

**FINAL REPORT OF SNOW PLOW CUTTING EDGE
TEST AND EVALUATION (T & E) PROGRAM,
FHWA WORK ORDER DTFH71-96-TE028-IA-43**

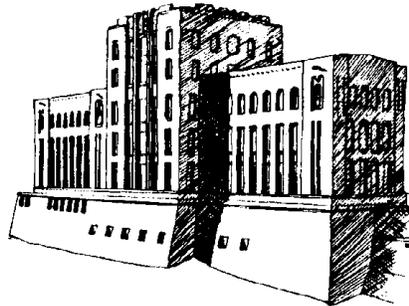
By

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For

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ABSTRACT

During the winters of 1996-97 and 1997-98, as part of an FHWA Test and Evaluation Program, two front mounted plows and two underbody plows have been instrumented so that the snow and ice scraping loads could be measured. These plows were used during standard snow and ice clearing operations. Three different cutting edge types were tested: One standard cutting edge, and two cutting edges designed according to the guidelines developed under SHRP Project H-204A. The two SHRP cutting edges are distinguished by the hardness of their carbide inserts. One has a carbide insert with a regular hardness (Rockwell A 87.5 to 89.0), while the other insert is somewhat softer than normal (Rockwell A 87.0 to 88.0). During each storm event, two different cutting edges were to be tested, so as to give direct comparisons. Information on plow routes, weather conditions, and operator observations were recorded for each plowing event.

INTRODUCTION

For those geographical regions of the World that experience winter weather on a regular basis, the removal of snow and ice from roads is a critical and costly task. Heavily traveled roads must in general be cleared of snow and ice rapidly after the onset of a winter storm, both for safety reasons and for economic reasons.

Studies have shown (e.g. Hanbali, 1994) that the number and severity of accidents often increases with the onset of a winter storm. Appropriate winter highway maintenance can improve road safety by maintaining appropriate friction levels on the pavement surface by the three methods of scraping and/or plowing, application of chemicals, and application of abrasives. Additionally (Nixon, 1997) there is some evidence that winter weather increases trip times significantly. This can be deleterious both for the individual motorist who may be late for work or otherwise inconvenienced and also for industry in general. In an effort to improve efficiency, manufacturing industries are increasingly making use of “just-in-time” practices, in which the road essentially serves as a warehouse. In keeping with these concerns, industrial representatives have indicated (Forkenbrock et al., 1994) that a reduction in transit times between two points is less beneficial than an increase in the predictability of travel times between two points. Put more simply, a decreased standard deviation on travel time is preferable to a decreased mean travel time. Improved winter highway maintenance would lead to a decrease in the standard deviation of travel time and would thus be of significant economic benefit.

In seeking to improve winter highway maintenance an additional concern must be addressed, namely the environment. There is increasing concern about how de-icing chemicals and abrasives may have a deleterious effect on the environment. This means that usage of these chemicals and abrasives will be limited, and other methods of winter maintenance must be improved. This means that plowing and scraping must become more efficient.

However, before scraping and plowing can be made more efficient, a means must be developed to measure that efficiency. Ideally the method developed must be easy to

use, reliable, and capable of providing repeatable results. It should not require expert handling, but rather should be able to be placed on regular winter maintenance equipment and be used with minimal additional training and effort by the regular plow operators.

The method used to determine the efficiency of a plow is measurement of the plowing load. The choice of the load to measure efficiency is not without problems, but experiments both in the laboratory (Nixon and Chung, 1992; Nixon, 1993; Nixon et al., 1996; Nixon and DeJong, 1997) and in closed-road tests (Nixon et al., 1993; Nixon, 1995; Nixon and Potter, 1996, 1997) have established that the horizontal scraping load is directly related to the amount of ice scraped by an underbody plow. Thus a higher load means that more ice is being scraped. It should be noted that this is not the case for snow removal. When plowing snow there is a minimal likelihood that the plow will rise up on top of the snow and bounce along the surface of the snow (unless the snow is heavily packed). However, in many situations a plow will do exactly this when plowing ice. Accordingly, for the limited situation of scraping ice (and perhaps packed snow) the horizontal scraping load may be taken as a good indicator of the quantity of ice scraped and thus of the effectiveness of the cutting edge.

The purpose of this study, then, has been first to instrument in-service trucks so as to measure the loads experienced by both the front plow and the underbody plow. Once instrumented, these trucks were used to measure the efficiency of three different cutting edges (described below). This second component was the main focus of the study. Figure 1a shows a typical cutting edge, in which the carbide insert is protected by a leading edge. In contrast, as shown in Figure 1b, the SHRP cutting edge design shows that the insert in the new design is exposed to shock loading. Figure 2 also shows the SHRP cutting edge, and the segmented nature of the insert is clearly visible.

The project experienced a number of difficulties. During the first winter (1996-97) no testing could be conducted because cutting edges were not delivered to the three participating states (Alaska, Iowa, and New Jersey) prior to the end of winter. This meant that the Phase I task of developing testing parameters using the instrumented plows could

not be carried out. To address this, a meeting was held at the 1998 Annual TRB Conference with the prime contractor, and the FHWA project manager. A representative from Alaska DOT was also present. Subsequent to this, Alaska DOT have now received the cutting edges and are testing them during the 1998-99 winter. They will report on their findings in Spring 1999.

INSTRUMENTATION

The two trucks used in this study were standard Iowa Department of Transportation tandem axle dump body trucks, with a Gross Vehicle Weight of 22,680 kg (25 Tons). They were based in the Oakdale Garage Facility, an Iowa DOT truck operations depot located about seven miles from Iowa City. This garage has the responsibility for maintaining parts of Interstate 80 and Highway 218, as shown in Figure 3. In so far as possible, the instrumentation was undertaken so that the trucks were essentially unchanged from the viewpoint of the operator. Each truck still had a second

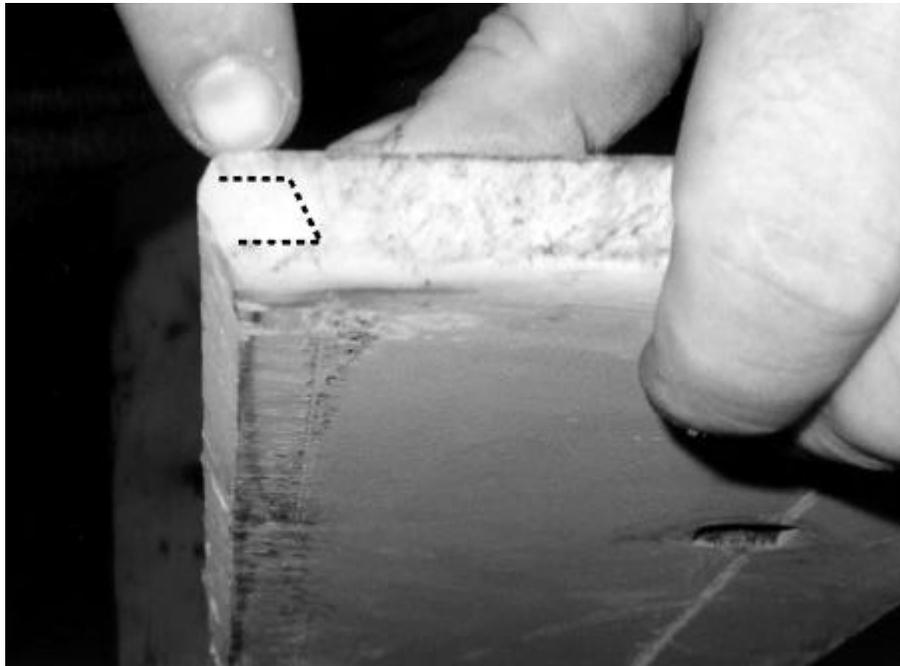


Figure 1a. Typical cutting edge with carbide insert protected by a leading edge.



Figure 1b. SHRP cutting edge, with exposed carbide insert in leading edge.



Figure 2. Segmented nature of the carbide insert in the SHRP cutting edge.

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Figure 3. The highway sections in which the testing trucks operate.

seat in the cab, and all electronics associated with the instrumentation had to be stowed beneath this seat, which placed fairly rigorous size constraints on the instrumentation package. Each truck has two operators assigned, and all four operators were instructed in the process of turning on and off the data collection system. The operators were extremely co-operative during this exercise, and the researchers extend their thanks to them and to their supervisor. Operators were instructed that they should, as far as possible, use the trucks as they normally would, in keeping with road and weather conditions. After each run in which data were collected, operators noted conditions, date and time in a simple log book.

Underbody Plow

The underbody plows were instrumented as described in Nixon and Potter (1996, 1997). The two main hydraulic cylinders shown in Figure 4 provide the down-force to the underbody plow. The third cylinder (there are two cylinders linked so that only one control is required) controls the rotation of the plow. The plow has a vertical range of

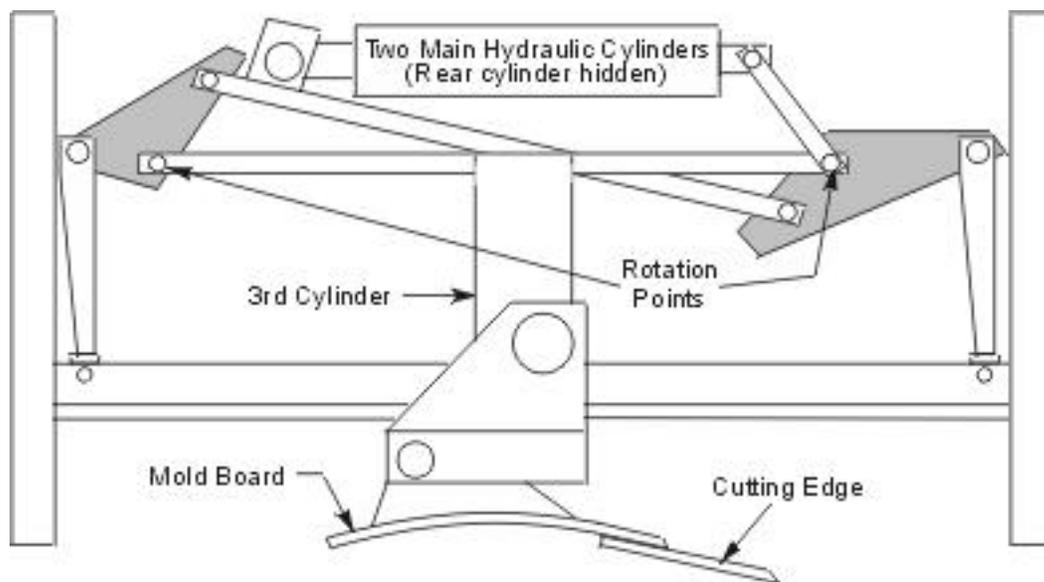


Figure 4. Schematic side view of the hydraulics that control the underbody plow. Activating cylinders are shown.

movement of about 15 cm, and can rotate through 60°. Figure 5 shows the actual underbody plow. The cutting edge is clearly visible, and the inclinometer is mounted in the circular metal container.



Figure 5. The actual underbody plow, showing both cutting edge and the inclinometer.

Three pressure sensors were located in the hydraulic lines going to the two main cylinders and to the third cylinder. These sensors had a capacity of 0 - 24 MPa (0 - 3,500 psi) and gave a linear output signal of 0 - 5 V. The inclinometer had a range of 0 - 90° and gave a linear output of 0 - 10 V. The data from these sensors were recorded using a CardCorder data logger (manufactured by Cranfield Impact Centre Ltd.). These data loggers are small (and can thus fit under the truck seat as required - see above) and rugged, having been originally designed for use in racing cars. The data loggers could record data at up to 1,000 Hz, and had a storage capacity of 1 Mb, on a special memory card. After testing, the card was removed from the data logger and transferred to a PC by using a PCMCIA card reader.

Clearly calibration of the system is critical to obtaining useful results. In a previous study (Nixon and Frisbie, 1993) considerable effort was expended to develop an effective calibration system, using portable hydraulic pumps capable of applying known loads to the underbody plow. Both trucks were calibrated on a number of occasions, and consistently produced linear and repeatable relationships between the applied force and the voltage from the pressure sensors. The inclinometers were more easily calibrated using an electronic protractor. This relationship was also linear (Potter, 1996).

The instrumentation for the underbody plow has now been used on a number of different vehicles under a variety of conditions. While not deployed throughout a fleet, it has now reached a point at which it may be considered a relatively mature technology, in so far as instrumenting an underbody plow is now no longer a research project in and of itself.

Front Mounted Plow

Measuring the forces on a front mounted plow is considerably more complex than measuring those on an underbody plow, primarily because the front plow (when used with a standard U.S. hitch) floats over the surface. That is, it is not forced down onto the road surface, in contrast with an underbody plow. Accordingly there are only two approaches that can be used to determine the forces experienced by a front mounted plow as it is used to plow ice or snow. The plow may be instrumented with strain gages to determine the strain induced in the plow by the plowing action. Alternatively, the accelerations experienced by the plow may be determined (using accelerometers). By relating these accelerations to those of the truck and the plow carrier (or hitch) the forces acting on the truck may be determined (Nixon et al., 1997). The approach chosen for this study was to use accelerometers. The primary reason for this choice was that attempts to use strain gages in prior experiments (as part of the SHRP H-206 project) experienced significant problems.

The vehicle was instrumented with twelve accelerometers, as shown schematically in Figure 6. Figure 7 shows the plow itself. Figure 7a shows how the accelerometers are mounted and connected. The metal boxes (seen close up in Figure 7b)

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Figure 6. Schematic diagram of the truck, hitch, and front plow, showing accelerometer location. Each accelerometer is identified by a letter. Thus, accelerometer A is mounted on the plow, and measures vertical acceleration.



Figure 7a. The front plow, with accelerometers mounted in the metal boxes.



Figure 7b. Detail of the protective mounts for the accelerometers.

contained the accelerometers, and the gray cable containers carried the wiring between the accelerometers. These protective measures did work, in so far as there were no difficulties experienced with damaged accelerometers or cabling. However, occasional loose connections proved troublesome, and as noted below, one non-functioning accelerometer effectively renders a complete test run useless.

Using appropriate free body diagrams (see Figure 8a for the Plow and 8b for the Plow Hitch) appropriate equations can be developed which allow the forces acting on the plow to be determined from the accelerations. While it is possible to determine loads on the plow from the accelerations alone, this can lead to significant errors. This problem of error accumulation can be avoided if the length of the spring between the carrier and the plow is known (see Figure 9). Accordingly, in more recent tests, the force in this spring was measured so that useful load data for the front plow could be obtained.

Cutting Edges

Three different cutting edges were used in this experiment. Two had the cross-sectional shape developed in the SHRP H-204 A Project (Nixon, 1993) and shown in Figure 10a. These cutting edges have a carbide insert that is situated on the leading edge of the cutting edge. The two cutting edges with this cross-section were differentiated by the hardness of the carbide insert. For the first cutting edge, termed cutting edge A, the insert has a hardness of between 87.5 and 89.0 on the Rockwell A scale. The second cutting edge, termed cutting edge B, has a softer carbide insert, with hardness between 83.3 and 87.5 on the Rockwell A scale. The third cutting edge used a standard shape, as shown in Figure 10b. The insert for this edge had a hardness of between 87.5 and 88.2 on the Rockwell A scale. All three cutting edges were manufactured by Kennametal, a company based in Latrobe, PA.

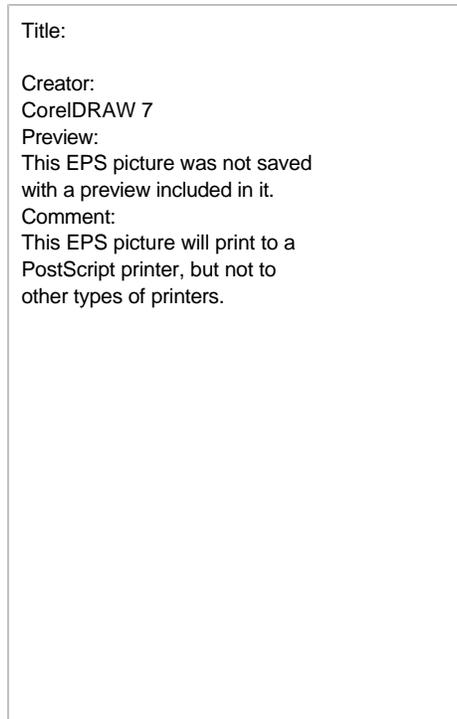


Figure 8a. Free body diagram for the plow, showing forces and relevant dimensions.

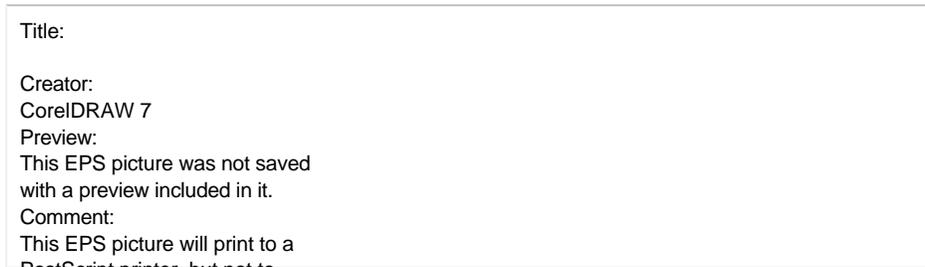


Figure 8b. Free body diagram for the plow hitch, again showing forces and relevant dimensions.

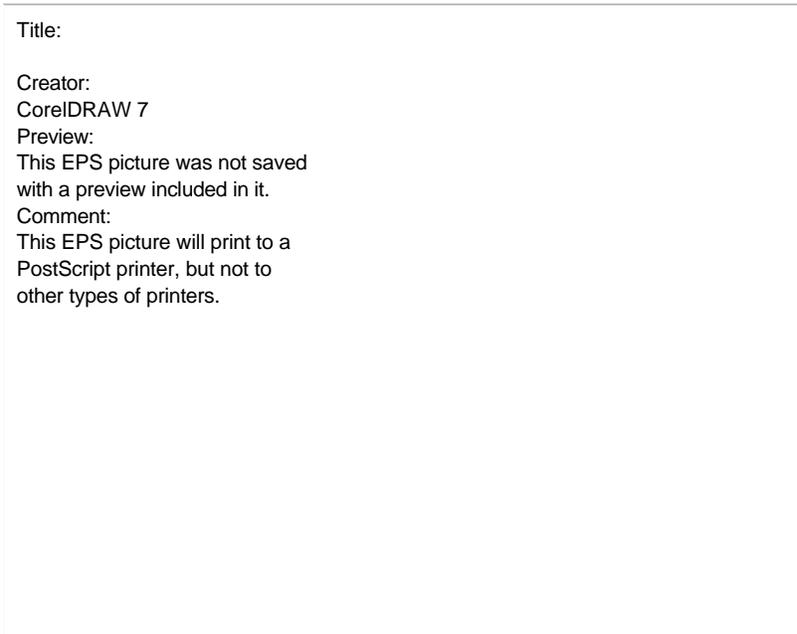


Figure 9. Schematic representation of the connection between plow and hitch, showing the length of the restoring spring.

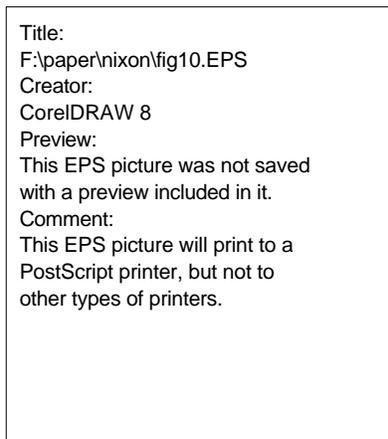


Figure 10. Cross section of cutting edges used. The SHRP blade (10a) came with two types of insert, one soft, the other harder. The regular blade (10b) had only one insert hardness.

RESULTS AND DISCUSSION

The results of this study must be considered disappointing, because of considerable, and ultimately unsolved difficulties with the data acquisition system. In essence, the job of collecting data from twelve accelerometers and one load cell (to measure the front plow loads) proved too complex for field deployment. The CardCorder failed repeatedly, and when it could be made to work, other difficulties with the accelerometers precluded a complete data record being assembled. Without data from all accelerometers and the load cell, the scraping loads cannot be determined.

In total, attempts to measure loads were made during twenty-one different storms. After each data collection attempt, operators would remove the data card from the CardCorder, and take it to a computer that was equipped with a card reader. The data were then downloaded to the computer, and subsequently collected by University of Iowa personnel for evaluation and analysis.

The complexity arises from having to have so many different sensors operating flawlessly in a very hostile environment. As noted above, the protective measures taken did work, but loose connections proved to be a major difficulty. The vibrations associated with plowing clearly require a very rigorous connection scheme that was not available through the equipment gathered for this project. In future studies of a similar type this must be kept in mind.

Figure 11 shows a typical load trace for the horizontal and vertical loads from an underbody plow (using a standard cutting edge). The relationship between vertical and horizontal loads shown on this trace is typical, in that the horizontal load is a fixed fraction of the vertical load. The horizontal load reflects the thickness of ice or compacted snow being removed from the pavement. In general, the higher the horizontal load, the more ice is being scraped. The vertical load reflects the effort required to keep the cutting edge removing ice. Previous limited testing with non-standard cutting edges, conducted in closed road situations, have shown that the ratio of vertical to horizontal forces can be

reduced by using a cutting edge shaped like the SHRP cutting edge. However, the endurance of such shapes is far from clear, as noted above.

One of the aims of the T&E project was to lower the ratio between vertical and horizontal forces for the underbody plow. A lower ratio implies more efficient removal of ice. Clearly, examining only one trace does not allow for comment on improvements in efficiency. As noted above, insufficient data were collected to allow for any detailed comment or insight on this issue that goes beyond that found in previous studies.

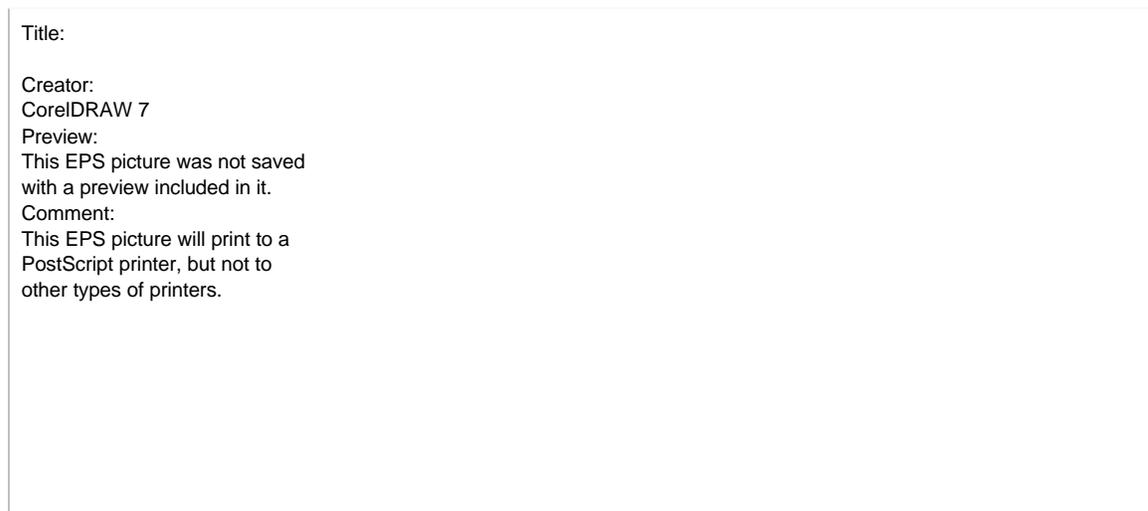


Figure 11. Load trace for horizontal and vertical forces from the underbody plow blade.

Figure 12 shows an example of the accelerations obtained for the front mounted plow (these readings came from the accelerometer D on the plow - see Figure 6). However, these individual data traces on their own are insufficient for a full determination of scraping loads. The value of the reading of a single accelerometer is only realized when the data are combined with all other accelerations, to determine the forces acting on the vehicle (and most especially the plow). This was one of the frustrations of the project. The failure of a single sensor essentially caused failure of the whole test run, since even if all other sensors worked, no meaningful data could be obtained without the data from the failed sensor. Each sensor provided a critical value for solving the force-acceleration

equations. Clearly, obtaining and placing redundant sensors on plow, hitch, and truck could solve this problem. Time and budgetary constraints did not allow this to be done. Given this, no direct comparison of scraping forces between the three cutting edges can be made, and thus no objective recommendation is possible.

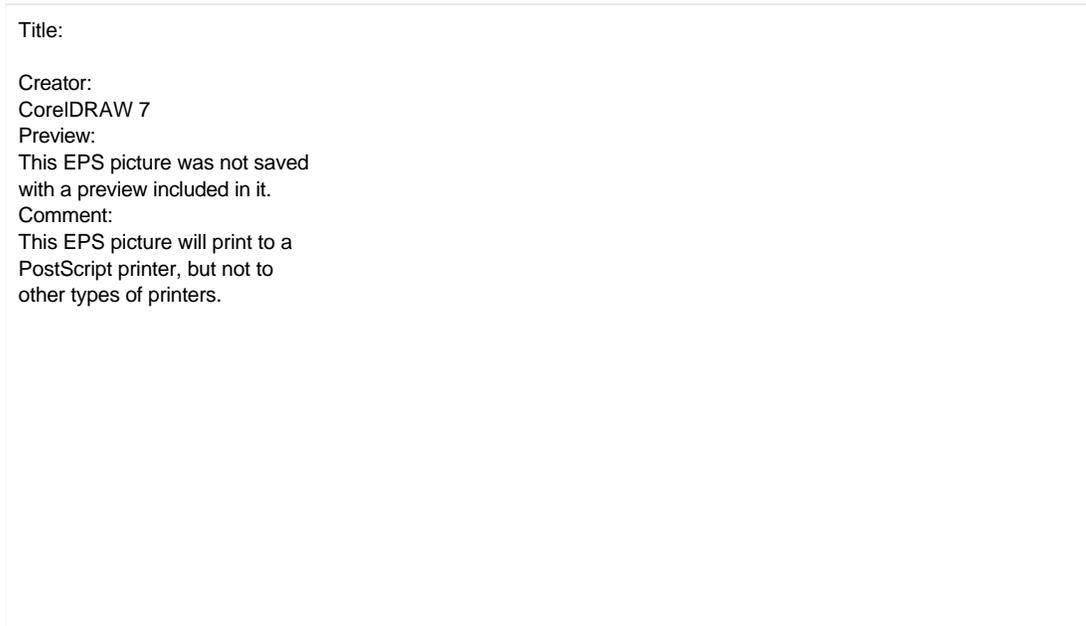


Figure 12. Typical data trace from an accelerometer mounted at position D on the front plow.

Personnel at the Iowa DOT Garage expressed considerable concern about the durability of the new cutting edge design. It was their opinion that this design would not be sufficiently durable for field operations.

This opinion was based on limited experience using the new cutting edge shapes. Iowa DOT personnel found that the cutting edges exhibited failure in one of two ways. Carbide inserts could be broken away from the cutting edge, due to their exposed position on the front of the cutting edge. In addition, wear of the carbide was relatively rapid (in comparison with the regular blades) such that the new cutting edges were worn out after one event's plowing. In this context, an event is one storm. However, the actual distance traveled by a truck in a given storm is not known, since the route for that plow may have

been traversed more than once during a storm. Nonetheless, the anecdotal evidence of the operators suggests that the SHRP design wore out more rapidly than the standard carbide insert cutting edge. It should be noted that these observations did not include tests with the softer of the carbide inserts. This may be important, since this softer insert was designed to avoid damage due to shock loading that appears to have caused the breaking away of the carbide inserts.

The major error with the approach taken herein has been to go from a research-based program (Nixon et al., 1997) to a field deployment of the same system. In the tests reported in Nixon et al., the truck scraped over distances on the order of 100 meters. This is clearly much shorter than a route of several tens of kilometers. A system that could be nursed along for short duration tests was not adequate to the additional rigors of field deployment. The equipment failed to perform as expected, or as required. In short, while it was stated above that “instrumenting an underbody plow is now no longer a research project in and of itself,” the same statement is far from being true for front mounted plows.

Insofar as lessons can be learned from a failed experimental program such as this, the following points are offered.

- Field instrumentation should be as simple as possible, especially if it is to be used in real world situations. In such situations, equipment must be expected to operate for a complete shift without adjustment, resetting, or any other operator involvement. This was clearly not the case for the front plow instrumentation.
- Electronic equipment, especially data loggers (without which no experimental data will be collected) should be carefully specified and rigorously tested prior to acceptance by the investigating party. Many of the difficulties in this project stemmed from a data logging system that failed to perform to project specifications. This was a result of trying to save money and remain within budget by going with a minimally capable

unit. In future studies, it may be that specially designed equipment is required for such a hostile environment.

- It is especially important when dealing with a situation in which only a limited number of events over a relatively short period of time can be measured, that researchers should have contingency plans established prior to the start of the program to deal with unexpected problems that arise, so that useful data can still be obtained. In this case, it would have made more sense to proceed with gathering data on the underbody plows alone, rather than continuing to struggle with the front mounted plows.
- The project was probably over-ambitious, in that it reached beyond the capabilities of present instrumentation technology.

CONCLUSIONS

As noted above, two trucks were instrumented with the intent of measuring scraping forces for both front-plow and underbody plows in full deployment. Due to equipment and data acquisition failures, no successful and complete load measures were made, and thus it is not possible to directly analytically compare the three cutting edges. To achieve useful information in studies of this nature, it is important that sufficient time be allowed in the project. In this case, two winter seasons were insufficient to develop a novel instrumentation method, work out the difficulties of using the new method, and then gather useful field data. This time factor should be a major consideration in future field studies.

ACKNOWLEDGEMENTS

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presented in this paper are those of the authors and are not necessarily those of the Federal Highway Administration.

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