THE APPLICATION OF THE CAVITATION CLEANING VEHICLE IN SNOW AND ICE OPERATIONS

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ABSTRACT

The cavitation phenomenon is the phenomenon whereby the bubbles (microbubbles) that are produced when water boils due to a lowering of pressure generate a destructive force when they come into contact with a solid body and return to the liquid water state. East Nippon Expressway Company Limited (hereafter NEXCO East) has recently introduced a cleaning device that makes use of this phenomenon.

This paper describes the operating principles of the cavitation cleaning vehicle and the story of its development, and also reviews the state of development of various devices aimed at extending its application to snow and ice operations.

KEYWORDS

CAVITATION JET / CAVITATION GENERATOR / THE DESTRUCTIVE POWER OF THE CAVITATION JET / DEVELOPMENT OF THE HIGH-SPEED CLEANER / DEVELOPMENT OF THE LANE MARKING CLEANING ATTACHMENT, DEVELOPMENT OF THE ABRASIVE AGENT-MIXING NOZZLE / SCOURING WORK USING ABRASIVE AGENT-MIXED CAVITATION / DEVICE TO BREAK UP SNOW AND ICE FROZEN HARD ONTO THE ROAD SURFACE.

1. INTRODUCTION

The cleaning of road tunnel light fixtures and interior walls etc., necessitates lane restrictions that can be a cause of accidents or congestion (Fig. 1). In addition work carried out with lane restrictions in place is hazardous work for the cleaning staff.

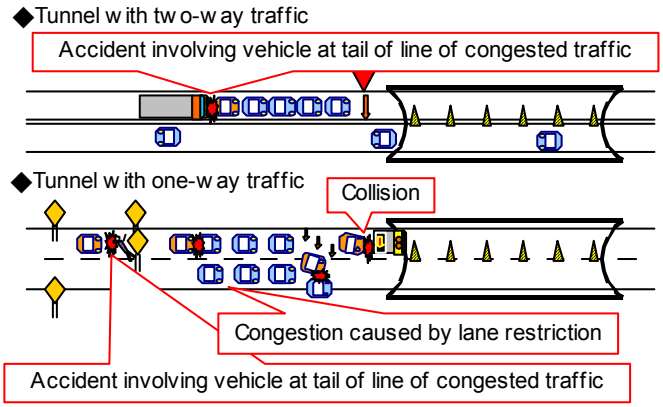

Fig.1- Lane restrictions lead to traffic congestion and accidents

Hitherto attempts have been made to scale down lane restrictions and work necessitating lane restrictions; now there has been developed a cavitation jet high-speed cleaner that makes it possible for tunnel light fixtures and lane markers, which become very dirty and are difficult to clean with a brush, to be cleaned at 50 km/h.（Figs 2,3）

Fig.2-Old-style cleaning using a rotating brush 1-2km/h

Fig.3-High-speed cavitation cleaning 50km/h

Other applications that have been developed in addition to cleaning are the scouring method in which an abrasive agent is mixed in with the cavitation jet, and a device which mixes rock salt in with the jet to break up frozen snow and ice on the road.

This is a report on these cavitation technologies.

2. THE CAVITATION JET

Cavitation is the phenomenon whereby the bubbles of water vapor generated when water boils produce a destructive force, noise or vibration the instant they are returned to the liquid water state because of the surrounding pressure. When the pressure within the flow of water becomes lower than the saturated vapor pressure, the liquid evaporates and bubbles are produced (Fig.4). These bubbles are instantly extinguished on account of the surrounding pressure, and the shockwave produced when this happens can destroy even metal. This phenomenon, from the generation of the bubbles to their disappearance, is called cavitation.

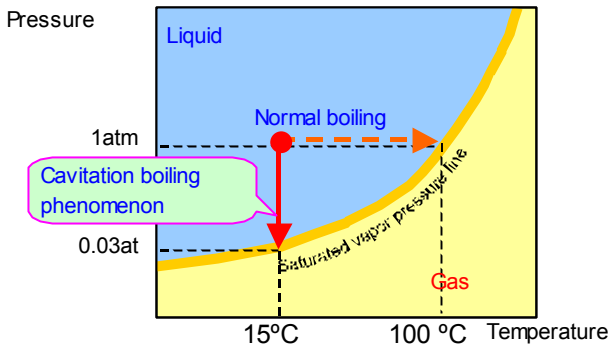

Fig.4-Cavitation and saturated vapor pressure

Cavitation has long been known as a destructive phenomenon that causes the destruction of ships' screws and pumps, and also gives rise to noise and vibration; and research into cavitation has mainly been done with the aim of keeping its generation in check.

Nowadays however, cavitation is being put to effective use; bubbles are generated efficiently in the stream of a jet of water and used to clean off graffiti, or to remove old paint from the exterior walls of buildings.（Fig.5）

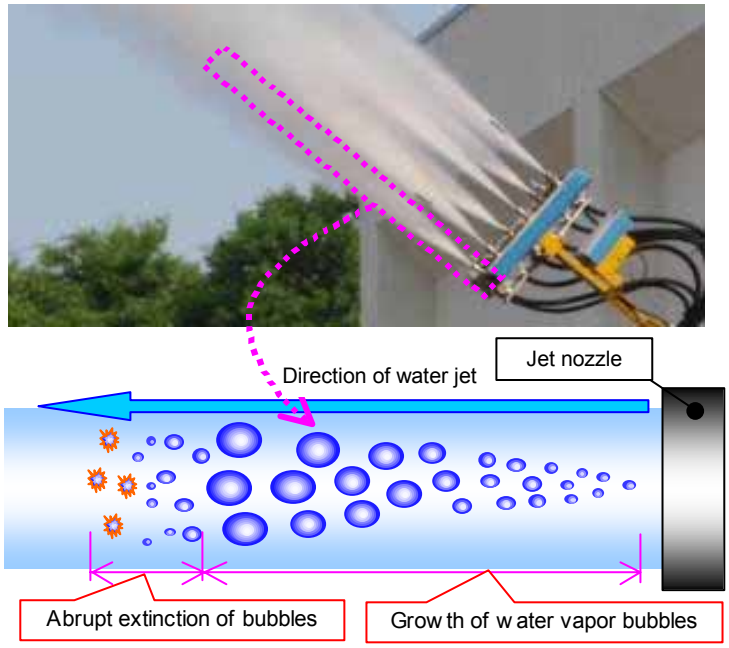

Fig.5-Generation and extinction of cavitation bubbles

Compared to an ordinary jet of water, a cavitation jet involves a lower water pressure and volume of water: when cleaning is carried out at a speed of 50 km/h almost all the water used for cleaning dissipates as vapor, so that skid accidents are not triggered as a result of the surrounding vehicles and road surface being wet. In addition this method is environmentally-friendly; the jet contains no detergents or any other substances that could pollute the environment, so that there is no need at all to dispose of dirty water after cleaning.

However, care is needed in using this method; when humidity is high, such as during rainfall, gasification does not always occur.

3. CAVITATION GENERATOR

The cavitation-generating device is structured as shown in Fig.6.

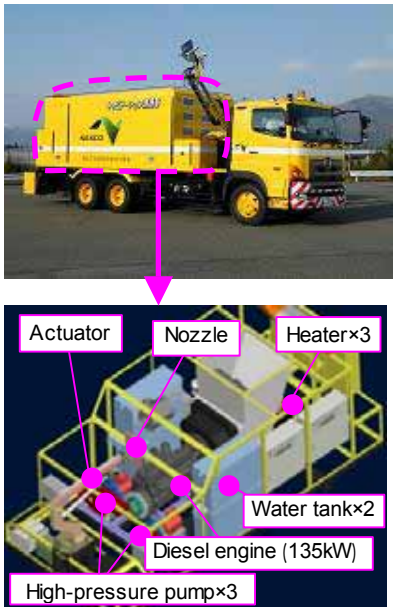

Fig.6-Inside the cavitation cleaner

The device works by first generating a jet of water from the cleaning water, and then generating cavitation bubbles in the jet of water.

In order to generate the jet of water a driving force produced from the diesel engine by means of a V-belt is used to operate a high-pressure (plunger) pump to pressurise cleaning water (mains water) from the water tank. To prevent the generation of cavitation within the high-pressure pump or piping from damaging the pumping equipment, at this time the temperature of the cleaning water is kept low.

Just before it reaches the jet nozzle the pressurised water is heated to around 80 degrees Centigrade so that it will readily boil. Because of the need for them to withstand high pressures, the heaters are of a special kind and expensive, but the heating must be the final process before the jet, to prevent cavitation occurring within the high-pressure pumping equipment. When finally this highly-pressurised hot water is expelled in a jet from the specially-structured nozzle, cavitation bubbles are generated within the jet of water.

4. THE DESTRUCTIVE POWER OF CAVITATION

Cavitation is known to be a phenomenon that can destroy even metal, which means there is a danger of it destroying the surface of the tunnel light fixtures and peripheral equipment if the jet is aimed at them for an extended period of time. Consequently there is a need to understand its destructive power and to take sufficient steps to ensure safety.

Fig.7-Failure test on tempered glass (8mm)

Fig.8-Failure test on cabling

In high-speed cleaning the jet of water is not usually aimed at any single point for a long period of time, but since it is conceivable that this might occur if the vehicle has to slow down or stop because of some obstacle, the destructive power of the cavitation jet was checked.

A plate of tempered glass 8mm thick (the kind of glass used for the emergency phone boxes inside tunnels) shatters in a matter of about 50 seconds when the jet is aimed at it from a distance of about 10 cm (Fig.7), while the covering on electricity and communications cabling of the type used in tunnels is destroyed in about 5 seconds when sprayed with the jet from a distance of about 10 cm. (Fig.8)

From the results of these tests, it was decided in developing the cavitation cleaner to fit an automatic stop mechanism so that the jet is not concentrated in one spot when the cleaner is close to the tunnel wall or travelling at low speed.

5. DEVELOPMENT OF THE HIGH-SPEED CLEANER

5.1 Development of the cleaning arm

The cleaning arm was developed to bring the nozzle up to the position of the tunnel light fixtures. The cleaning arm could be hi-tech, rather like a robotic arm, but a hydraulic cleaning arm was developed to satisfy the following conditions. (Fig. 9)

1) Durability is important, since the cleaner is to be used outdoors. A simple structure is best.
2) As it will be vehicle-mounted, it must be able to withstand vibration. The hydraulic arm has a good track record in use with vehicle-mounted boom lifts, cranes, etc.
3) Practical application of general-purpose, high-performance hydraulic power.

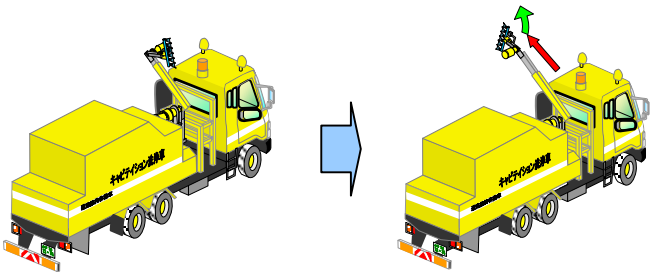

Fig.9-Illustration of cleaning arm operation

There are four drive shafts, to control boom rotation, angle of horizontal elevation, extension and angle of horizontal elevation of the nozzle section, to cope with the many different positions and angles at which tunnel light fixtures are installed.

5.2 The high-speed cleaner nozzle position control device (GPS-linked automatic nozzle position control device)

Before a vehicle loaded with this device enters a tunnel at a speed of over 50 km/h and commences to clean the tunnel light fixtures, it is necessary first to adjust the nozzle to the position of the light fixtures, which is different for each tunnel.

Since the objective of this device is to reduce lane restrictions while improving the cleaning function, it is necessary to be able to adjust the nozzle position to the light fixtures while travelling at over 50 km/h, without stopping. However; at this speed it is impossible for an operator relying on eyesight alone to adjust the position by manipulating a lever, and so the “GPS-linked automatic nozzle position control device” was developed. This uses GPS to measure the distance from the current position to the entrance to the tunnel and automatically adjusts the nozzle gradually to match the position of the light fixtures. (Fig.10)

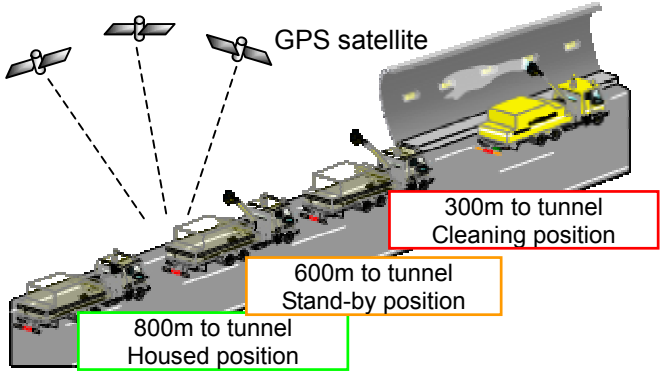

Fig.10-GPS-linked automatic position control device

This work requires in advance the latitude and longitude data for the tunnel entrance and measured data on the position of the light fixtures for each tunnel, for both the nearside lane and the overtaking lane; but with this GPS-linked control device it is possible to implement everything from preparation to cleaning while moving at a speed of over 50km/h.

It has been verified that even with the nozzle separated by a distance of up to about 55 cm, the cleaning effect is better than with the old method of cleaning; the positioning of the nozzle does not need to be all that accurate, and even with some amount of shaking of the nozzle due to the motion of the vehicle, a satisfactory cleaning effect can be ensured.

5.3 Safety devices

The following safety devices have been developed so that cleaning work can be undertaken safely at speed on the expressway with ordinary vehicles travelling close by.

1) Function to prevent the nozzle section coming into contact with road fixtures
The device was fitted with a function whereby when the laser sensor near the nozzle section detects the proximity of an object, or the touch sensor touches an obstacle, the actuator automatically retracts to avoid it. (Fig.11). During this evasive action, the amount of hydraulic fluid is increased over normal operation so that speedy evasion is possible.

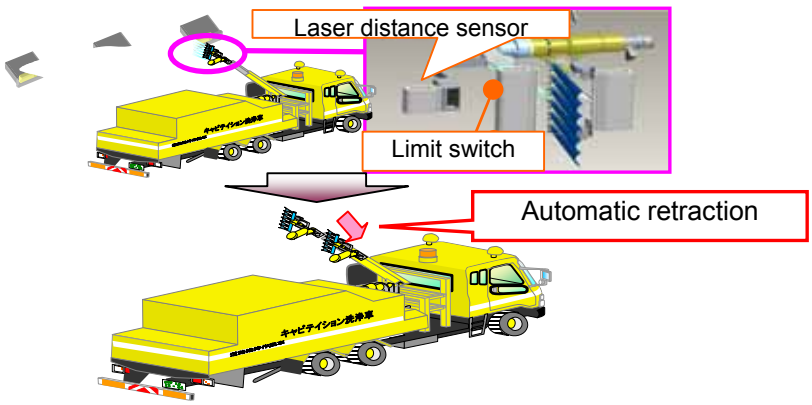

Fig.11-Contact avoidance device

2) Reduction of damage when the nozzle section has come into contact with an object
Various shock absorbing measures to reduce damage in the event of the evasive action described above not being enough to prevent the nozzle section hitting a light fixture or other object have been implemented (Fig.12). To prevent the nozzle section falling off and hitting an ordinary vehicle following behind, a wire has been attached to prevent the nozzle dropping.

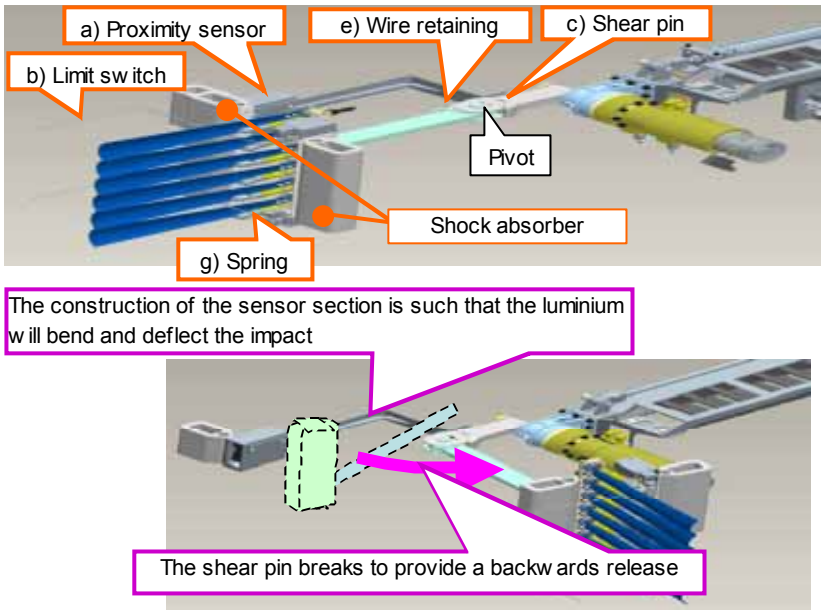

Fig.12-Strategy to prevent contact by the nozzle

3) Measures to prevent breakage of road fixtures by the powerful destructive force of the cavitation jet

In order to ensure that road fixtures are not damaged by the powerful destructive force of the cavitation jet, the function to automatically stop the cavitation jet when in close proximity to items or when moving at slow speed was developed. This was made possible through monitoring of proximity by means of a laser distance sensor mounted close to the nozzle section and through constant monitoring of speed by extraction of the vehicle speed pulse signal from the vehicle itself. In this way it is possible to prevent road fixtures being damaged because of the cavitation jet being concentrated on one spot.

6. DEVELOPMENT OF A LANE MARKING CLEANER ATTACHMENT

An attachment was developed that cleans heavily soiled lane markings inside tunnels by directing the cavitation jet at the road surface (Fig.13).

Fig.13-Lane marking cleaner attachment in operation

Since the lane marking cleaner attachment would also damage the road surface when the vehicle is moving at low speed or stationary, it is fitted with a device to turn down the power of the jet to match the speed of the vehicle.

Position alignment is carried out while watching the surveillance camera image.

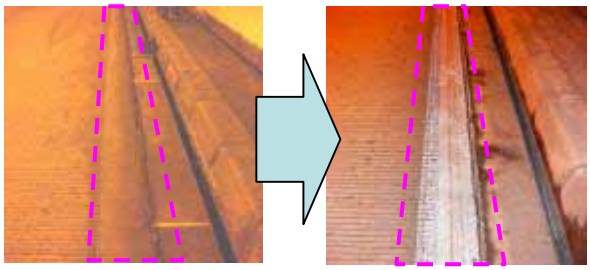

Fig.14-Lane marking before and after cleaning

Up until now there had been no effective way to clean lane markings, but this attachment has made high speed cleaning possible, enabling effective visual guidance for tunnel traffic to be restored.

7. DEVELOPMENT OF AN ABRASIVE AGENT-BLENDING NOZZLE

Apart from high-speed cleaning, a cavitation jet can also be used to remove graffiti or to remove old paint from the exterior of buildings, but the scouring method requires greater destructive power.

In order to raise the destructive power of the cavitation jet without making the apparatus too large, a nozzle capable of blending in an abrasive agent was developed. (Fig.15)

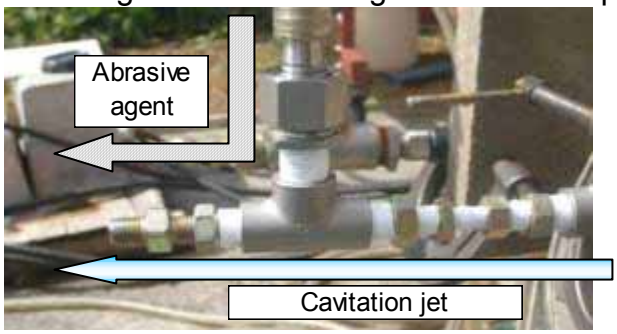

Fig.15-Outward appearance of abrasive agent-blending nozzle

This is a nozzle with a T-shaped blender pipe attached close to the outlet for the cavitation jet, set up in such a way that the impetus of the cavitation jet generates a vacuum inside the T-shaped pipe, thus sucking in the abrasive agent and mixing it into the cavitation jet. (Fig. 16)

This makes it possible to combine the destructive power of shot blasting with the cavitation jet.

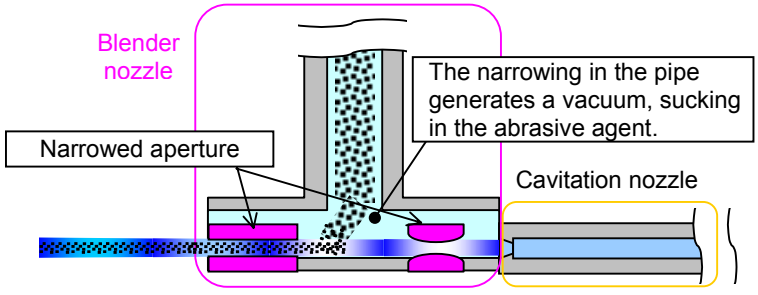

Fig.16-Cross-sectional diagram of the abrasive-blending nozzle

A variety of abrasive agents can be used.

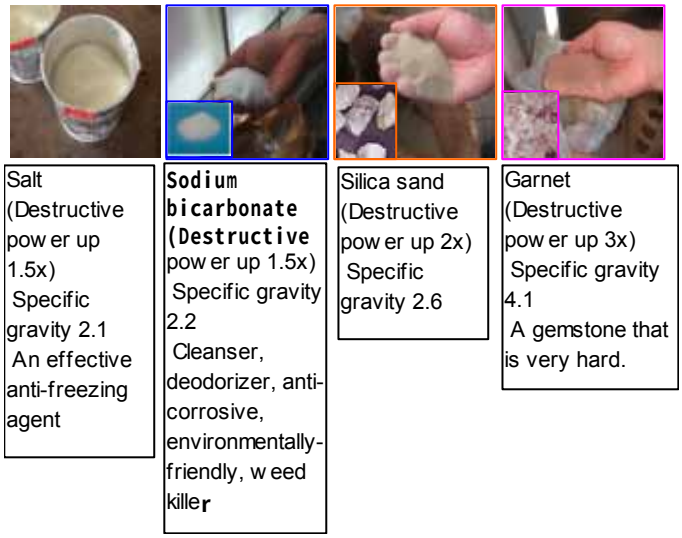

Fig.17-Properties of different abrasive agents

8. SCOURING WORK USING ABRASIVE AGENT-MIXED CAVITATION

The silica sand used in ordinary shot blasting is inexpensive and provides twice the destructive power of cavitation that has no abrasive agent mixed in. Compared to shot blasting using only a jet of air, it is less noisy and does not generate the fine dust that can damage the lungs. Scouring work using this silica sand-mixed cavitation is possible, facilitating work on welded areas and uneven surfaces. To speed up the work, garnet, which is very hard and has a high specific gravity, can be used.(Fig.18).

Fig.18-Scouring work using abrasive-mixed cavitation

When scouring work is carried out with sodium bicarbonate mixed in the cavitation jet, while rust and paint that is firmly stuck on cannot be removed, ordinary red rust can be transformed into black oxide.

Paint that is still strongly adhering to the surface should be left as it is, and in experiments using corrosion test equipment rust that has turned to black oxide has been shown to have corrosion-resistant properties (though the film of black oxide is not strong).

It is thought that the red rust is transformed into black oxide through the alkaline sodium bicarbonate and the impact of the cavitation; thus the chemical properties of the abrasive agent do not simply intensify the destructive force, but can even bring about a compositional change.

In order to then make the film of black oxide still stronger, a surface treatment with a black oxide replacement primer will provide an inexpensive, low-noise scouring method and finish. Corrosion-resistant properties can be further enhanced with a coat of paint to finish, but this is a choice that should be made by comparing cost and frequency of maintenance. In addition sodium bicarbonate is widely used as an environmentally-friendly cleanser and deodorizer (it is also used as a raising agent in cooking). When utilized to clean toilet floors, where both dirt and odour are severe, it is possible to clean thoroughly even into nooks and crannies that cannot be reached with a brush. Furthermore, it has been confirmed that sodium bicarbonate-mixed cavitation caused weeds to wither, although weeds belonging to the family of Gramineae (grasses) will not perish unless the cavitation bubbles are aimed directly and steadfastly at them.

9. DEVICE TO BREAK UP SNOW AND ICE FROZEN HARD ONTO THE ROAD SURFACE

9.1 Rock salt feeder

A device to mix rock salt with the cavitation was developed to break up snow and ice frozen hard onto the road surface. (Fig.19)

The device comprises a rock salt storage hopper, rock salt feeder piping and a mixing nozzle.

Rock salt is something that is generally used in snow and ice control, and can be supplied from the storage depots for de-icing chemicals set up at road administration facilities.

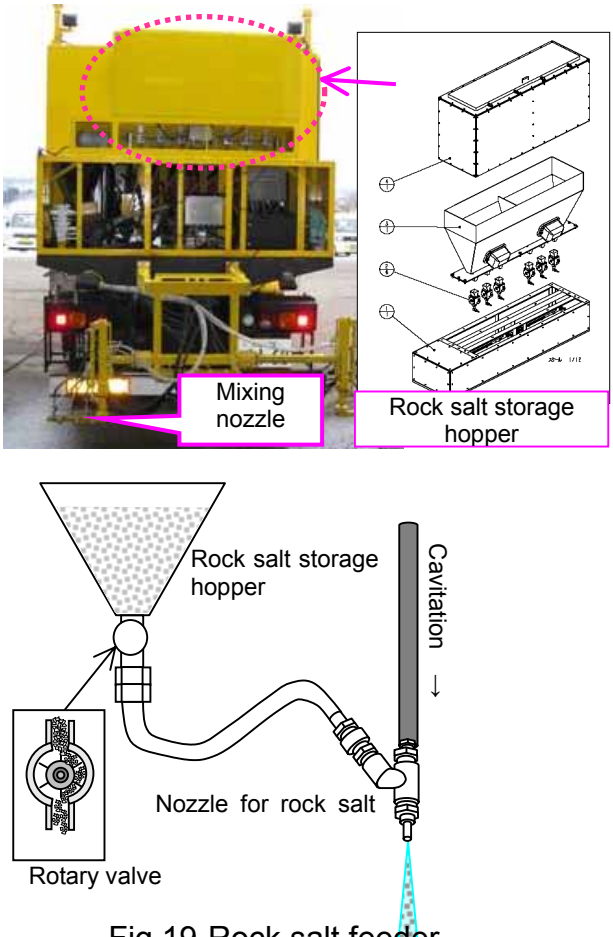

Fig.19-Rock salt feeder

9.2 The swinging rock salt-mixing nozzle

The cavitation apparatus is normally used for cleaning, and the jet stream from the cleaning nozzle spreads out in a fan shape.

This cleaning nozzle with its fan-shaped jet is well suited to cleaning over large areas, but it lacks the destructive power needed for localized ice break-up. For this reason improvements were made so as to produce a straight jet.

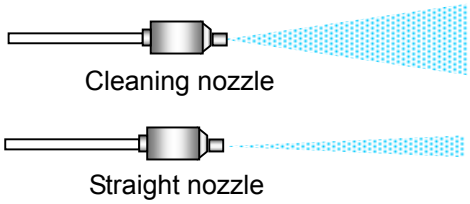

Fig.20-Improvement of the cavitation nozzle

This improved the power of the jet to penetrate snow and ice but made it more difficult to work over a flat surface; and so a mechanism to swing the nozzle back and forth was developed.

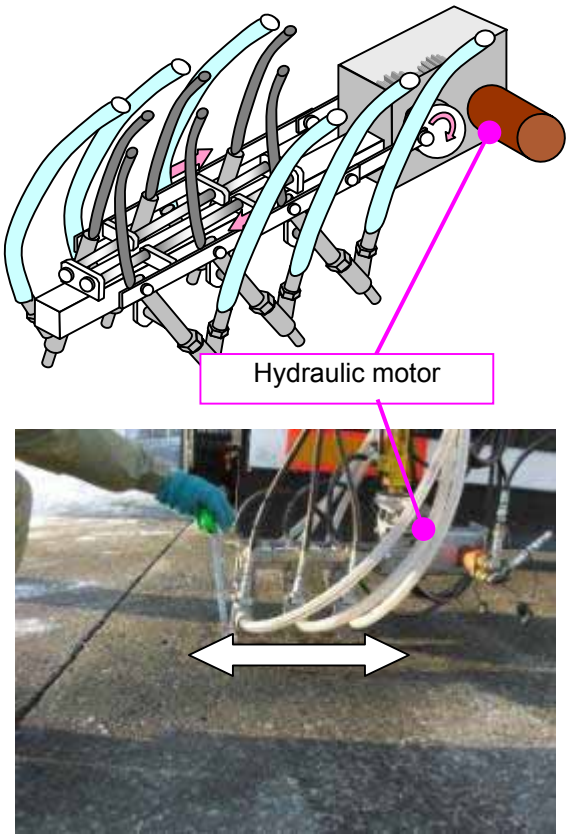

Fig.21-Mixing nozzle swing

9.3 Field tests

This apparatus was subjected to field tests. The tests were carried out in Yokote City, Akita Prefecture, early in the morning when temperatures were at their lowest (air temperature of -8ºC, road temperature of roughly -3 ºC).

The swing mechanism has a working speed of several kilometers per hour, and was effective in breaking up the snow and ice.

However, when the road temperature is low the ice is frozen firmly to the road surface, so that where the jet does not strike the ice is not removed.

Fig.22-Break-up of snow and ice frozen hard onto the road surface

Mixing in rock salt raises the destructive power of the cavitation jet 1.5 times and the amount of rock salt supplied is enough to provide a sufficient concentration of salt (20%); but the rock salt bounced off the road surface and scattered, so that the actual concentration of salt was low.

Fig.23-The cavitation jet being emitted from a swinging nozzle

There are other problems that have not been completely resolved; for example, the phenomenon of the salt clogging when the air temperature falls drastically. On-site work should receive continued support.

10. CONCLUSION

This equipment was initially developed as a high-speed cleaner, the aim being to reduce lane restrictions. However, it was found that mixing in an abrasive agent allows it to be used for various different applications, such as scouring work or breaking up snow and ice.

In addition, apart from mixing in abrasive agents, it is also possible to raise the specific gravity of the cavitation jet and increase its destructive power by mixing a macromolecular polymer into the water tank. The possibility remains that mixing in some other substances could vastly expand the range of applications.

Studies to expand the range of applications, not only on roads but into other fields, will continue.