed (mph)	Lane Position	CH_2 (ksi)	CH_4 (ksi)	CH_5 (ksi)	CH_6 (ksi)	CH_7 (ksi)	CH_8 (ksi)	CH_9 (ksi)	CH_10 (ksi)	CH_11 (ksi)	CH_12 (ksi)	CH_13 (ksi)	CH_14 (ksi)	CH_15 (ksi)	CH_17 (ksi)	CH_18 (ksi)	CH_19 (ksi)	CH_20 (ksi)	CH_21 (ksi)	CH_22 (ksi)	CH_23 (ksi)	CH_29 (ksi)	CH_30 (ksi)	CH_31 (ksi)	CH_32 (ksi)
Truck	5	Fog	0.42	0.25	0.09	2.75	3.35	1.23	0.71	0.62	1.26	0.22	0.29	1.71	0.60	2.93	3.29	2.23	0.24	0.59	0.41	0.17	3.75	4.37	0.25	1.14
Truck	5	Truck	0.07	0.20	0.09	1.49	3.81	0.71	0.44	0.49	1.42	0.35	0.13	1.38	0.42	1.88	1.36	1.20	0.17	0.46	0.68	0.17	2.08	2.32	0.21	1.48
Truck	5	Passing	1.14	0.72	0.41	0.50	0.90	0.44	1.82	1.27	1.78	1.39	1.09	0.20	0.37	0.37	0.85	0.38	0.94	1.31	0.97	0.35	0.48	0.33	0.07	0.46
Truck and Trailer	5	Fog	0.47	0.25	0.10	3.30	4.40	1.25	0.70	0.71	1.74	0.30	0.30	2.70	0.69	3.42	3.16	2.28	0.23	0.68	0.65	0.26	4.07	4.18	0.35	1.76
Truck and Trailer	5	Truck	0.36	0.20	0.10	1.60	4.17	0.90	0.49	0.58	2.18	0.44	0.19	1.81	0.39	2.39	1.60	1.45	0.19	0.59	0.94	0.17	2.51	2.96	0.24	1.76
Truck and Trailer	5	Passing	1.28	0.78	0.37	0.37	0.99	0.14	2.00	1.41	2.70	1.42	0.99	0.34	0.19	0.25	0.79	0.26	0.95	1.77	1.43	0.37	0.57	0.43	0.09	0.53
Truck	55	Truck	0.33	0.21	0.09	1.42	3.80	0.79	0.41	0.53	1.40	0.36	0.15	1.46	0.66	1.89	1.44	1.18	0.25	0.57	0.67	0.13	2.03	2.22	0.15	1.41
Truck	64	Truck	0.49	0.36	0.17	1.67	3.61	0.82	0.60	0.59	1.98	0.50	0.19	1.46	0.65	2.25	1.76	1.22	0.28	0.67	0.90	0.22	1.90	2.35	0.16	1.66
Truck	55	Passing	1.16	0.68	0.35	0.52	1.03	0.38	1.70	1.12	2.01	1.26	1.00	0.28	0.31	0.42	0.74	0.31	0.74	1.23	0.98	0.29	0.56	0.43	0.06	0.52
Truck	60	Passing	1.04	0.65	0.45	0.51	1.08	0.47	1.66	1.02	1.86	1.08	1.02	0.34	0.59	0.74	0.79	0.49	0.74	1.14	0.99	0.30	0.56	0.43	0.09	0.57
Truck and Trailer	54	Truck	0.37	0.35	0.09	2.05	4.32	0.91	0.63	0.64	2.51	0.44	0.24	1.66	0.45	2.19	1.91	1.77	0.36	0.77	1.09	0.15	2.49	3.01	0.18	1.75
Truck and Trailer	55	Passing	1.79	0.78	0.36	0.54	0.98	0.48	2.16	1.77	2.67	1.26	1.08	0.32	0.32	0.33	1.06	0.35	1.18	2.30	1.49	0.47	0.81	0.57	0.11	0.62

2.2 JASPER BRIDGE, OVER MIDDLE FORK OF WILLAMETTE RIVER (BRIDGE NUMBER 04117A)

The Jasper Bridge is located near Jasper, Oregon and crosses the middle fork of the Willamette River on Highway 222. The bridge consists of 9 spans (Figures 2.16a-c): a single span reinforced concrete deck girder northeast approach span, two steel truss main spans, and six reinforced concrete deck girder southwest approach spans. The bridge was designed in 1950.

2.2.1 Description of Tested Spans

The southwest approach spans, shown in Figure 2.17, were selected as test spans because of their ease of accessibility from the ground. The approach span lengths from the southeast are as follows: 48 ft, 60 ft, and 48 ft, with simple supports at Pier 3 and Bents 4 and 7, forming two 3-span continuous sections. The spans have a roadway width of 26 ft, and a total width of 29 ft-9 in.

Four girders support the 6.5 in. thick reinforced concrete deck, with diaphragms 10 in. x 41 in. located at the quarter points of each span. The girder widths are constant at 13.5 in. but the overall girder height varies from 42 in. at midspan to 63 in. at the continuous support locations. Bent caps are 16 in. x 68 in. and supported by 24 in. square columns. The specified concrete compression strength was 3300 psi and the reinforcing steel consisted of intermediate grade (nominally 40 ksi yield stress) deformed square bars.

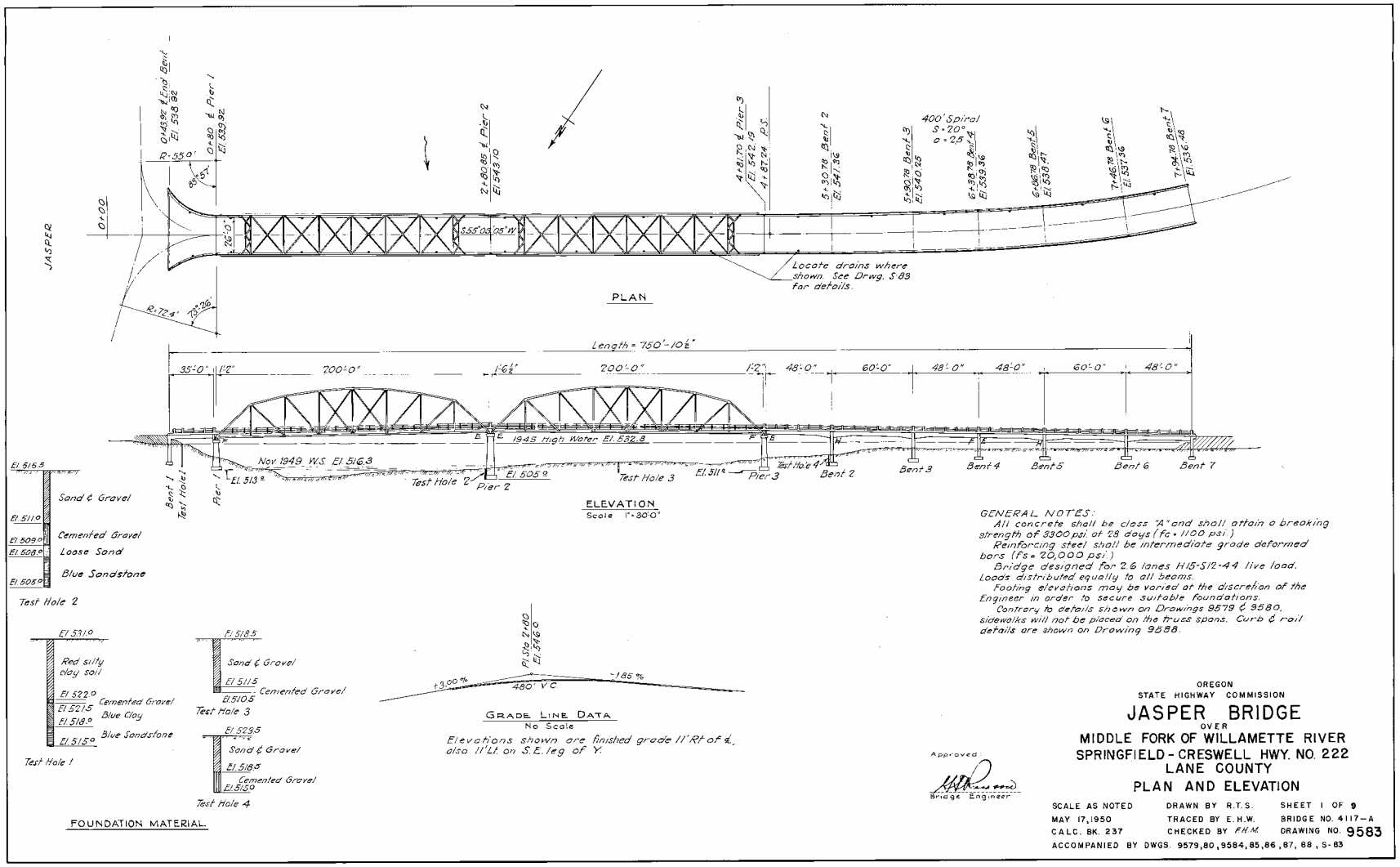

Figure 2.16a: Design drawings for Jasper Bridge

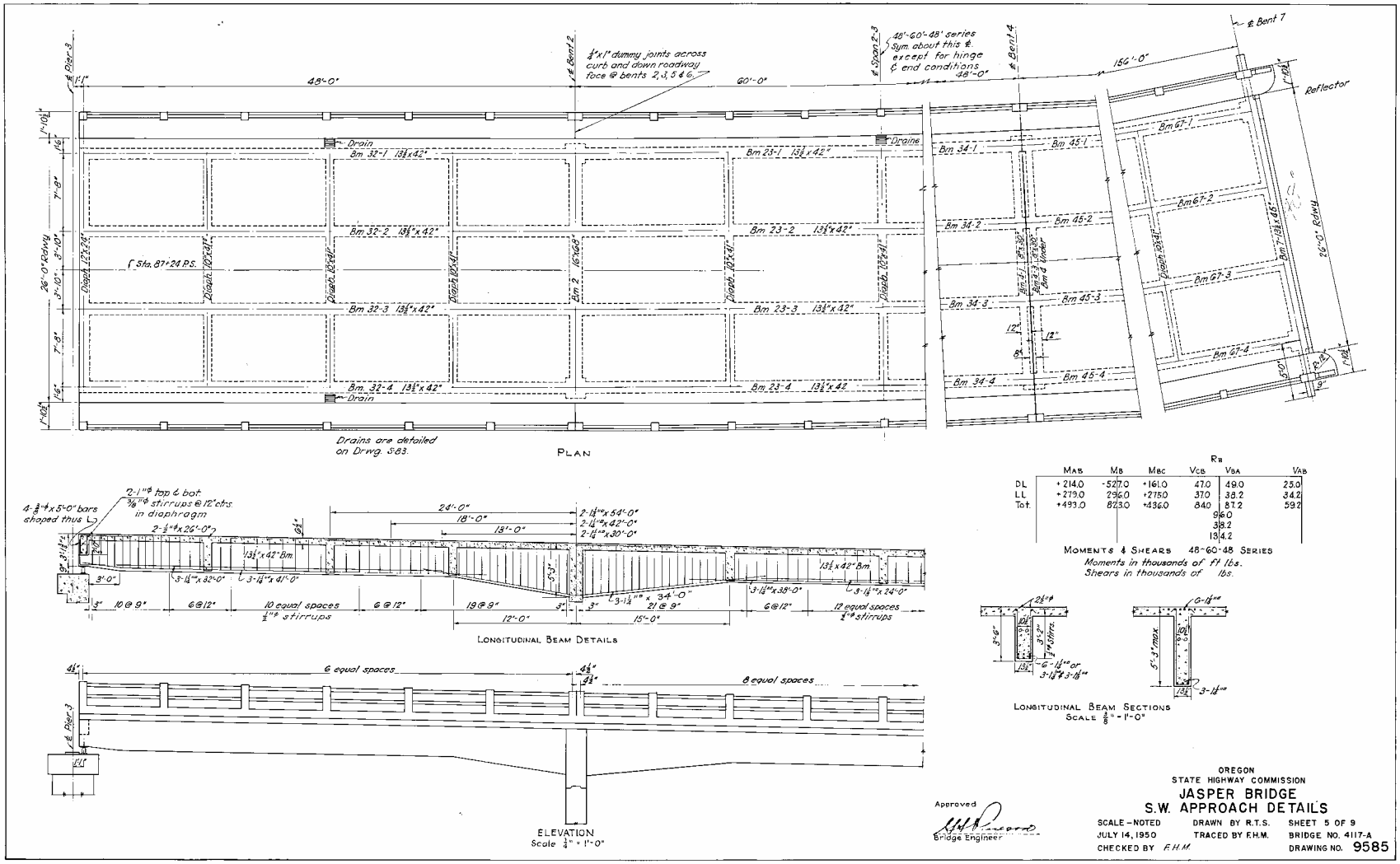

Figure 2.16b: Design drawings for Jasper Bridge

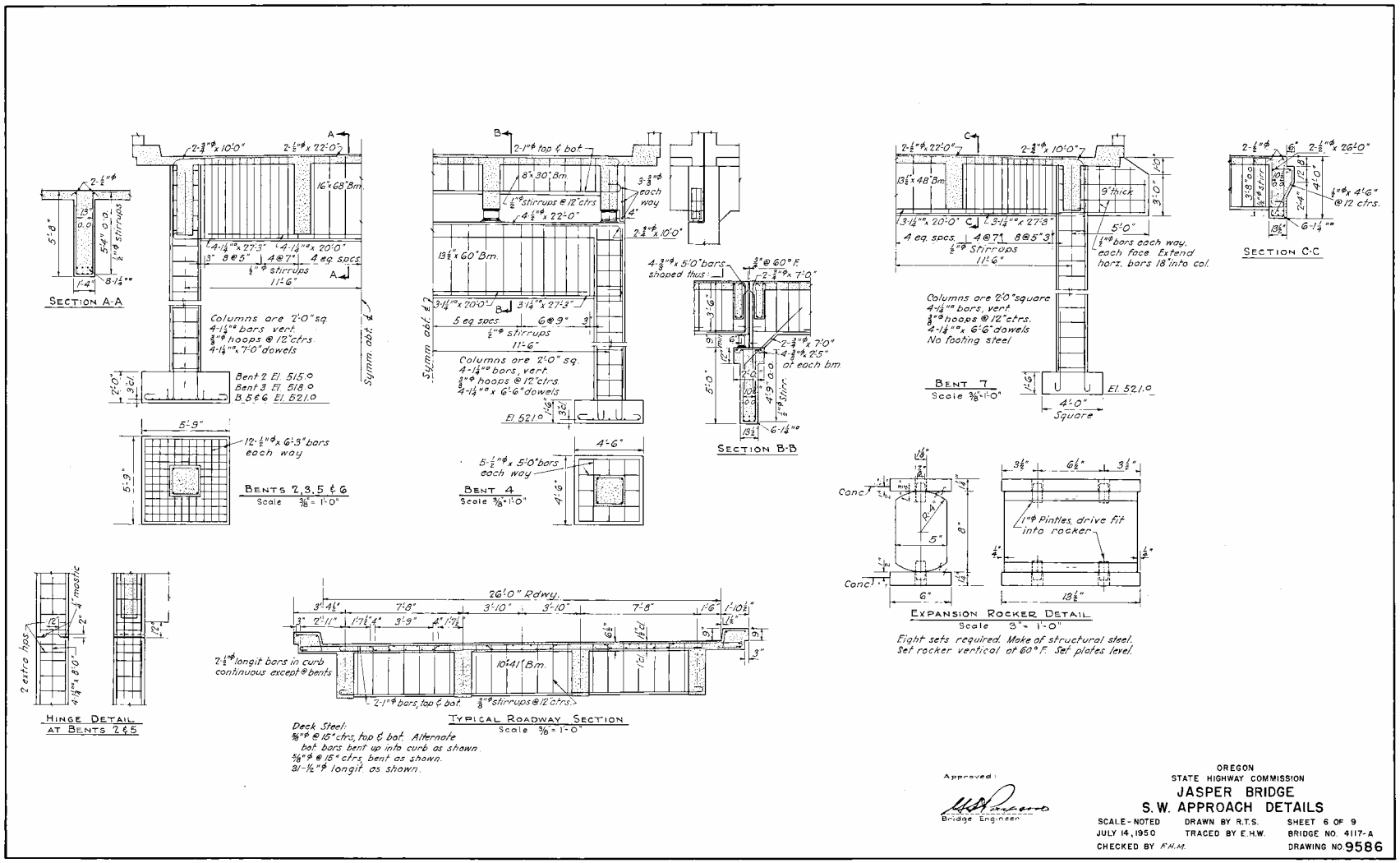

Figure 2.16c: Design drawings for Jasper Bridge

Figure 2.17: Portion of Jasper Bridge selected for field investigation

2.2.2 Crack Mapping and Instrumentation

The crack mapping and instrumentation techniques corresponded closely with those for the McKenzie Bridge as described above. Diagonal-tension crack patterns for the girders and bent caps are shown in Figures 2.18a-g. Twenty-seven (27) locations were selected for instrumentation. At four of these locations, strain gages were installed on opposite stirrup legs crossing a diagonal crack to compare the stirrup stress at the interior and exterior face of the girder.

Two locations were identified where multiple stirrups cross a diagonal crack. At these locations, two stirrups were instrumented to measure the profile of stirrup stresses along the length of the crack. Single stirrup legs were instrumented at the other eighteen locations. Position sensors were installed at four locations to assess crack displacements. Instrumentation locations and channel numbers are identified schematically in Figure 2.19.

Data were again collected using a Campbell Scientific CR9000 data acquisition system. During the ambient monitoring period, data were sampled at 100 Hz. A digital high-pass filter was utilized with a cut-off frequency of 40 Hz. A digital camera was triggered by response events to identify sources of larger stirrup stress cycles. The data acquisition system converted sensor readings into corresponding stresses and displacements, and stored the data for later retrieval and analysis.

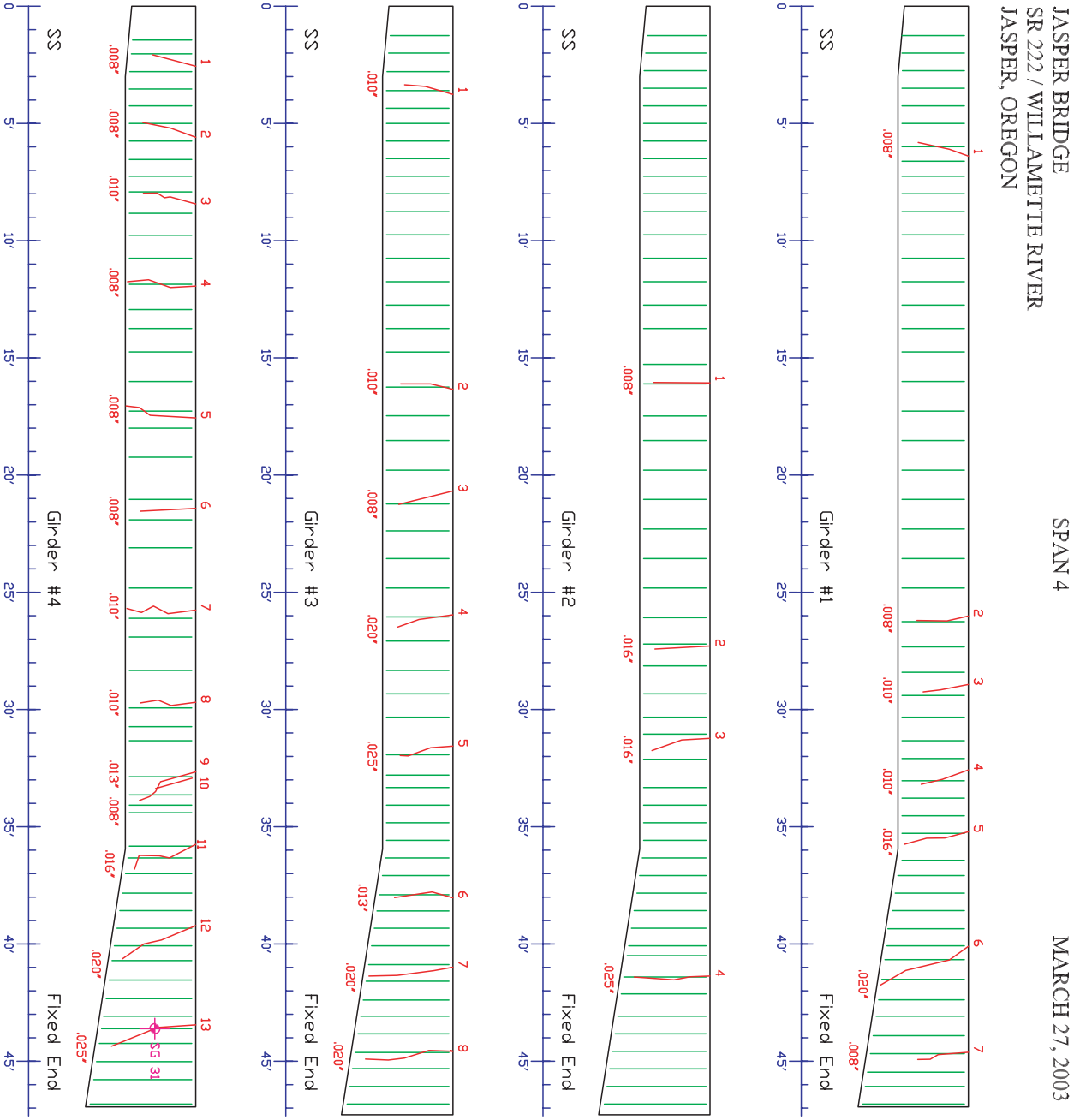

Figure 2.18a: Jasper Bridge crack and instrument locations on span 4

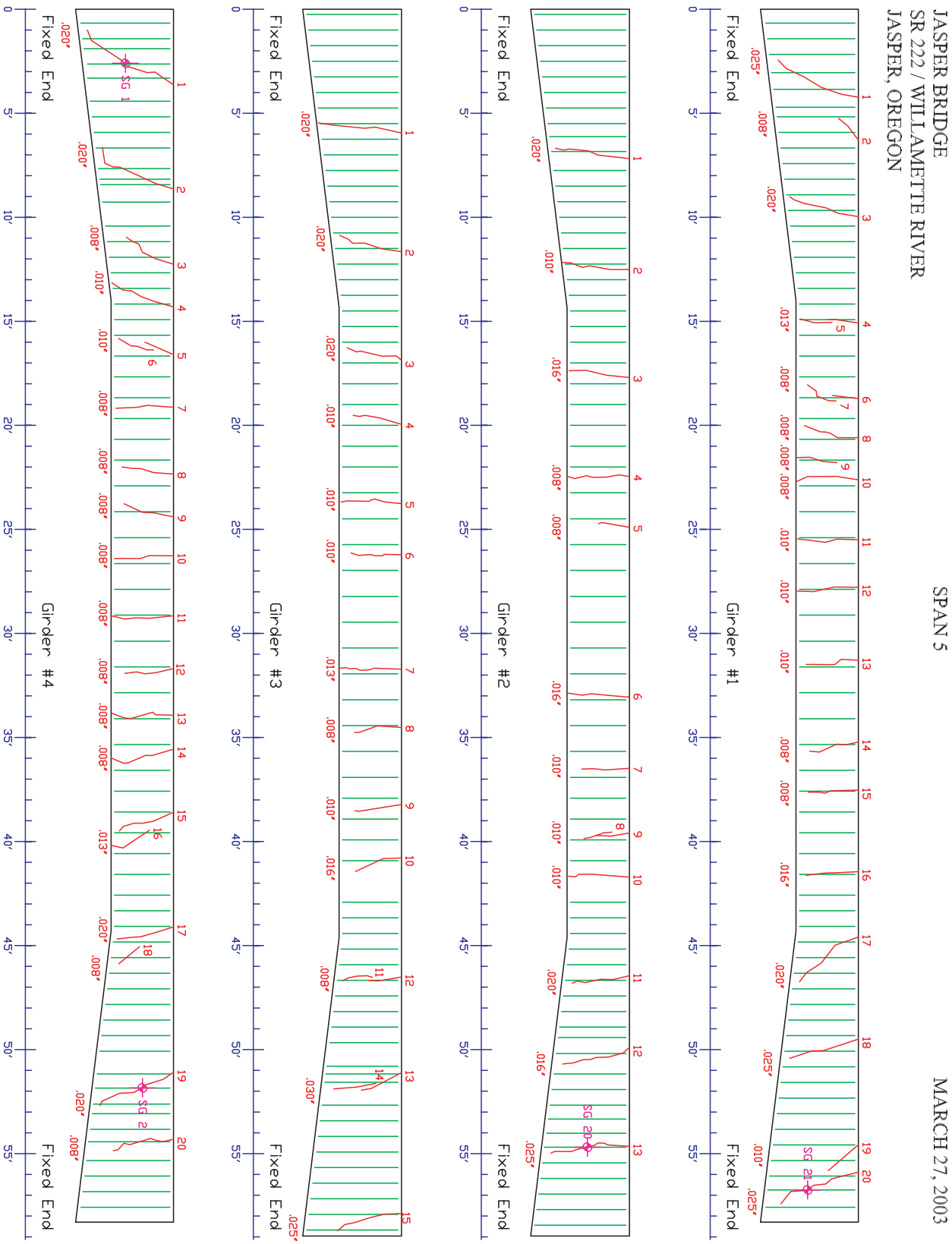

Figure 2.18b: Jasper Bridge crack and instrument locations on span 5

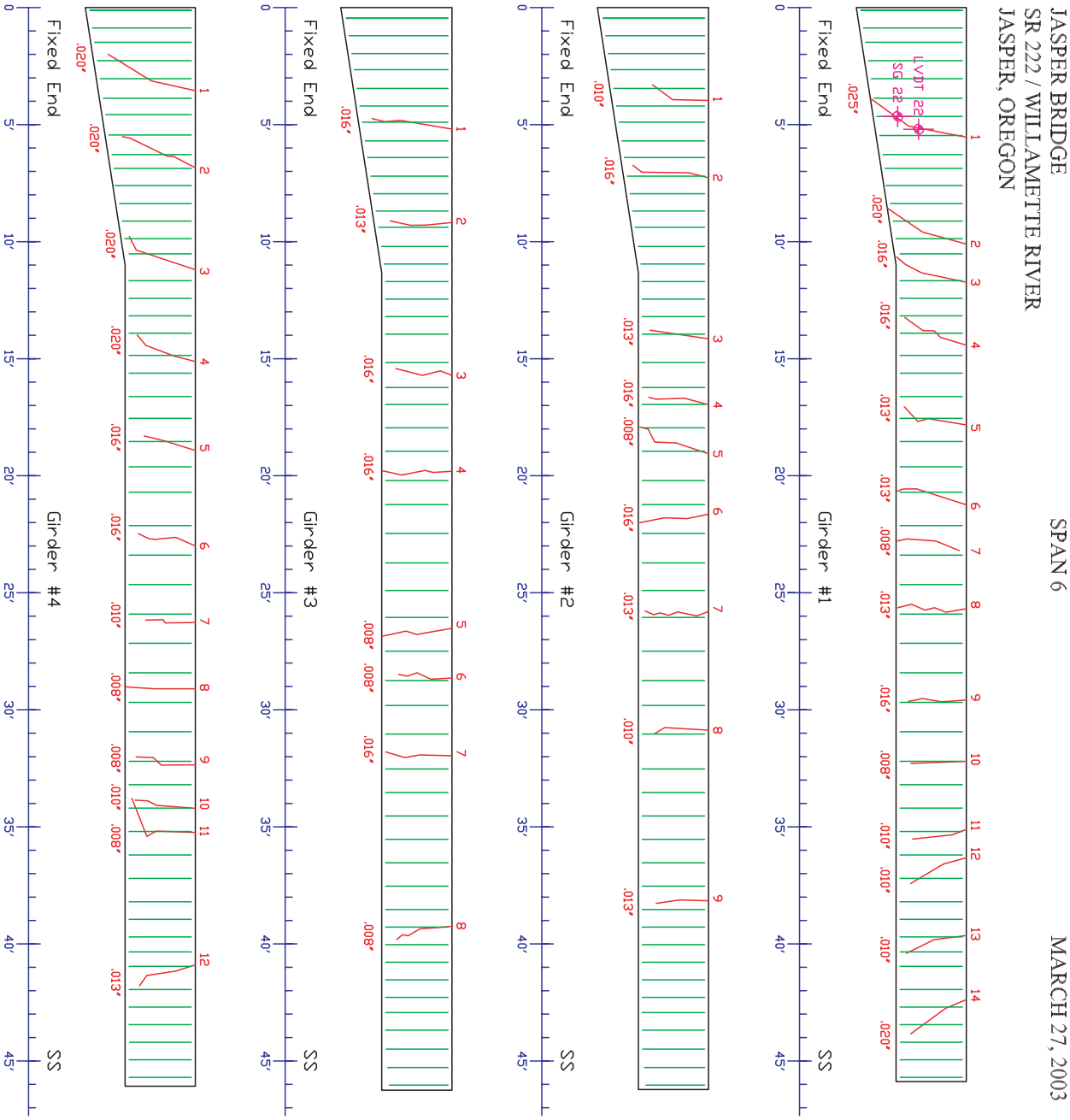

Figure 2.18c: Jasper Bridge crack and instrument locations on span 6

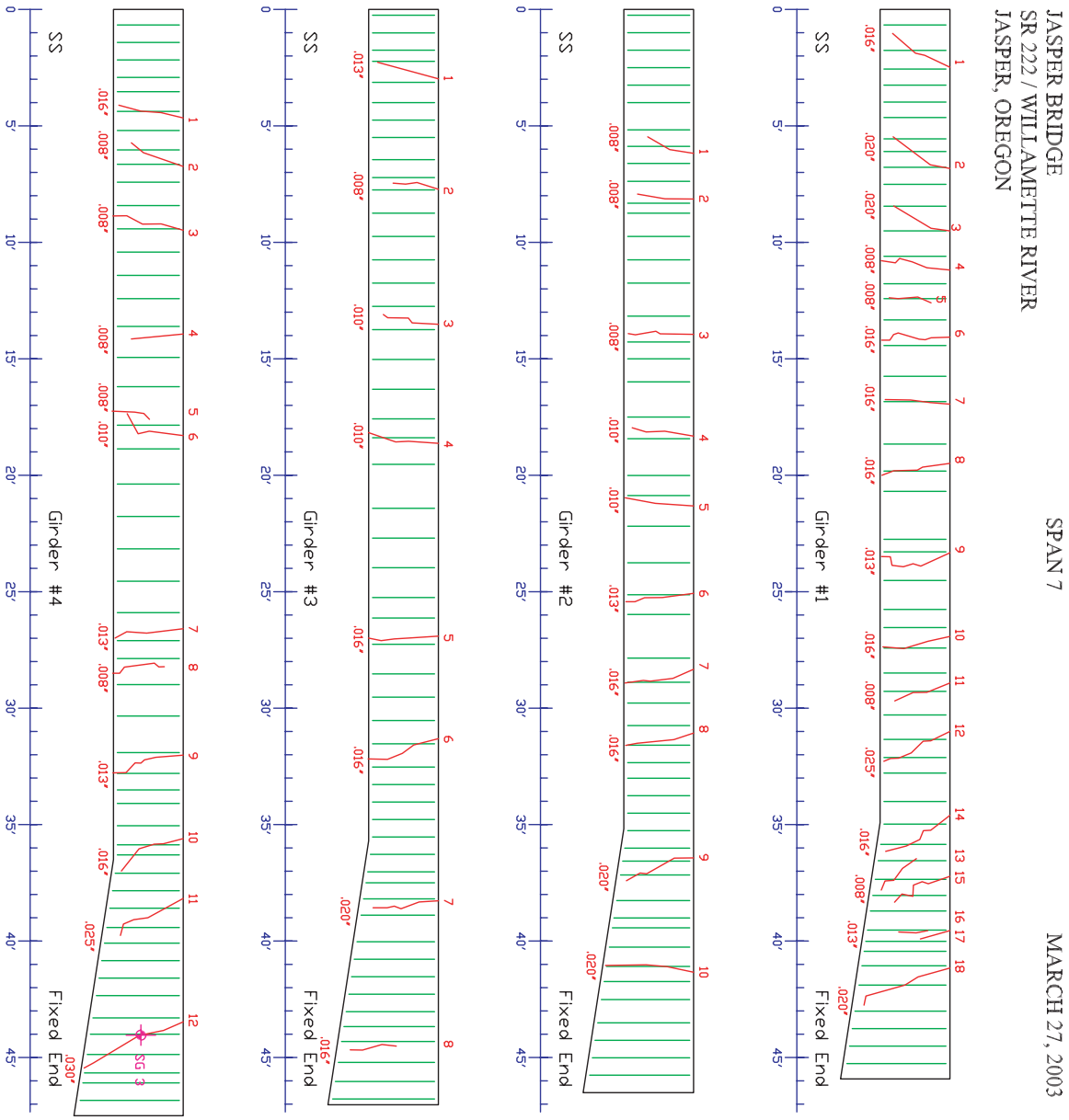

Figure 2.18d: Jasper Bridge crack and instrument locations on span 7

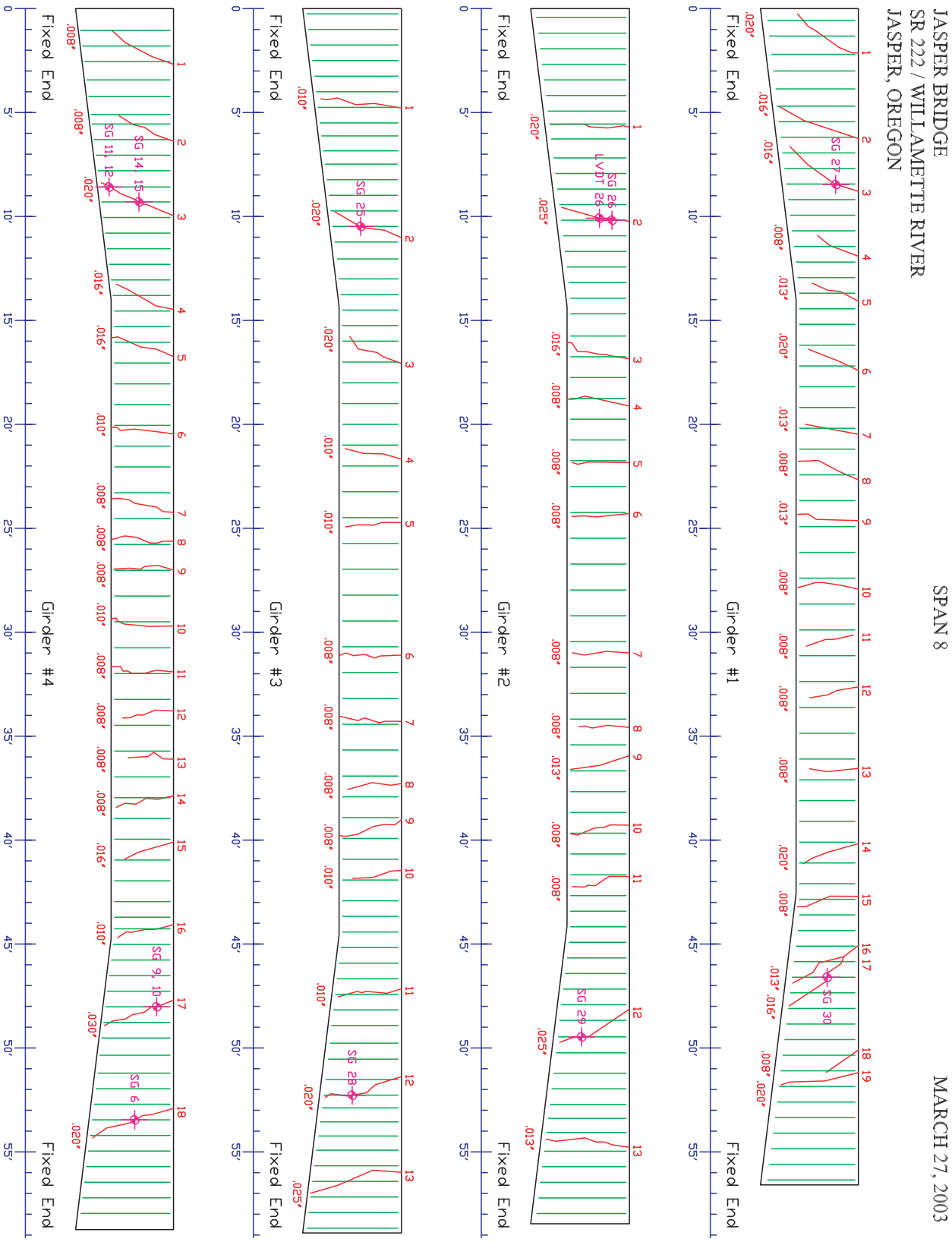

Figure 2.18e - Jasper Bridge crack and instrument locations on span 8

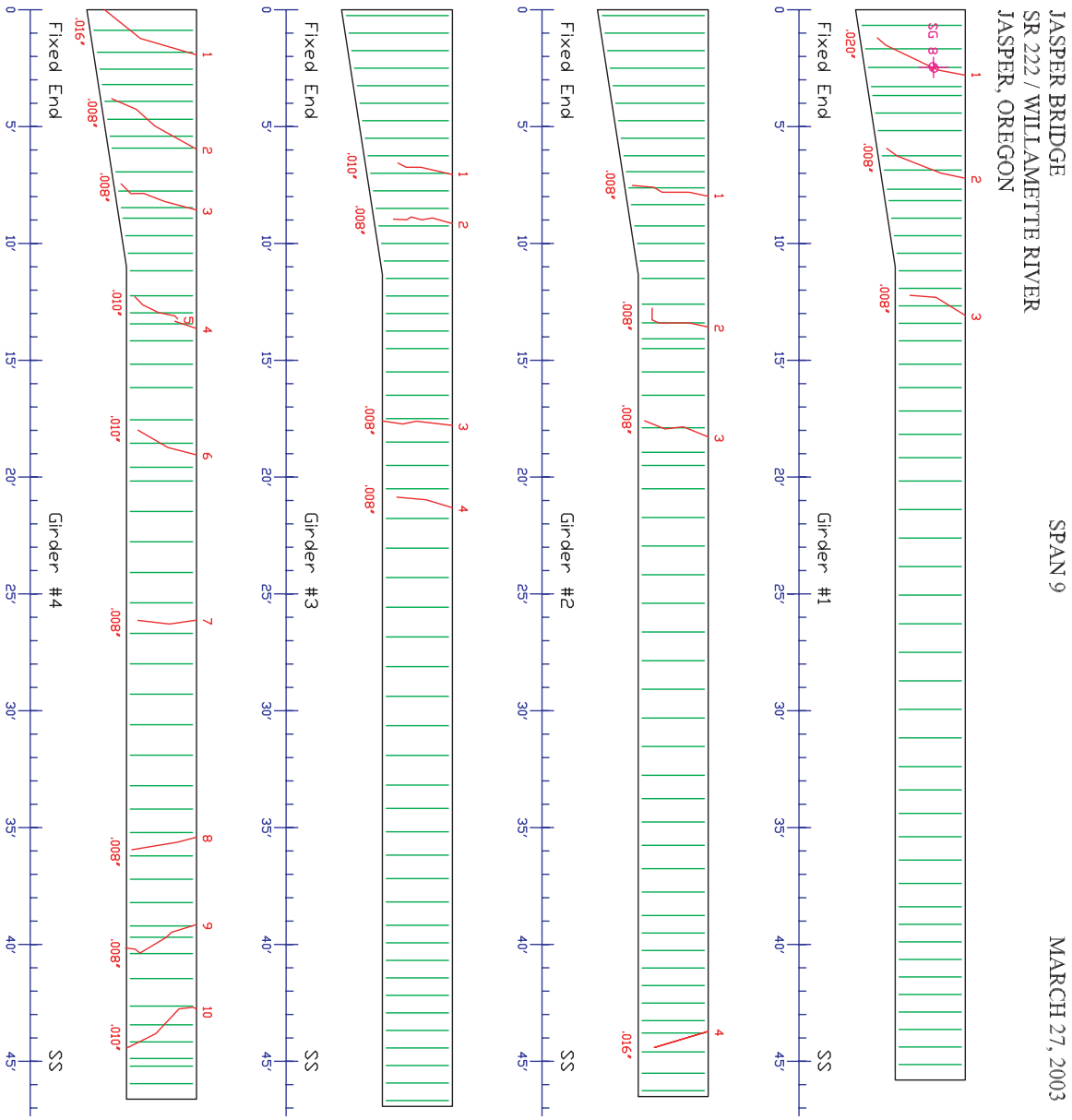

Figure 2.18f: Jasper Bridge crack and instrument locations on span 9

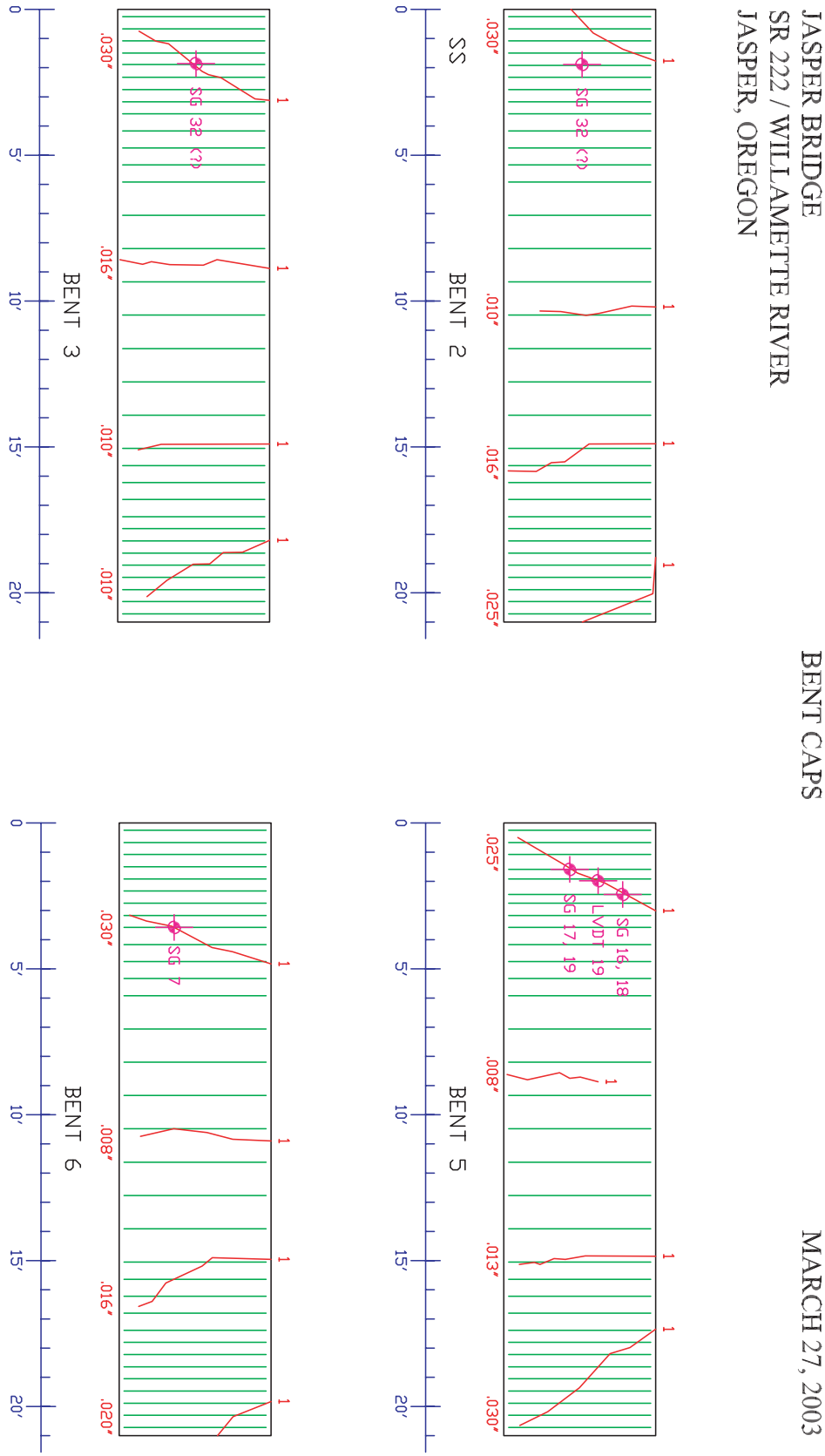

Figure 2.18g: Jasper Bridge crack and instrument locations on bent caps

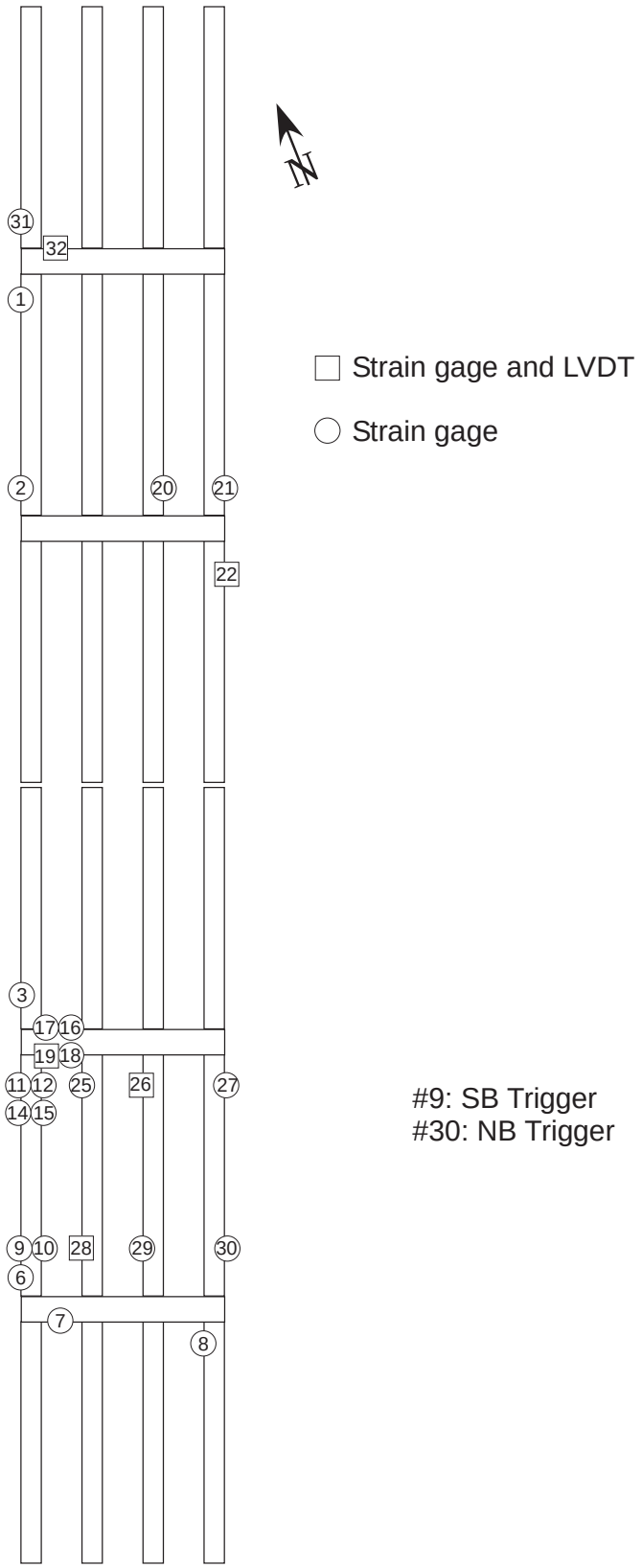

Figure 2.19: Schematic of sensor locations on Jasper Bridge

2.2.3 Testing Method

Three types of live load data were collected: response under ambient traffic loading, response under controlled truck loading, and response under commercial truck loads determined from a temporary vehicle weigh-station. The shear stirrup stresses and crack displacements generated by ambient traffic were recorded over a period of 11 days, in April 2003. The system also recorded individual event histories when stress thresholds exceeded 2.0 ksi at sensor location CH_9 (northbound) or 1.5 ksi at sensor location CH_30 (southbound).

For each northbound trigger event, data were recorded for eight seconds prior to and two seconds following the trigger. The pre and post trigger times were interchanged for the southbound trigger events. During these events, a video image of the corresponding vehicle was produced. Based on the video images taken during daylight hours, the observed vehicle configurations were categorized and are summarized in Figure 2.20. The type of cargo being transported by the observed vehicles is summarized in Figure 2.21. The most commonly observed axle configuration was 3-2 and the most frequently observed cargo type was forest products.

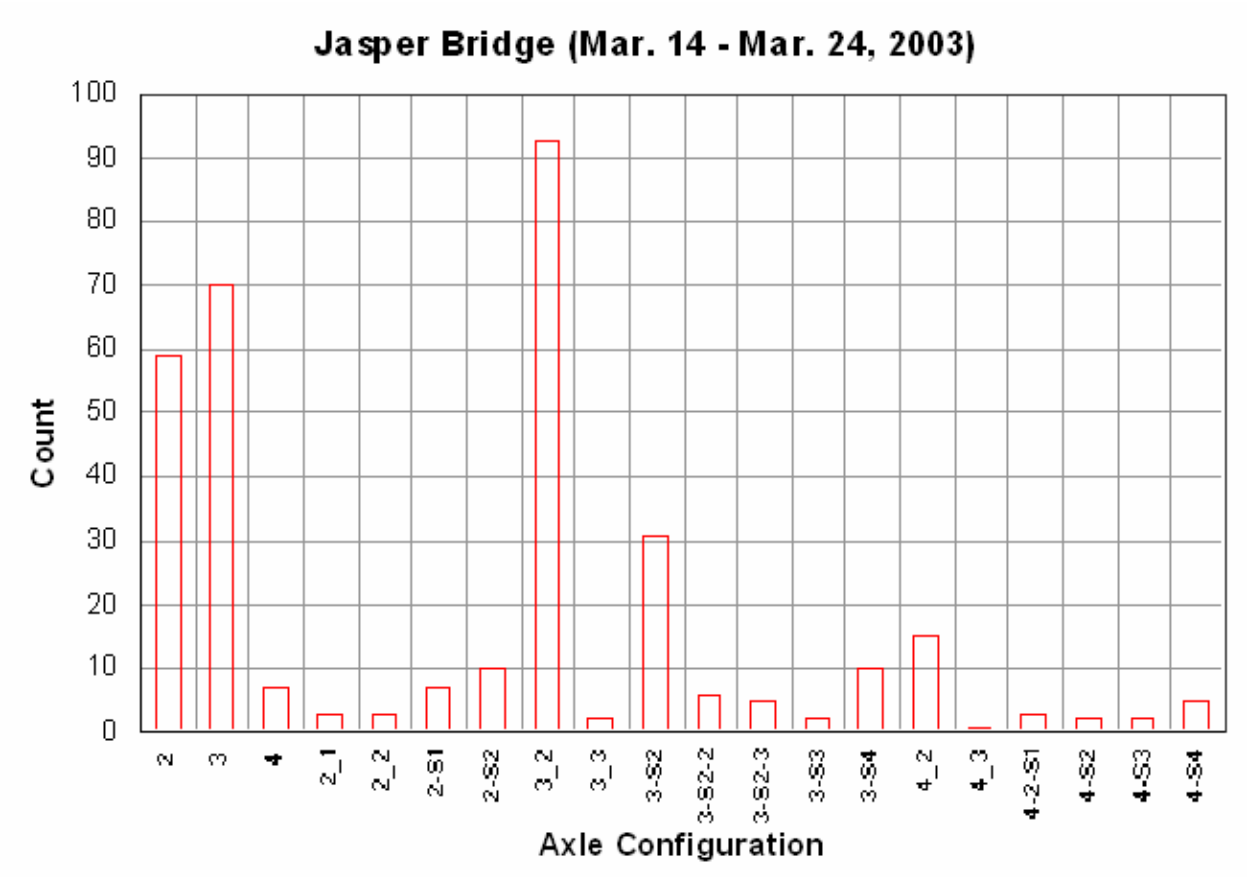

Figure 2.20: Classification of vehicle configuration based on video data from Jasper Bridge

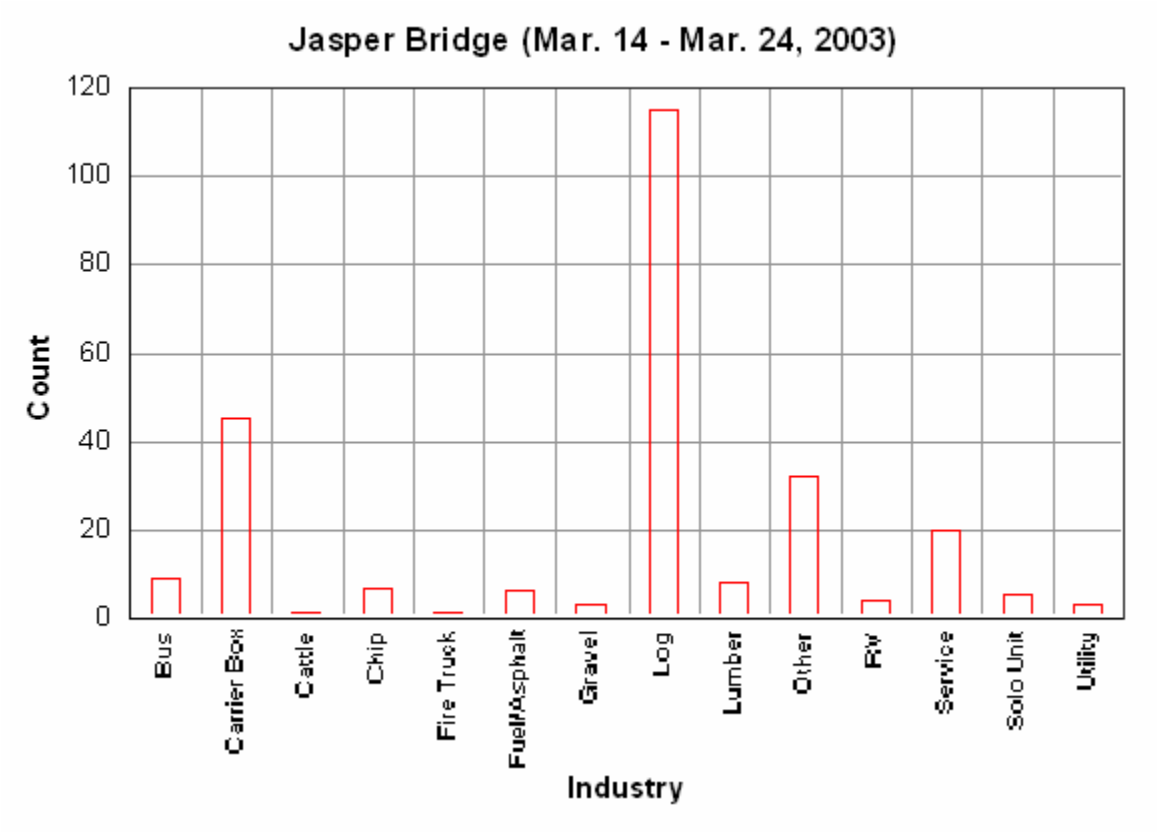

Figure 2.21: Classification of cargo type based on video data from Jasper Bridge

Controlled truck tests were conducted using a heavily loaded ODOT maintenance truck as shown in Figure 2.22a. The axle weights and spacing were determined before the test and are shown in Figure 2.22b. Traffic was temporarily stopped so that the control truck would be the only vehicle on the structure during data collection. The control truck passed over the bridge at several designated speeds and lane positions.

Figure 2.22a: Test truck used on Jasper Bridge

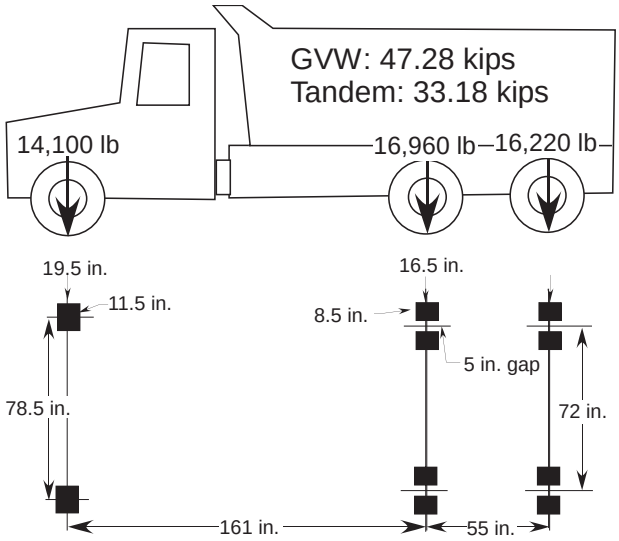

Figure 2.22b: Truck axle spacing and weights for tests on Jasper Bridge

Truck locations relative to girder positions are shown in Figure 2.23. Stirrup stresses for each of the test runs are shown in Figures 2.24a-j. and crack motions are shown in Figures 2.25 a-b. Test data are summarized in Tables 2.2a-b.

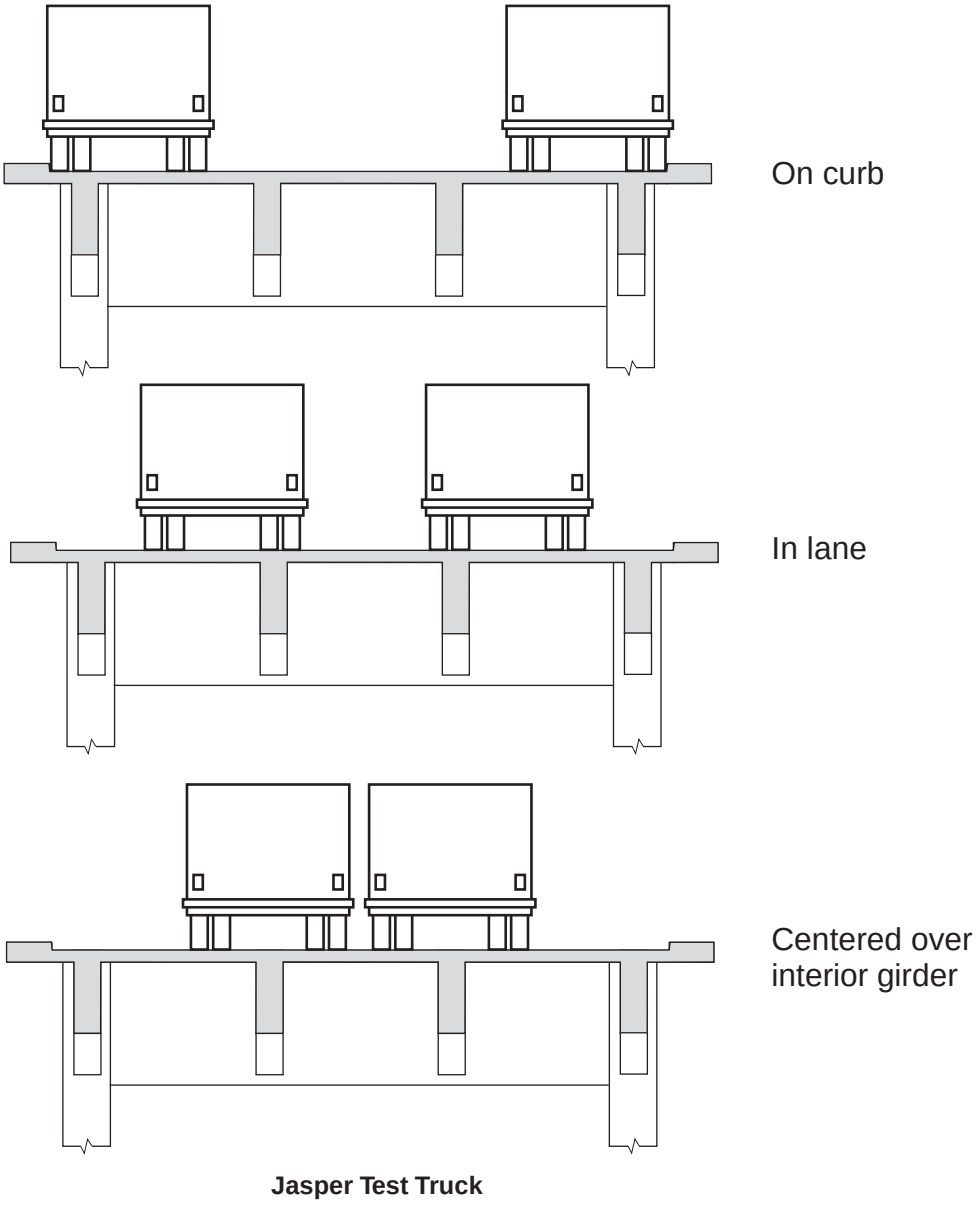

Figure 2.23: Truck position relative to girders for tests on Jasper Bridge

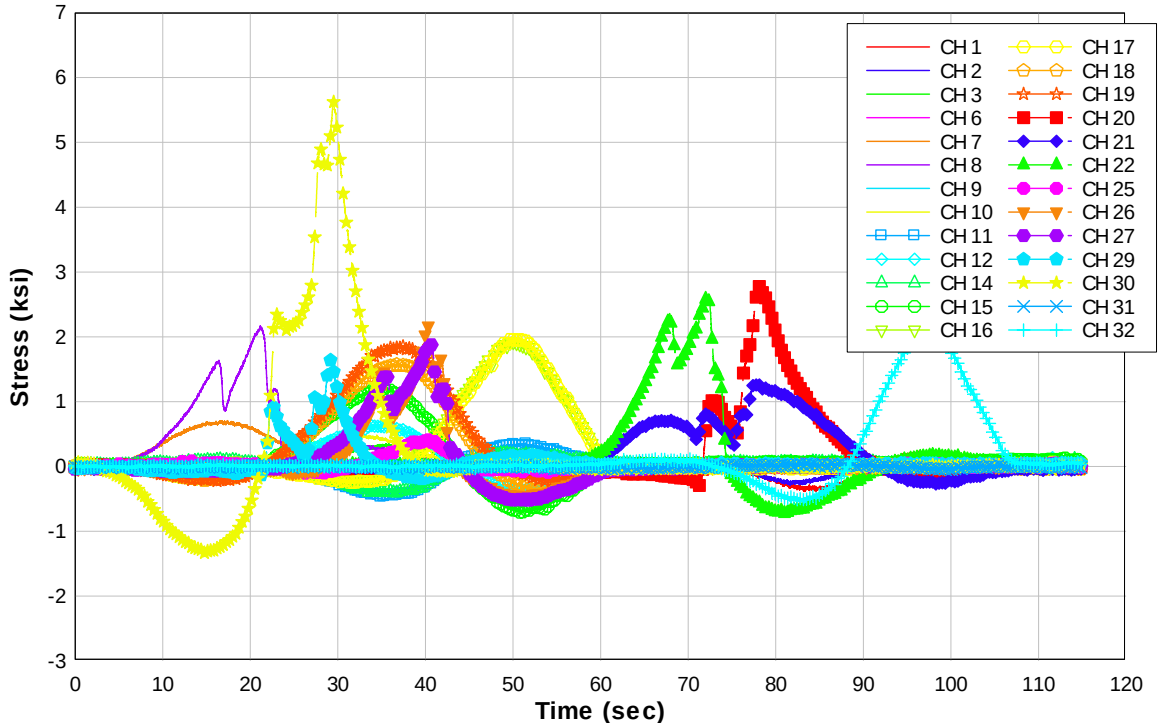

Figure 2.24a: Stirrup stress response for test truck heading northbound on curb at 3 mph

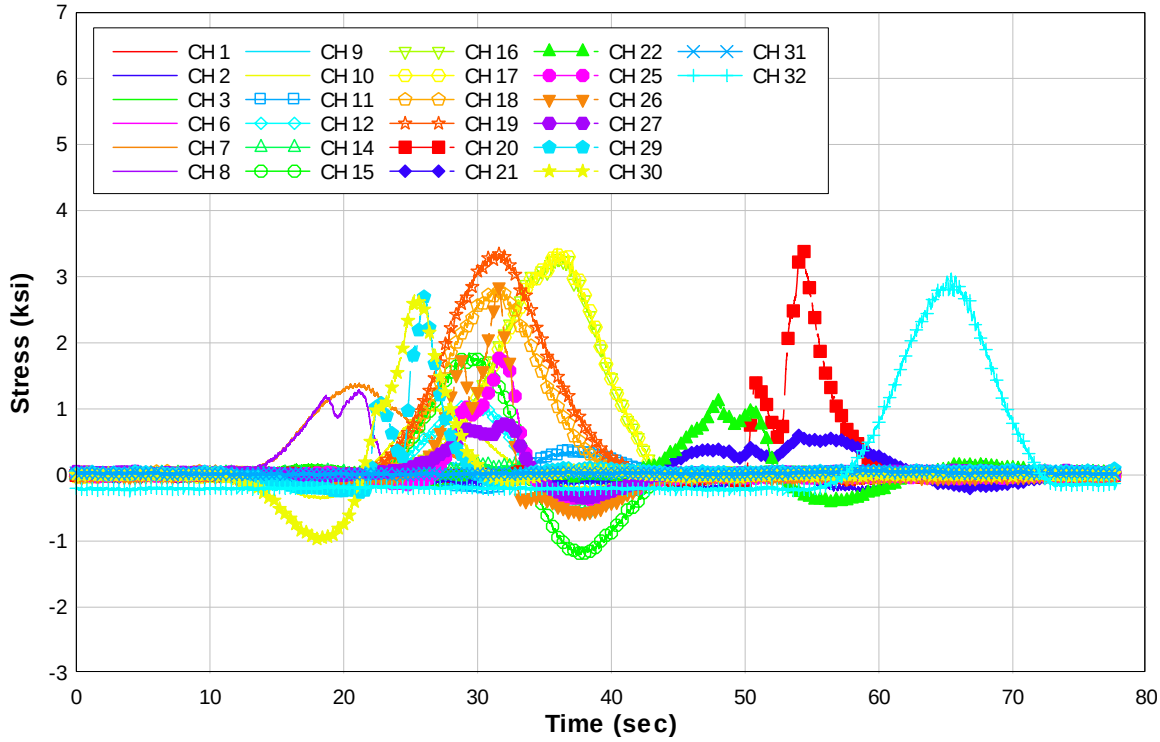

Figure 2.24b: Stirrup stress response for test truck heading northbound centered over first interior girder at 3 mph

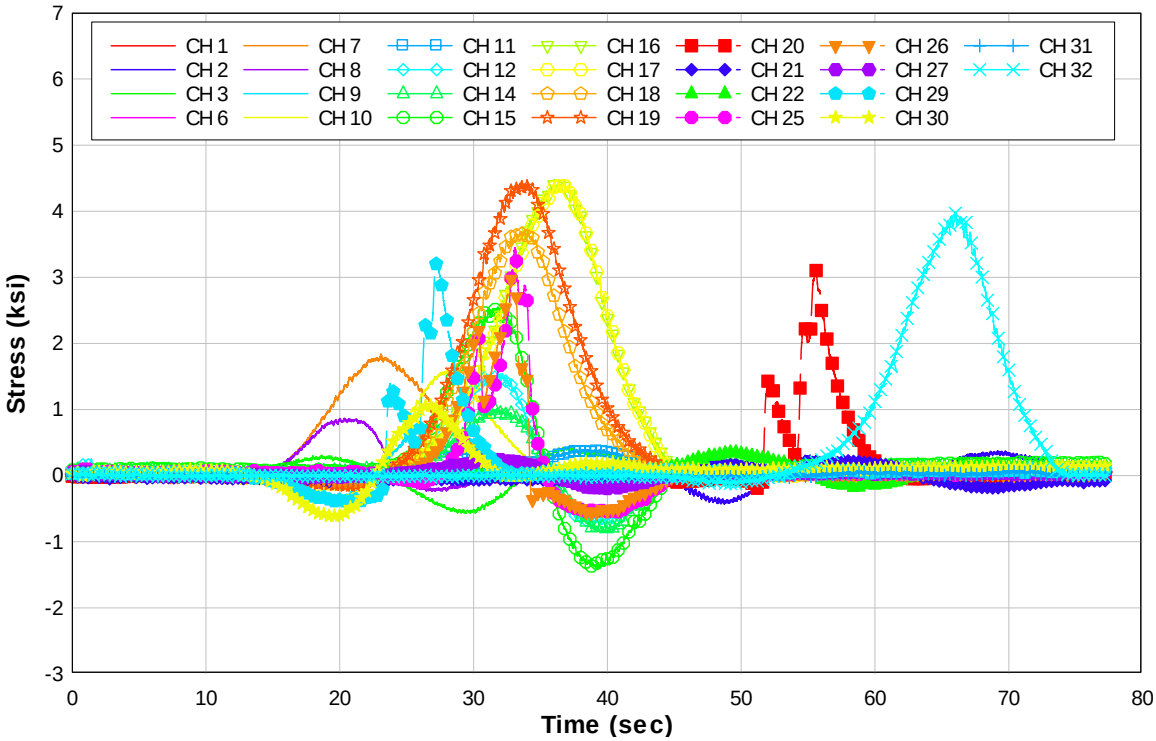

Figure 2.24c: Stirrup stress response for test truck heading northbound centered over second interior girder at 3 mph

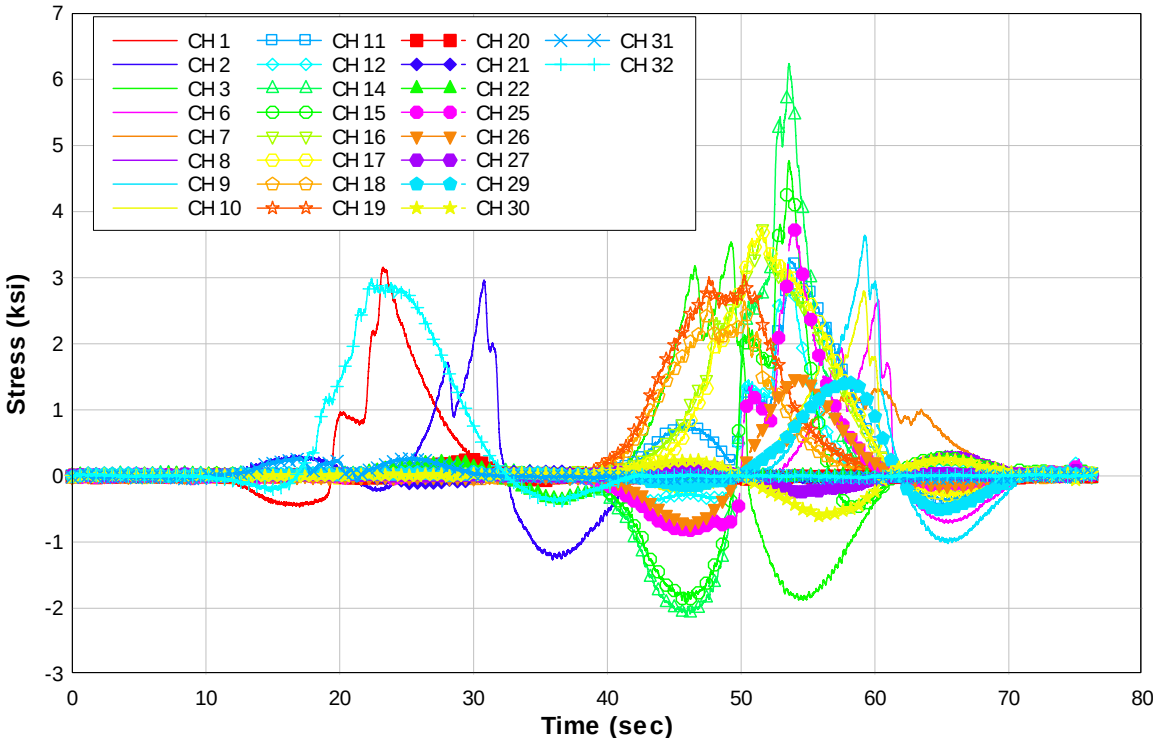

Figure 2.24d: Stirrup stress response for test truck heading southbound on curb at 3 mph

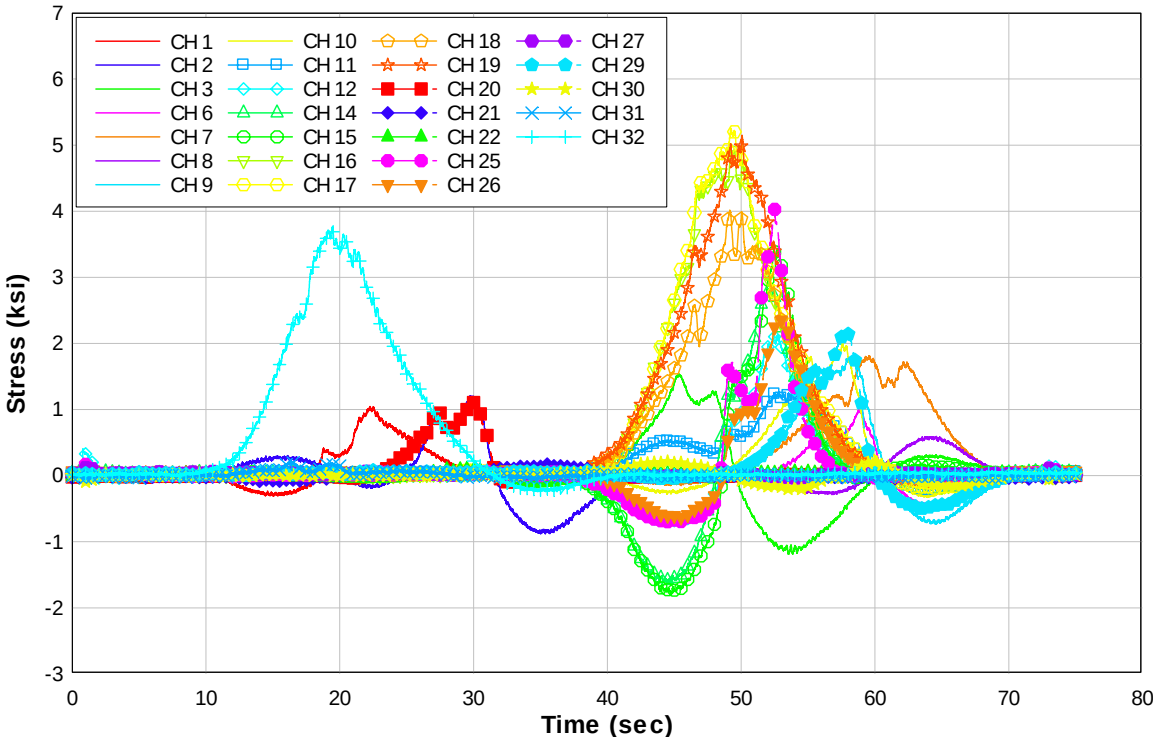

Figure 2.24e: Stirrup stress response for test truck heading southbound centered over first interior girder at 3 mph

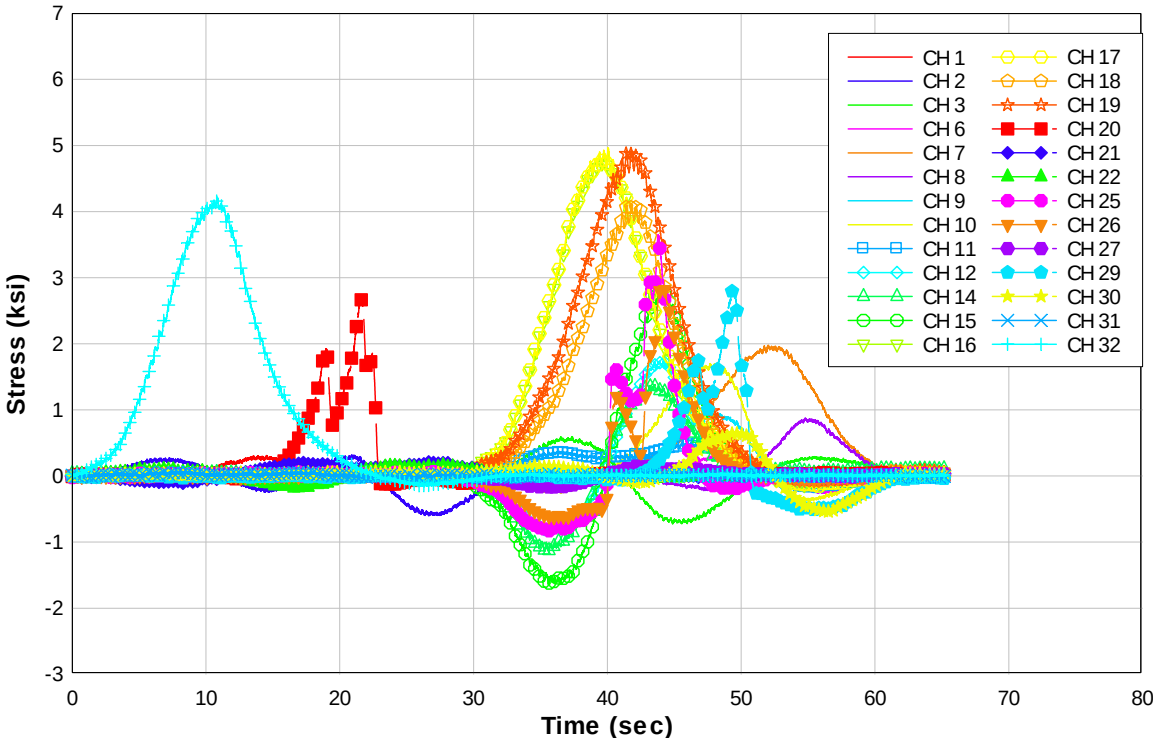

Figure 2.24f: Stirrup stress response for test truck heading southbound centered over second interior girder at 3 mph

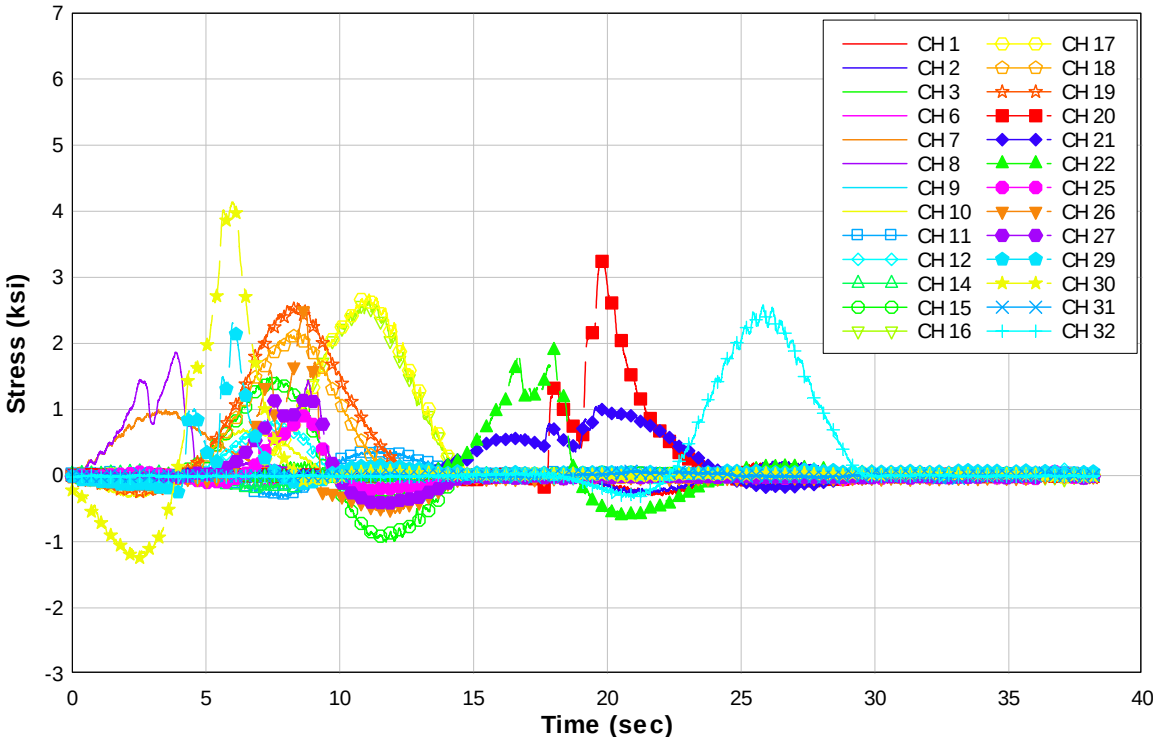

Figure 2.24g: Stirrup stress response for test truck in northbound lane at 5 mph

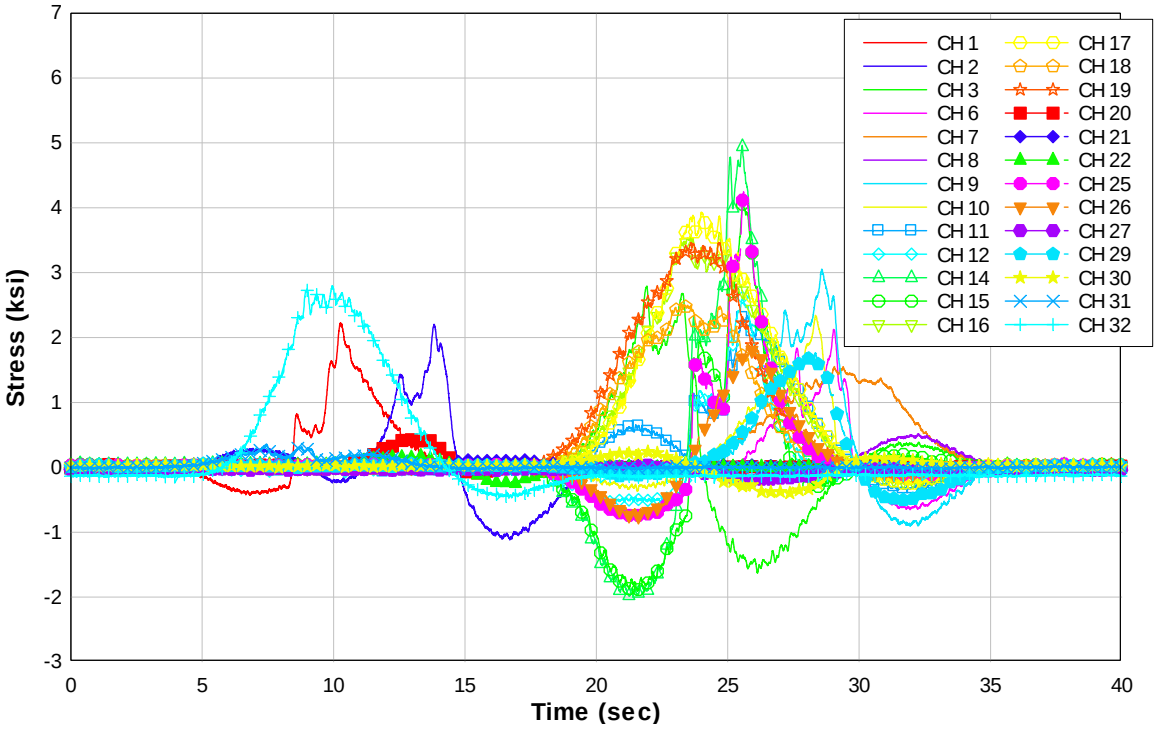

Figure 2.24h: Stirrup stress response for test truck in southbound lane at 5 mph

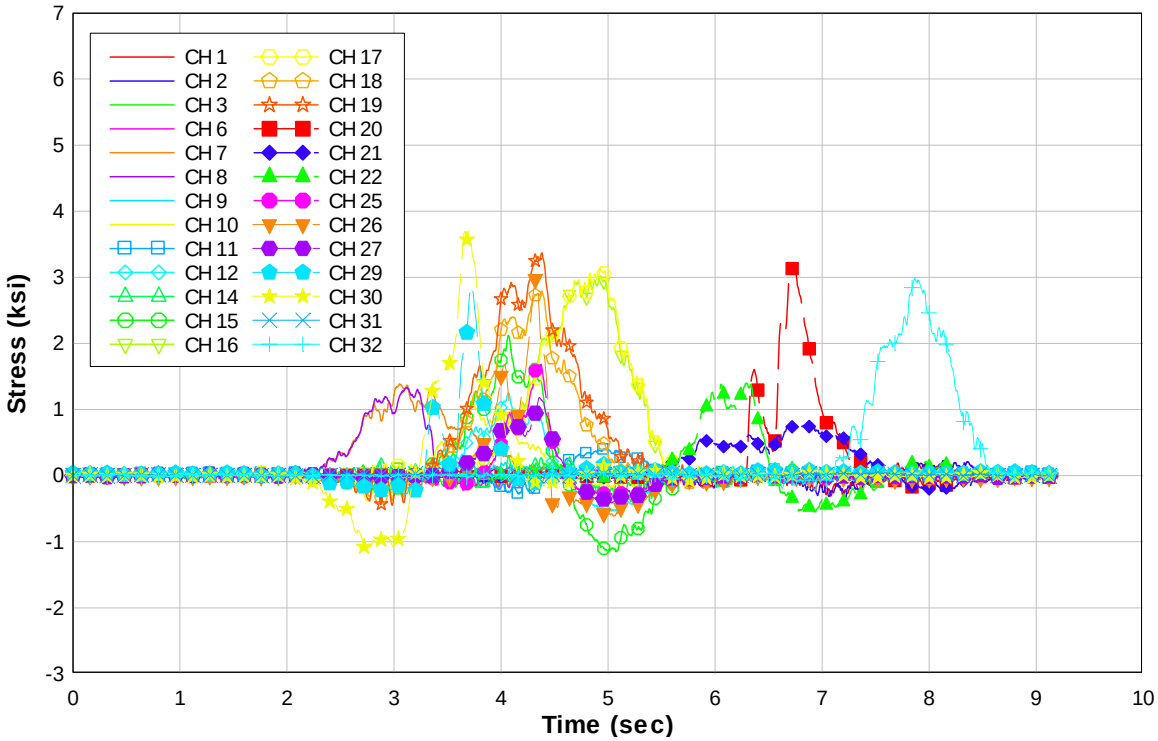

Figure 2.24i: Stirrup stress response for test truck in northbound lane at 34 mph

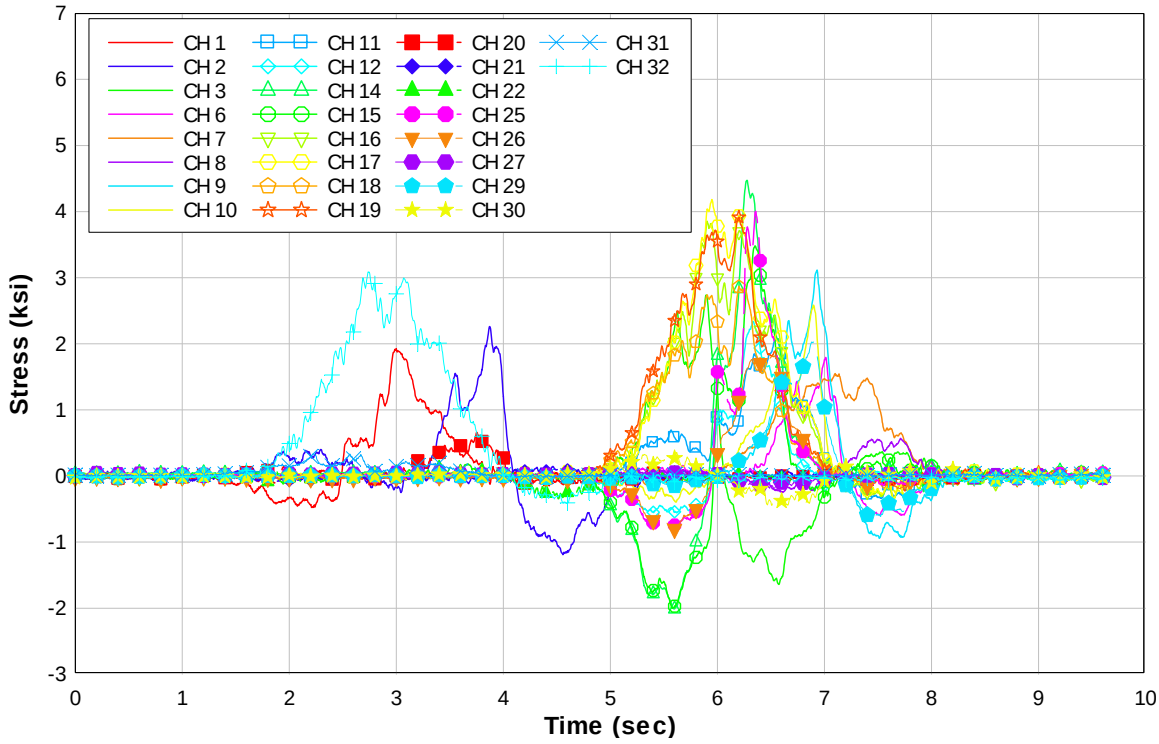

Figure 2.24j: Stirrup stress response for test truck in southbound lane at 32 mph

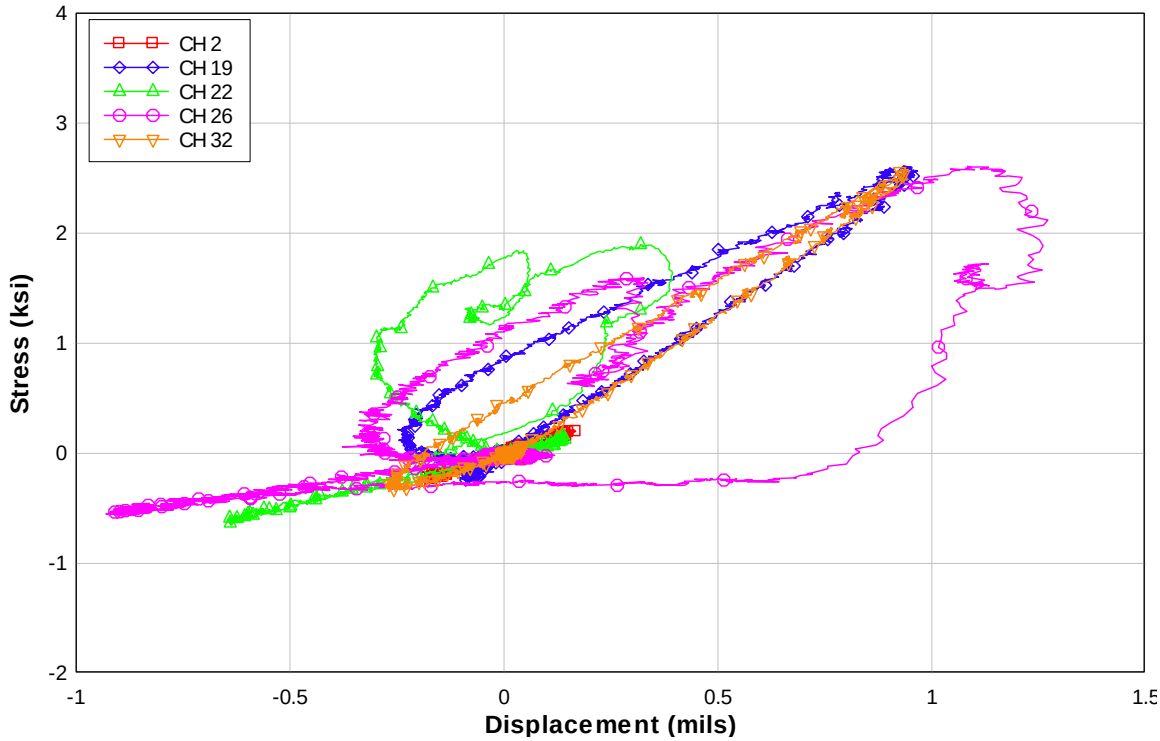

Figure 2.25a: Crack displacement-Stirrup stress response for test truck in northbound lane at 5 mph

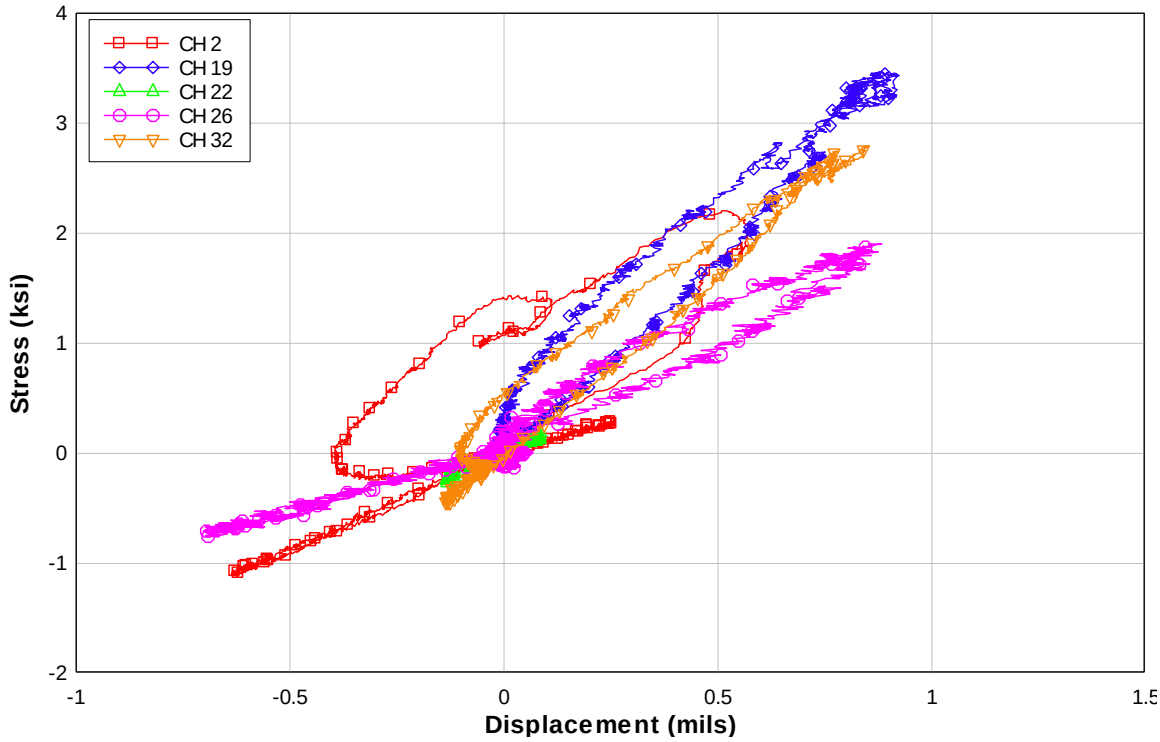

Figure 2.25b: Crack displacement-Stirrup stress response for test truck in northbound lane at 5 mph

Table 2.2a: Stresses at instrumented locations for slow speed tests of ODOT truck moving over Jasper Bridge

Maximum Stress

Truck Location	CH 1 (ksi)	CH 2 (ksi)	CH 3 (ksi)	CH 6 (ksi)	CH 7 (ksi)	CH 8 (ksi)	CH 9 (ksi)	CH 10 (ksi)	CH 11 (ksi)	CH 12 (ksi)	CH 14 (ksi)	CH 15 (ksi)	CH 16 (ksi)	CH 17 (ksi)	CH 18 (ksi)	CH 19 (ksi)	CH 20 (ksi)	CH 21 (ksi)	CH 22 (ksi)	CH 25 (ksi)	CH 26 (ksi)	CH 27 (ksi)	CH 29 (ksi)	CH 30 (ksi)	CH 31 (ksi)	CH 32 (ksi)
NB curb	0.24	0.22	0.35	0.11	0.71	2.17	0.17	0.50	0.36	0.65	0.22	1.22	1.94	1.99	1.59	1.87	2.80	1.28	2.63	0.44	2.17	1.90	1.66	5.65	0.06	2.16
NB Lane	0.20	0.22	0.23	0.15	1.00	1.87	0.10	0.71	0.38	0.83	0.13	1.49	2.64	2.75	2.20	2.61	3.24	1.06	1.90	0.98	2.61	1.45	2.32	4.14	0.08	2.58
NB Center Girder 2	0.13	0.21	0.17	0.14	1.39	1.29	0.27	1.03	0.36	1.11	0.18	1.84	3.36	3.43	2.80	3.37	3.43	0.62	1.12	1.80	2.84	0.81	2.76	2.73	0.09	3.05
NB Center Girder 3	0.18	0.38	0.43	0.26	1.84	0.87	0.76	1.59	0.40	1.54	1.02	2.55	4.46	4.45	3.70	4.43	3.12	0.24	0.39	3.45	3.02	0.26	3.24	1.08	0.08	3.98
SB Center Girder 2	0.31	0.31	0.59	0.34	1.98	0.88	0.94	1.70	0.51	1.75	1.38	2.81	4.92	4.97	4.11	4.92	2.70	0.23	0.18	3.65	2.89	0.16	2.85	0.66	0.08	4.22
SB Center Girder 3	1.05	1.21	1.54	1.00	1.81	0.59	1.80	2.01	1.25	2.14	2.83	3.44	4.93	5.26	4.01	5.15	1.14	0.17	0.11	4.08	2.42	0.16	2.26	0.23	0.22	3.76
SB Lane	2.23	2.20	2.79	2.12	1.55	0.52	3.05	2.34	2.33	2.63	4.96	4.05	3.62	3.93	2.53	3.47	0.51	0.14	0.19	4.25	1.90	0.05	1.76	0.29	0.36	2.79
SB Curb	3.16	2.96	3.54	2.66	1.33	0.38	3.64	2.80	3.29	3.24	6.24	4.77	3.78	3.72	2.70	3.04	0.29	0.10	0.23	3.75	1.49	0.15	1.48	0.28	0.28	2.99

Minimum Stresses

Truck Location	CH 1 (ksi)	CH 2 (ksi)	CH 3 (ksi)	CH 6 (ksi)	CH 7 (ksi)	CH 8 (ksi)	CH 9 (ksi)	CH 10 (ksi)	CH 11 (ksi)	CH 12 (ksi)	CH 14 (ksi)	CH 15 (ksi)	CH 16 (ksi)	CH 17 (ksi)	CH 18 (ksi)	CH 19 (ksi)	CH 20 (ksi)	CH 21 (ksi)	CH 22 (ksi)	CH 25 (ksi)	CH 26 (ksi)	CH 27 (ksi)	CH 29 (ksi)	CH 30 (ksi)	CH 31 (ksi)	CH 32 (ksi)
NB curb	-0.38	-0.29	-0.51	-0.26	-0.08	-0.09	-0.26	-0.29	-0.48	-0.39	-0.42	-0.72	-0.21	-0.26	-0.39	-0.25	-0.30	-0.28	-0.74	-0.12	-0.48	-0.55	-0.21	-1.33	-0.06	-0.56
NB Lane	-0.30	-0.29	-0.33	-0.18	-0.08	-0.16	-0.12	-0.33	-0.33	-0.51	-0.25	-1.01	-0.07	-0.08	-0.22	-0.26	-0.18	-0.22	-0.65	-0.23	-0.56	-0.47	-0.28	-1.26	-0.06	-0.34
NB Center Girder 2	-0.17	-0.25	-0.18	-0.11	-0.11	-0.05	-0.25	-0.36	-0.23	-0.59	-0.47	-1.21	-0.06	-0.12	-0.18	-0.22	-0.18	-0.21	-0.43	-0.41	-0.60	-0.35	-0.29	-0.98	-0.02	-0.25
NB Center Girder 3	-0.11	-0.43	-0.57	-0.20	-0.14	-0.24	-0.37	-0.36	-0.16	-0.72	-0.86	-1.40	-0.06	-0.16	-0.13	-0.18	-0.27	-0.21	-0.18	-0.58	-0.60	-0.22	-0.41	-0.64	-0.05	-0.13
SB Center Girder 2	-0.14	-0.60	-0.72	-0.26	-0.09	-0.23	-0.51	-0.37	-0.20	-0.83	-1.16	-1.64	-0.15	-0.17	-0.10	-0.10	-0.15	-0.13	-0.20	-0.83	-0.64	-0.19	-0.53	-0.56	-0.05	-0.16
SB Center Girder 3	-0.31	-0.88	-1.19	-0.49	-0.15	-0.29	-0.74	-0.33	-0.23	-0.71	-1.63	-1.79	-0.19	-0.21	-0.07	-0.10	-0.12	-0.10	-0.16	-0.72	-0.65	-0.06	-0.50	-0.23	-0.06	-0.24
SB Lane	-0.43	-1.12	-1.63	-0.65	-0.14	-0.24	-0.91	-0.37	-0.35	-0.54	-1.98	-1.91	-0.25	-0.27	-0.11	-0.10	-0.11	-0.06	-0.28	-0.76	-0.76	-0.24	-0.54	-0.45	-0.04	-0.47
SB Curb	-0.47	-1.27	-1.88	-0.71	-0.14	-0.28	-1.02	-0.27	-0.38	-0.40	-2.10	-1.90	-0.23	-0.32	-0.07	-0.07	-0.09	-0.13	-0.39	-0.82	-0.75	-0.25	-0.54	-0.62	-0.09	-0.41

Stress Range

Truck Location	CH 1 (ksi)	CH 2 (ksi)	CH 3 (ksi)	CH 6 (ksi)	CH 7 (ksi)	CH 8 (ksi)	CH 9 (ksi)	CH 10 (ksi)	CH 11 (ksi)	CH 12 (ksi)	CH 14 (ksi)	CH 15 (ksi)	CH 16 (ksi)	CH 17 (ksi)	CH 18 (ksi)	CH 19 (ksi)	CH 20 (ksi)	CH 21 (ksi)	CH 22 (ksi)	CH 25 (ksi)	CH 26 (ksi)	CH 27 (ksi)	CH 29 (ksi)	CH 30 (ksi)	CH 31 (ksi)	CH 32 (ksi)
NB curb	0.62	0.51	0.86	0.37	0.79	2.25	0.43	0.79	0.84	1.04	0.64	1.94	2.15	2.25	1.97	2.13	3.10	1.56	3.37	0.56	2.65	2.44	1.87	6.98	0.13	2.72
NB Lane	0.50	0.51	0.56	0.33	1.08	2.03	0.22	1.05	0.71	1.34	0.39	2.50	2.72	2.83	2.42	2.87	3.42	1.28	2.55	1.21	3.17	1.92	2.60	5.40	0.14	2.92
NB Center Girder 2	0.30	0.47	0.35	0.25	1.50	1.34	0.53	1.39	0.59	1.70	0.65	3.05	3.42	3.55	2.98	3.59	3.60	0.83	1.55	2.21	3.44	1.16	3.05	3.71	0.12	3.31
NB Center Girder 3	0.28	0.81	1.00	0.46	1.98	1.11	1.13	1.95	0.56	2.25	1.88	3.95	4.53	4.61	3.84	4.61	3.38	0.45	0.57	4.03	3.61	0.49	3.64	1.72	0.14	4.12
SB Center Girder 2	0.45	0.92	1.32	0.61	2.07	1.11	1.46	2.07	0.71	2.58	2.54	4.44	5.07	5.14	4.21	5.02	2.85	0.36	0.38	4.49	3.53	0.35	3.38	1.22	0.12	4.38
SB Center Girder 3	1.35	2.09	2.73	1.49	1.97	0.88	2.53	2.34	1.48	2.85	4.46	5.23	5.12	5.47	4.08	5.25	1.26	0.27	0.27	4.80	3.06	0.22	2.77	0.46	0.28	4.01
SB Lane	2.66	3.32	4.42	2.78	1.70	0.75	3.96	2.71	2.68	3.16	6.95	5.96	3.87	4.20	2.64	3.57	0.62	0.19	0.46	5.01	2.66	0.29	2.31	0.74	0.40	3.27
SB Curb	3.63	4.23	5.42	3.37	1.47	0.66	4.66	3.07	3.67	3.64	8.34	6.68	4.01	4.04	2.77	3.11	0.38	0.23	0.62	4.57	2.23	0.40	2.01	0.90	0.37	3.40

Table 2.2b: Maximum stress at instrumented locations for traveling speed tests of ODOT truck moving over Jasper Bridge

Truck Location	CH 1 (ksi)	CH 2 (ksi)	CH 3 (ksi)	CH 6 (ksi)	CH 7 (ksi)	CH 8 (ksi)	CH 9 (ksi)	CH 10 (ksi)	CH 11 (ksi)	CH 12 (ksi)	CH 14 (ksi)	CH 15 (ksi)	CH 16 (ksi)	CH 17 (ksi)	CH 18 (ksi)	CH 19 (ksi)	CH 20 (ksi)	CH 21 (ksi)	CH 22 (ksi)	CH 25 (ksi)	CH 26 (ksi)	CH 27 (ksi)	CH 29 (ksi)	CH 30 (ksi)	CH 31 (ksi)	CH 32 (ksi)
NB Lane 34mph	0.20	0.23	0.19	0.15	1.39	1.33	0.21	1.07	0.41	1.25	0.30	2.12	3.02	3.13	2.79	3.37	3.18	0.78	1.40	1.68	2.99	1.18	2.89	3.73	0.06	2.99
SB Lane 32mph	1.92	2.26	2.74	1.79	1.55	0.57	3.12	2.58	2.07	2.34	4.47	3.48	3.85	4.18	2.87	3.92	0.66	0.14	0.18	4.01	1.82	0.07	2.03	0.36	0.33	3.09

Additionally, the test truck was positioned at specific locations where the steering axle was located over a bent or end support and held at that location to determine static stirrup stress magnitudes as illustrated in Figure 2.26. The truck was positioned against the curb for each of these tests. Test positions are shown in Figure 2.27 and strain measurements for each of these positions are summarized in Tables 2.3a-d.

Figure 2.26: Static positioning of test truck along curb for Jasper Bridge

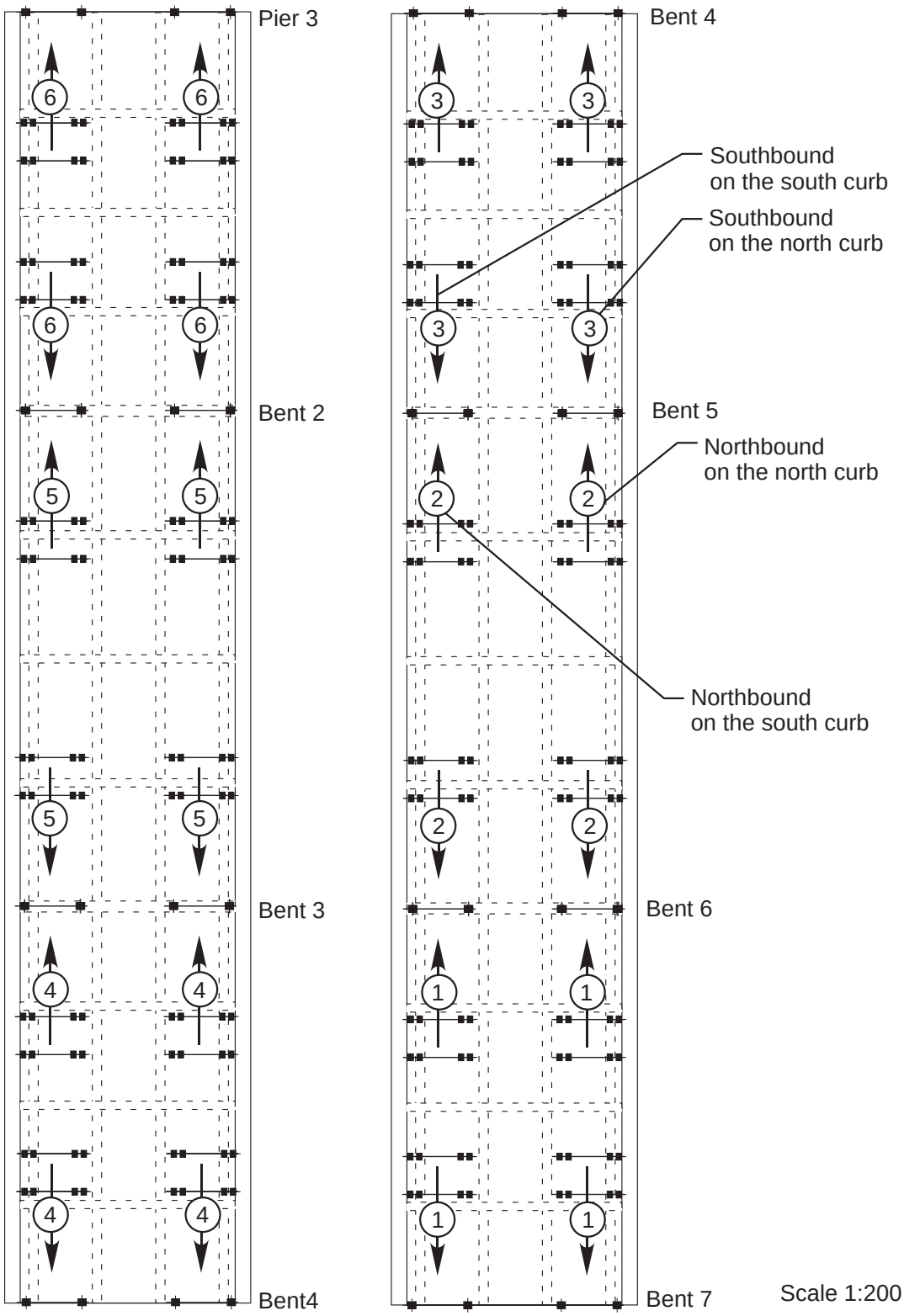

Figure 2.27: Static positioning locations for test truck on Jasper Bridge

Table 2.3a: Stresses at instrumented locations when ODOT truck oriented northbound against the north curb and stationary with steering axle over bents for Jasper Bridge

Truck Location	CH 1 (ksi)	CH 2 (ksi)	CH 3 (ksi)	CH 6 (ksi)	CH 7 (ksi)	CH 8 (ksi)	CH 9 (ksi)	CH 10 (ksi)	CH 11 (ksi)	CH 12 (ksi)	CH 14 (ksi)	CH 15 (ksi)	CH 16 (ksi)	CH 17 (ksi)	CH 18 (ksi)	CH 19 (ksi)	CH 20 (ksi)	CH 21 (ksi)	CH 22 (ksi)	CH 25 (ksi)	CH 26 (ksi)	CH 27 (ksi)	CH 29 (ksi)	CH 30 (ksi)	CH 31 (ksi)	CH 32 (ksi)
1	0.05	0.02	0.07	0.09	0.60	1.29	0.08	-0.22	0.02	-0.03	0.11	-0.06	0.05	0.02	-0.17	-0.16	-0.02	-0.02	0.02	0.08	-0.01	-0.07	-0.26	-1.24	0.02	0.08
2	0.08	0.04	0.30	-0.08	-0.07	0.06	-0.07	0.24	-0.35	0.49	-0.27	0.83	0.29	0.20	1.44	1.69	-0.02	-0.03	0.04	0.63	1.82	1.71	-0.31	-0.06	0.02	0.09
3	0.10	0.05	-0.24	0.13	-0.07	-0.07	0.09	-0.11	0.19	-0.22	0.19	-0.43	1.20	1.24	-0.29	-0.17	-0.01	-0.02	0.02	-0.26	-0.29	-0.42	0.12	0.08	0.01	0.09
4	0.17	0.11	0.10	0.07	-0.07	-0.05	0.07	0.00	0.02	0.08	0.13	0.13	0.10	0.02	-0.06	-0.02	-0.52	0.37	2.06	0.03	0.02	0.00	0.03	0.13	0.01	0.17
5	-0.15	-0.09	0.14	0.08	-0.07	-0.03	0.10	0.00	0.01	0.09	0.16	0.16	0.14	0.00	-0.06	-0.01	0.12	0.30	-0.27	0.04	0.02	0.02	0.04	0.16	0.03	0.06
6	0.26	0.21	0.17	0.09	-0.07	0.01	0.11	0.00	0.01	0.13	0.20	0.20	0.13	0.02	-0.06	-0.01	-0.01	-0.15	0.18	0.08	0.02	0.03	0.06	0.20	-0.02	1.30
start zero	0.04	0.02	0.02	0.05	-0.03	-0.02	0.00	0.01	0.00	0.03	0.04	0.04	0.03	0.01	0.01	0.02	-0.01	0.00	0.00	0.02	0.01	-0.03	-0.04	-0.01	0.00	0.05
end zero	0.14	0.11	0.18	0.07	-0.07	0.01	0.10	0.00	0.02	0.14	0.22	0.23	0.15	0.02	-0.07	0.01	-0.01	-0.05	0.07	0.10	0.02	0.01	0.07	0.21	0.00	0.13

Table 2.3b: Stresses at instrumented locations when ODOT truck oriented southbound against the north curb and stationary with steering axle over bents for Jasper Bridge

Truck Location	CH 1 (ksi)	CH 2 (ksi)	CH 3 (ksi)	CH 6 (ksi)	CH 7 (ksi)	CH 8 (ksi)	CH 9 (ksi)	CH 10 (ksi)	CH 11 (ksi)	CH 12 (ksi)	CH 14 (ksi)	CH 15 (ksi)	CH 16 (ksi)	CH 17 (ksi)	CH 18 (ksi)	CH 19 (ksi)	CH 20 (ksi)	CH 21 (ksi)	CH 22 (ksi)	CH 25 (ksi)	CH 26 (ksi)	CH 27 (ksi)	CH 29 (ksi)	CH 30 (ksi)	CH 31 (ksi)	CH 32 (ksi)
6	0.22	0.19	0.04	0.02	0.01	0.03	0.03	-0.02	0.02	0.03	0.06	0.04	0.02	0.03	0.00	0.02	-0.01	-0.09	0.16	0.02	0.03	0.02	0.04	0.01	-0.01	1.88
5	-0.11	-0.13	0.09	0.03	0.01	0.02	0.07	0.03	0.01	0.04	0.05	0.06	0.02	0.05	0.03	0.05	1.71	0.93	-0.56	0.05	0.01	0.03	0.05	0.06	0.00	-0.29
4	0.11	0.16	0.11	0.05	0.00	0.03	0.09	0.05	0.02	0.06	0.07	0.08	0.05	0.05	0.02	0.04	-0.41	0.32	0.75	0.06	0.01	0.01	0.04	0.06	0.01	0.07
3	0.08	0.11	-0.24	0.15	-0.02	-0.01	0.15	-0.09	0.31	-0.32	0.22	-0.52	1.92	1.97	0.10	0.35	0.03	0.02	0.04	-0.23	-0.36	-0.47	0.18	0.16	0.01	0.04
2	0.11	0.13	0.22	-0.12	0.21	0.26	-0.10	0.40	-0.14	0.34	-0.06	0.60	-0.06	-0.13	0.53	0.63	0.05	0.01	0.05	-0.09	0.05	0.22	1.37	5.64	-0.01	0.05
1	0.10	0.14	0.25	0.16	0.36	0.34	0.12	-0.17	0.06	0.06	0.19	0.06	0.10	0.06	-0.10	-0.06	0.06	0.01	0.04	0.16	0.07	0.09	-0.18	-0.95	0.00	0.05
start zero	0.03	0.04	0.01	0.02	0.01	0.01	0.03	-0.02	0.01	0.00	0.02	0.02	0.00	0.00	0.01	0.02	-0.01	0.01	-0.01	0.00	0.00	0.00	0.01	0.01	0.01	0.04
end zero	0.13	0.16	0.23	0.11	0.01	0.07	0.13	0.04	0.03	0.16	0.18	0.18	0.10	0.04	0.04	0.06	0.08	0.00	0.06	0.13	0.08	0.11	0.07	0.15	0.01	0.08

Table 2.3c: Stresses at instrumented locations when ODOT truck oriented northbound against the south curb and stationary with steering axle over bents for Jasper Bridge

Truck Location	CH 1 (ksi)	CH 2 (ksi)	CH 3 (ksi)	CH 6 (ksi)	CH 7 (ksi)	CH 8 (ksi)	CH 9 (ksi)	CH 10 (ksi)	CH 11 (ksi)	CH 12 (ksi)	CH 14 (ksi)	CH 15 (ksi)	CH 16 (ksi)	CH 17 (ksi)	CH 18 (ksi)	CH 19 (ksi)	CH 20 (ksi)	CH 21 (ksi)	CH 22 (ksi)	CH 25 (ksi)	CH 26 (ksi)	CH 27 (ksi)	CH 29 (ksi)	CH 30 (ksi)	CH 31 (ksi)	CH 32 (ksi)
1	0.04	0.01	0.31	-0.61	0.56	0.23	-0.74	-0.09	-0.24	0.15	-0.02	0.19	-0.15	-0.22	-0.02	-0.04	0.02	-0.01	0.00	-0.08	-0.12	0.02	-0.60	0.21	0.01	0.02
2	0.06	0.02	-1.48	-0.10	0.30	-0.13	0.34	0.50	2.80	3.11	5.56	4.52	3.24	3.38	1.65	2.01	0.01	-0.01	0.03	3.88	1.21	-0.17	0.34	-0.28	-0.01	0.04
3	0.06	0.05	0.65	0.08	-0.11	0.02	-0.05	-0.18	0.38	-0.90	-1.67	-1.48	0.26	0.11	1.11	1.28	0.03	0.00	0.03	-1.18	-0.41	0.06	-0.11	0.19	0.01	0.04
4	0.04	-1.27	0.00	0.04	-0.04	-0.03	0.05	0.00	0.04	0.03	0.11	0.06	0.03	-0.01	-0.01	0.03	-0.09	0.08	-0.24	0.01	0.02	-0.02	0.02	0.05	0.02	-0.22
5	1.96	-0.36	0.05	0.04	-0.04	-0.02	0.07	0.02	0.05	0.08	0.15	0.09	0.03	0.02	-0.01	0.05	-0.08	-0.08	0.10	0.05	0.03	0.00	0.04	0.07	0.08	3.05
6	-0.32	0.27	0.06	0.06	-0.03	-0.01	0.07	0.01	0.06	0.09	0.15	0.12	0.06	0.00	-0.03	0.05	0.08	-0.02	0.04	0.08	0.02	-0.02	0.02	0.08	0.12	-0.11
start zero	-0.01	0.03	0.02	0.01	-0.01	0.01	0.01	0.00	0.00	0.01	0.04	0.03	0.02	-0.01	-0.01	0.01	0.01	-0.01	0.01	0.03	0.01	0.03	0.03	0.06	-0.02	0.02
end zero	0.11	0.13	0.06	0.05	-0.03	-0.02	0.08	0.02	0.04	0.07	0.16	0.11	0.06	0.01	-0.02	0.05	0.05	0.00	0.05	0.06	0.02	-0.01	0.04	0.10	0.02	0.03

Table 2.3d: Stresses at instrumented locations when ODOT truck oriented southbound against the south curb and stationary with steering axle over bents for Jasper Bridge

Truck Location	CH 1 (ksi)	CH 2 (ksi)	CH 3 (ksi)	CH 6 (ksi)	CH 7 (ksi)	CH 8 (ksi)	CH 9 (ksi)	CH 10 (ksi)	CH 11 (ksi)	CH 12 (ksi)	CH 14 (ksi)	CH 15 (ksi)	CH 16 (ksi)	CH 17 (ksi)	CH 18 (ksi)	CH 19 (ksi)	CH 20 (ksi)	CH 21 (ksi)	CH 22 (ksi)	CH 25 (ksi)	CH 26 (ksi)	CH 27 (ksi)	CH 29 (ksi)	CH 30 (ksi)	CH 31 (ksi)	CH 32 (ksi)
6	-0.49	0.32	0.10	0.06	0.00	0.02	0.07	0.02	0.02	0.00	0.10	0.11	0.01	0.03	0.03	0.08	0.11	0.06	-0.03	0.08	0.02	0.05	0.03	0.09	0.14	0.99
5	0.25	2.26	0.13	0.08	-0.02	0.01	0.09	0.05	0.02	0.02	0.11	0.12	0.06	0.06	0.04	0.07	0.28	-0.06	0.19	0.09	0.03	0.03	0.02	0.12	-0.03	0.77
4	-0.01	-0.92	0.07	0.06	-0.04	0.01	0.09	0.05	0.02	-0.02	0.07	0.07	0.07	0.08	0.03	0.10	-0.06	0.06	-0.21	0.08	-0.01	0.03	0.03	0.14	-0.03	-0.23
3	0.06	0.10	2.62	0.15	-0.13	0.04	-0.02	-0.14	0.47	-0.91	-1.90	-1.62	2.02	1.83	2.67	3.04	0.03	0.00	0.03	-1.25	-0.54	0.12	-0.08	0.32	-0.04	-0.03
2	0.06	0.11	-0.66	1.91	0.92	-0.21	3.76	3.48	0.90	-0.26	0.19	-0.43	0.73	0.84	0.05	0.17	0.03	0.01	0.03	0.37	0.39	-0.05	1.44	-0.29	-0.04	-0.02
1	0.06	0.13	0.33	-0.37	0.19	0.23	-0.49	-0.03	-0.15	0.10	0.01	0.26	-0.08	-0.11	-0.04	0.01	0.02	0.01	0.04	0.08	-0.05	0.04	-0.35	0.32	-0.05	0.00
zero start	0.03	0.08	0.06	0.05	0.02	-0.02	0.06	0.02	-0.03	-0.02	0.05	0.08	0.01	0.05	0.04	0.07	0.04	0.01	0.01	0.03	0.03	0.04	0.01	0.07	-0.03	0.00
zero end	0.05	0.13	0.10	0.09	-0.01	-0.01	0.11	0.04	0.02	0.04	0.06	0.16	0.09	0.06	0.00	0.06	0.03	-0.02	0.03	0.15	0.02	0.03	0.04	0.21	-0.06	-0.02

A temporary vehicle weigh-station was used to obtain vehicle weight and axle spacing of commercial trucks crossing the bridge from the south. The data collection was performed on April 17, 2003 and April 23, 2003 from 9:00 a.m. to 1:00 p.m. The truck axle weights were determined from jump scales, and axle spacings were measured; these are shown in Figure 2.28 and summarized in Table 2.4.

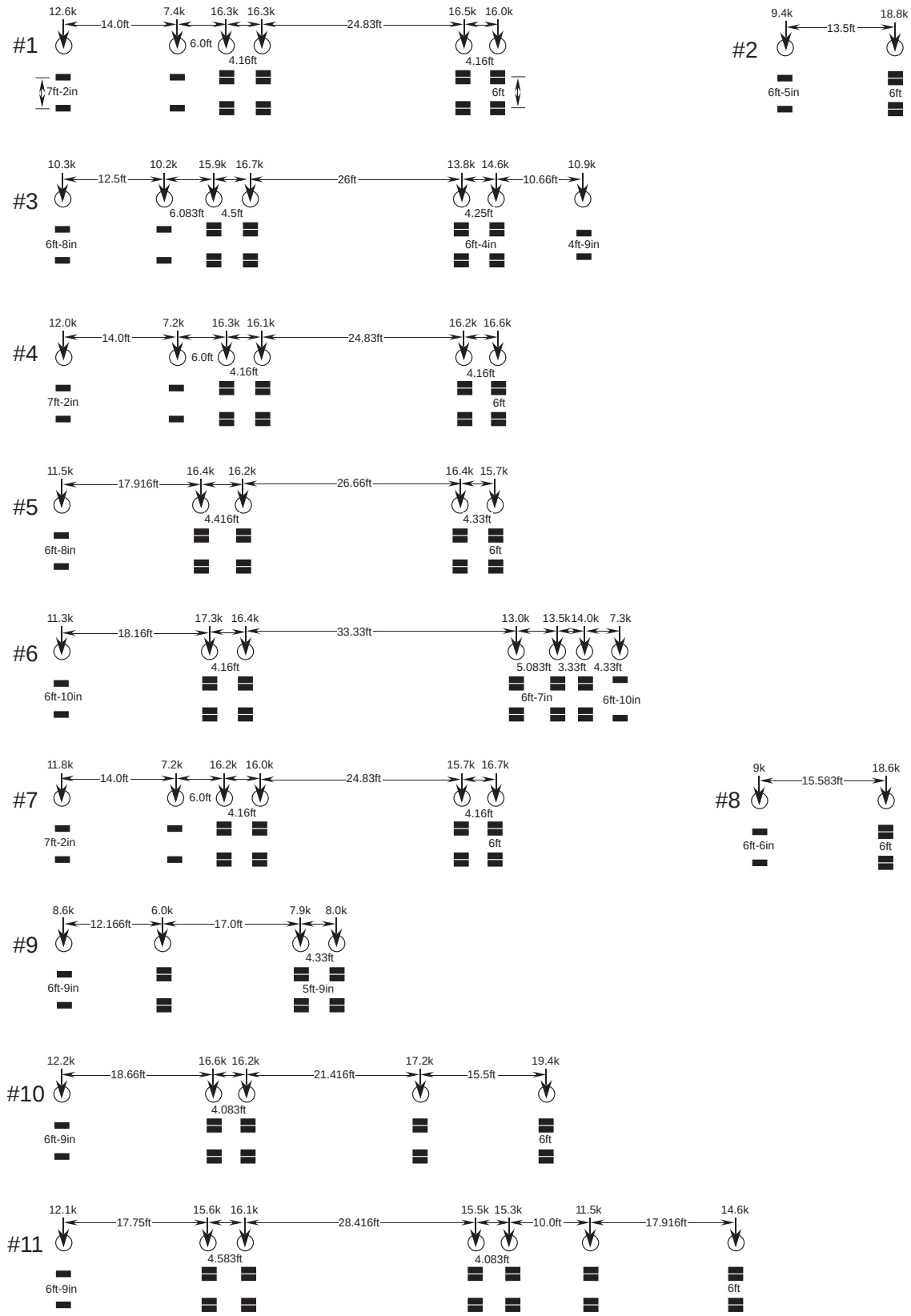

Figure 2.28: Axle weights and spacing for series of trucks crossing the Jasper Bridge

Table 2.4: Truck and axle weights from field measured trucks on Jasper Bridge

Truck ID	Gross Vehicle Weight (GVW) (kips)	Tandem Weight (kips)	Total Axle Weight within an 11 ft Length (kips)
1	84.8	32.5	40
2	28.2	18.8	28.2
3	92.4	32.6	42.8
4	84.4	32.8	39.6
5	76.2	32.6	32.6
6	92.8	33.7	47.8
7	83.6	32.4	39.4
8	27.6	18.6	27.6
9	30.5	15.9	15.9
10	81.6	32.8	32.8
11	100.7	31.7	42.3
ODOT Truck	47.28	33.2	33.2

After weighing and measuring axles, the trucks crossed the bridge and the induced stirrup stresses were measured and images were taken of each of these vehicles as shown in Figures 2.29a-k. The test data are summarized in Tables 2.5a-c. The influence of vehicle parameters (such as gross vehicle weight, tandem weight, and axle weights) on stirrup stress magnitude was evaluated within an 11 ft distance. For the trucks in the study, this corresponded to the most compact length of approximately evenly spaced axles as illustrated for Truck #6 in Figure 2.28.

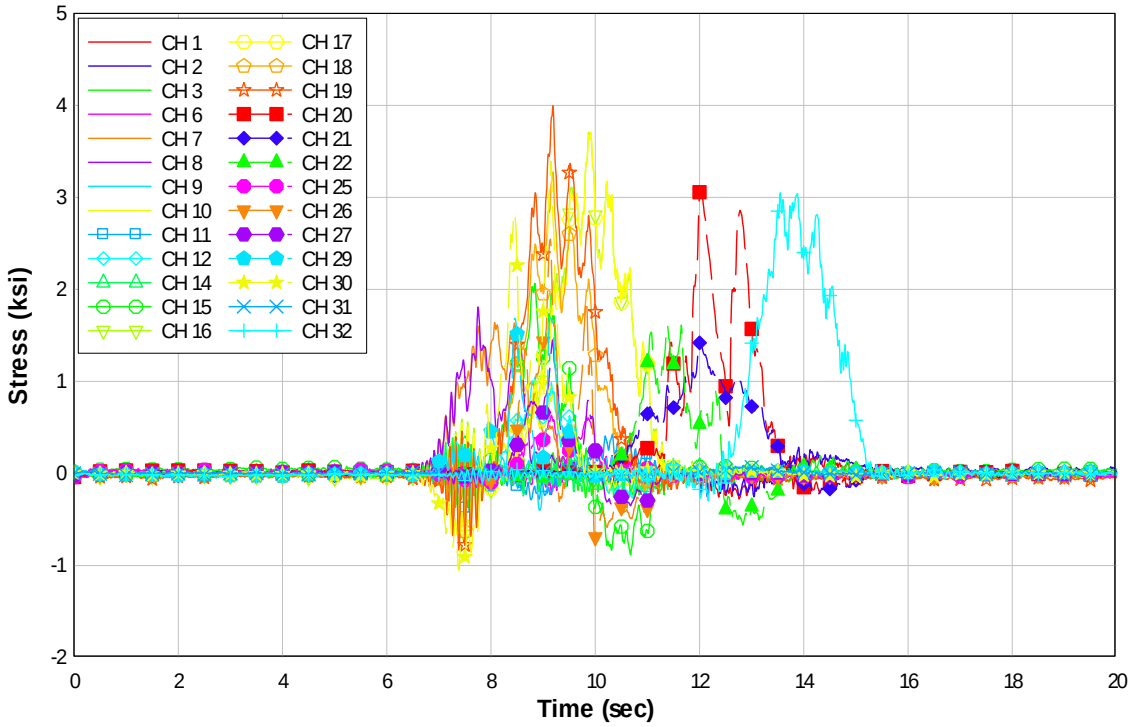

Figure 2.29a: Truck photograph and stress history produced for Truck #1 March 20, 2003

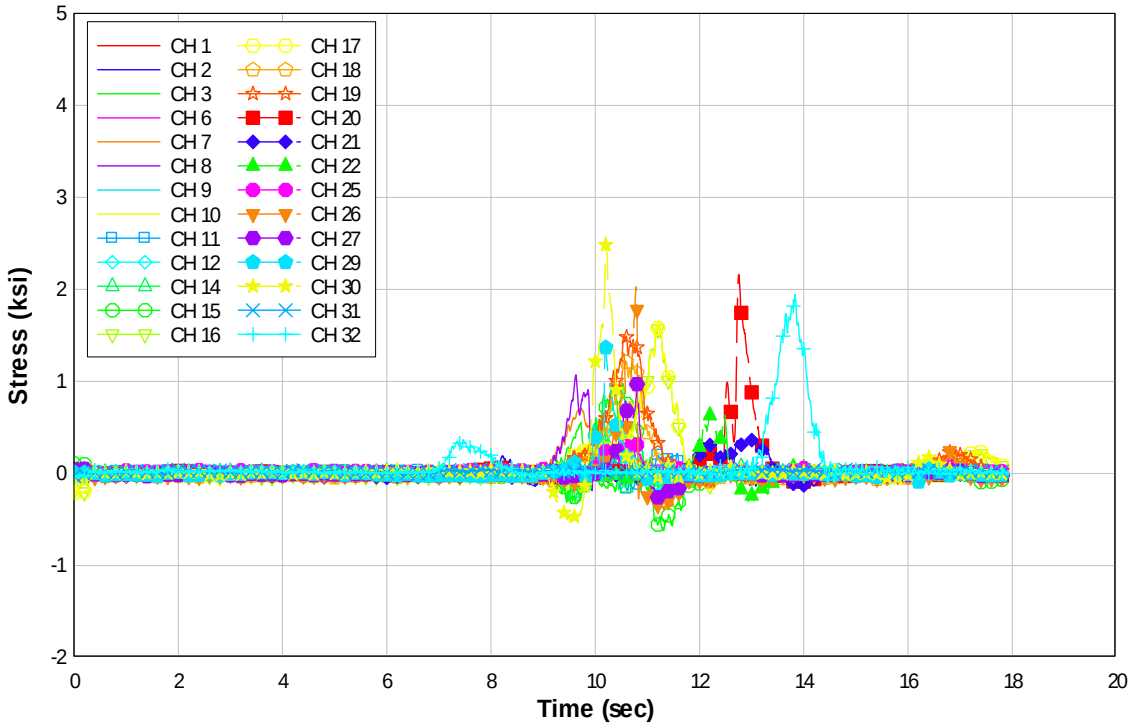

Figure 2.29b: Truck photograph and stress history produced for Truck #2 (note that first rear axle is not on roadway)

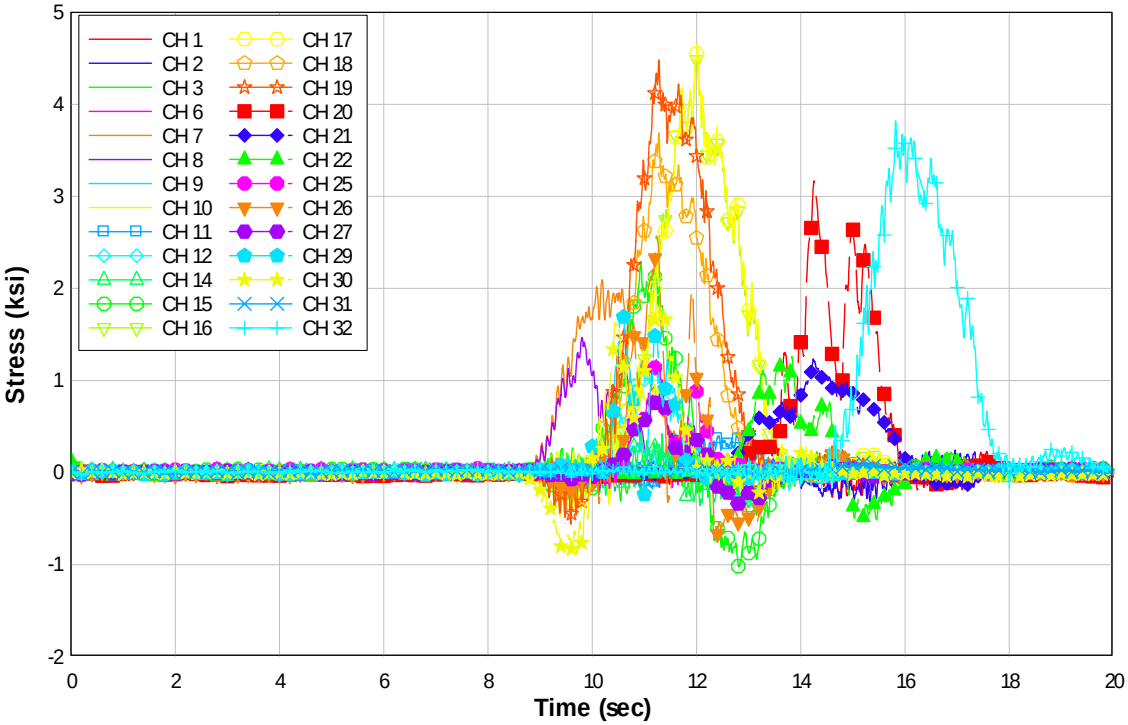

Figure 2.29c: Truck photograph and stress history produced for Truck #3

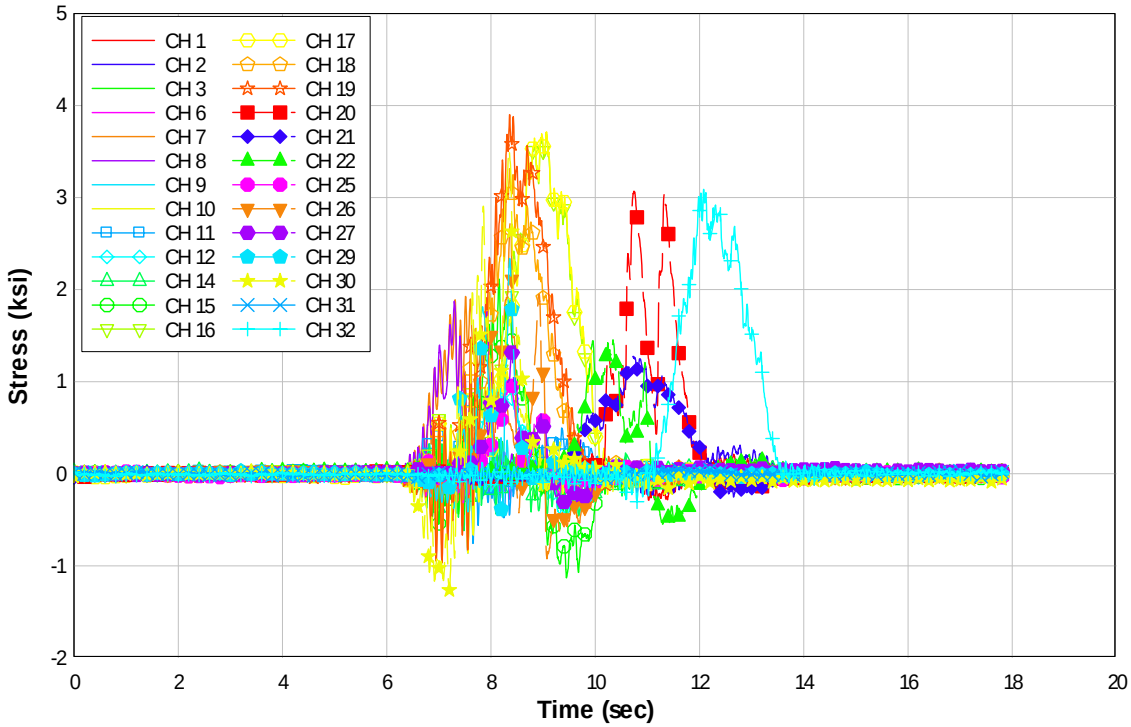

Figure 2.29d: Truck photograph and stress history produced for Truck #4

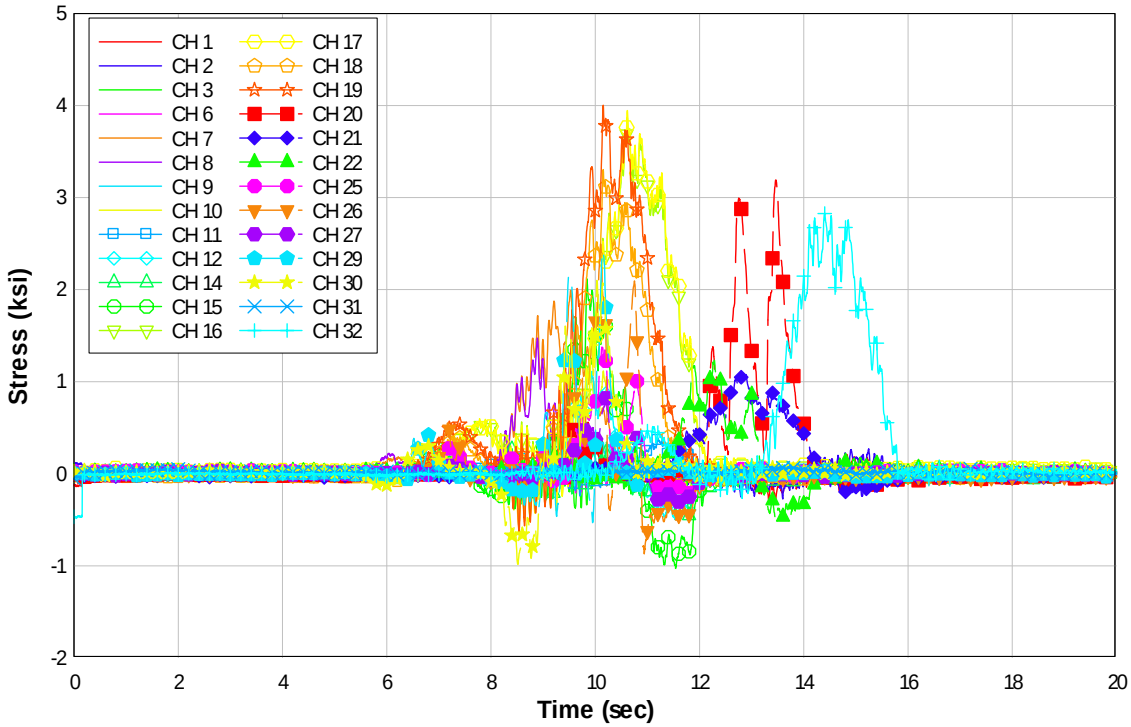

Figure 2.29e: Truck photograph and stress history produced for Truck #5

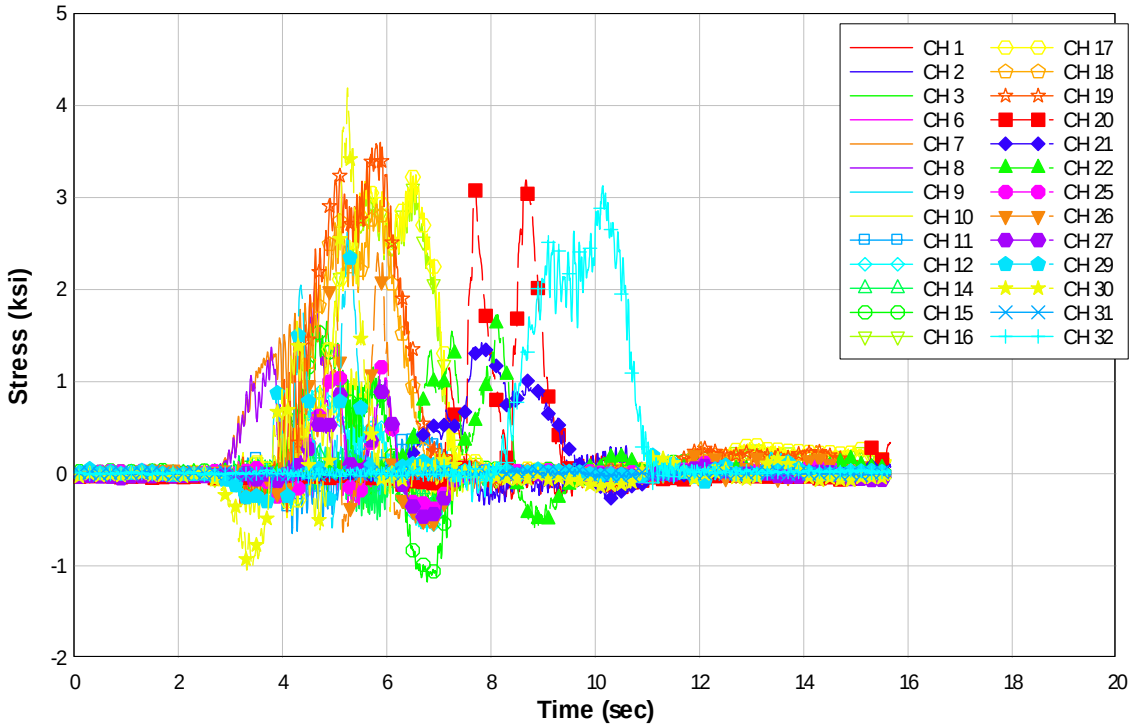

Figure 2.29f: Truck photograph and stress history produced for Truck #6

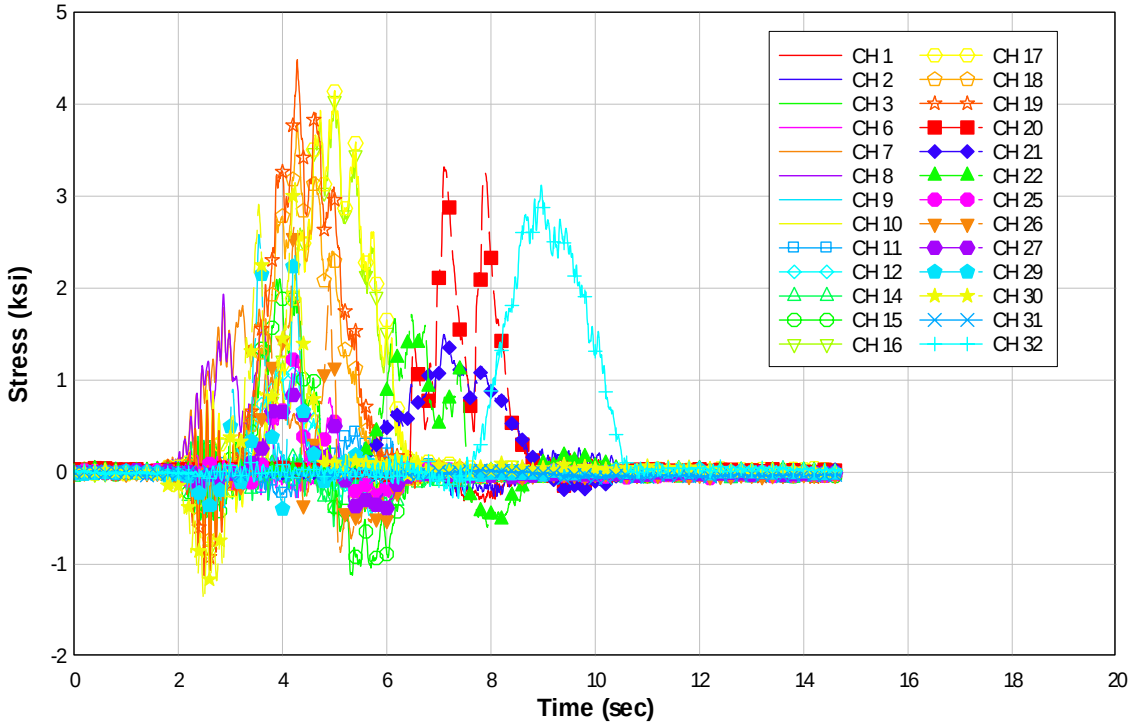

Figure 2.29g: Truck photograph and stress history produced for Truck #7

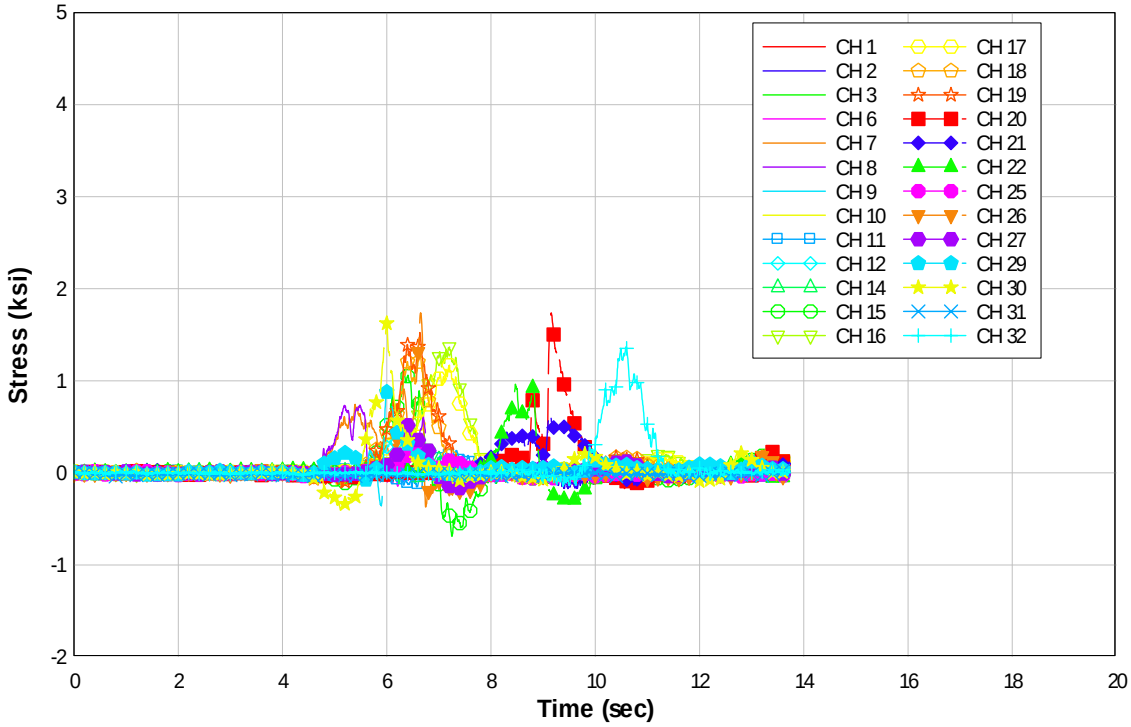

Figure 2.29h: Truck photograph and stress history produced for Truck #8 on April 1, 2003

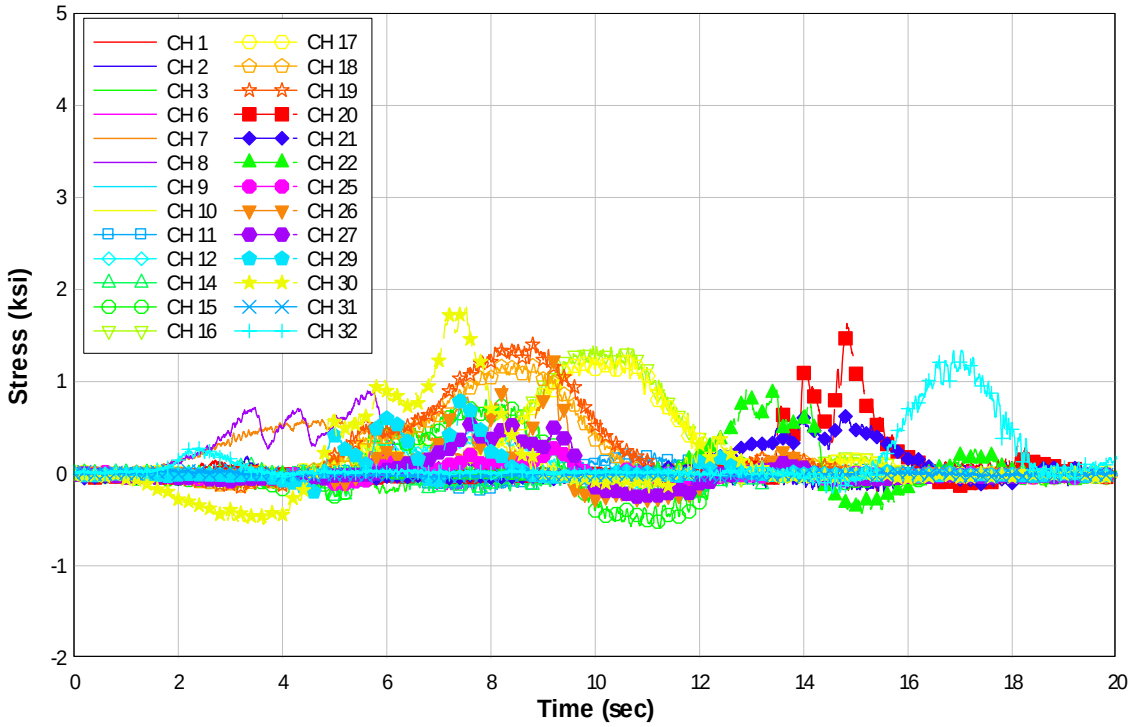

Figure 2.29i: Truck photograph and stress history produced for Truck #9

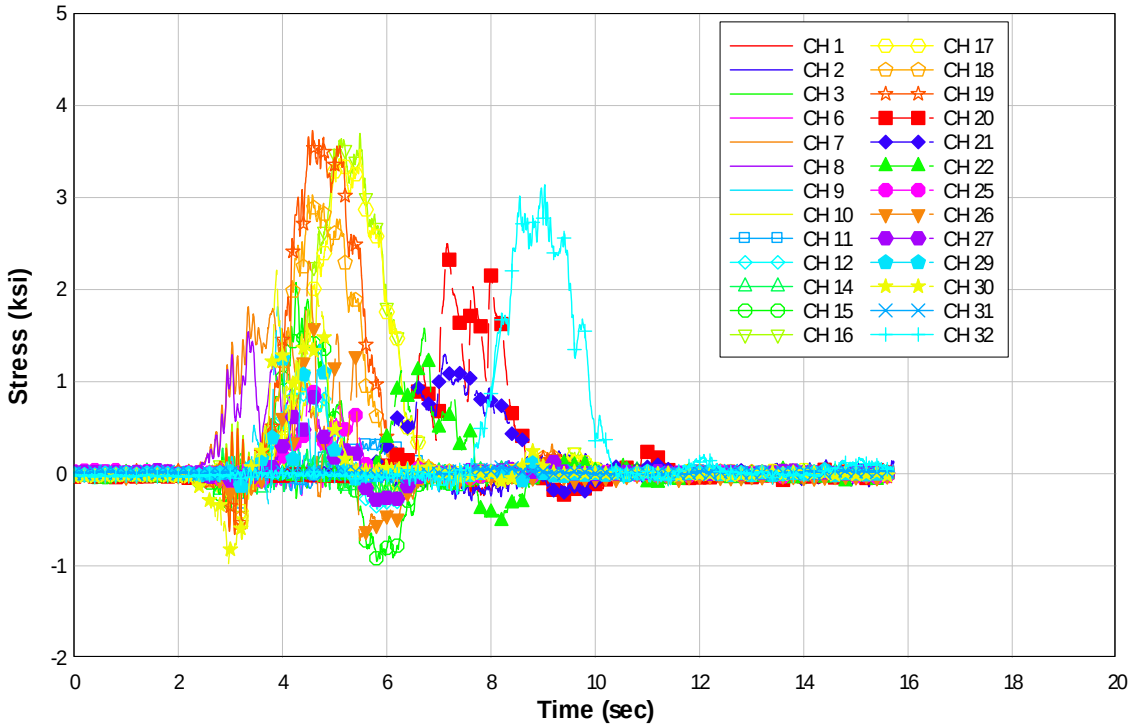

Figure 2.29j: Truck photograph and stress history produced for Truck #10

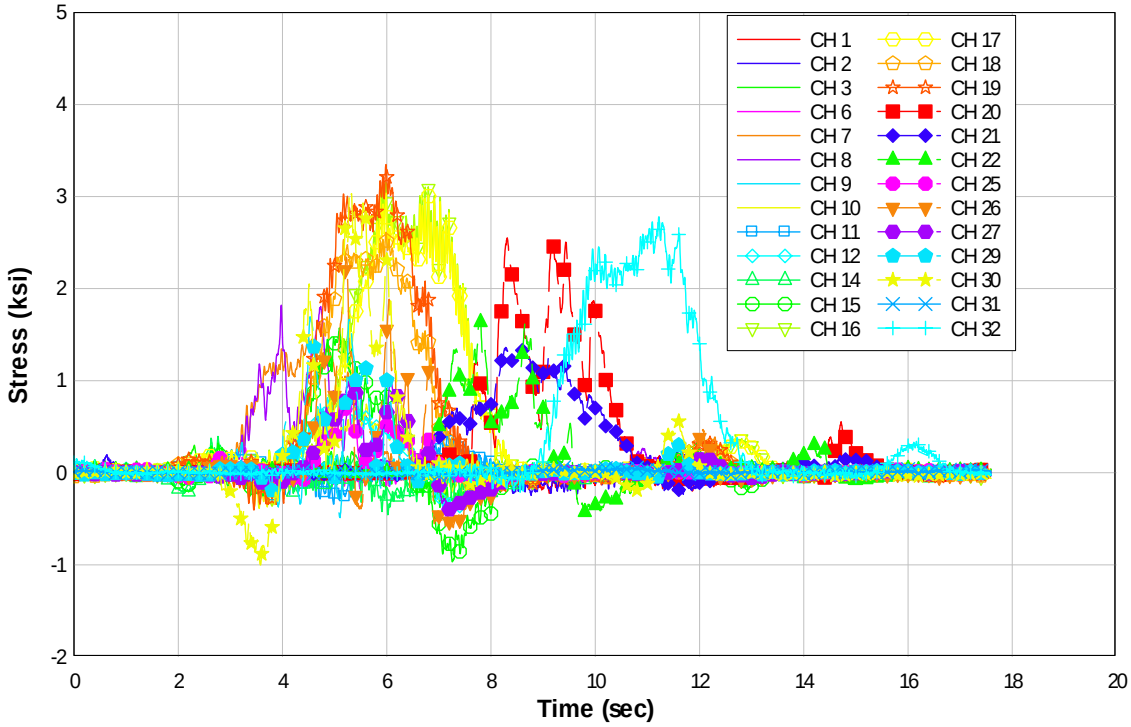

Figure 2.29k: Truck photograph and stress history produced for Truck #11

Table 2.5a: Maximum stresses for real trucks on Jasper Bridge

Truck ID	GVW (kips)	CH 1 (ksi)	CH 2 (ksi)	CH 3 (ksi)	CH 6 (ksi)	CH 7 (ksi)	CH 8 (ksi)	CH 9 (ksi)	CH 10 (ksi)	CH 11 (ksi)	CH 12 (ksi)	CH 14 (ksi)	CH 15 (ksi)	CH 16 (ksi)	CH 17 (ksi)	CH 18 (ksi)	CH 19 (ksi)	CH 20 (ksi)	CH 21 (ksi)	CH 22 (ksi)	CH 25 (ksi)	CH 26 (ksi)	CH 27 (ksi)	CH 29 (ksi)	CH 30 (ksi)	CH 31 (ksi)	CH 32 (ksi)
1	84.8	0.20	0.29	0.38	0.20	1.64	1.81	0.23	0.89	0.43	1.04	0.39	2.07	3.71	3.71	3.28	3.99	3.09	1.42	1.62	0.64	2.55	1.45	1.70	3.39	0.09	3.05
2	28.2	0.10	0.19	0.56	0.26	0.71	1.07	0.48	0.70	0.32	0.57	0.61	0.98	1.65	1.66	1.23	1.50	2.16	0.41	0.65	0.36	2.03	1.00	1.37	2.51	0.07	1.95
3	92.4	0.17	0.24	0.27	0.18	2.09	1.47	0.33	0.96	0.43	1.19	0.49	2.29	4.60	4.67	3.69	4.48	3.17	1.23	1.26	1.23	2.57	0.85	1.76	1.97	0.12	3.82
4	84.4	0.21	0.31	0.45	0.31	1.93	1.87	0.52	1.11	0.79	1.12	0.62	2.11	3.69	3.71	3.31	3.90	3.07	1.28	1.46	1.03	2.73	1.32	2.34	3.54	0.07	3.09
5	76.2	0.21	0.27	0.24	0.15	1.99	1.47	0.48	1.12	0.39	1.17	0.56	2.12	3.87	3.94	3.31	4.00	3.19	1.08	1.23	1.38	2.49	0.83	2.43	2.10	0.10	2.83
6	92.8	0.22	0.30	0.45	0.40	1.93	2.05	0.62	1.14	0.57	0.95	0.64	1.66	3.15	3.28	2.97	3.60	3.19	1.42	1.73	1.40	2.71	1.02	2.66	4.19	0.06	3.13
7	83.6	0.20	0.27	0.52	0.49	1.81	1.93	0.66	1.11	0.49	1.19	0.66	2.10	4.04	4.15	3.79	4.48	3.32	1.50	1.71	1.24	2.69	1.27	2.58	3.15	0.05	3.12
8	27.6	0.17	0.15	0.17	0.08	0.74	0.74	0.11	0.41	0.24	0.49	0.17	1.12	1.37	1.17	1.31	1.52	1.74	0.64	0.96	0.35	1.74	0.61	0.88	1.62	0.04	1.37
9	30.5	0.15	0.19	0.33	0.19	0.60	0.90	0.42	0.54	0.23	0.44	0.39	0.80	1.39	1.28	1.20	1.44	1.63	0.64	0.93	0.28	1.24	0.57	0.87	1.88	0.05	1.34
10	81.6	0.21	0.25	0.24	0.15	1.82	1.54	0.32	0.89	0.40	1.14	0.43	2.08	3.70	3.52	3.03	3.73	2.50	1.30	1.58	0.97	2.31	0.86	1.81	2.21	0.09	3.14
11	100.7	0.21	0.25	0.30	0.27	1.46	1.82	0.33	0.75	0.45	0.86	0.39	1.57	3.16	3.04	2.61	3.35	2.57	1.36	1.66	0.79	2.34	0.99	1.70	3.03	0.07	2.78
ODOT	47.28	0.20	0.23	0.19	0.15	1.39	1.33	0.21	1.07	0.41	1.25	0.30	2.12	3.02	3.13	2.79	3.37	3.18	0.78	1.40	1.68	2.99	1.18	2.89	3.73	0.06	2.99

Table 2.5b: Minimum stresses for real trucks on Jasper Bridge

Truck ID	GVW (kips)	CH 1 (ksi)	CH 2 (ksi)	CH 3 (ksi)	CH 6 (ksi)	CH 7 (ksi)	CH 8 (ksi)	CH 9 (ksi)	CH 10 (ksi)	CH 11 (ksi)	CH 12 (ksi)	CH 14 (ksi)	CH 15 (ksi)	CH 16 (ksi)	CH 17 (ksi)	CH 18 (ksi)	CH 19 (ksi)	CH 20 (ksi)	CH 21 (ksi)	CH 22 (ksi)	CH 25 (ksi)	CH 26 (ksi)	CH 27 (ksi)	CH 29 (ksi)	CH 30 (ksi)	CH 31 (ksi)	CH 32 (ksi)
1	84.8	-0.28	-0.25	-0.38	-0.23	-0.07	-0.11	-0.39	-0.49	-0.40	-0.26	-0.29	-0.88	-0.67	-0.60	-0.67	-0.83	-0.21	-0.23	-0.56	-0.15	-0.74	-0.35	-0.40	-1.05	-0.04	-0.30
2	28.2	-0.14	-0.17	-0.20	-0.10	-0.05	-0.19	-0.13	-0.23	-0.18	-0.22	-0.29	-0.62	-0.23	-0.22	-0.11	-0.12	-0.12	-0.16	-0.30	-0.08	-0.39	-0.26	-0.20	-0.55	-0.04	-0.10
3	92.4	-0.27	-0.32	-0.31	-0.19	-0.06	-0.05	-0.37	-0.47	-0.33	-0.37	-0.47	-1.02	-0.34	-0.36	-0.45	-0.56	-0.19	-0.17	-0.51	-0.19	-0.68	-0.35	-0.28	-0.89	-0.04	-0.20
4	84.4	-0.30	-0.23	-0.46	-0.39	-0.13	-0.10	-0.58	-0.64	-0.86	-0.47	-0.62	-1.13	-0.83	-0.86	-0.80	-0.97	-0.17	-0.25	-0.60	-0.31	-0.92	-0.31	-0.47	-1.27	-0.06	-0.30
5	76.2	-0.30	-0.27	-0.38	-0.21	-0.10	-0.07	-0.39	-0.57	-0.31	-0.50	-0.45	-1.03	-0.42	-0.44	-0.55	-0.63	-0.19	-0.24	-0.49	-0.24	-0.87	-0.33	-0.53	-0.99	-0.06	-0.49
6	92.8	-0.28	-0.34	-0.47	-0.32	-0.12	-0.34	-0.25	-0.49	-0.65	-0.63	-0.50	-1.17	-0.46	-0.48	-0.34	-0.42	-0.18	-0.26	-0.65	-0.42	-0.63	-0.49	-0.59	-1.05	-0.05	-0.30
7	83.6	-0.33	-0.26	-0.43	-0.30	-0.10	-0.06	-0.55	-0.74	-0.49	-0.49	-0.59	-1.12	-0.94	-0.96	-0.92	-1.13	-0.17	-0.21	-0.60	-0.35	-0.87	-0.43	-0.45	-1.41	-0.08	-0.28
8	27.6	-0.14	-0.17	-0.14	-0.14	-0.07	-0.13	-0.10	-0.16	-0.15	-0.16	-0.12	-0.69	-0.08	-0.06	-0.12	-0.16	-0.17	-0.13	-0.32	-0.09	-0.37	-0.21	-0.36	-0.41	-0.06	-0.15
9	30.5	-0.21	-0.21	-0.29	-0.19	-0.07	-0.09	-0.15	-0.19	-0.22	-0.27	-0.27	-0.59	-0.10	-0.09	-0.17	-0.17	-0.18	-0.14	-0.43	-0.14	-0.32	-0.26	-0.21	-0.55	-0.05	-0.22
10	81.6	-0.24	-0.29	-0.32	-0.23	-0.08	-0.08	-0.43	-0.58	-0.48	-0.38	-0.32	-0.95	-0.54	-0.48	-0.62	-0.66	-0.24	-0.21	-0.53	-0.15	-0.72	-0.32	-0.34	-1.02	-0.06	-0.22
11	100.7	-0.22	-0.25	-0.40	-0.18	-0.10	-0.11	-0.18	-0.39	-0.34	-0.42	-0.46	-0.97	-0.27	-0.20	-0.34	-0.40	-0.20	-0.23	-0.44	-0.15	-0.60	-0.40	-0.49	-1.00	-0.04	-0.21
ODOT	47.28	-0.31	-0.34	-0.32	-0.18	-0.05	-0.11	-0.22	-0.39	-0.28	-0.54	-0.43	-1.15	-0.26	-0.23	-0.37	-0.45	-0.17	-0.24	-0.55	-0.30	-0.61	-0.42	-0.29	-1.23	-0.03	-0.22

Table 2.5c: Stress ranges for real trucks on Jasper Bridge

Truck ID	GVW (kips)	CH 1 (ksi)	CH 2 (ksi)	CH 3 (ksi)	CH 6 (ksi)	CH 7 (ksi)	CH 8 (ksi)	CH 9 (ksi)	CH 10 (ksi)	CH 11 (ksi)	CH 12 (ksi)	CH 14 (ksi)	CH 15 (ksi)	CH 16 (ksi)	CH 17 (ksi)	CH 18 (ksi)	CH 19 (ksi)	CH 20 (ksi)	CH 21 (ksi)	CH 22 (ksi)	CH 25 (ksi)	CH 26 (ksi)	CH 27 (ksi)	CH 29 (ksi)	CH 30 (ksi)	CH 31 (ksi)	CH 32 (ksi)
1	84.8	0.48	0.54	0.75	0.43	1.71	1.92	0.63	1.39	0.83	1.31	0.68	2.95	4.37	4.32	3.95	4.83	3.31	1.65	2.18	0.79	3.29	1.80	2.10	4.44	0.13	3.35
2	28.2	0.23	0.36	0.75	0.37	0.76	1.26	0.60	0.93	0.50	0.79	0.90	1.60	1.87	1.89	1.35	1.62	2.28	0.57	0.95	0.45	2.42	1.26	1.57	3.06	0.12	2.05
3	92.4	0.44	0.56	0.58	0.37	2.15	1.51	0.70	1.43	0.75	1.57	0.95	3.32	4.93	5.03	4.14	5.04	3.36	1.40	1.77	1.42	3.25	1.21	2.05	2.86	0.16	4.02
4	84.4	0.51	0.54	0.92	0.70	2.05	1.97	1.10	1.75	1.66	1.59	1.24	3.25	4.52	4.58	4.11	4.87	3.24	1.53	2.05	1.34	3.65	1.63	2.81	4.81	0.14	3.39
5	76.2	0.51	0.55	0.62	0.36	2.10	1.55	0.87	1.69	0.70	1.67	1.01	3.14	4.29	4.39	3.85	4.63	3.38	1.32	1.73	1.61	3.36	1.16	2.96	3.08	0.15	3.31
6	92.8	0.49	0.64	0.91	0.72	2.04	2.39	0.87	1.62	1.22	1.58	1.14	2.83	3.62	3.76	3.31	4.02	3.37	1.69	2.38	1.83	3.35	1.52	3.25	5.24	0.11	3.43
7	83.6	0.53	0.53	0.95	0.79	1.91	2.00	1.21	1.84	0.98	1.68	1.25	3.22	4.98	5.10	4.71	5.61	3.48	1.70	2.31	1.59	3.56	1.69	3.03	4.56	0.13	3.40
8	27.6	0.31	0.32	0.31	0.23	0.82	0.86	0.21	0.58	0.40	0.65	0.29	1.81	1.45	1.23	1.43	1.68	1.91	0.77	1.28	0.44	2.11	0.81	1.24	2.03	0.10	1.52
9	30.5	0.36	0.40	0.61	0.38	0.67	0.99	0.57	0.73	0.45	0.71	0.67	1.39	1.49	1.37	1.37	1.61	1.81	0.78	1.36	0.41	1.56	0.82	1.08	2.44	0.11	1.56
10	81.6	0.44	0.54	0.56	0.38	1.89	1.62	0.74	1.47	0.88	1.53	0.74	3.03	4.24	4.01	3.65	4.39	2.73	1.51	2.11	1.12	3.03	1.18	2.16	3.23	0.15	3.36
11	100.7	0.43	0.50	0.70	0.45	1.56	1.93	0.51	1.13	0.79	1.29	0.85	2.54	3.43	3.23	2.95	3.75	2.77	1.59	2.09	0.95	2.94	1.39	2.18	4.03	0.12	2.99
ODOT	47.28	0.51	0.57	0.51	0.33	1.44	1.45	0.43	1.46	0.69	1.79	0.72	3.27	3.28	3.36	3.16	3.82	3.35	1.02	1.95	1.98	3.60	1.60	3.18	4.96	0.09	3.21

The relationships between stirrup stress and gross vehicle weight, tandem weight, and axle weights within a length of 11ft are shown in Figures 2.30 a, b, and c. As seen in these figures, gross vehicle weight did not correlate well with stirrup stress at instrumented locations. Stirrup stresses on main girders were more strongly influenced by the tandem weight, while the stirrup stresses on the bent caps were more strongly influenced by axle weights within the 11ft distance.

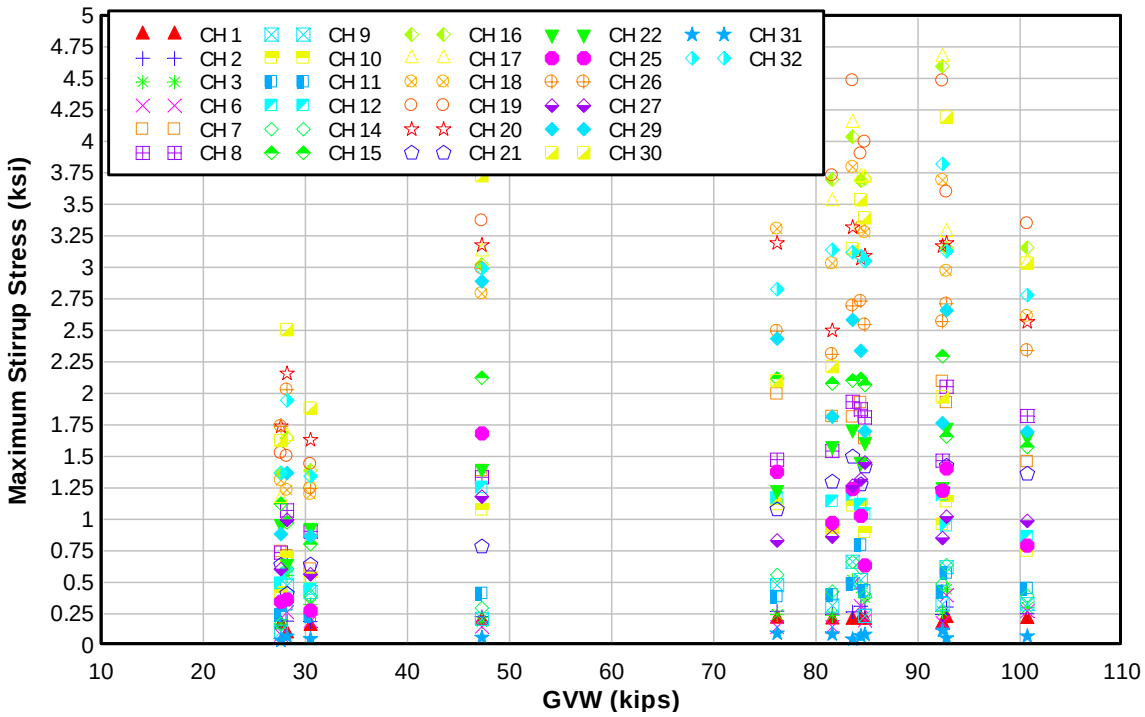

Figure 2.30a: Maximum stirrup stress produced for each known truck gross vehicle weight crossing Jasper Bridge

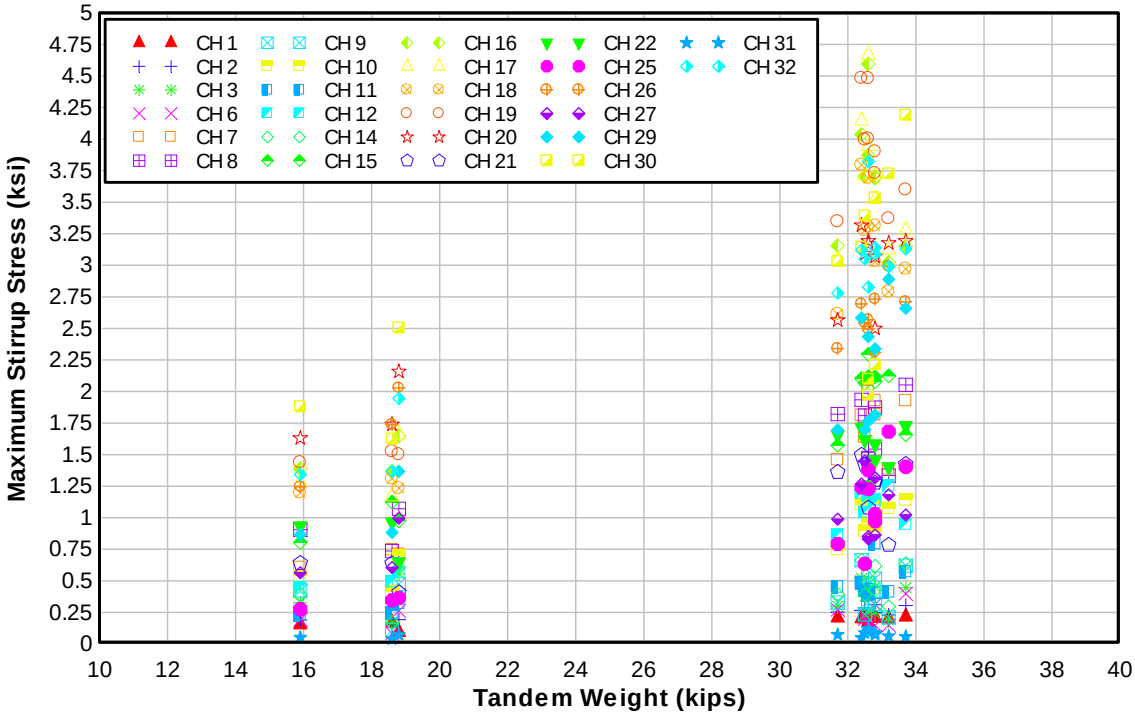

Figure 2.30b: Maximum stirrup stress produced for the maximum tandem weight on each known truck crossing Jasper Bridge

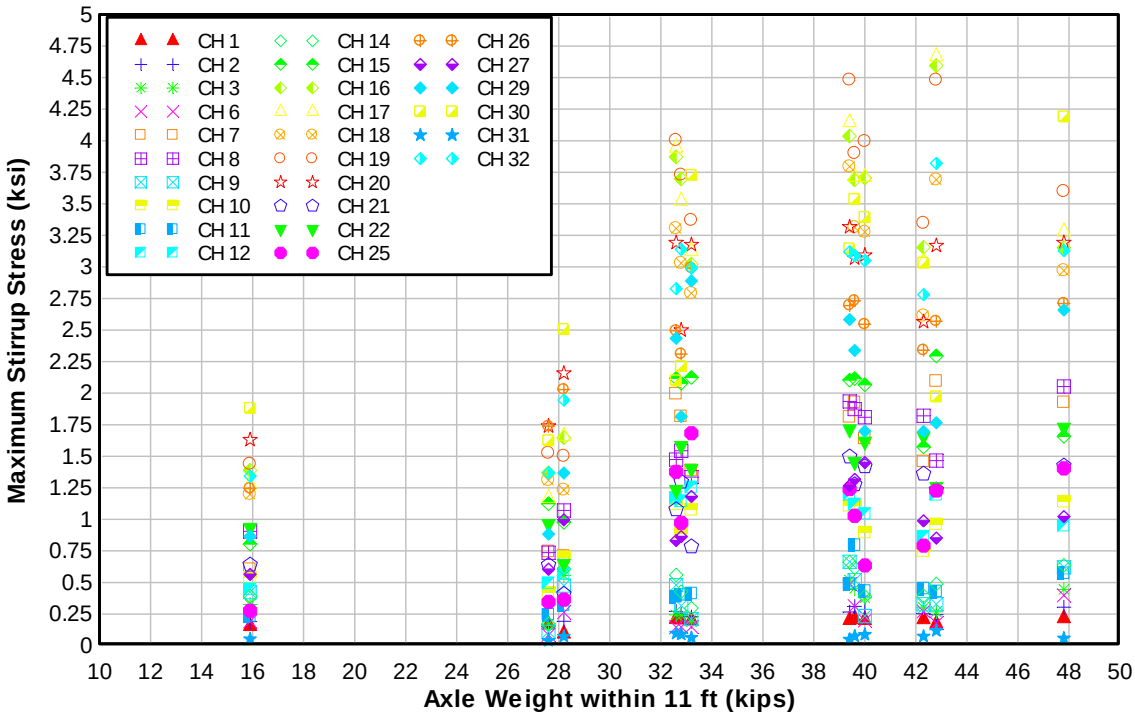

Figure 2.30c: Maximum stirrup stress produced for the axle weight within an 11 ft length on each known truck crossing Jasper Bridge

2.3 15 MILE CREEK BRIDGE, I84 EAST AND WESTBOUND, THE DALLES, OR (BRIDGE NUMBER 308A)

15 Mile Creek Bridge is located on I-84, just east of The Dalles, OR and spans 15 Mile Creek. The bridge consists of 5 spans, as shown in Figures 2.31a-c, with three box-girder main spans and two reinforced concrete deck girder spans at the northeast approach. The bridge carries two traffic lanes in the eastbound direction and two traffic lanes in the westbound direction. The bridge was designed in 1960.

2.3.1 Description of Tested Spans

The approach spans, shown in Figure 2.32, were selected for field study. The approach spans have equal span lengths of 52 ft that are continuous over Bent 5. Eastbound spans have a roadway width of 30 ft - 5.5 in. and westbound spans have a roadway width of 31 ft - 11.5 in. The eastbound and westbound deck overhangs share a longitudinal joint along their lengths that does not permit significant force transfer between spans. This was verified by field tests.

Four girders support two traffic lanes in each direction. The girders have an overall height of 48 in. with web widths that taper from 16.5 in. between quarter points to 24 in. at the support face. Diaphragms are 9 in. x 46 in. and located at the quarter points of each span. The concrete deck is 7 in. thick. Bent caps are supported by 15 in. diameter circular columns with the exterior girder framing into the bent cap outboard of the columns.

The bridge was designed in 1960. The specified concrete compression strength was 3300 psi and reinforcing steel consisted of ASTM A305 intermediate grade round bars with nominal yield stress of 40 ksi.

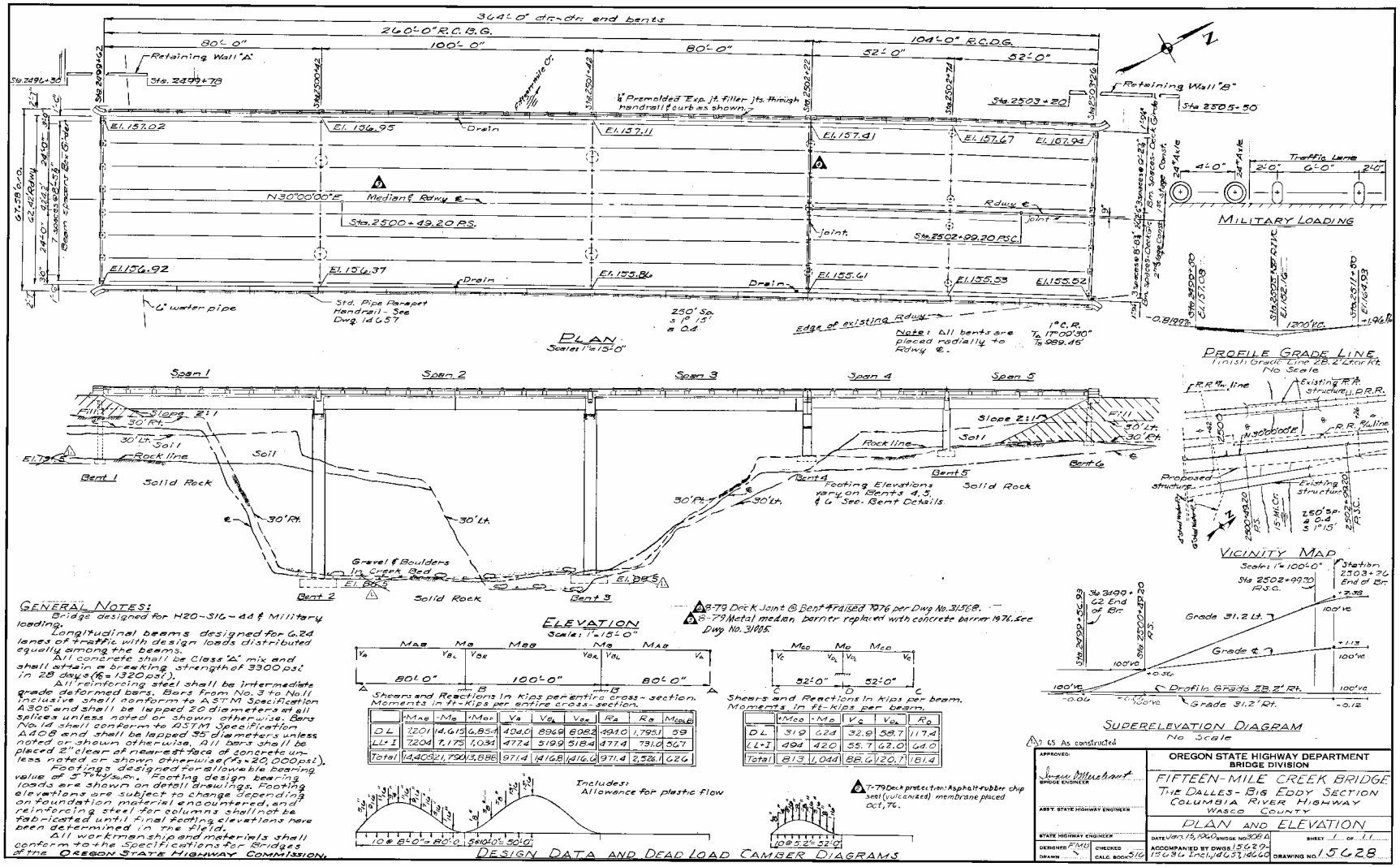

Figure 2.31a: Design drawings for 15 Mile Creek Bridge

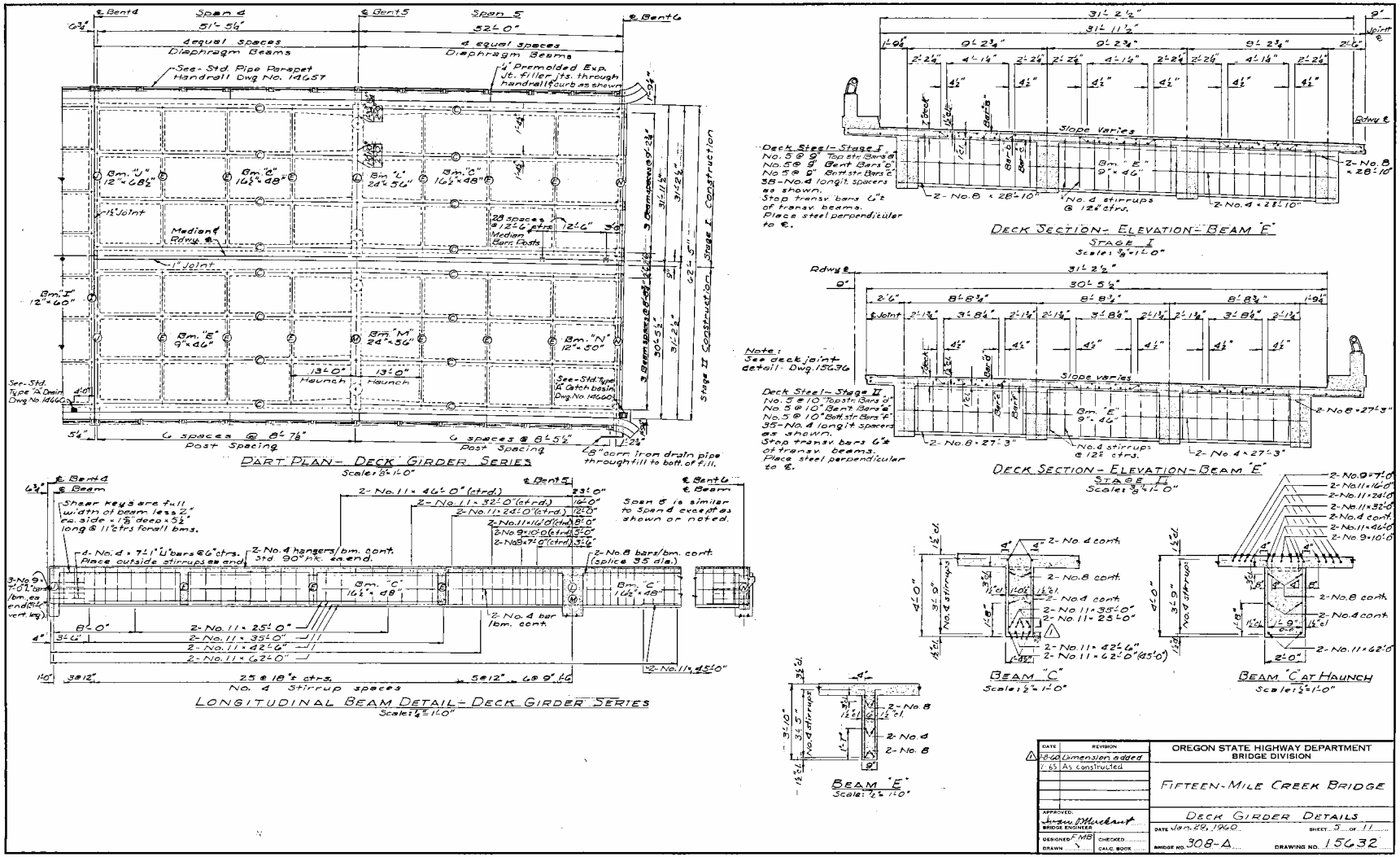

Figure 2.31b: Design drawings for 15 Mile Creek Bridge

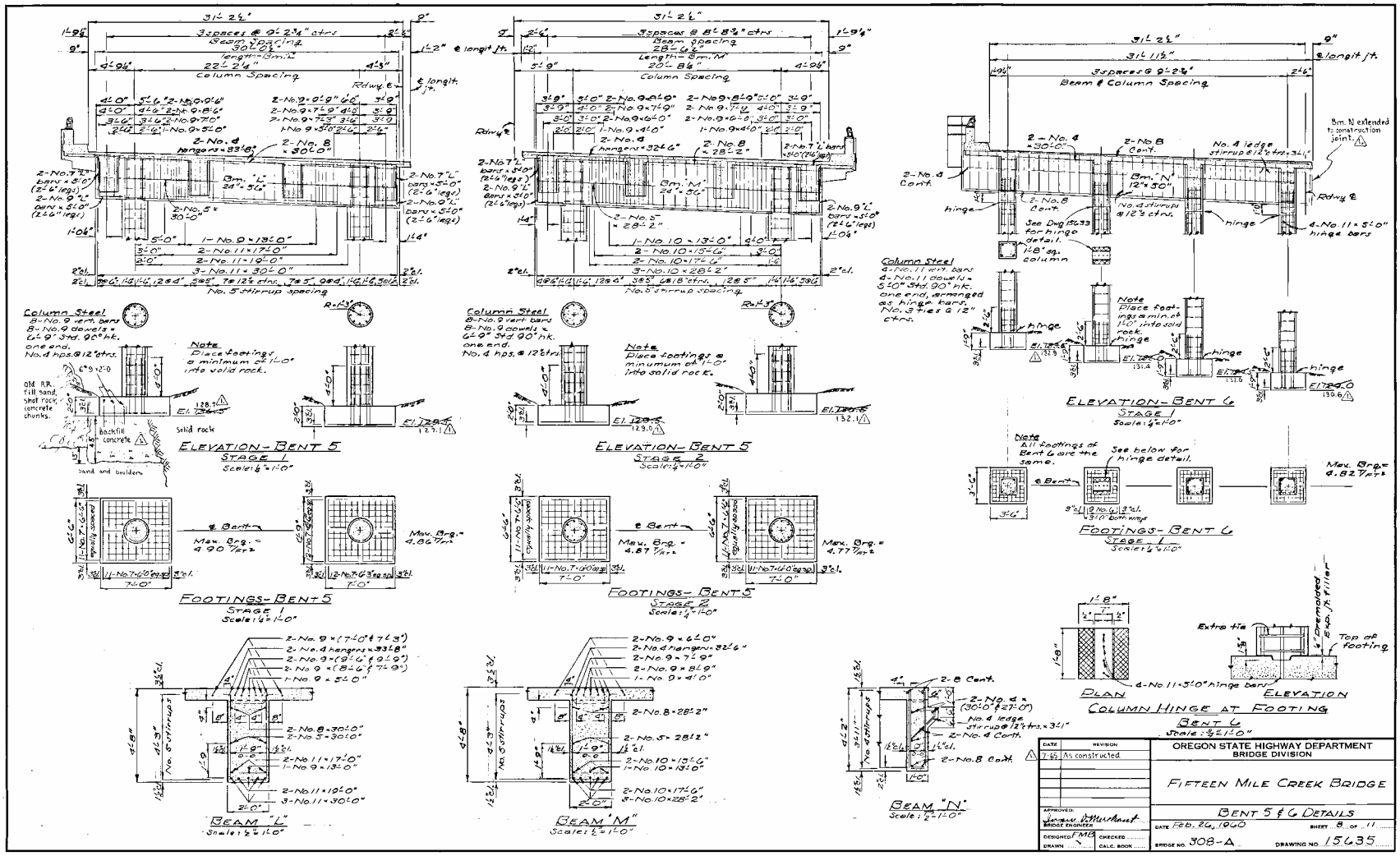

Figure 2.31c: Design drawings for 15 Mile Creek Bridge

Figure 2.32: Portion of 15 Mile Creek Bridge selected for field investigation

2.3.2 Crack Mapping and Instrumentation

The crack mapping and instrumentation techniques corresponded closely with those reported above. Diagonal-tension crack patterns for the girders and bent caps are shown in Figures 2.33a-e. Twenty-seven locations were selected for instrumentation. At two locations on the bent cap, strain gages were installed on multiple stirrup legs crossing a diagonal crack. At other locations, a single stirrup leg was instrumented. At two exterior girder locations, the flexural steel was instrumented, one on the eastbound and one on the westbound lanes near midspan of span 4 (T_east and T_west).

Position sensors were installed at six locations. Instrumentation locations and channel numbers are identified schematically in Figure 2.34. Data were again collected using a Campbell Scientific CR9000 data acquisition system. During the ambient monitoring period, data were sampled at 50 Hz. A digital high-pass filter was utilized with a cut-off frequency of 20 Hz. No digital camera was used for this field study due to communication problems with the camera. The data acquisition system converted sensor readings into corresponding stresses and displacements, and stored the data for later retrieval and analysis.

15 MILE CREEK BRIDGE SPAN 5 - EAST-BOUND LANES DECEMBER 15, 2003
I-84 / 15 MILE CREEK
THE DALLES, OREGON

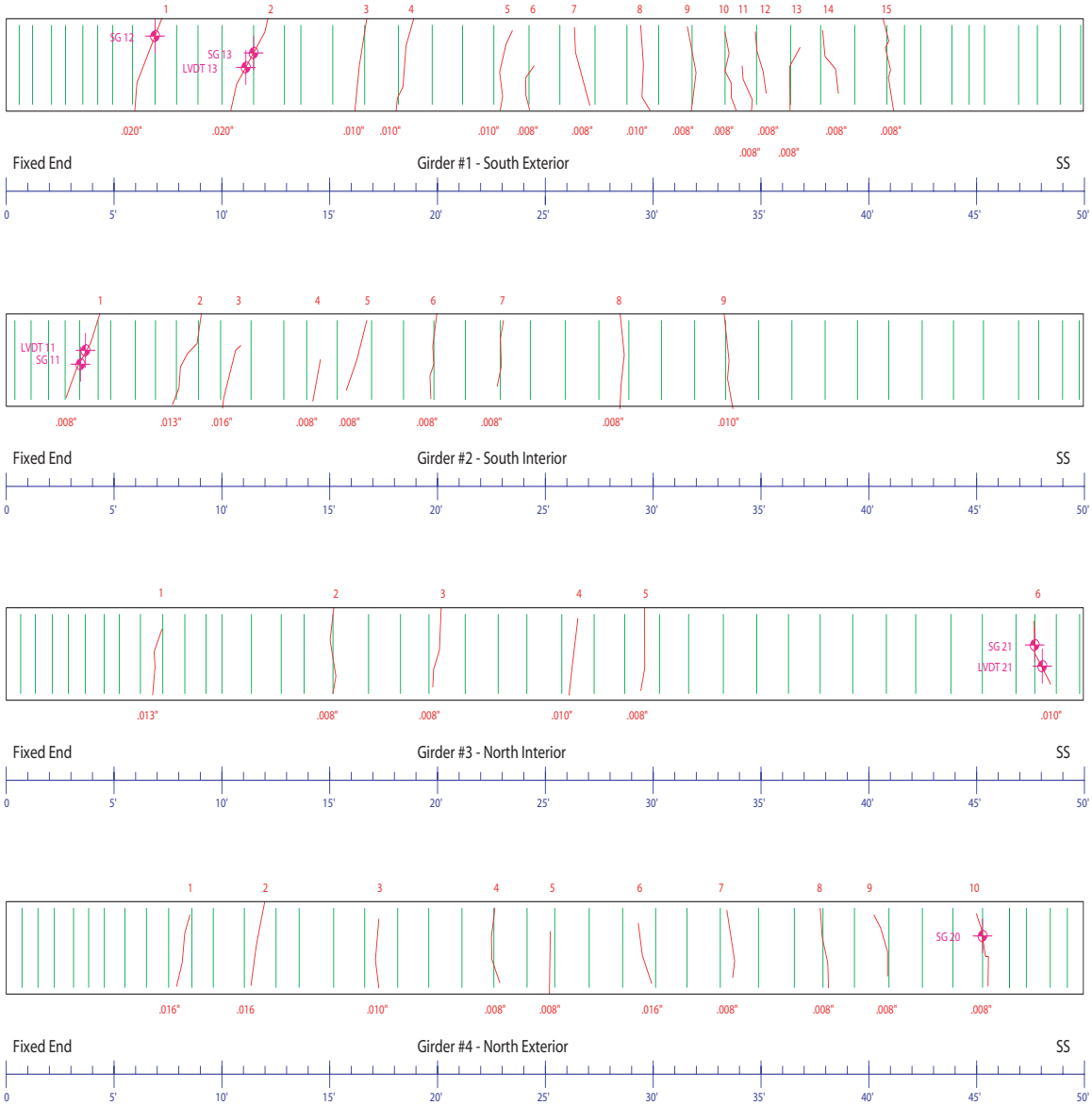

Figure 2.33a: 15 Mile Creek Bridge crack, stirrup, and instrumentation locations on span 5 eastbound

15 MILE CREEK BRIDGE
I-84 / 15 MILE CREEK
THE DALLES, OREGON

SPAN 4 - EAST-BOUND LANES

DECEMBER 15, 2003

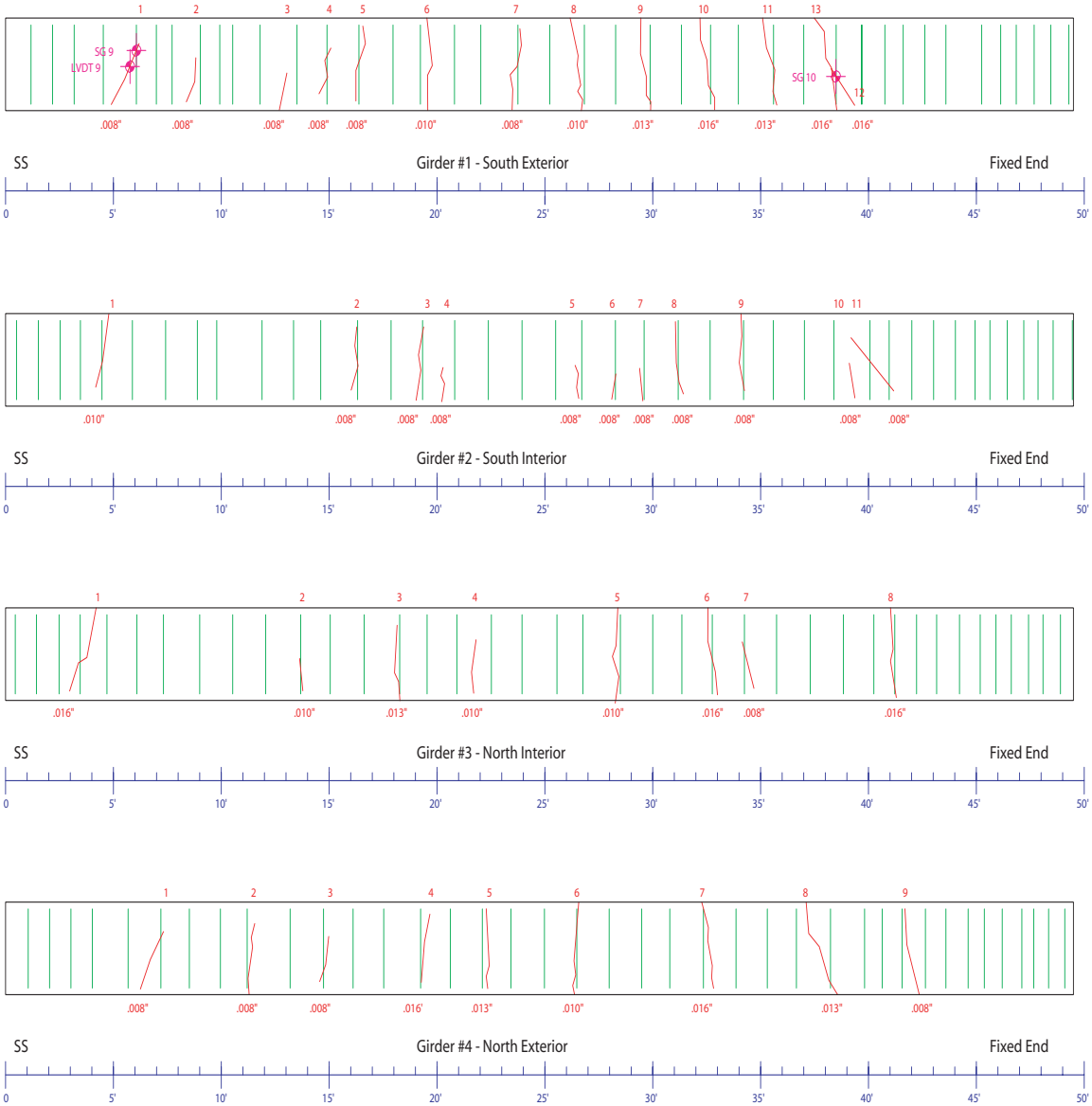

Figure 2.33b: 15 Mile Creek Bridge crack, stirrup, and instrumentation locations on span 4 eastbound

15 MILE CREEK BRIDGE SPAN 5 - WEST-BOUND LANES DECEMBER 15, 2003
I-84 / 15 MILE CREEK
THE DALLES, OREGON

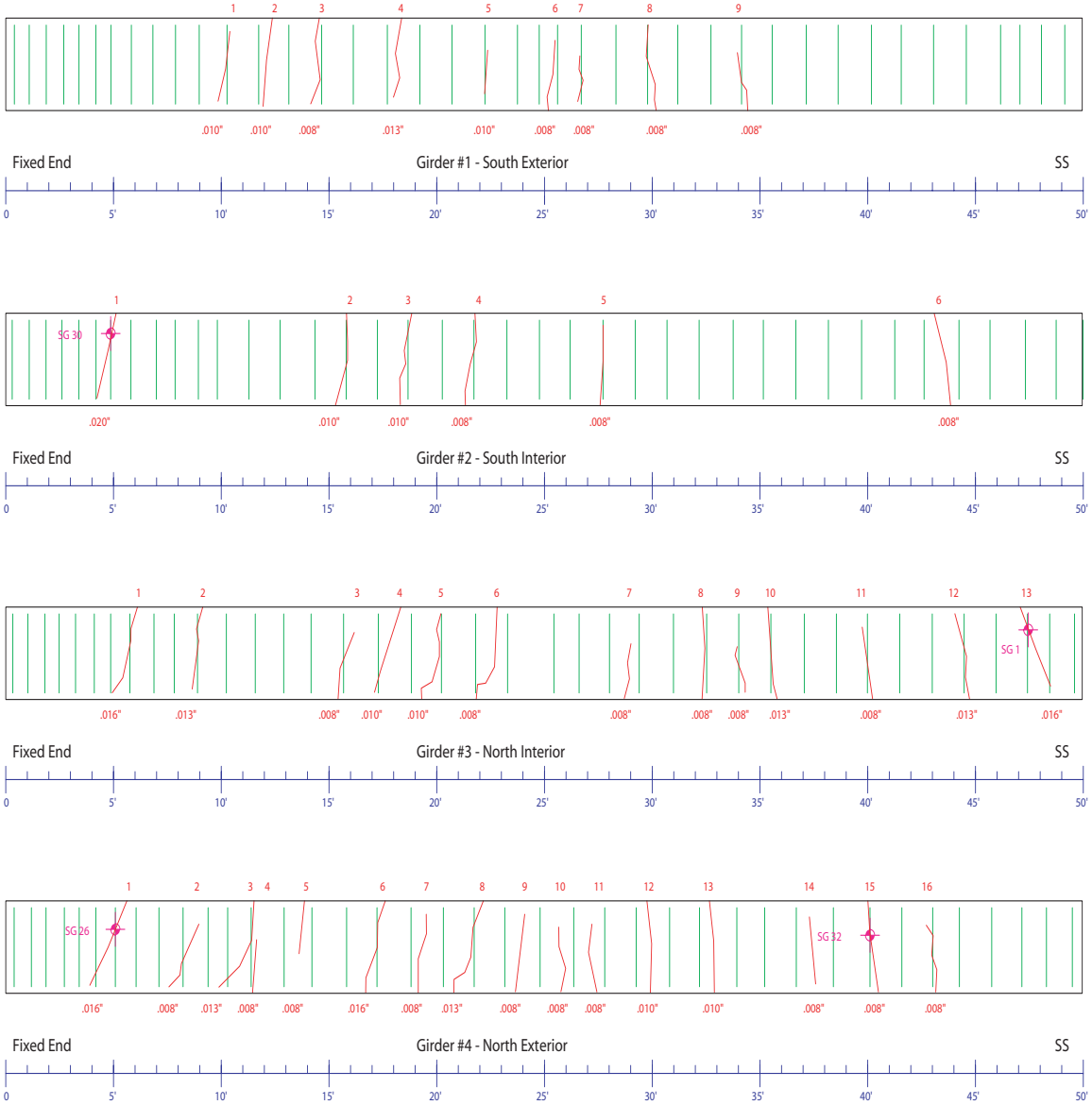

Figure 2.33c: 15 Mile Creek Bridge crack, stirrup, and instrumentation locations on span 5 westbound

15 MILE CREEK BRIDGE
I-84 / 15 MILE CREEK
THE DALLES, OREGON

SPAN 4 - WEST-BOUND LANES

DECEMBER 15, 2003

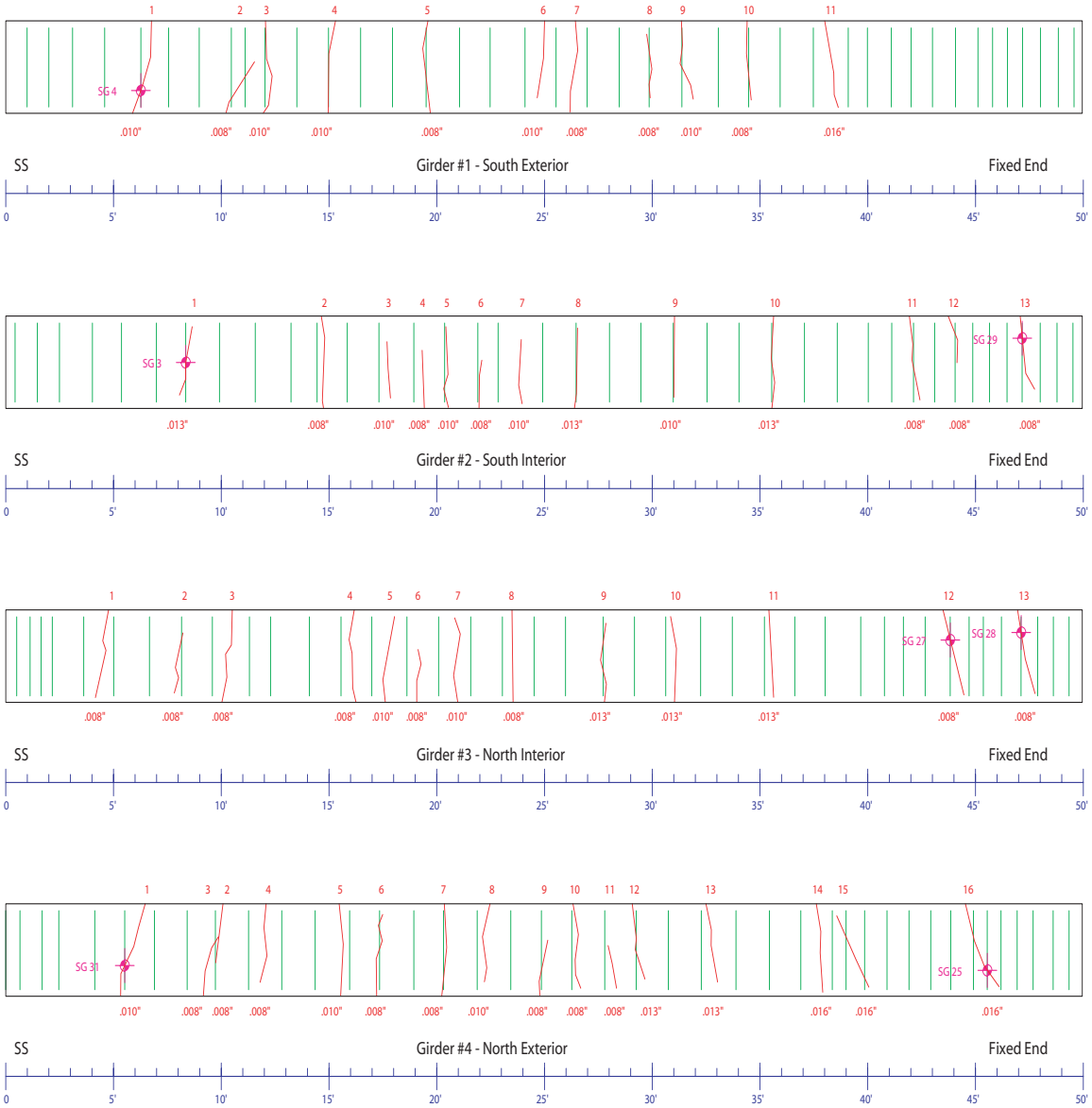

Figure 2.33d: 15 Mile Creek Bridge crack, stirrup, and instrumentation locations on span 4 westbound

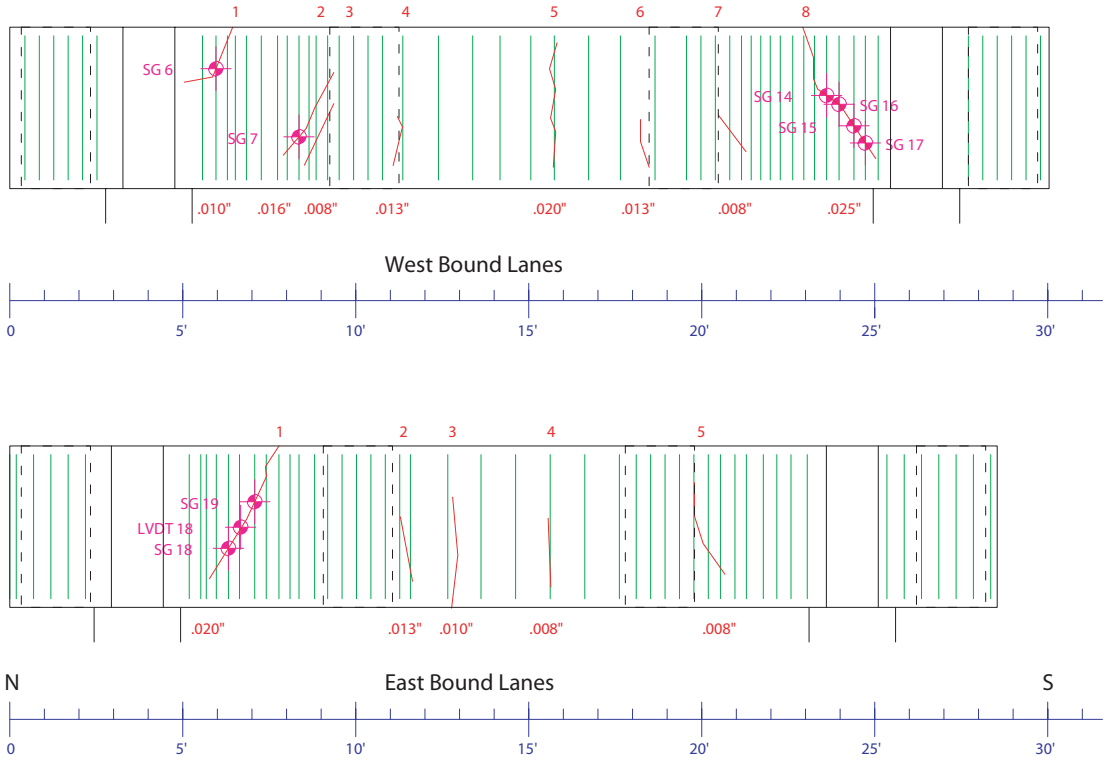

Figure 2.33e: 15 Mile Creek Bridge crack, stirrup, and instrumentation locations on bent caps

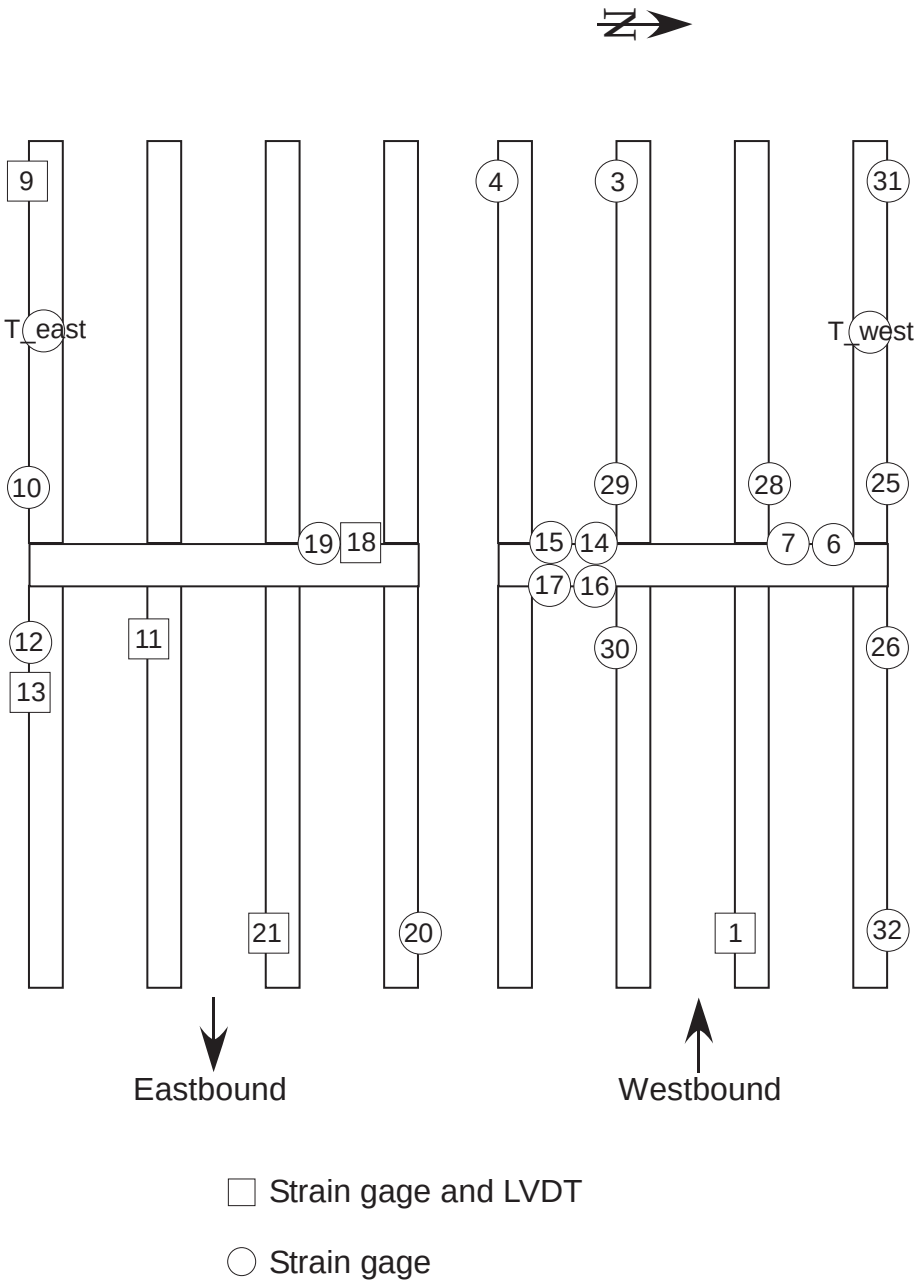

Figure 2.34: Schematic locations of instrumentation on 15 Mile Creek Bridge

2.3.3 Testing Method

Two series of live load data were collected: response under ambient traffic loading and response under controlled truck loading. The stirrup reinforcing stresses and crack displacements generated by normal traffic flow were recorded over a period of 8 calendar days from January 15 to 23, 2004. Individual event histories were recorded by the data logger when stress thresholds

exceeded 2.25 ksi at sensor location T_EAST or 2.75 ksi at sensor location T_WEST. For each trigger event, data were recorded for six seconds prior to and following the trigger. These event histories were used to confirm the presence of the larger magnitude stress ranges.

Controlled truck tests were conducted using a heavily loaded ODOT maintenance truck, as shown in Figure 2.35a. Axle weights and spacing were determined after the test and are shown in Figure 2.35b. Traffic was temporarily slowed using a rolling roadblock so that the control truck would be the only vehicle on the bridge during data collection. The control truck passed over the bridge at several designated speeds and lane positions. Test speeds varied from 5 mph to 66 mph.

Figure 2.35a: Test truck used on 15 Mile Creek Bridge

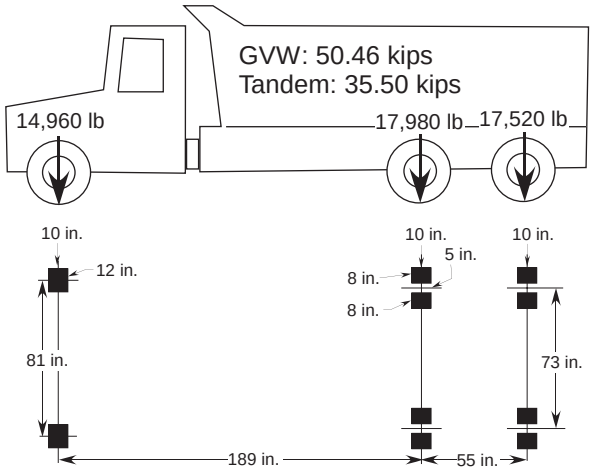

Figure 2.35b: Axle weights and spacing for test truck used on 15 Mile Creek Bridge

Lane locations included placing the truck in the truck lane and in the passing lane. Lane positions and the corresponding truck positions relative to the girder locations are illustrated in Figure 2.36. During each pass of the control truck, stirrup stresses and crack deflections were recorded for each instrumented location. Stirrup strain histories for each of the test runs are shown in Figures 2.37a-l and the crack motions are shown in Figures 2.38a-d. Peak values and stress ranges are summarized in Tables 2.6a and b.

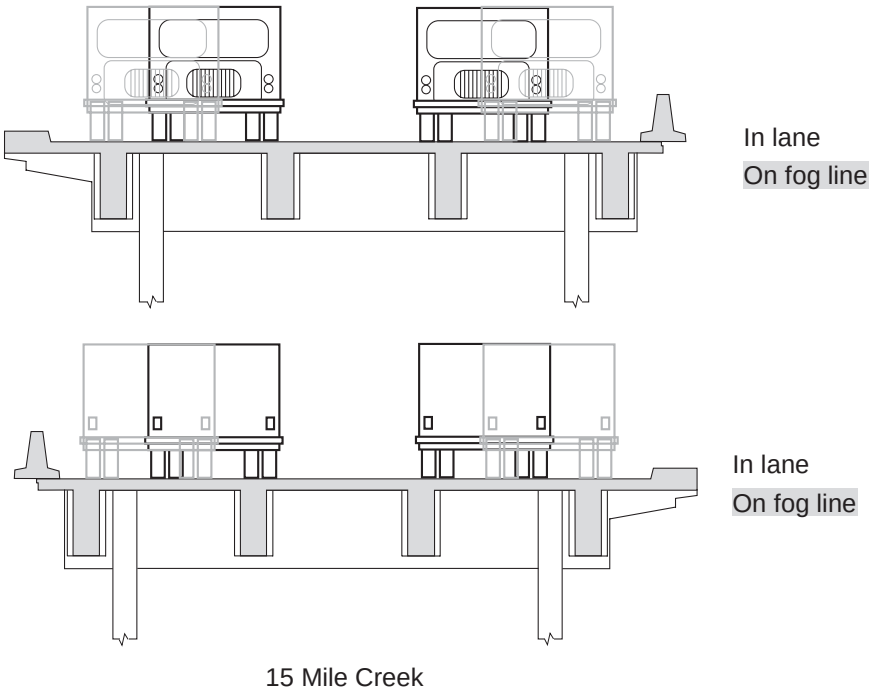

Figure 2.36: Test truck lane location relative to girder positions on 15 Mile Creek Bridge

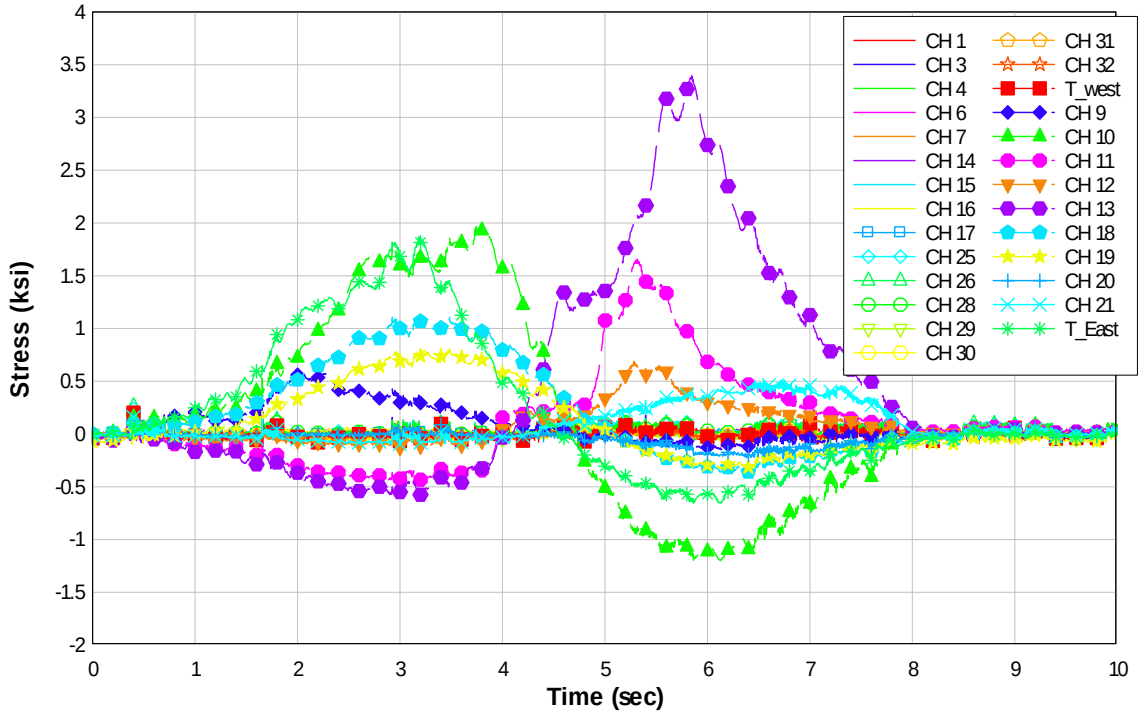

Figure 2.37a: Stirrup stress response for test truck in east-bound truck lane at 5 mph

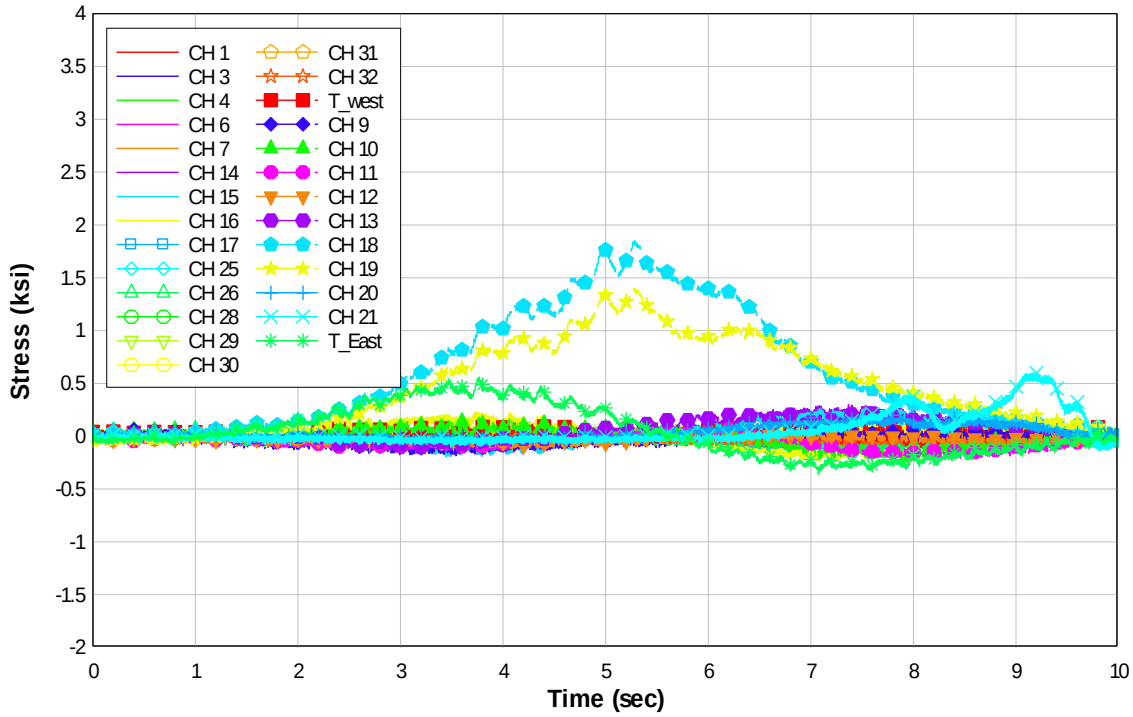

Figure 2.37b: Stirrup stress response for test truck in east-bound passing lane at 5 mph

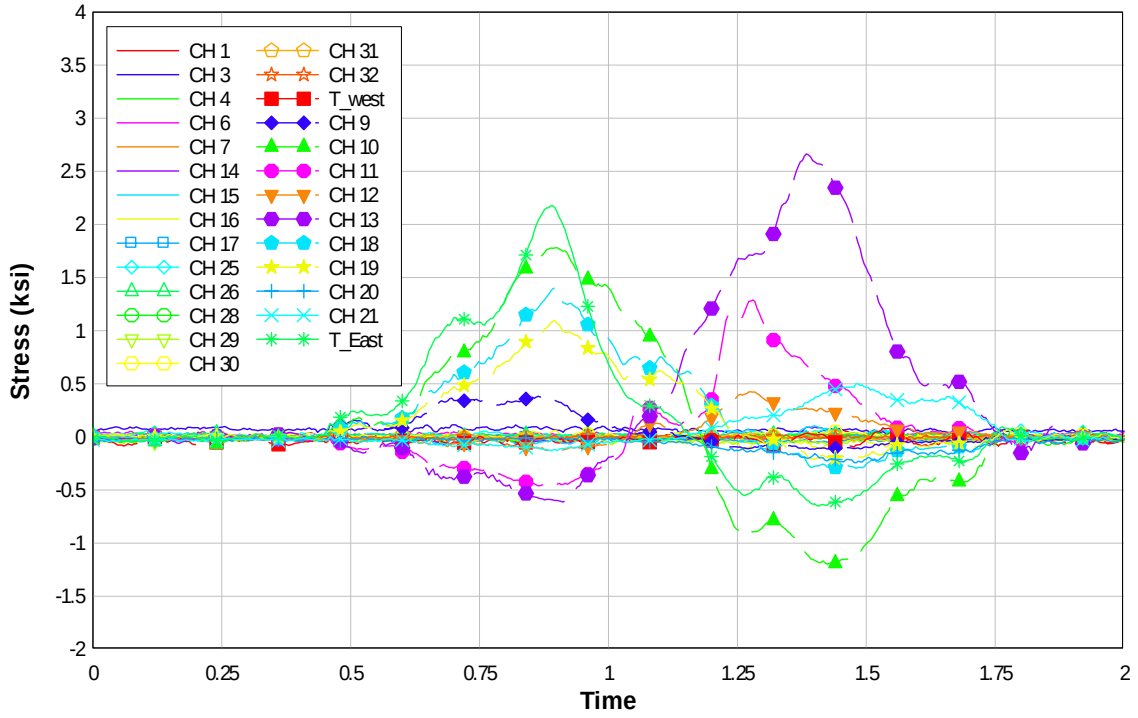

Figure 2.37c: Stirrup stress response for test truck in east-bound truck lane at 55 mph

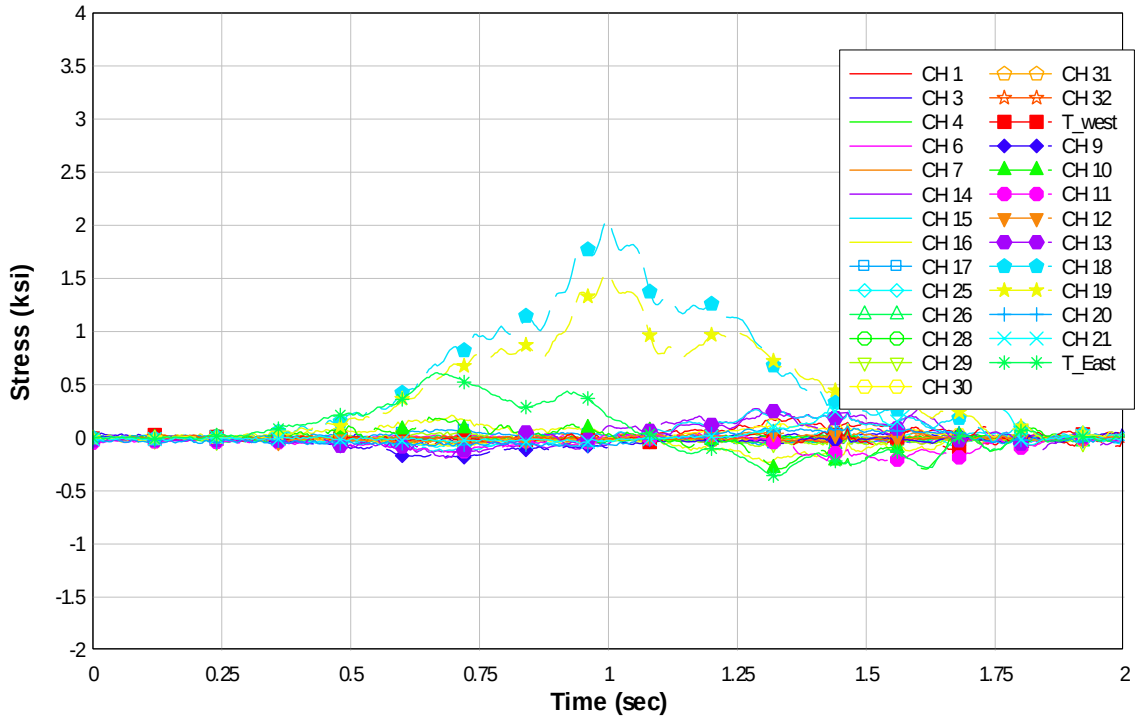

Figure 2.37d: Stirrup stress response for test truck in east-bound passing lane at 55 mph

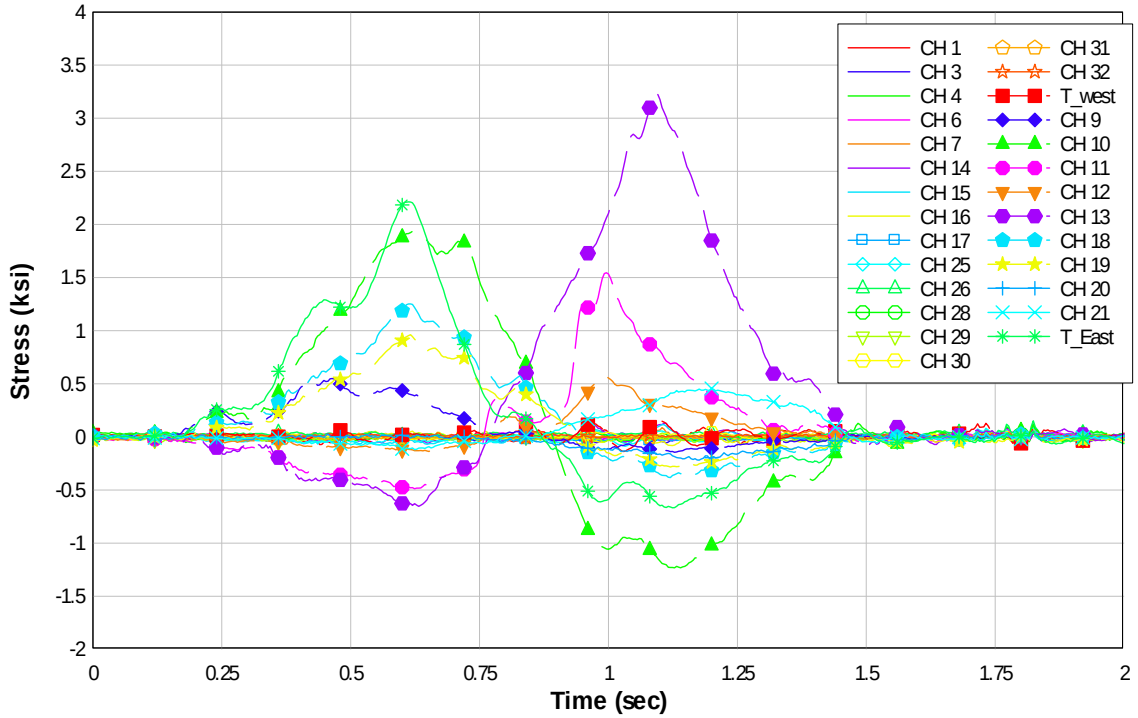

Figure 2.37e: Stirrup stress response for test truck in east-bound truck lane at 65 mph

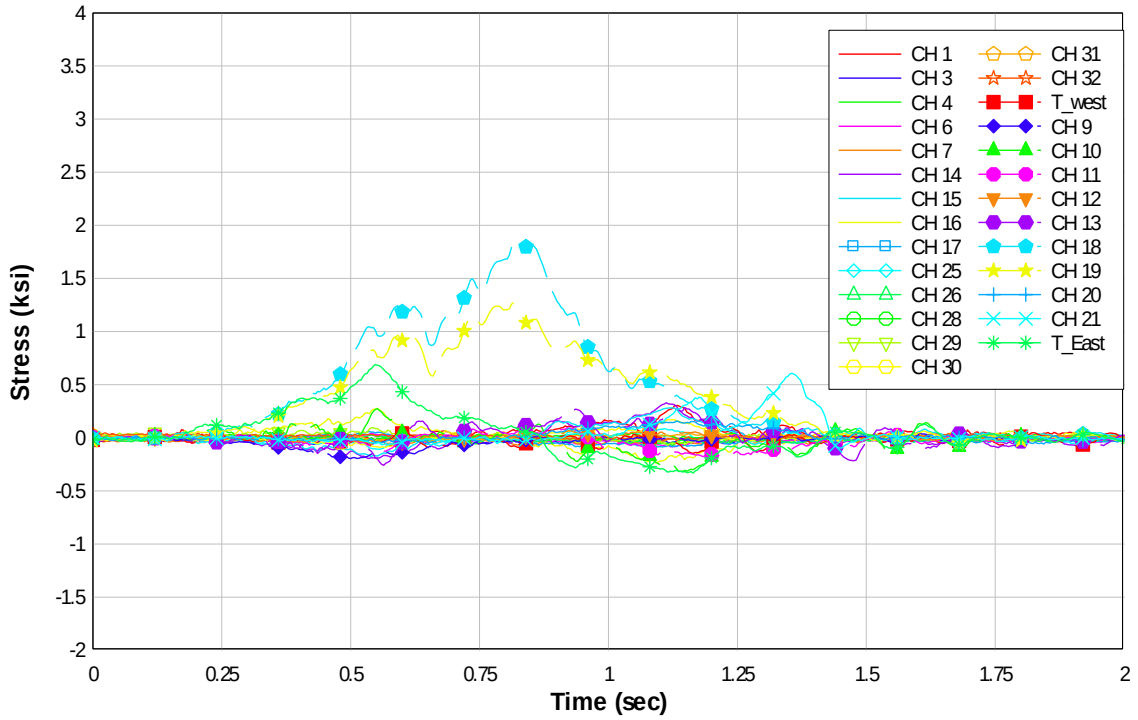

Figure 2.37f: Stirrup stress response for test truck in east-bound passing lane at 65 mph

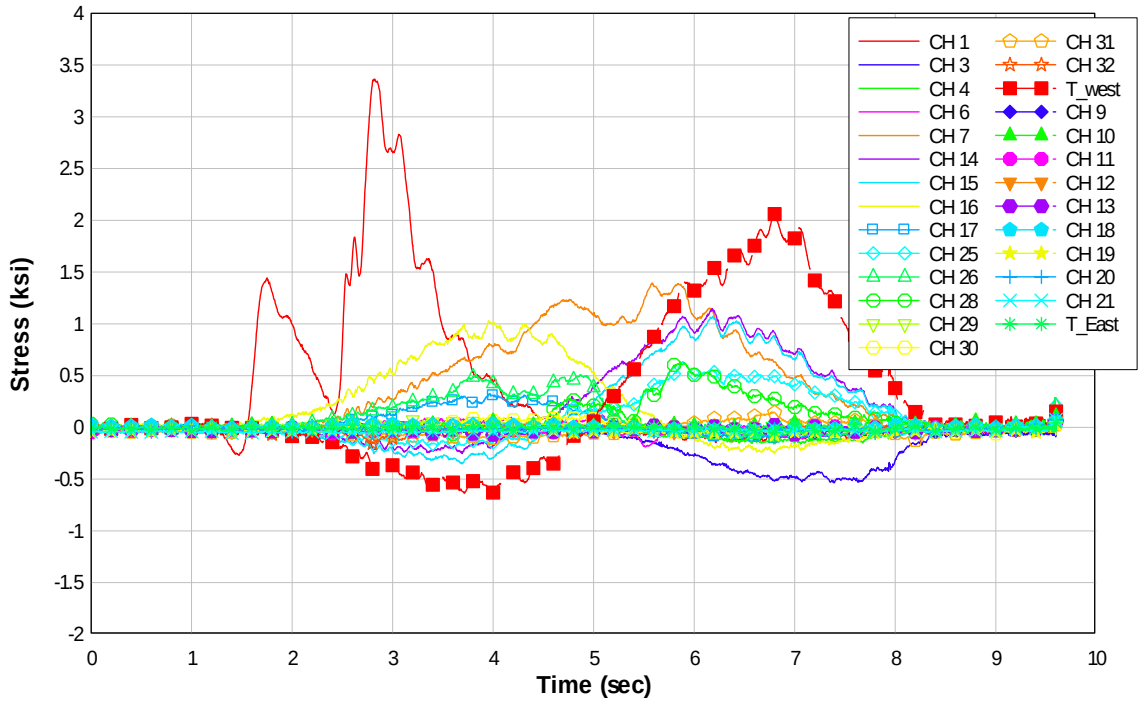

Figure 2.37g: Stirrup stress response for test truck in west-bound truck lane at 5 mph

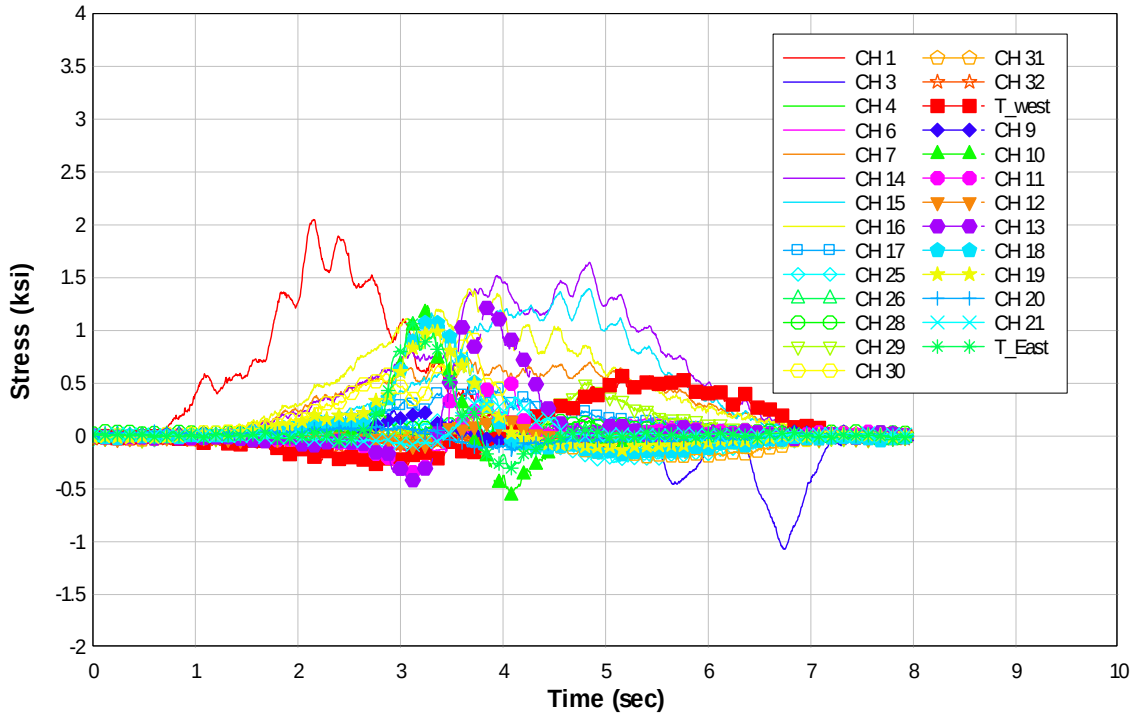

Figure 2.37h: Stirrup stress response for test truck in west-bound passing lane at 5 mph

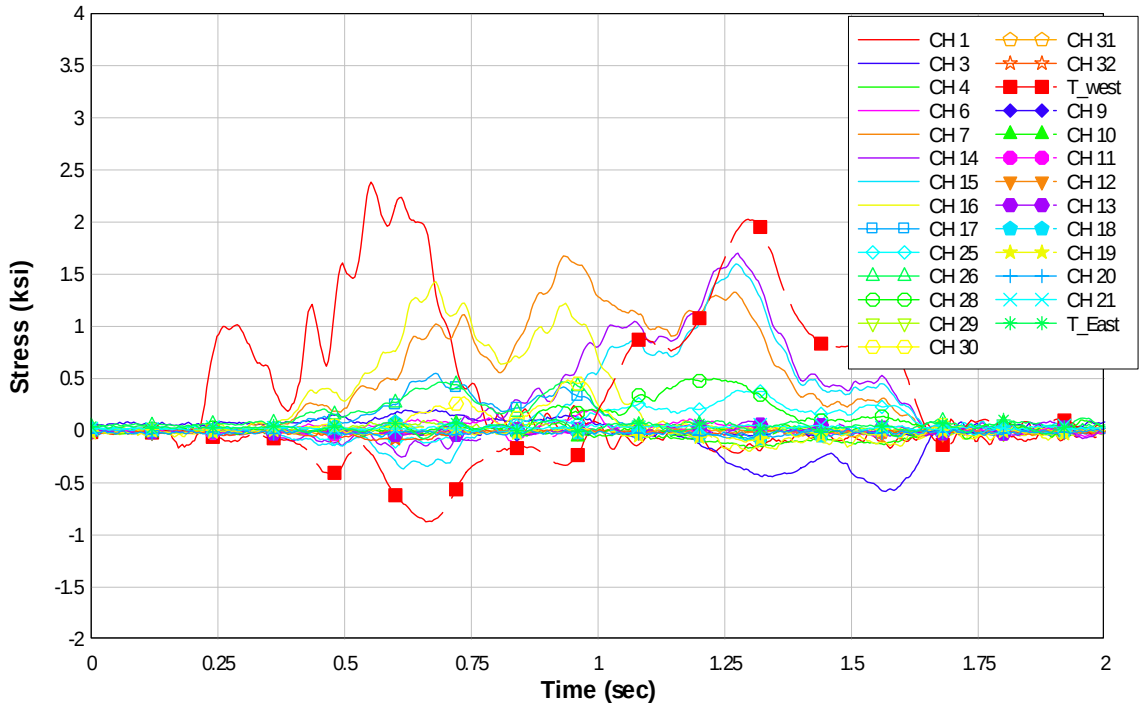

Figure 2.37i: Stirrup stress response for test truck in west-bound truck lane at 55 mph

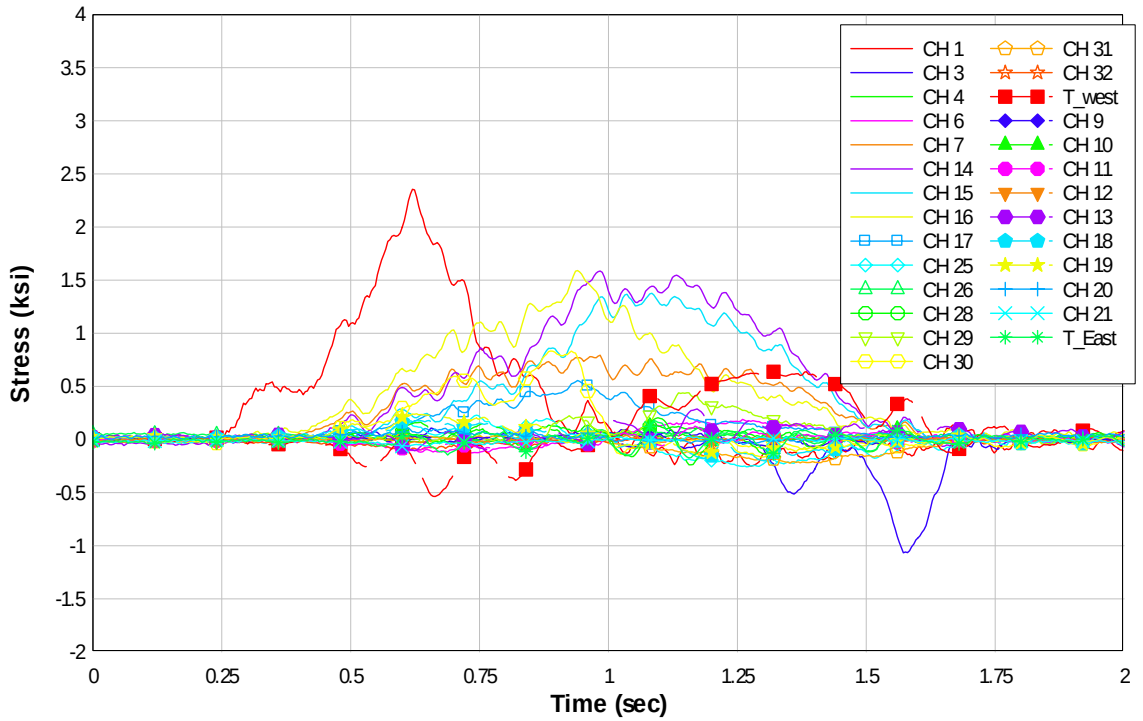

Figure 2.37j: Stirrup stress response for test truck in west-bound passing lane at 55 mph

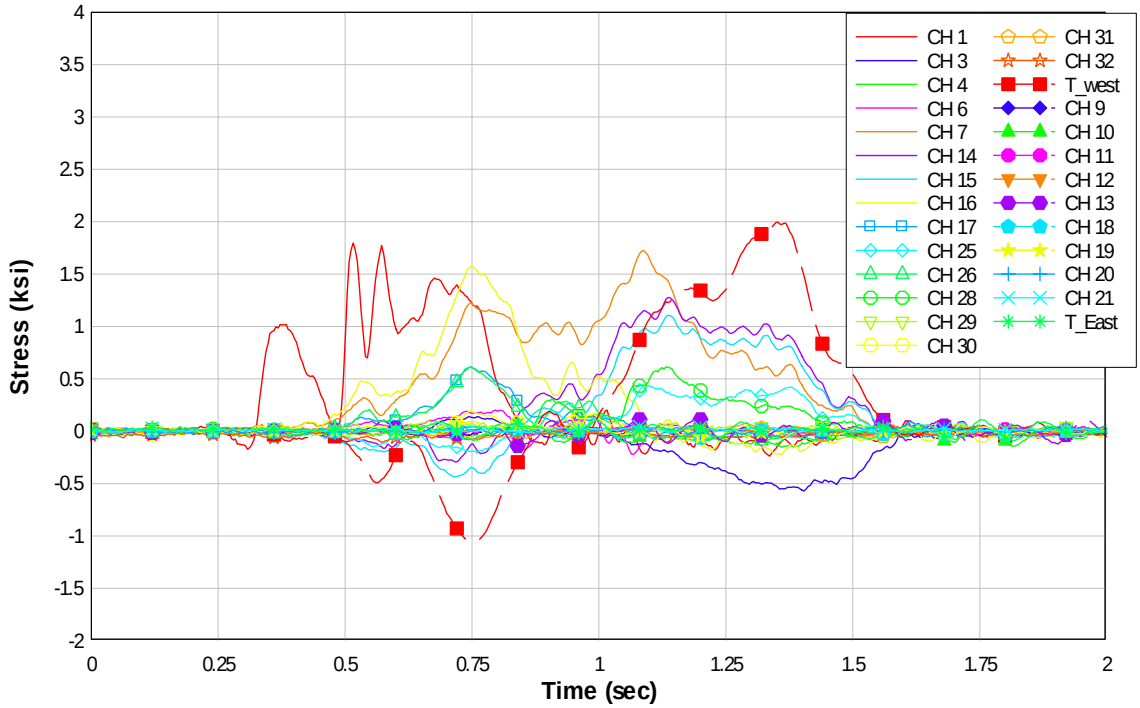

Figure 2.37k: Stirrup stress response for test truck in west-bound truck lane at 65 mph

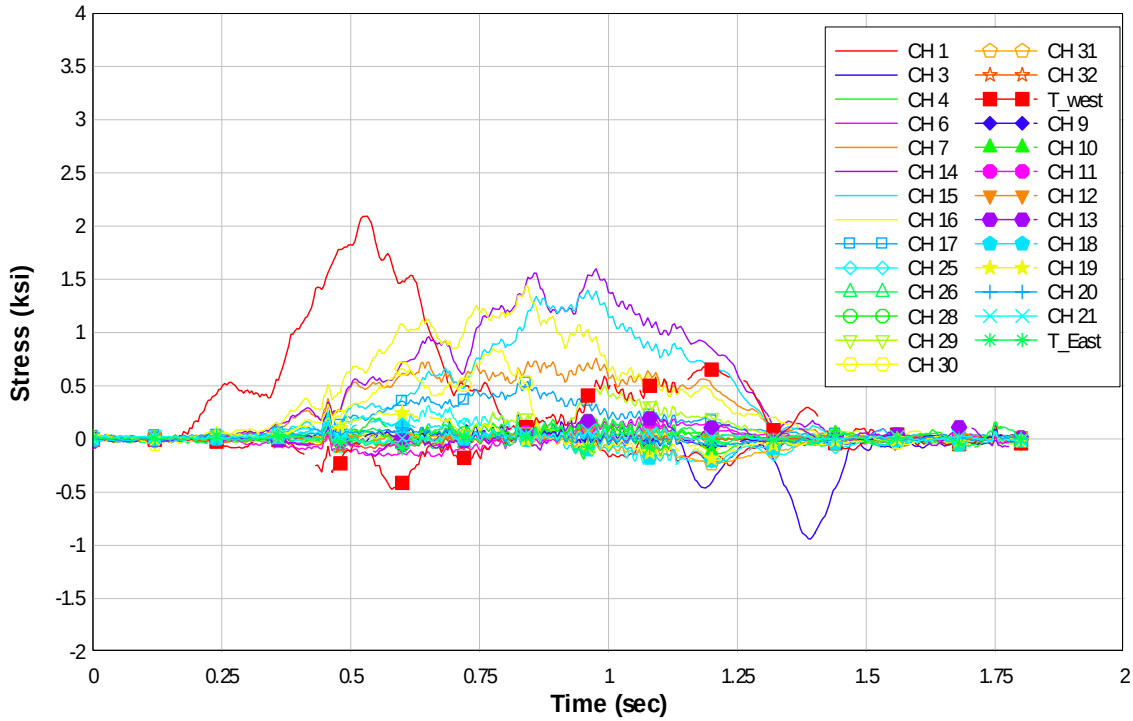

Figure 2.37l: Stirrup stress response for test truck in west-bound passing lane at 65 mph

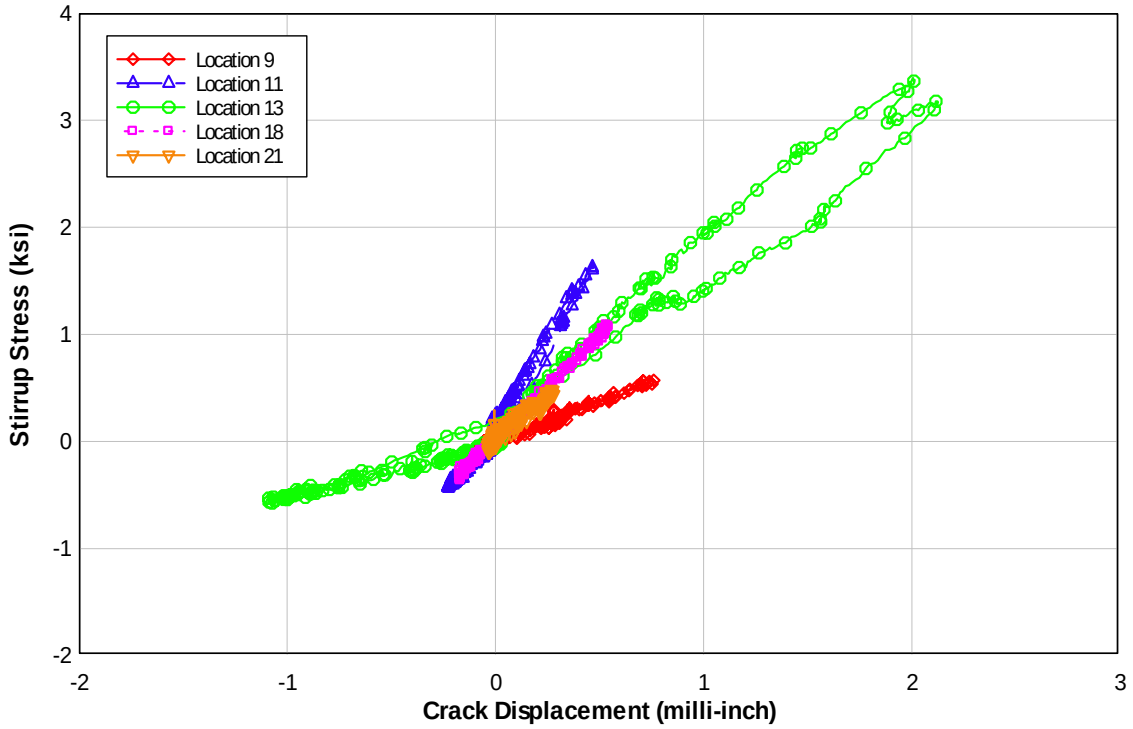

Figure 2.38a: Crack displacement-Stirrup stress response for test truck in east-bound truck lane at 5 mph

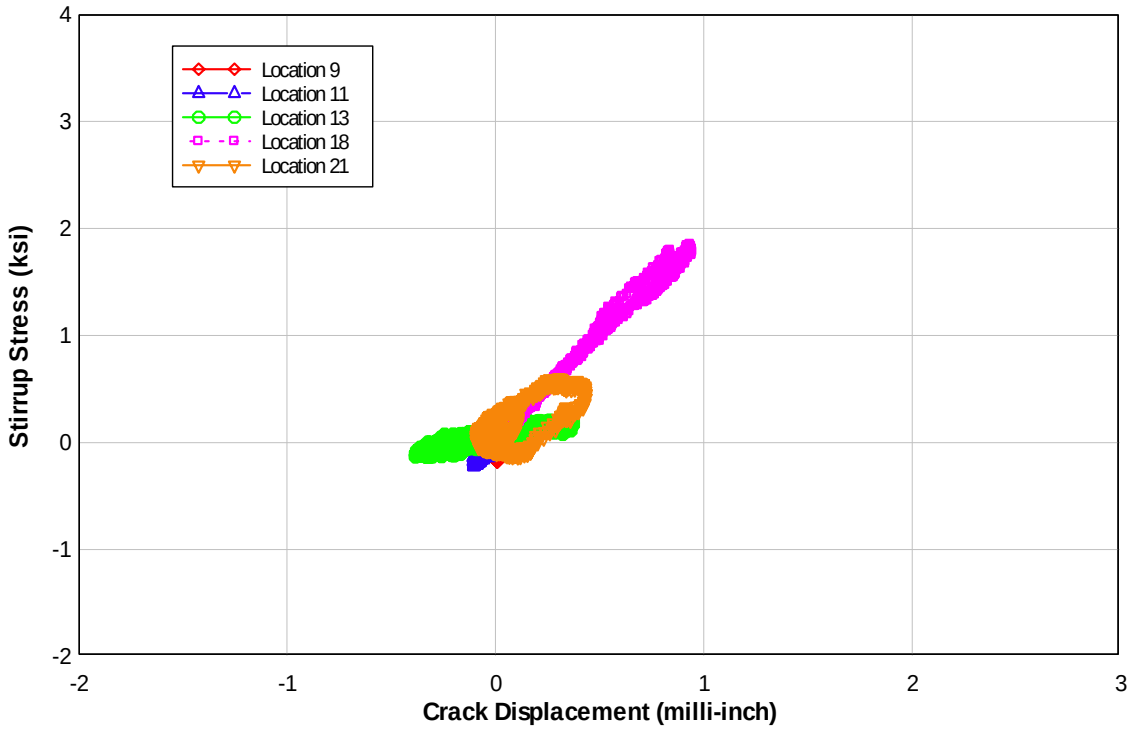

Figure 2.38b: Crack displacement-Stirrup stress response for test truck in east-bound passing lane at 5 mph

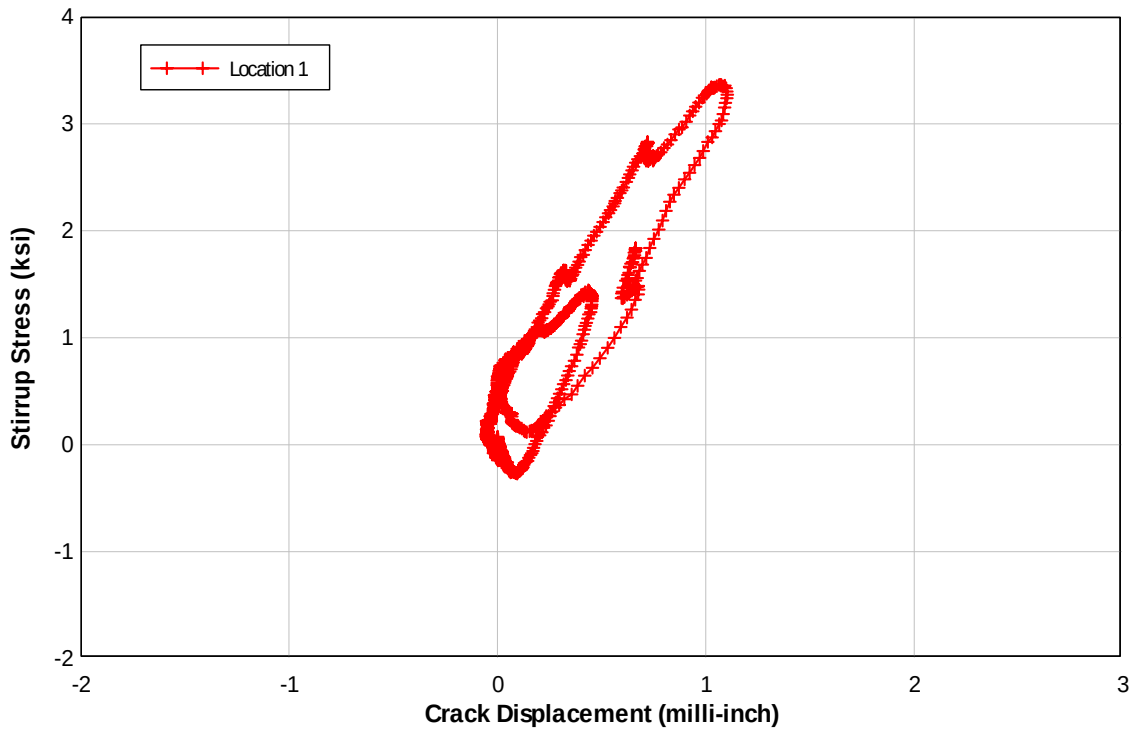

Figure 2.38c: Crack displacement-Stirrup stress response for test truck in west-bound truck lane at 5 mph

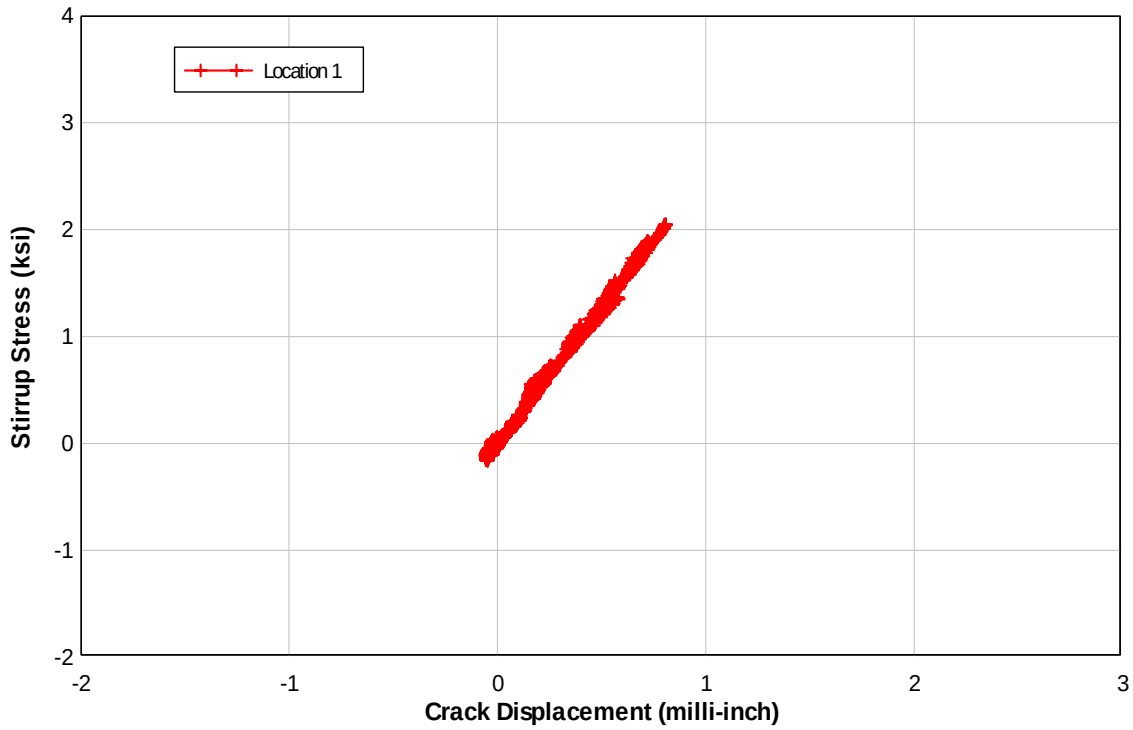

Figure 2.38d: Crack displacement-Stirrup stress response for test truck in west-bound passing lane at 5 mph

Table 2.6a: Maximum and minimum stresses and stress ranges at instrumented locations for test truck westbound on 15 Mile Creek Bridge

Maximum Stress

Truck Direction	Lane Position	Speed (mph)	CH_1 (ksi)	CH_3 (ksi)	CH_4 (ksi)	CH_6 (ksi)	CH_7 (ksi)	CH_14 (ksi)	CH_15 (ksi)	CH_16 (ksi)	CH_17 (ksi)	CH_25 (ksi)	CH_26 (ksi)	CH_28 (ksi)	CH_29 (ksi)	CH_30 (ksi)	CH_31 (ksi)	CH_32 (ksi)	T_West (ksi)
Westbound	Driving	5	3.37	0.15	0.16	0.12	1.40	1.15	1.07	1.03	0.33	0.63	0.51	0.63	0.15	0.12	0.15	0.08	2.07
Westbound	Passing	5	2.05	0.08	0.07	0.18	0.73	1.65	1.40	1.40	0.46	0.16	0.07	0.16	0.52	0.99	0.04	0.02	0.58
Westbound	Driving	55	2.38	0.20	0.04	0.20	1.68	1.70	1.60	1.43	0.55	0.39	0.47	0.50	0.10	0.49	0.04	0.02	2.03
Westbound	Driving	66	1.80	0.14	0.05	0.20	1.72	1.28	1.11	1.57	0.61	0.44	0.61	0.62	0.10	0.20	0.08	0.00	2.00
Westbound	Passing	55	2.36	0.11	0.07	0.19	0.79	1.59	1.38	1.59	0.56	0.23	0.12	0.14	0.44	0.83	0.04	0.03	0.64
Westbound	Passing	65	2.09	0.37	0.22	0.21	0.76	1.60	1.40	1.44	0.54	0.32	0.21	0.20	0.50	0.85	0.15	0.06	0.68

Minimum Stress

Truck Direction	Lane Position	Speed (mph)	CH_1 (ksi)	CH_3 (ksi)	CH_4 (ksi)	CH_6 (ksi)	CH_7 (ksi)	CH_14 (ksi)	CH_15 (ksi)	CH_16 (ksi)	CH_17 (ksi)	CH_25 (ksi)	CH_26 (ksi)	CH_28 (ksi)	CH_29 (ksi)	CH_30 (ksi)	CH_31 (ksi)	CH_32 (ksi)	T_West (ksi)
Westbound	Driving	5	-0.27	-0.53	-0.16	-0.19	-0.07	-0.25	-0.35	-0.25	-0.11	-0.18	-0.10	-0.08	-0.03	-0.08	-0.12	-0.16	-0.64
Westbound	Passing	5	-0.16	-1.07	-0.06	-0.15	-0.03	-0.03	-0.03	-0.03	-0.04	-0.25	-0.04	-0.02	-0.05	-0.09	-0.21	-0.10	-0.30
Westbound	Driving	55	-0.21	-0.58	-0.17	-0.11	-0.05	-0.25	-0.37	-0.20	-0.08	-0.12	-0.01	-0.05	-0.04	-0.04	-0.06	-0.09	-0.87
Westbound	Driving	66	-0.24	-0.57	-0.15	-0.22	-0.05	-0.29	-0.43	-0.22	-0.07	-0.20	-0.09	-0.04	-0.04	-0.06	-0.07	-0.11	-1.07
Westbound	Passing	55	-0.25	-1.07	-0.04	-0.13	-0.05	-0.09	-0.04	-0.01	-0.03	-0.26	-0.03	-0.04	-0.05	-0.14	-0.22	-0.10	-0.54
Westbound	Passing	65	-0.25	-0.94	-0.08	-0.16	-0.04	-0.05	-0.05	-0.03	0.00	-0.24	-0.11	-0.05	-0.05	-0.10	-0.23	-0.09	-0.47

Stress Range

Truck Direction	Lane Position	Speed (mph)	CH_1 (ksi)	CH_3 (ksi)	CH_4 (ksi)	CH_6 (ksi)	CH_7 (ksi)	CH_14 (ksi)	CH_15 (ksi)	CH_16 (ksi)	CH_17 (ksi)	CH_25 (ksi)	CH_26 (ksi)	CH_28 (ksi)	CH_29 (ksi)	CH_30 (ksi)	CH_31 (ksi)	CH_32 (ksi)	T_West (ksi)
Westbound	Driving	5	3.63	0.68	0.32	0.31	1.46	1.40	1.43	1.28	0.44	0.81	0.61	0.71	0.18	0.20	0.27	0.23	2.70
Westbound	Passing	5	2.21	1.15	0.13	0.33	0.76	1.68	1.43	1.43	0.50	0.41	0.11	0.18	0.56	1.09	0.25	0.12	0.88
Westbound	Driving	55	2.60	0.78	0.21	0.32	1.72	1.95	1.97	1.63	0.63	0.50	0.48	0.55	0.14	0.53	0.10	0.11	2.90
Westbound	Driving	66	2.03	0.71	0.21	0.42	1.77	1.57	1.54	1.80	0.69	0.64	0.70	0.66	0.14	0.25	0.15	0.11	3.06
Westbound	Passing	55	2.61	1.18	0.11	0.32	0.85	1.67	1.42	1.60	0.58	0.49	0.15	0.18	0.49	0.97	0.26	0.12	1.17
Westbound	Passing	65	2.35	1.31	0.30	0.37	0.80	1.65	1.45	1.47	0.54	0.56	0.32	0.25	0.55	0.95	0.38	0.15	1.15

Table 2.6b: Maximum and minimum stresses and stress ranges at instrumented locations for test truck eastbound on 15 Mile Creek Bridge

Maximum Stress

Truck Direction	Lane Position	Speed (mph)	CH_9 (ksi)	CH_10 (ksi)	CH_11 (ksi)	CH_12 (ksi)	CH_13 (ksi)	CH_18 (ksi)	CH_19 (ksi)	CH_20 (ksi)	CH_21 (ksi)	T_East (ksi)
Eastbound	Driving	5	0.58	1.97	1.66	0.69	3.40	1.11	0.81	0.13	0.51	1.87
Eastbound	Passing	5	0.13	0.18	0.08	0.05	0.22	1.85	1.40	0.20	0.60	0.56
Eastbound	Driving	55	0.38	1.78	1.29	0.43	2.67	1.40	1.09	0.01	0.50	2.18
Eastbound	Driving	64	0.55	1.94	1.55	0.58	3.24	1.25	0.96	0.06	0.46	2.21
Eastbound	Passing	55	0.06	0.20	0.06	0.07	0.28	2.06	1.56	0.11	0.60	0.61
Eastbound	Passing	65	0.05	0.27	0.10	0.07	0.28	1.86	1.27	0.16	0.61	0.69

Minumum Stress

Truck Direction	Lane Position	Speed (mph)	CH_9 (ksi)	CH_10 (ksi)	CH_11 (ksi)	CH_12 (ksi)	CH_13 (ksi)	CH_18 (ksi)	CH_19 (ksi)	CH_20 (ksi)	CH_21 (ksi)	T_East (ksi)
Eastbound	Driving	5	-0.15	-1.20	-0.44	-0.13	-0.57	-0.36	-0.33	-0.23	-0.10	-0.66
Eastbound	Passing	5	-0.18	-0.25	-0.23	-0.12	-0.14	-0.04	-0.10	-0.10	-0.14	-0.36
Eastbound	Driving	55	-0.12	-1.20	-0.47	-0.13	-0.61	-0.29	-0.21	-0.24	-0.13	-0.65
Eastbound	Driving	64	-0.14	-1.23	-0.49	-0.14	-0.65	-0.38	-0.28	-0.22	-0.12	-0.67
Eastbound	Passing	55	-0.18	-0.30	-0.22	-0.06	-0.19	-0.04	-0.02	-0.08	-0.07	-0.37
Eastbound	Passing	65	-0.20	-0.32	-0.18	-0.06	-0.26	-0.04	-0.06	-0.05	-0.10	-0.33

Stress Range

Truck Direction	Lane Position	Speed (mph)	CH_9 (ksi)	CH_10 (ksi)	CH_11 (ksi)	CH_12 (ksi)	CH_13 (ksi)	CH_18 (ksi)	CH_19 (ksi)	CH_20 (ksi)	CH_21 (ksi)	T_East (ksi)
Eastbound	Driving	5	0.73	3.16	2.10	0.82	3.97	1.48	1.14	0.36	0.61	2.53
Eastbound	Passing	5	0.32	0.43	0.30	0.17	0.35	1.89	1.51	0.29	0.74	0.92
Eastbound	Driving	55	0.50	2.98	1.76	0.55	3.28	1.70	1.30	0.25	0.63	2.83
Eastbound	Driving	64	0.69	3.17	2.03	0.72	3.89	1.64	1.24	0.27	0.57	2.88
Eastbound	Passing	55	0.24	0.49	0.28	0.13	0.47	2.10	1.58	0.20	0.66	0.98
Eastbound	Passing	65	0.24	0.59	0.27	0.13	0.54	1.90	1.33	0.21	0.70	1.02

2.4 AMBIENT TRAFFIC INDUCED STIRRUP STRESS

Ambient traffic induced stresses in stirrups at crack locations were monitored at each bridge for a period of at least 8 days. The stress-ranges and numbers of cycles recorded at the instrumented locations are shown in Figures 2.39a, b, and c for McKenzie River, Jasper, and 15 Mile Creek Bridges, respectively.

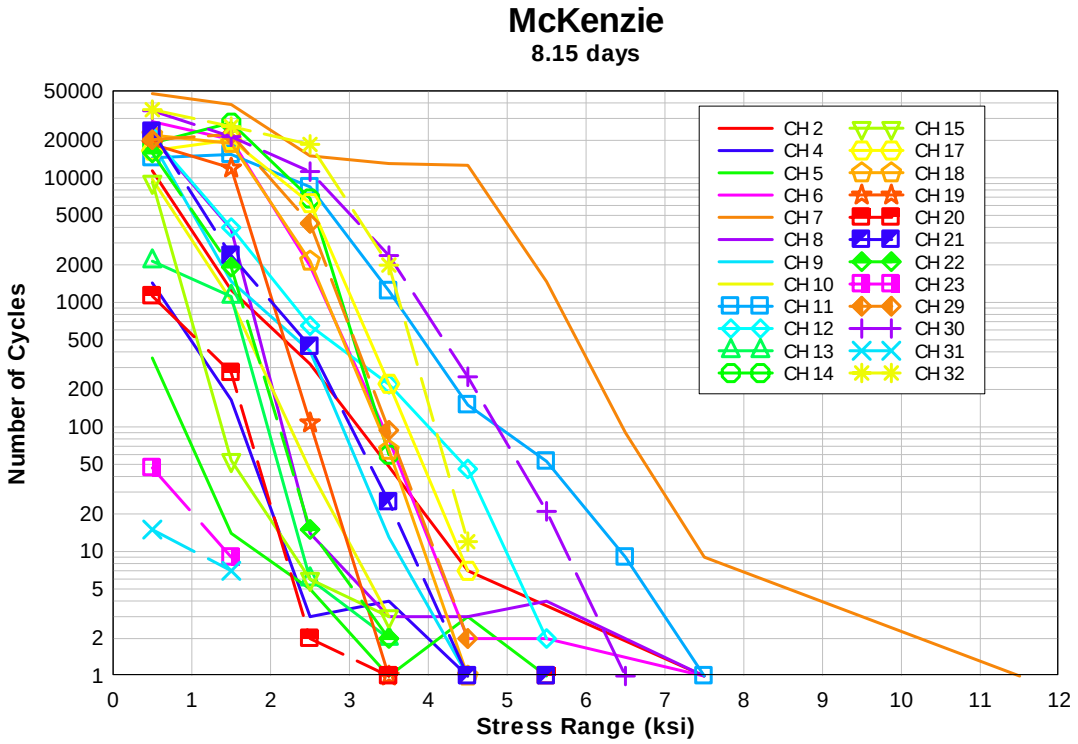

Figure 2.39a: S-N response for all instrumented locations on McKenzie River Bridge for period of 8.15 days

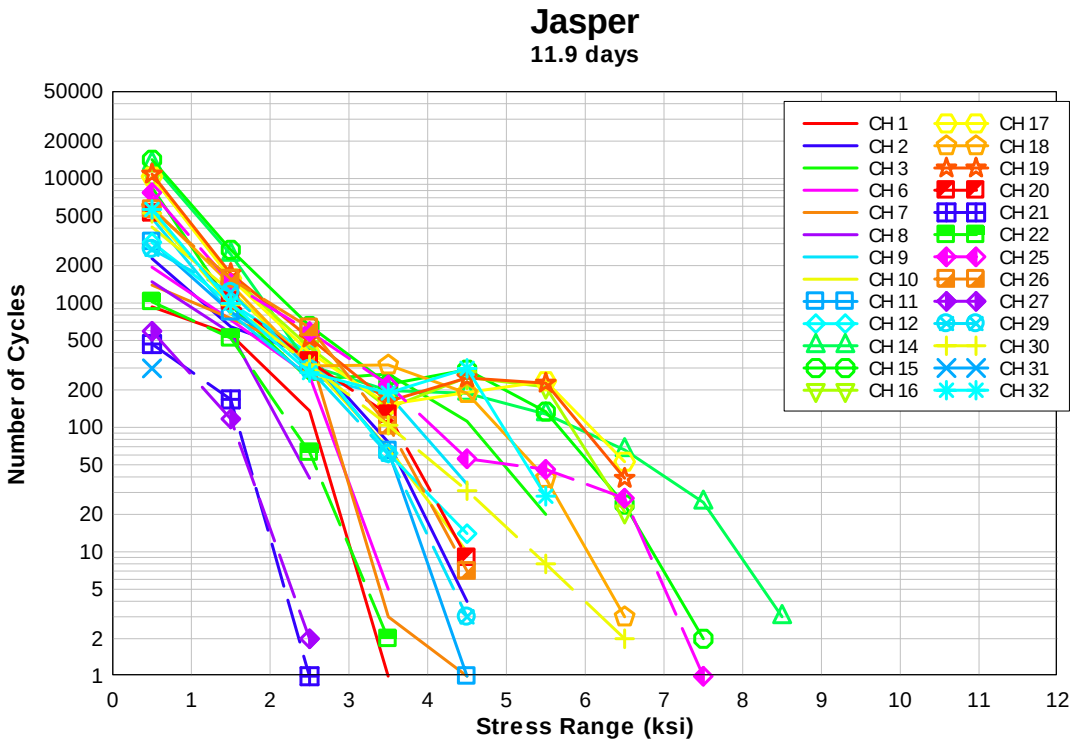

Figure 2.39b: S-N response for all instrumented locations on Jasper Bridge for period of 11.9 days

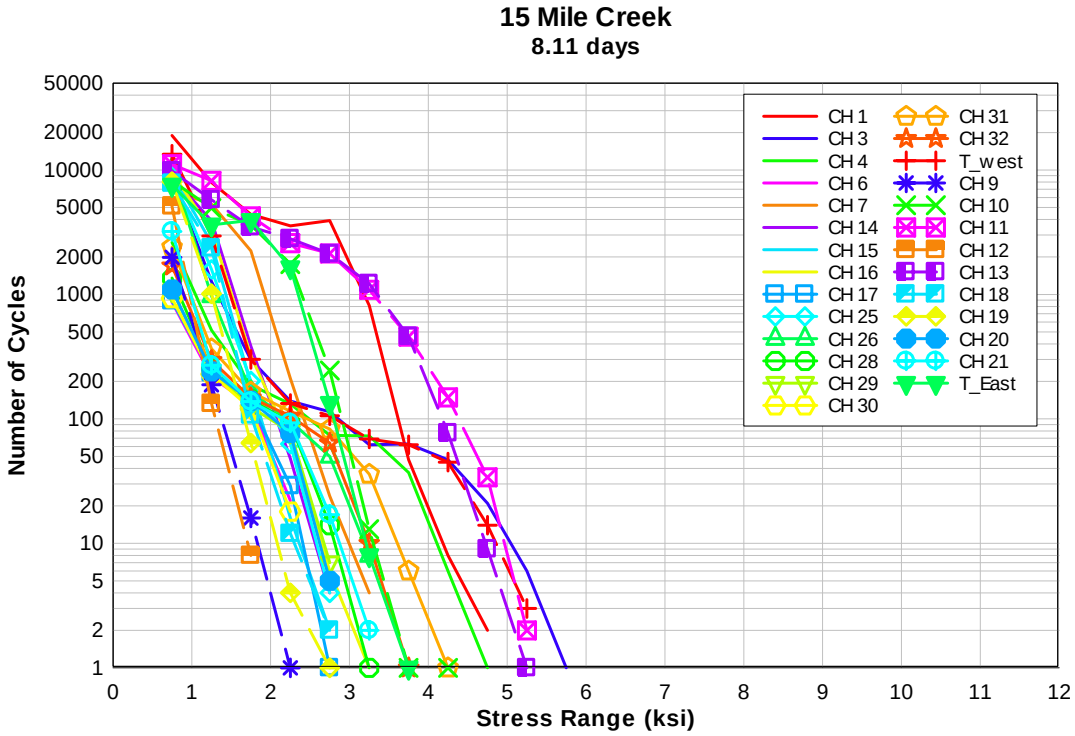

Figure 2.39c: S-N response for all instrumented locations on 15 Mile Creek Bridge for period of 8.1 days

The largest single stress-range measured at any location was approximately 12 ksi. Using Miner's Rule (*Miner 1945*), the variable amplitude stresses can be described as an equivalent constant amplitude stress-range for each of the instrumented locations:

$$SR_{eqv} = \sqrt[3]{\sum \frac{n_i}{N_{tot}} SR_i^3} \qquad \textbf{(2-1)}$$

where SR_i is the ith stress-range, n_i is the number of cycles observed for the ith stress-range, and N_{tot} is the total number of cycles at all stress ranges.

The equivalent constant amplitude stress-ranges were below 2 ksi at all locations (except for one on McKenzie River Bridge – 2.64 ksi at Location 7, an interior girder at the southern simple-support of the 3-span continuous portion) as seen in Table 2.7a, b, and c for McKenzie River, Jasper, and 15 Mile Creek Bridges, respectively.

Table 2.7a: Equivalent constant amplitude stress range for instrumented locations on McKenzie bridge

Instrument Location	Number of Cycles Measured in Field	Equivalent Constant Amplitude Stress Range (ksi)	Projected # of Cycles in 50 years	Laboratory Stress Range to Simulate 50 years of service
CH_2	13021	1.019	29171771	2.49
CH_4	1609	1.005	3604745	1.22
CH_5	383	1.580	858059	1.19
CH_6	50676	1.289	113532654	4.95
CH_7	128525	2.636	287942702	13.82
CH_8	25006	0.886	56022526	2.69
CH_9	21222	0.882	47544991	2.54
CH_10	10832	0.800	24267616	1.84
CH_11	39814	1.880	89197827	6.67
CH_12	26516	1.150	59405475	3.56
CH_13	3267	1.088	7319267	1.68
CH_14	53599	1.564	120081236	6.13
CH_15	9324	0.551	20889148	1.21
CH_17	43220	1.604	96828505	5.84
CH_18	43203	1.336	96790419	4.87
CH_19	30775	1.131	68947183	3.68
CH_20	1403	0.976	3143230	1.13
CH_21	26420	0.899	59190400	2.78
CH_22	17764	0.791	39797815	2.14
CH_23	56	0.865	125460	0.34
CH_29	46997	1.471	105290357	5.51
CH_30	69947	1.759	156706697	7.53
CH_31	22	1.050	49288	0.31
CH_32	81645	1.790	182914467	8.06

Table 2.7b: Equivalent constant amplitude stress range for instrumented locations on Jasper Bridge

Instrument Location	Number of Cycles Measured in Field	Equivalent Constant Amplitude Stress Range (ksi)	Projected # of Cycles in 50 years	Laboratory Stress Range to Simulate 50 years of service
CH_1	1627	1.37	2495189	1.47
CH_2	3386	1.53	5192815	2.10
CH_3	10091	1.49	15475693	2.94
CH_6	2938	1.33	4505756	1.75
CH_7	2544	1.53	3901513	1.91
CH_8	2097	1.09	3215987	1.28
CH_9	6104	1.44	9361176	2.42
CH_10	5734	1.34	8793739	2.19
CH_11	4393	1.39	6737164	2.09
CH_12	4534	1.45	6953403	2.20
CH_14	16590	1.77	25442647	4.14
CH_15	18191	1.68	27897962	4.05
CH_16	13076	1.86	20053529	4.01
CH_17	13007	1.91	19947710	4.11
CH_18	8142	1.81	12486681	3.34
CH_19	13811	1.89	21180735	4.16
CH_20	6776	1.32	10391765	2.29
CH_21	637	1.00	976912	0.79
CH_22	1611	1.22	2470651	1.31
CH_25	10090	1.65	15474160	3.26
CH_26	7978	1.38	12235168	2.52
CH_27	712	0.89	1091933	0.73
CH_29	4285	1.41	6571534	2.09
CH_30	6691	1.39	10261408	2.40
CH_31	298	0.50	457017	0.31
CH_32	7432	1.87	11397815	3.33

Table 2.7c: Equivalent constant amplitude stress range for instrumented locations on 15 Mile Creek Bridge

Instrument Location	Number of Cycles Measured in Field	Equivalent Constant Amplitude Stress Range (ksi)	Projected # of Cycles in 50 years	Laboratory Stress Range to Simulate 50 years of service
CH_1	39652	1.72	89229223	6.09
CH_3	10749	1.31	24188564	3.00
CH_4	3655	1.45	8224877	2.33
CH_6	1241	1.12	2792633	1.25
CH_7	14644	1.25	32953514	3.17
CH_14	13154	1.02	29600555	2.51
CH_15	12151	0.94	27343496	2.26
CH_16	13162	1.00	29618557	2.45
CH_17	1284	1.14	2889396	1.29
CH_25	10845	0.93	24404593	2.15
CH_26	11324	0.94	25482491	2.20
CH_28	1859	1.20	4183323	1.54
CH_29	1534	1.20	3451973	1.44
CH_30	1301	1.09	2927651	1.24
CH_31	3173	1.32	7140228	2.02
CH_32	2320	1.29	5220715	1.78
T_West	17095	1.18	38469020	3.15
CH_9	2191	0.84	4930425	1.14
CH_10	18794	1.46	42292293	4.03
CH_11	30032	1.86	67581258	6.02
CH_12	5268	0.78	11854624	1.41
CH_13	25764	1.92	57976942	5.91
CH_18	10279	0.94	23130919	2.13
CH_19	9129	0.86	20543064	1.87
CH_20	1559	1.20	3508231	1.44
CH_21	3734	1.03	8402651	1.67
T_East	16940	1.47	38120222	3.91

Fatigue tests of rebar indicate that long-life can be achieved if the stress-range is below 10 ksi at bend or tack welds (*McGregor 1997*). If no significant stress concentrations are found on the rebar, long-life can be achieved if the stress-range is below 20 ksi. Typical fatigue S-N curves for deformed reinforcing bars are shown in Figure 2.40. Given the relatively low equivalent constant amplitude stress-range identified at instrumented locations (52 diagonal crack locations on 3 different bridges), metal fatigue leading to fracture of the embedded stirrups is unlikely. However, there may be other sources of deterioration such as bond fatigue, repeated overloads, or corrosion that may adversely impact structural performance over time.

Field measured stress ranges and numbers of cycles for each instrumented stirrup location were used to determine an equivalent stress range for laboratory specimens subject to large numbers of service-level loads. For high-cycle laboratory specimens, 2,000,000 cycles of repeated loading was chosen to assess potential capacity deterioration under service conditions. The stress range required to produce equivalent damage in laboratory specimens at 2,000,000 cycles as that for bridge girders in the field over a period of 50 years, was estimated by computing an equivalent

stress range per Equation 2-1. It was conservatively assumed that the field recorded stress ranges and numbers of cycles remained constant over the life of the bridge.

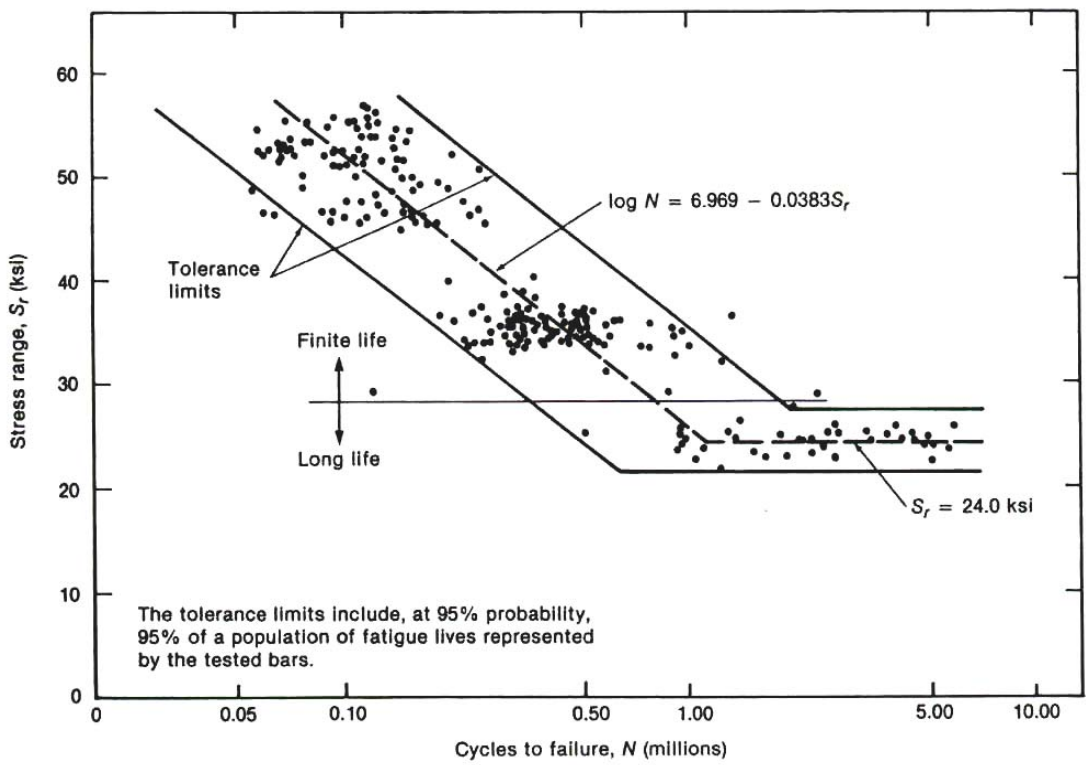

Figure 2.40: Fatigue behavior of reinforcing steel (*MacGregor 1997*)

The stress ranges required to impose stirrup damage equivalent to 50 years of service life for the laboratory specimens are shown in Tables 2.7a, b, and c. Later laboratory testing of full-size girder specimens was performed within and beyond this range of stresses to simulate high-cycle service-level loads occurring over the life of the bridge to assess their possible influence on structural behavior.

2.5 DYNAMIC INFLUENCE/IMPACT

As vehicles move across the bridge at speed, the static force effects may be amplified due to the dynamic response of the structure under the moving load and/or due to impact of the wheels on the deck surface, due to uneven approaches or deck surface imperfections. Using the control test truck data at each of the stirrup strain locations, an impact/dynamic coefficient was determined as the ratio of the peak strain produced by the truck as it moves in the marked lane at traveling speed, over the peak strain when the truck moves in the marked lane slowly (5 mph) across the bridge. For these comparisons, a minimum slow speed stirrup stress of 0.75 ksi was selected so that impact ratios using very small stress magnitudes would not skew results.

Additionally, impact coefficients were determined only for the truck lane position that produced the highest stress magnitude at the stirrup location for each of the different test speeds (for example: if the maximum stress is produced in a stirrup when the truck is in the passing lane, impact coefficients were determined for all test speeds, but only when the truck is located in the passing lane). This is consistent with the specification approach of applying impact effects to the maximum load effect.

For all test runs, the impact coefficients are shown in Figure 2.41. Solid symbols in this figure represent bent cap locations. As seen in this figure, there were cases when the dynamic effects reduce the strain amplitude (ratios less than 1.0). The single largest impact coefficient determined for any of the three bridges was 1.33. There is a trend of smaller impact coefficients as the creep stress magnitude increases.

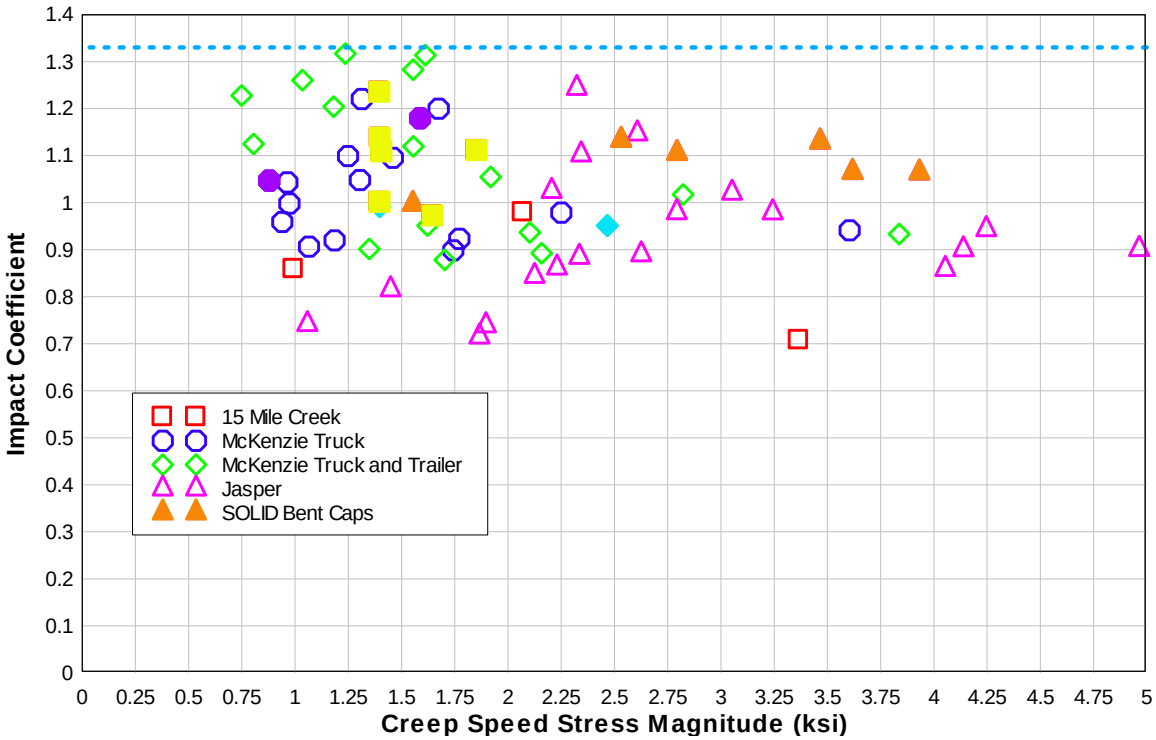

Figure 2.41: Impact coefficients for all three field study bridges

Previously completed field tests (*Higgins, et al. 2004*), identified an event with a larger impact coefficient of 1.46. Statistical analysis of the field data for the three field study bridges discussed here and the previously completed study described by Higgins, *et al*. (*2004*) was performed. Girders and bent caps were considered separately, and impact coefficients are shown in Table 2.8.

Table 2.8: - Statistical analysis of impact coefficients

	15 Mile Creek			McKenzie Bridge			Jasper Bridge			Willamette		
Girders	Average = 1.013			Average = 1.053			Average = 0.964			Average = 1.285		
	Maximum = 1.236			Maximum = 1.317			Maximum = 1.244			Maximum = 1.463		
	Normal	P_f	β	Normal	P_f	β	Normal	P_f	β	Normal	P_f	β
	μ = 1.013 σ = 0.189	0.0467	1.677	μ = 1.053 σ = 0.142	0.0255	1.951	μ = 0.964 σ = 0.154	0.0087	2.377	μ = 1.285 σ = 0.150	0.3821	0.300
Bent Caps	Average = 1.095			Average = 1.042			Average = 1.082					
	Maximum = 1.236			Maximum = 1.180			Maximum = 1.133					
	Normal	P_f	β	Normal	P_f	β	Normal	P_f	β			
	μ = 1.095 σ = 0.120	0.0251	1.958	μ = 1.042 σ = 0.133	0.0152	2.165	μ = 1.083 σ = 0.062	0.00003	3.984			

The AASHTO Standard Specification (*AASHTO 2002*) uses an impact factor of:

$$I = \frac{50}{L + 125} \qquad \text{AASHTO Eq. 3-1} \qquad \textbf{(2-2)}$$

where L is the length (ft) of the span loaded to produce the maximum load effect.

The maximum impact fraction is 30% (*AASHTO 2002*). This is the same impact factor that has been used in previous editions of the Specification. For a typical bridge (span length of 55 ft), the calculated impact fraction was 28%. The AASHTO LRFD Specification (*AASHTO LRFD 1998*) uses an impact factor of 15% for the fatigue load combination and 33% for factored load combinations.

On average, field measured impact fractions were less than those recommended by either AASHTO provision, and the maximum measured was close to 1.33. While a single instrumented location on a previous bridge produced an impact coefficient of 1.46, it seems unlikely that the shear force and moment acting on all components at a section (including several girders, the deck, multiple cracked/uncracked webs, and many stirrups) would all increase by this magnitude. Thus, based on statistical analysis of the impact coefficients of the field studied bridges and the trend of reduced impact magnitude with increasing stress levels, a 1.33 impact factor is recommended for amplification of the shear force effects. Selection of this value corresponds to a probability of exceedence of 0.026, 0.009, and 0.047 for the McKenzie River, Jasper, and 15 Mile Creek Bridges, respectively. This indicates that in the case of 15 Mile Creek Bridge, approximately 1 in every 213 trucks could produce a locally higher stirrup stress than that provided by the specification value of 1.33.

2.6 LOAD DISTRIBUTION

Distribution of shear across the multiple girders on each of the bridges was inferred from the relative magnitude of the peak measured stirrup strains in each girder across an instrumented section of the bridge. Distribution of shear was determined from maximum measured stirrup strains for truck passages at a creep speed (5 mph) in each of the lane positions.

Distribution factors were determined for a single truck in the lane and for two trucks in both lanes. Multiple lane load distributions were computed by superimposing the effects of the truck

in the passing lane with the truck located in the truck lane. The measured strain in each girder at a section of the bridge was divided by the sum of the strains on all girders at the section to determine the distribution factor.

Where possible, stirrup stresses from all girders at a given section were used to determine the distribution factors. Where adjacent girders were not instrumented, stresses in the uninstrumented girder were inferred based on symmetry of response from adjacent instrumented girders when the truck was positioned in the lane adjacent lane. At some instrumentation locations, stirrup strains on a girder that would have been more heavily loaded appeared to be lower than the adjacent girders. This was typically due to vertically oriented cracks which did not produce significant tension in the stirrup even when the load was positioned close to the instrumented location.

When available, measured data from each girder were used to determine the distribution factors. This resulted in conservative values. Distribution factors based on strain measurements for each of the field study bridges are shown in Tables 2.9a to 2.9e. As seen in these tables, worst case load distribution factors for shear (based on very low stress measured on one of the girders) were approximately 0.8 for one-lane loaded and 0.4 for two-lanes loaded. More typically, where consistent data were obtained across all girder lines, load distribution factors for shear were approximately 0.4 for one-lane loaded or 0.26 for two-lanes loaded. The distribution factors calculated here represent the proportion of the statical shear on the bridge assigned to an individual girder at the section under consideration.

Distribution factors for shear and moment were calculated using the previous AASHTO specifications, as well as the current AASHTO Standard Specification and AASHTO LRFD for comparison with field data results. The 1953 Standard Specification (*AASHO 1953*) load distribution factors were based on girder spacing. A wheel load fraction of S/5 was applied for interior girders with concrete floors on bridges supporting two or more traffic lanes, where S (ft) is the average spacing of girders. Exterior girders were designed assuming wheel loads were distributed by the deck acting as a simple beam between the girders. This technique is referred to as the “lever rule”. No distribution was permitted for the wheel/axle load located at the end of the girder.

The current AASHTO Standard Specification (*AASHTO 2002*) employs the same basic provisions for shear load distribution but now uses a wheel load fraction of S/6 for similar bridges with two or more traffic lanes. For the girder spacing and the AASHTO HS25 design truck, the shear forces and equivalent distribution factors were determined for the interior and exterior girders of the field study bridges. No distribution was used for the wheel/axle load located directly over the location where the shear force was computed and the other wheel loads were distributed as permitted by the code (S/5 for 1953 and S/6 for 2002). The code values are for two or more traffic lanes and thus multiple presence of load is implied in the distribution values.

Table 2.9a: Girder distribution for ODOT truck and truck and trailer traveling at crawl speed and located in different lane positions on McKenzie River Bridge (Note: TT is truck with trailer see Figure 2.12b)

ch 18,14,12,9

	Truck Fog	Truck Truck	Truck Passing	TT Fog	TT Truck	TT Passing	Two Trucks in Lane	TT Two Trucks in Lane
G1	72%	52%	16%	65%	50%	13%	34%	32%
G2	22%	35%	4%	28%	37%	6%	19%	21%
G3	1%	4%	14%	2%	4%	15%	9%	10%
G4	5%	9%	67%	5%	9%	65%	38%	37%

ch 10,13,15,19

	Truck Fog	Truck Truck	Truck Passing	TT Fog	TT Truck	TT Passing	Truck Two Trucks Lane	TT Two Trucks Lane
G1	83%	74%	16%	81%	70%	10%	45%	40%
G2	3%	6%	7%	4%	5%	4%	6%	5%
G3	3%	3%	25%	2%	3%	24%	14%	14%
G4	10%	17%	51%	13%	21%	61%	34%	41%

ch 29,23,20

	Truck Fog	Truck Truck	Truck Passing	TT Fog	TT Truck	TT Passing	Truck Two Trucks Lane	TT Two Trucks Lane
G1	64%	59%	14%	62%	61%	17%	36%	39%
G2	33%	31%	14%	33%	32%	15%	23%	23%
G3	2%	4%	15%	3%	2%	14%	9%	8%
G4	2%	6%	57%	2%	5%	54%	32%	30%

Table 2.9b: Girder distribution for real trucks traveling northbound on Jasper Bridge

CH 11,12,14,15,25,26,27

	Truck ID 1	2	3	4	5	6	7	8	9	10	11	34mph ODOT
G1	26%	25%	15%	21%	14%	17%	20%	19%	22%	17%	20%	17%
G2	45%	51%	45%	44%	43%	45%	43%	54%	49%	45%	47%	43%
G3	11%	9%	21%	16%	24%	23%	20%	11%	11%	19%	16%	24%
G4	18%	15%	19%	19%	18%	16%	18%	16%	18%	20%	17%	15%

CH 9,10,29,30

	Truck ID 1	2	3	4	5	6	7	8	9	10	11	34mph ODOT
G1	60%	56%	45%	53%	39%	54%	48%	59%	58%	48%	58%	51%
G2	20%	20%	27%	23%	30%	23%	26%	21%	18%	26%	21%	27%
G3*	13%	15%	18%	16%	20%	15%	17%	14%	14%	17%	14%	16%
G4	7%	9%	10%	8%	10%	8%	9%	6%	10%	9%	7%	6%

CH 2,20,21

	Truck ID 1	2	3	4	5	6	7	8	9	10	11	34mph ODOT
G1	22%	10%	19%	20%	17%	21%	22%	18%	19%	24%	24%	13%
G2	48%	55%	50%	48%	51%	48%	48%	50%	48%	46%	46%	54%
G3*	26%	30%	27%	27%	28%	26%	26%	27%	27%	25%	25%	29%
G4	4%	5%	4%	5%	4%	5%	4%	4%	6%	5%	5%	4%

Table 2.9c: Girder distribution for ODOT truck traveling at crawl speed and located in different lane positions on Jasper Bridge

CH 11,12,14,15,25,26,27

	NB N Curb	NB Lane	NB CL G2	NB CL G3	SB CL G2	SB CL G3	SB Lane	SB S Curb	Two Trucks in Lane
G1	37%	25%	13%	3%	2%	2%	1%	2%	13%
G2	42%	45%	45%	37%	35%	27%	20%	15%	33%
G3	9%	17%	28%	43%	44%	45%	44%	38%	30%
G4	12%	12%	14%	17%	19%	27%	36%	45%	24%

CH 9,10,29,30

	NB N Curb	NB Lane	NB CL G2	NB CL G3	SB CL G2	SB CL G3	SB Lane	SB S Curb	Two Trucks in Lane
G1	74%	60%	44%	20%	14%	5%	6%	6%	33%
G2	14%	23%	30%	39%	39%	34%	25%	20%	24%
G3*	9%	13%	19%	27%	29%	32%	31%	31%	22%
G4	3%	4%	7%	14%	18%	29%	38%	43%	21%

CH 2,20,21

	NB N Curb	NB Lane	NB CL G2	NB CL G3	SB CL G2	SB CL G3	SB Lane	SB S Curb	Two Trucks in Lane
G1	22%	17%	10%	4%	5%	5%	3%	2%	10%
G2	48%	52%	56%	57%	57%	31%	12%	6%	32%
G3*	26%	28%	30%	32%	32%	32%	32%	33%	30%
G4	4%	4%	3%	7%	7%	33%	52%	59%	28%

Table 2.9d: Girder distribution for static truck position #2 on Jasper Bridge

CH 11,12,14,15,25,26,27 Static Truck Position 2

	Stirrup Force (kips)	NB North Curb	Stirrup Force (kips)	NB South Curb	Two Trucks at curbs
G1	2.05	48%	-0.21	-3%	22.6%
G2	1.54	36%	1.03	14%	25.1%
G3	0.54	13%	3.29	45%	28.8%
G4	0.14	3%	3.20	44%	23.5%
Total	4.27		7.30		
	16.6%		28.4%		

CH 9,10,29,30 Static Truck Position 2

	Stirrup Force (kips)	SB North Curb	Stirrup Force (kips)	SB South Curb	Two Trucks at curbs
G1	7.01	79%	-0.36	-6%	36.5%
G2	1.09	12%	1.15	20%	16.1%
G3*	0.61	7%	2.05	35%	21.2%
G4	0.13	1%	2.95	51%	26.2%
Total	8.84	kips	5.80	kips	
	34.4%	of shear	22.6%		

CH 2,20,21 Static Truck Position 2

	Stirrup Force (kips)	SB North Curb	Stirrup Force (kips)	SB South Curb	Two Trucks at curbs
G1	0.75	28%	-0.04	-1%	13.2%
G2	1.42	52%	0.23	7%	29.7%
G3*	0.65	24%	1.12	34%	28.9%
G4	-0.11	-4%	2.01	61%	28.1%
Total	2.70		3.32		
	10.5%		12.9%		

Table 2.9e: Girder distribution for ODOT truck traveling at crawl speed and located in different lane positions on 15 Mile Creek Bridge

Eastbound

ch20, 21

	Truck	Passing	Two Trucks in Lane
G1	9%	14%	11%
G2	36%	42%	39%
G3*	42%	36%	39%
G4*	14%	9%	11%

ch11,12

	Truck	Passing	Two Trucks in Lane
G1*	4%	64%	34%
G2*	1%	31%	16%
G3	31%	1%	16%
G4	64%	4%	34%

Westbound

ch31,3,4

	Truck	Passing	Two Trucks in Lane
G1	24%	14%	19%
G2*	25%	24%	24%
G3	25%	34%	30%
G4	26%	28%	27%

ch25,28,29

	Truck	Passing	Two Trucks in Lane
G1	47%	10%	29%
G2	35%	9%	22%
G3	8%	30%	19%
G4*	10%	50%	30%

ch26,30

	Truck	Passing	Two Trucks in Lane
G1	31%	4%	17%
G2*	59%	7%	33%
G3	7%	59%	33%
G4*	4%	31%	17%

ch32,1

	Truck	Passing	Two Trucks in Lane
G1	1%	0%	0%
G2	62%	37%	50%
G3*	37%	62%	50%
G4*	0%	1%	0%

The 1953 AASHTO provisions did not require that exterior girders carry at least the amount of shear for the interior girders, but all girders were required to be able to carry the statical shear at any section. The current specification requires that exterior girders carry the same or greater magnitude of shear as interior girders. Load distribution factors were also determined by AASHTO LRFD per section 4.6.2.2. The LRFD provisions to determine the distribution factors for the interior girders consider the girder stiffness, girder spacing, span length, and thickness slab for moment and only the girder spacing for shear. Exterior girders use the lever rule for both moment and shear distribution, as well as the check per section 4.6.2.2.2d.

Load distribution factors for each of the methods is shown in Table 2.10 for the Standard specification, Table 2.11 for the LRFD specification, and Table 2.12 for the controlling cases. As seen in Table 2.12, the 1953 AASHTO load distribution method produces higher girder design forces than the current Standard Specification. As the Standard Specifications use wheel distribution factors, direct comparison between LRFD and Standard Specification factors will depend on the shape of the influence line for the load effect considered. For typical vintage RCDG bridge spans and indeterminacy, LRFD distribution factors would produce larger design moments and shears than if the Standard Specification factors were used. Comparison of the field estimated and code specified load distribution factors indicated that the specification conservatively assigns shear load effects on individual girders.

Table 2.10: Wheel load distribution factor by lever rule (AASHTO Standard Specification)

Bridge	Girder Spacing (ft)	Curb Dist. (ft)	Exterior Girder DF	Controlling # Lanes Loaded	Interior Girder DF	Controlling # Lanes Loaded	Exterior Girder DF Axle	Interior Girder DF Axle
McKenzie (3 span)	9.00	1.50	1.443	1	1.889	2	0.722	0.944
McKenzie (1 span)	9.00	1.50	1.443	1	1.889	2	0.721	0.944
Willamette Newberg (2 span)	8.67	2.00	1.538	1	1.846	2	0.769	0.923
Willamette Newberg (1 span)	6.50	2.06	1.403	1	1.291	2	0.701	0.645
Willamette Springfield	7.25	2.00	1.446	1	1.621	2	0.723	0.810
Jasper	7.67	1.50	1.346	1	1.696	2	0.673	0.848
15 Mile Creek EB	8.73	1.77	1.487	1	1.854	2	0.744	0.927
15 Mile Creek WB	9.23	1.77	1.517	1	1.916	2	0.759	0.958

Table 2.11: Lane load distribution by AASHTO LRFD Specification

Bridge	One Lane *Exterior* Girder Shear DF	Two Lane *Exterior* Girder Shear DF	2 LN Control *Exterior* Girder Shear DF	One Lane *Interior* Girder Shear DF	Two Lane *Interior* Girder Shear DF	One Lane *Exterior* Girder Moment DF	Two Lane *Exterior* Girder Moment DF	2 LN Control *Exterior* Girder Moment DF	One Lane *Interior* Girder Moment DF	Two Lane *Interior* Girder Moment DF	One Lane *Exterior* Girder Reaction	Two Lane *Exterior* Girder Reaction
McKenzie (3 span)	0.866	0.884	0.884	0.720	0.884	0.866	0.843	0.866	0.620	0.843	0.740	0.900
McKenzie (1 span)	0.866	0.884	0.884	0.720	0.884	0.866	0.851	0.866	0.626	0.851	0.740	0.900
Willamette Newberg (2 span)	0.923	0.861	0.923	0.707	0.861	0.923	0.822	0.923	0.602	0.822	0.757	0.915
Willamette Newberg (1 span)	0.842	0.707	0.842	0.620	0.707	0.842	0.675	0.842	0.508	0.675	0.648	0.773
Willamette Springfield	0.868	0.761	0.868	0.650	0.761	0.868	0.703	0.868	0.523	0.703	0.654	0.814
Jasper	0.808	0.791	0.808	0.667	0.791	0.808	0.693	0.808	0.515	0.693	0.723	0.891
15 Mile Creek EB	0.892	0.865	0.892	0.709	0.865	0.892	0.798	0.892	0.587	0.798	0.748	0.903
15 Mile Creek WB	0.910	0.900	0.910	0.729	0.900	0.910	0.831	0.910	0.608	0.831	0.753	0.930

Table 2.12: Load distribution factors for controlling cases by AASHTO LRFD Specification and Standard Specifications

Bridge	AASHTO LRFD Exterior Shear	AASHTO LRFD Interior Shear	AASHTO LRFD Exterior Moment	AASHTO LRFD Interior Moment	Lever Rule Exterior Girder DF Axle	Lever Rule Interior Girder DF Axle	S/6 Distribution Axle	S/5 Distribution Axle
McKenzie (3 span)	0.900	0.884	0.900	0.843	0.944	0.944	0.750	0.900
McKenzie (1 span)	0.900	0.884	0.900	0.851	0.944	0.944	0.750	0.900
Willamette Newberg (2 span)	0.923	0.861	0.923	0.822	0.923	0.923	0.722	0.867
Willamette Newberg (1 span)	0.842	0.707	0.842	0.675	0.645	0.645	0.542	0.650
Willamette Springfield	0.868	0.761	0.868	0.703	0.810	0.810	0.604	0.725
Jasper	0.891	0.791	0.891	0.693	0.848	0.848	0.639	0.767
15 Mile Creek EB	0.903	0.865	0.903	0.798	0.927	0.927	0.727	0.873
15 Mile Creek WB	0.930	0.900	0.930	0.831	0.958	0.958	0.769	0.923

2.7 COMBINED DEAD AND LIVE LOAD STRESS IN STIRRUPS

Stresses in stirrups, including that produced from weight of permanent components and the wearing surface, combined with superimposed live load stresses, were determined using data from the Jasper Bridge. Field stirrup stress data were used for the loading case of the test truck statically positioned on the bridge, at the curb, with the steering axle centered over the support. This enabled precise location of the loads for comparison with shear forces determined from elastic structural analysis.

The force carried by the stirrups was estimated by counting the numbers of stirrups crossing the diagonal crack, assuming uniform stress for all stirrups crossing the cracks, and multiplying by the nominal stirrup area. The vertical force in the stirrups was compared with the statical shear force at the section from analysis, and indicated that the stirrups carried between 10% and 35% of the applied shear as seen in Table F9d. It is anticipated that the dead load shear is carried at the girder section in the same proportion as the live load shear.

2.8 STIRRUPS STRESS DISTRIBUTIONS ACROSS A SINGLE CRACK

Comparisons of measured stirrup stress magnitudes on the same diagonal crack were performed from table values of maximum stirrup stress. Two different instrumentation configurations were investigated: 1) instrumented stirrups located on the same girder face or 2) instrumented stirrups located on opposite faces of the same girder. For the case where stirrups were instrumented on the same face of a girder, the stirrup located closer to the flexural tension region tended to have higher stress than the stirrup located near the compression face.

In cases where stirrups were located on opposite faces of the same crack, the stresses on the two stirrup legs were not necessarily equal, although they tended to be reasonably correlated when the load was located close to the instrumented section. Stirrups located across diagonal cracks in bent caps tended to have approximately equal stresses.

2.9 CONCLUSIONS

Field investigations of three cast-in-place reinforced concrete deck girder bridges were conducted. The bridges were designed between the period of 1950 to 1960 and incorporated single span, 2-span continuous and 3-span continuous approach spans. The bridges were inspected, and instrumented. Data from instrumented locations were collected under ambient traffic conditions as well as during controlled truck testing. Based on field data collection and subsequent analysis, the following conclusions are made:

- Exterior girders tended to exhibit more widespread diagonal cracking than interior girders.
- Diagonal cracks tended to be concentrated within the quarter span length adjacent to support locations. Vertical cracks associated with flexural tension were located in flexural tension

regions, and vertical cracks attributed to shrinkage tended to be distributed throughout the span length.

- Stirrups crossing the same diagonal crack, did not necessarily exhibit the same magnitude of stress. Stirrups located closer to the flexural tension region tended to have higher stress than those closer to the flexural compression region.

- Stirrups crossing the same diagonal crack on opposite faces of the girder tended to have similar stress magnitudes, particularly when the load was located close to the diagonal crack.

- Under ambient traffic loading, the single largest stress range measured on any of the stirrups in the bridges was 11.5 ksi.

- Based on the ambient traffic induced stress ranges, an equivalent stress range was determined for each of the instrumented locations. The equivalent constant amplitude stress range was below 2 ksi at all but one instrumented location (Location 7 on McKenzie River Bridge 2.67 ksi).

- Comparison of measured stress ranges with the fatigue behavior of deformed reinforcing bars, indicates that high-cycle fatigue leading to fracture of the stirrups is unlikely.

- Impact coefficients were determined for each of the instrumented locations. For the field study bridges; impact coefficients were below that recommended by the AASHTO LRFD provisions for strength determination.

- Load distribution factors for shear were determined based on the ratios of stirrup stress magnitudes across instrumented sections of the bridges. Using the most conservative data, the distribution factors for shear and hence the loading of girders were less than those recommended by the AASHTO provisions.

- Stress ranges required to produce the estimated equivalence of 50 years of service life damage in laboratory specimens were determined from field data for use in subsequent laboratory testing.