NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594

November 8, 2007

MODELING GROUP STUDY Report No. 07-115

A. ACCIDENT

Place : Minneapolis, Minnesota
Date : August 1, 2007
Vehicle : I-35W bridge
NTSB No. : HWY07MH024
Investigator : Gary Van Etten

B. DETAILS OF THE STUDY

This study documents the reconstructed locations of vehicles, pedestrians and construction materials on the bridge at the time of the collapse, along with their sizes and weights. The temperature and wind conditions as reported from a weather station on the campus of the University of Minnesota on the day of the collapse are also tabulated.

Vehicles and pedestrians

Following the accident, each vehicle was labeled with a letter and number indicating their general position on the collapsed bridge. The A vehicles (A1 – A32) were generally south of pier 6. The B vehicles (B1 – B21) were generally in the central span of the bridge between pier 6 and pier 7. The C vehicles (C1 – C37) and E vehicles (E1 – E6) were generally north of pier 7. The D vehicles (D1 – D17) were recovered from the water, and were found to have generally come from the center span between pier 6 and pier 7. Additionally, construction workers on the bridge were identified with a P (pedestrian) designation (P1 – P17). Two of these pedestrians (P3 and P14) were later found to have been inside vehicle A10 at the time of the collapse.

The locations of vehicles, equipment and materials were determined using their post-accident positions, photographs and witness statements. Using Automated Computer Aided Drafting software, AutoCAD, each item was positioned on a scale drawing of the bridge, as shown in Figure 1a, with magnified views in Figures 1b – 1g. Table 1 lists the x and y position of the center of each vehicle (as determined using the AutoCAD drawing), along with the wheelbase and width of each vehicle, which were found from the vehicle year, make and model, using Canadian Vehicle Specifications version 2007.1. The origin of the coordinate system is taken at pier 6 at the centerline of the bridge, with the x-axis to the north along the centerline of the bridge, and with the y-axis perpendicular to the bridge

toward the west. Southbound vehicles will therefore generally have positive y coordinates and northbound vehicles will generally have negative y coordinates. Uncertainty in the placement of the A, B, C and E vehicles is estimated to be ± 10 feet. Uncertainty in the placement of the D vehicles is estimated to be ± 25 feet.

Estimated vehicle weights were found and verified using several methods. Most of the vehicles weights were measured using a calibrated crane scale as they were removed from the site. Vehicles that were not weighed with the crane scale were weighed at the Minneapolis Police impound lot using Minnesota State Police Commercial Vehicle Inspectors certified portable scales. Measured weights were then crosschecked with weights from the Canadian Vehicle Specifications. The vehicle weights were adjusted to include occupants and cargo, and in some cases to exclude water or debris. Adult occupants were assigned an estimated weight of 200 lbs, child occupants were specified a weight from 50 lbs to 100 lbs, depending on age. The construction workers on the bridge were each assigned an estimated weight of 200 lbs. The gross adjusted vehicle weights are listed in Table 1.

More detailed information on the wheel spacing and weight distributions of the multi-axle vehicles is provided in Table 2. The information in Table 2 is based on a number of assumptions. All tractors were assumed to have a 230-inch wheelbase. Tandem axle spacing was taken to be 50 inches. Vehicles B15 and D16 were assumed to have 30-foot wheelbases, while vehicle C24 was assumed to have a 20-foot wheelbase (with the tag axle assumed to be up off the pavement). The trailers for vehicles A2, A31 and B16 were assumed to be 53 feet long and the trailer for vehicle A32 was assumed to be 40 feet long. The distance from the kingpin to the rear axles was estimated to be 40 feet for 53-foot trailers and 30 feet for the 40-foot trailer. A common commercial vehicle weight distribution for each axle was used to determine the load per axle.

Construction equipment and materials

Construction vehicles and materials associated with the resurfacing activity were located in the left two southbound lanes on the main span, as shown in Figure 2. The construction vehicles are included with the other vehicles in Tables 1 and 2.

Four loads of coarse aggregate (gravel) and four loads of fine aggregate (sand) were located in the leftmost southbound lane just north of pier 6, as shown in Figure 2. Delivery records indicated that the weight of the coarse aggregate was 184,380 pounds, and the weight of the fine aggregate was 198,820 pounds. The sizes and shapes of the aggregate piles at the time of the accident were estimated with information from three different sources, as described below.

1. Construction workers involved in the resurfacing activity reported that the aggregate was located between Pier 6 and the centerline of Span 7 and that it was pushed into the inside leftmost closed southbound lane, giving the aggregate piles a width of approximately 12 feet. It was estimated that the coarse aggregate

extended north from pier 6 approximately 55 feet and the fine aggregate extended another 59 feet farther north from the end of the coarse aggregate pile.

2. Measurements were taken on piles of aggregate from a delivery to another job site of a similar quantity of coarse and fine aggregate. See Figure 3. The coarse aggregate pile was approximately 16 feet wide, 60 feet long, and 5 feet tall (at its peak), while the fine aggregate pile was approximately 14 feet wide, 51 feet long, and 6 feet tall (at its peak).

3. A photograph taken from a commercial airline flight at 15:48 Central Daylight Time showed the coarse and fine aggregate piles on the bridge, as indicated in Figure 4. Photogrammetry was used to measure the locations of points on the boundaries of the piles, as indicated in Figure 5. The photogrammetric measurements were made using known dimensions from the design drawings and measurements taken from a scaled post-accident photograph of the bridge deck. Figure 6 compares the boundaries of the aggregate piles in the photograph with the boundaries as reported by the construction workers.

The construction workers indicated that the aggregate piles were pushed up against the barrier along the center of the bridge after the photograph was taken in order to clear space for the passage of construction vehicles. The photograph shows the boundary between the coarse and fine aggregate piles approximately 70 feet north of pier 6, and it is assumed that the position of this boundary did not change. The construction workers indicated that the aggregate piles were somewhat tapered, being wider to the south and more compressed to the north in order to allow for construction vehicle traffic. It was also assumed that the final sizes of the aggregate piles were similar to those measured at the other job site. The approximate size of the coarse aggregate pile was taken to be 60 feet long and about 16 feet wide at the south end and 14 feet wide at the north end. The fine aggregate pile was taken to be 55 feet long and about 14 feet wide at the south end and 12 feet wide at the north end. The coarse aggregate was therefore assumed to extend from 10 feet to 70 feet north of pier 6, and the fine aggregate was assumed to extend from 70 to 125 feet north of pier 6, as shown in Figure 2. The weights and positions of the aggregate (and other assorted construction materials) are also indicated in Table 3, giving x and y positions for the four corners enclosing each item.

The construction workers also reported that the widths of the two southbound lanes open to traffic had been reduced to 11.5 feet each to allow for resurfacing of two complete lanes.

Table 4 summarizes the weights on various parts of the bridge.

Environment

Temperature, wind direction and wind speed as measured at a weather station on the campus of the University of Minnesota are provided in Table 5. The data was downloaded from http://www.weatherpages.com/wxhistory.html. The weather station is at 44.975° North, 93.234° West, while the center of the bridge was at 44.979° North, 93.245° West.

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Table 1. Positions and weights of vehicles and pedestrians.					
Vehicle	Center x (feet)	Center y (feet)	Wheelbase (inches)	Width (inches)	Gross Weight (lbs)
A1 resurfacer	-567	-10	380 (length)	102	64750
A1 water tank	-592	-5	120	102	13000
A2 tractor	-460	-28	230	102	7000
A2 trailer	-483	-25	480	102	20000
A3	-359	-14	105	69	4100
A4	-312	-5	102	67	2700
A5	-494	33	50	54	6850
A6 trailer	-587	52	50	54	2800
A7 trailer	-639	65	50	54	4050
A8	-701	84	50	54	7050
A9	-324	-17	100	69	4300
A10	-283	-20	142	80	8200
A11	-267	-7	155	79	5200
A12	-302	11	142	80	8800
A13	-234	-20	104	68	3300
A14	-216	-9	107	70	3300
A15	-193	-21	116	79	4800
A16	-157	-21	111	70	4800
A17	-109	-21	106	68	3200
A18	-126	-9	120	74	4800
A19	-165	-9	108	72	4300
A20	-90	-9	102	66	3000
A21	-58	-21	131	78	6400
A22	-56	-9	107	68	3900
A23	-3	-9	116	77	4700
A24	30	-21	103	69	3300
A25	-104	7	133	80	6100
A26	-103	37	107	70	3500
A27	-144	7	137	80	6000
A28	-180	37	104	71	4100
A29	-209	37	107	70	3500
A30 bus	-238	50	209	94	24300
A31 tractor	-266	37	230	102	15500
A31 trailer	-246	37	480	102	35600
A32 tractor	-142	49	230	102	12700
A32 trailer	-127	49	360	102	9700

Table 1 (continued). Positions and weights of vehicles and pedestrians.					
Vehicle	Center x (feet)	Center y (feet)	Wheelbase (inches)	Width (inches)	Gross Weight (lbs)
B1	95	-21	110	73	4100
B2	74	-9	114	70	4000
B3	123	-9	106	69	3700
B4	188	-21	130	75	5100
B5	141	-21	106	71	4600
B6	224	-22	110	72	3400
B7	238	-9	106	70	3400
B8	279	-9	106	69	3100
B9	330	-9	115	78	4000
B10	309	-21	114	74	4300
B11	227	20	50	54	1800
B12	219	14	50	54	2200
B13	209	20	50	54	2200
B14	197	14	50	54	2200
B15	167	8	360	102	51400
B16 tractor	159	27	230	102	24745
B16 trailer	179	27	480	102	48035
B17	410	37	105	70	3500
B18	388	49	103	67	2700
B19	398	-9	104	78	3700
B20	438	-9	95	65	2500
B21	212	7	50	54	3300

Table 1 (continued). Positions and weights of vehicles and pedestrians.					
Vehicle	Center x (feet)	Center y (feet)	Wheelbase (inches)	Width (inches)	Gross Weight (lbs)
C1	482	37	109	69	3700
C2	488	49	111	70	4400
C3	541	37	111	73	3600
C4	545	49	102	67	3150
C5	623	37	111	73	3800
C6	594	49	126	74	4150
C7	670	49	103	67	2850
C8	534	-21	108	72	3600
C9	568	-8	107	67	4050
C10	626	-21	135	77	6700
C11	700	-8	102	67	2600
C12	739	49	140	75	5200
C13	792	49	104	69	3500
C14	772	37	109	73	3600
C15 trailer	785	22	120	80	7400
C16	728	37	114	79	5100
C17	776	-8	99	67	2700
C18	742	-8	105	70	3700
C19	734	-21	118	76	5200
C20	825	37	112	72	4600
C21	851	49	106	73	4700
C22	890	49	107	69	3400
C23	926	37	104	70	3900
C24	926	25	240	102	40000
C25	936	49	108	70	3700
C26	970	37	109	72	3600
C27	984	48	113	71	4300
C28	1014	37	118	79	6200
C29	979	7	150	80	13400
C30	1024	7	153	80	7950
C31	1056	48	121	77	4400
C32	1106	7	142	80	7000
C33	1094	49	99	67	2500
C34	1132	50	142	78	5300
C35	1088	37	110	75	4400
C36	1124	37	114	74	4000
C37	738	16	300 (est.)	300 (est.)	11856

Table 1 (continued). Positions and weights of vehicles and pedestrians.					
Vehicle	Center x (feet)	Center y (feet)	Wheelbase (inches)	Width (inches)	Gross Weight (lbs)
D1	137	37	120	79	4800
D2	267	37	102	67	3800
D3	183	37	106	68	3600
D4	279	49	106	70	3200
D5	309	37	112	69	4000
D6	229	37	153	80	7750
D7	336	49	106	69	4250
D8	219	50	112	72	4200
D9	361	-21	95	70	3200
D10	349	37	103	69	3500
D11	170	50	103	69	3400
D12	110	50	107	72	4000
D13	81	37	103	70	4400
D14	59	50	111	70	3950
D15	131	18	50	54	8955
D16	123	26	360	102	48200
D17	14	50	106	72	3600
E1	824	-21	108	72	3800
E2	865	-21	102	67	2600
E3	813	-8	106	69	3200
E4	911	-8	110	70	3300
E5	849	-8	104	70	3500
E6	-357	58	99	68	3300

Table 1 (continued). Positions and weights of vehicles and pedestrians.					
Pedestrians	X position (feet)	Y position (feet)			Gross Weight (lbs)
P1	866	22			200
P2	881	20			200
P3	In A10				
P4	872	15			200
P5	876	6			200
P6	885	12			200
P7	224	15			200
P8	717	6			200
P9	179	17			200
P10	859	15			200
P11	228	25			200
P12	717	12			200
P13	763	6			200
P14	In A10				
P15	775	7			200
P16	186	15			200
P17	132	14			200

Table 2. Estimated commercial vehicle axle weight distributions.						
Vehicle		Axle 1	Axle 2	Axle 3	Axle 4	Axle 5
A2	Weight Percentage	12 %	22 %	22 %	22 %	22 %
	Distance from Axle 1 (inches)	0	205	255	685	735
	Total Weight = 27,000 lbs	3240	5940	5940	5940	5940
A31	Weight Percentage	12 %	22 %	22 %	22 %	22 %
	Distance from Axle 1 (inches)	0	205	255	685	735
	Total Weight = 51,100 lbs	6132	11242	11242	11242	11242
A32	Weight Percentage	12 %	44 %	44 %		
	Distance from Axle 1 (inches)	0	205	565		
	Total Weight = 22,400 lbs	2688	9856	9856		
B15	Weight Percentage	14 %	43 %	43 %		
	Distance from Axle 1 (inches)	0	335	385		
	Total Weight = 51,400 lbs	7196	22102	22102		
B16	Weight Percentage	12 %	22 %	22 %	22 %	22 %
	Distance from Axle 1 (inches)	0	205	255	685	735
	Total Weight = 72,780 lbs	8734	16012	16012	16012	16012

Table 2 (continued). Estimated commercial vehicle axle weight distributions.						
Vehicle		Axle 1	Axle 2	Axle 3	Axle 4	Axle 5
C24	Weight Percentage	14 %	43 %	43 %		
	Distance from Axle 1 (inches)	0	215	265		
	Total Weight = 40,000 lbs	5600	17200	17200		
D16	Weight Percentage	14 %	43 %	43 %		
	Distance from Axle 1 (inches)	0	335	385		
	Total Weight = 48,200 lbs	6748	20726	20726		

Table 3. Construction equipment and materials.			
Item	Corner X (feet)	Corner Y (feet)	Weight (lbs)
Coarse aggregate	10	2	184380
	70	2	
	70	16	
	10	18	
Fine aggregate	70	2	198820
	125	2	
	125	14	
	70	16	
Cement mixer and cement	201	3	1500
	208	3	
	208	10	
	201	10	
Barrels	821	4	1500
	835	4	
	835	11	
	821	11	
Portable toilet 1	-40	3	250
	-36	3	
	-36	7	
	-40	7	
Portable toilet 2	839	4	250
	843	4	
	843	8	
	839	8	

Table 4. Summary of weight distribution on various parts of the bridge at the time of the collapse (lbs).				
	South of Pier 6	Center span between Pier 6 and Pier 7	North of Pier 7	TOTAL
Southbound Traffic	112,200	64,650	98,050	274,900
Southbound Closed lanes	41,900	578,735	91,691	712,326
Northbound Traffic	66,300	57,100	44,950	168,350
Northbound Closed lanes	104,750	0	0	104,750
TOTAL	325,150	700,485	234,691	1,260,326

Table 5. Temperature and wind conditions on August 1, 2007 as measured at the weather station on the campus of the University of Minnesota.

Time	Temperature (° F)	Wind Direction (Degrees)	Wind Speed (mph)	Wind Gust (mph)
00:01:00	78.6	170	10	0
00:31:00	77.9	170	10	0
01:01:00	77.3	180	6	0
01:31:00	77.0	180	6	0
02:01:00	76.4	200	4	0
02:31:00	76.1	200	4	0
03:02:00	75.3	0	0	0
03:31:00	74.6	210	5	0
04:01:00	74.4	200	5	0
04:31:00	74.1	200	5	0
05:01:00	73.5	210	6	0
05:31:00	73.6	210	6	0
06:01:00	73.5	210	8	0
06:31:00	73.6	210	8	0
07:01:00	75.0	210	10	18
07:31:00	79.0	210	10	18
08:01:00	80.9	220	9	18
08:31:00	79.1	220	9	18
09:01:00	81.4	210	9	0
09:31:00	82.6	210	9	0
10:01:00	84.1	220	11	0
10:31:00	84.3	220	11	0
11:01:00	87.0	210	11	18
11:31:00	87.9	210	11	18
12:01:00	87.7	230	17	23

Table 5 (continued). Temperature and wind conditions on August 1, 2007 as measured at the weather station on the campus of the University of Minnesota.

Time	Temperature (° F)	Wind Direction (Degrees)	Wind Speed (mph)	Wind Gust (mph)
12:01:00	87.7	230	17	23
12:31:00	90.5	230	17	23
13:01:00	90.7	240	13	21
13:31:00	91.1	240	13	21
14:31:00	91.4	220	17	21
15:01:00	92.4	200	14	23
15:31:00	91.8	0	0	0
16:01:00	92.8	0	0	0
16:31:00	92.9	210	18	26
17:01:00	91.8	220	17	24
17:31:00	91.6	220	17	24
18:01:00	92.1	230	10	0
18:31:00	91.5	0	0	0
19:01:00	87.6	0	0	0
19:31:00	86.7	220	13	20
20:01:00	86.7	210	10	0
20:31:00	83.3	200	8	0
21:01:00	82.1	240	9	0
21:31:00	79.0	240	9	0
22:01:00	78.1	0	0	0
22:31:00	79.7	270	4	0
23:01:00	81.3	250	10	0
23:31:00	79.0	250	10	0

Figure 1a - Scale Diagram of Pre-Collapse Bridge

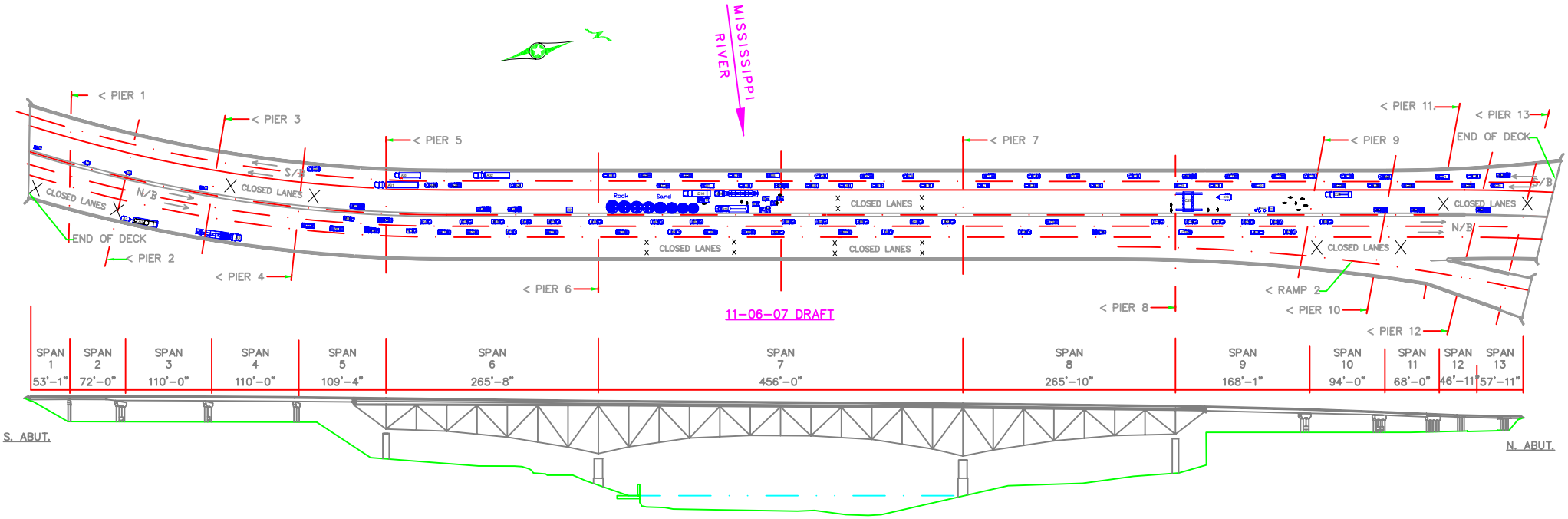


Figure 1b - Scale Diagram of Pre-Collapse Bridge(Zoom 1 of 6)

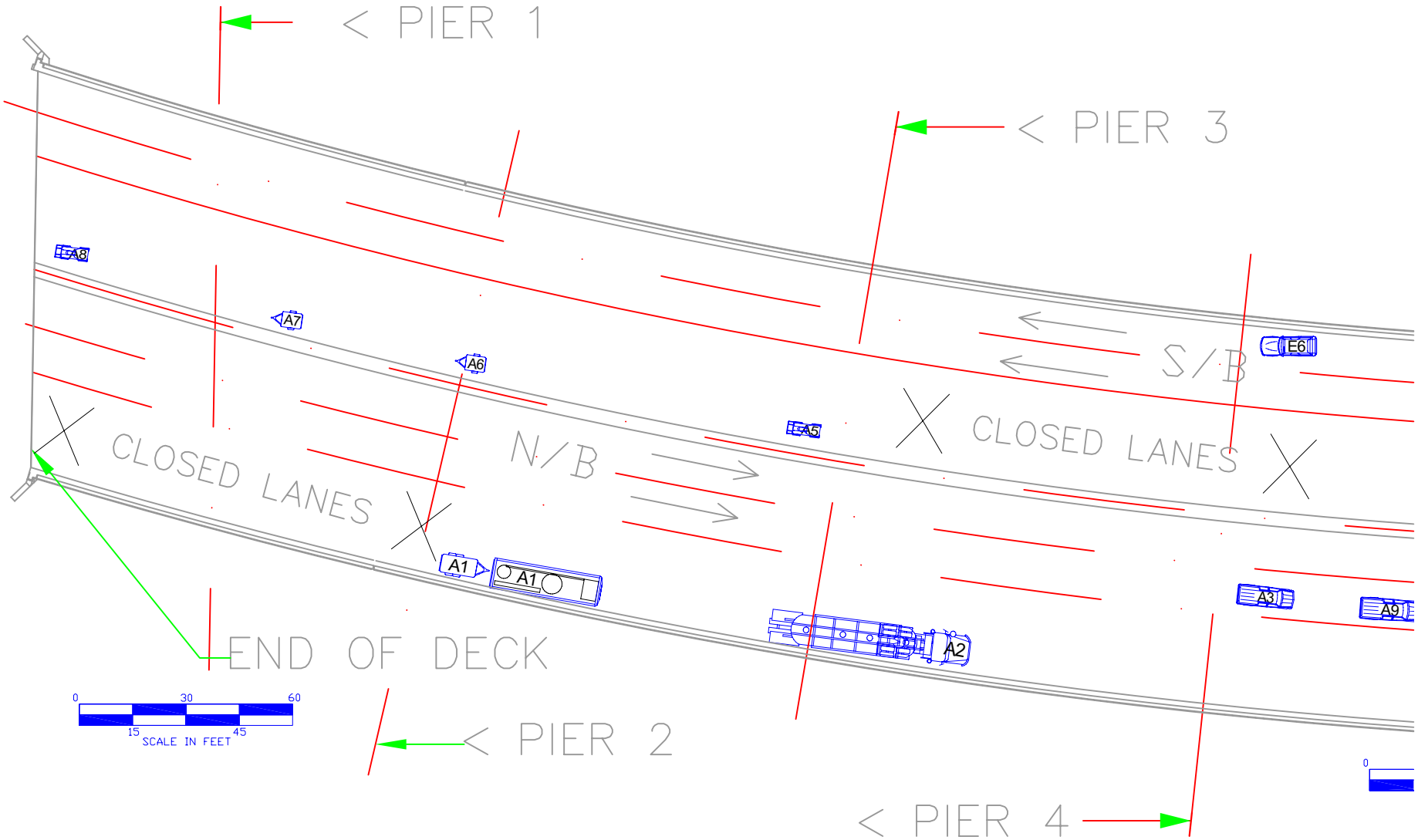


Figure 1c - Scale Diagram of Pre-Collapse Bridge (Zoom 2 of 6)

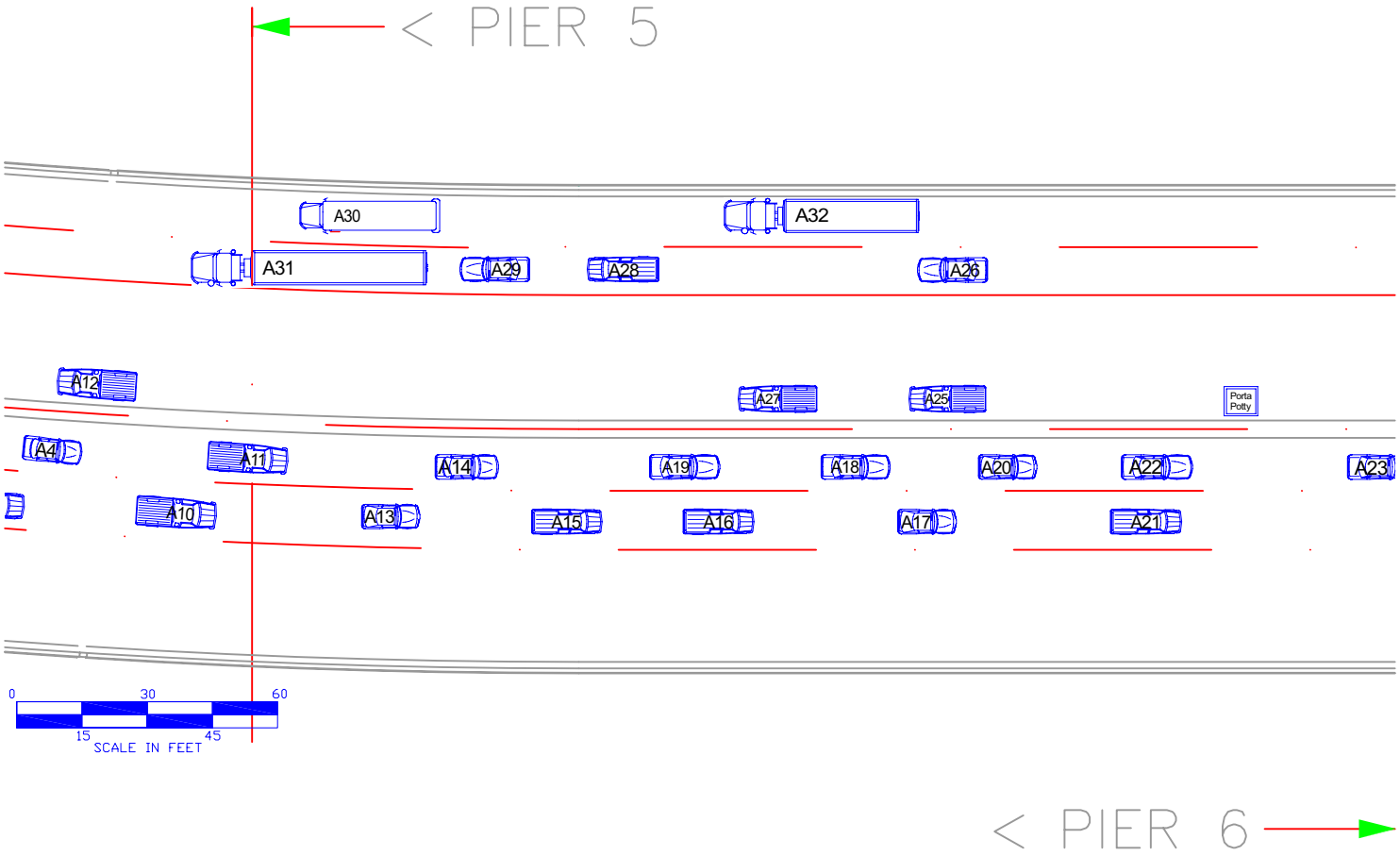


Figure 1d - Scale Diagram of Pre-Collapse Bridge (Zoom 3 of 6)

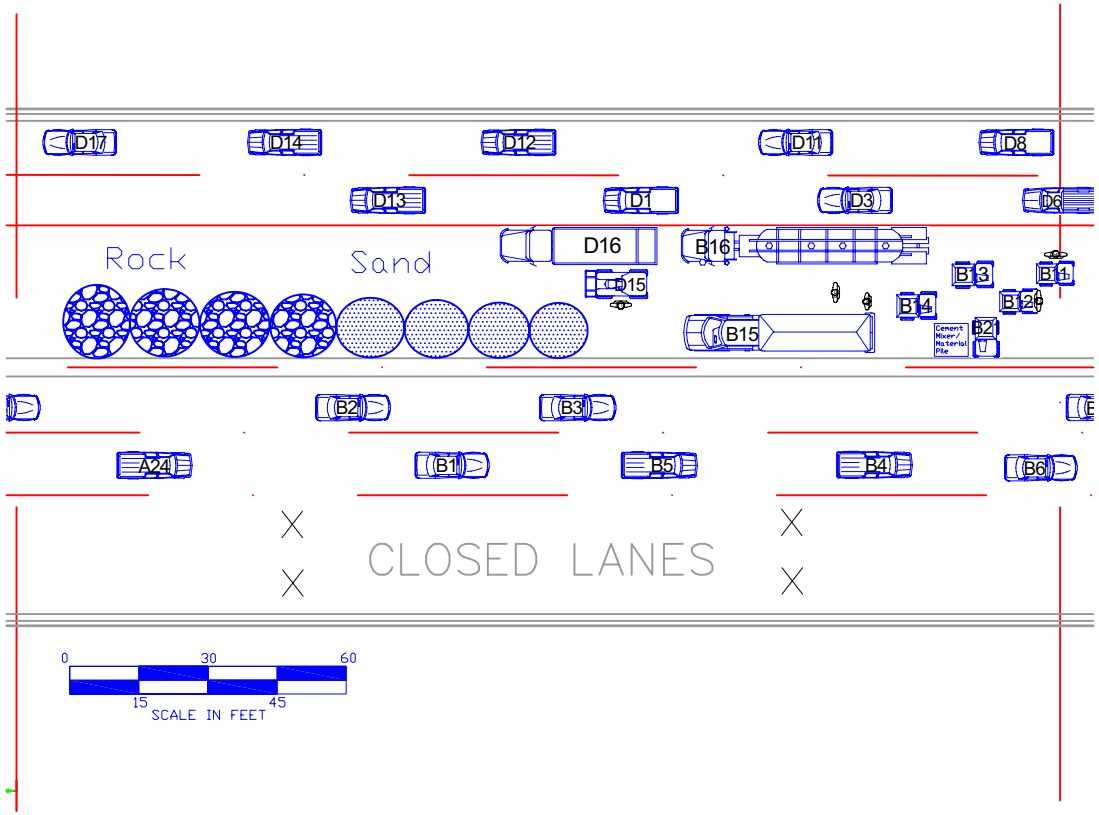


Figure 1e - Scale Diagram of Pre-Collapse Bridge (Zoom 4 of 6)

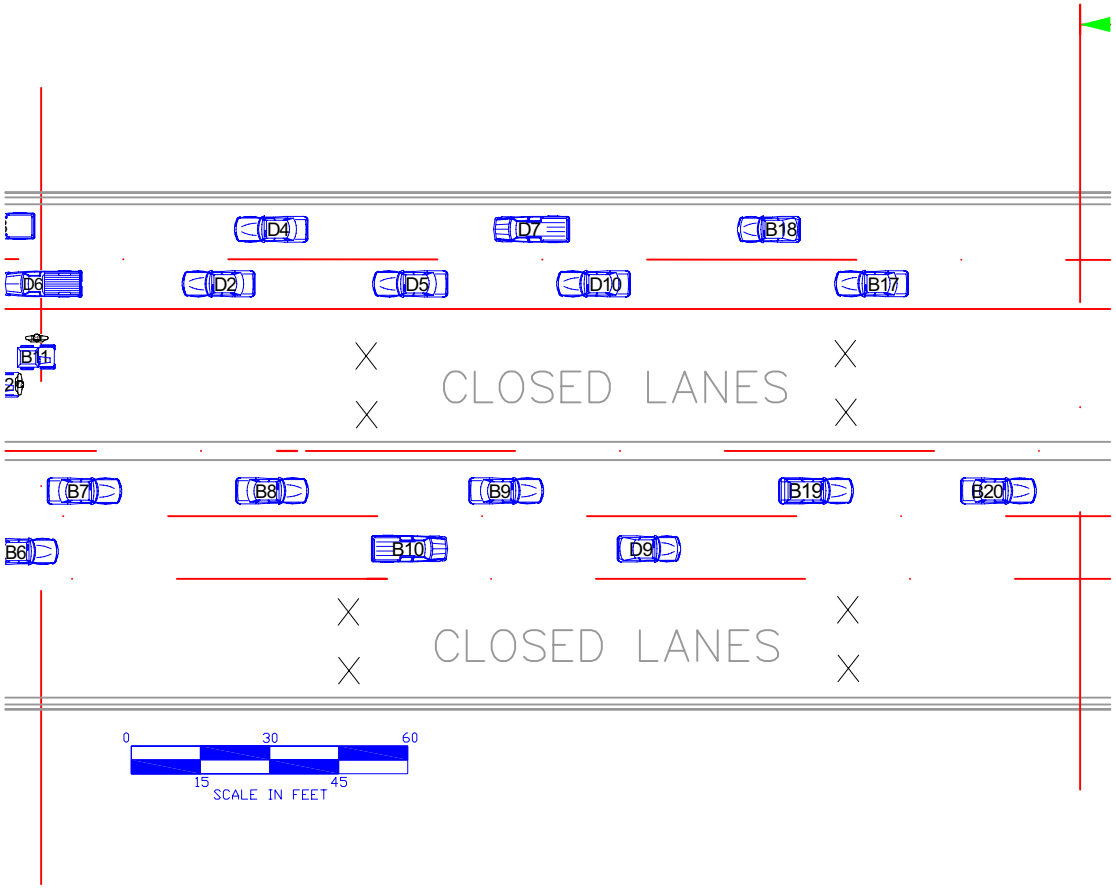


Figure 1f - Scale Diagram of Pre-Collapse Bridge (Zoom 5 of 6)

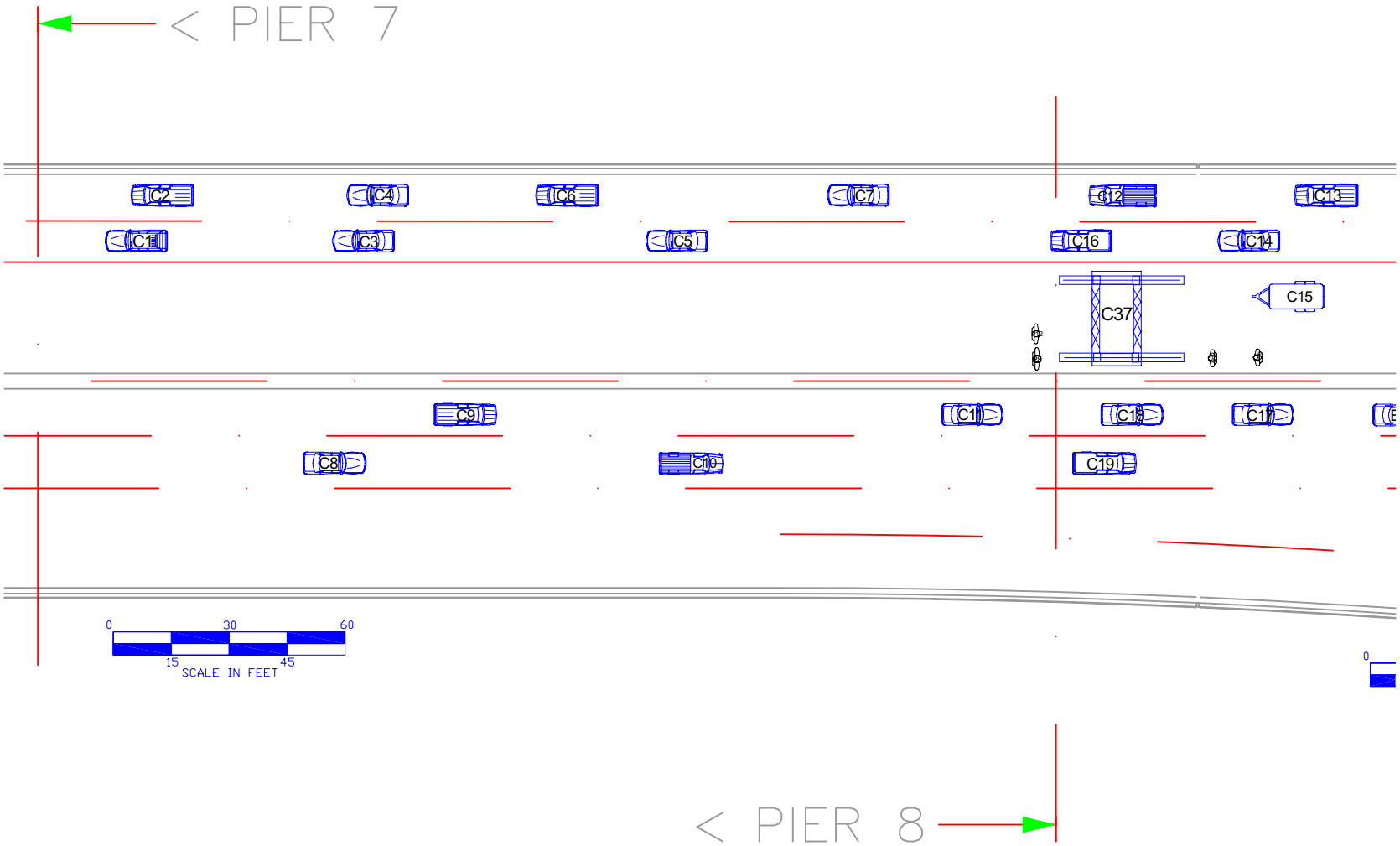


Figure 1g - Scale Diagram of Pre-Collapse Bridge (Zoom 6 of 6)

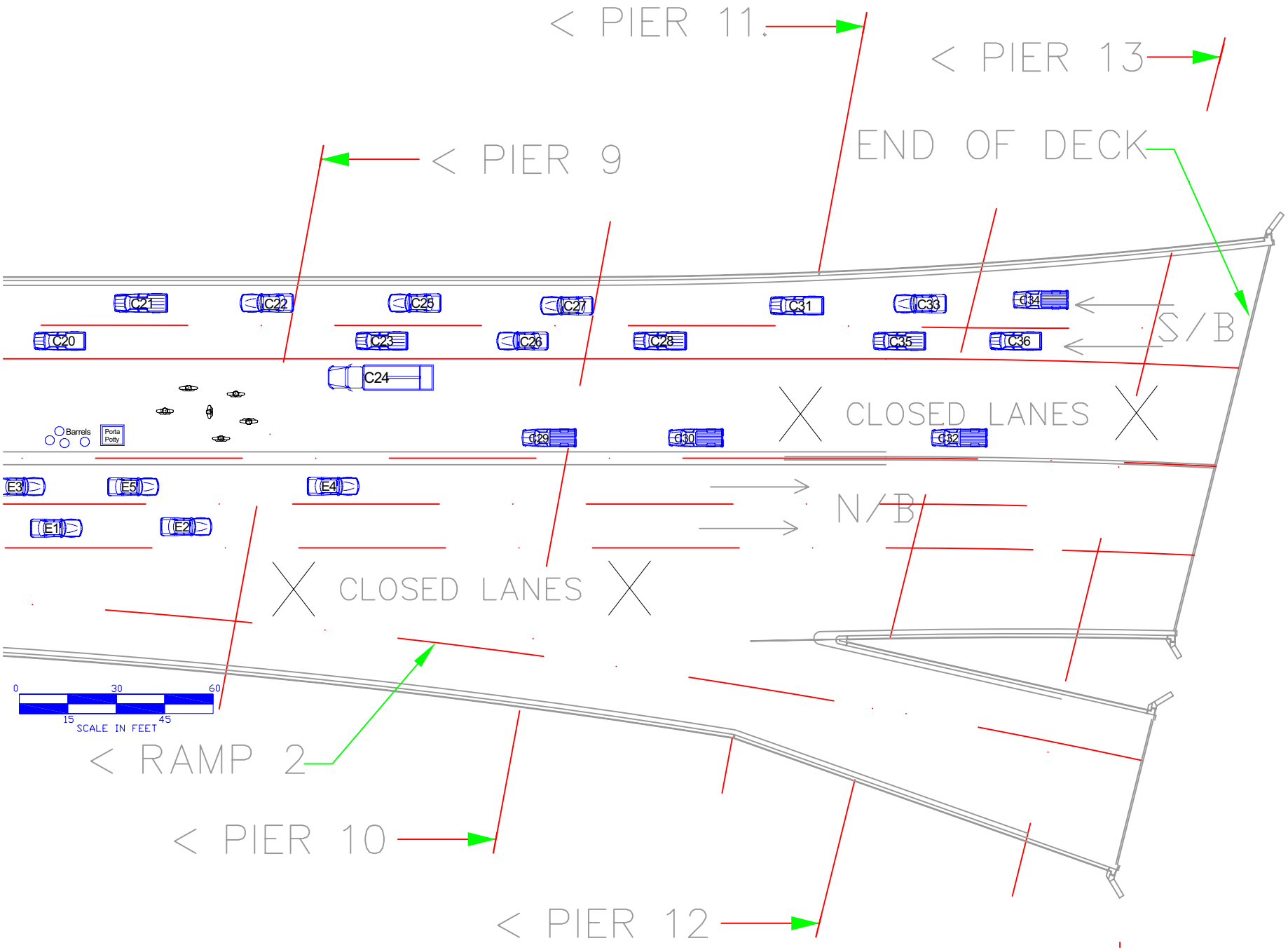
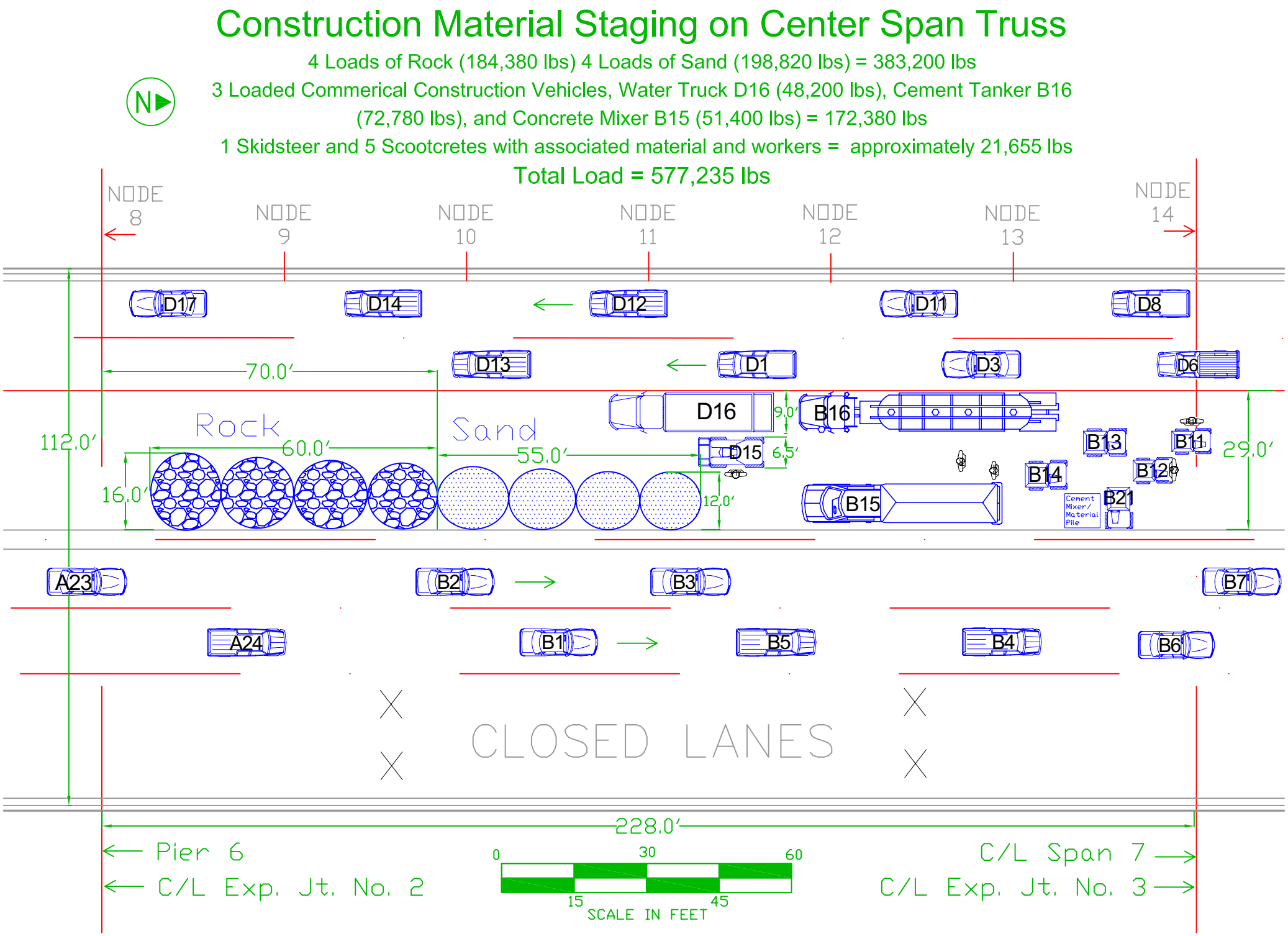


Figure 2 – Construction Staging Area



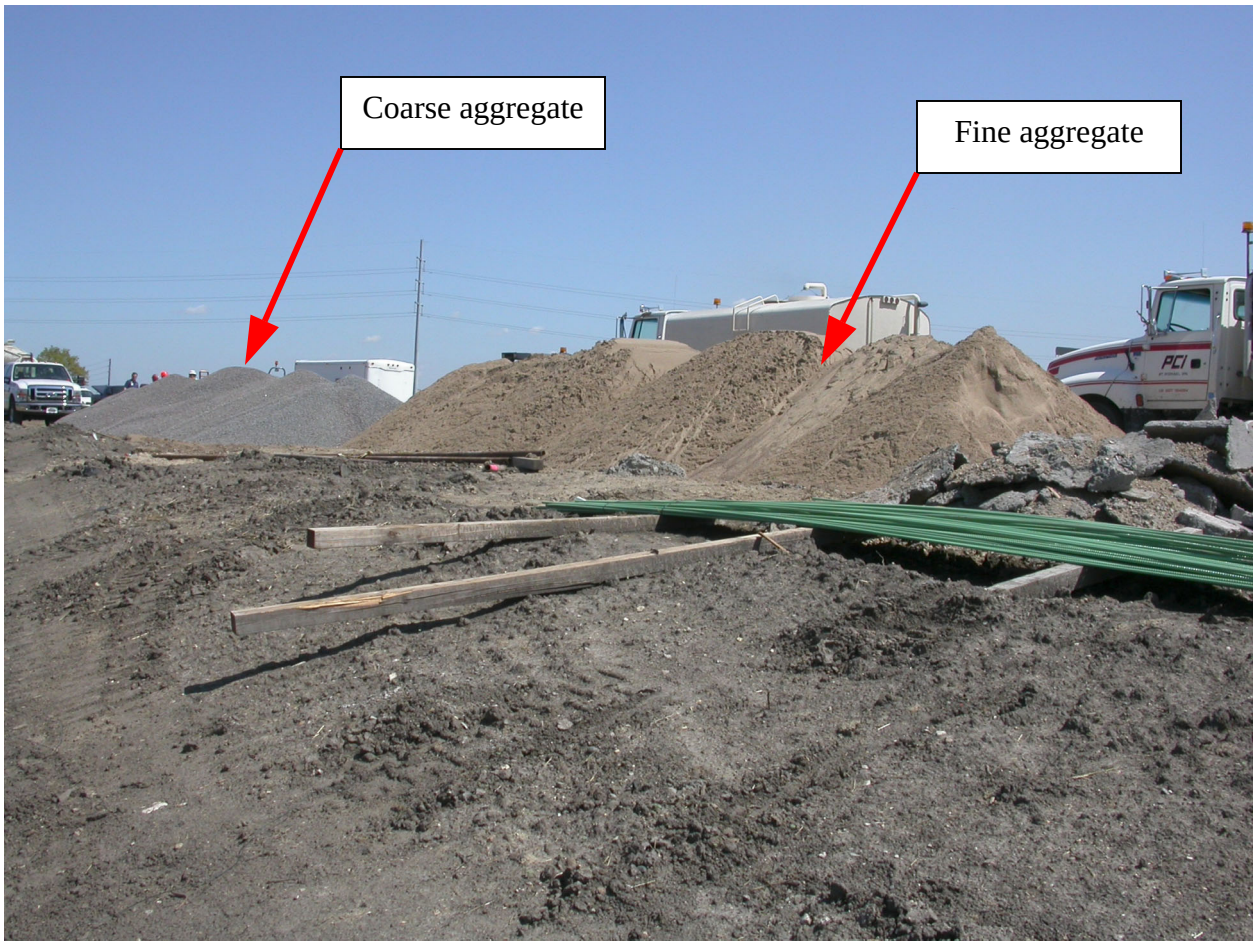


Figure 3. Piles of aggregate delivered to another job site. The quantities of coarse and fine aggregate were similar to the quantities placed on the bridge on the day of the accident. The coarse aggregate pile was approximately 16 feet wide, 60 feet long, and 5 feet tall (at its peak), while the fine aggregate pile was approximately 14 feet wide, 51 feet long, and 6 feet tall (at its peak).

Figure 4. Photograph showing the locations of the aggregate piles on the bridge on August 1, 2007 at 15:47:58 Central Daylight Time.

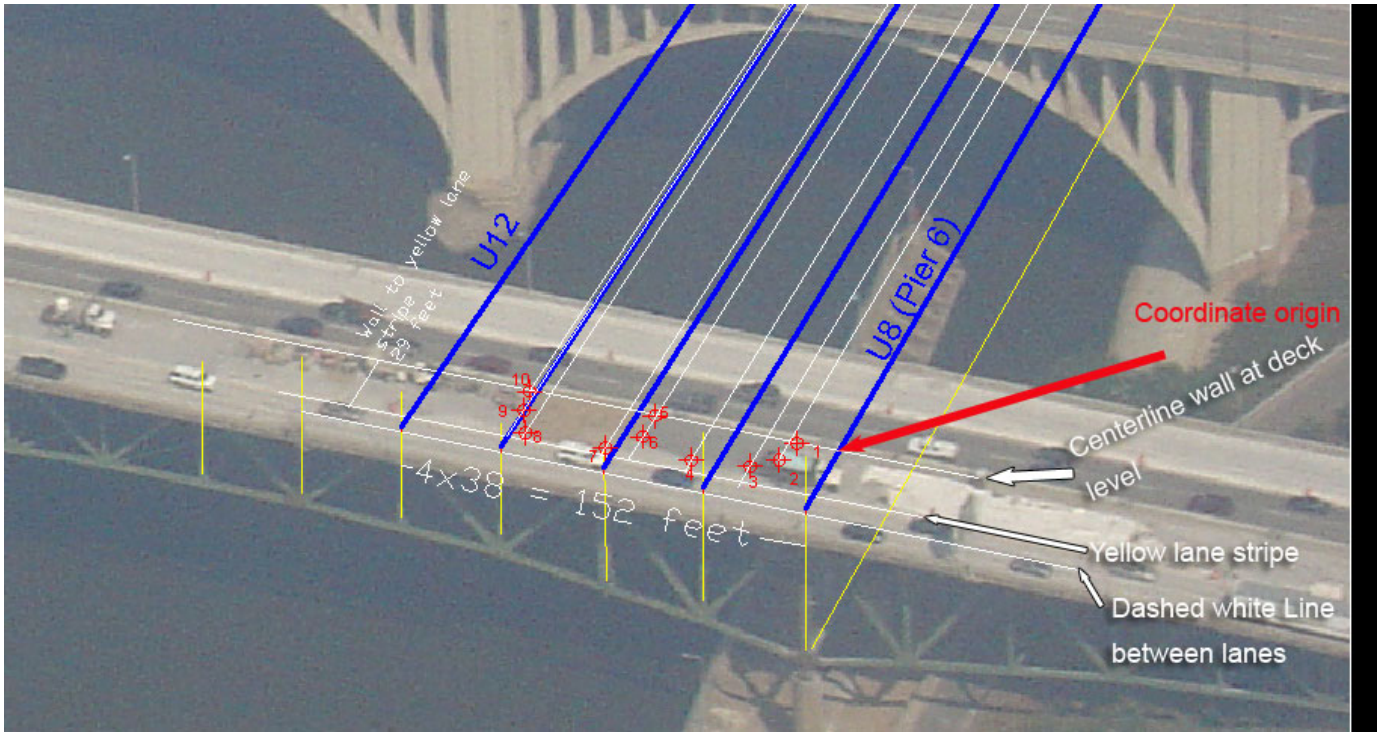


Figure 5. Figure 4 as annotated to indicate reference positions and measurements.

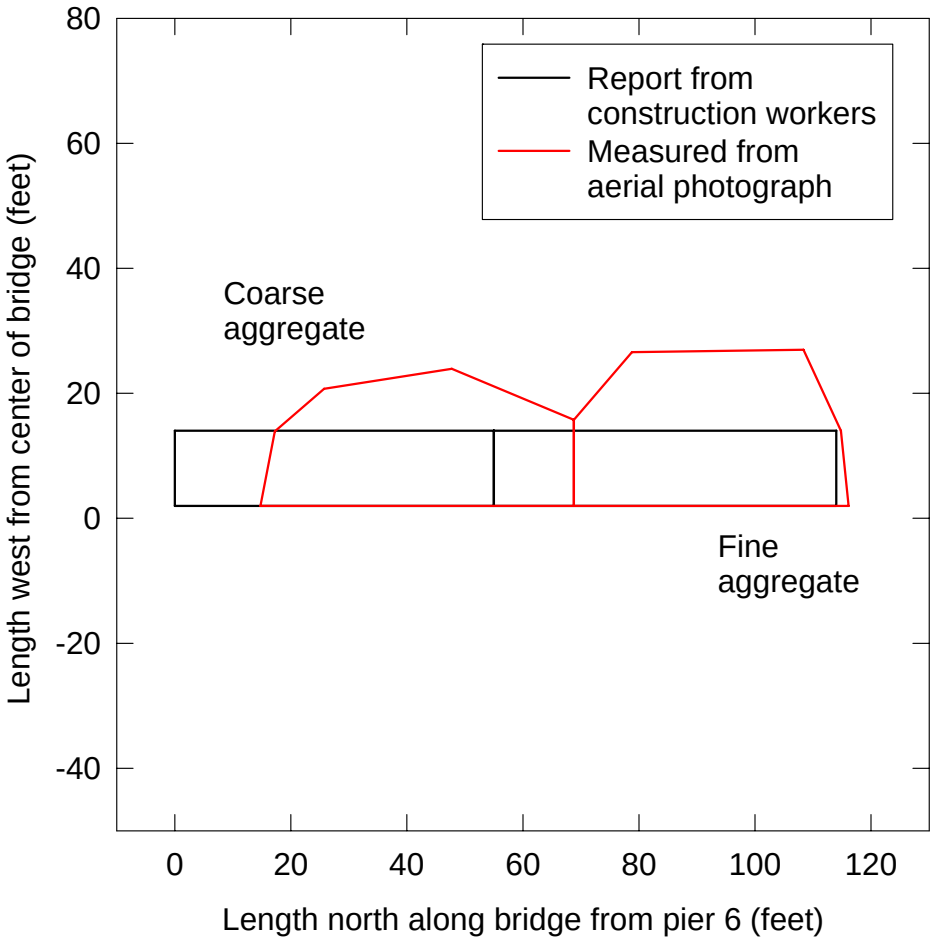


Figure 6. Locations of the coarse and fine aggregate piles as reported by construction workers and as measured from the aerial photograph in Figure 4.