

# QUIET PAVEMENT BREAKING RESEARCH AND DEVELOPMENT AT THE INSTITUTE OF GAS TECHNOLOGY SINCE 1962

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This paper reports research and development work by the Institute of Gas Technology on three nonconventional and quieter ways of breaking concrete pavement: plasma torch cutting, microwave cracking, and microwave cracking aided by a high-pressure water jet. The work, done under the sponsorship of gas distribution utilities, covers a 10-year span from 1962 to 1972. The most recent method, microwave cracking aided by a high-pressure water jet, has the potential of being quieter than conventional methods, of creating no shock to underlying or adjacent facilities, and of raising no dust. Its water use is minimal, and its power consumption and production rates are estimated as equal to or better than conventional large boom-mounted breakers.

•THE PROBLEM this specific research was trying to alleviate is the noise of pavement breaking with conventional pneumatic, mechanical, and hydraulic pavement breakers. Construction and maintenance crews, as well as the general public, have long suffered this seemingly unavoidable side effect of breaking up pavement to effect gas main construction, repairs, and replacements.

In spite of our tight gas supply situation and its effect on new construction, increased attention to maintenance, relocations, and replacements will most likely keep pavement breaking at past levels, if not above them. In addition, there is increased public and labor union awareness of the undesirable effects of noise. Recent federal, state, and municipal regulations limiting noise levels and exposures suggest that the problem will receive increased attention in the years ahead.

## FEDERAL LEGISLATION AND ADMINISTRATION

Of nationwide interest is the recently passed federal Occupational Safety and Health Act of 1970 (OSHA) (1), which led to the creation of an administrative section within the Department of Labor made up of some 2,000 persons and headed by an Assistant Secretary. There were also staffs in seven regional offices throughout the United States (New York City, Philadelphia, Atlanta, Chicago, Kansas City, Dallas, and San Francisco). For noise provisions, the new act adopted the regulations of the older Walsh-Healey Public Contracts Act. These regulations place limits on the amount of time a worker may be exposed to various noise levels during his 8-hour workday. These levels are given in Table 1.

If we compare these sound levels to those that an operator of a hand-held or boom-mounted jackhammer hears, we find that the permissible duration time (working time) per workday is quite short, and, in many work situations, unacceptably short. The only legal solutions are to use several workers per tool, quiet the tool, or break pavement another, quieter way. The use of ear plugs or muffs is not considered by OSHA to be more than a temporary solution (presuming you could get workers to consistently wear them), and, of course, this does nothing to diminish the public nuisance.

Using several workers is generally uneconomical. It neither reduces the public nuisance nor satisfies the community noise-level ordinances as fostered by the Office of Noise Abatement of the Environmental Protection Agency. Such community noise level ordinances specify acceptable instantaneous noise limits at property lines or at 50 ft from the source, and these may be harder to meet than the higher levels and durations permitted by OSHA at the operator's ear. Quieting the tool has been attempted over the years and has succeeded to various degrees, although market response to the attachments developed has been minimal. One reason for this minimal response is that most attachments are exhaust mufflers, which reduce the power output of the pneumatic tool. Another, less rational, reason is that many construction men associate noise with productivity; that is, if you are not making noise, you are not working.

#### INITIAL WORK, 1962

The Institute of Gas Technology (IGT) began to develop low-noise methods of pavement removal in 1962 under the sponsorship of the Consolidated Edison Company of New York, a combined gas and electric utility serving New York City. That the utility serving our nation's largest city should take the lead in seeking quieter ways of doing its work should be no surprise. With most of its facilities—mains and cables—under the "wall-to-wall" paving of New York, ConEd was further obliged to do much of its work at night to minimize interference with traffic. Day or night, New York's "canyons of steel" cause any noises to reverberate and seem magnified. Consider, too, the utility employee working over a noisy jackhammer all night and trying to sleep during a typical day in New York City.

To begin developing a method for quieter pavement breaking, IGT selected and investigated 10 potential nonconventional methods then viable. Speed, costs, availability of equipment, and noise characteristics of the methods were compared in literature and in preliminary laboratory work. All methods were capable of destroying the structural integrity of concrete paving, which was considered to be the hardest kind to remove. After investigation the field was narrowed to one method, plasma flame, for which equipment was then readily available. Plasma flame also appeared to offer the best means of cutting a variety of paving materials in addition to concrete, such as asphalt, asphalt-concrete composites, and reinforcing bars or wires.

#### PLASMA FLAME DEVICE, 1963-1965

Plasma is defined as a highly ionized, electrically conducting, compressible fluid. Both hot and cool plasmas exist. Neon signs and fluorescent lights are examples of cool-plasma applications. I am concerned here, however, with hot plasmas such as those formed in direct-current arc discharges. Such hot plasmas can be either stationary or flowing. Arc-welding and electric-arc furnaces for melting are examples of stationary hot-plasma devices. IGT selected a flowing hot-plasma torch capable of directing an extremely hot gas through an orifice in one of the electrodes. (The hot-plasma torch, developed by Gage of Union Carbide Corporation in the early 1950's, is capable of temperatures from 10 000 to 20 000 K.) A simplified cutaway drawing of the Plasmadyne Corporation torch used initially is shown in Figure 1. A dc arc for heating the gas is maintained between a solid tungsten electrode and a hollow, water-cooled copper electrode with the gas, initially argon, forced through under high pressure. Other, less expensive gases were gradually interchanged with argon; later work completely eliminated the need for argon.

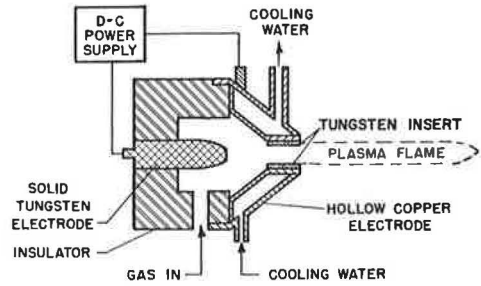
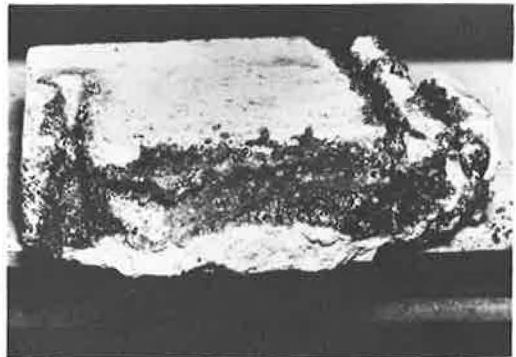
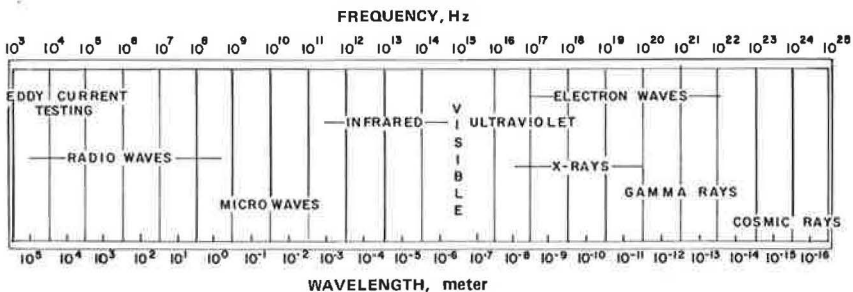
A 150-kW dc generator with variable voltage was used to establish and maintain the arc; a control console monitored voltage, current, and gas flow; and a resistor bank controlled operating currents during start-up. This generator, control console, resistor bank, and the torch (Fig. 1) made up the total equipment package. All elements except the generator are shown in Figure 2.

The system cuts concrete by melting it and blowing much of the lava out of the cut (Fig. 3). The cut considerably weakened the concrete below and adjacent to it, which made breakage possible without full-depth cutting. The most significant variable affecting the depth of the cut was the rate of travel along the concrete, with a low penetration

**Table 1. Permissible noise exposures.**

Duration per Day (hours)	Sound Level (dBA, slow response)
8	90
6	92
4	95
3	97
2	100
1½	102
1	105
½	110
<¼	115

Notes: When daily noise exposure is composed of two or more periods of noise exposure of different levels, their combined effect should be considered, rather than the individual effect of each. If the sum of the following fractions:  $C_1/T_1 + C_2/T_2 \dots C_n/T_n$  exceeds unity, then the mixed exposure should be considered to exceed the limit value.  $C_n$  indicates the total time of exposure at a specified noise level, and  $T_n$  indicates the total time of exposure permitted at that level. (Exposure to impulsive or impact noise should not exceed 140 dBA peak sound pressure level.)

**Figure 1. Plasma torch.****Figure 2. Plasma torch cart with sound-attenuation housing.****Figure 3. Concrete with cuts made by plasma torch.****Figure 4. Electromagnetic spectrum showing relative position of microwaves.**

at 10 to 12 in./min. and a 4-in. penetration at  $\frac{1}{2}$  in./min. However, the original torch had to be rebuilt several times because of melting from the radiant heat that resulted from the lower travel speed. New torch designs were developed to overcome this short life. These new torches also gave (a) 100 percent use of less expensive gases such as hydrogen and nitrogen, but not methane (natural gas); (b) quick production of slag sumps to drain off flowing lava; (c) lower noise levels; and (d) higher power levels.

Further development was halted, however, by a need for higher power levels for faster cutting. The 150-kW source already was considered almost "too big" for gas company field purposes. It also had a borderline high noise level (even when muffled) that would increase with the otherwise desirable higher power levels.

The search then turned to another of the original 10 nonconventional methods—microwave radiation, which promised quieter operation, lower power requirements, and available hardware.

#### MICROWAVE DEVICE, 1966-1969

Microwaves are electromagnetic waves of short wavelength and consequently high frequency. They have higher frequencies than most radio waves and lower frequencies than infrared or visible light (Fig. 4). Like radio waves they can penetrate most electrical nonconductors and, to some extent, poor conductors. Like light, microwaves can be reflected or focused by using metallic mirrors or lenses. They can also be directed through metal piping, metal ductwork, or flexible metal-containing wall conduits.

Principal industrial uses of microwaves are for cooking or other processing of foods and for drying of lumber and its products. Microwaves also have medical and communications applications. What I am concerned with here is another possible industrial use of the internal heating ability of microwaves: the expansion of local areas of concrete (hot spots) to induce tensile failure between them.

One of the initial applications of microwave heat cracking was demonstrated in 1962 by the Mullard Company of Great Britain, which used it to fracture rock (3). The Mullard applicator consisted of a probe inserted into a predrilled hole some 2 in. in diameter in an 18-in. basalt cube, which was then cracked. The British Building Research Station also cracked 9-in.-thick concrete by microwaves in 1962 or earlier. (The Russians had reportedly used microwaves to crack rock in 1952.)

IGT microwave development began with an extensive literature search into the re-creation of concrete to microwave energy and a survey of available equipment. As a result IGT purchased the Mullard equipment and conducted many laboratory studies of the behavior of concrete under microwave radiation.

From this work several microwave applicators were designed, constructed, and tested. All of them were to alleviate the necessity of predrilling a hole as required for the probe type of applicator. One, a multihorn applicator design, was selected for further development because its linear alignment allowed crack location and direction to be reasonably well controlled.

The cracks produced were quite fine but ran the full depth of the concrete. The faces of a crack were rough, however, with a surface texture not unlike that produced by mechanical breakage methods. This created an interlock that prevented the concrete from being lifted out vertically unless some horizontal separation took place first.

After additional laboratory testing and refinement of this design, equipment elements were assembled for a field unit. A design was developed and built (Fig. 5) featuring a pair of applicator horns and one 5-kW output microwave-generating magnetron mounted in each of two caster-equipped modules. These modules were connected with flexible cables and hoses (for cooling water) to a van (Fig. 6) containing the power supply, which consisted of an ac generator driven by an engine-power take-off, transformers, ac to dc converters, and a magnetron cooling system. We also developed a microwave cavity (oven) for asphalt removal.

After laboratory testing and modification, field testing of the mobile equipment was done at IGT and in the New York City area (Fig. 7) under the sponsorship of ConEd. The results of these tests follow.

1. Concrete was cracked with low noise (the van's engine made most of the noise)

**Figure 5. Microwave applicator modules.**



**Figure 6. Microwave van.**



**Figure 7. Microwave van and equipment in New York City.**



**Figure 8. Backhoe removal of microwave-cracked concrete from a free edge.**



**Figure 9. Use of an air hammer to break away microwave-fractured concrete.**



and could be readily removed with a backhoe when working from a free edge as a starting point (Fig. 8).

2. If no free edge was available, as would be true for a midstreet repair hole, conventional tools (e.g., air hammers) were needed to provide room for the cracked, but interlocked, concrete to separate. Conventional tool use, however, was reduced to one-fifth to one-third the time required without microwave cracking (Fig. 9).

3. Cracks were easily controllable by the multihorn linear arrangement, and it could outline a hole or divide the concrete into manageable-sized pieces (Fig. 10).

4. With the 10-kW power level (two 5-kW adjacent modules), pavement cracking rates of 0.3 to 1 ft/min occurred with concrete from 9 to 5 in. thick. An 11-in.-thick concrete machinery foundation was readily cracked.

5. Extraneous microwave radiation was less than the maximum established health levels and is therefore safe (Fig. 11).

6. Sensitive, broad-band equipment could detect no radio and television interference.

7. Gas utility street crews performed the general operation of the microwave equipment.

8. Successful cracking was done after heavy rainfalls, although in one instance free water had to be baked out of a porous type of concrete by the microwaves before the usual heating and cracking took place.

9. Top layers of concrete less than 2 in. thick tended to spall and crater off down to the interface between layers rather than crack along the horn line.

10. No shock was transmitted to underlying gas or water mains, cable duct, sewers, etc., or to adjacent structures as is often the case with conventional pavement breaking methods, especially the larger boom-mounted and drop-hammer types.

At the conclusion of this work in 1969, the interlocking nature of the cracks was considered the major deterrent to field acceptance.

#### PAVEMENT BREAKING WORK SINCE 1970

High-pressure water jets are being investigated, tested, and constructed as a companion to the microwave concrete-breaker. When concrete samples were preweakened with microwave-induced cracks, water-jet shots effectively exploited those cracks (Fig. 12) and overcame the interlock problem caused by the uneven surface of the crack plane.

Both the microwaves and water jet caused the concrete to fail in tension. Because the tensile strength of concrete is only one-tenth its compressive strength (i.e., tensile strength of 300 to 600 psi versus compressive strength of 3,000 to 6,000 psi), less energy is required for breaking than with conventional methods that generally begin by exceeding compressive strength.

Further, the microwave preweakening considerably lessens the pressures and energy levels reported for water-jet devices used on nonpreweakened concrete. The overall system including microwaves and water jets also appears to provide faster breakage of concrete than unassisted water jets.

The basic component in producing the high-velocity water jet is a pressure intensifier (Fig. 13) consisting of two cylinders. The larger cylinder can be cocked by air, gas, or hydraulic fluid against a closed pressure vessel, which contains a compressed gas that acts like a spring when the cocking fluid is removed. When this happens, the gas spring forces the large piston, rod, and small piston (end of rod) into the water cylinder, which forces water at high pressure out of a small-diameter nozzle. The velocity of this small jet of water is quite high and imparts its energy to a small area of the concrete. The amount of water used is minimal. In addition to producing low noise levels, the water jet has the advantage of causing no shock to underlying facilities or adjacent structures and of raising no dust.

Current work at IGT involves building and field testing two portable water-jet devices under the sponsorship of six gas distribution utilities: Consumers' Gas Company (Toronto), Long Island Lighting Company (Hicksville), Consolidated Natural Gas Service Company (Cleveland), Southern California Gas Company (Los Angeles), Brooklyn Union Gas Company (Brooklyn), and Consolidated Edison Company of New York (New York City).



Figure 10. Example of microwave fracture pattern on 5-in.-thick concrete.

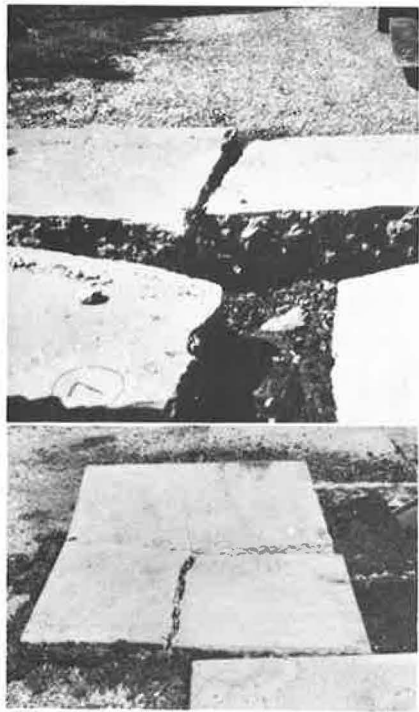


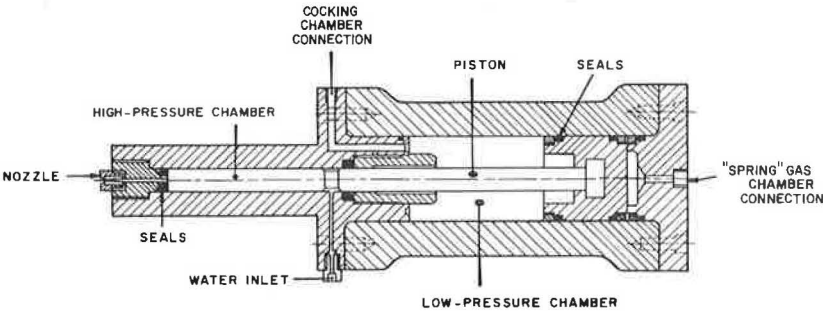
Figure 11. Checking for stray microwave radiation.



Figure 12. Results of three water-jet shots on microwave-cracked concrete.



Figure 13. Single-stage intensifier for producing high-pressure water jets.



The jets will first be compared in the laboratory with results previously achieved with a nonportable, laboratory water-jet device. Next, they will be compared with their microwave companion and then together both will be compared with conventional pavement breaking methods in relation to production rate, noise, shock, and dust. This will be done on uniform pavement slabs, including reinforced and asphalt-topped pavement. The systems will also be tried on frozen earth and, later, field-demonstrated in "sponsor territory."

Commercialization will require design and testing of preproduction prototypes based on the results of our current work. Both water jets and microwave equipment probably could be considerably reduced in size and weight and be more conveniently packaged as a system once operating parameters are established. I hope that an American manufacturer can be interested in providing the world's gas utilities and other pavement breakers with a desirable product that might help to quiet things down a bit and make pavement breaking a bit more tolerable and law-abiding.

#### REFERENCES

1. Occupational Safety and Health Act of 1970, Public Law 91-596, S. 2193.
2. New Scientist, May 31, 1962.