kta
structural engineers

SNOW LOADS

1. Introduction

Sprung Instant Structures Inc have been constructing Tension Membrane Fabric Structures for over 30 years. During that period, Sprung Instant Structures have refined the design of its structures to take advantage of the structure's behavior to limit the amount of snow on the structure. The structures use very low friction materials, have unobstructed sliding paths and the structures vibrate under light impulse. In light winds, or even when doors are closed in a Sprung Structure snow will slide off the roof.

In the commentary for ASCE-7-02, it is recognized that "*Glass, plastic, and fabric roofs of continuously heated structures are seldom subjected to much snow load because of their heat loss causing snow melt and sliding. For such specialty roofs, knowledgeable manufactures and designers should be consulted*", and the commentary continues wiith "*Little snow accumulates on warm air-supported fabric structures because of their geometry and slippery surface*".

This report presents the applicable ASCE-7 design provisions for snow loads, research in snow loads on slope surfaces, research on the Sprung Structure's performance in high snow loads area, observations of the behavior of structures in the field, and recommendations for snow loading provisions when designing Sprung Structures.

2. Code Snow Loads

The model design standard used in the United States of America for loading is "Minimum Design Loads for Buildings and Other Structures" (ASCE-7). The applicable provisions for Sprung Structures are shown below. The sliding factor shown is applicable for roofs composed of metal, slate, glass, and membranes (bituminous, rubber or plastic).

ASCE-7 – Section 7

P_f = 0.7 Ce Ct I p_g Cs

P_g	-	Ground Snow Load			
C_t	-	Thermal Factor	C_t	=	0.85 to 1.20
I	-	Importance Factor	I	=	1.0
Ce	-	Wind Exposure Factor	Ce	=	0.9 to 1.1
Cs	-	Sliding Factor	1.0	>	Cs > 0.0

$$Cs = \frac{70^\circ - \alpha}{65^\circ}$$ For warm slippery roofs (Fig 7-2)

$$Cs = \frac{70^\circ - \alpha}{55^\circ}$$ For cold slippery roofs (Fig 7-2)

Sprung Structures have a roof slope of 26°. The sliding factor would be 0.68 for a warm slippery roof or 0.80 for a cold slippery roof using ASCE-7 provisions. However research has found that glass roofs retain less snow than metal roofs. Research on the snow retention on sloping surfaces is discussed in the next section.

3.0 Research

3.1 Research in Canada

A considerable amount of research has been done on snow loads by Dr. D. Taylor of the National Research Council of Canada in the 1970's and 1980's. Dr. Taylor has investigated snow accumulations, heavy snow loads and snow sliding off roofs.

Dr. D. Taylor investigated the behavior of sliding snow on metal and glass surfaces between 1973 and 1983. Dr. Taylor's research indicated that snow slid off on cold glass surfaces at a much lower roof slope, and that a sliding factor of less than 0.4 would be more appropriate compared to the predicted values of 0.68 or 0.80 from ASCE- 7 for a 26° sloped glass roof. Dr. Taylor's paper is found in Appendix "A".

3.2 Work done for Sprung Instant Structures

In 1988 Sprung Instant Structures retained AGRA Earth & Environmental Ltd. to find the coefficient of friction of the outer membrane used on Sprung Structures. AGRA found that the coated material used has a lower coefficient of friction than glass. The summary of AGRA's tests is found in Appendix "B".

In 1996 Sprung Instant Structures Ltd. retained Campbell Woodall and Associates Consulting Engineers Ltd. (CWA) to consolidate the work on snow resistance of Sprung Structures done up to that time and to verify the research of Dr. Taylor and AGRA. CWA checked the past performance of 34 Sprung Structures at fifteen sites across Canada. Daily snow falls and ground snow depths were obtained for these sites from Environment Canada for the time period the structures were in use. The snow depths and daily snow falls were converted into an equivalent load using the same snow densities that were used in developing the snow loads in the 1990 National Building Code of Canada supplement. The results of CWA's findings are shown in Tables 2 and 3. Past performance of Sprung Structures indicate a sliding factor of 0.40 may be too high.

Table 2
Number of Months Structures Subjected Different Measured Ground Snow Loads

Measured Ground Snow Load [psf]	20	30	40	50	60	70	80	90	100	Maximum
30' and 50' Structures	633	264	169	64	32	12	7	3	2	110 psf
40', 60' and 88' Structures	183	113	70	40	29	29	29	22	22	200 psf

Table 3 List of Structures and Locations

Size	Location	Period	Maximum Measured Ground Snow Load
30'	Whistler, B.C.	1987 - 1996	111 psf
50'	St. John's, Nfld.	1991 - 1996	54 psf
50'	Sidney, N.S.	1985 - 1996	55 psf
50'	Moncton, N.B.	1987 - 1996	56 psf
50'	Quebec City, Que.	1987- 1996	47 psf
50'	Sept Illes, Que.	1987 - 1996	35 psf
50'	Goose Bay, Nfld.	1993 - 1996	72 psf
50'	Gauge Town, N.B.	1981 - 1996	54 psf
50'	Kitimat, B.C.	1984 - 1996	112 psf
40'	Norman Wells	1990 - 1996	42 psf
40'	Kitimat, B.C.	1984 - 1996	112 psf
60'	PosteMontagnais, Que	1988 - 1996	100 psf
60'	Moncton, N.B.	1987 - 1996	56 psf
60'	Inuvik, N.W.T.	1990 - 1996	47 psf
60'	Sparwood, B.C.	1982 - 1996	33 psf
60'	Roger's Pass, B.C.	1983 - 1996	200 psf
88'	Goose Bay, Nfld.	1990 - 1996	59 psf
88'	Ottawa, Ontario	1987 - 1996	61 psf

4.0 Behavior of Sprung Structures in the Field

Monitoring the behavior of structures in the field is important. Observations of full size structures provide a clearer understanding of how the structures behave under different environmental conditions that would not be possible from experimental work. The photographs in Appendix C give indications of the structures' behavior under different conditions.

Sprung Structures have been erecting structures in areas with ground snow loads up to and over 200 psf since 1972. In all of these situations the structures have not shown any structural distress and have performed well despite the fact that these structures have a capacity to only resist roof loads of 9 psf to 19 psf.

Photographs C-1 and C-2 show a structure in Karsen, B.C. while photograph C-5 was taken at Snowqualmie Pass, Washington State, C-7 Vail, Colorado and C-8 Colorado Springs, Colorado. Photographs C-2 to C-4 and C-6 show the amount of snow that has slid off the roof of the structures. Please note the lack of snow on these structures.

Field observations have indicated that Sprung Structures release snow under very low snow falls (4 inches of snow). Photograph C-9 and C-10 show two structures releasing snow after a very light snow fall. At most, the snow build up will be from 6 to 10 inches prior to sliding off.

Another behavior observed, is when there is a large snowfall and rainfall immediately afterwards. It was observed that most, if not all of the snow released off the Sprung Structure prior to the rain fall and if there was still some snow, the snow released as soon as the rain occurred. In the Christmas snowstorms of 1997 in British Columbia and Washington State, 3 inches of rain occurred after a 24-inch snowfall. Sprung Structures performed well while a number of other types of building did not. What pictures cannot show are the effects of wind causing the structure to vibrate (flutter) and the snow releasing off the roof due to the vibration. Sprung is now installing canopies over doorways to protect people from sliding snow, which is readily released, from the roof. Sprung has a video of this occurring with a Structure in Washington State.

Table 3 lists structures installed in higher snow load areas and Appendix D has letters attesting to Sprung Structures' performance in different parts of North America.

5. Conclusions

.1 The slope factors calculated in the design standard ASCE-7-02 do not reflect the performance of unobstructed slippery surface of Sprung Structures. ASCE-7-02 equations predict much higher roof snow loads being imposed on Sprung Structures than field observations would indicate.

.2 Past history of Sprung Structures indicates that the structures shed snow and can be used in high snow load areas.
Structures have been installed in high snow areas (such as the Roger's Pass, B.C. and Alaska) for a period of many years and have performed well, even when, the measured ground snow depths and the predicted roof loads far exceeded the roof capacity of the Structure.

.3 Past history with Sprung Structures indicates the structures perform well in areas of high winter rainfall in combination with snow. Examples being, Kitimat B.C. or Seattle, Washington State where structures must be able to support 200 psf of ground snow in combination with 3" of rain.

.4 It is likely that the maximum snow load that a Sprung Structure has to resist is under 6.0 psf no matter where the structure is located provided the snow is cleared away from the perimeter of the structure.

David P. Thompson, M.Sc., P.Eng.
Kta Structural Engineers Ltd.

Snow on sloping roofs

Inclined glass and metal roofs have become very popular in the last 20 years - and a few have become very unpopular because of their problems. Designers as a matter of course account for the snow loads but have often forgotten that snow and ice on slippery sloping roofs may slide off, endangering people and property below.

In 1974 (survey No. 4) six inclined metal and asphalt shingled roofs (Fig. 2) were built in a sheltered wood lot at the NRC in Ottawa to study the influence of slope and surface roughness on the snow loads (Taylor 1985). The roofs were 2.4 x 2.4 m, north facing, sheltered from the wind, and had slopes from 0 to 60°. Three were prepainted steel and three asphalt-shingled. In the following years five more roofs, including two of glass at 20 and 35° slopes (Fig 3), were added to the site as shown in Table 1.

Figure 2. The 6 original sloping roofs during heavy snow 1976 - front to back 20° m, 35° m&a, 50° m&a, 60° a (m = metal, a = asphalt)

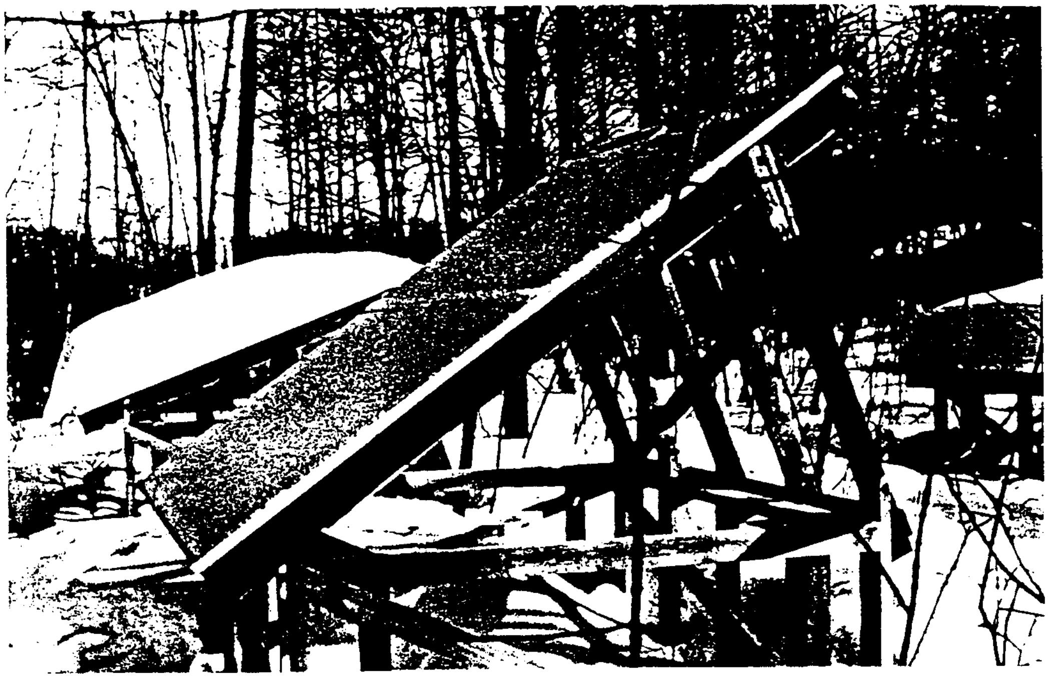


Figure 3. Snow on a 35° and, at the rear, a 20° sloped glass roof. The snow on the 20° roof is just beginning to creep off the roof, whereas the 35° glass roof has slid a number of times.

Table 1. Experimental roofs at sloping roof site

	Slope from Horizontal			
Year of installation	Green Pre-Painted Steel	Green Asphalt Shingles	Glass	Years of Record
1974	20°, 35°, 50°	35°, 50°, 60°	-	12
1977	0°	-	-	9
1979	10°	20°	-	7
1983	-	-	20°, 35°	3

Snow depths and densities were measured weekly (Taylor 1987). As a result of this survey and corroborating surveys in the USA (Sack 1988), changes were made to the 1990 NBC to allow reduced design loads on slippery sloping roofs where the snow could slide off entirely (Fig 4). The interesting point was that although the survey was focussed on improving design loads in the NBC, engineers, architects and the public were much more concerned about problems due to falling snow and ice; there was an avalanche of

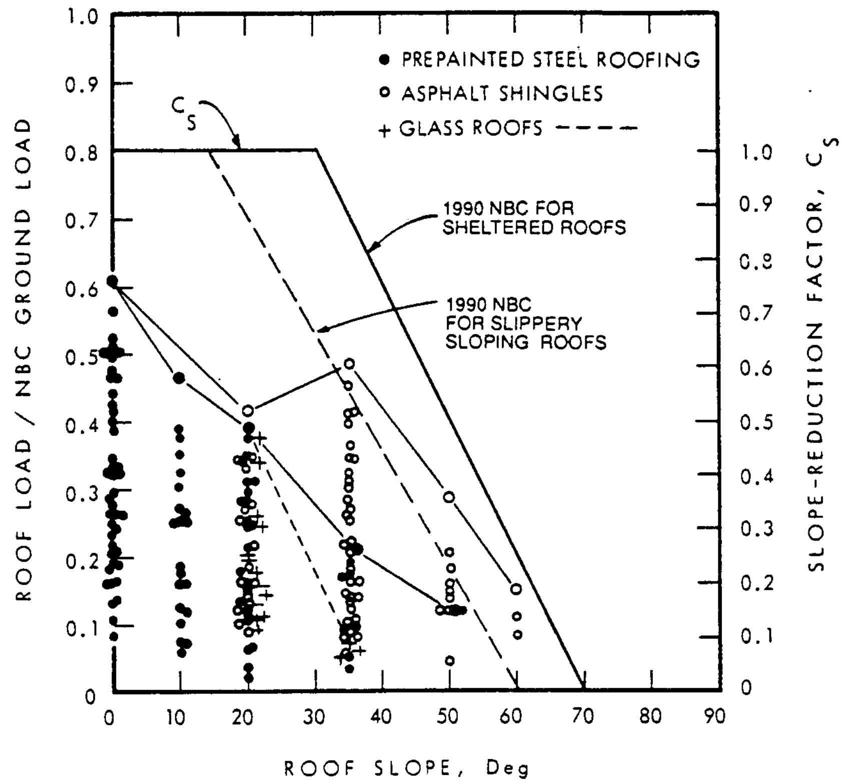


Figure 4. Data from 1974-1986 plotted versus ratio of roof load to National Building Code ground loads. Axis on right is the slope reduction factor C_S. At 50° there were many measurements of zero snow on the steel roofs.

enquiries! Many had been caught unaware. The following are some anecdotal cases:

1. In one instance, owners of a row of asphalt-shingled condominium townhouses had them reroofed with metal. From the first snowfall, snow was avalanching onto their front walks, their driveways and their cars; they could not let their children play outside due to the danger.
2. In another a new arena occupying an entire city block was not accepted by the owner because snow and ice were falling onto the city sidewalks around the building. They apparently needed a mile of snow fences (and ultimately perhaps a mile of gutters too).
3. At a building on the east coast, snow and ice were accumulating, then sliding off sloping aluminum window sills on a multi-storey building and falling to the streets below, creating a hazard. A similar situation

HARDY BBT LIMITED REPORT

Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

Our Project No.
Your Reference No. March 28, 1988

CA08538

Sprung Instant Structures Ltd.
1001 - 10th Avenue SW
Calgary, Alberta
T2R 0B7

Attention: Mr. P. Bos

Dear Sir:

Subject: Tedlar and Herculite Fabrics
Friction Coefficient With Snow

At the request of Mr. W. Babowal of Babowal Builders & Engineers Ltd., two fabrics were tested. The purpose of testing was to determine the coefficient of friction between snow and each fabric.

Tests were conducted at two temperatures, -15oC and -1oC using a walk-in freezer. A Karol-Warner Direct Shear Machine was used to measure the test parameters.

The fabrics were cut and glued to a movable shear table. Snow was then placed in a collar which was held stationary with respect to the fabric and table. Normal (vertical) loads were applied to the snow/collar assembly and a lateral force applied to the movable table. Two lateral forces per test were recorded, the maximum force required to initiate motion and the force required to maintain constant velocity. These are the static and kinetic friction forces respectively. Three normal loads were applied for each test sequence. The fabrics orientations were varied with respect to the direction of the motion. Direction one is perpendicular to direction two. The friction coefficients were calculated by dividing the lateral force by the normal force on the snow.

The results are presented below. These are average values of the the three normal loads per test. 'S' designates the static coefficient while 'K' designates the kinetic coefficient.

FABRIC	ORIENT.	TEST @ -15oC	TEST @ -1oC
Tedlar	1	S = 0.12 K = 0.10	S = 0.02 K < 0.01
	2	S = 0.06 K = 0.06	S = 0.01 K < 0.01

Herculite	1	S = 0.11 K = 0.09	S = 0.02 K = 0.01
	2	S = 0.12 K = 0.10	S = 0.02 K = 0.02

The friction coefficient at -1oC is approaching zero. This is likely caused by water, in equilibrium with snow, acting as a lubricant thereby reducing the frictional forces. At 0°C or greater, the friction would be zero since water cannot take shear.

The Tedlar fabric's coefficient is related to the stitching orientation. This results from the surface smoothness which is greatest parallel to the main chords and lowest perpendicular to theses chords.

To summarize, the maximum static coefficient is 0.12 on the Tedlar and Herculite fabrics. The minimum friction coefficient on the Tedlar fabric is 0.06 as discussed above.

We trust the above is all that is required. Should you have any questions, please do not hesitate to call Jeff Small at 248-4331.

Yours truly,

Hardy BBT Limited

Jeff Small, E.I.T.

Per

Don Empey, P. Eng.

JS:ww

PROFESSIONAL ENGINEERS ALBERTA
D. P. E.

PERMIT TO PRACTICE
HARDY BBT LIMITED
Signature
Date 11.04.88
PERMIT NUMBER: P 4546
The Association of Professional Engineers, Geologists and Geophysicists of Alberta

cc: Mr. W. Bobowal
c/o Babowal Builders & Engs. Ltd.
108, 208 - 57th Avenue SW
Calgary, Alberta

HBT AGRA Limited

Engineering & Environmental Services

221 - 18 Street S.E.
Calgary, Alberta
T2E 6J5
Tel (403) 248-4331
Fax (403) 248-2188
Telex: 03-821886

THE ALBERTA BUSINESS AWARDS OF DISTINCTION 1993

CA-10506
3 June, 1994

Sprung Instant Structures Ltd.
1001 - 10th Avenue S.W.
Calgary, Alberta
T2R 0B7

Attention: **Mr. Peter Bos**

Dear Sir:

RE: "Tedlar" Fabric Frictional Testing

Further to our test report, dated March 28 1988, regarding friction factor testing of your "Tedlar" fabric under snow loading, Mr. Kase Vanden Ende, P.Eng. of Structural Design Associates Inc. (Lynnwood, Washington, U.S.A.) has requested a review of calculations incorporating this data.

As stated in our report, testing of the fabric at -1°C under a snow load gave a static friction factor of 0.01. Mr. Vanden Ende has used this value in determining if snow will rest on a "Tedlar" fabric roof with a 26° pitch. The attached diagram summarizes Mr. Vanden Ende's calculations.

It is the opinion of HBT AGRA Limited that, although the calculations may be simplistic, they are accurate in estimating the forces expected.

We thank you for the opportunity to assist you with this project. Please contact the undersigned if we can be of further service.

Yours truly,

HBT AGRA Limited

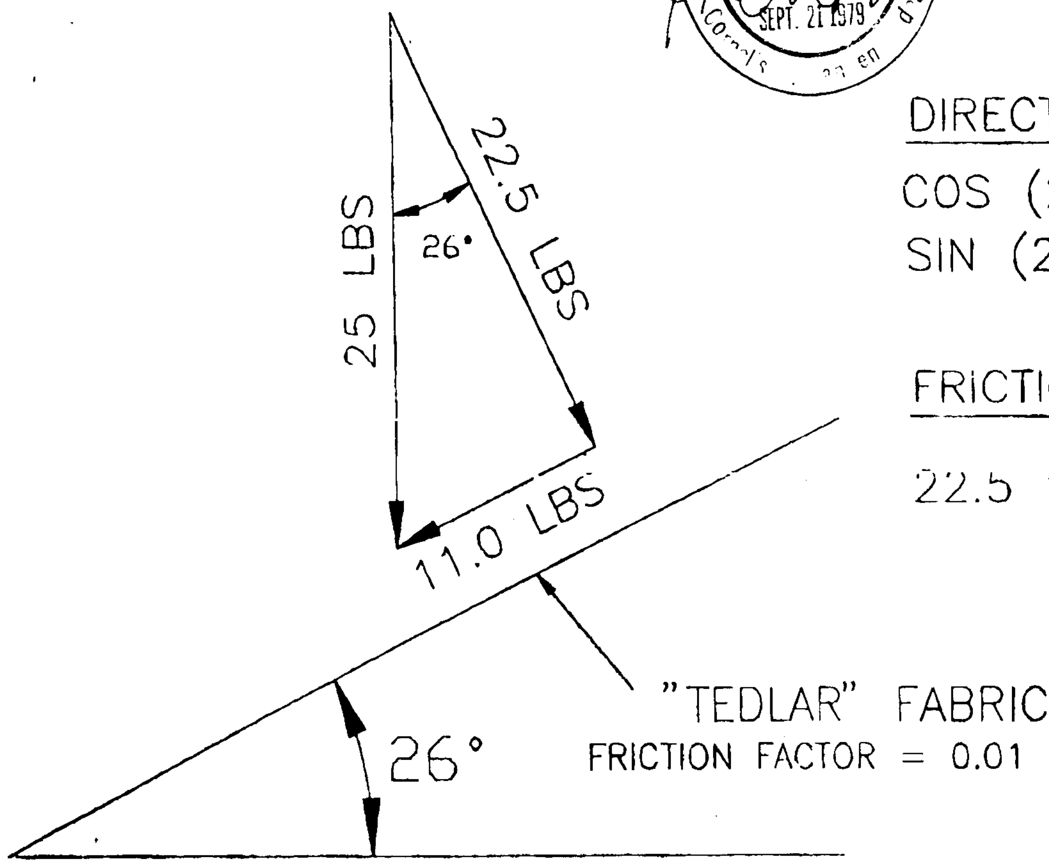
Randal B. Smith, P.Eng.
Building Sciences Engineer
Materials Division

Reviewed by:
Signature
Date 5-3/94
R.W. Forfylow, P.Eng.

CA-10506.RBS

FRICTIONAL ANALYSIS OF 1 SQUARE FOOT OF ROOF AREA

DESIGN SNOW LOAD = 25 PSF



FRICTION FACTOR = 0.01 @ −1oC

DIRECTIONAL LOADS

COS (26) x 25 LBS = 22.5 LBS

SIN (26) x 25 LBS = 11.0 LBS

FRICTIONAL RESISTANCE

22.5 LBS x 0.01 = 0.225 LBS

REGISTERED PROFESSIONAL ENGINEER 10,379 OREGON SEPT. 21 1979

STATE OF ALASKA 49TH CORNELIS D. VANDEN ENDE #CE-4872 REGISTERED PROFESSIONAL ENGINEER

CORNELIS D. VANDEN ENDE STATE OF WASHINGTON 9475 REGISTERED PROFESSIONAL ENGINEER EXPIRES 12/22/96

HBT AGRA Limited	SPRUNG INSTANT STRUCTURES LTD.
Engineering & Environmental Services	SDA SNOW LOAD FRICTION CALCULATION
	CXXXXXX DIAGRAM #

PICTURES

Karsen, BC (Photograph C-1)

Karsen,BC (Photograph C-2)

Jefferson County, Kentucky (Photograph C-3)

Park City, Utah (Photograph C-4)

Snowqualmie Pass - SkiResort located at the summit, Washington State (PhotographC-5)

30' Structure - Calgary, Alberta, Canada (Photograph C-6)

Vail, Colorado - 70’ x 130’ (Photograph C-7)

Colorado Springs, Colorado - 60’ x 100’ (Photograph C-8)

Calgary, Alberta Ground Snow Load 19 psf
Picture taken one day after 4" snowfall
Note: Evidence ofsnow sliding from roof
(Photographs C-9 and C-10)

Interior British Columbia (Photograph C-11)

Proper SnowClearance (Photograph C-12)

LETTERS

City of CRIPPLE CREEK

WORLD'S GREATEST GOLD CAMP

P. O. BOX 430
CRIPPLE CREEK, CO 80813
PHONE: (719) 689-2502
FAX: (719) 689-2774

July 8, 1994

Keri Sprung Avery
Sprung Instant Structures
123 Townsend Street, Suite 375
San Francisco, CA 94107

To Whom It May Concern:

Recently we purchased a 60' x 100' Sprung Instant Structure which is used to store equipment in Cripple Creek, CO, Elevation 9,494. The design snow load for this area is 40 lbs per square feet. The structure has performed perfectly by shedding all snowfall and standing in high winds during winter storms.

Yours Truly,

Chip Huffman
Director of Public Works

WHISTLER
MOUNTAIN

June 21, 1994

To Whom it May Concern:

We have had a 30 ft. wide by 40 ft. long Spring Instant Structure in place at out our ski resort since 1987.

During the 1993/94 season we received approximately 326 cm. (128 inches of snow).

The design snow load for Whistler, B.C.,as per the National Building Code of Canada, is 180 pounds per square foot.

During the past five years of use, our Sprung Structure has consisitently shed all snowfall off the roof of the structure and has functioned very effectively for Whistler Mountain Ski Corporation as a ski camp and Olympic Station.

Yours truly,

Ron Tobin,
Manager Building Maintenance
WHISTLER MOUNTAIN SKI CORPORATION
RT/vh

Whistler Mountain Ski Corporation
P.O. Box 67, Whistler, British Columbia, Canada, VON 1B0
Phone: (604) 932-3210 Facsimile: (604) 932-6374

January 23, 1996

Mr. Jeffrey Williams
Sprung Instant Structures
5000 Tilghman St.
Allentown PA 18104-9102

Re: Performance of Sprung Instant Structures in Utica, New York

Dear Jeff:

This letter is being written to provide documentation regarding the performance of seven Sprung Structures owned by Niagara Mohawk Power Corporation in Utica, New York.

The Structures in use in Utica, were constructed in July, 1993, and have been in continuous service since that date. The Utica area generally receives in excess of 120" of snow yearly, and the Sprung Structures on our site have performed well. Snow which falls on the structure is generally shed from the roof before it accumulates to a level in excess of 1 foot. Additionally, during minor snow events, the accumulated snow on the roof is generally shed within several hours of the end of the snowfall.

To date, we have not observed any adverse structural or physical impacts due to snow, rain or ice accumulation on the Sprung Structures. Additionally, we have incurred only minimal expenses to maintain the units, despite their usage under an extreme heavy construction environment.

Overall, we have been extremely pleased with the performance of the Sprung Structures, and the reliability of their technical staff.

Sincerely yours,

W. Curtis Nichols, PE
NMPC Harbor Point Site Engineer

NORTH AMERICAN METALS CORP.

June 8, 1994

TO WHOM IT MAY CONCERN:

We are presently utilizing a 40 ft. wide by 50 ft. long Sprung Instant Structure which has been located at our Golden Bear Mine operation 60 miles east of Juneau, Alaska since September 1992.

The design snow load for the area this structure is located is 120 pounds per square foot.

This Sprung Instant Structure has performed exceptionally well, by shedding all snowfall off the structure and in fact survived being partially buried under an avalanche in 1992.

Yours truly,

GOLDEN BEAR MINE
NORTH AMERICAN METALS CORP.

Ken McKinley
Buyer

KM/cjd

#1500 - 700 WEST PENDER STREET, VANCOUVER, B.C. V6C 1G8
PHONE (604) 684-9648 FAX: (604) 684-3123

ALASKA
INTERSTATE
CONSTRUCTION, INC.

649 W. 54th Ave.
P.O. Box 233769
Anchorage, Alaska 99523-3769
(907) 562-2792 • TELEPHONE
(907) 562-4179 • FACSIMILE

June 13, 1994

To Whom It May Concern:

Since 1984 AIC has utilized numerous Sprung Instant Structures in Deadhorse, Alaska (Prudhoe Bay) as follows:

> One structure 88.6 ft by 262.3 ft in place from November 1984 through 1987. At that time this structure was taken down and moved to another construction site and utilized for two years. From there the structure was taken down and sold to another contractor which is still using it.
>
> One structure 50 ft by 110 ft in place from January 1985 to January 1988.
>
> One structure 60 ft by 200 ft in place from January 1991 to present.

The design snow load for this region of Alaska is 40 pounds per square foot.

All of the above mentioned Sprung Instant Structures have performed exceptionally well under the harsh climatic conditions which our region presents.

Through all the years of use of these structures, all snowfall has successfully shed off the roof of the structure.

Sincerely,

ALASKA INTERSTATE CONSTRUCTION, INC.

John Ellsworth
President

THE CITY OF NEW YORK
DEPARTMENT OF CORRECTION
SHORE ROAD TRAILER
EAST ELMHURST, NEW YORK 11370

ANTHONY J. SCHEMBRI
COMMISSIONER

JOSEPH F. COLON
CHIEF
DIVISION I

DATE : June 28, 1994

TO : Whom it may concern

FROM : Joseph F. Colon, Chief, Division I

SUBJECT : SPRUNG INSTANT STRUCTURES

****

Since 1989 Riker's Island has been using Sprung Instant Structures to house inmates.

At maximum population, over 2000 inmates sleep, eat and exercise inside these Sprung Structures, which also include such services as Medical and Dental Facilities and a Law Library.

The list of existing structures are as follows:

40 each	Sprung Instant Structures	50 ft wide x 120 ft long
8 each	Sprung Instant Structures	50 ft wide x 120 ft long
1 each	Sprung Instant Structure	50 ft wide x 80 ft long
1 each	Sprung Instant Structure	60 ft wide x 120 ft long
1 each	Sprung Instant Structure	60 ft wide x 260 ft long
1 each	Sprung Instant Structure	88.6 ft wide x 256 ft long
1 each	Sprung Instant Structure	88.6 ft wide x 256 ft long

53 Sprung Instant Structures in total.

The design snow load for Riker's Island, New York is 30 pounds per square foot.

All snowfall, including the exceptionally high levels received during the 1993 winter season, has shed from the roof of all of these structures as advertised.

Joseph F. Colon
Joseph F. Colon
Chief
Division I