Marquam Bridge Repair: Latex-Modified-Concrete Overlay and Joint Replacement

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The Marguam Bridge in Portland, Oregon, provides a crossing of the Willamette River for the north-south I-5 freeway. After 17 yr of service, the bridge, which was opened to traffic in 1966, had a badly worn deck and numerous deck expansion joints in need of repair. The bridge has a daily traffic count of approximately 86,000 vehicles. Because of lack of capacity of detour routes, complete closure to traffic could be permitted only during night hours. To correct the deck and joint problems, a contract was awarded in May 1983 for a latex-modified-concrete overlay and joint repair. On a previous job with a 3-percent grade, the tendency of the finished surface to shift downhill during the early cure stages was noted, and it was thought that this tendency could be a major problem on this structure with ramps on 6-percent grades and 0.10 ft/ft supers. Type III cement was suggested; it was tried and was found to be a workable solution. Narrow pour widths required by traffic staging were as significant a factor to surface irregularities as were the steep slopes. The pour widths also restricted the pour rate. Three years after completion of the overlay, a check on the wear was made. This found wide variation in the projected life due to traffic patterns and irregular wear in the individual wheel tracks. From the survey, a general conclusion can be made that the latex-modified-concrete has equivalent or possibly better wear resistance than the original concrete surface had. Also from this information and a similar survey on the I-205 Columbia River Bridge, a normal wheel track wear rate of 0.0313 in./yr per 10,000 average daily traffic (ADT) can be anticipated.

The Marquam Bridge and ramps in Portland, Oregon, provide a crossing of the Willamette River for the I-5 north-south freeway. They are also a segment of I-5 and of the I-405 inner city loop (Figure 1). The bridge was opened to traffic in 1966. The photographs shown in Figures 2 and 3 are general views of the structure. The main spans are a double-deck cantilevered truss with 301-ft side spans, 90-ft cantilevers, and a 260-ft center suspended span. The approach ramps begin with a single or multiple poured-in-place span followed by several 60–80-ft precast prestressed spans. The remainder and majority of the ramps' length are simple composite welded girder spans 85–178 ft long. The ramps have varying horizontal curvature up to a maximum of 8°, superelevation varying up to a maximum of 0.10 ft/ft, and grades up to a maximum of 6 percent. This difficult alignment plus the traffic made for an unusual and challenging overlay job.

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CONDITION OF DECK AND JOINTS

Prior to and after award of the contract, surveys were made to determine the extent of work needed to be done. (Overlay contract was awarded May 10, 1983.) Both surveys found significant wear throughout the structure, with a number of spans that had the top mat of reinforcing exposed and a number of locations with loose angles at the joints (Figures 4 and 5). Based on the elevation of the armored corners at the joint, approximately 0.5–1 in. of rutting in the wheel tracks occurred during the 17-yr life of the deck. Bridge plans showed 1.5-in. cover on the top mat of reinforcing, which apparently was not available in some cases. Where the steel was exposed, it showed very little rusting and appeared to be well bonded. Checks on the chloride content found 1–2 lb/yd^3 in the top 1 in. These minimal amounts are the result of using very limited amounts of chlorides in the sanding materials during the winter months. The first survey showed some small areas with delaminations. These were checked with cores through the deck and no problems were found.

Figure 6 shows a detail of the double-angle armored corner joints. Poor consolidation of concrete under the horizontal leg plus traffic created a void which was found at all locations. Where it was severe, flexing of the angle between the studs caused the stud welds to fracture. At these loose angle locations, the overlay plans specified removing all of the joint and replacing it with a strip seal. A recheck found only portions of the joints needed removal so it was decided to use the Figure 6 detail throughout.

Figure 7 shows the paving dam detail for the finger plate joints on the main span. The existing plates are part of the structural steel stringer system and were all found in good condition.

TRAFFIC

Traffic was a major consideration; the ADT for the bridge was in excess of 47,000 northbound and 39,000 southbound. On the west interchange, there is an approximately 60–40 split between I-5 and I-405, with 60 percent on I-5 (Figure 1).

The specifications permitted night closure of the bridge between 8:00 p.m. and 6:00 a.m. with traffic detoured via I-405. To avoid restricting the detouring, the E and F ramps linking I-405 with I-5 had to be overlaid first. During daylight hours, the bridge had to remain open; this meant on the sections between pier 1 and D13 – C13 (Figures 4 and 5), with

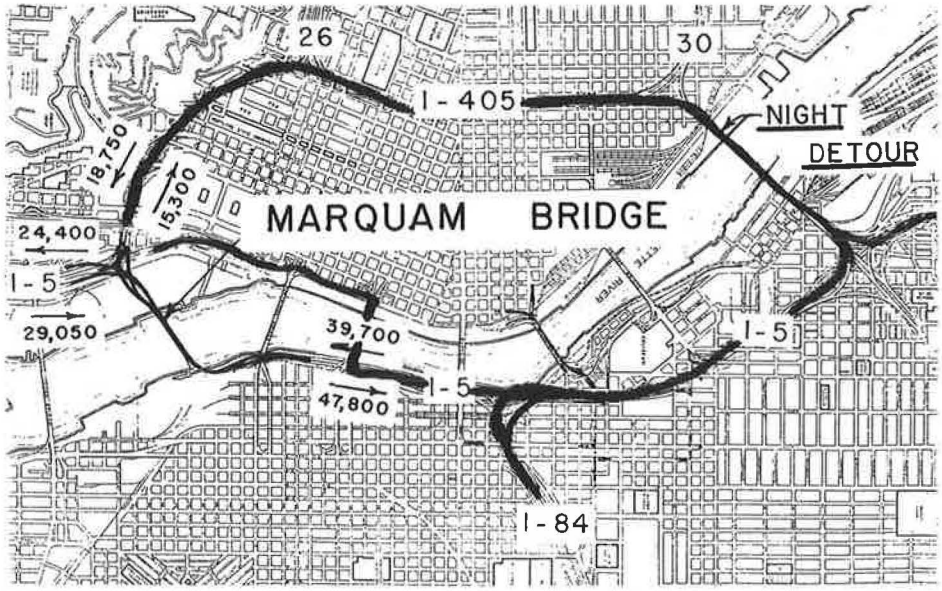


FIGURE 1 Portland inner freeway loop—ADTs and night detour.

a ramp width of 32 ft, the pour width would be limited to approximately 10.5 ft. This pour width was tried on the first stage of the lower deck, and it was found difficult to maintain the cones and barricades separating the traffic from the work area. It was decided to revise the staging, widening the first pour to the center and restricting traffic to one lane. Because this caused some backup of traffic, the contractor agreed to expedite the work in this section.

MIX DESIGN—LATEX-MODIFIED CONCRETE

On a previous bridge that had a 3-percent grade, it was noted that latex-modified concrete had a tendency to shift downhill during the wet cure period, leaving an undulating, unacceptable surface. This presented a significant problem for the Marguam Bridge with its 10-percent super and 6-percent grade. The Dow representative knew of a successful overlay placed on a steep grade, using type III cement. Based on this information, trial mixes were made using both type II and type III cements from Kaiser Permanette, Oregon Portland Cement, and Ideal Cement. Slump was measured immediately after it came from the mixer and at 5-, 10-, and 15-min intervals. Also, small 1.5-in.-thick slabs were formed and poured on the maximum grade that was anticipated. These gave a check on workability, and after 30 min they were jarred to see if there was a tendency for movement down the slope. From this it appeared that a mix with a 3-in. or less slump after 5 min would maintain an acceptable surface. The Kaiser type III gave a 5–6-in. initial slump followed by a 3.-in and 2-in. slump at 5 and 10 min plus good workability; therefore Kaiser type III was recommended. All of the others showed little difference in the initial and other slumps, and it was felt a 3-in. initial slump could have placing and finishing problems. Table 1 gives the mix data that resulted from these tests. It might be noted the coarse aggregate is a ¾ minus crushed basalt, which was desired for wear resistance.

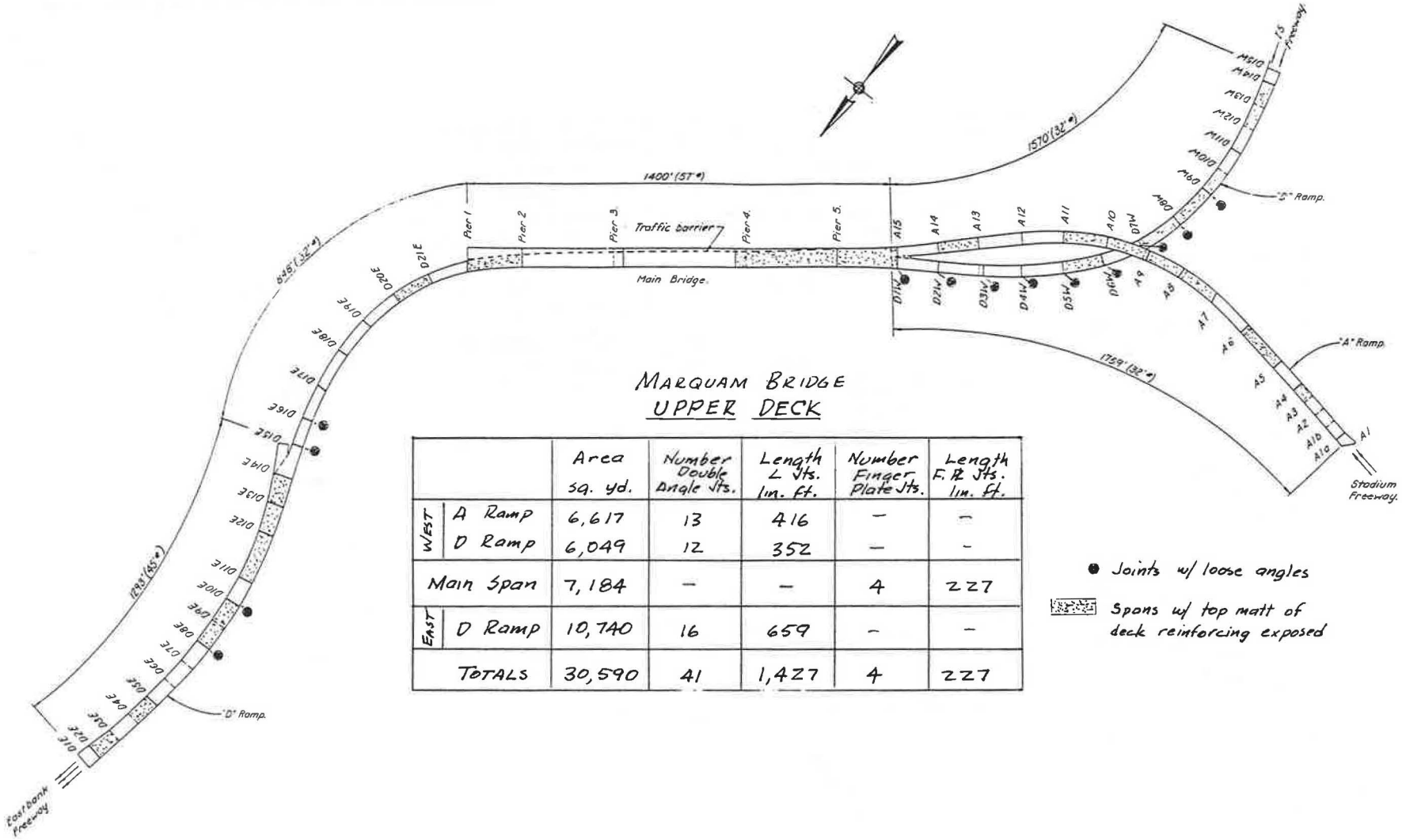
CONSTRUCTION

Deck Joints

From Figures 4 and 5, one of the first things that become apparent is the number of deck joints that require repair and addition of the 1-in. plate paving dam. On the approach ramps,

FIGURE 2 Marquam Bridge west approach ramps and main spans.

FIGURE 3 Marquam Bridge east approach ramps.



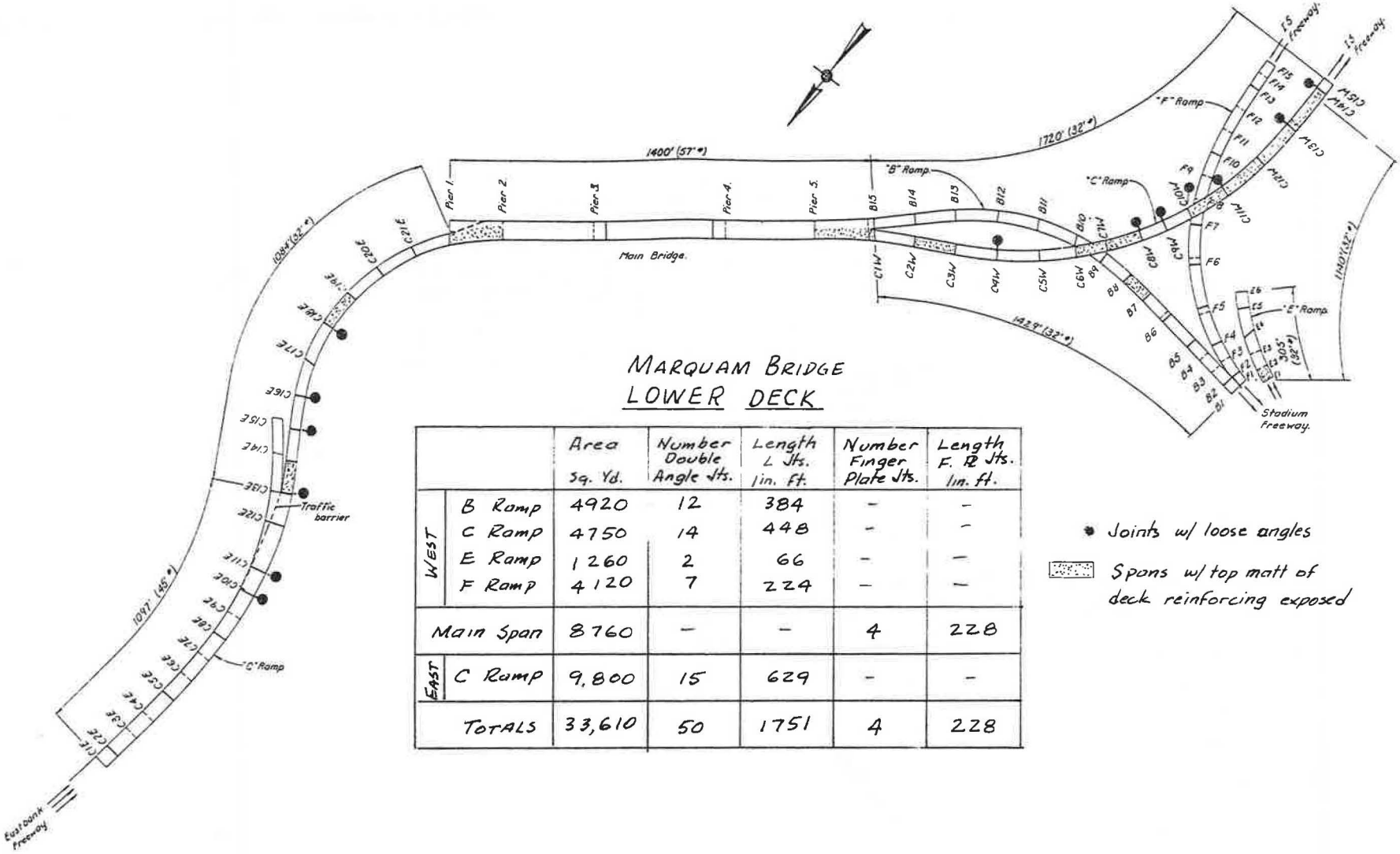
MARQUAM BRIDGE
UPPER DECK

		Area sq. yd.	Number Double Angle Jts.	Length L Jts. lin. ft.	Number Finger Plate Jts.	Length F. P. Jts. lin. ft.
WEST	A Ramp	6,617	13	416	–	–
	D Ramp	6,049	12	352	–	–
Main Span		7,184	–	–	4	227
EAST	D Ramp	10,740	16	659	–	–
TOTALS		30,590	41	1,427	4	227

● Joints w/ loose angles

▒ Spans w/ top matt of deck reinforcing exposed

FIGURE 4 Upper deck—loose angles and exposed reinforcing.



MARQUAM BRIDGE
LOWER DECK

		Area Sq. Yd.	Number Double Angle Jts.	Length L Jts. lin. ft.	Number Finger Plate Jts.	Length F. P. Jts. lin. ft.
WEST	B Ramp	4920	12	384	–	–
	C Ramp	4750	14	448	–	–
	E Ramp	1260	2	66	–	–
	F Ramp	4120	7	224	–	–
Main Span		8760	–	–	4	228
EAST	C Ramp	9,800	15	629	–	–
TOTALS		33,610	50	1751	4	228

FIGURE 5 Lower deck—loose angles and exposed reinforcing.

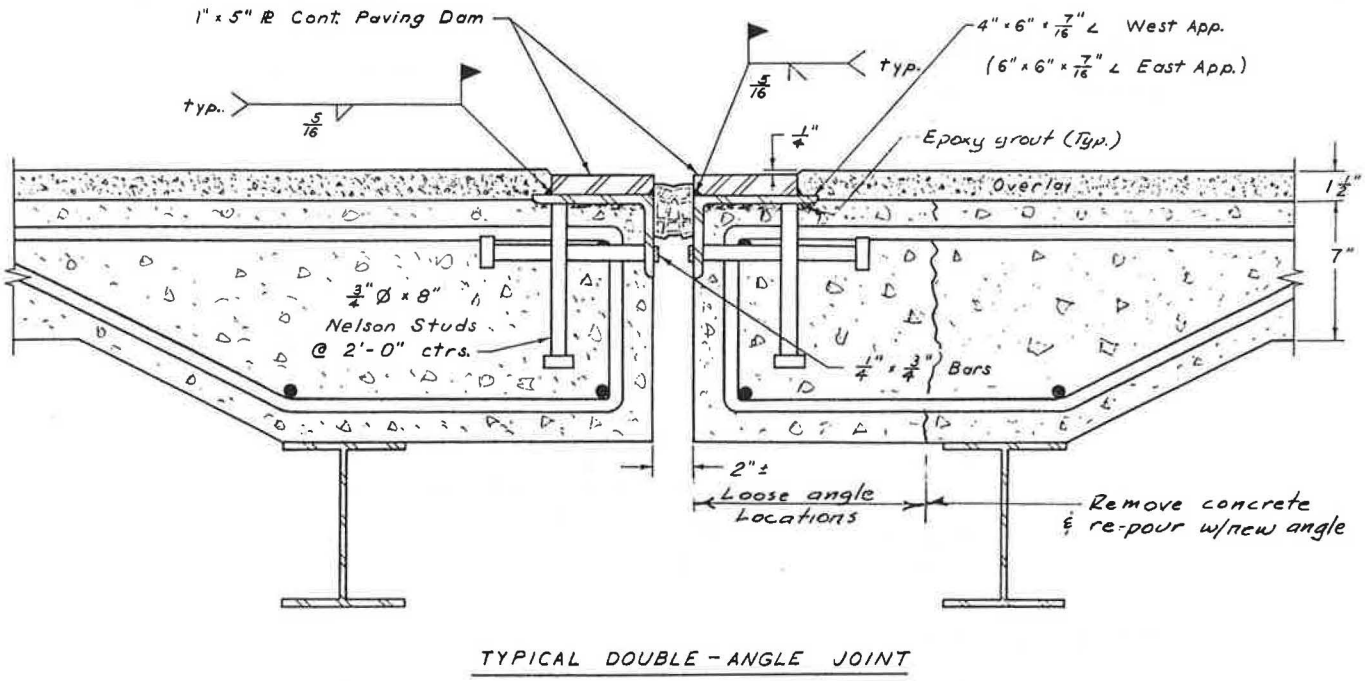


FIGURE 6 Typical double-angle joint.

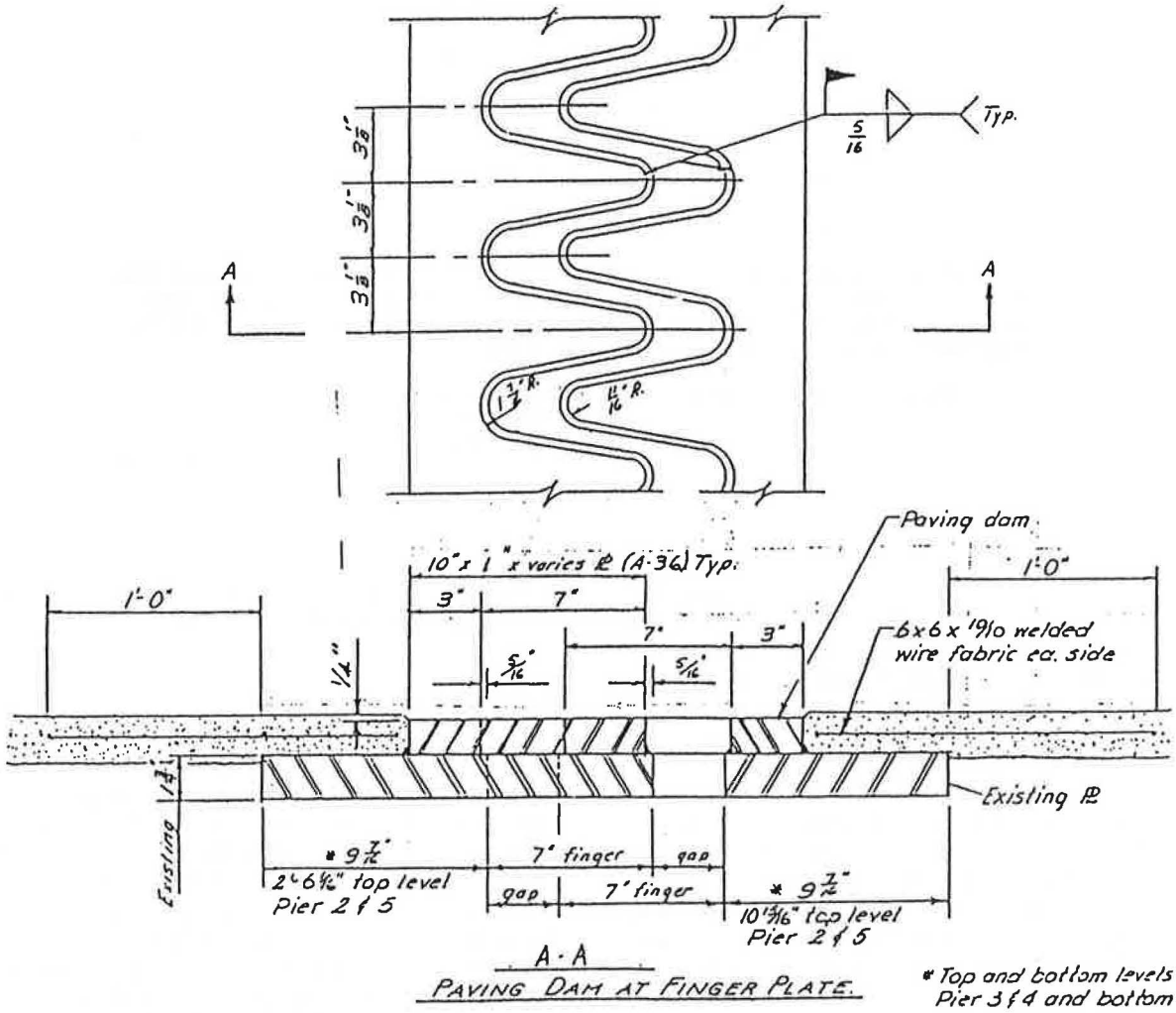


FIGURE 7 Paving dam at finger plate.

TABLE 1 MIX DESIGN AND TEST DATA

Aggregate Gradation:

Coarse	% Passing	Fine	%Passing
1"	100	3/8"	100
3/4	90 - 100	#4	90 - 100
3/8	20 - 50	#16	45 - 75
#4	0 - 10	#30	25 - 55
#200	0 - 1.5	#50	5 - 30
		#100	0 - 8

Concrete Mix Designs:

Cement	7 sacks/cy Type III	
Latex	3.5 gal/sack	
Water	maximum = 2 gals/sk	w/c = 0.33
Slump	3 - 5 inches	
Coarse Agg.	50%	
Fine Agg.	50%	

Concrete Cylinder Strengths:

No minimum strength specified

29 Tests taken

7 day breaks -	minimum	2120 psi
	maximum	4970 psi
	average	3688 psi
28 day breaks -	minimum	3610 psi
	maximum	6555 psi
	average	5296 psi

Pullout Bond Tests:

100 psi minimum specified

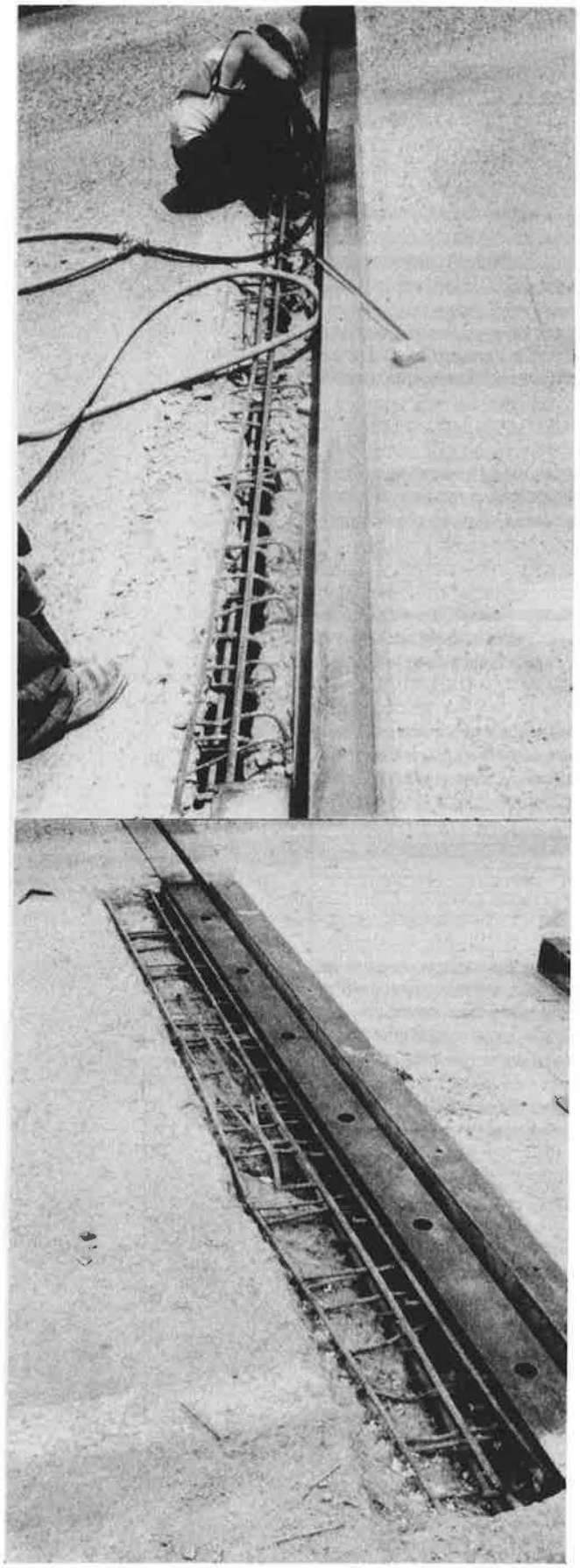
This test was made using a 3-inch diameter core taken through the overlay into the deck approximately 1/4 inch. A pulling cap was bonded to the core with epoxy. From the 25 tests taken, 18 failed in the epoxy bond of the cap to the core.

Results of 25 tests -	minimum	191 psi
	maximum	478 psi
	average	300 psi

the average span length works out to be approximately 130 ft, which means with a normal night's run the overlay would cross four or five joints. To avoid transverse construction joints, it was decided to do the joint work first. This started with sounding the angles with a hammer to determine the sections requiring removal and replacement. A typical joint that required the removal of one angle is shown in the pictures of Figure 8. The pour back was made using latex-modified concrete. Because of its flow characteristics, good bond and easy cure, this is in our opinion an excellent material for such repairs. This was followed with the welding of the 1-in. × 5-in. paving dam and pressure-grouting the angles with epoxy grout. Welding the paving dam tended to lift the horizontal leg of the angle so grouting could not be done before this welding. A total of 210 gal of epoxy were used for the 3,178 linear ft of angle joint, about 8.5 oz/ft of joint. Where removal of the angles was necessary, approximately 6 weeks lead time before placing the overlay was needed.

Deck Preparation

Because of the significant number of spans with exposed deck reinforcing, shot blasting was specified for the deck preparation. Two "Blastrac" units were used for the cleaning plus a bag unit to retrieve the dust. This method removed 0.125–0.25 in. of the fine aggregate-cement mortar, but did not remove or fracture the large aggregate. This left a smoother surface than the grooves from a rotary milling machine, which raised the question of the bonding surface. Based on the pullout tests (Table 1), this proved to be more than adequate to meet the required 100 psi. Fifty-eight shifts were needed



to do the 64,200 yd^2, giving an average of 1,107 yd^2/shift. Areas that could not be reached with the shot blaster were done with single or multiple-headed scabblers. This work as well as setting screeds and work on the joints was done during the day on the half of the ramp closed to traffic. Just before the overlay was placed, the deck was cleaned with high pressure water to remove any remaining dust and steel shot.

Latex-Modified Overlay

All concrete pours were made during the night, when the bridge could be closed to traffic. Concrete was delivered by three Daffin high-production mobile mixers adapted for latex concrete with a 6 yd^3 capacity. The stockpiles for recharging were located approximately 5 mi from the job site. The haul presented no problem, but the stockpile site was limited in size, requiring frequent deliveries by the aggregate producer. With the water in the latex considered, the free moisture in the sand could not exceed 10 percent to maintain the desired water-cement ratio. Some of the sand was delivered directly after washing and exceeded this limit. The problem was solved by the aggregate producer making multiple stockpiles as the material was produced and by making deliveries from the oldest, giving the excess water time to drain.

Finishing was accomplished with two Bidwell dual-drum deck finishers. Because many of the ramps were 32 ft wide, most of the pours were 16 ft wide. Pours were made going both up and down the grade. Pouring down the grade seemed to produce the best surface, and it was preferable for wetting down ahead of the pour. The deck finisher was supported on 2-in. steel pipe screeds. It was general practice to check adjustment of the machine by running the length of the pour and checking the match to the paving dams at the deck joints. One crew made all the pours. The second finishing machine was used where there was a second pour location or a change in width.

The concrete mix with the type II cement worked as anticipated except that control of the water was difficult. Even with the multiple stockpiles, there were variations in the free moisture in the aggregates, and a 6-in. slump as it comes directly from the mixer is difficult to judge. A second problem was the coarse aggregate, which in the beginning had a gradation on the coarse side of the specified limits. The Bidwell finisher in our opinion is as good as any that are available, but with close to 10 percent of the coarse aggregate retained on the ¾ sieve and the overlay thickness near the plan 1.5 in., the finisher would not seal the surface, so hand-finishing was required. The aggregate was adjusted to the finer side of the limits, and there was no further problem.

An inherent problem was the 16-ft pour width, which allowed the dumping of only one truck. Hand-finishing was required on the edges, a relatively large area. If the staging had permitted closing the ramp during the cure period, a better riding surface could have been obtained by pouring full width. Pour no. 56 in Figure 9 shows a maximum production for a single shift of 2,000 yd^2. This pour, located on the east upper-deck

FIGURE 8 Typical joint replacement: loose angle removed (*top*) and new angle installed and deck ready to be poured back (*bottom*).

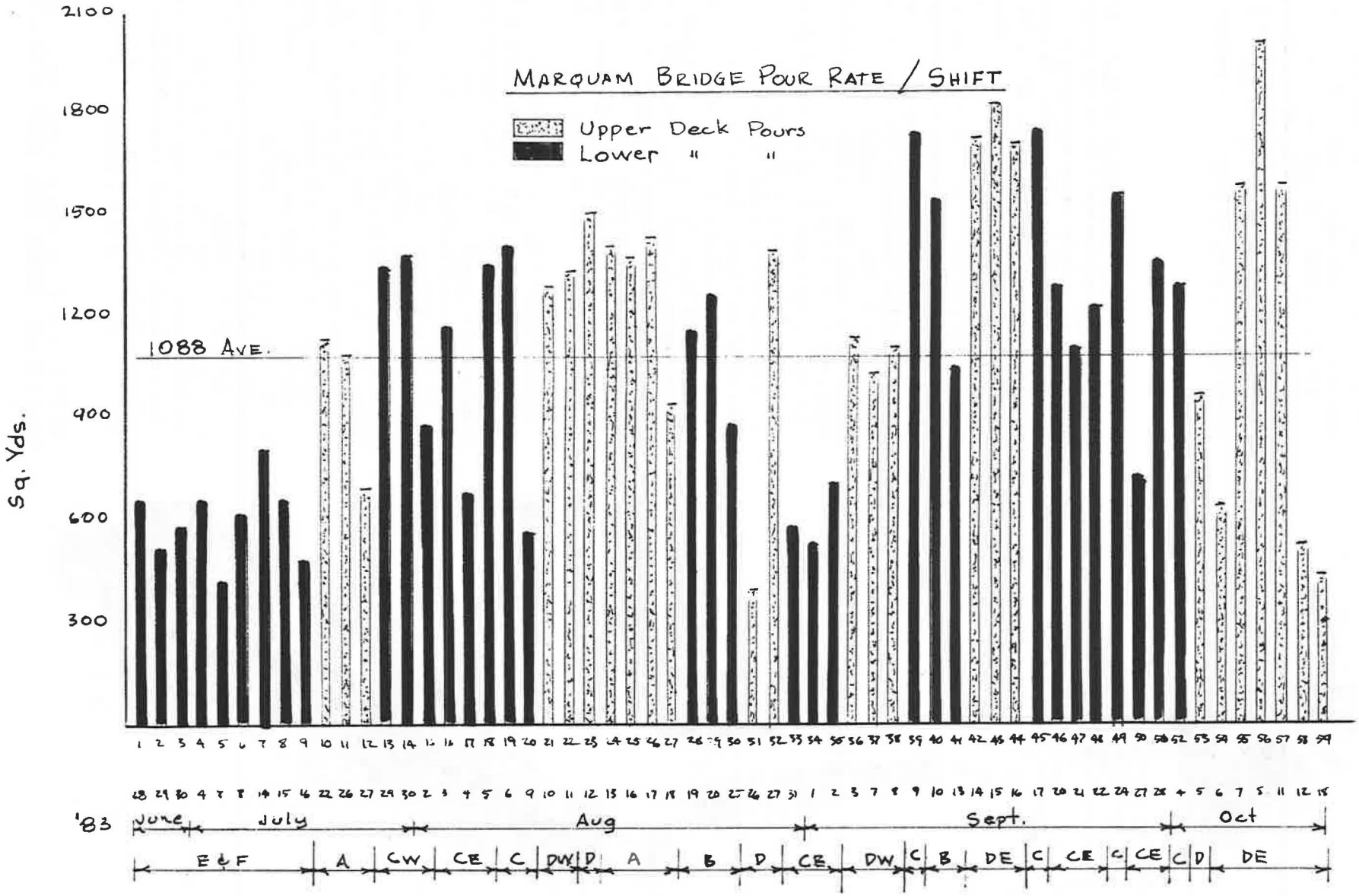
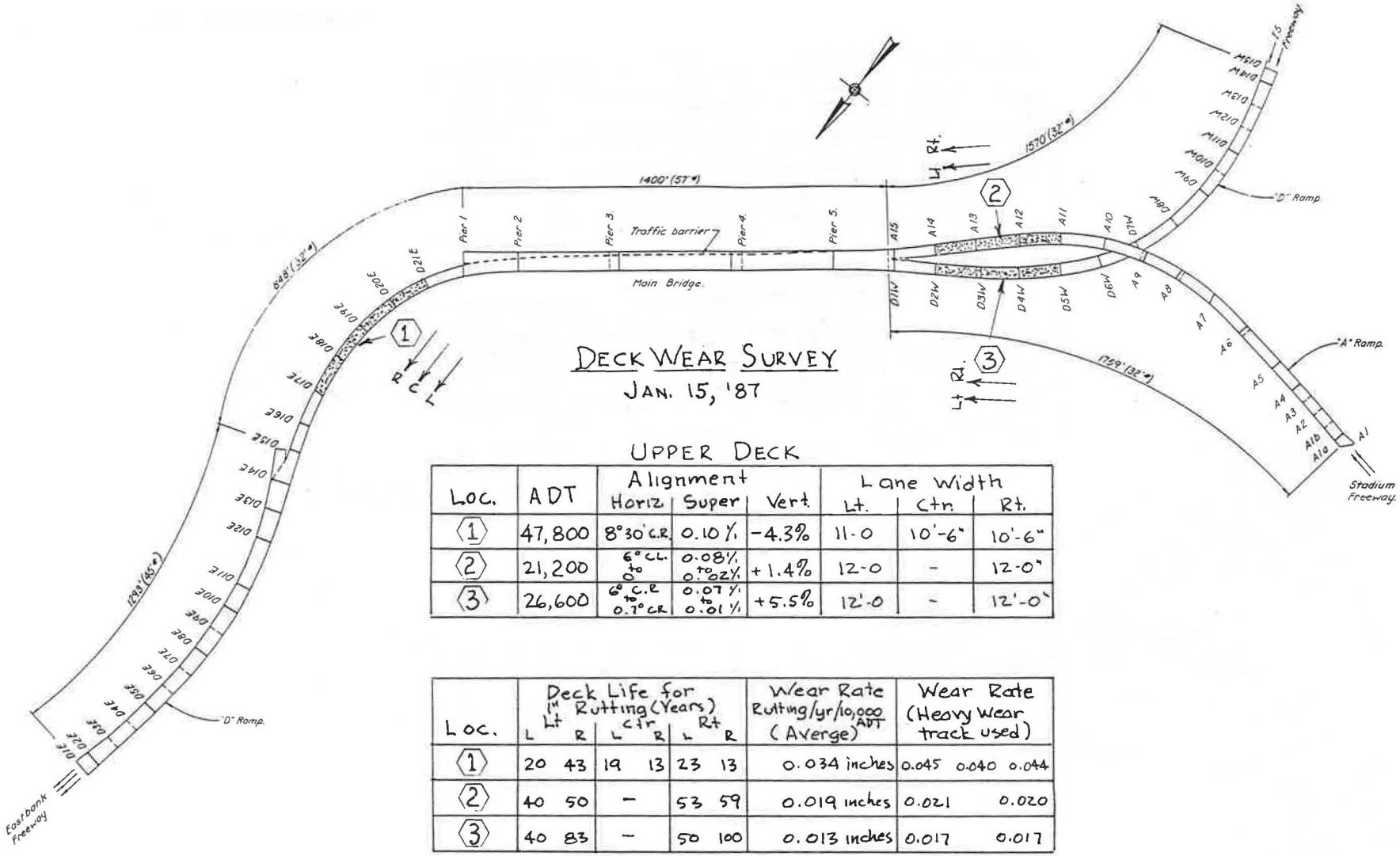


FIGURE 9 Pour record.

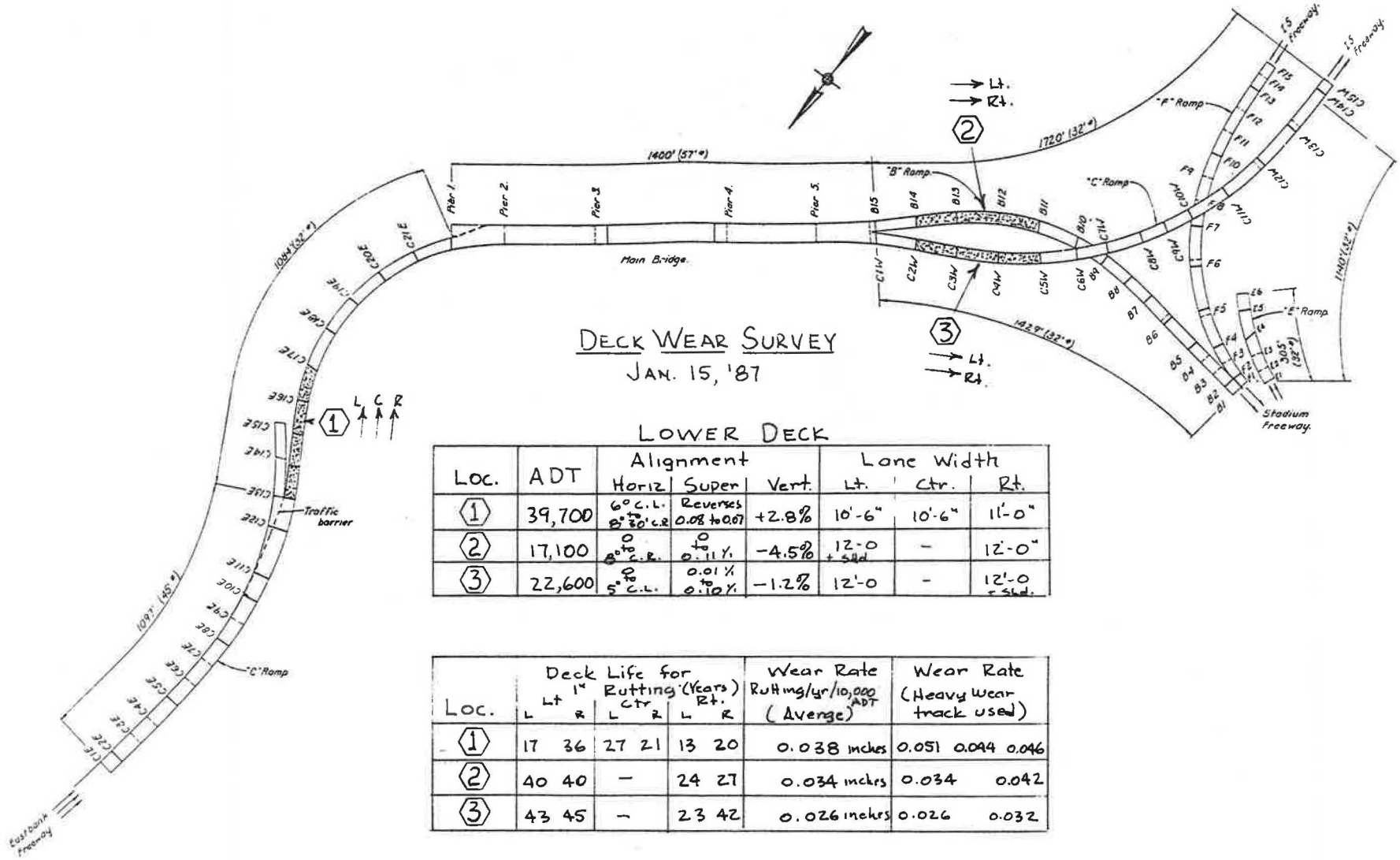


UPPER DECK

Loc.	ADT	Alignment Horiz.	Alignment Super	Alignment Vert.	Lane Width Lt.	Lane Width Ctr.	Lane Width Rt.
1	47,800	8°30' C.R.	0.10 %	-4.3%	11-0	10'-6"	10'-6"
2	21,200	6° C.L. to 0°	0.08% to 0.02%	+1.4%	12-0	-	12-0"
3	26,600	6° C.R to 0.7° C.R	0.07 % to 0.01 %	+5.5%	12'-0	-	12'-0"

Loc.	Deck Life for 1" Rutting (Years) Lt L	Lt R	Ctr L	Ctr R	Rt L	Rt R	Wear Rate Rutting/yr/10,000 ADT (Averge)	Wear Rate (Heavy Wear track used)		
1	20	43	19	13	23	13	0.034 inches	0.045	0.040	0.044
2	40	50	-		53	59	0.019 inches	0.021		0.020
3	40	83	-		50	100	0.013 inches	0.017		0.017

FIGURE 10 Deck wear survey—upper deck.



LOWER DECK

Loc.	ADT	Alignment Horiz	Alignment Super	Alignment Vert.	Lane Width Lt.	Lane Width Ctr.	Lane Width Rt.
1	39,700	6° C.L. 8° to 30' C.R.	Reverses 0.08 to 0.07	+2.8%	10'-6"	10'-6"	11'-0"
2	17,100	0 8° to C.R.	0 to 0.11 %	−4.5%	12'-0 + Shld	–	12'-0"
3	22,600	0 5° C.L.	0.01 % 0.10 %	−1.2%	12'-0	–	12'-0 + Shld.

Loc.	Deck Life for 1" Rutting (Years) Lt. L	Lt. R	Ctr. L	Ctr. R	Rt. L	Rt. R	Wear Rate Rutting/yr/10,000 ADT (Average)	Wear Rate (Heavy Wear track used)		
1	17	36	27	21	13	20	0.038 inches	0.051	0.044	0.046
2	40	40	–		24	27	0.034 inches	0.034		0.042
3	43	45	–		23	42	0.026 inches	0.026		0.032

FIGURE 11 Deck wear survey—lower deck.

ramp, varied in width from 28 ft to 32 ft. It is one of the better riding segments of concrete deck.

Some bond failures occurred at the center line bulkhead after the first half was poured. The cause was not determined, but the failures could have been due to deflections in the deck caused by traffic running next to the pour. To find the bad areas, the edge was sounded with a hammer. The hollow sounding areas were marked, then saw cut, removed, and repoured with the adjoining pour. Seldom did they extend more than 1 ft from the bulkhead into the first pour.

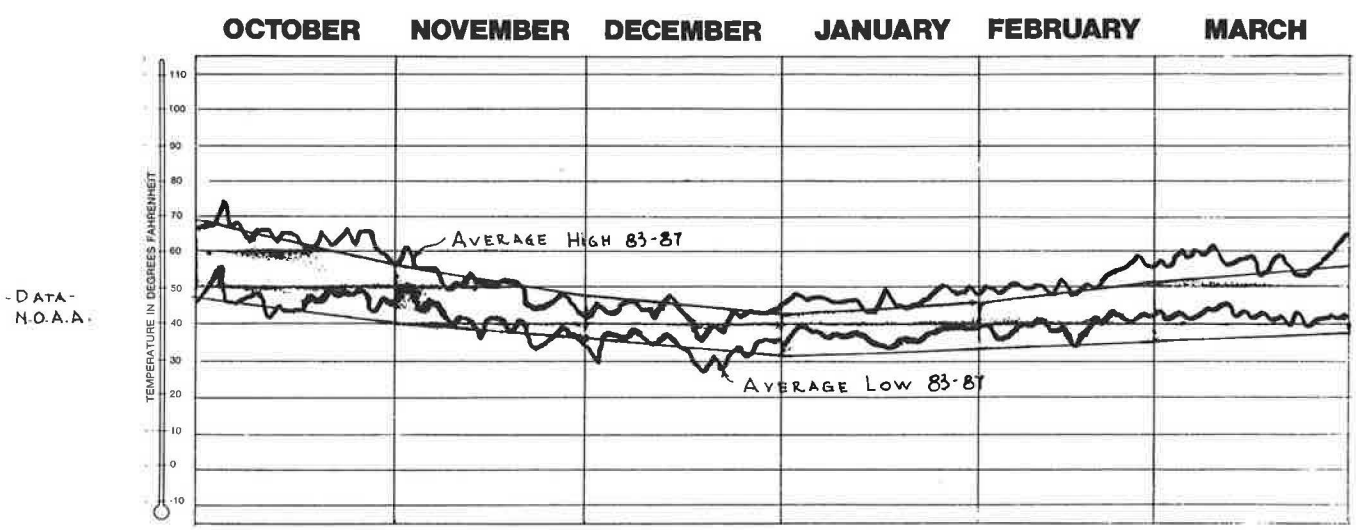
The riding quality of the completed overlay is acceptable but not good. Some shifting in the steep grade areas occurred, and hand-finishing of the deck and construction joints contributed to the surface irregularities. Eleven days with a large deck grinder were needed to bring the surface into the 0.125-in. in 10-ft tolerance.

Figure 9 shows the pour rate per shift for the 59 pours required to do the job. The 1,088 yd² average translated to 612 linear feet, 16 ft wide. It might be noted that of 20 workdays in July, pours were made 11 nights; of 23 workdays in August, pours were made 19 nights, and of 21 workdays in September, pours were made 18 nights. Continuous production requires close coordination of all phases. Shot blasting cannot be done in wet weather, and weather caused some delay in July. The method of deck preparation was never far in advance of the pouring and, in some instances, limited the pour size. The average production rate is the direct result of being able to pour from only one truck on most pours. Pour 56 with the 2,000-yd² rate used two trucks. The year before the Marquam job, this office worked on the overlay of the I-205 Columbia River Bridge. This project was almost twice the area, two trucks placed at the same time on all pours, and the average pour rate was 2,400 yd²/shift.

Costs

There were five bidders on this project. The low bid was approximately $5,000 less than the second and $831,000 less than the high bid. The following are the major items, some of which are combined. These are the final costs and 1983 prices.

	Unit Cost	*Quantity*	*Total Cost*
1 Mobilization			$ 221,000
2 Traffic items			321,943
3 Deck preparation	$ 4.00/yd²	63,389	253,556
4 Latex mod. Overlay	15.09/yd²	63,389	956,712
5 Finger-plate joints	60.00/lin ft	403.5	24,210
6 Paving dam w/comp. seal	85.17/lin ft	3,178	270,658
7 Epoxy grout joint	56.01/lin ft	3,178	178,179
8 Replace joint angles	180.42/lin ft	406	73,250
TOTAL			$2,299,508



DAYS HIGHS BELOW FREEZING

83-84	0	0	7	0	0	0
84-85	0	0	3	0	0	0
85-86	0	7	1	0	0	0
86-87	0	0	0	0	0	0

DAYS LOWS BELOW FREEZING

83-84	0	0	13	9	1	0
84-85	0	1	8	19	11	1
85-86	2	16	25	0	6	0
86-87	0	0	4	9	0	0

FIGURE 12 Climatological data—deck wear period.

PERFORMANCE

In January of 1987, after about 3 yr of service, the areas shown in Figures 10 and 11 were straightedged and the depth of the wheel ruts measured. Of interest was the expected life of the overlay and a comparison of the wear rate on the narrow three lane section of the east ramps to the west ramps. At the same time, after about 4 yr of service, a similar survey was made on the I-205 Columbia River Bridge.

Figure 12 shows the average high and low air temperatures for the winter months during the survey period. Also given are the number of days the temperature was below freezing for the full day and for part of a day. It is general practice to sand icy surfaces, and the abrasive effect of this material plus the use of studded tires or tire chains can significantly affect the amount of wear. It can be noted that, with the exception of portions of November and December, the average highs and lows are above the mean temperature range, and there were a total of only 18 days when temperatures remained below freezing. From this we would have to assume the wear measured is somewhat less than might normally be expected.

The traffic count, alignment, and lane width, which could be possible factors in the wear, are shown in Figures 10 and 11. At about 20-ft intervals, the depth of the wheel tracks was measured, averaged, and prorated to give the years for a 1-in. rut shown in the lower block. Of significance is the much heavier wear found at several locations in the outside wheel track. As expected, the narrow lanes on the east ramps show the shortest life. By comparison, the original deck after 17 yr had an estimated 1-in. wear in this area. During the 17 yr, the layout was changed from the two-lane design to the narrow three lanes, which shifted the wear pattern and extended the life of the deck. With this in mind, in our opinion the minimum 13 yr shown makes the latex overlay equal or possibly superior to the original deck.

To compare the east and west ramps, the wear rates given in Figures 10 and 11 need to be considered. Also, as a further reference the survey from the I-205 Columbia River Bridge is useful. This structure is on a 3-percent grade with light horizontal curvatures (1° maximum) and shows a relatively even wear pattern. The wear rate at this location is approximately 0.031 in. rutting per yr per 10,000 ADT, and in our opinion might be considered a normal rate. The west ramps of the upper deck (Figure 10, locations 2 and 3) give a rate of about half of this figure. Both of these areas are subject to lane changing, so have less well-defined wheel tracks and were probably a poor choice for the survey. The west ramps on the lower deck (Figure 11, locations 2 and 3) have rates close to the norm. The east ramps, when all the measurements are averaged, also give a rate close to 0.031 in. However, because of the uneven wear pattern, this would not be a valid rate on which to predict life expectancy. Using measurements from the heavy wear tracks, the second rate shown on the two figures was determined. This indicates the rate for the narrow east lanes is approximately 50 percent higher.

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