What Makes a Good Snow Fence?
Results From 12 Years of Testing
at the Ontario Ministry of Transportation

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ABSTRACT
A variety of new types of snow fences were introduced in the late 1970's and early 1980's, providing more possible ways to effectively and economically control drifting snow on highways. The Ontario Ministry of Transportation (MTO) began investigations in 1978 to determine whether the new products offered advantages over the standard wood slat fence and ought to be considered as alternatives to it.

Seventeen products were tested including vertical slats (wood and metal), polyethylene lattices, polyethylene, polyester and nylon nets, and horizontal straps of polyester and fabric.

No significant differences were seen among the fence types in the proportion of drifting which they intercepted nor the maximum volume of snow which they trapped. The vertical wood slat fence was superior to the other fences in terms of overall handling and installation properties and annual cost of use, and both the wood and metal slat fences performed best in the overall evaluation of durability.

The analysis also identified a minimum value of tensile strength (450 kg) and a maximum elongation (0.6% per kg of applied load) which should be met by snow fence materials.

INTRODUCTION
The Ontario Ministry of Transportation (MTO) has used snow fences for many decades to minimize localized visibility problems and snow accumulation due to drifting on highways. MTO typically erects snow fences on private land because the standard highway right of way is too narrow to permit accumulation of a snow drift without impinging on the road shoulder and pavement. The private land in most cases is used for agriculture, dictating that fences must be removed during the short period between spring snowmelt and crop planting, and reinstalled between harvesting and the first expected snowfall. This requires a large expenditure in labour as well as increasing the handling and consequent wear of fence materials.

A variety of synthetic snow fences were introduced to the market in the late 1970's and early 1980's which were believed to offer more effective and economic snow control. MTO began a testing program to determine whether any of the new types had advantages over the standard wood slat fence. Advantages would be accrued if alternative fences lasted longer, could be installed with less manpower, trapped more snow or stored the same volume of snow in a shorter drift which does not encroach on the road.

This paper reports on the findings of investigations over the period 1978-90 into the snow trapping capabilities, handling and durability properties, and the cost of a variety of new snow fence products.

TEST MATERIALS AND SITES

Fence types included in the MTO test program fall into four categories (Table 1):

* vertical slat (wood, metal)
* horizontal slat (polyester, impregnated fabric)
* lattice (polyethylene)
* net (polyester, polyethylene, nylon).

This includes the standard snow fence used at MTO (MTO, 1977) which is a vertical picket made from 3.8 cm (1.5 in) wide by 1.2 m (4 ft) long wood slats joined together by twisted wire. For comparative purposes the products are identified in Table 1 using a letter code.

MTO's tests were conducted at five locations in central Ontario: Cookstown, Barrie, Mount Forest, Horning's Mills, and Stayner. Fences were erected on private land outside of the highway right of way as part of the normal winter maintenance program. Site selection criteria included flat, featureless land with consistent ground cover and unobstructed wind fetch.

At each site, wood slat fences were installed adjacent to the test fences to provide a standard for comparison. All test fences were erected with a 20 cm bottom gap on steel T-posts or U-flange, following manufacturer's instructions for attaching the fence to the posts.

Table 1/ Snow Fence Evaluation Program

Type	I.D. Code	Height (m)	Material	Years Tested	Total
Vertical Slat	a	1.2	wood	all	12
	b	1.8	metal	81	1
Lattice	c	1.2	polyethylene	86, 87, 88	3
	d	1.2	polyethylene	81, 84, 85, 86, 87, 88, 89	7
	e	1.8	polyethylene	84, 85, 86, 88, 89	5
	f	1.2	polyethylene	86, 87, 88	3
	g	1.2	polyethylene	89	1
	h	1.0	polyethylene	79, 81, 84, 88	4
	i	1.2	polyethylene	86, 87, 88, 89	4
	j	1.2	polyethylene	81	1
Net	k	1.2	polyethylene	89	1
	l	1.2	nylon	78, 79	2
	m	1.2	polyester	83	1
Horizontal Slat	n	1.2	polyester	86, 87, 88	3
	o	1.8	polyester	88	1
	p	1.2	impregnated fabric	88	1
	q	1.8	impregnated fabric	88	1

APPROACH

The fences were evaluated using five general factors: installation and handling, durability, drift capacity, fence efficiency, and overall cost. The following sections describe the specific approaches used in the comparisons.

Installation, Handling and Durability

The first procedure was to identify the qualitative factors which affect the ease of fence erection and susceptibility to material damage from operational and environmental loads. These were identified through discussions with snow erection crews and direct experience. The factors relating to installation and handling include unrolling, joining sections, tensioning, alignment, attaching, bending and handling safety. Stretching, sagging, abrasion and breaking were used to evaluate overall durability. The factors are described in detail in a later section. The fences were given a positive or negative score on each of the factors based on operational experience during the trials, and the scores were summed to give an overall product comparison.

The second procedure was used to provide a quantitative measure of fence tensile strength requirements during installation procedures. Experience showed that certain lattice-type fences broke while being tensioned for installation. As shown in Figure 1, one end of a section of fence was fixed to a post. The other end was fastened to a proving ring and then tensioned using a truck or loader. The load was increased in steps and read from a dial gauge on the proving ring until the fence failed. The rate of load application was not measured but corresponded with typical operating conditions at MTO.

The third procedure of the installation and handling evaluation was a task analysis, comparing the manpower required to install a standard, 60 m section of each fence. Fence installation was divided into identifiable manual tasks and the time and number of persons required to perform each one was estimated. Manpower loadings were not directly measured but were estimated after observation of several installations, making adjustments for unrelated logistical delays.

Stretching and sagging were observed to impact strongly on the durability of a fence and material elongation was used as a quantitative measure of durability. This involved measuring the length of the top and bottom edges of the fence with a steel tape during the tensile strength tests as lateral tension was increased (Figure 1). Elongation was calculated as the vertically averaged percent increase in fence length per kilogram of applied load.

Finally, observed fence performance was used to estimate the expected useable lifespan of each type.

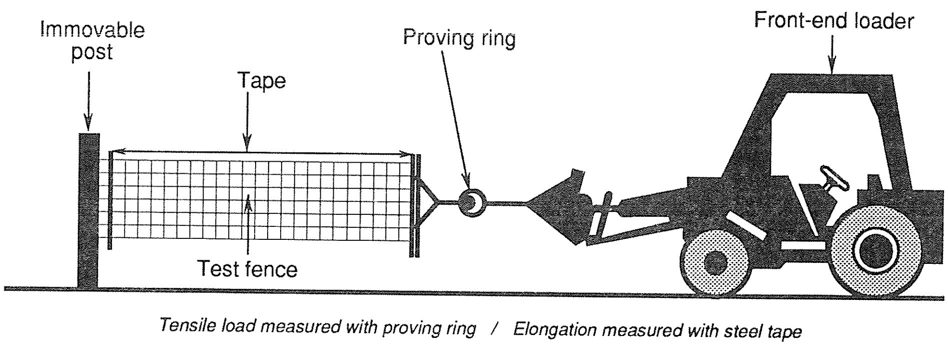

Figure 1/ Set-up for tensile strength and elongation tests

Drift Capacity

Previous studies suggest that snow drifts reach a stable maximum volume determined by the height, porosity and geometry of the snow fence or barrier (Tabler, 1980; 1990). These effects were investigated by measuring the cross-sectional area of the maximum drift attained in each season. Area was measured either by repeated level surveys or by measuring snow height against graduated rods which were driven into the ground at set distances perpendicular to the fence.

Fence Efficiency

Fence efficiency refers to the proportion of the total snow flux between the ground surface and the fence height which is captured by the fence and thus prevented from drifting onto the highway.

It was not possible to measure the actual snow flux at the test sites. Instead, snow captured by each test fence was compared with that captured by adjacent wood slat fences. It was assumed that all wood slat fences have a similar efficiency and provide a suitable standard for comparison. This approach minimizes differences arising from variations in snow flux between sites.

Prior to 1988, data were obtained only for the winter maximum snow drift, but in the 1988/89 and 1989/90 seasons, measurements were obtained on a snow drifting event basis when possible and at least weekly through the winter period. Prior to analysis of the latter seasons, periods having adverse weather conditions in which snow drifts melted or snow was redistributed along the fence rows were removed from the record.

Cost

The overall cost of the fences was compared by calculating a Total Annual Cost (TAC) which includes the purchase cost, the expected longevity and the annual installation cost, as

$$TAC=AIC+ACC,$$

where the annual installation cost (AIC) is the estimated manpower requirement to install a 60 metre (100 foot) section of fence multiplied by the labour rate, and the annual capital cost (ACC) is the purchase price per 60 metre section divided by the fence lifespan (L). L was estimated from the results of the durability analysis as described below.

RESULTS

Installation and Handling

The first part of this analysis involved developing a list of the qualitative factors which impact on the skill, dexterity or time taken to install a fence.

These are described below.

Unrolling: A positive score on this factor indicates that the fence lay flat on the ground after unrolling and prior to lifting against the fence posts. A negative score indicates that the ends of the fence tended to re-roll unless weights or extra people were used to hold them down.

Stiffness: A positive score on this factor indicates that the material stood on its own when raised against the fence posts prior to tensioning. A negative score indicates that it collapsed unless held against the posts. This required additional people to position the fence during tensioning.

Joining: A positive score on this factor indicates that adjacent sections of fence material could be joined either with wire ties or by weaving a 2.5 x 5 cm (1x2 in) wooden slat through the voids of overlapped sections. A negative score indicates that the voids were too small or the fence too stiff to do this easily. This size slat was found by experience to be the smallest which will not break under tensioning load.

Tensioning: A positive score on this factor indicates that a 30 metre section of fence could be tensioned laterally to the point that there was no visible catenary. A negative score indicates that the fence ribs broke before full tensioning of a 30 metre section. In such cases either the fence could not be fully tensioned or it had to be tensioned in shorter sections, which was more time consuming.

Alignment: A positive score on this factor indicates that wire-ties could be inserted through voids in the fence and around the fence post without having to align the post to the voids. A negative score indicates that fence and posts had to be carefully aligned for wire-ties to be inserted without damaging the fence. This was typical of fences with small voids.

Attachment: A positive score on this factor indicates that the fence could be attached to the post with simple wire-ties. A negative score indicates that the fence had first to be sandwiched between wooden slats to avoid the fence being cut by the ties. This was true for all fences of synthetic material.

Bending: A positive score on this factor indicates that the fence material would bend along its length, conforming with rolling topography. A negative score indicates that it did not bend and this resulted in variations in the gap between the fence and the ground.

Handling Safety: A positive score on this factor indicates that the fence edges would not easily cut bare hands, and a negative score indicates that they would.

The scores attained by each fence are shown on Table 2. The wood slat fence (a) ranked highest on the installation and handling factors, followed by horizontal slat and net materials. A metal slat fence (b) had similar properties to the wood fence except for handling safety. All but two (h) and (i) of the lattice type fences

Table 2/ Snow Fence Handling and Durability Characteristics

Fence	Installation and Handling Characteristics																		Score	Rank	Durability Characteristics								Score	Rank
	1		2		3		4		5		6		7		8		9				10		11		12		13			
	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-	+	-			+	-	+	-	+	-	+	-		
a	√		√		√		√		√		√		√		√		√		9	1	√		√		√		√		4	1
b	√		√		√		√		√		√		√			√	√		8	2	√		√		√		√		4	1
c		√		√		√		√		√		√		√	√			√	1	7		√		√		√		√	0	4
d		√		√	√		√			√		√		√	√			√	3	5		√		√		√		√	0	4
e		√		√	√		√			√		√		√	√			√	3	5		√		√		√		√	0	4
f		√		√	√			√		√		√		√	√			√	2	6		√		√		√		√	0	4
g		√		√		√		√		√		√		√	√			√	1	7		√		√		√		√	0	4
h		√	√		√		√			√		√		√	√			√	4	4	√		√			√	√		3	2
i		√	√		√		√			√		√		√	√			√	4	4	√		√			√	√		3	2
j		√	√			√	√		√			√		√		√		√	3	5		√		√		√		√	0	4
k	√			√	√		√		√			√	√		√			√	6	3		√	√			√		√	1	3
l	√			√	√		√		√			√	√		√			√	6	3	—	—	—	—	—	—	—	—	—	—
m	√			√	√		√			√		√		√	√			√	4	4	√			√		√		√	1	3
n	√		√			√	√		√			√		√	√		√		6	3	√		√		√			√	3	2
o	√		√			√	√		√			√		√	√		√		6	3	√		√		√			√	3	2
p	√		√			√	√		√		√		√		√		√		8	2		√	√			√		√	1	3
q	√		√			√	√		√		√		√		√		√		8	2		√	√			√		√	1	3

— *indicates data not available*

List of Characteristics:

1. Unrolling
2. Stiffness
3. Joining
4. Tensioning
5. Alignment
6. Attachment
7. Bending
8. Safety
9. Wind
10. Stretching
11. Sagging
12. Abrasion
13. Cutting

scored poorly on the installation factors, and several were particularly difficult to install because they could not be properly tensioned.

The strength tests shown in Figure 2 corroborate the qualitative evaluation of tensioning. The lattice fences which broke during the tensioning operation, (c), (f), and (g), failed at tensile loads of less than 450 kg, while those that did not break, (a), (i), and (d), had tensile strengths of 450 kg or greater.

It should be noted that the tensile strength and elongation of polyester and polyethylene are temperature sensitive, and tests were performed at only one temperature (30°C). Additional testing should be conducted to extend the results to the range of snow fence operating temperatures.

Results of the task analysis are summarized in Table 3. No distinction in manpower requirements could be made among the different lattice type fences, and with one exception, differences among the other types were minor. Manpower requirements for all of these ranged from 5.1 to 6.6 hours. One brand (n,o) of horizontal strap fence was exceptional, requiring 11.9 hours for installation of a 60 metre section.

Table 3/ Manpower Requirements for Snow Fence Installation *

Fence Type	Total Manhours	%
Vertical Slat -wood, metal	6.5	100
Horizontal Slat -polyester -impregnated fabric	11.9 6.6	183 102
Lattice -polyethylene	6.2	96
Net -polyester, polyethylene	5.1	72

* 1.2 m high, 60 m long section including posts, joins, and braces.

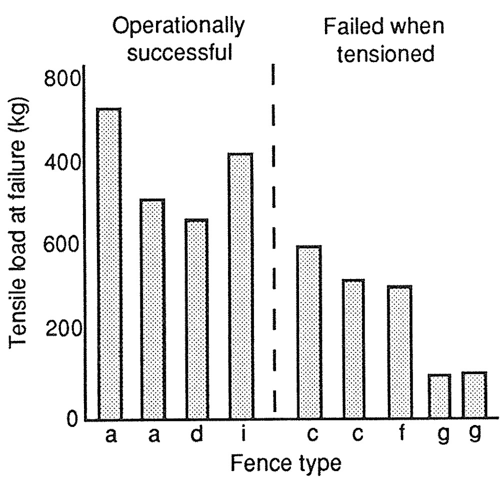

Figure 2/ Snow fence strength limits during tensioning (Ambient temp. 30 °C)

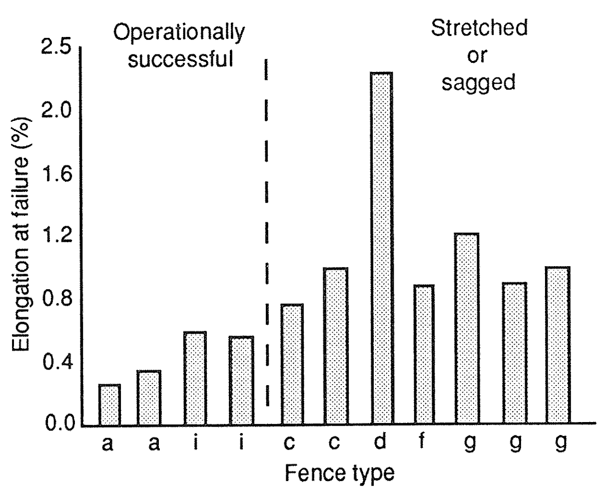

Figure 3/ Snow fence elongation at tensile failure (Ambient temp. 30 °C)

DURABILITY

Four qualitative factors were identified which affect the rate at which fences are damaged by environmental forces or operational incidents (and are assumed to be surrogates for fence longevity under operational use). They are explained below.

Stretching Due to Wind Pressure: A positive score on this factor indicates that the fence was not stretched by wind pressure. A negative score indicates that pressure from the wind stretched the fence, creating a down-wind bulge between posts. This resulted in uneven drifts and in some cases allowed the fence to work loose from the posts, causing permanent deformation and reducing the utility of the fence in subsequent years.

Sagging Due to Snow: A positive score on this factor indicates that the fence shape was not distorted by burying in deep snow. A negative score indicates that it sagged under the weight of overlying snow. The consequences of sagging are similar to those for stretching. In addition, sagging reduced the fence's snow-trapping performance.

Abrasion: A positive score on this factor indicates that the fence material was not affected by winter-long vibrating against the posts or wood slats. A negative score indicates that the fence material was worn thin or roughened where it contacted with fence posts or wooden slats. Synthetic fences frequently failed at points of abrasion and therefore, signs of abrasion were taken as an indicator of a reduced useful lifespan.

Breaking: A positive score on this factor indicates that the fence did not break over the winter season. A negative score indicates that the fence broke due to abrasion or failure in tension.

Table 3 shows the scores attained by each fence. Vertical slat fences ranked highest on the durability factors. The second rank included two lattice fences (h,i) and two horizontal straps (n, o). Most of the lattice fences (c,d,e,f,g,j) were prone to all types of material damage and ranked lowest on durability.

Quantitative measures of fence material elongation corroborated the results of the qualitative evaluations, as shown in Figure 3. Fences which did not stretch or sag, (a) and (i), had measured elongations at tensile failure of 0.6 percent or less per kg of applied load, while those which did sag or stretch, (c) and (d) and (g), had higher elongations.

As noted in the description of tensile testing, properties of the tested materials are temperature sensitive and the tests should be extended to the range of snow fence operating temperatures.

No direct measure of fence longevity could be made because not all fences had the same long-term environmental exposure; however, subjective estimates can be derived from the performances observed during the tests. Patrol personnel observed that wood slat fences last an average of 7 years. Most of the synthetic fences broke and all were abraded during each year they were tested; their performance was unacceptably degraded. Fences which broke in service (c-g,j,k,m-q) were classified as having a useful life of 1 year. Use of fence (b) was also discontinued after one year because of excessive rusting and bending. Fences (h) and (i) have been used for 4 years to date without failing and fences (n) and (o) were used for 3 years before failing: this provided a measure of their minimum useful lifespan. Insufficient data are available to categorize fence (i).

DRIFT CAPACITY

The maximum measured cross-sectional area of drifts of each test fence are compared in Table 4 with the capacity of similar fence types estimated from empirical models by Tabler (1990;1980). While two cases, wood slat (a) and lattice fence (h), show drift volumes close to or exceeding the estimates of drift capacity, no conclusions can be drawn from the data because the values are within the experimental error which is estimated to be +/-10%. In addition, repeated measurements in 1988/89 and 1989/90 suggest that drifts did not fill to capacity during the test program.

Table 4/ Snow Drift Capacity*

Fence Type	Estimated Capacity[1] (m^2)	Maximum Measured[2] (m^2)	(year)	Difference (m^2)
a	29	27.8	1981	-1.2
b	66	26.0	1981	-40.0
c	29	23.0	1986	-6.0
d	29	22.5	1986	-8.1
e	66	26.3	1986	-39.7
f	29	26.0	1986	-3.0
g	29	13.3	1989	-15.7
h	20	22.3	1981	2.3
i	29	23.11	1986	-5.9
j	29	25.4	1981	-3.6
k	X	12.38	1989	X
l	X	21.9	1978	X
n	X	20.9	1987	X
o	X	30.0	1986	X
p	X	11.9	1988	X

1. Tabler, 1980, 1990
2. M.T.O., 1978-1989
X. Unknown

*m2 of drift cross-sectional area per metre of fence length

FENCE EFFICIENCY

Fence efficiency was measured by comparing the volume of snow captured by test fences with that captured by wood slat fences, on both an annual basis and a sample period basis. Annual efficiency is shown in Table 5. One brand of lattice fence (i) had consistently larger drifts than the wood slat fence, averaging 11 percent greater over four years. While data points show other fences which accumulated more snow than wood fence, the inter-annual variability and small number of samples does not permit sound conclusions to be drawn from the annual data.

Trends may also be masked in the annual data by differential snow melt or redistribution prior to drift measurement, and the comparison was therefore repeated using only data from time periods which experienced weather conditions conducive to drift accumulation. Seven or eight sample periods, depending on fence location, were available for comparison in each of 1988/89 and 1989/90 (Table 6).

A Student's 't' test was used to compare the snow accumulation between test fences and wood slat fences on a sample period basis. In both years, the data do not show a significant difference between accumulation at the test fences and adjacent wood slat fences. This conclusion is also true for fence (i) which did have a larger accumulation on an annual basis.

Table 5/ Snow Fence Catch Efficiency

Maximum Drift Cross-Sectional Area as % of Area at 1.2 m Wood Slat Fence

	Fence Type														
Year	b	c	d	e	f	g	h	i	j	k	l	n	o	p	q
1978											124				
1979											52				
1981	115						124		117						
1985			110	113											
1986		95	98		103			102				102			
1987		97	98	112	92			124				96			
1988		98	87	69	90		82	113				87	84	61	71
1989			107	90		83		105		84					
Mean	115	97	100	96	95	83	103	111	117	84	88	95	84	61	71

Note: Fences not necessarily filled to capacity.

Table 6/ Sample Statistics for Snow Drift Cross-Sectional Area

Fence Type (1.2 m)	**Year**	**#. of Samples**	**Drift X-Section Growth (m^2) Mean**		**Variance**		**Student's 't'**
			Test Fence	**Wood Fence**	**Test Fence**	**Wood Fence**	
c	1988/89	7	2.8	2.9	4.4	4.2	.07
d	1988/89	7	2.6	2.9	1.4	4.2	.29
d	1989/90	8	1.9	2.9	5.1	22.7	.28
f	1988/89	7	2.6	2.4	2.6	1.7	.23
g	1989/90	8	2.1	2.4	15.6	22.7	.07
h	1988/89	7	1.9	2.2	1.2	1.1	.53
i	1989/90	7	2.6	2.1	19.8	18.3	.12
k	1989/90	8	2.9	2.3	19.0	8.6	.23
n	1988/89	8	2.5	2.4	1.9	1.6	.15
p	1988/89	8	2.0	2.4	2.0	1.6	.57

Notes:
1. Sample periods with adverse weather conditions are excluded.
2. Variance is the best estimate of population variance based on the sample (Gregory, 1963).
3. Student's 't' statistic:

$$t = \frac{|\bar{a} - \bar{b}|}{\sqrt{\frac{\hat{\sigma}^2}{n_a} + \frac{\hat{\sigma}^2}{n_b}}}$$

4. The difference between samples is statistically significant at 95% confidence level if the 't' statistic exceeds 2.365 for 8 samples or 2.447 for 7 samples (Cangelasi, Taylor, and Rice, 1976).

COST

The cost analysis shown in Table 7 used the manpower requirement for installation (Table 3), the purchase price and the estimated lifespan (see above) to estimate a Total Annual Cost for each fence, where data were available.

Table 7/ Snow Fence Life Cycle Cost*

Fence	a	b	c	d,e	f	g	h,i	j	k	l	m	n,o	p,q
AIC	100	100	96	96	96	96	96	96	72	72	72	183	102
L	7	1	1	1	1	1	4	1	1	1	1	3	1
ACC	100	-	1094	1465	1394	-	380	1794	776	-	-	439	-
TAC	100	-	273	340	327	-	146	399	203	-	-	229	-

* Costs in each row are expressed as a percent of the cost for fence (a) per 60 m section of 1.2 m tall fence, installed

AIC = Annual Installation Cost, proportional to Manpower Requirements (Table 3)
L = Expected Lifespan (years)
ACC = Annual Capital Cost; Cost / Lifespan
TAC = Total Annual Cost; sum of AIC and ACC

- data not available

Total annual cost varied by a factor of 4 among the fences. The wood slat fence (a) provided the lowest TAC and the lattice fence (j) the highest. Type (h,i) lattice fence was significantly lower than others in its class because of its greater estimated lifespan. The analysis clearly shows the importance of durability in determining the cost of using different types of snow fence.

CONCLUSIONS AND DISCUSSION

Nine factors were identified which affect the ease of installation and handling of snow fences. Overall, the standard wood slat fence was easier and safer to install than the other fence types. This conflicts with manufacturers' claims that synthetic fences, being lighter, are easier to handle and install. Field experience has shown that this benefit is countered by sharper edges, lower tensile strength, additional installation materials and other factors. In addition, typical MTO practice of trucking the materials to the installation site negates the benefit of reduced material weight. Synthetic fence would, however, rank higher in situations where the materials must be carried by hand.

One of the installation factors, tensioning performance, was related to a measurable material property. The measurements indicate that fence materials which can withstand a tensile load of 450 kg or greater will withstand the tensile force typically exerted during installation procedures used by MTO. Only one of the lattice type fences tested met this criteria.

The effort required to erect snow fences averaged about 6 person-hours for all but one fence type. The exception, type (n) horizontal strap, required twice the effort of the other types.

Four factors were identified which affect the durability of snow fence. According to these factors only the metal fence (b) was as durable as wood slat.

Measurements of fence elongation at tensile failure corroborated the observed performance of sagging or stretching. Fences which had elongation of less than 0.6 percent per kg of applied load at tensile failure did not experience sagging or stretching due to environmental forces. Only one of the synthetic materials tested (h,i) achieved this performance.

High incidences of abrasion and breaking were observed on most of the synthetic fences and as a consequence their estimated lifespan was very low. This is in conflict with the manufacturers' estimate that the fence's longevity exceeds that of wood fences. The primary reason for the short lifespan shown in this study was either abrasion to the point that the fence failed during tensioning or cutting by wire-ties or sharp post edges during the winter season. This indicates that even if the material is immune from chemical weathering or deterioration, its useful life is governed by its susceptibility to cutting or tearing. Synthetic fences cannot be easily repaired after installation, and a break or tear during the field season creates an unacceptable highway safety hazard.

Insufficient data were collected to compare the drift capacity of the fences tested. Information in the literature suggests that fences with similar height and void ratio have similar capacities. It is concluded that so long as porosity is similar, similar total drift capacity can be expected for wood slats and the other fences tested.

Statistical comparisons of fence efficiency also showed no significant differences between wood slat and the various fences tested and it can be concluded that similar efficiency can be expected of wood slats and other fences which have similar height and porosity.

Annual costs varied widely among fences, but all were greater than the standard wood-slat fence.

Considering all the factors investigated, none of the alternative fences provided a clear advantage over the wood slat fence and many of them exhibited significant disadvantages in terms of handling, durability and cost. Two types of synthetic fences (h,i) had similar performances to the wood slat fence on these factors. In terms of snow-trapping capacity and efficiency, the data suggest that wood slat and alternative fences of similar height and porosity perform equally well.

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