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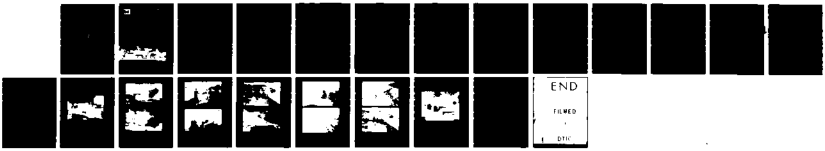

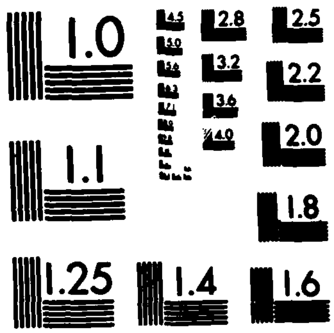

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EVALUATION OF THREE STATE-OF-THE-ART WATER-JET SYSTEMS FOR CUTTING/REMOVING CONCRETE

by

Carl E. Pace

Structures Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

September 1982
Final Report

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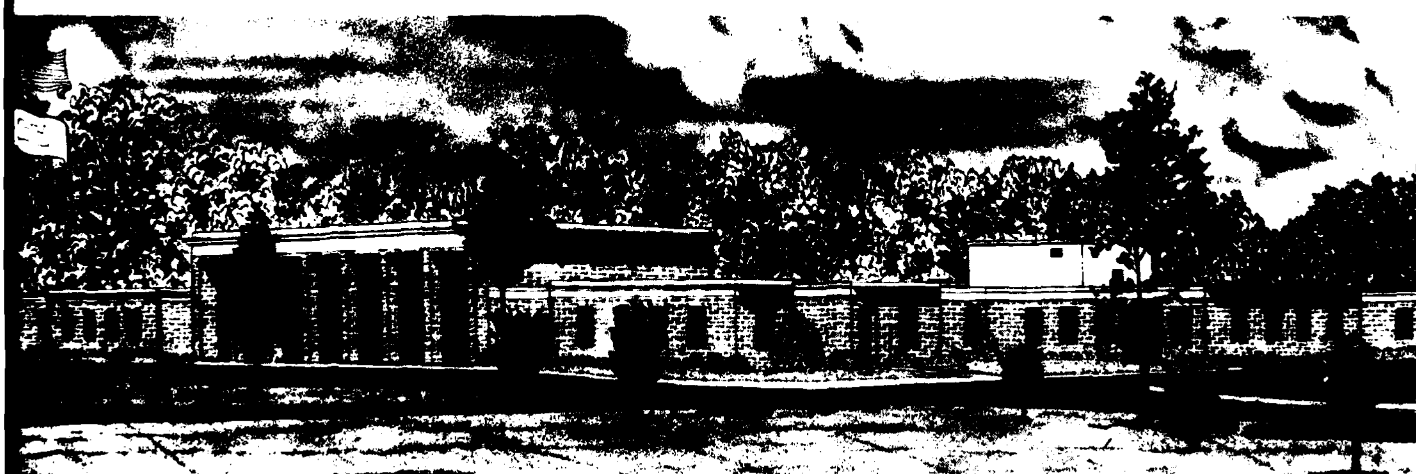

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report documents a demonstration project ~~conducted at the U. S. Army Engineer Waterways Experiment Station~~ to evaluate the capability of three water-jet systems for cutting or removing concrete or both. The Corps of Engineers is interested in the potential of this technology for such applications as rapid cutting of bomb-damaged sections of airfield pavement and removing of deteriorated sections of concrete structures at Civil Works projects. Because water-jet systems are capable of transmitting, without mechanical constraint, all of

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20. ABSTRACT (Continued)

the available horsepower of their power sources into the concrete cutting/removing operation, they may prove to be an extremely efficient means of conducting such operations.

Representatives of the University of Missouri at Rolla and the Colorado School of Mines demonstrated systems employing relatively low water pressures (10,000 psi). A representative of IIT Research Institute demonstrated a system employing a relatively high water pressure (40,000 psi). The demonstrations were conducted on a 12-in.-thick airfield pavement test section containing a chert aggregate and in which the concrete compressive strength was 8000 psi.

The low-pressure water jets were able to cut a 6-in. slot in the concrete for a distance of 1-1/2 ft in a period of 14 minutes (a rate of 6.4 ft per hour). The relatively high-pressure water jet cut at rates of 9.6 ft per hour for shallow cuts (less than 5 in.) and 3 ft per hour for deeper cuts (greater than 5 in.). In addition, one of the low-pressure systems was used to remove some surface concrete.

The results of this evaluation indicate that, although these water-jet systems did not demonstrate a capability for efficiently cutting concrete airfield pavements, the technology has potential. The low-pressure system demonstrated a capability for removing surface concrete efficiently.

Preface

This report describes an evaluation of the state of art of equipment for water-jet cutting of concrete that was conducted for the Office, Chief of Engineers, U. S. Army, by the Structures Laboratory (SL) of the U. S. Army Engineer Waterways Experiment Station (WES).

The study was performed under the direction of Messrs. Bryant Mather and William J. Flathau, Chief and Assistant Chief, respectively, SL; and Mr. John M. Scanlon, Jr., Chief, Concrete Technology Division, SL. WES Program Manager for this work is Dr. George M. Hammitt of the Geotechnical Laboratory; Technical Coordinator is Dr. Carl E. Pace of the SL. Dr. Pace prepared this report.

Funds for publication of the report were provided from those made available for operation of the Concrete Technology Information Analysis Center (CTIAC). This is CTIAC Report No. 54.

Commander and Director of WES during the study and the preparation of this report was COL Tilford C. Creel, CE. Mr. F. R. Brown was Technical Director.

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Conversion Factors, Non-SI to SI (Metric) Units of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
feet per minute	0.00508	metres per second
gallons (U. S. liquid) per minute	0.00006309	cubic metres per second
horsepower (550 ft-lb/sec)	745.6999	watts
inches	0.0254	metres
pounds (force) per square inch	6894.757	pascals

EVALUATION OF THREE STATE-OF-THE-ART WATER-JET SYSTEMS FOR CUTTING/REMOVING CONCRETE

Background

1. Water jets have been used extensively in mining operations and are now being used in laboratories and by industry for precision cutting of many different materials. They are also being used to cut slabs of granite in quarrying operations for making panels, monuments, and tombstones. Hcwever, water-jet cutting, especially in hydraulic mining operations, is not a new technology; it was employed by the Egyptians, and was used around the beginning of this century in mines in California. The technology is rapidly becoming economical and efficient for mining coal in the United States, but is used even more extensively in Europe.

2. In addition to increased cutting efficiency, the major advance in mining with water-jet systems has been the use of hydraulics in controlling the lance. The lance can be remotely controlled permitting the operator to work a safe distance from the actual cutting operation.

3. Water-jet cutting is an accepted practice in the Soviet Union, China, Japan, and Canada, as well as Europe and the United States. Until recently, it has received the most attention in the Soviet Union, China, and Japan. The technology has developed slowly, and there now appear to be two principal schools of thought with respect to its further development for cutting concrete: one favoring very high pressures (40,000 to 600,000 psi*), and the other relatively low pressures (10,000 to 20,000 psi). In addition, some of the researchers using low pressures are including abrasives in the water. Both groups are concerned about the angle of spray and the effects of combinations of nozzles.

4. Because of their capability of transmitting, without mechanical restraint, all the available horsepower of their power sources into

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 3.

the concrete cutting operation, water-jet systems potentially have a considerable advantage over mechanical systems. With sufficient horsepower, it is feasible to develop cutting speeds at least in the range of 15 to 20 ft/min for cuts through a 1-ft thickness of concrete. It is this potential that persuaded the Corps of Engineers to undertake an evaluation of available systems for cutting of concrete with water jets. The results of this evaluation would then be used to assist the Corps in determining the desirability of continued research in the area, both from the Military and the Civil Works standpoint.

Objective

5. The Corps of Engineers has a continuing interest in new technologies for the efficient cutting of concrete, especially for application to repair and rehabilitation operations. This study was initiated to investigate the use of water jets as a means of efficiently and economically cutting away bomb-damaged concrete in airfield pavements and to determine their potential for removing surface concrete from Civil Works structures being repaired and/or rehabilitated.

Scope

6. The study was limited to determining the feasibility of using available water-jet systems in lieu of the mechanical systems presently in use for cutting concrete.

Approach

7. To observe the latest developments in water-jet systems for cutting concrete, it was decided that a number of the leading developers in the field would be asked to demonstrate their capability at the U. S. Army Engineer Waterways Experiment Station (WES). Each would be requested to present its views about water-jet cutting technology and then demonstrate its water-jet system.

8. Five organizations are recognized for their leading roles in research and development in water-jet cutting technology over the last 10 years:

- a. University of Missouri at Rolla (UMR).
- b. Colorado School of Mines (CSM).
- c. IIT Research Institute.
- d. Flow Industries.
- e. Hydronautics, Inc.

Each of these organizations was asked to submit a bid for participating in the demonstration. Initially, the two lowest bidders (UMR and CSM) were accepted to demonstrate their state-of-the-art systems for water-jet cutting of concrete. Later, it was decided to accept the third lowest bidder (IIT) to determine whether it could outperform the other two.

9. Each was to cut through a 12- to 18-in.-thick concrete slab for a distance of 15 ft. The demonstration was also to consist of removing approximately 4 to 6 in. of concrete over a small area. A sample of the concrete to be cut was sent to each organization for use in calibrating its water-jet cutting equipment.

Test Section

10. The demonstrations were conducted at WES on a 12-in.-thick airfield pavement test section containing a chert aggregate and for which the concrete compressive strength was 8000 psi.

Tests and Results

Low-pressure systems

11. UMR and CSM demonstrated low-pressure water jets on 30 July 1981. The UMR system used a 150-hp pump (Figure 1) to create a water pressure of about 11,000 psi and a flow rate of approximately 13 to 15 gpm. The 11,000-psi stream of water was applied from a hydrostatically controlled tractor (Figure 2) which was equipped with a high-pressure rotating coupling and a variable traversing mechanism which

was developed by Dr. Roger Raether of the North American Product Development Company.

12. CSM used a hydroblaster to create a water pressure of about 10,000 psi and a flow rate of about 4 gpm which was applied to the concrete through laboratory traversing equipment (Figure 3). The hydroblaster is a very compact piece of equipment and can be transported on a pickup truck.

13. As preparations for the demonstrations began and some trial cuts were made in the concrete, it became apparent that the systems were not as far advanced in the area of cutting concrete as had been hoped. The UMR system cut a slot approximately 6 in. deep for a distance of about 1-1/2 ft (Figure 4) in the approximately 8000-psi concrete (a rate of 6.4 ft/hour). It was not able to cut the chert aggregate in the concrete.

14. The best way to cut a slot in concrete is to remove the relatively soft matrix, producing a slot of such width that the matrix can be removed from around the aggregate by at least a couple of nozzles while some of the water ejects the aggregate without trying to cut it. This technique was tried with the UMR system, but the equipment had not been developed to the extent that the results were satisfactory.

15. The CSM system cut several inches deep in the concrete as shown in Figure 5. An abrasive was used in the water, but again the aggregate could not be cut. This system was no more effective in cutting the concrete than the UMR system, principally because the technology had not been developed to its full potential.

16. The UMR system was also used to remove some surface concrete (Figure 6). The effort was satisfactory and demonstrated the system's potential for removing deteriorated concrete from structures being repaired and rehabilitated. The surface concrete was removed in about 4-1/2 minutes but was not removed in a regular manner because the advance mechanism on the tractor had not been automated. Also, the concrete removed was not deteriorated. Therefore, if the nozzles were advanced properly and the water pressure was effectively regulated, it

should be possible to effectively remove deteriorated surface concrete in a few passes.

17. Later conversations with Dr. Raether indicated that there has been substantial advancement in equipment and methodology and that surface concrete is now being removed much more efficiently than was done by UMR on 30 July 1981. Water-jet removal of deteriorated concrete could result in tremendous cost savings in the repair and rehabilitation of old Corps of Engineers structures. This is especially true considering that the water jet can remove concrete which is underwater as well as that above water and that with enough horsepower it can remove deteriorated concrete at substantial distances from the end of the nozzle.

18. The noise level of the UMR equipment was about 90 db at a distance of 20 ft from the cutting operation. The noise level of the CSM equipment at a distance of 20 ft was about 97 db. Earplugs or muffs would thus be required for the operators and anyone else in the area.

High-pressure system

19. In December 1981, a team from IIT Research Institute demonstrated a 40,000-psi water jet on the same 12-in.-thick concrete test section used in the low-pressure demonstrations. The IIT water jet was mounted in a frame that was controlled from a remote instrument panel (Figure 7). It used steel water pipes instead of hoses due to the higher working pressures.

20. The IIT water jet cut at a slightly faster rate than the low-pressure systems demonstrated by UMR and CSM: 9.6 ft per hour for shallow cuts (less than 5 in.) and 3 ft per hour for deeper cuts (greater than 5 in.). This rate is still well short of the rapid airfield repair program requirements. The IIT system cut at a faster rate and also gave a cleaner cut (a smoother vertical cut). However, the chances of equipment maintainability and reliability problems increase with the higher water pressures.

Discussion

21. The Corps of Engineers is interested in all pressures although the 10,000- to 15,000-psi range systems are of particular interest for

cutting of concrete because equipment for producing this pressure is commercially available and is now being used in cutting granite and in cleaning applications. The lower pressure equipment can also be operated with less chance of wear and failures.

22. The demonstrations at WES showed that a slot can be cut in concrete, but this application of the technology is new and has not been developed to its full potential.

Conclusions and Recommendations

23. Because water-jet systems have the advantage of the horsepower of their power sources being transmitted directly from the pump through the high-pressure line by the fluid to the concrete, many problems associated with mechanical devices such as wear and bearing and thrust limitations are eliminated. Water-jet cutting has the capability of becoming a very effective technology in the cutting of concrete. However, there has not been enough experience and development in this application to demonstrate its potential at this time.

24. The removal of surface concrete was satisfactory, and it appears that the water jet has application for removing deteriorated concrete in the repair and rehabilitation of older structures.

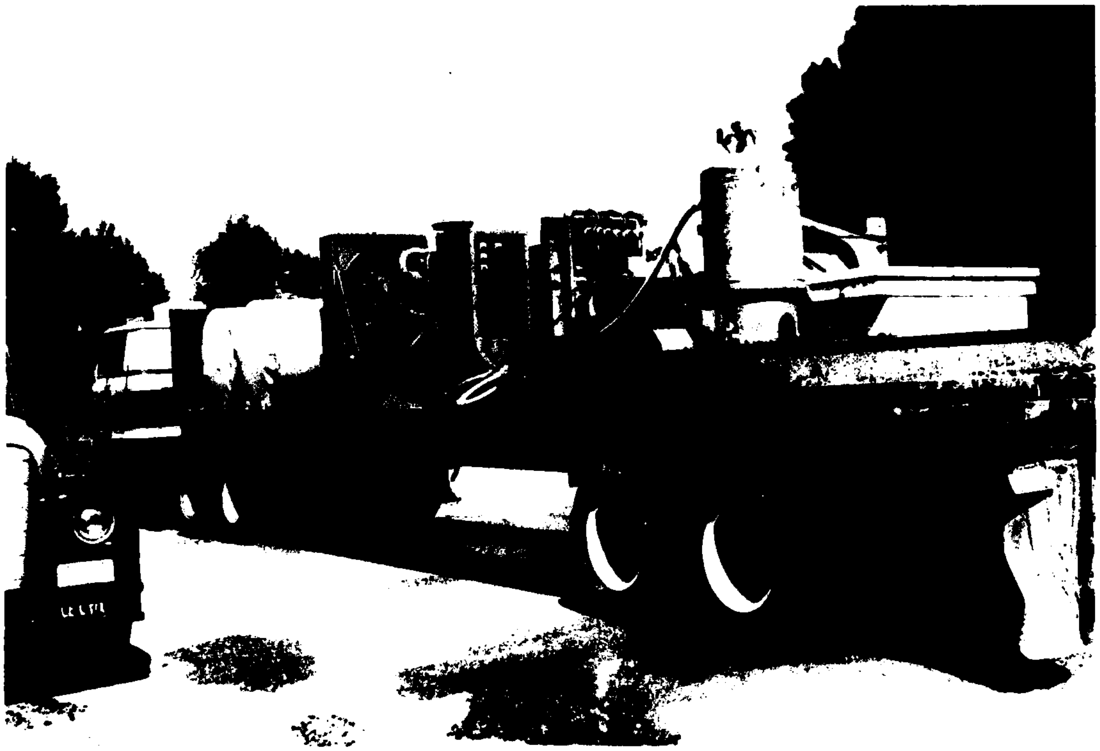
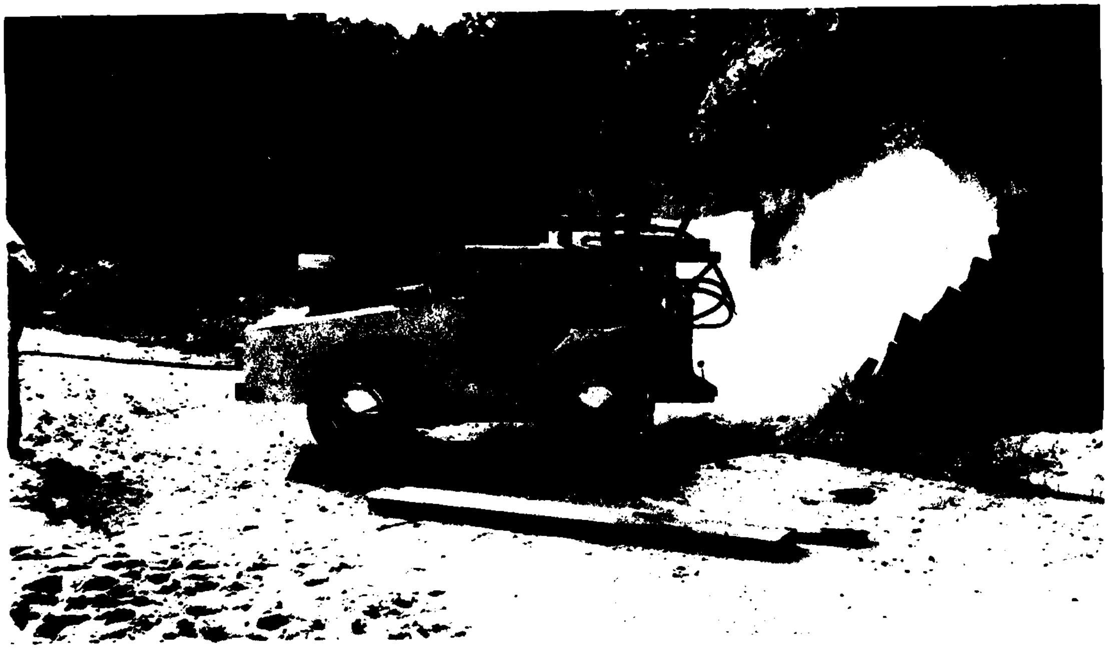
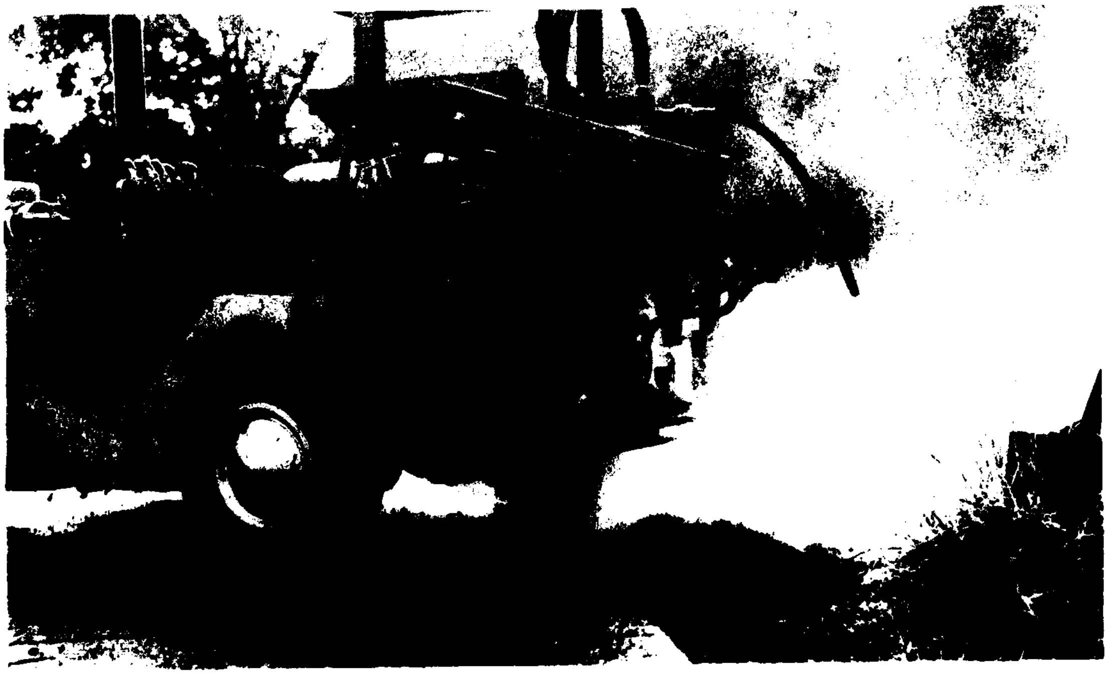


Figure 1. UMR 150-hp pumping equipment loaded on a semitrailer

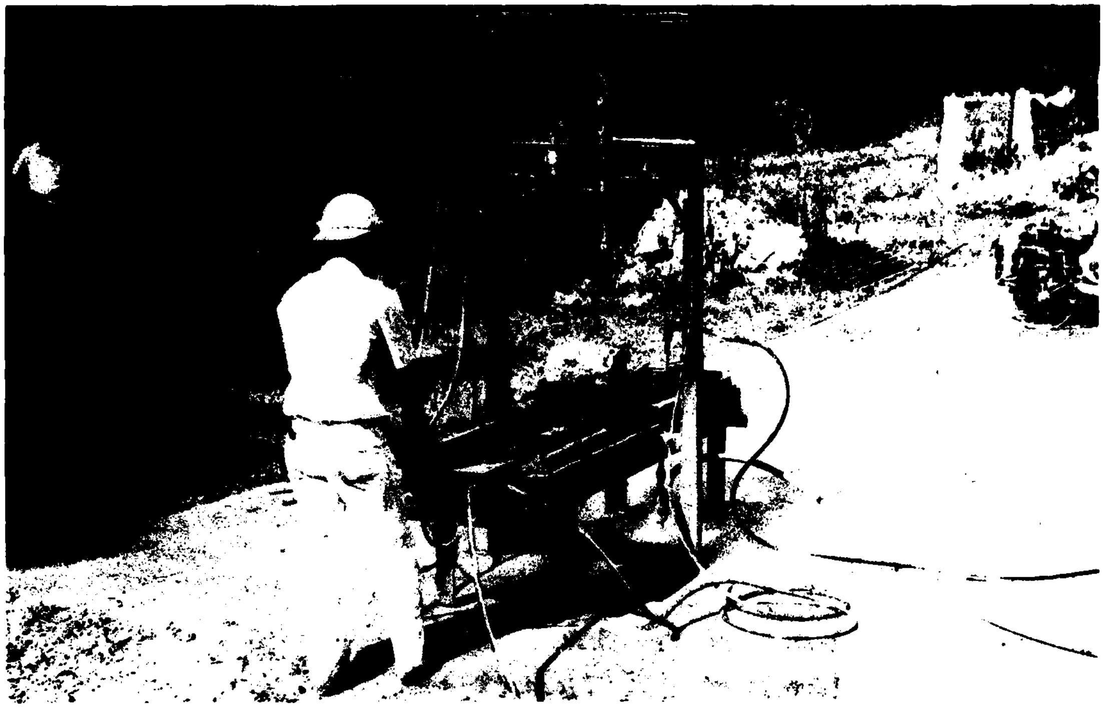


a. Overall view



b. Close-up of system in use

Figure 2. Hydrostatically controlled tractor used by UMR to apply its water jet



a. Overall view

b. System in use

Figure 3. Laboratory traversing equipment used by CSM to apply its water jet

Figure 4. Two views of 6-in.-deep, 1-1/2-ft-long slot cut with UMR system

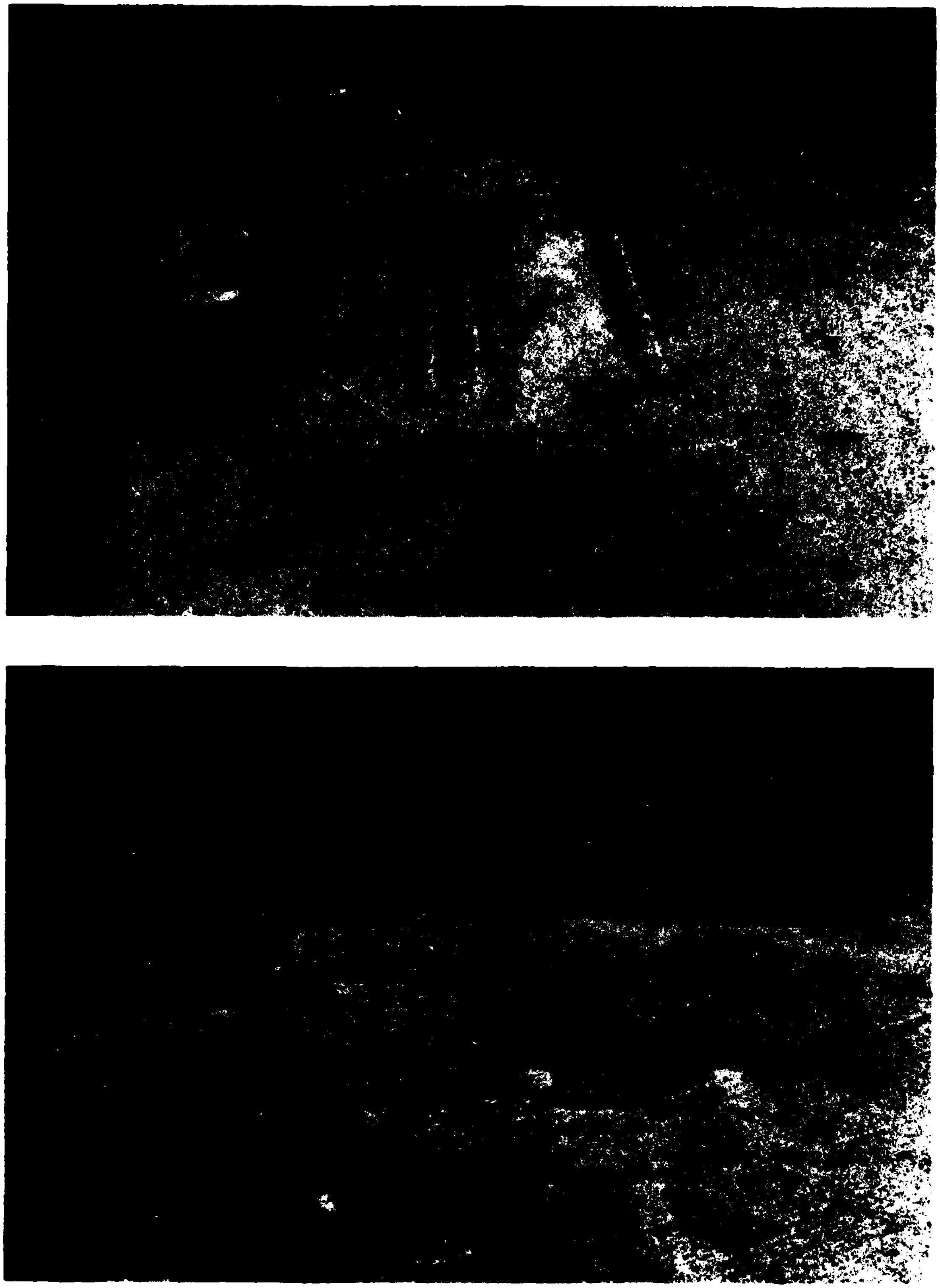


Figure 5. Two views of cuts made with CSM system

Figure 6. Two views of surface concrete removal performed with UMR system

Figure 7. IIT water-jet system in use

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