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UCRL-ID-108595

**SEISMIC REFRACTION STUDIES AT
THE PAINTER STREET BRIDGE SITE,
RIO DELL, CALIFORNIA**

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September, 1991

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Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

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1. OVERVIEW

This report summarizes the results of seismic refraction P- and S-wave measurements, at the site of the Painter Street bridge, in Rio Dell, California. The bridge is spanning highway US 101, 4 miles south of Fortuna, in northwestern California.

This study was performed to provide an estimate of material properties for the foundation of the bridge, in support of a seismic stability analysis of the bridge performed at LLNL by D. McCallen. The Rio Dell region is seismically active and the Painter Street bridge is one of only 2 bridges of its type in California, instrumented for strong motion recordings.

Figures 1 and 2 show photographs of the site, and Figure 3 shows the location of the seismic traverses. Additional overview information is given in Appendix A.

2. INSTRUMENTATION AND LAY-OUT

We used a 12-channel Geometric/Nimbus ES 1210 Signal Enhancement Seismograph, which can be seen on Figure 1b. We operated with 100-ft long lines having P- and S- wave geophones at 10 ft intervals. The source was a 10-lb seismic hammer striking a metal plate, for the P-waves, and hitting a 4" x 6" timber under the front wheels of a car, for the S-waves. Typically, we recorded for 200 msec, giving 2 ms time intervals on the fine grid plots.

The layout of traverses shown on Figure 3, indicates a "forward" and "reverse" direction. Reverse profiling is useful when there is reason to believe that there are sloping or uneven interfaces under the ground surface.

The tests were conducted in the course of three site visits

June 26, 1991:	traverses 1A and 2A	F. Heuze, D. McCallen, T. Nelson
July 6-7, 1991:	traverses 1B, 3, and 4	F. Heuze, R. Swift
July 15, 1991:	traverse 2B	F. Heuze, R. Swift

The seismograph failed on July 15, precluding additional measurements on that visit.

a)

b)

Figure 1: Overview at West Abutment. Lines 1A and 1B.

a)

b)

Figure 2: View at Grade Level: a) Southbound b) Northbound

Figure 3: Lay-out of Traverses

3. TEST RESULTS

Several measurements were taken along each line, for redundancy. In total, we obtained 45 such records, 24 for compression waves, and 21 for shear waves. The times of first arrivals are given in Appendix B.

The results are summarized in Figures 4 to 17, indicating the line number, the direction (F for forward, R for reverse), the wave type (P or S), and the time of first arrival versus distance. The labeling of symbols also indicates the repeat of a measurement. For example, 1B-P4(F) is Line 1B, fourth P-wave measurement, in the forward direction. For each line, the P-wave results are given first. Regression slopes indicated in the figures were done by inspection.

Based on these results, summary estimates of compression and shear wave speeds are selected as:

Line 1:	$V_p = 1,400 \text{ ft/sec}$ $V_s = 620 \text{ ft/sec}$
Line 2:	$V_p = 3,400 \text{ to } 5,000 \text{ ft/sec}$ $V_s = 833 \text{ ft/sec}$
Line 3:	$V_p = 2,200 \text{ ft/sec}$ $V_s = 745 \text{ ft/sec, 1}^{st} \text{ layer, 30.9 ft deep}$ $= 1,389 \text{ ft/sec, 2}^{nd} \text{ layer}$
Line 4:	$V_p = 1,290 \text{ ft/sec, 1}^{st} \text{ layer, 11.3 ft deep}$ $= 2,725 \text{ ft/sec, 2}^{nd} \text{ layer}$ $V_s = 645 \text{ ft/sec, 1}^{st} \text{ layer, 10.1 ft deep}$ $= 909 \text{ ft/sec, 2}^{nd} \text{ layer, 10.1 to 23.4 ft}$ $= 2,350 \text{ ft/sec, 3}^{rd} \text{ layer, below 23.4 ft}$

Further analysis is provided in the Discussion chapter, which follows.

Figure 4

Figure 5

Figure 6

Figure 7

Figure 8

Figure 9

Figure 10

Figure 11

Figure 12

Figure 13

Figure 14

Figure 15

Figure 16

Figure 17

4. DISCUSSION

The test results can be further analyzed, as follows:

- concerning S-wave speed, which is of primary interest for the seismic analyses, there appears to be a fairly consistent range of values from around 600 ft/s on top of the east abutment to between 645 and 909 ft/s at grade level, for the first 20 ft layer.
- the P-wave speeds, on the other hand, have a broader range. This may well be due to significant variations in moisture content. For example, the high velocity measured on line 2A on June 25 could be related to the very saturated local conditions, as a sprinkler was observed to flow continuously at that location. For sands under low confining stress, the P-wave speed in a saturated condition can easily be 5 times higher than that in a dry state [1].
- some geologic structure can be inferred at some locations. For example, records for lines 3 and 4 show slope discontinuities, typical of layering. The estimated depths were obtained based on standard seismic refraction formulas for multiple layers [2]. The first P-wave interface could very well be the ground water surface.
- if the interface between layers is not planar and horizontal, more information on its profile can be gained by using the forward and reverse records for a single traverse, together, and calculating interface depth at the various geophone locations [3]. This can be done with the P- or S-waves. For completeness, forward and reverse plots are shown, on the same figure, for each of the three instances when both were obtained at Rio Dell: 1B-P waves, 1B-S waves, and 3-P waves. Figure 18 gathers the results from Figures 5 and 6 for P-waves from traverse 1B. Whereas wave speed estimates selected by inspection were within 10% of each other (1,452 and 1,323 ft/sec), it appears equally plausible to show linear regressions with a slope of 1400 ft/sec for forward and reverse, on Figure 18. So, Figure 18 does not indicate any irregular interface detected with the 100-ft traverses. Similar conclusions can be drawn from the plots of Figure 19. It is also the case for Figure 20, where the range stops at 90 ft, and thus does not reveal the potential structure indicated in Figure 15, where a traverse was extended to 110 ft.

Figure 18

Figure 19

Figure 20

- estimating shear (G) and bulk (K) moduli from wave speeds requires a knowledge of material density ρ which is not available from direct measurements, at this time. However, 3 borings were made before bridge construction, essentially under the center pillar and at both abutment locations. The center hole, B-2, was logged for soil type and blow count (N) from Standard Penetration Tests (SPT). This is summarized in Figure 21. Depending upon the degree of compaction, the unit weight (γ) for a silty sand, for example, may vary between 85 and 125 lbs/ft³. To give a sense of the possible values for G and K, we take an average value of density

$$\rho = \frac{\gamma}{g} = \frac{100 \text{ lbs/ft}^3}{32.2 \text{ ft/sec}^2}$$

Figure 21: Log of Boring B-2, Enlarged from Figure A-3 in Appendix A.

Now, with $G = \rho V_s^2$ and $K = \rho \left[V_p^2 - \frac{4}{3} V_s^2 \right]$ we estimate:

$$\begin{aligned} \text{for } V_s = 600 \text{ ft/sec and } V_p = 2,000 \text{ ft/sec} \quad G &= 7,764 \text{ psi} \\ K &= 75,914 \text{ psi} \end{aligned}$$

$$\begin{aligned} \text{for } V_s = 900 \text{ ft/sec and } V_p = 3,000 \text{ ft/sec} \quad G &= 17,469 \text{ psi} \\ K &= 170,807 \text{ psi} \end{aligned}$$

- estimating Poisson's ratio, ν , does not require density. The equation used is

$$\nu = \frac{1-2r}{2(1-r)} \quad \text{where} \quad r = \left(\frac{V_s}{V_p} \right)^2$$

Using average values, we estimate:

Line 1	$V_s = 620 \text{ ft/sec}$	$V_p = 1,400 \text{ ft/s}$	$r = 0.196$	$\nu = 0.38$
Line 2	$V_s = 833 \text{ ft/sec}$	$V_p = 4,200 \text{ ft/s}$	$r = 0.039$	$\nu = 0.48$
Line 3	$V_s = 745 \text{ ft/sec}$	$V_p = 2,200 \text{ ft/s}$	$r = 0.115$	$\nu = 0.44$
Line 4 layer 1	$V_s = 645 \text{ ft/sec}$	$V_p = 1,290 \text{ ft/s}$	$r = 0.250$	$\nu = 0.33$
layer 2	$V_s = 909 \text{ ft/sec}$	$V_p = 2,725 \text{ ft/s}$	$r = 0.111$	$\nu = 0.44$

- From the above information we can, in turn, estimate Young's modulus (E) values from $E = 2G(1+\nu)$; taking an average for ν as 0.40:

$$\text{for } V_s = 600 \text{ ft/sec and } V_p = 2,000 \text{ ft/sec} \quad E = 21,739 \text{ psi}$$

$$\text{for } V_s = 900 \text{ ft/sec and } V_p = 3,000 \text{ ft/sec} \quad E = 48,913 \text{ psi}$$

which are representative numbers for the soils described in the log of hole B-2 [1].

5. REFERENCES

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6. ACKNOWLEDGMENTS

We are grateful for the participation of David McCallen and Tom Nelson in the first field measurements, on June 26, and to Jay Zucca for the loan of the seismic equipment. We also appreciate the review comments from Richard Carlson, and the fine typing by Kathleen Kirk.

7. APPENDIX A

Additional information on the Painter Street Overcrossing.

Figure A-1: General Plan.

Figure A-2: Foundation Plan.

Figure A-3: Log of Test Borings.

Figure A-2

8. APPENDIX B

**Times of First Arrivals (msec) From the 45 Records of
Traverses 1A, 1B, 2A, 2B, 3, and 4**

Table B-1: First Arrival Times (ms) of P-waves and S-waves for Six Alignments,
Painter St. Bridge Site, Rio Dell, CA

Range (ft)	10	20	30	40	50	60	70	80	90	100	110
Line 1A, P, Forward											
1A-P1(F)	9	16	24	26	30	-	-	-	-	-	-
1A-P2 (F)	13	19	24	30	-	-	54	62	-	-	-
Line 1A, S, Forward											
1A-S1 (F)	18	38	52	68	80	96	-	-	-	-	-
1A-S2 (F)	17	38	54	67	81	97	-	-	-	-	-
Line 1B, P, Forward											
1B-P1 (F)	10	16	22	28	35	-	56	-	66	-	-
1B-P2 (F)	11	17	24	-	-	46	52	-	-	80	-
Line 1B, P, Reverse											
1B-P3 (R)	10	18	23	28	-	-	-	60	68	75	-
1B-P4 (R)	11	18	24	-	43	50	-	66	74	78	-
Line 1B, S, Forward											
1B-S1 (F)	22	38	50	-	91	-	-	132	152	162	-
1B-S2 (F)	26	46	55	-	88	-	128	142	160	-	-
1B-S3 (F)	22	-	54	-	92	110	125	142	160	-	-
Line 1 B, S, Reverse											
1B-S4 (R)	18	34	48	72	90	104	-	-	-	-	-
1B-S5 (R)	18	34	48	72	90	104	-	134	148	-	-
1B-S6 (R)	22	34	46	74	90	104	-	-	-	-	-
Line 2A, P, Forward											
2A-P1 (F)	6	9	11	13	14	16	17	-	-	-	-
2A-P2 (F)	6	8	11	-	-	15	16	-	-	-	-
2A-P3 (F)	6	8	9	14	-	-	-	-	-	-	-
2A-P4 (F)	6	8	10	12	15	17	-	-	-	-	-
2A-P5 (F)	6	8	10	12	13	-	-	-	-	-	-
Line 2A, S, Forward											
2A-S1 (F)	-	-	-	-	78	92	102	110	-	140	-
2A-S2 (F)	-	-	-	68	82	98	108	122	132	144	-
2A-S3 (F)	-	-	-	-	78	92	102	-	-	-	-
2A-S4 (F)	-	32	-	76	88	102	112	-	142	152	-
2A-S5 (F)	-	-	-	74	88	104	112	128	140	150	-
2A-S6 (F)	-	-	-	72	86	102	112	-	-	148	-

Range (ft)	10	20	30	40	50	60	70	80	90	100	110
Line 2B, P, Forward											
2B-P1 (F)	10	12	15	-	20	25	-	-	-	-	-
2B-P2 (F)	9	12	15	16	20	24	26	36	-	42	-
2B-P3 (F)	10	14	14	16	22	-	-	-	-	-	-
Line 3, P, Forward											
3-P1 (F)	8	-	16	-	24	-	32	36	-	-	-
3-P2 (F)	8	14	18	-	26	-	34	38	46		-
3-P3 (F)	8	14	18	22	-	-	32	-	-	-	-
3-P4 (F)	8	14	18	22	28	-	34	38	-	-	-
Line 3, P, Reverse											
3-P5 (R)	8	14	18	22	28	32	-	38	44	-	-
3-P6 (R)	9	14	16	-	30	34	36	-	-	-	-
3-P7 (R)	10	14	18	22	-	-	-	-	-	-	-
Line 3, S, Forward											
3-S1 (F)	-	36	50	66	-	92	116	-	134	142	148
3-S2 (F)	-	36	-	66	-	94	112	114	132	142	148
3-S3 (F)	-	36	-	-	-	82	112	114	134	142	148
3-S4 (F)	-	38	50	64	-	89	-	112	130	140	146
Line 4, P, Forward											
4-P1 (F)	10	14	-	-	-	-	42	-	-	-	-
4-P2 (F)	8	16	-	-	-	38	-	-	-	-	-
4-P3 (F)	8	15	-	31	-	38	-	-	-	-	-
Line 4, S, Forward											
4-S1 (F)	16	-	46	62	72	82	88	92	96	102	-
4-S2 (F)	12	-	46	62	72	84	86	90	96	100	-
4-S3 (F)	14	30	48	62	72	86	88	92	98	102	-

END

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