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ARIZONA DEPARTMENT OF TRANSPORTATION
ARIZONA TRANSPORTATION RESEARCH CENTER

STATE-OF-THE-ART REPORT ON SNOW PLOW DESIGN

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I. INTRODUCTION

Arizona Department of Transportation snow plow operators experience a number of problems which may be solved through research activities. With the higher speeds in snow removal used on state highways these problems include: snow blow-over, overheating of equipment, flying gravel and debris which cause damage to windshields, difficult maneuverability and reduced safety. Attempts to solve some of these problems by operators and technicians are usually based on trial and error methods, which appears to be very costly and dangerous.

The objective of the present effort is to gather all available information on; design standards for ideal snow plow moldboard configuration, optimum plow attack angle for snow and ice scraping, ideal snow plow swing angle and plow "frog frame" universal frame hitch and horsepower required for low and high speed operations. There is also a need to determine advantages and disadvantages of using a load sensing hydraulic system for plow, spreader and dump functions versus the conventional open center system.

Available information on snow plow designs gathered during the literature search and input from present snow plow manufacturers is summarized in this report.

II. TYPES OF SNOW PLOWS

A multitude of plows are available for snow and ice control work, and the particular design should be chosen to match the type of snow condition expected in the area, the nature of the road systems and the truck that will be used to propel the plow.

The following is a summary of the major types of snow plows as described in the "Manual for Deicing Chemicals":

1. High Speed Plow is characterized by a conical-shaped moldboard, which is small on one end and large on the other end. It is typically used on very large vehicles (5 tons or more) and plows the snow in only one direction, usually to the right-hand side of the road. The moldboard is contoured so that the snow leaves from the large end on the blade and is directed out to the side. In light blowing snow, this feature improves the visibility of the driver so that he can achieve a higher plowing speed. Minimum power is also required to push the plow.

2. Two-Way Plow is popular for all around use; it is a straight-edged plow with a constant cross section moldboard made in sizes ranging from 8 feet to 14 feet in width; used on vehicles ranging in size from utility vehicles up to the largest four-wheel drive plow trucks. The power-angling characteristics

are useful for plowing either to the right or to the left on multiple-lane roads and, upon occasion, are used for pushing snow directly ahead of the truck. The constant cross section of the moldboard limits the speed of plowing. Snow has a tendency to come up over the front of the moldboard thus reducing the visibility of the driver.

3. Two Way High Speed Plow is a compromise between the high-speed and two-way plow. It has a straight cutting edge and a double-formed moldboard, which is capable of casting snow either to the right or to the left, depending upon the orientation of the plow.

4. Vee Plow is useful in areas where moderate drifting may occur. Typically a Vee plow is mounted on a large four-wheel drive truck.

5. Wing Plow is used for pushing back high drifts or the accumulated snow left over from earlier storms along the edge of the road. In addition it is also used often for plowing light snow on a multi-lane highway. In this operation, the snow collected by the truck's front-mounted two-way plow is caught by the wing and pushed back further, thus increasing the width of road cleared in a single pass by one truck.

6. Underbody Scrapers are useful for removal of hard packed snow from roadways. These plows are capable of exerting downward pressure on the cutting edge of the plow and breaking through ice and hard pack under some circumstances. Underbody plows are also useful for removing light accumulations of snow (up to 2 inches).

7. Road Graders that are used during the summer for grading shoulders are used in the winter time for snow-plowing operations. Such a unit is useful for both straight-line operations and for clearing parking lots and other large areas. The easily controlled scraper blade is often the only piece of equipment that is capable of removing hard pack and ice from roadway surfaces.

8. Rubber-Tired Front-End-Loader equipped for plowing are extremely useful for urban snow plowing, capable of maneuvering in very tight quarters.

III. ADDITIONAL FEATURES OF PLOWS

All snow plows must be able to be lifted from the surface of the roadway by the operator through remote control, usually accomplished by a hydraulic control system operated from the cab. In addition, plows should have a mechanism, where by the moldboard or the whole plow itself trips when it meets an immovable object, such as a manhole cover, thereby minimizing the shock transmitted to the truck and driver.

All front-mounted plows must have a hitch firmly attached to the frame of the truck and to which the plow itself can be attached rapidly when needed. A wide variety of hitches are available, many of which are fabricated or modified in the maintenance shops of the various municipalities. Many organizations find that plow cutting edges that have tungsten carbide inserts eliminate the need for changing cutting edges, give far longer service, and are well worth the additional purchase cost.

For areas where the minimum temperature is 28-32^{O}F, rubber cutting edges for snow plows have been used with some success for removing freshly fallen or slushy snows from roads equipped with raised reflectorized traffic markers. Rubber or polyurethane cutting edges are not useful when temperatures are below the critical temperature range of 28-32^{O}F and steel and carbide-insert blades are needed to remove the snow.

IV. CLASSIFICATION OF SNOW-REMOVAL EQUIPMENT

Proceedings of an International Symposium on "Snow Removal and Ice Control Research" (6) suggested that every price of snow-removal equipment should be valued and classified for the type of work it is expected to do. A suggested division is as follows:

No.	Type of Work	Type of Equipment
1.	Snow-dozing	Very slow moving equipment
2.	Snow-plowing	Slow moving equipment
3.	Snow-throwing	Fast moving equipment
4.	Snow-blowing	Rotaries of various types

At slow speeds snow is pushed or plowed, but at the faster speeds of 20 to 30 mph it is thrown. In fact, too little is known about the snow-throwing possibilities; that is receiving some attention in Japan.

V. ENGINEERING STUDIES ON SNOW REMOVAL

Because adequate information and data are not available, the design and manufacture of snow-removal equipment has changed very little since the 1930's (6). In 1967, David Minsk of U.S. Army Cold Regions Research and Engineering Laboratory stated that no engineering study has been made in the United States to provide a sound basis for snow removal equipment development. In 1970, an examination of material in technical libraries, including the National Research Council Library confirmed that this was still true.

VI. SNOW REMOVING PERFORMANCE OF THE SNOW PLOW TRUCK

Tests were conducted to ascertain the performance of 7-to-10 ton capacity 4-wheel drive trucks in Japan (6) in the winters of 1965-66 and 1966-67. Trucks equipped with snowplows have been tested for the capability of removing snow 5 to 20 cm deep at speeds of 15 to 30 km/hour. Because of difficulties of controlling natural conditions such as snow density, air temperature, wind, and road surface conditions there is a considerable spread of the data.

Field studies of the performance of these trucks with snowplows produced the following results:

- Working resistance of the truck consists of the truck's rolling resistance that varies with its speed, sliding resistance of snowplow, and snow accelerating resistance expressed as a square of the truck speed,

- At a truck speed of less than 7.5 mph, snow-removing performance of the one-way plow is not effective because the plow pushes snow without throwing,

- Snow-removing efficiency of the plow falls as the square of the truck speed,

- The distance snow is thrown increases with the square of the plow speed,

- The plow with the conical surface performed better than one with a cylindrical surface.

Consequently, the necessary truck driving force required by the plow consists of truck running resistance, plow sliding resistance, and snow-removing resistance all put together.

VII. RESEARCH ON AIR LUBRICATED SNOW PLOW

A paper presented at the Second International Symposium on Snow Removal and Ice Control Research held in New Hampshire in 1978 (2) reports on research on an air lubricated snow plow, sponsored by the National Research Council of Canada. One of the methods investigated was a means of reducing the dynamic friction of snow on a snow plow blade. Air is supplied to the surface of a blade to provide a lubricating film.

This concept used a small standard cylindrical design snow plow modified to provide the air-lubricated feature. To provide air to a blade surface, a false blade surface was installed in front of the existing blade. The false blade surface was made of aluminum perforated and oriented to give directional flow to the supply air. Air was supplied from fan outlets by a number of flexible hoses.

The first few tests with this plow showed two things rather dramatically; air provides a virtually frictionless surface and without friction the snow flow is uncontrollable. After observing snow explosions resulting from the air lubricated blade hitting a snow accumulation, consideration was given to designing the blade to give directional control of the flowing snow while still taking advantage of the air lubrication. This air lubricated snow plow contained a much larger perforated blade surface. The initial tests of this snow plow blade mounted on a standard vehicle has provided the desired directional control. However, it will take further development and evaluation of this principle to determine its
possible merits for high speed snow removal or improved snow plow efficiency at existing speeds.

VIII. A STUDY ON THE RESISTANCE OF SNOWPLOWING AND THE RUNNING STABILITY OF SNOW-REMOVAL TRUCKS

Another paper presented at the Second International Sumposium held in New Hampshire in 1978 (2) dealt with the resistance of snowplowing and the running stability of a snow-removal truck at high speed. This study was sponsored by the Ministry of Education in Japan. The resistance of snowplowing was obtained from the results of field experiments, while running stability was derived by calculating the maximum speed of the snow removal truck without unstable motion on both a tangent and curved road section.

This study is the first of its kind to approach various problems. Because of the lack of data which can be used directly from field experiment, numerous assumptions were used. From the calculation of the running stability of a snow-removal truck, which depends largely on experience, a rough outline of the operation has been obtained. Numerous problems such as the visual field of the following vehicles remains unresolved.

IX. SNOWPLOWING VISIBILITY IMPROVEMENT WITH TURNING VANES MOUNTED TO SNOW-CAPS

The Ministry of Transportation and Communication for Ontario Province experimented with various rubber flaps, louvres, and venetian blind devices mounted on the snow plow trucks in an attempt to reduce driver visibility problems with only a limited success.[3]

Following numerous wind and water tunnel tests a new concept involves a concave turning vane mounted over and just behind the cab on a framework. This deflects the air flow down over the back of the truck.

Also under development was a modified turning vane that can be mounted on the top edge of the plow blade, extending over the lip of the plow. Mounted at the correct angle, the vane will catch most of the snow spillover and deflect it down over the back of the plow onto the highway, improving the driver visibility.

X. SNOWPLOW RESEARCH BY HENKE MANUFACTURING CORPORATION

Snowplows were recently tested by Henke Manufacturing Corporation at the Chrysler Corporation testing ground at Chelsea, Michigan. Test were run in a 200-foot long wide water trough at speeds from 10-35 miles per hour. High-speed sequential photographs taken at six exposures per second were made during each test run. These graphically illustrate that with the proper relationship of cutting edge layback angle and moldboard intercepting radii, water flows smoothly up the moldboard, curls over and is discharged effectively to the side. The water does not curl back into the path of the plow and operator vision is not obscurred by "flurries" over the top of the moldboard onto the truck windshield.

Figure 1 illustrates the effect of varying the cutting edge layback angle and the importance of properly blending the moldboard radii to gather the load and carry it away to discharge. At the ideal angle, snow and ice are scraped from the road surface with minimum effort. Too steep an angle requires excessive power and causes the plow to "chatter" on the road surface whereas an angle laid back too far tends to cause the plow to skim up and over ice and hard packed snow surfaces.

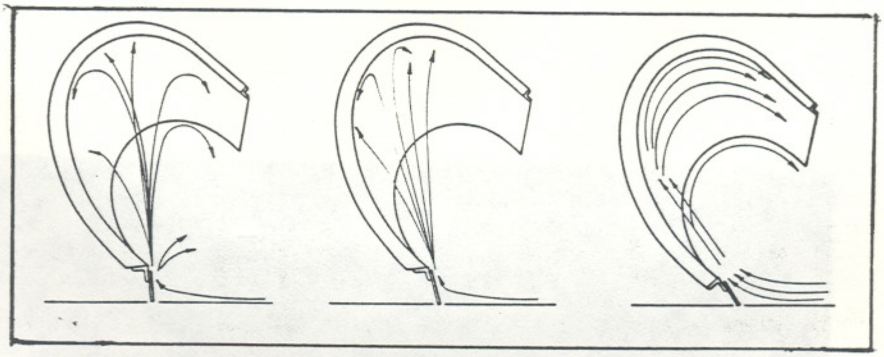


Figure 1. Diagrams show how changes in cutting edge layback angle affect plow efficiency.

The discharge wings on the reversible plow, commonly called "mouse ears" are also effective in accomplishing a smooth, evenly placed discharge alongside the roadway. (Figure 2)

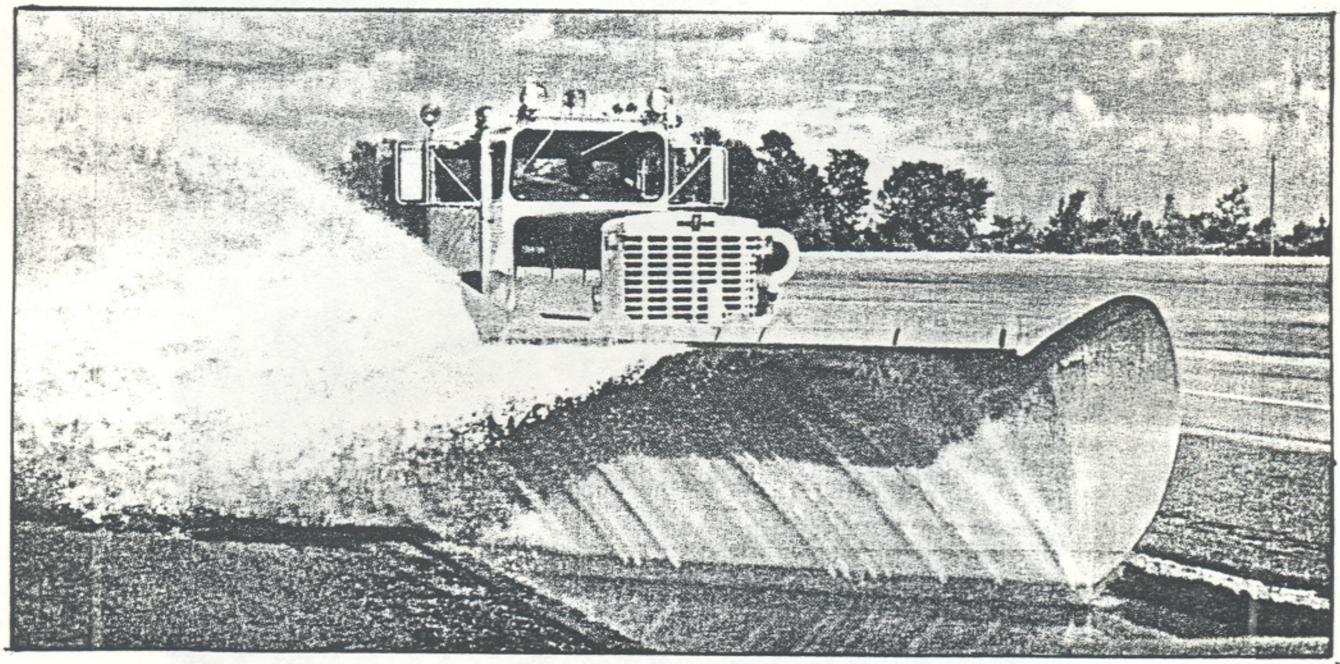


Figure 2. Discharge wings on the reversible plow.
IDEAL cutting edge layback and proper moldboard radii interception results in good load carrying displacement and discharge.

Conversely, tests run with improper cutting edge layback angle produced excessive flurries over the moldboard as well as flurries to both sides of the plow, indicating poor load carrying characteristics. This series confirmed a phenomenon experienced and described by operators in snow. As the plow enters the water, the thrust of the water from the improperly angled cutting edge strikes the upper radius of the moldboard, causing the plow to lift. The improper intercepting radius forces the water to curl over in a rolling motion back into the path of the cutting edge, contributing further to the lifting action. As the amount of water moved is reduced, the plow settles back down, only to repeat the cycle again.

Although all the tests were preliminary in nature, they are valuable in planning future tests.

An effective automatic quick coupling system (AQC), developed by Henke which provides a high versatility of the snow plowing equipment is shown in Figure 3.

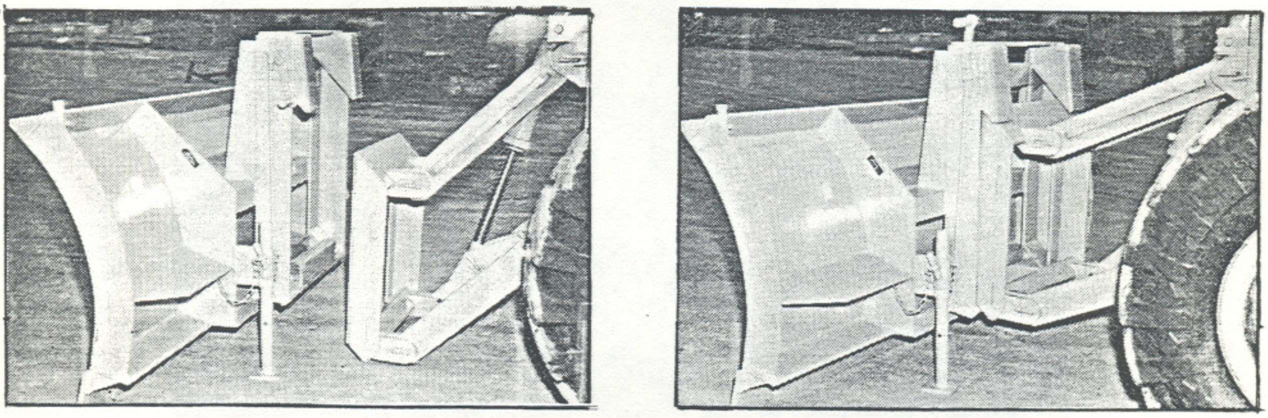


Figure 3. Automatic Quick Coupler.

By use of spring loaded self-locking cam, the automatic coupling to the attachment is achieved without pins resulting in no downtime or maintenance of pins. An operator can hook to the attachment without leaving the comfort of his cab in less than 10 seconds. Both male and female coupling mechanism were designed to be common. As a result of this common design, this enables the same attachment to be used on either end loaders or motor graders of different makes and models.

The automatic locking of the attachment to the prime mover is accomplished by a spring loaded "cam latch" located in the bottom of the automatic quick coupler female of the attachment portion of the AQC system. It improves operator safety by eliminating operator intervention in the automatic quick coupling process. The AQC system is designed to accept hydraulic down pressure.

The Henke AQC attachment female portion is available for converting the existing and competitive brand truck mounted blowers, sweepers and other attachments to the AQC coupling system.

Henke is also developing a load sensing hydraulic system for the plow. The hydraulic cylinders, located on each side of the plow, are cross-plumbed through a pressure sensitive valve system.

According to Michael Green, the President of Henke Manufacturing Cooperation, the problems in snow plow design are in snow plow trip systems. Basically, four different types of trip systems are available:

1) Standard mechanical over center type (Figure 4)

2) 4-extention spring trip (Figure 5)

3) One-way spring trip (Figure 6)

4) Trip cutting edge (Figure 7)

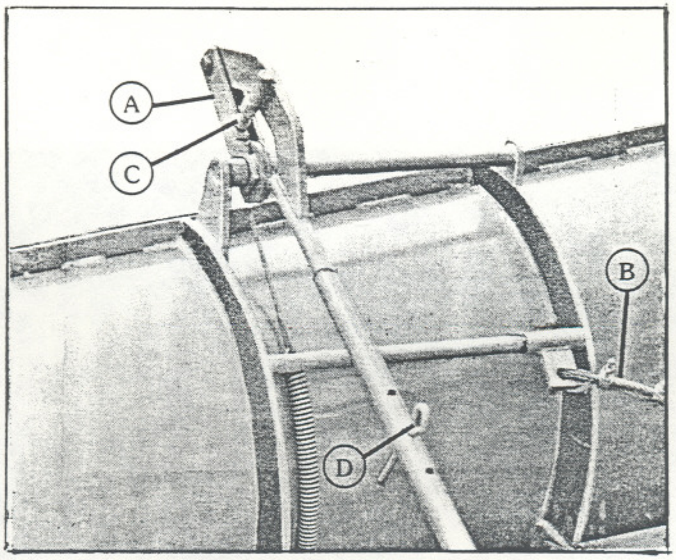


Figure 4. Standard mechanical over center type trip.

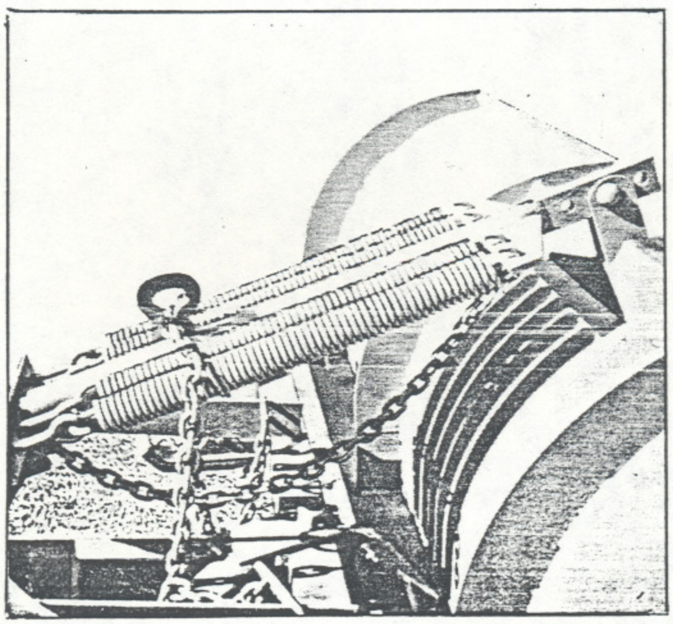


Figure 5. 4-extension spring trip.

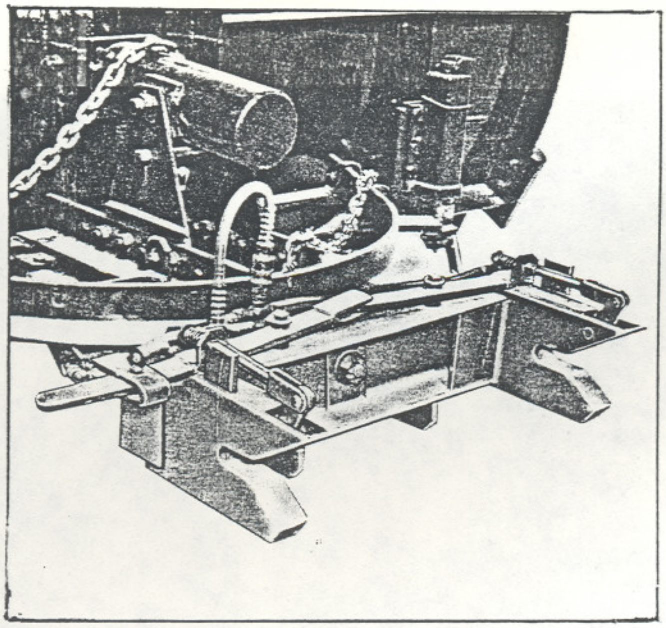


Figure 6. One way spring trip.

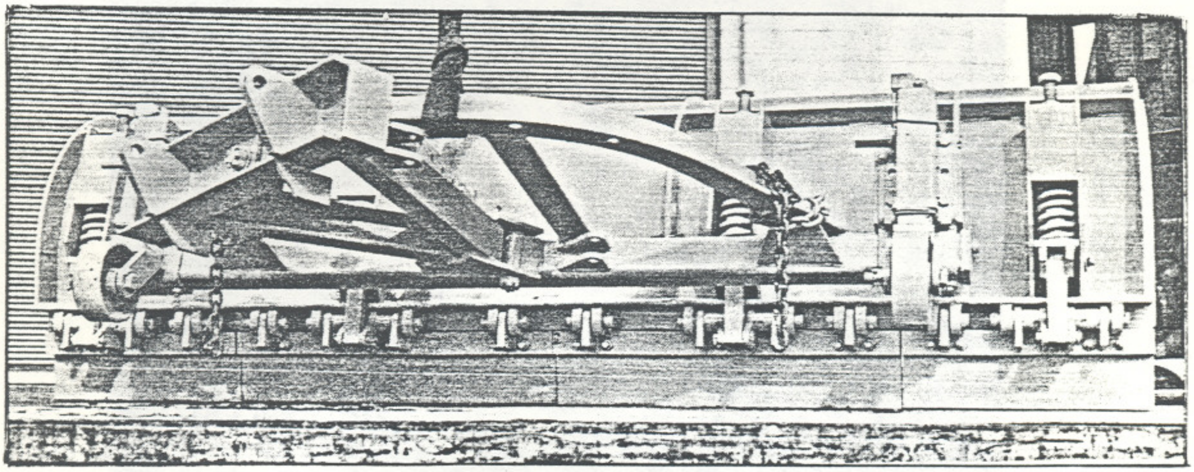


Figure 7. Trip cutting edge.

Another problem appears to be a mismatch between the horse power of the plow truck and the weight of the plow. If the truck is too powerful, damage to the snow plow results and if the plow is too heavy, damage to the truck may result when the plow trips.

Overheating of the truck engine has been stated to be a result of improper truck horsepower, type of snow plow combination, and improper plow swing length for the plowing conditions.

During the recent plow study, Henke used a 400 HP truck developed by ASHKOSH Truck Corporation which appears to be suitable for snow plowing. (Figure 8)

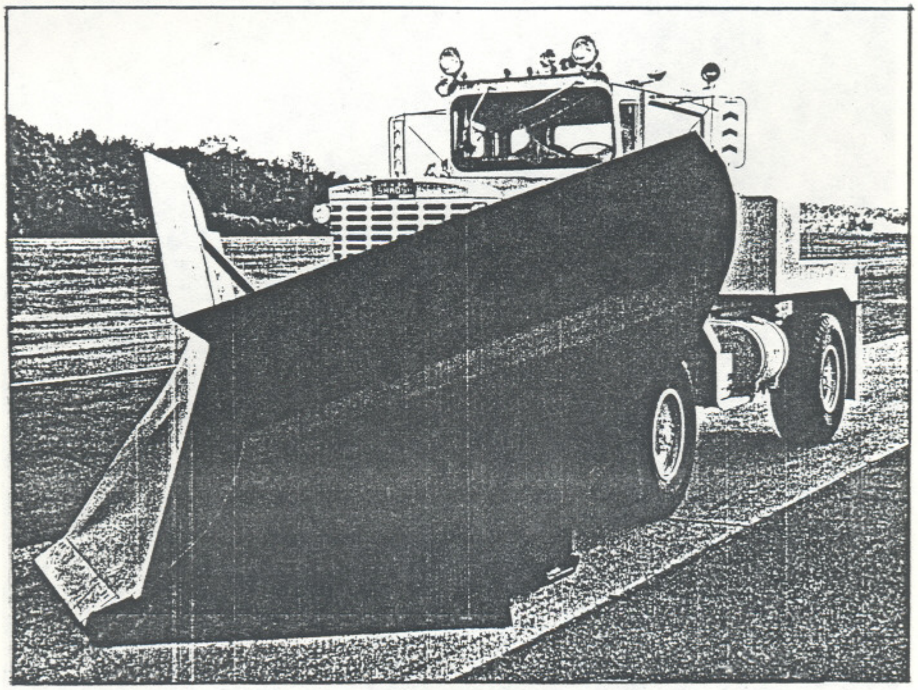
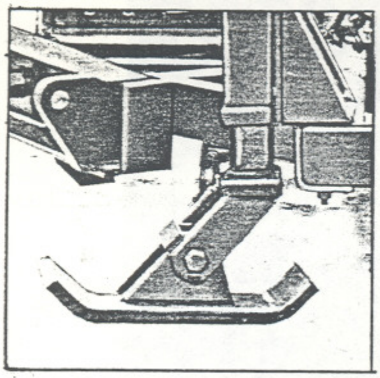


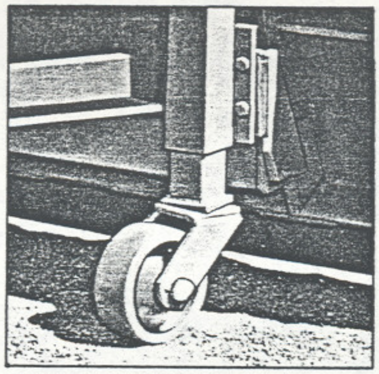
Figure 8. OSHKOSH truck with Vee plow.

Another area to be investigated is related to snow plow running gears which provide the vertical guidance to snow plow. The standard running gears are screw adjustable.

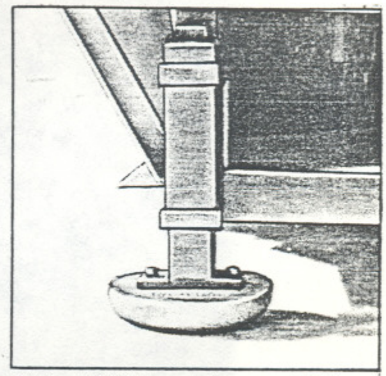
The types of available running gears are in Figure 9



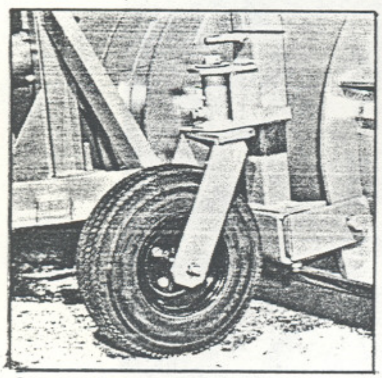
Screw adjustable shoes are standard equipment
1 × 6 shoes on 36R-30-47 one ways
1 × 6 shoes on 42R-39-52 one ways



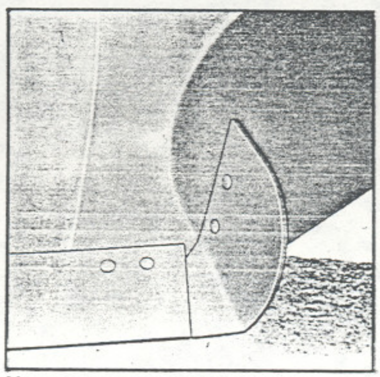
Optional 3″ × 8″ steel wheel fits shoe yoke



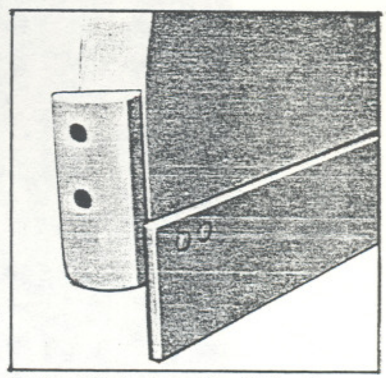
Optional 7½″ dia. mushroom or 11½″ dia. mushroom



Optional Screw adjustable pneumatic wheels



Nose guard for 6″ or 8″ cutting edge standard on all one way plows.



Optional Curb shoes. Specify 1 or 2 required

Figure 9. Types of running gears.

XI. STRATEGIC HIGHWAY RESEARCH PROGRAM

The National Workshop at Dallas/Fort Worth, Texas Airport in September 1985 has addressed the need for snowplow design research[4]. It was stated that the past practice generally treated plow design independently of the design and capabilities of the prime mover; plow and truck must be considered as a system for optimum performance. No scientifically-based design improvement efforts have been undertaken in the United States. Fundamental plow design improvements have resulted from studies in Sweden, Japan, Switzerland, Germany, and Great Britain, and are optimized for their particular conditions. With the exception of Japan, no work is currently underway, and the particular needs of U.S. maintenance engineers are not being addressed.

The need for this effort was identified as one of the four recommended by the Highway Maintenance Research Needs Workshop in 1974. No action has been taken to implement the recommendation for research on this topic, and the need still remains.

The objective of this research needs to be establishment of design criteria and preparation of design details and specifications for displacement plows based on aerodynamic/hydrodynamic principles, material handling characteristics of snow, and ice cutting mechanics leading to standard designs for different types of snow and climatic conditions. Plow and carrier as a system for optimum design has to be considered.

XII. TRANSPORTATION RESEARCH BOARD RESEARCH ACTIVITIES

The Transportation Research Board Committee on "Winter Maintenance" is concerned with all aspects of snow and ice removal including snowplowing and disposal procedures. From the recent discussions with David Minsk, the chairman of this committee, it appears that snowplowing is only a small part of these activities which are not to be initiated earlier than the Fall, 1986.

XIII. SNOW PLOW MANUFACTURERS

The following manufactureres were identified and located within the United States:

Henke Manufacturing Corporation
P.O. Box 818
2105 E. Bremer Avenue
Waverly, Iowa 50677
319-352-5150

Schmidt Engineering and Equipment
4703 W. Electric Avenue
Milwaukee, Wisconsin 53219
414-672-2229

Viking Manufacturing Company

P.O. Box 218

Harrisville, New York 13648

315-543-2321

XIV. CONTACTS MADE

All of the three manufactures have been contacted and requested to provide any available information on the state-of-the-art of snow plow design.

Henke Manufacturing Corporation has been visited by Rudy Kolaja, of the Arizona Transportation Research Center on April 11, 1986. The other two manufacturers did not provide any information on snow plow design except the location of the close-by dealerships.

David Minsk of U.S. Army Gold Regions Research and Engineering Laboratory, 72 Lyme Road, Hanover, New Hampshire 03755, Phone No. (603) 646-4474, has provided information about the TRB research project on "Winter Maintenance".

Dave Green, OSHKOSH Truck Corporation, Wisconsin, Phone No. (414) 235-9150, has been contacted in regard to sizing the snow plow trucks in relation to different types and sizes of snow plows. He stated that determination of proper truck-plow combinations is highly theoretical and needs to be investigated. In most cases the capital and operating cost of ideal trucks for snow plowing is excessive, since these trucks are used on average only between 120-200 hours a year.

XV. SUMMARY AND CONCLUSIONS

Design and manufacturing of snow removal equipment has changed very little since the 1930's. No scientifically-based design improvement efforts have been undertaken in the United States. Fundamental plow design improvements have resulted from studies in Sweden, Japan, Switzerland, Germany, and Great Britain, and are optimized for their particular conditions.

The recent tests of snow plows by Henke Manufacturing Corporation seem to provide solutions to some of snow plowing problems experienced by ADOT. Truck driver visibility can be improved as well as overheating of truck engines during snow plowing can be eliminated by proper cutting edge lay back angle and moldboard intercepting radii of the plow. Effective and smooth discharge can be accomplished using discharge wings, called "mouse wings" on reversible plows.

Automatic quick coupling system made by Henke provides a high versatility of the snow plowing equipment. Load sensing hydraulic system is under development by Henke.

OSHKOSH Truck Corporation is manufacturing a range of trucks suitable for snow plowing.

XVI. RECOMMENDATIONS

A demonstration project in cooperation with a manufacturing company such as Henke and OSHKOSH utilizing the results of the described up-to-date technology and the knowledge is being suggested. Proven technology by this project could be adopted by ADOT to improve the current snow plow removal activities.

The following aspects of snow plowing technology appear to be deficient and further research is suggested:

1) Determination of optimum size and horsepower of snow plow truck size and type of snow plow.

2) Determination of optimum snow plow radii under a variety of snow conditions and truck-plow combinations.

3) Investigations of snow plow trip systems in relation to types of plows and truck sizes.

4) Investigation of a variety of snow plow running gears and determination of optimum types in relation to snow plowing conditions, type of roadways etc.

5) Economic analysis of ideal and optimum snow plows, snow plow trucks & their operations determined appropriate for ADOT use.

XVIII. LIST OF REFERENCES

1. David L. Richardson, "Manual for Deicing Chemicals: Application Practices", National Environmental Research Center, U.S. Environmental Protection Agency, Cincinnati, Ohio, December 1974.

2. "Snow Removal and Ice Control Research", Proceedings of the Second International Symposium, Hanover, New Hampshire, 1978, Sponsored by TRB.

3. "Snow Plowing Visibility Improved with Turning Vanes Mounted to Plows-Cabs", Better Roads, Volume 45, No. 7, July 1975.

4. Strategic Highway Research Program, National Workshop, Dallas/Fort Worth, Texas Airport, Participant Workbook, September 18-20, 1985.

5. Snow Plow Research, Public Works, September 1985.

6. Snow Removal and Ice Control Research, Proceedings of an International Symposium held April 8-10, 1970, Special Report 115, Highway Research Board.