TECHNICAL ASSISTANCE REPORT

EFFECT OF CONCRETE REMOVAL EQUIPMENT AND METHODS ON THE CONDITION OF DECK CONCRETE LEFT IN PLACE

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(The opinions, findings, and conclusions expressed in this report
are those of the author and not necessarily
those of the sponsoring agencies.)

Virginia Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the
Virginia Department of Transportation and the
University of Virginia)

Charlottesville, Virginia

August 2000
VTRC 01-TAR1

ABSTRACT

This report describes the evaluation of the condition of concrete samples taken from sections of a five-span bridge in which the concrete in the parapet and deck along the exterior beam was removed using six different methods. Deck and parapet concrete was removed with 30-lb (14-kg) hammers, 90-lb (41-kg) hammers, a 750 ft-lb (104 m-kg) hoe ram, and a Universal Processor 50 concrete crusher. Parapet concrete was also removed with a hoe ram and a concrete crusher. A seventh test section served as an undisturbed control.

Four tests of concrete samples taken adjacent to the exterior beams and approximately 4 ft (1.2 m) from the beams did not indicate that the concrete was damaged by any of the removal methods. The tests involved (1) determining the compressive strength of cores, (2) determining the tensile bond pullout strength of transverse bars in cores, (3) determining the permeability to chloride ion of cores, and (4) microscopically examining specimens to determine if the bond between the concrete and the reinforcing bar was damaged.

Compared to the use of the 30-lb hammer, the use of the hoe ram and crusher to remove the deck and parapet concrete provided a reduction in time of 94 percent and a reduction in cost of 59 and 58 percent, respectively. In view of the much higher efficiency and lower cost associated with highly mechanized techniques of concrete removal, the Virginia Department of Transportation should employ the use of alternatives to the 30-lb hammer more frequently.

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INTRODUCTION

Bridges are often widened rather than replaced to accommodate increases in the volume of traffic. Typically, the parapet and deck along the side to be widened are removed to the center of the exterior beam. Typically, the concrete is removed with 30-lb (14 kg) pneumatic hammers even though the method is slow and labor intensive. Larger pneumatic hammers, hoe rams, and concrete crushers can expedite the removal of the concrete, but departments of transportation usually do not use them because of concerns about damage to the concrete left in place.

PURPOSE AND SCOPE

The purpose of this research was to evaluate the condition of concrete left in place after the removal of concrete parapet and deck concrete with 30-lb and 90-lb pneumatic hammers, a hoe ram, and a concrete crusher. The evaluation was based on seven methods of removal on a five-span bridge with a noncomposite reinforced deck and steel beams. The bridge sacrificed was the westbound lane of Route 40 over the Nottaway River in Sussex County, Virginia. The deck was constructed in the late 1970s and contained epoxy-coated No. 5 bars in the top mat and uncoated black No. 5 bars in the bottom mat. The hoe ram evaluated was a HY-RAM model 725 with an impact energy of 750 ft-lb (104 m-kg).[1] The crusher evaluated was a Universal Processor 50, part number L1020.[2]

METHODS

Seven test sections were designated on the bridge. A typical test section is shown in Figure 1. Table 1 indicates the type of removal equipment used for each test section and includes a control section in which no removal work was done. For test sections 2 through 5, the final 6 in of deck width adjacent to the centerline of the beams was removed with 30-lb (14 kg) hammers. For test sections 6 and 7, only the parapet was removed. Samples of concrete to be evaluated were saw cut full depth, loaded onto a truck, and delivered to the Virginia Transportation Research Council. Eight full-depth 4-in-diameter (102-mm) cores were also removed along the outside perimeter of each deck sample. Four were removed next to the exterior beam, and four approximately 4 ft (1.2 m) from the beam.

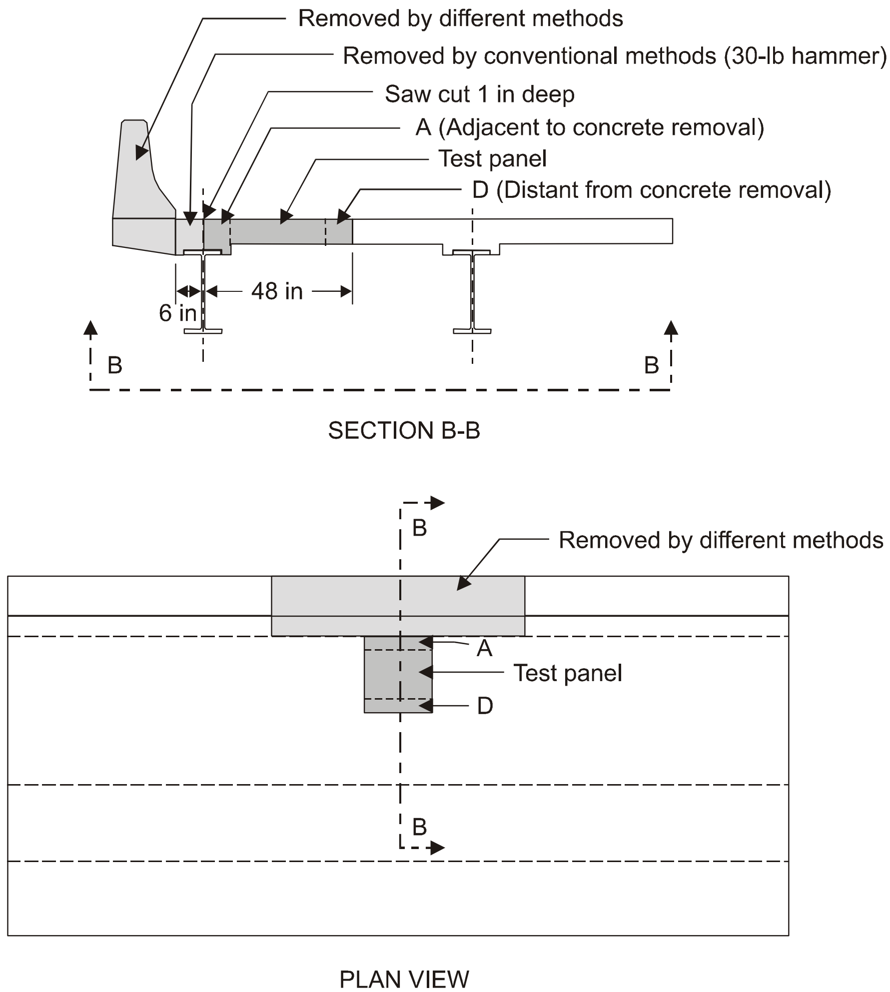

Figure 1. Typical Test Section (1 in = 25.4 mm).

Table 1. Concrete Removal Scenarios

Test Section	Bridge Span	Concrete Removed	Equipment Used	Deck Thickness, in		10-ft Section Personnel-Hours Required	10-ft Section Approximate Cost, $[a]	Entire Bridge Approximate Cost, $[a]
				Sample B	Sample C			
1	1	None	None	9.5	9.75	-	-	-
2	1	D + P[b]	30-lb hammer	9.0	9.25	18.00	675	21,938
3	2	D + P	90-lb hammer	10.0	9.75	8.00	345	11,213
4	3	D + P	Hoe ram	8.5	8.25	1.15	275	8,938
5	4	D + P	Crusher	8.25	8.25	1.00	284	9,230
6	5	P	Hoe ram	12.0	9.0	0.42	100	3,250
7	5	P	Crusher	11.75	9.0	0.17	49	1,593

[a]Provided by Bryant Contracting, Inc.
[b]D = deck; P = parapet.
1 in = 25.4 mm; 1 ft = 0.305 m; 1 lb = 0.454 kg.

Four of the cores from each test section were tested for permeability to chloride ion in accordance with AASHTO T 277 with the idea that damage to the concrete might be indicated by microcracks that would cause an increase in permeability. Two 2-in-thick (51-mm) slices were tested from each core except where only one slice could be obtained because of the presence of reinforcement.

Four of the cores from each test section were tested in compression in accordance with ASTM C 42. Cores were saw cut on each end to provide a surface perpendicular to the axis of the core and to remove imperfections. Cores ranged in length from 5 to 8 in (127 to 203 mm).

Test sections were saw cut into smaller samples by a member of the Virginia Department of Transportation's Hampton Roads District bridge crew. The smaller samples are shown in Figure 2 for test sections 1 through 5 and in Figure 3 for test sections 6 and 7.

Samples from sections A and B were taken to identify damage close to the exterior beam, and samples from sections C and D were taken to identify damage approximately 4 ft (1.2 m) from the exterior beam.

Samples A and D were used for petrographic examinations. One slice approximately 1 in thick, 4 in (102 mm) wide, and 5½ in (140 mm) long was saw cut along the centerline of a transverse reinforcing bar, polished on a lapping machine, and examined under a microscope to determine if the bond between the reinforcing bar and the concrete had been damaged.

Samples B, C, and E were used to measure tensile bond pullout strength. Samples were turned on their saw-cut face and drilled with a 4-in-diameter (102 mm) core barrel centered on a transverse reinforcing bar. One or two cores were obtained from each sample. The cores were 7 in (178 mm) long. The top 3½ in (89 mm) of each core was removed by saw cutting the

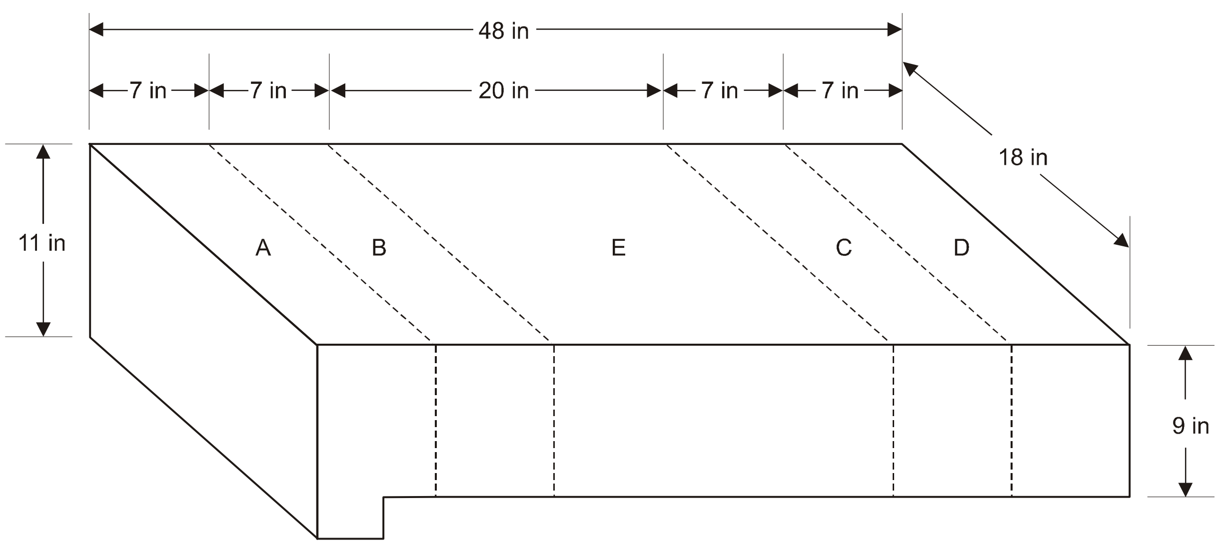

Figure 2. Slab Sections 1 Through 5 (1 in = 25.4 mm).

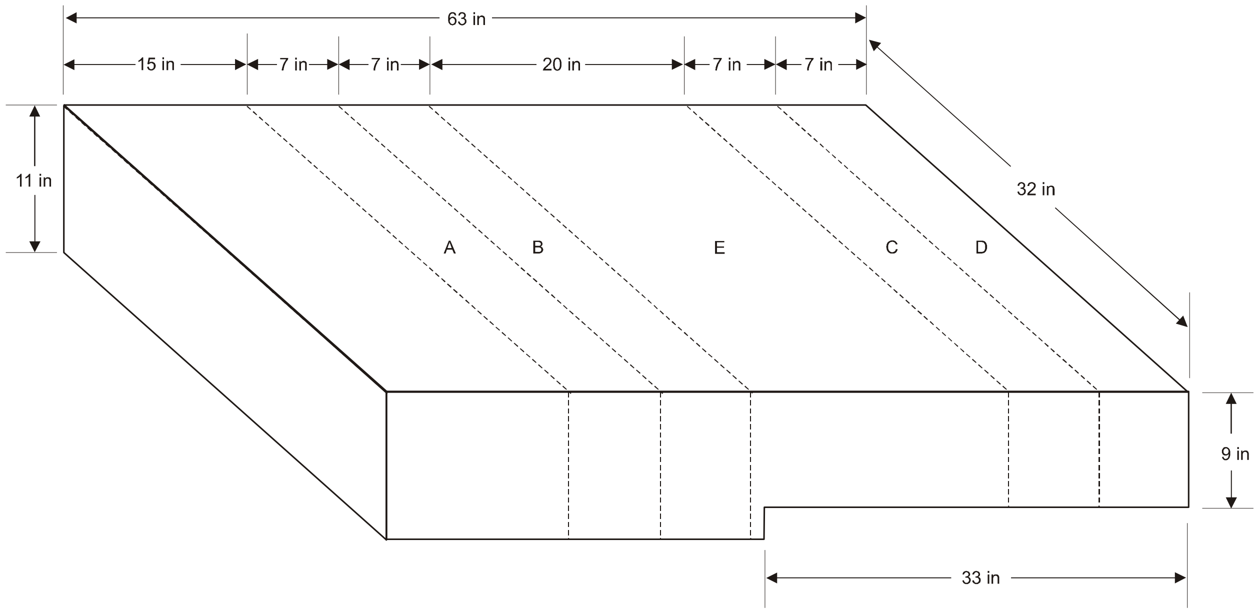

Figure 3. Slab Sections 6 and 7 (1 in = 25.4 mm).

concrete perpendicular to the bar at the 3½-in level and using a crusher to remove the top portion of the concrete from the core. The samples were placed in a universal testing machine, and the bar was pulled from the concrete base by restraining the concrete base with a steel plate with a hole in the center as the bar was pulled in tension. The loading rate was 2,000 lb/min (8.9 kN/min). Results of tests on cores from samples B and C were compared to determine if there was a reduction in strength attributable to concrete removal. Cores from sample E were used to increase the number of cores with no coating on the bars.

The test procedure was modeled after ASTM C 234, but concrete samples were 4-in-diameter (102-mm) cores rather than 6-in (152-mm) cubes cast in the laboratory. Results of the test provide an indication of the pullout strength of the reinforcing bar, and it is assumed that damage to the concrete would result in reduced strength.

RESULTS

Removal Operation

Figures 4, 5, and 6 show concrete being removed using 90-lb (41-kg) hammers, a hoe ram, and a concrete crusher. Each piece of equipment was used to remove a 10-ft-long (3.1 m) section of the parapet and exterior edge of the deck or just the parapet. The contractor's estimates for the time required and total cost for the removal are given in Table 1. Use of the hoe ram and crusher provided considerable savings in both time and cost. Compared to the use of the 30-lb (14-kg) hammer, the time required to remove the deck and parapet with the hoe ram or crusher was 94 percent less. The use of the hoe ram and crusher provided a reduction in cost of 59 and 58 percent, respectively, compared to the use of the 30-lb hammer. The crusher was more effective than the hoe ram in removing the parapet.

Figure 4. Concrete Removed From Parapet Using 90-lb Hammers

Figure 5. Parapet Demolished Using Hoe Ram

Figure 6. Concrete Removed Using Concrete Crusher

Compressive Strength of Cores

Table 2 shows the results of compressive strength tests on cores. Values were adjusted for differences in the height of the cores as required by ASTM C39-8.2 and increased to reflect the 85 percent reduction in strength based on tests of cores as recommended in ACI 301-17.3.2.3.[3,4] Only two average strengths were less than the average strengths for the control areas (none). The two lower strengths were for cores taken 4 ft (1.2 m) from the exterior beam for the hoe ram and 30-lb (14-kg) hammer. The two lower strengths were within one standard deviation (approximately 500 psi [3.4 MPa]) of the average strength for the control cores. Consequently, the results do not indicate a reduction in strength that could be attributed to any of the concrete removal methods. All strengths far exceeded the deck design strength of 4,000 psi (27.6 MPa).

Table 2. Compressive Strength of Cores (psi)

Removal Method	Average Strength Near Exterior Beam	Average Strength Approximately 4 Ft From Beam
None	6060	6260
30-lb hammer	6650	5990
90-lb hammer	6070	6450
Hoe ram	6740	5750
Crusher	6730	6360
Hoe ram/parapet	6620	7580
Crusher/parapet	7210	7490
All methods	6580	6550

1 ft = 0.305 m; 1 lb = 0.454 kg; 1 psi = 6.89 kPa.

Tensile Bond Pullout Strength

Table 3 shows the results of tensile bond pullout tests on cores with epoxy-coated reinforcing bars. The results were computed by dividing the load on the reinforcing bar at failure by the surface area of the reinforcing bar embedded in the concrete. Cores typically broke into three pieces of concrete base and one reinforcing bar (Figure 7). Only three average strengths were less than the average strengths for the control areas (none). The three lower strengths were for cores taken near the exterior beam for the 90-lb (41-kg) hammer, crusher, and the crusher/parapet. The three lower strengths were within one half of one standard deviation (approximately 200 psi [1.4 MPa]) of the average strength for the control cores. Consequently, the results do not indicate a reduction in tensile bond pullout strength that could be attributed to any of the concrete removal methods.

Table 3. Tensile Bond Pullout Strength (psi)

	Near Exterior Beam		Approximately 4 Ft From Beam	
Removal Method	**No. Specimens**	**Average Strength**	**No. Specimens**	**Average Strength**
None	2	1141	5	880
30-lb hammer	1	1370	1	1265
90-lb hammer	2	1108	4	994
Hoe ram	2	1535	4	1009
Crusher	2	1033	2	1420
Hoe ram/parapet	1	1385	4	921
Crusher/parapet	2	1093	4	1056
All methods	12	1214	24	1018

1 ft = 0.305 m; 1 lb = 0.454 kg; 1 psi = 6.89 kPa.

Figure 7. Tensile Bond Pullout Strength Specimens After Testing. *Left,* epoxy-coated bar; *right,* black bar.

Table 4 provides the tensile bond pullout strengths of 39 specimens with epoxy-coated reinforcement and 28 specimens with uncoated bars. The 20 percent reduction in strength for the coated bars can be attributed to the lack of bond between the concrete and the epoxy coating. An inspection of the failed cores showed concrete bonded to the uncoated bars and no concrete bonded to the epoxy coating on the coated bars. The bond pullout strength provided by epoxy-coated bars can be attributed to the mechanical action between the knurls on the bars and the concrete.

Table 4. Tensile Bond Pullout Strength (psi)

Removal Method	No. Epoxy-Coated Specimens	Average Strength Epoxy-Coated Bars	No. Uncoated Specimens	Average Strength Uncoated Bars
None	9	899	3	1398
30-lb hammer	3	1165	5	1380
90-lb hammer	6	1032	7	1176
Hoe ram	6	1184	4	1692
Crusher	4	1226	3	1225
Hoe ram/parapet	6	1083	2	1426
Crusher/parapet	5	1160	4	1436
All methods	39	1107	28	1390

1 lb = 0.454 kg; 1 psi = 6.89 kPa.

Permeability to Chloride Ion

Table 5 shows the results of permeability tests (AASHTO T 277) on slices of cores. Test results are reported in coulombs with values ranked as follows:

- 1000 to 2000, low permeability
- 2000 to 4000, moderate permeability
- >4000, high permeability.

All but two values were in the moderate range, indicating no difference in permeability. The permeability for the control (none) adjacent to the beam was in the low range, which suggests that all methods of removal cause damage, which increases permeability. However, considering that the value for the control 4 ft (1.2 m) from the beam was in the moderate range, the low value was likely an anomaly related to sample size. Likewise, the high value 4 ft from the beam for the hoe ram was an anomaly because the value adjacent to the beam was in the moderate range. In addition, the use of the 30-lb (14-kg) hammers yielded values in the moderate range. Consequently, the results did not show a difference in permeability that could be attributed to the methods of concrete removal.

Table 5. Permeability to Chloride Ion (Coulombs)

Removal Method	No. Specimens Near Exterior Beam	Permeability	No. Specimens Approximately 4 Ft From Beam	Permeability
None	3	1626	4	2910
30-lb hammer	4	3036	3	3916
90-lb hammer	4	2564	4	3118
Hoe ram	3	3846	4	5446
Crusher	3	2693	4	3683
Hoe ram/parapet	4	3172	4	3260
Crusher/parapet	4	3460	4	3299
All methods	25	2914	27	3662

1 ft = 0.305 m; 1 lb = 0.454 kg.

Petrographic Examinations

Two slabs, one with top mat and one with bottom mat, were cut from the sections. Polished slabs exposing approximately 4.7 in (120 mm) in length of reinforcing bar were examined at about 10X magnification for defects induced by the removal process. No clearly brittle fractures were noted in any of the slabs. One to three vertically oriented cracks were noted in slabs 3ART, 4ALT, 4ALB, 4ART, and 4ARB. These cracks were all associated with areas where plastic movement of the concrete appeared to have occurred. Consequently, their cause was likely related to construction and not to concrete removal. No damage was apparent in any of the slabs.

Specific observations were as follows:

lART Concrete not tight around bar, evidence of plastic deformation, extensive areas of mill scale on bar under epoxy coating.

lARB Tight around bar, small area of corrosion on bar.

2ART Tight at top of bar, fair below.

2ARB Tight at top of bar, not tight below.

3ART Tight bond around bar, some mill scale on bar under epoxy coating.

3ARB Tight bond around bar.

4ART Fairly tight around bar; one crack, vertical, toward bottom mat; some mill scale under epoxy coating.

4ARB Fairly tight around bar.

5ART	Fairly tight around bar, one plastic crack.
5ARB	Fairly tight to not tight around bar, two or three cracks associated with plastic deformation of concrete.
5ALT	Not tight around bar; three cracks, two above and one below bar, associated with areas of poor consolidation.
5ALB	Tight around bar.
5DLT	Tight around bar.
5DLB	Tight at top of bar, not tight below.
7ART	Tight around bar.
7ARB	Tight at top of bar, not tight below.

CONCLUSION

Samples of bridge deck concrete tested for compressive strength, tensile bond pullout strength, and permeability to chloride ion and examined with a microscope do not indicate that removing deck and parapet concrete with 30-lb (14-kg) hammers, 90-lb (41 kg) hammers, a 750 ft-lb (104 m-kg) hoe ram, and a Universal Processor 50 concrete crusher damages the deck concrete remaining in place when a 6-in-wide (152-mm) strip of deck concrete adjacent to that to be left in place is removed with 30-lb hammers. Compared to the use of the 30-lb hammer, the use of the hoe ram and crusher to remove deck and parapet concrete provides for major reductions in time and cost. These results apply to noncomposite reinforced concrete decks on steel beams.

In view of the much higher efficiency and lower cost associated with highly mechanized techniques of concrete removal, the Virginia Department of Transportation should use alternatives to the 30-pound hammer more frequently.

RECOMMENDATIONS

1. Concrete removal equipment comparable to that evaluated in this study should be used to remove bridge deck and parapet concrete on noncomposite, reinforced concrete decks on steel beams when economics justify the use.

2. Evaluations similar to those done for this study should be done for composite, reinforced concrete decks on steel beams and concrete beams. Evaluations should include the effects of different contractors and equipment that is larger than that used in this study.

ACKNOWLEDGMENTS

This project was conceived by Vince Roney, VDOT's Hampton Roads District Structure & Bridge Engineer. His staff contracted the deck removal work, saw cut the test sections, and delivered the section to the Virginia Transportation Research Council (VTRC). They also took video and digital pictures of the removal work. The Hampton Roads District Materials Division provided cores from the deck. The research would not have been possible without the efforts of the Hampton Roads District personnel. Cost and time estimates were provided by Bryant Contracting, Inc., who also removed the concrete.

Mike Burton, Bill Ordel, Sam Mosley, and Bobby Marshall, VTRC lab technicians, prepared and tested specimens. Steve Lane, a Senior Research Scientist in VTRC's Materials Group, examined the polished specimens for damage and prepared the report on the petrographic examination.

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