A COMPARISON OF THE DIGITAL RESISTOGRAPH WITH THE RAM PENETROMETER

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ABSTRACT

The digital resistograph (DR) is a microprocessor-based probe which is used to rapidly obtain strength index profiles similar to the profiles obtained with the ram penetrometer. The current version of the DR can collect as many as 500 strength profiles in a work day. In this study the DR is compared to the ram penetrometer for repeatability, learnability and ease of use. Additional studies were conducted to determine just how sensitive the DR readings are to penetration rate. The test results did show that the instrument has a repeatability at least as good as the ram penetrometer. The DR has a decided edge in terms of learnability. Two novices were found to give roughly the same DR profiles after a minute of instruction, whereas the ram penetrometer is widely known to show a wide range of results when used by novices. One of the the primary problems with the DR was durability, as the instrument frequently malfunctioned and failed to work properly in cold conditions. The DR shows much promise for becoming a substantial improvement over the ram penetrometer, provided a more reliable and durable version can be engineered.

INTRODUCTION

The ram penetrometer has for many years been the standard instrument for obtaining strength profiles of alpine snow cover (Perla and Martenelli, 1975). Once mastered, the instrument can give repeatable strength profiles in typical alpine snow. However snow cover with thin weak layers or ice crusts always posed a problem for all but very experienced users. In addition an instant profile plot could not be obtained, since the strength index had to be calculated and then plotted by hand. Typically two persons were necessary to obtain the profiles, as one would operate the probe and

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hammer while the other recorded the data. In spite of these shortcomings the ram penetrometer proved to be a simple, durable and reliable instrument which in the hands of an experienced operator provided repeatable profiles of snow cover strength.

C. C. Bradley (1966) later developed the resistograph in an attempt to resolve some of the shortcomings of the ram penetrometer. This instrument could produce a graphical plot of the strength profile which could be instantly reviewed in the field. In this way it helped the field person make an on-site stability assessment, something that could not be done with the ram penetrometer. In addition the resistograph could obtain profiles considerably more quickly than with the ram penetrometer. Some disadvantages included user sensitivity, an appreciable learning curve, an a significant weight factor which affected its portability. As such it did represent a significant improvement over the ram penetrometer. However, its weight and cost prevented it from becoming widely accepted as a field instrument.

The digital resistograph (DR) was recently developed in an attempt to obtain an instrument which could quickly provide strength profiles similar the ram penetrometer (Dowd and Brown, 1984). The primary motivation was the development of an instrument which could digitally store the profiles and allow rapid and repeated profiling and instant graphical display of strength profiles in the field. In addition it was designed so that the data could later be off-loaded to obtain hard copies of the profiles. The original instrument developed by Dowd and Brown (1984) satisfied all of these requirements. However this original model could only store about 25 profiles, and the data could not be conveniently off-loaded onto a personal computer. Rather it was designed to loaded directly onto an X-Y plotter, but this was a very time consuming process. In a research study by Karl Birkeland on strength distributions in avalanche paths (Birkeland et al, 1990), a very large number of strength profiles (on the order of 1000 profiles) was required in the span of a few days, thereby necessitating an instrument which would have much larger memory and faster data transfer to permanent storage for later analysis. This resulted with the development of a second generation instrument. The instant plot feature was dropped from this second model, since this feature could not be developed in time for the 1988-89 winter season. The second model did include a more advanced microprocessor and EPROM (erasable programmable read only memory) moldules which could be plugged into the DR and could store up to 150 profiles. These could quickly be unplugged and a new one installed to continue profiling. As many as 500 profiles could be made in one day, thereby making this an excellent research instrument.

This study was conducted in order to determine if a microprocessor-based penetrometer such as the DR could provide strength profile information with good accuracy and reliability. The standard against which the DR was compared was the ram penetrometer, since this is the most widely used instrument. Measures of the instrument performance included repeatability, learnability, sensitivity to insertion rate, durability and reliability. These last two criteria are determined by the way the instrument is engineered so that it operates properly under a wide variety of conditions and can withstand sustained use.

Repeatability is a measure of how closely the instrument can reproduce profiles when used repeatedly in identical snow covers. This is not necessarily a measure of accuracy, since profiles taken directly adjacent to each other may give very similar profiles yet fail to reflect the actual snow cover stratigraphy. At the same time, spatial variability in natural snow cover makes this test somewhat difficult to perform with absolute confidence that two adjacent profiles are actually measuring identical stratigraphies.

Learnability is a subjective measure of the ease with which the instrument can be learned. The ram penetrometer is an instrument that requires practice before one can use it in a wide variety of snow covers and feel confident that a good measure of the actual strength profile is being obtained. Expert instruction, of course, decreases the learning time, but for most field personnel, mastering this instrument requires practice. As with the measure of repeatability, the assessment of learnability is subjective, and any comparison with other instruments such as the ram penetrometer will reflect the user's own preferences.

Sensitivity to insertion rate is a measure of how the instrument readings will change with the rate at which the penetrometer is pushed through the snow cover. Previous studies by Dowd and Brown (1986) indicated that the readings produced with the DR were not significantly affected by the insertion rate, but this previous study did not include insertion rates approaching one meter per second.

The study in the 1988-89 winter was conducted late in the winter on Bradley Meadow in the Bridger Range. Due to the winter weather, the snow cover had an uncomplicated stratigraphy with only a few thin crusts or hard layers. The second study was performed late in the winter of 1989-90 just after a large storm event which produce approximately one meter of snowfall. The site was at the Bridger research site just north of Bridger Bowl Ski Area. This snow cover also did not have much layering but was substantially deeper than the previous year.

FIELD EVALUATION OF THE DIGITAL RESISTOGRAPH

Repeatability Studies: An earlier study (Dowd and Brown, 1986) had shown that, with an experienced operator, the DR could give reproducible results and that it provided excellent sensitivity to layering. To supplement these earlier studies a user with a moderate amount of experience (approximately 30 profiles over a five year period) performed multiple probes of late winter snow cover in both 1989 and 1990. The results of these evaluations are shown in Figures 1(a) and 2(a). The first study was done on Bradley Meadow and consisted of making four profiles space at 30 cm intervals along a straight line perpendicular to the fall line. From Figure 1(a), it can be seen that the three profiles shown there give very similar profiles, although some deviation begins to emerge below 140 cm for one of the profiles. It should be noted that one profile was terminated at 120 cm where a hard crust was situated, giving a false impression that this was the ground level. A fourth profile which is not shown was very similar to the three shown here. The standard error for the three profiles sown in Figure 1(a) was found to be E = 9.16. The standard error is determined by the expression:

$$E = \frac{1}{N \cdot M} \sum_{j=1}^{N} \sum_{i=1}^{M} \left| R_{ji} - R_{ave_i} \right| \qquad (1)$$

N is the number of profiles taken, and and M is the number of points in each profile where the strength was measured. R_{ji} and R_{avei} are, respectively, the strength index of the j^{th} profile at the i^{th} data point and the averaged strength index at the i^{th} point. Ordinarily this would give a good measure of the repeatability of the strength profiles. However, if there occurs a shift in the depths at which specific layers occur between profiles, a large deviation between profiles can result even if the profiles look the same. Such shifts in position of layers can occur for a number of reasons, including variations in deposition, wind scour or drifting. Another probable cause would be operator error in the starting position of the penetrometer cone at the beginning of the probe. If the readings are averaged over the depth of the profile, the correlations look much better,

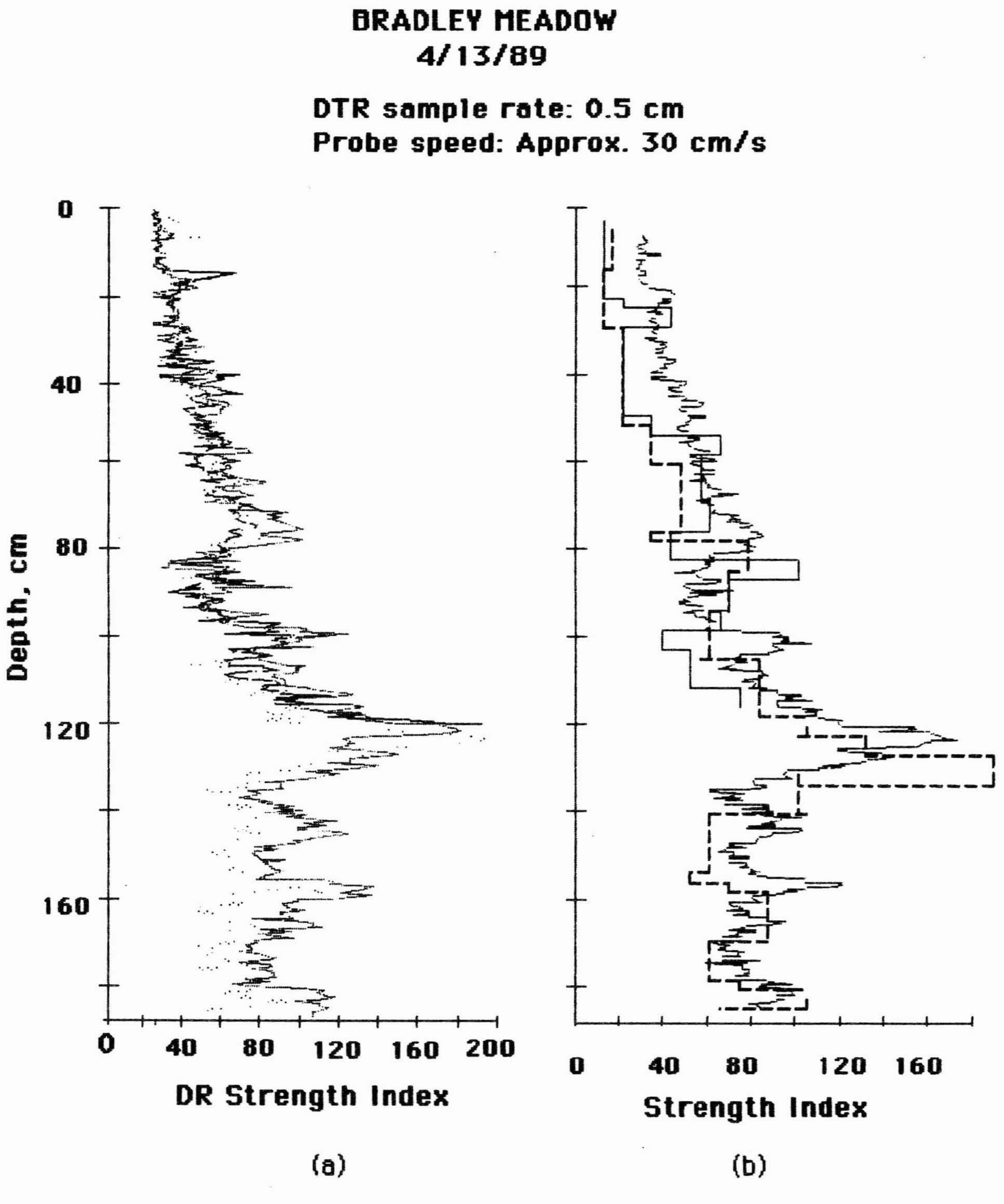


Figure 1. Profiles on Bradley Meadow. Part (a) illustrates three DR profiles taken in 30 cm intervals. Part (b) compares the average of the three DR profiles with two ram profiles taken directly adjacent to the DR profiles.

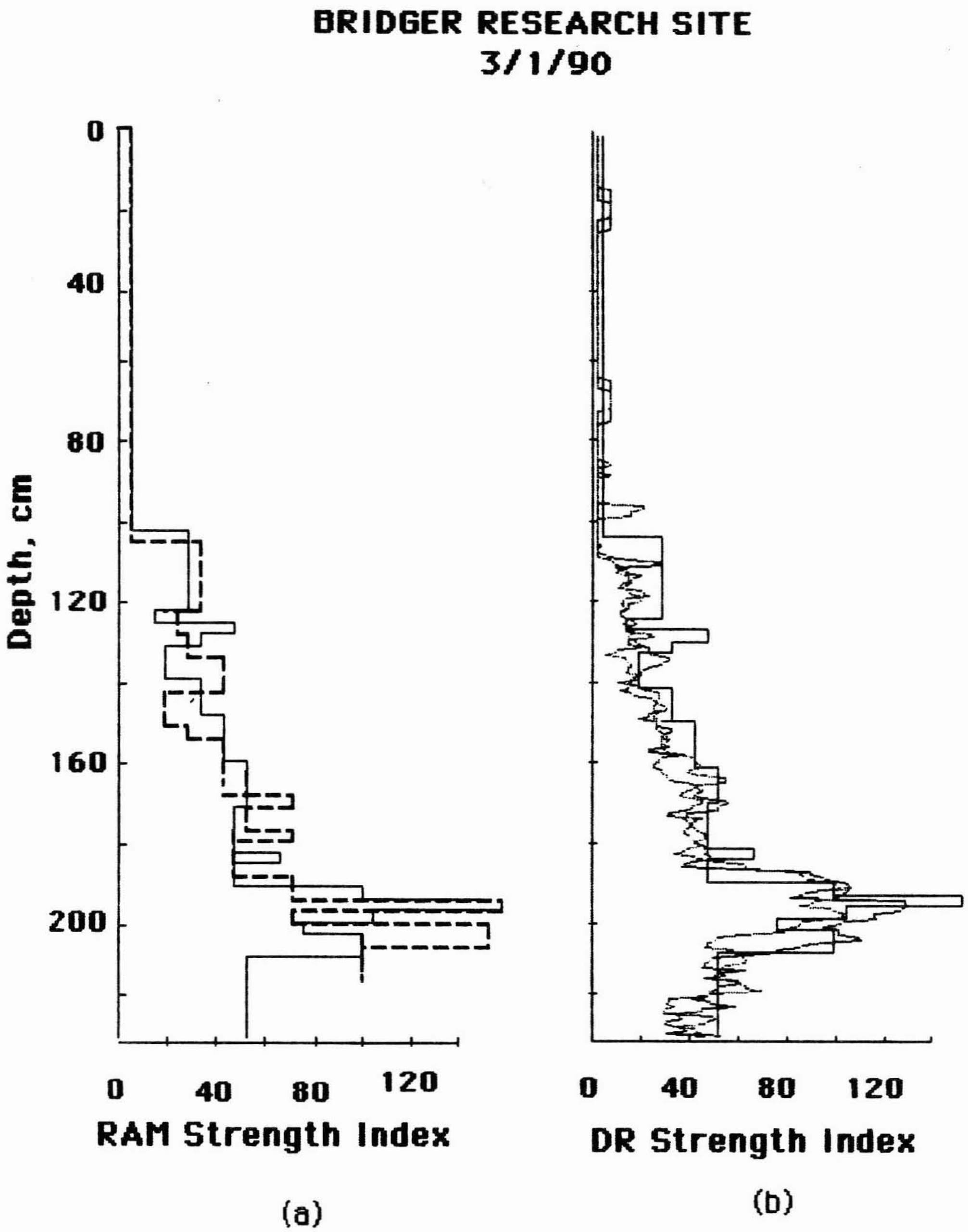


Figure 2. DR and ram profiles taken at the Bridger site. Part (a) illustrates two ram profiles taken within 30 cm of each other. Part (b) gives a comparison of two DR profiles with one of the ram profiles.

as any shift in depth of layering is averaged out. The three DR profiles had an average index of R = 56.9 over the first 120 cm with a standard deviation of D = 3.45. The ram profiles, which were taken directly adjacent to the DR profiles, had an average ram index of R = 47.3 with a standard deviation of 4.88 for the top 120 cm of the snow cover. The top 120 cm was chosen, since for both the DR and ram profiles, one profile was terminated at that depth. The lower average ram index appears to be attributable to the lower values in the top 60 cm of the snow cover. Between depths of 60 cm and 120 cm the two instruments gave very similar values.

For the Bridger profiles taken the following year, similar results were obtained. The three DR profiles taken at this site had an average strength index of 19.86 over the top 200 cm with a standard deviation of 0.37. The ram profiles gave an averaged ram index of 20.75 with a standard deviation of D = 0.42. The relative performance of these two instruments will be discussed later.

Speed Studies: Figure 3 illustrates the results of studies to determine the effect of insertion rate on the DR strength readings. Part (a) of that figure shows three profiles taken at different insertion rates. It can be noted that the general characteristics of the three curves are similar. Over the first 100 cm of penetration the profiles are so close that it is difficult to distinguish the three profiles. However below this level there is a significant shift with respect to depth for the fastest insertion rate. In fact all of the profiles experience increased deviations below 150 cm. This may be due to either spatial variations due to natural causes, the instrument or the operator. The mean DR strength indices for the three profiles was R = 86.8, 91.8, and 88.4, respectively for the slow, intermediate and fast speeds. The standard deviation for the three profiles was D = 2.56.

The speed studies conducted the following year at the Bridger site are of questionable value, as the DR did not appear to be functioning properly. During the profiling it was recorded the load value only every 4 cm rather than every 0.5 cm as it was programed to do. The reason for this is not clear. Figure 3(b) shows the profiles for the three speeds indicated. Only the top 125 cm are shown, since the DR stopped operating at that depth on the fastest profile. As can be seen, the correlation between the three profiles is very good until a depth of 105 cm is reached, where the fastest

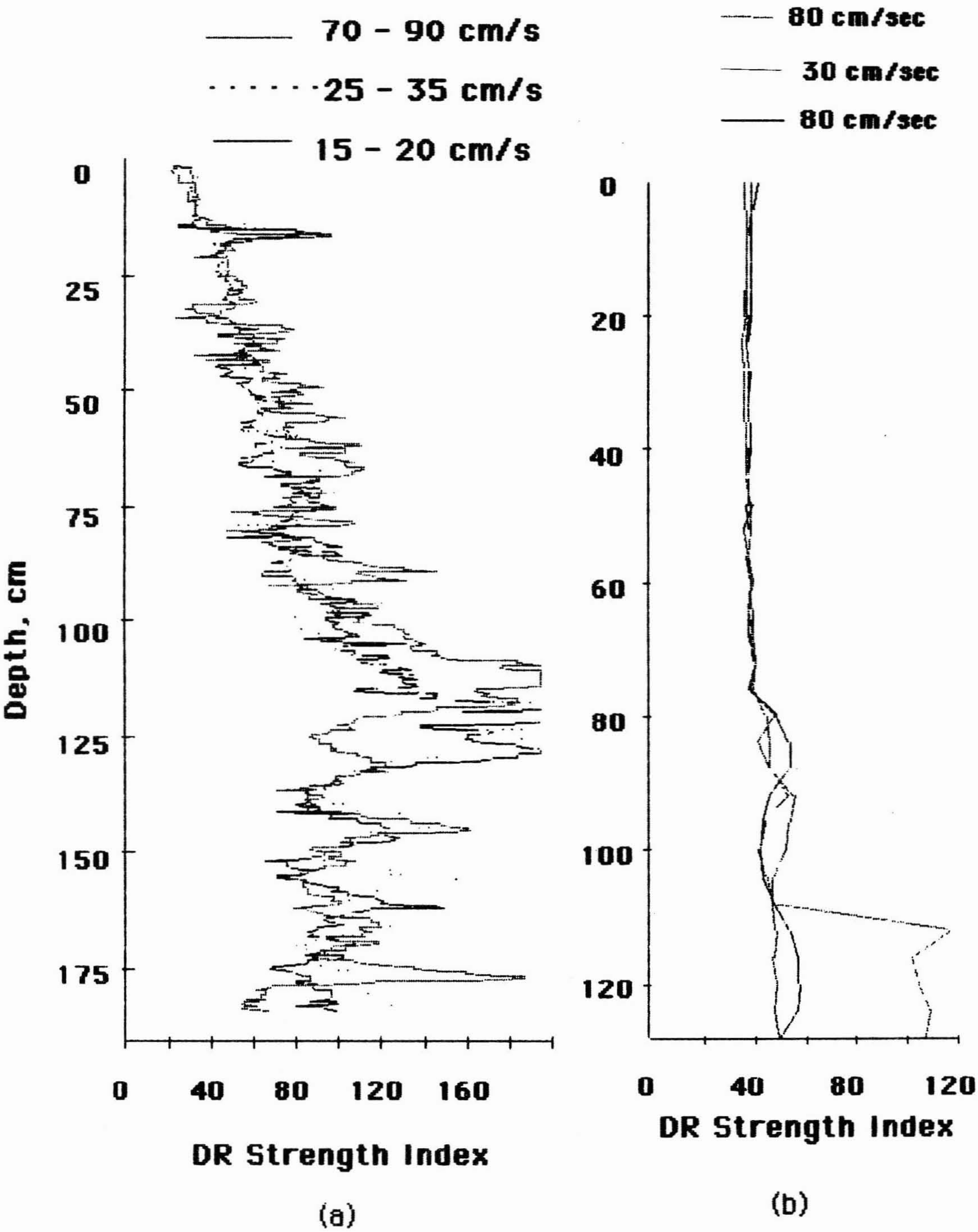
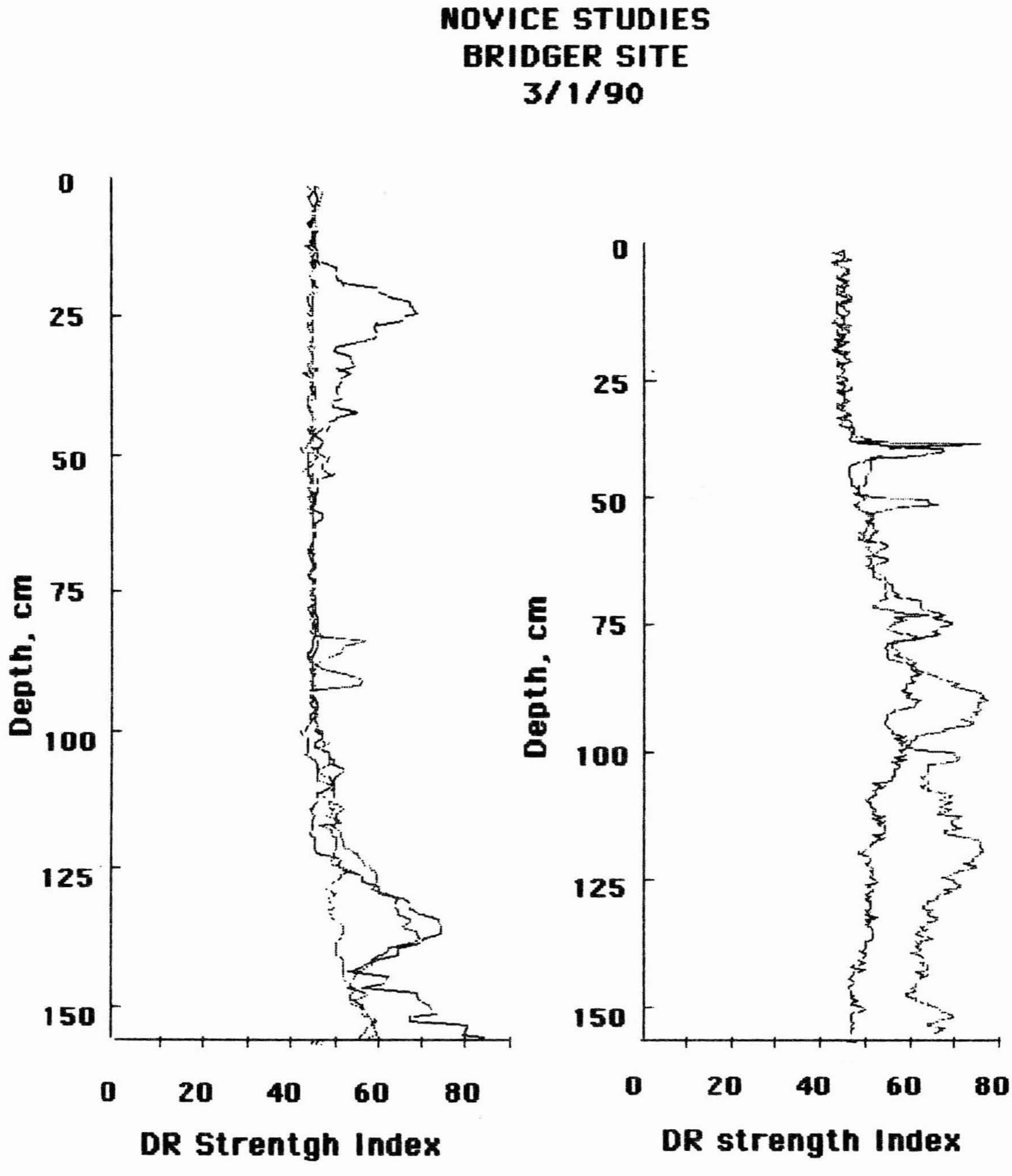


Figure 3. Speed studies for the digital resistograph. Part (a) shows results on Bradley Meadow (4/13/89), and Part (b) illustrates results of similar studies at the Bridger site (3/1/90).



(a) First novice

(b) Second novice

Figure 4. Profiles taken by two novices to assess variability of results obtained without formal instruction.

profile deviated substantially from the other two. It should be noted that the top 100 cm of snow cover was new snow from a recent storm and is therefore fairly uniform in properties. Consequently the test shown in figure 3(b) is not a particularly good evaluation, other than to say that penetration speed does not appear to affect the measured strength index under uniform snow stratigraphy.

Novice Studies: Figure 4 illustrates the profiles obtained by two novices at the Bridger site. Both operators had never used a DR before Just prior to making the profiles shown here they were given only about one minute of instruction on the use of the instrument. The penetration speed used by the novices were roughly about 30 cm/s, although the penetration speed probably varied considerably during profiling and between individual profiles. The operator for part (a) had a mean DR index of R = 49.7 for the three profiles with a standard deviation of D = 2.57, while the operator for part (b) obtained a mean index of R = 53.5 with D = 4.85. These values of standard deviation were larger than obtained by the operator (with moderate experience) for Figures 1 and 2.

DISCUSSION AND CONCLUSIONS

It has already been demonstrated that the DR does have the potential for becoming a very effective tool for evaluating slope stability and for use as a research tool. Among the major advantages are: (a) the ability to rapidly take profiles repeatedly, (b) instant display of strength index profiles in the field, and (c) digital storage in the field of a large number of profiles which can later be quickly off-loaded onto a personal computer for hard copies. The study performed here was done to determine if the DR could produce data of a quality similar to the ram penetrometer.

By observing Figures 1 and 2, one can see that the DR does have a finer resolution than the ram penetrometer for detecting subtle layering. One reason for this is that the DR uses a smaller cone than the ram. It will detect thin layers quite readily, whereas the ram will tend to punch through these small layers undetected, unless the operator is experienced and careful to work his way slowly down through the layering.

One annoying characteristic of the DR in its current configuration is the "jitter" displayed in the profiles. This is probably due to the fact that as it is pushed down through the snow cover, the snow structure experiences intermittent collapse adjacent to the cone. The current DR is programmed to measure the resistance every 0.5 cm. Consequently the resistance reading may at one time be made just prior to collapse and the next time just after the collapse of the adjoining snow, resulting with this jitter. This could readily be dealt with by programming the DR to read the resistance every 0.1 cm and average every five reading to smooth out the data that is actually stored in the DR memory.

In terms of repeatability, the DR and ram appeared to be equal in performance. Figures 1 and 2 show that they produced similar profiles, and the two instruments appeared to achieve similar correlation between successive profiles.

Insertion rate for the DR does not appear to be a problem. Figure 3 shows that there is no appreciable affect on performance for insertion rates between 10 cm/s and 50 cm/s. Above 70 cm/s there appeared to be some shift in the output. However this is a very fast rate of penetration and requires a concerted effort to consistently make successive profiles at this rate. The authors have found that rates on the order of 20-30 cm/s was more comfortable to use and could be done smoothly and consistently. This rate requires only a few seconds to complete a profile for normal snow cover depths in the Bridger Range.

In terms of learnability, the DR, like the ram penetrometer, requires a learning curve. We could not make a direct comparison with the ram, since we did not perform novice studies with the ram. As a consequence our conclusions will must be based upon our past experience in training novices in the use of the ram penetrometer. The DR, while appearing to be easier to learn, did show that one has to develop the technique of consistently inserting the DR through the snow cover at a constant and repeatable speed without any jerks or stops. Figure 4 shows the profiles of two novices who had no previous experience, whereas Figure 1(a) illustrates the profiles for an operator with moderate experience (about 30 profiles over a five year period). The two profiles shown in Figure 2(b) were also done with this same operator. These results do indicate that the DR can be operated in a reliable manner after a 30 minute practice session. In the view of the authors, this makes it somewhat easier to learn than the ram penetrometer.

A few words should be said about durability of the DR. In its current configuration the DR displayed a propensity to malfunction, so much so that it never could be used for more than several days without some problem arising. One problem was associated with the penetrometer tip containing the cone and load cell for measuring the cone resistance. The assembly would wear out after only 1000 to 1200 profiles. While this may seem like a considerable number of profiles, that number can actually be achieved in only three days of work. This significantly limited its value as a research instrument. Another problem was associated with the erratic behavior of the microprocessor and the liquid crystal display. Often the display would not function, and this could be attributed to low temperatures. The micro processor often did not record data in the appropriate manner, sometimes skipping data points.

In order for the DR to become accepted as a good field instrument, these problems will have to be corrected. This involves engineering the instrument so that the next design will have the reliability needed in a field instrument. Use of low temperature liquid crystal displays, mill-spec electronics and more durable (and properly sealed) load cells should correct these problems.

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