Learning Event 2018 - GPD Turkey

Glass Performance Days 2018
March 07-09, 2018, Istanbul, Turkey

Case study from
New Istanbul Airport – Largest in Europe

Window glass panel design methods

Mehmet Burak Yılmaz
PhD, PE, M.ASCE, Structural Eng.
mehmetburakyilmaz@macrostatic.com
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WINDOW GLASS PANEL

What does the **window glass pane** mean in terms of structural calculations?

Can **structural analysis** be performed for non-structural elements?

Is the window glass a **non-structural** element?

Which **loads & effects** should we take into consideration in the calculation of window panes?

Is there a **constant** value for the bending **strength** of the glass for all load situations?

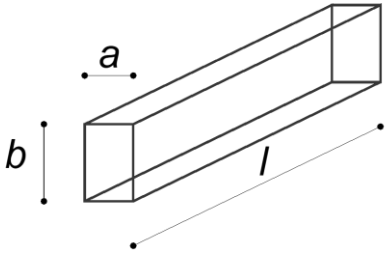
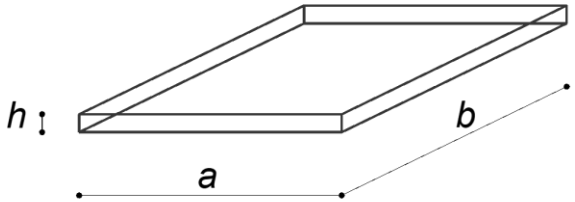
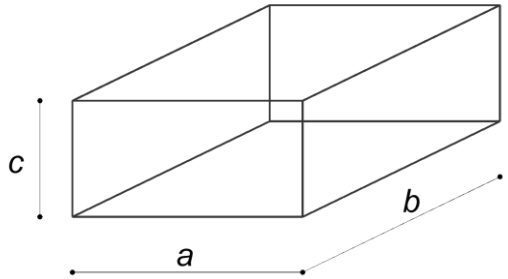
Is there any **load sharing** between the inner and outer panes of IGU?

How should we **combine the loads**?

How does **interlayers** of laminated glass affect the calculations?

WINDOW GLASS PANEL

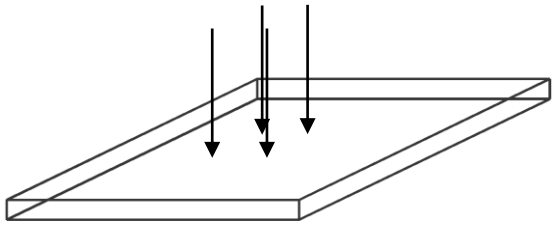
STRUCTURAL ELEMENTS IN STRUCTURAL ANALYSIS

TYPE OF ELEMENTS		USAGE IN FACADE
FRAME	 $a,b < l/2$	Aluminium curtain wall profiles, glass columns & beams, steel rods
PLATE, MEMBRANE, SHELL	 $h < \frac{a,b}{10\text{-}20}$	Window glass panels, aluminium panels, connecting plates, etc.
SOLID	 *a, b, c can be any value*	Silicone, bolts, screws, etc.

WINDOW GLASS PANEL

STRUCTURAL ELEMENTS IN STRUCTURAL ANALYSIS

PLATE



All loads are perpendicular to the plane

FINALLY!

We assume that:

- Dead load (self load) of glass in vertical window glass panel is negligible for stress states. Because in-plane bending capacity of window glass panel is always adequate for standard application.
- Buckling of the panel is restricted by edge constraint conditions of pressure plates or structural silicone for standard application.
- The panel is supported by all sides. There is no point support.

We can analyse Window Glass Panel as a plate element

WINDOW GLASS PANEL

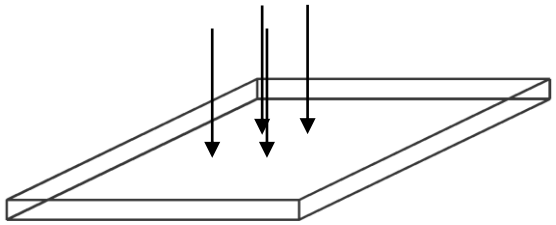
STRUCTURAL ELEMENTS IN STRUCTURAL ANALYSIS

Now we have defined the type of the problem in structural theory.

WINDOW GLASS PANEL

STRUCTURAL ELEMENTS IN STRUCTURAL ANALYSIS

PLATE



All loads are perpendicular to the plane

I want to celebrate the International Women's Day of all women and Sophie Germain.

$$\frac{\partial^4 w}{\partial x^4} + 2\frac{\partial^4 w}{\partial x^2 \partial y^2} + \frac{\partial^4 w}{\partial y^4} = \frac{q}{D}$$

Marie-Sophie Germain

Marie-Sophie Germain

Born	1 April 1776 Rue Saint-Denis, Paris, France
Died	27 June 1831 (aged 55) Paris, France
Residence	France
Nationality	French
Known for	Elasticity theory and number theory (e.g. Sophie Germain prime numbers)
	Scientific career
Fields	Mathematician, physicist, and philosopher
Academic advisors	Carl Friedrich Gauss (epistolary correspondent)
	Notes
Other name:	Auguste Antoine Le Blanc

WINDOW GLASS PANEL

STRUCTURAL ELEMENTS IN STRUCTURAL ANALYSIS

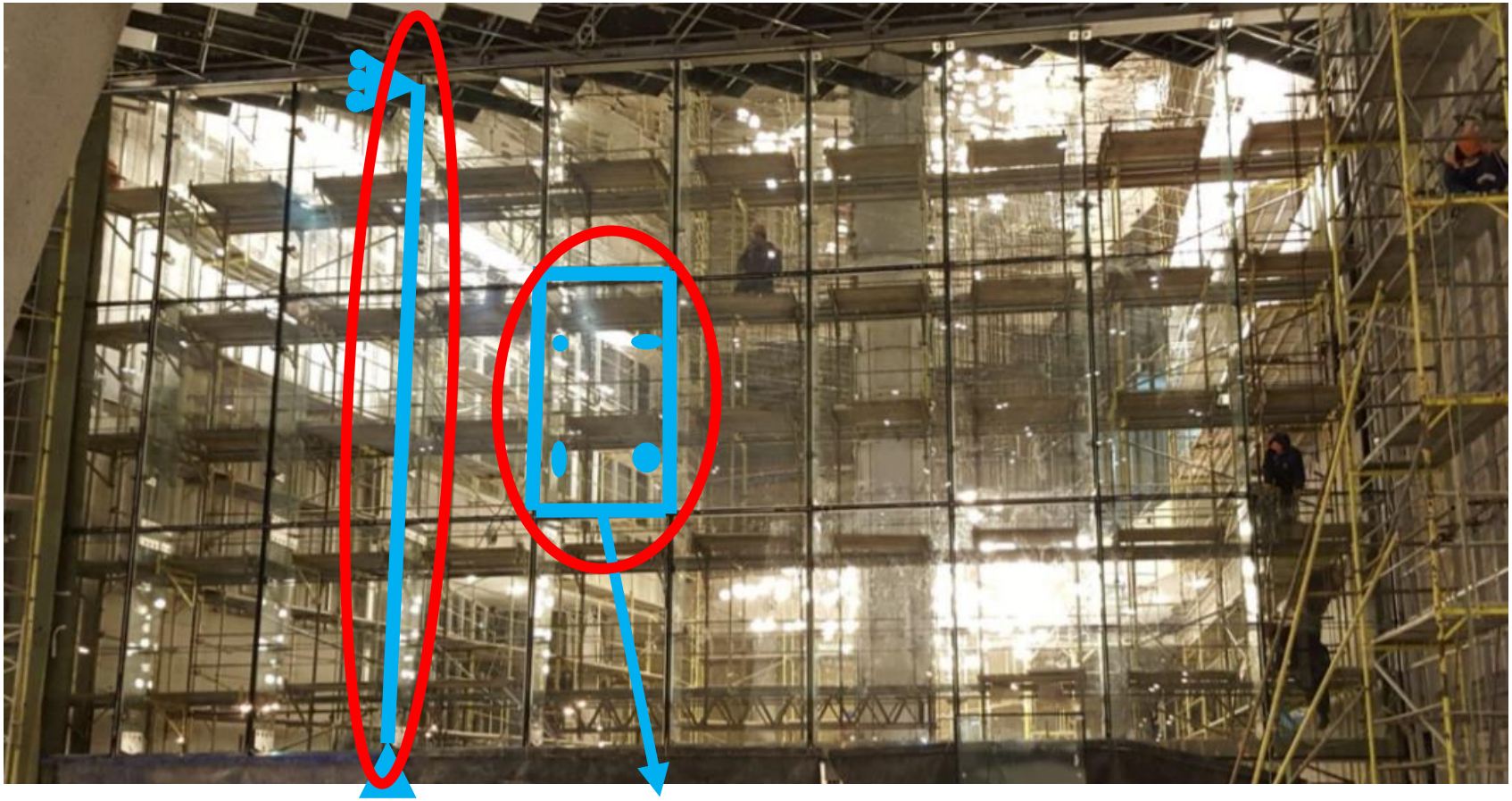
LET'S TRY TO FIND

"WINDOW GLASS PANEL"

ON NEXT SLIDES

WINDOW GLASS PANEL

STRUCTURAL ELEMENTS IN STRUCTURAL ANALYSIS

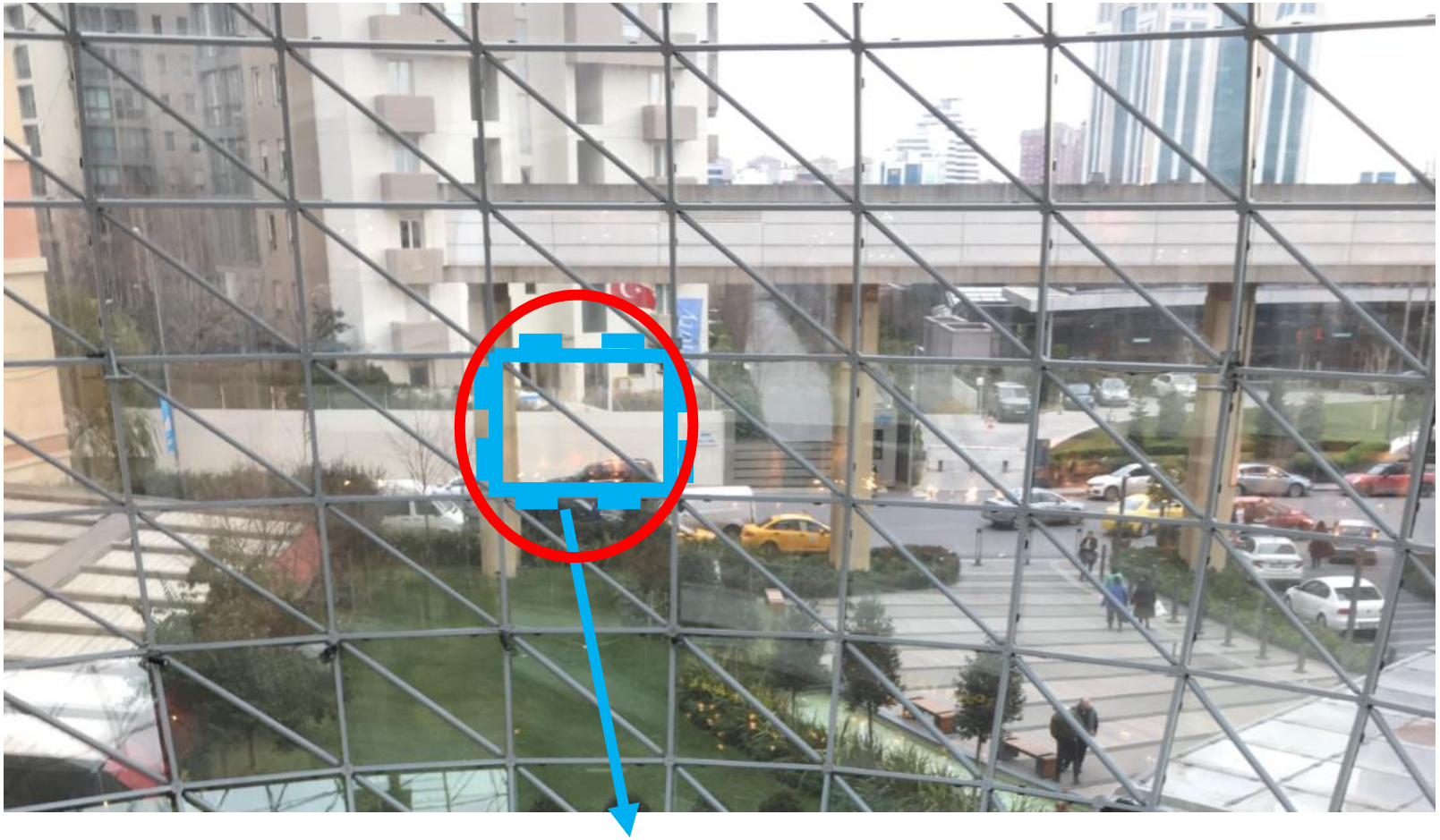


Column
FRAME

Point supported
SHELL

WINDOW GLASS PANEL

STRUCTURAL ELEMENTS IN STRUCTURAL ANALYSIS



Local edge supported **SHELL**

WINDOW GLASS PANEL

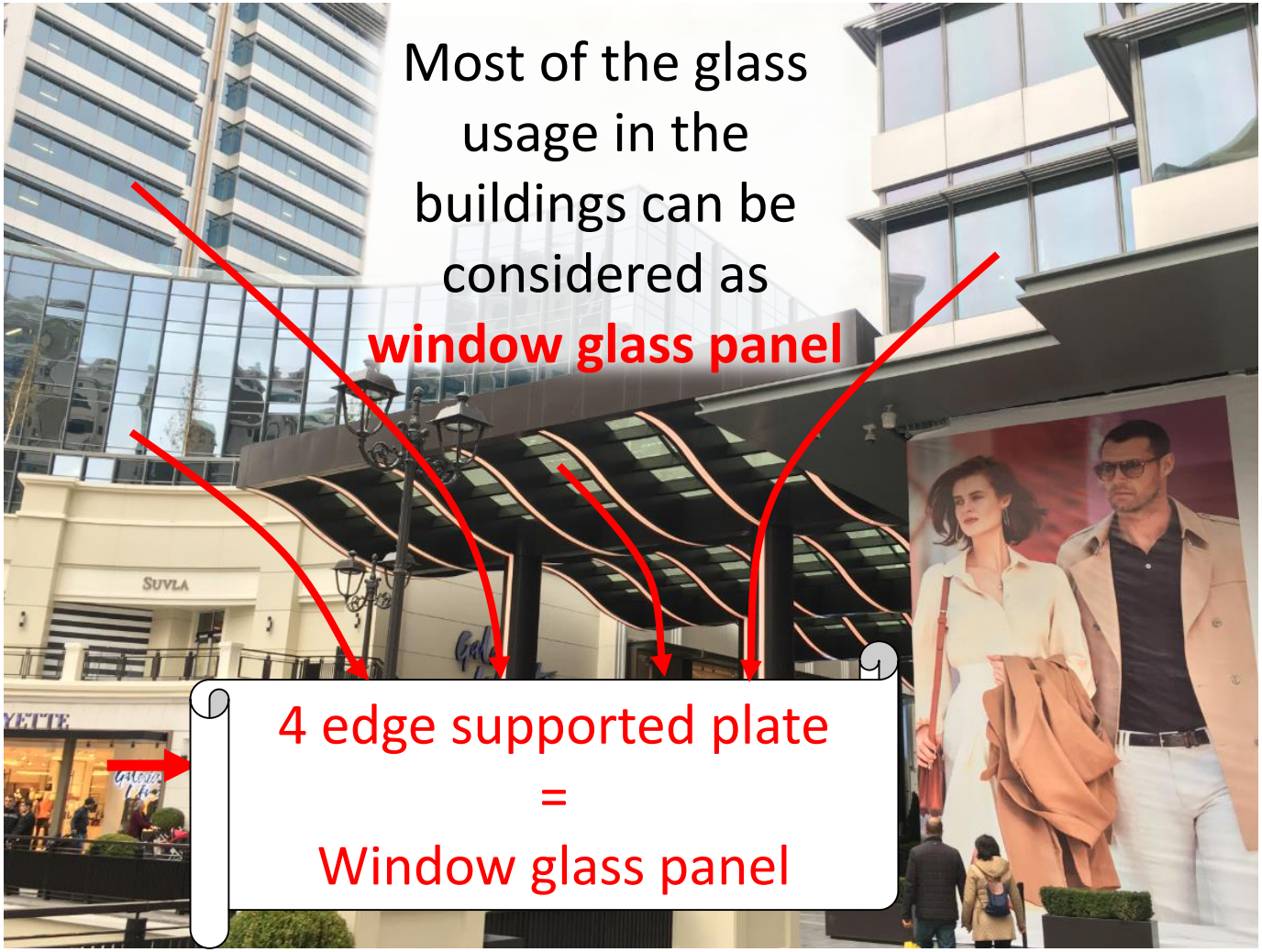
STRUCTURAL ELEMENTS IN STRUCTURAL ANALYSIS

Two-edge supported **SHELL** (buckling should be checked)

WINDOW GLASS PANEL

STRUCTURAL ELEMENTS IN STRUCTURAL ANALYSIS

FINALLY!



WINDOW GLASS PANEL

DESIGN

1

DIMENSIONS OF PANEL AND INITIAL THICKNESS OF PANES

2

PURPOSE OF USAGE AND DETERMINATION OF LOADS

3

COMBINATION OF LOADS

4

DISTRIBUTION OF LOADS FOR INNER & OUTER PANES

5

DETERMINATION OF STRESSES AND DEFLECTIONS FOR EACH COMB.

6

DETERMINATION OF DESIGN STRENGTH FOR EACH COMBINATIONS

7

CHECK!

$\sigma_{max} < f_{g,d}$

&

$w_{max} < w_d$

WINDOW GLASS PANEL

DESIGN

1 DIMENSIONS OF PANEL AND INITIAL THICKNESS OF PANES"

2 PURPOSE OF USAGE AND DETERMINATIO N OF LOADS

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5 DETERMINATION OF STRESSES AND DEFLECTIONS FOR EACH COMB.

6 DETERMINATIO N OF DESIGN STRENGTH FOR EACH COMBINATIONS

7 CHECK!

$\sigma_{max} < f_{g,d}$

&

$w_{max} < w_d$

STRUCTURAL DESIGN IS AN ITERATIVE PROCESS FOR GLASS!

WINDOW GLASS PANEL

LOADS

2

PURPOSE OF USAGE AND DETERMINATION OF LOADS

PURPOSE OF USAGE	LOADS (ACTIONS)
Curtain wall infill	Wind
Curtain wall & Barrier	Snow
Skylight	Dead Load
Skylight (only maintainance access)	Altitute Load (ΔH, Δp)
Skylight (public access)	Climate Load (seasonal, daily)
Blast resistant	Solar Irradiance
Bullet shield	Live Load
Space shuttles	Soft body impact (Class)
(1200˚C short period)	Hard body impact, hail impact
	Blast loads (TNT, petrochemical), bullet, fire etc.

WINDOW GLASS PANEL

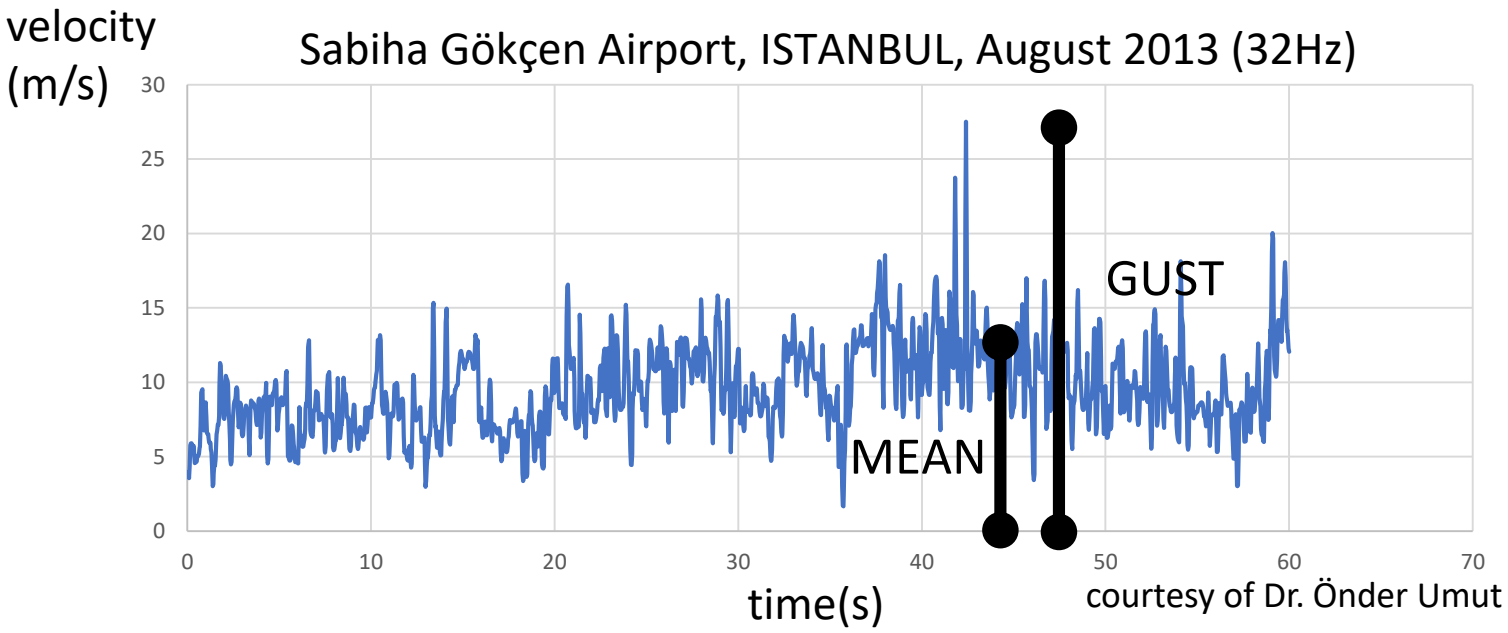
LOADS

LOADS (ACTIONS)

Wind

PURPOSE OF USAGE AND DETERMINATION OF LOADS

duration?
Short, medium, long
effects on strength and rigidity



courtesy of Dr. Önder Umut

WINDOW GLASS PANEL

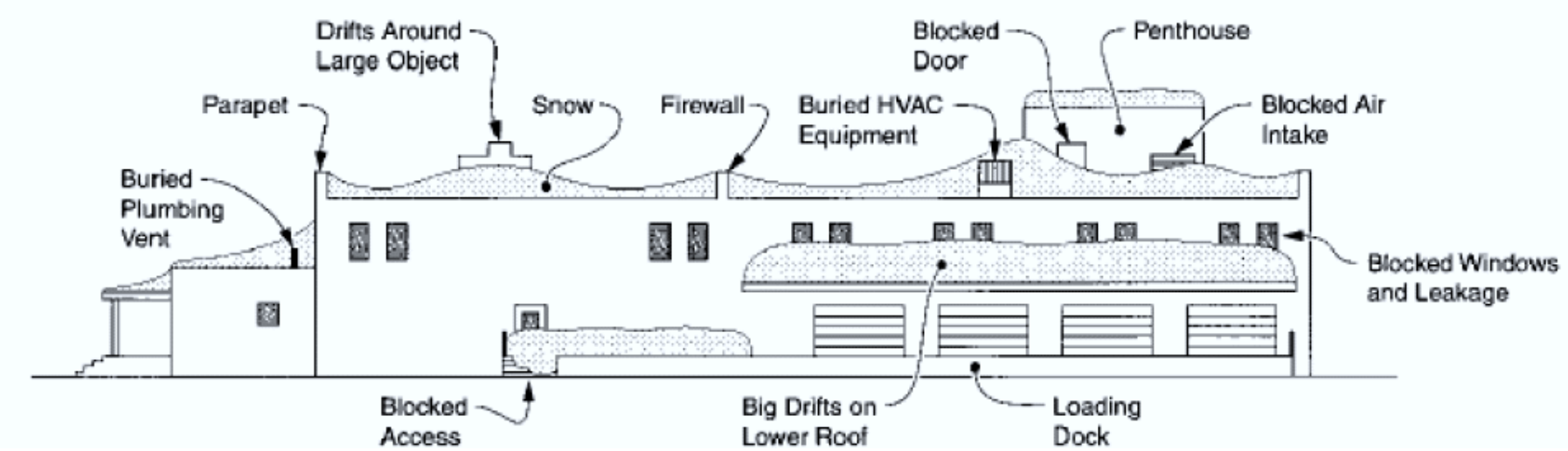
LOADS

LOADS (ACTIONS)

SNOW

PURPOSE OF USAGE AND DETERMINATION OF LOADS

duration?
Short, medium, long
effects on strength and rigidity



WINDOW GLASS PANEL

LOADS

LOADS (ACTIONS)

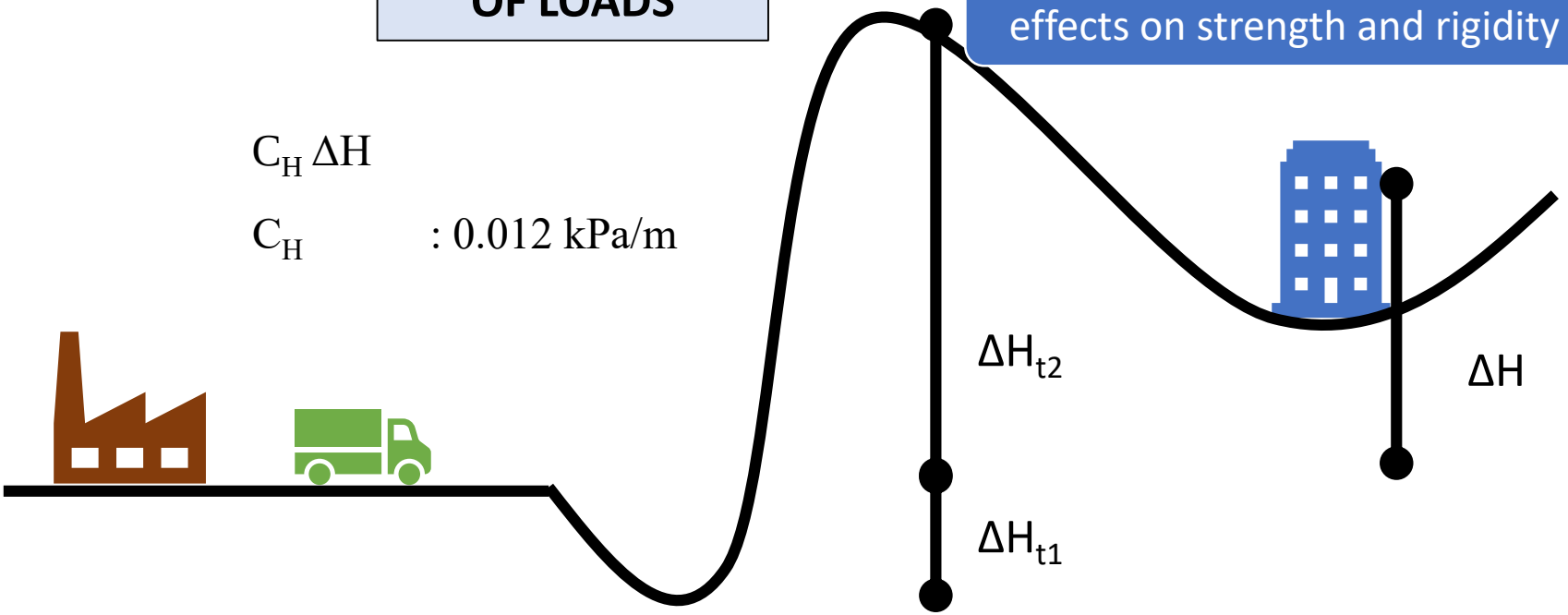
ALTITUDE

PURPOSE OF USAGE AND DETERMINATION OF LOADS

duration?
Short, medium, long
effects on strength and rigidity

$C_H \Delta H$

C_H : 0.012 kPa/m



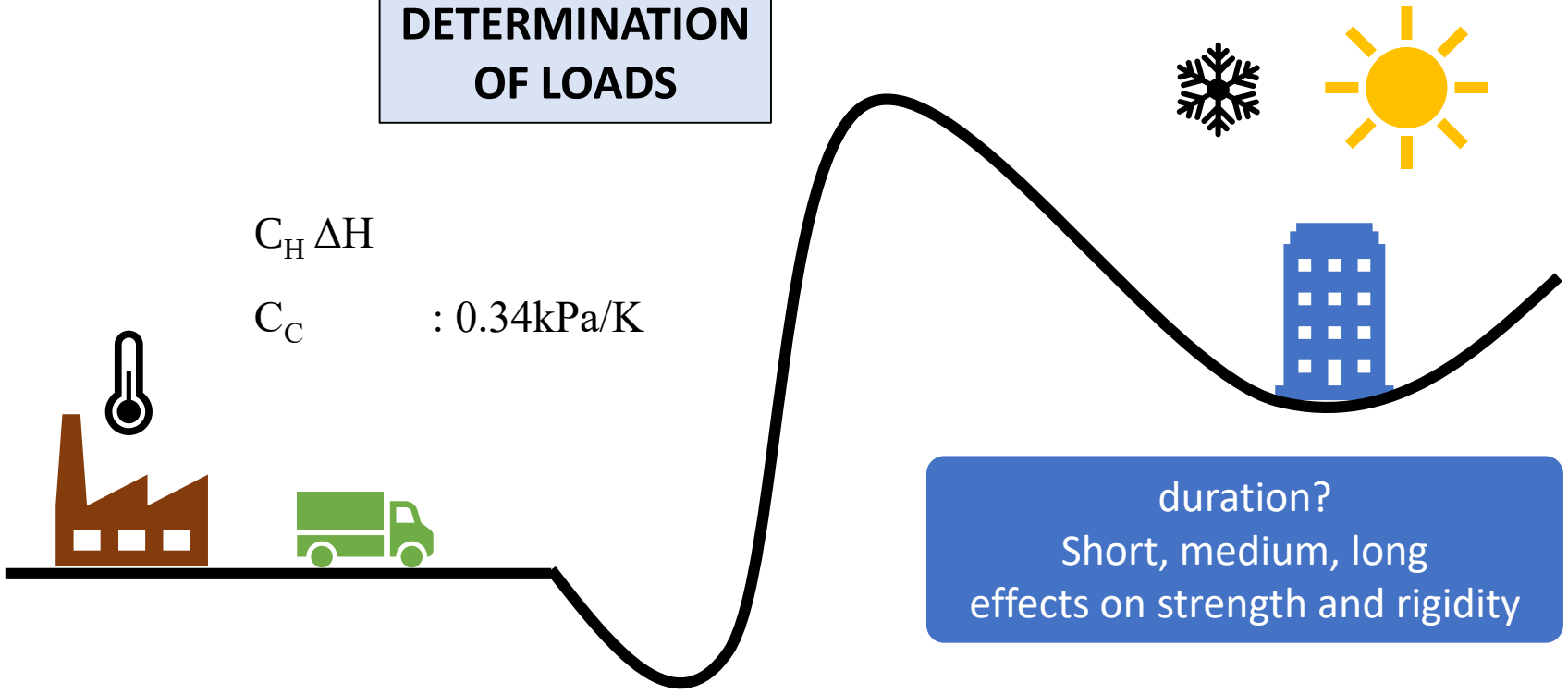
WINDOW GLASS PANEL

LOADS

LOADS (ACTIONS)

CLIMATE

PURPOSE OF USAGE AND DETERMINATION OF LOADS



duration?
Short, medium, long
effects on strength and rigidity

WINDOW GLASS PANEL

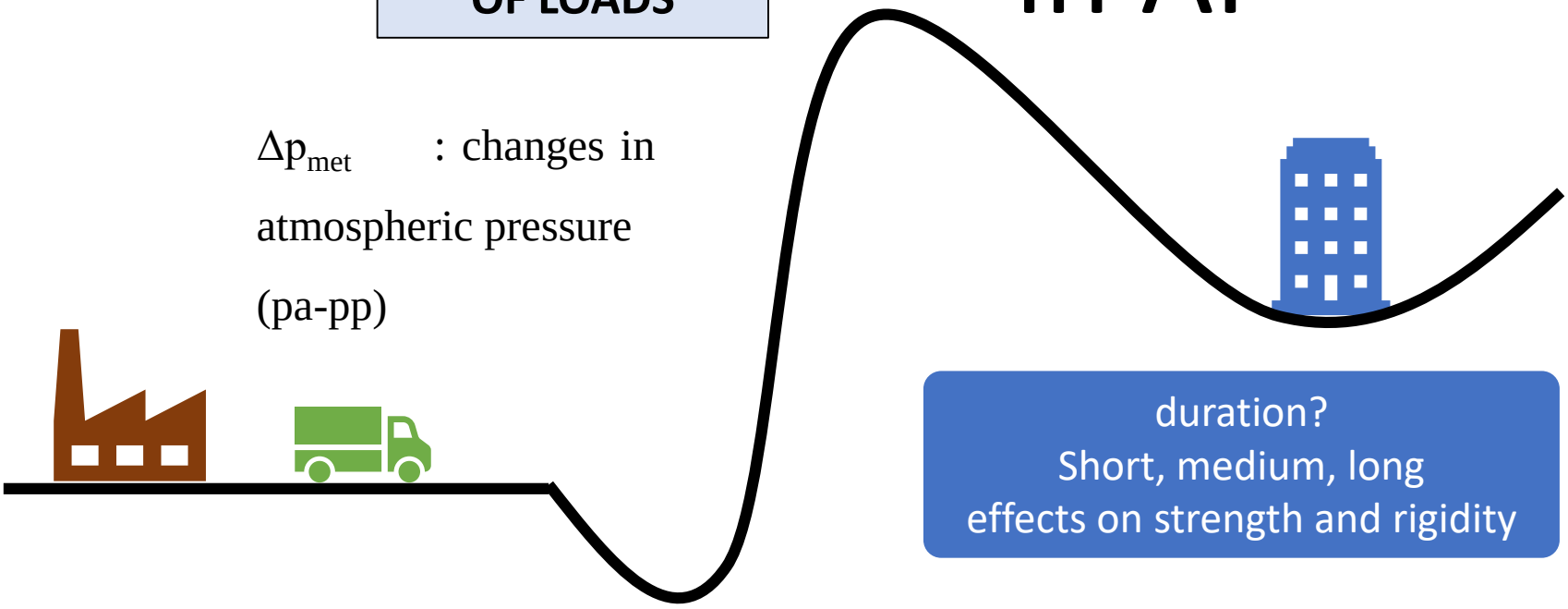
LOADS

LOADS (ACTIONS)

CHANGES in AP

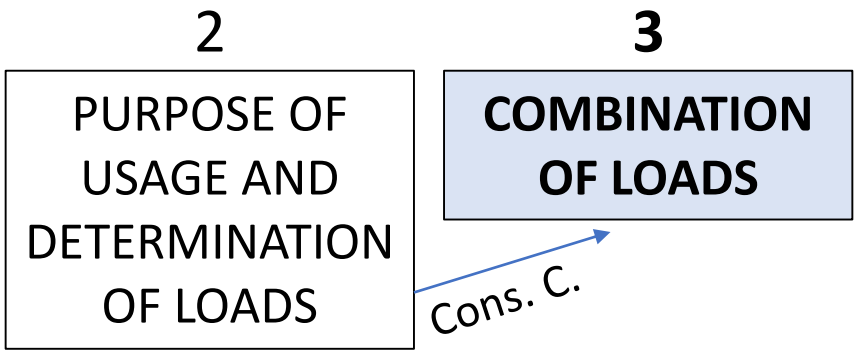
PURPOSE OF USAGE AND DETERMINATION OF LOADS

Δp_{met} : changes in atmospheric pressure (pa-pp)



duration?
Short, medium, long
effects on strength and rigidity

WINDOW GLASS PANEL DESIGN

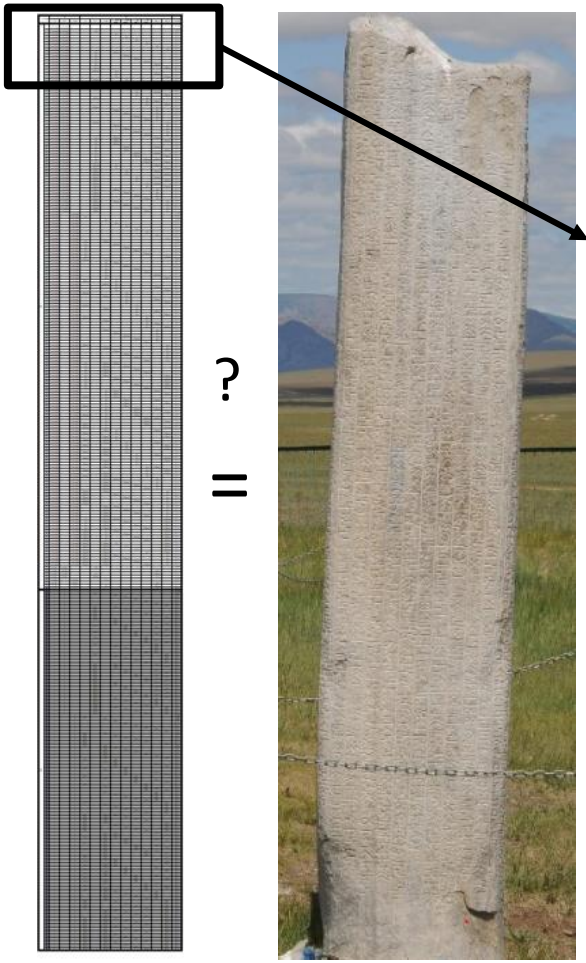


classes of consequences EN1990

CC1 (storage b., greenhouse, ..)
CC2 (residential, office, ..)
CC3 (public b., shopping malls, ..)
CC0 non-structural (extreme. limited conseq)

WINDOW GLASS PANEL DESIGN

Orkhon inscriptions??



?

=

3

COMBINATION OF LOADS

LOADS (ACTIONS)

Wind
Snow
Dead Load
Altitute Load (ΔH, Δp)
Climate Load (seasonal, daily)
Live Load

	EN16612												
	G			Q									
	DL	ALs	ALw	SL	CLs	CLw	LL-Point-inner	LL-Point-outer	LL-Line-inner	LL-Line-outer	WLs	WLp	kmod
1	γ_G	γ_G											0.29
3	γ_G	γ_G		γ_Q									0.45
4	γ_G	γ_G			γ_Q								0.58
5	γ_G	γ_G				γ_Q							0.58
6	γ_G	γ_G					γ_Q						0.69
7	γ_G	γ_G						γ_Q					0.69
8	γ_G	γ_G							γ_Q				0.89
9	γ_G	γ_G								γ_Q			0.89
10	γ_G	γ_G									γ_Q		0.74
11	γ_G	γ_G										γ_Q	0.74
12	γ_G	γ_G		γ_Q	$\gamma_Q\Psi_{0,i}$								0.58
13	γ_G	γ_G		γ_Q		$\gamma_Q\Psi_{0,i}$							0.58
14	γ_G	γ_G		γ_Q			$\gamma_Q\Psi_{0,i}$						0.69
15	γ_G	γ_G		γ_Q				$\gamma_Q\Psi_{0,i}$					0.69
16	γ_G	γ_G		γ_Q					$\gamma_Q\Psi_{0,i}$				0.89
17	γ_G	γ_G		γ_Q						$\gamma_Q\Psi_{0,i}$			0.89
18	γ_G	γ_G		γ_Q							$\gamma_Q\Psi_{0,i}$		0.74
19	γ_G	γ_G		γ_Q								$\gamma_Q\Psi_{0,i}$	0.74
20	γ_G	γ_G		$\gamma_Q\Psi_{0,i}$	γ_Q								0.58
21	γ_G	γ_G			γ_Q	$\gamma_Q\Psi_{0,i}$							0.58
22	γ_G	γ_G			γ_Q		$\gamma_Q\Psi_{0,i}$						0.69
23	γ_G	γ_G			γ_Q			$\gamma_Q\Psi_{0,i}$					0.69
24	γ_G	γ_G			γ_Q				$\gamma_Q\Psi_{0,i}$				0.89
25	γ_G	γ_G			γ_Q					$\gamma_Q\Psi_{0,i}$			0.89

prEN16612:2017

WINDOW GLASS PANEL

DESIGN

1

DIMENSIONS OF PANEL AND INITIAL THICKNESS OF PANES

2

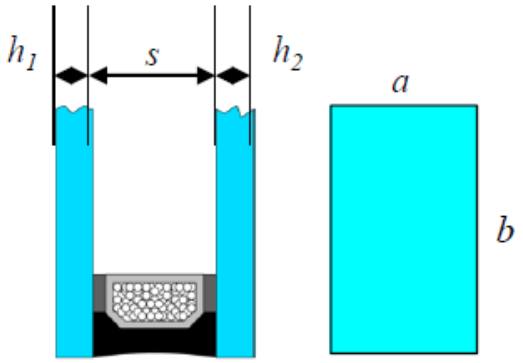
PURPOSE OF USAGE AND DETERMINATIO N OF LOADS

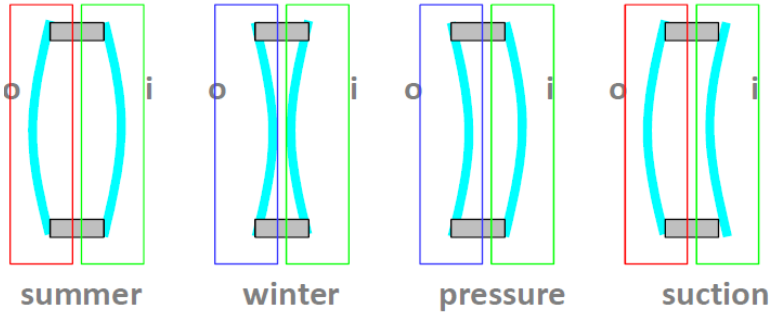
Viscoelastic beha.
Load duration

Relative effective stiffness

4

DISTRIBUTION OF LOADS FOR INNER & OUTER PANES





WINDOW GLASS PANEL

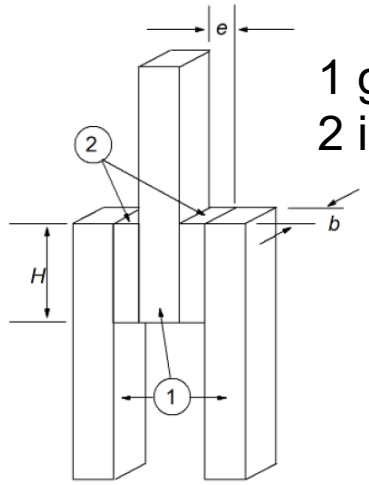
DESIGN

INTERLAYERS

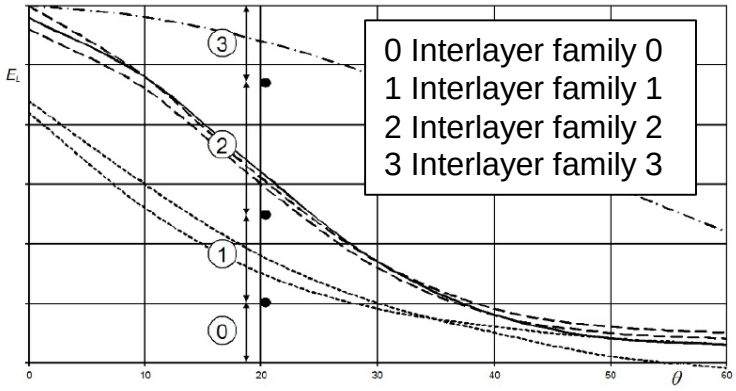
Polyvinyl butyral (PVB)
Ionoplast Polymers
Ethylene Vinyl Acetate (Cross-Linked EVA)
Cast in Place (CIP) liquid resin
Thermoplastic polyurethane (TPU)

4

DISTRIBUTION OF LOADS FOR INNER & OUTER PANES



1 glass
2 interlayer



Viscoelastic properties of interlayers

prEN16613:2017

WINDOW GLASS PANEL DESIGN

Table D.3 — Value of ω associated with interlayer stiffness family and load case

Load case		Family 0	Family 1	Family 2
1	Wind gust load (Mediterranean areas)	0	?	?
2	Wind gust load (other areas)	0	0,3	0,7
3	Wind storm load (Mediterranean areas)	0	?	?
4	Wind storm load (other areas)	0	?	?
5	Personnel balustrade loads - normal duty	0	0,1	0,5
6	Personnel balustrade loads - crowds	0	0	0,3
7	Maintenance loads	0	0	0,1
8	Snow load - external canopies and roofs of unheated buildings	0	0,1	0,3
9	Snow load - roofs of heated buildings	0	0	0,1
10	Climatic loads on insulating glass units: summer	0	?	?
11	Climatic loads on insulating glass units: winter	0	?	?
12	Permanent	0	0	0

Load duration

Viscoelastic beha.

4

DISTRIBUTION OF LOADS FOR INNER & OUTER PANES

İt's hard to determine! But it is worth!

$$h_{ef;w} = \sqrt[3]{\sum_k h_k^3 + 12\omega\left(\sum_i h_k h_{m,k}^2\right)}$$

Effective thickness

WINDOW GLASS PANEL DESIGN

1 DIMENSIONS OF PANEL AND INITIAL THICKNESS OF PANES

2 PURPOSE OF USAGE AND DETERMINATIO N OF LOADS

3 COMBINATION OF LOADS

4 DISTRIBUTION OF LOADS FOR INNER & OUTER PANES

5 **DETERMINATION OF STRESSES AND DEFLECTIONS FOR EACH COMB.**

Large deflection Theory!

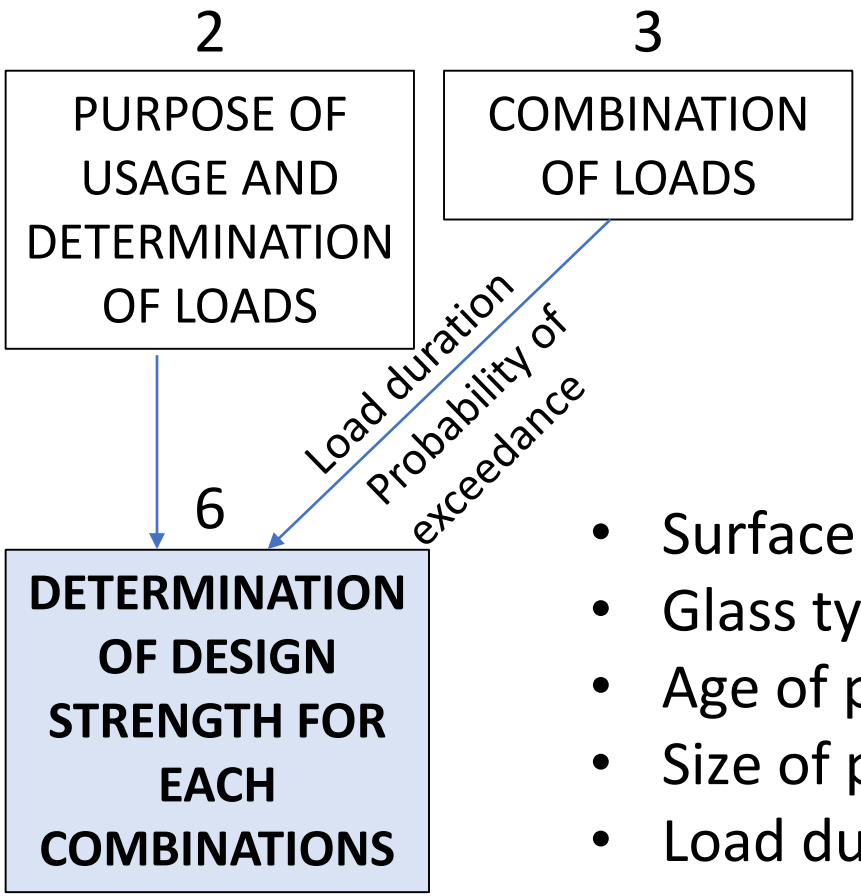
$$\sigma_{max} = k_1 \frac{a^2}{h^2} F_d$$

4 edge supported plate
=
Window glass panel

$$w_{max} = k_4 \frac{a^4}{h^3} \frac{F_d}{E}$$

WINDOW GLASS PANEL

DESIGN



- Surface conditions
- Glass type
- Age of pane
- Size of pane
- Load duration
- Surrounding medium

WINDOW GLASS PANEL

DESIGN

$$f_{g;d} = \frac{k_{mod} k_{sp} f_{g;k}}{\gamma_{M;A}} + \frac{k_v (f_{b;k} - f_{g;k})}{\gamma_{M;v}}$$

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6

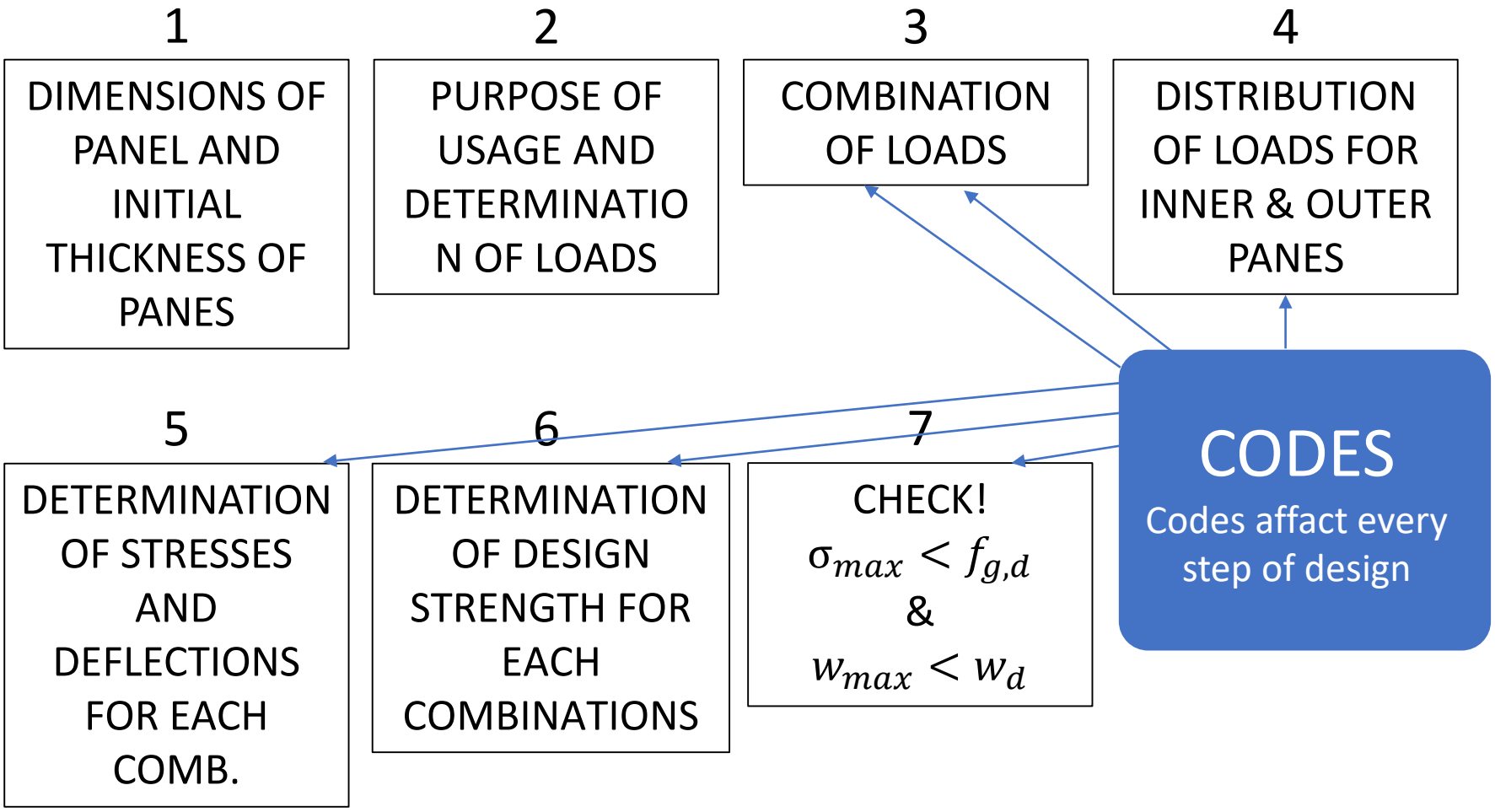
DETERMINATION OF DESIGN STRENGTH FOR EACH COMBINATIONS

Duration	Example	k_{mod}
5 seconds	Single gust	1.00
30 seconds	Domestic balustrade load	0.89
5 minutes	Workplace/public balustrade load	0.77
10 minutes	Multiple gust (storm)	0.74
30 minutes	Maintenance access	0.69
5 hours	Pedestrian access	0.60
1 week	Snow load short-term	0.48
1 month	Snow load medium-term	0.44
3 months	Snow load long-term	0.41
50 years	Permanent (e.g. self-weight and altitude pressure)	0.29

Base glass material	Characteristic bending strength $f_{b;k}$ (N/mm^2)		
	Thermally toughened	Heat-strengthened	Chemically toughened
Float glass or drawn sheet	120	70	150

WINDOW GLASS PANEL

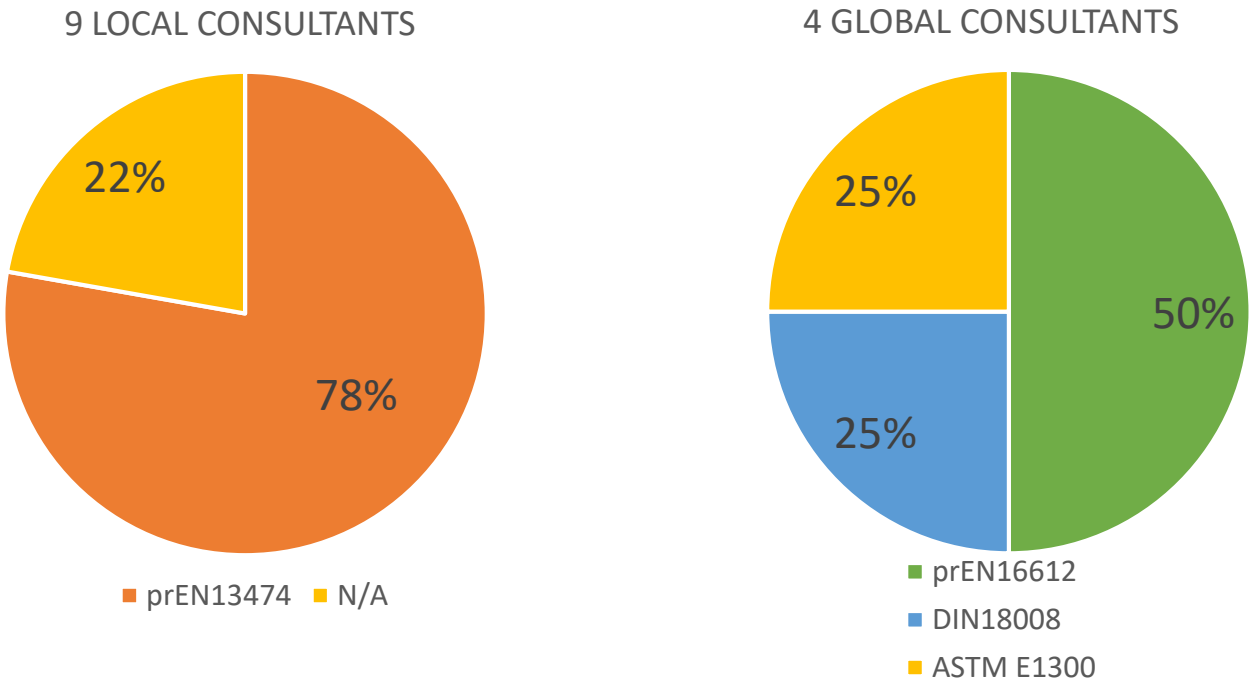
CODES



WINDOW GLASS PANEL

CODES

GLASS DESIGN CODES FOR BUILDINGS IN TURKEY



WINDOW GLASS PANEL

THANK YOU FOR YOUR ATTENTION