Snow Drift Loading

NCSEA Webinar
March 29 2018
Michael O'Rourke PE , Ph.D.
Rensselaer

1

Objective

Webinar will present a detailed review of snow drift loading in ASCE/SEI 7. Intended for seasoned structural engineers in that the "Why" will be addressed as well as the "What".

2

Outline General

- Current Provisions
- Future Directions

Current Provisions

- Drift Losses
- Leeward Drifts
- Windward Drifts
- Parapet Wall Drifts
- RTU Drifts
- Drifts on Adjacent Structures
- Gable Roof Drifts (aka Unbalanced Load)

Future Directions

- Regional Differences – Winter windiness
- Revised Windward Drift Relations
- Snow Capture Walls

5

Current Provisions

- **Drift Losses**
- Leeward Drifts
- Windward Drifts
- Parapet Wall Drifts
- RTU Drifts
- Drifts on Adjacent Structures
- Gable Roof Drifts (aka Unbalanced Load)

6

Drift Losses


7

Drift Losses

In the US most snow related structural performance issues are due to drifted snow. Problems are due to large localized loading rather than uniform loading

Snow Load Type	*Number of Cases*	*Percentage*
Roof Step Drift	12	22
Parapet Wall Drift	6	11
Gable Roof Drift	12	22
Combined Drift	8	15
Open Air and Freezer Buildings	8	15
Sliding Snow	1	2
Others	7	13
Total	54	100

8

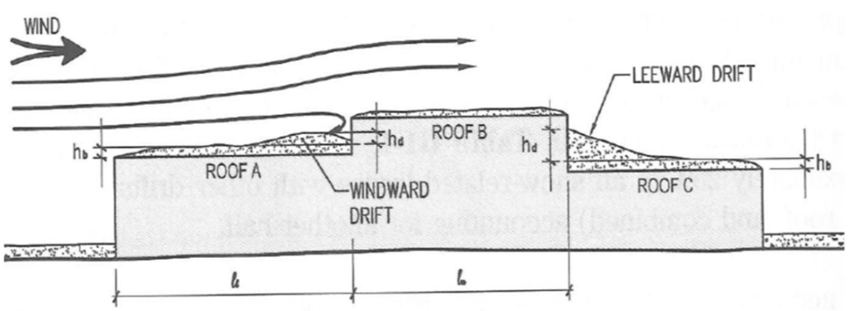
Current Provisions

- Drift Losses
- **Leeward Drifts**
- Windward Drifts
- Parapet Wall Drifts
- RTU Drifts
- Drifts on Adjacent Structures
- Gable Roof Drifts (aka Unbalanced Load)

9

Leeward Drifts

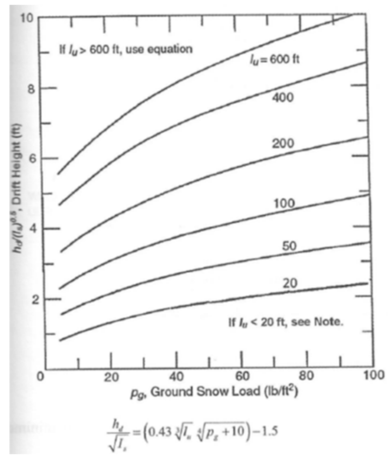
- Form **downwind** of roof step



10

Leeward Drifts

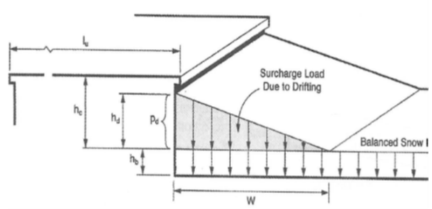
- ☐ Drift size based on empirical relation between upwind fetch and ground snow load from FM Global database

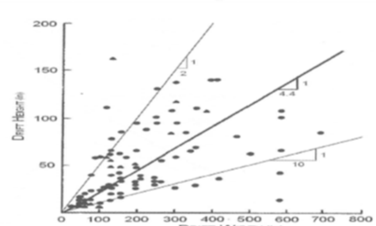


11

Leeward Drift

- ☐ For $h_c > h_d$ (non-full drift) width $w = 4\ h_d$
- ☐ Based on observations
- ☐ Taken to be the **average** angle of repose for drifted snow

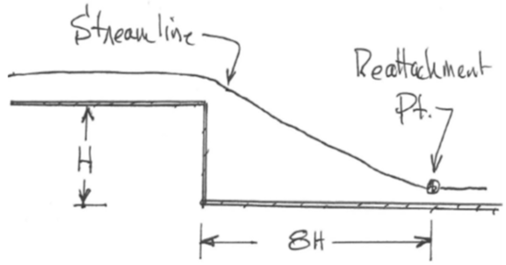




12

Leeward Drift

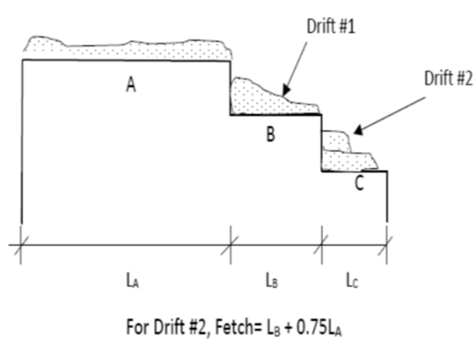
- For $h_c < h_d$ use $h_d = h_c$ and $w = 4\ h_d^2/h_c$ but not greater than $8h_c$
- First from matching areas
- Second from reattachment point for step



13

Leeward Drift

- Steps in series
- Trapping efficiency ~ 50%
- Drift 1 need not be full before snow on A contributes to Drift 2



14

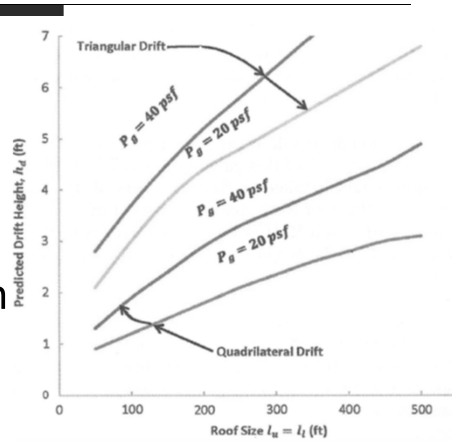
Current Provisions

- ☐ Drift Losses
- ☐ Leeward Drifts
- ☐ **Windward Drifts**
- ☐ Parapet Wall Drifts
- ☐ RTU Drifts
- ☐ Drifts on Adjacent Structures
- ☐ Gable Roof Drifts (aka Unbalanced Load)

15

Windward Drifts

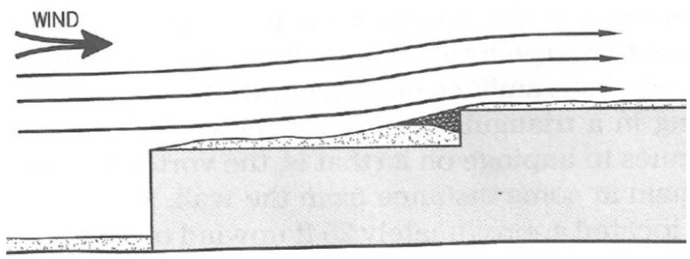
FM Global database had mix of triangular and quadrilateral shapes. 'Tri's were larger and correlated with upper roof length 'Quad's were smaller and correlated w/ lower roof length.



16

Windward Drifts

- ☐ All Leeward’s are triangular
- ☐ All Windward’s are **initially** quads
- ☐ Some Windward’s morph into triangular



17

Windward Drifts

- ☐ Unfortunately no wind direction in FM Global database, hence unsure if specific triangular was leeward or windward
- ☐ In 1988, 1993 & 1995 beta = 0.5, while in 2005, 2010 & 2016 beta = 0.75

$$(h_d)_{windward} = \text{beta}\ (h_d)_{leeward}$$

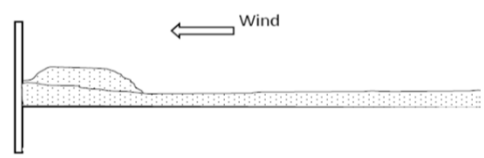
18

Current Provisions

- Drift Losses
- Leeward Drifts
- Windward Drifts
- **Parapet Wall Drifts**
- RTU Drifts
- Drifts on Adjacent Structures
- Gable Roof Drifts (aka Unbalanced Load)

Parapet Wall Drifts

- By their nature, Parapet Wall Drifts are Windward since they form **upwind** of the wall/step
- Fetch is along wind length of roof



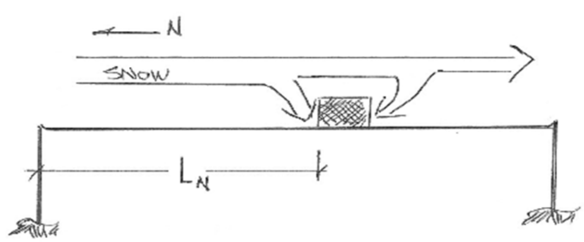
Current Provisions

- Drift Losses
- Leeward Drifts
- Windward Drifts
- Parapet Wall Drifts
- **RTU Drifts**
- Drifts on Adjacent Structures
- Gable Roof Drifts (aka Unbalanced Load)

21

RTU Drifts

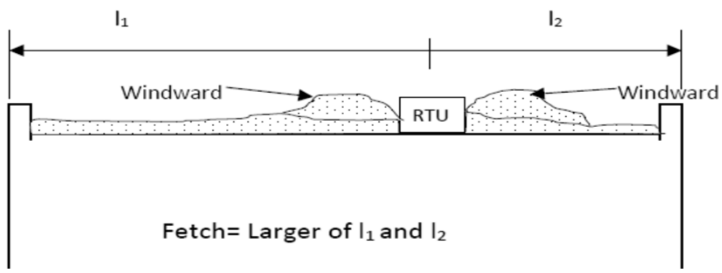
For North wind – Drift North of RTU is windward drift w/ fetch = L_N. Drift South of RTU is leeward drift w/ effective fetch < L_N



22

RTU Drifts

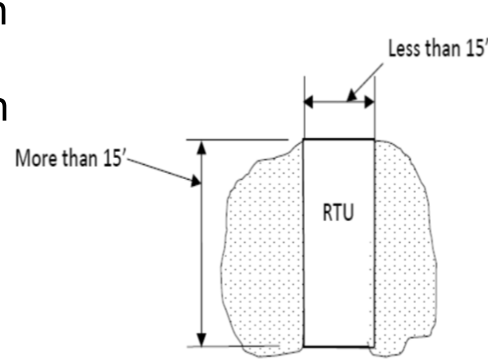
- For simplicity in ASCE 7 , both are taken to be windward drifts, using the larger of the two fetch distances



23

RTU Drifts

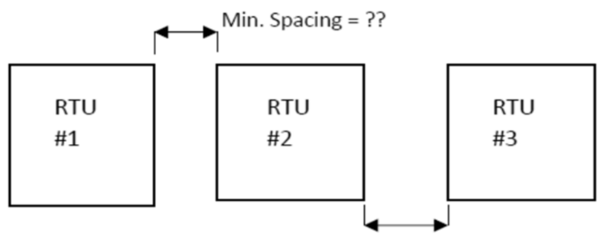
- If one of the plan dimensions < 15 ft. , RTU drift can be neglected at those sides
- Drifts will form, but they are small in horizontal extent



24

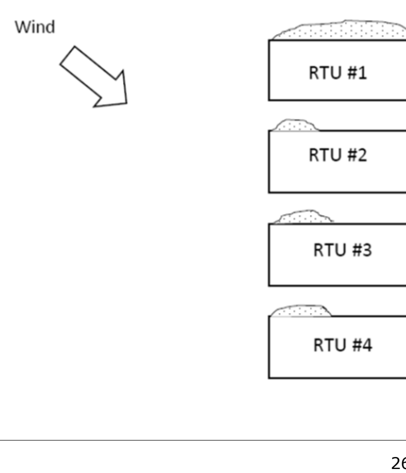
RTU Drifts

- FAQ for RTU's: What is the min. spacing of 12'x12' RTUs to avoid drifts?
- None, 15 ft limit envisions 1 RTU per bay and simple framing



RTU Drifts

- FAQ..The upwind RTU shields the others from drift loads , right ?
- Only if the first one is real tall and wind blows in **one** direction



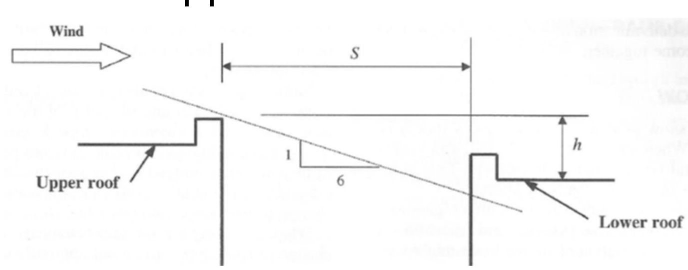
Current Provisions

- Drift Losses
- Leeward Drifts
- Windward Drifts
- Parapet Wall Drifts
- RTU Drifts
- **Drifts on Adjacent Structures**
- Gable Roof Drifts (aka Unbalanced Load)

27

Adjacent Structure Drift

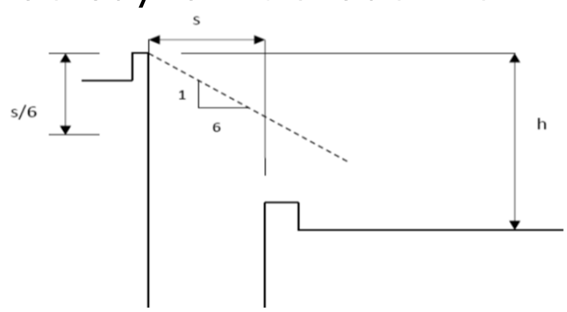
- Drifts are assumed to form on lower roof if it is close to (s < 20’) **and** low enough (s<6h) to be in aerodynamic shade of upper level roof



28

Adjacent Structure Drift

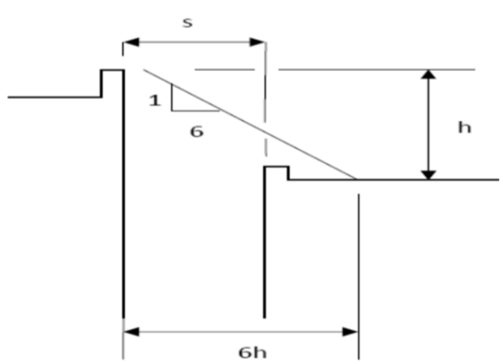
Drift height is **smaller** of h_d for upper roof snow source and (h-s/6) space below aerodynamic shade line



29

Adjacent Structure Drift

Horizontal extent is **smaller** of $6h_d$ or (6h-s)



30

Adjacent Structure Drift

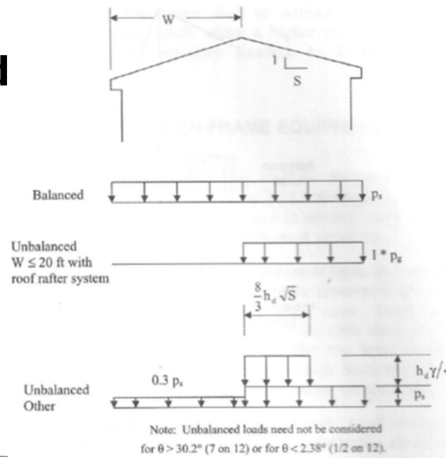
For small gaps we have an inconsistency. For ordinary leeward drifts, the width is $4h_d$, unless $h_d > h_c$ in which case we set the height at h_c and increase the width. For adjacent drifts we do not start with 4 h_d and then possibly increase the width, we start with the 1 on 6 shade line. This approach is conservative and simpler, but for small gap the width could be 6 h_d

Current Provisions

- Drift Losses
- Leeward Drifts
- Windward Drifts
- Parapet Wall Drifts
- RTU Drifts
- Drifts on Adjacent Structures
- **Gable Roof Drifts** (aka Unbalanced Load)

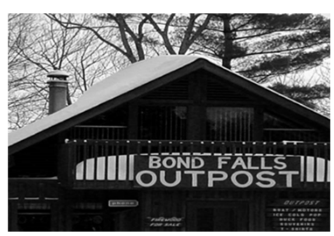
Gable Drifts-Roof Rafter

Two unbalanced loads. **Uniform load** specified for roof rafter systems (W≤20’ , prismatic , simple span eave-ridge). Members likely from **uniform load** span tables.



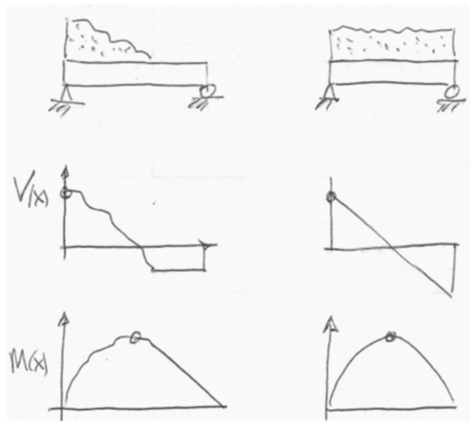
Gable Drifts-Roof Rafter

- Expected drift shape **not** uniform eave to ridge
- V_{max} & M_{max} for uniform Ip_g > V_{max} & M_{max} for expected drift shape



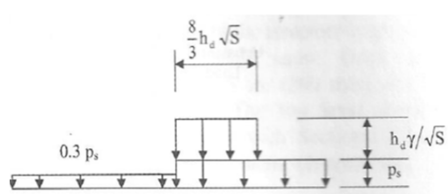
Gable Drifts – Roof Rafter

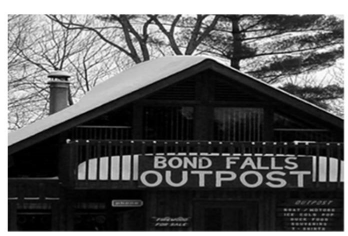
- **Location** of uniform load M_{max} (midspan) not same as for expected drift
- OK since roof rafters are **prismatic**



Gable Drifts – "Others"

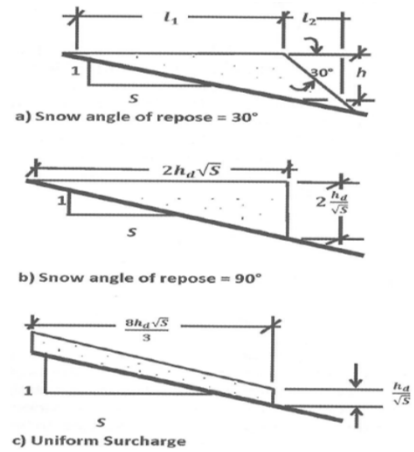
- The location of the drift surcharge for "others" more realistic – **immediately downwind of ridge**





Gable Drifts – "Others"

- Two potential shapes for a horizontal top surface shown
- Top likely most accurate, bottom (one actually used) more SE friendly



37

Gable Drifts – "Others"

- Surcharge X-sectional area based on **leeward roof step relation** for h_d
- Water Flume tests suggest **similar trapping efficiency**

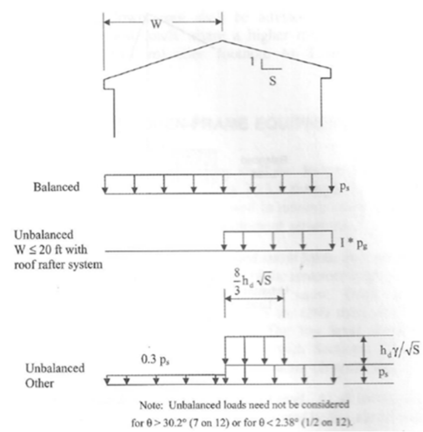
EXPOSURE	VELOCITY RANGE (ft/sec)	GABLE ROOF 2.5 DEGREE	GABLE ROOF 5 DEGREE	GABLE ROOF 10 DEGREE	LEEWARD ROOF STEP
Rural	0.25-0.45	32%	37%	44%	55%
Suburban	0.30-0.45	43%	50%	59%	47%
Urban	0.30-0.45	43%	49%	53%	58%

Table 1 Average Trapping Efficiencies for Gable Roof and Leeward Roof Step Geometries.

38

Gable Roof Drifts – Slope Limits

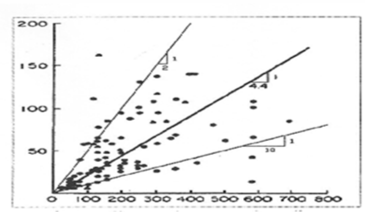
- ☐ There is a **range of roof slopes** which require gable drifts
- ☐ Lower limit is ½ on 12
- ☐ Upper limit is 7 on 12



39

Gable Drifts -Upper Limit

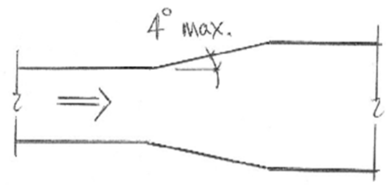
- ☐ Observations by TTEA- unbalance for 6 on 12 & less
- ☐ Consistent with max slope of roof step drifts 1V:2H
- ☐ Angle of repose of drifted snow < 30°

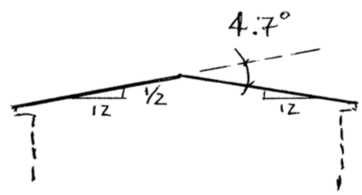


40

Gable Drift -Lower Limit

- Minimal case histories w/ slopes less than ½ on 12
- Venturi tube has angle < 4º to avoid separation
- ½ on 12 has ridge angle > 4º hence separation & drift





General Outline

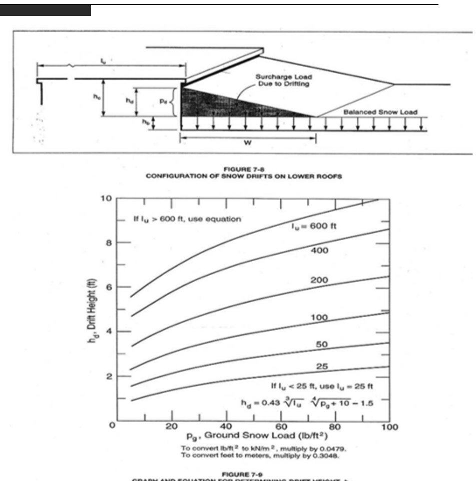
- Current Provisions
- **Future Directions**

Future Directions

- **Regional Differences – Winter Windiness**
- Revised Windward Drift Relations
- Snow Capture Walls

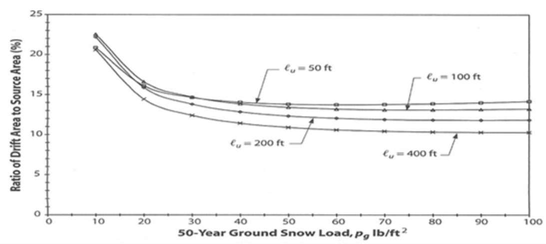
Winter Windiness

- ASCE drifts based on FM Global loss data
- Drift height function of fetch l_u & ground load p_g
- Wind speed **not currently included**



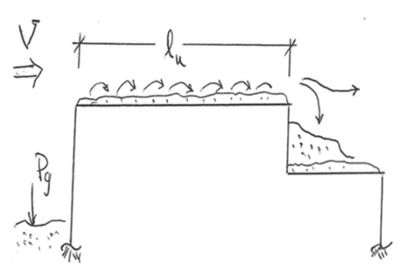
Winter Windiness

- Convenient to normalize step drift by size of snow source area
- Drift Ratio = DR = drift/source
  DR = .5 h_d w γ/l_u P_g



Winter Windiness - Simulation

- Transport rate (# / hr / foot width) based on Tabler & Takeuchi
  $T_r(V) = .00048V^{3.8}$
  $T_r(V)*(L/750)^{0.5}$
- Assumed **trapping efficiency** of 50% based on water flume tests at Rensselaer



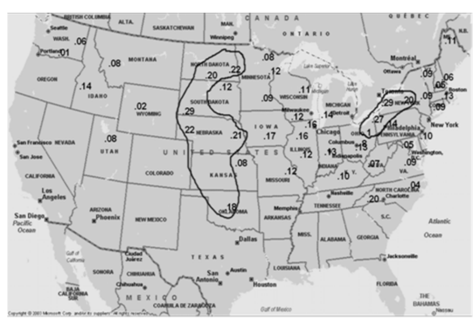
Winter Windiness - Simulation

- Cocca simulated max annual drift for 19 winters (1977-96) at 46 locations across the US
- DR for the 50 year event determined

Station Number	Station Name	Station Number	Station Name
1	Spokane, WA	24	Springfield, IL
2	Yakima, WA	25	Grand Rapids, MI
3	Boise, ID	26	Indianapolis, IN
4	Helena, MT	27	Lexington, KY
5	Salt Lake City, UT	28	Akron, OH
6	Lander, WY	29	Columbus, OH
7	Bismarck, ND	30	Charleston, WV
8	Fargo,	31	Asheville, NC
9	Rapid City, SD	32	Raleigh, NC
10	Aberdeen, SD	33	Richmond, VA
11	Scottsbluff, NE	34	Baltimore, MD
12	Norfolk, NE	35	Philadelphia, PA
13	Topeka, KS	36	Williamsport, PA
14	Oklahoma City, OK	37	Erie, PA
15	International Falls, MN	38	Buffalo, NY
16	Duluth, MN	39	Syracuse, NY
17	Minneapolis, MN	40	Albany, NY
18	Des Moines, IA	41	Hartford, CT
19	St. Louis, MO	42	Boston, MA
20	Madison, WI	43	Concord, NH
21	Green Bay, WI	44	Burlington, VT
22	Chicago, IL	45	Portland, ME
23	Rockford, IL	46	Caribou, ME

Winter Windiness - Simulation

- For l_u = 250 ft.
- DR for Buffalo ~ .29
- DR for Yakima~ .06
- DR_{ASCE} = .126 for Buffalo w/ P_g = 39
- DR_{ASCE} = .135 for Yakima w/ P_g = 30



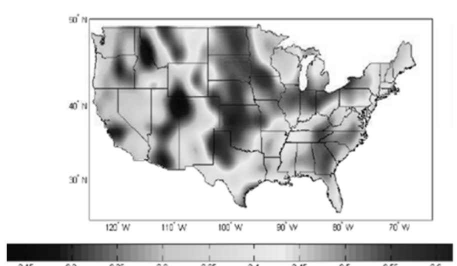
Winter Windiness

Physics based simulation results suggest that there are **significant differences** between expected (50 year MRI) drift size for locations with the **same** fetch and **similar** Pg.

Yakima appears to have infrequent and/or weak winter winds while Buffalo appears to have frequent and/or strong winter winds

Winter Windiness

- Three wind parameters were considered
- W_1~ mean Nov-Mar wind speed
- **W_2~ % V>10 mph for Nov-Mar**
- W_3 ~mean Nov-Mar $V^{3.8}$ for V>10



Winter Windiness

- Multiple regression gives following code suitable relation for Drift Ratio
  $DR = 4.53\, W_2^{1.66} / P_g^{.262}\, l_u^{.295}$
- Drift Size becomes

  Drift Size(#/ft width) = $DR\, P_g\, l_u$

  Drift Size = $4.53\, W_2^{1.66}\, P_g^{.738}\, l_u^{.705}$

51

Winter Windiness

W_2 varies 0.149 (Yakima) - 0.715 (Boston)

($(.715/.149)^{1.66} = 13.5$

P_g varies 5 psf (TX) – 70 psf (MN)

$(70/5)^{.738} = 7.01$

l_u typically varies from 100 to 1500 ft

$(1500/100)^{.705} = 6.74$

Winter Windiness has **stronger influence** than either ground load or fetch

52

Winter Windiness

- Current ASCE 7 drift function of fetch and ground snow load
- Physics based simulation suggests that winter windiness has larger influence
- Drift relation w/ winter windiness:
  - typical site ~ 30 % ↓ wrt ASCE
  - calmest site (Yakima) ~ 90 % ↓
  - windiest site (Boston) ~ 70 % ↑

53

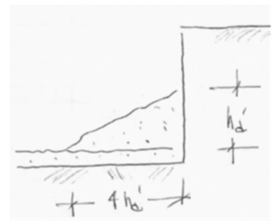
Future Directions

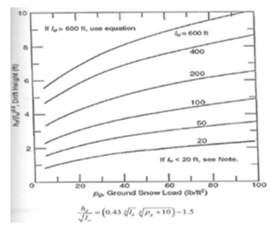
- Regional Differences – Winter windiness
- **Revised Windward Drift Relations**
- Snow Capture Walls

54

Revised Windward Drifts

Current ASCE 7 windward drift is right triangular w/ height h_d' , width 4 h_d' where h_d' is 75 % of that for leeward. Hence x-sectional area of windward ~ 56 % of leeward.

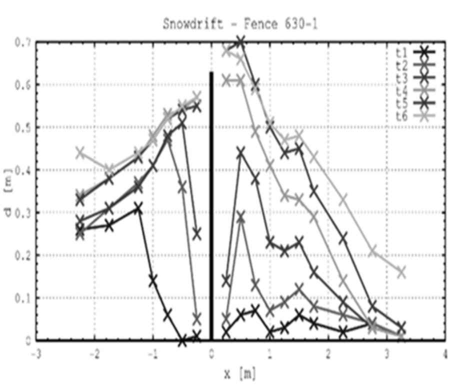




55

Revised Windward Drifts

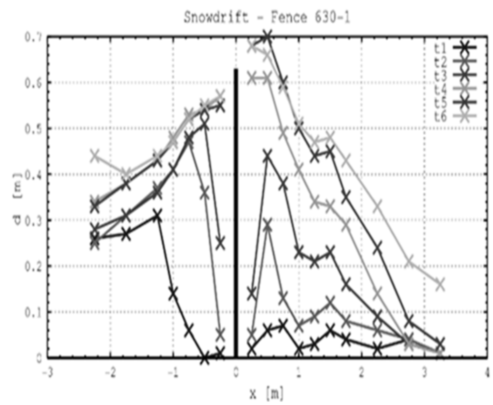
- Recent field measurements from Norway provides better understanding
- Snapshots in time of drift formation – wind from left



56

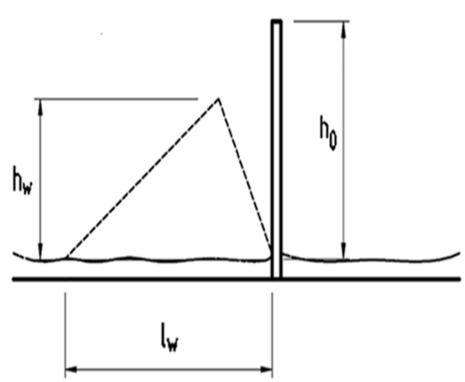
Revised Windward Drifts

- Blue line is **Phase I** – only windward drift formation , 100% trapping efficiency
- Other lines are **Phase II** - both leeward & windward drifts



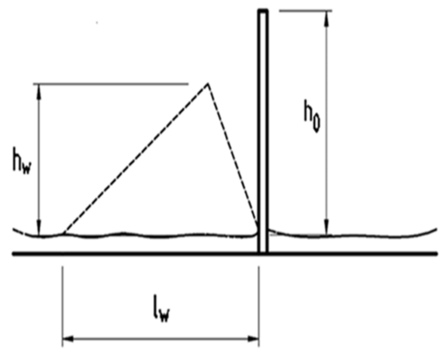
Revised Windward Drifts

- Phase I shape triangle but not right triangle
- Stagnation point at ~ .6 h_o wind below results in downward vortex and gap at wall



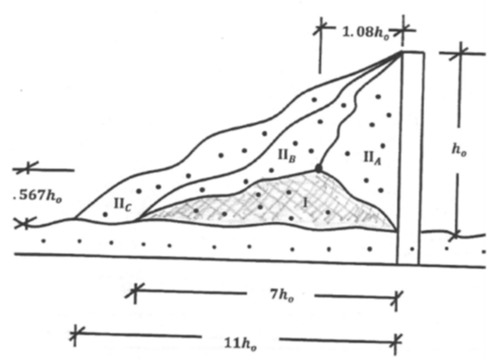
Revised Windward Drifts

- $h_w \sim .57\ h_o$
- $l_w \sim 7\ h_o$
- Transition from Phase I to II starts when drift height at stagnation point
- Horizontal extend now ~ 7 times height



Revised Windward Drifts

- When Phase I filled , quad morphs into right triangle shape
- Full Phase II windward now right triangle w/ 1 to 11 rise to run



Revised Windward Drifts

- Assuming that the leeward trapping efficiency in Phase II is 50 %, knowing the growth of the leeward drift wrt the Phase II windward ($wind_{II}/lee_{II}$ ~ 45 %), the windward Phase II trapping efficiency ~ 25%
- Compared current and revised windward drifts for p_g = 10 or 40 psf, l_u = 50 or 500 ft., h = 4 or 12 ft.

Revised Windward Drifts

- Drift heights surprisingly close. Drift widths different revised/current ranges from 1.4 to 3.3

					ASCE 7			Proposed Approach			
Comb	P_g	$l_u(ft.)$	$h(ft.)$	DR	$h_w(ft.)$	$l_w(ft.)$	$A_w(ft^2)$	$h_w(ft.)$	$l_w(ft.)$	$A_w(ft^2)$	Shape
1	10	50	4	.21	1.38	5.52	3.8	1.48	18.3	13.5	I
2	10	50	12	.21	1.38	5.52	3.8	1.48	18.3	13.5	I
3	10	500	4	.20	3.54	20.6	36.6	3.54	38.9	68.8	II_C
4	10	500	12	.20	4.28	17.1	36.6	4.58	56.6	129	I
5	40	50	4	0.14	2.03	8.1	8.2	2.54	17.8	22.5	II_B
6	40	50	12	0.14	2.03	8.1	8.2	2.15	26.6	28.6	I
7	40	500	4	0.11	2.55	20.4	26.0	2.55	28.1	35.8	II_C
8	40	500	12	0.11	5.67	22.7	64.3	5.98	73.8	220.6	I

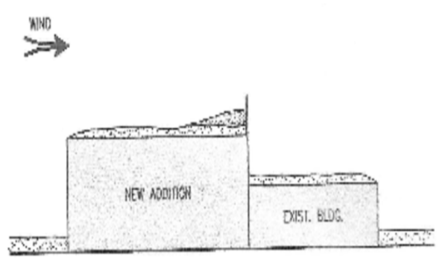
Future Directions

- Regional Differences – Winter windiness
- Revised Windward Drift Relations
- **Snow Capture Walls**

63

Snow Capture Wall

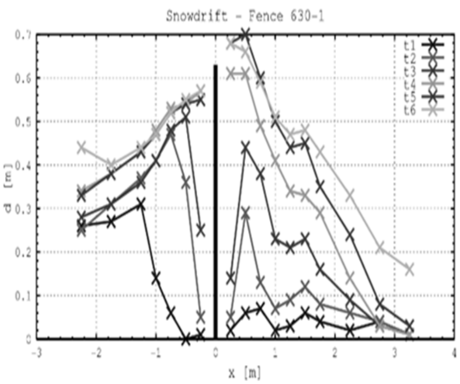
- New taller **addition** adjacent to **existing** roof is common issue
- One solution is tall wall at the common column line that traps the upper level snow



64

Snow Capture Wall

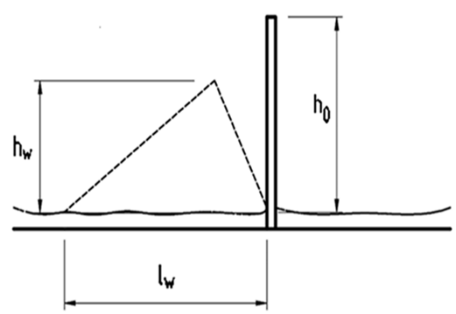
- Full scale field measurements by Potac & Thiis are useful
- Windward drift height before significant leeward drift formation **key parameter**



65

Snow Capture Wall

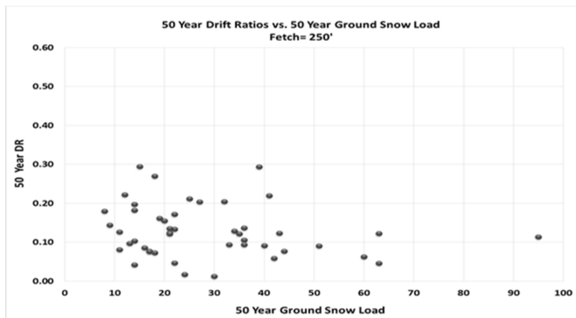
- Windward only drift cross-sectional area $A_w = h_w l_w / 2$
- Normalized area A_w/h_o^2 ranged from 1.15 to 2.49 with a mean of 2.0



66

Snow Capture Wall

- Roof Step Drift Ratios variable - DR generally decreasing functions of P_g & l_u



67

Snow Capture Wall

- Want wall big enough to capture all expected snow transport
- Factor of **2** since DR based on capture of **half** expected snow transport (trapping efficiency = 50 %)

$$A_w \gamma > 2\ DR\ P_g\ l_u$$

$$A_w = \alpha h_o^2$$

$$h_o > \sqrt{2\ DR\ p_g\ l_u / \alpha\gamma}$$

68

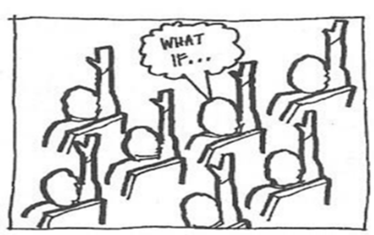
Snow Capture Wall

- Which DR & α should be used ??
- Largest h_o based on two combinations :
  #1 mean DR & α = 1.15
  #2 mean+1 s.d. DR & α = 2.0 (mean)
- Surprisingly large h_o in feet

P_g (psf)	l_u (ft)			
	50	250	500	1000
10	3.9	6.9	9.0	12.0
20	5.6	10.1	13.1	16.1
40	7.4	13.4	17.3	21.4

69

Thank you for your attention
Questions ???



70