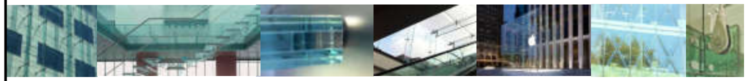
TMMOB İMO İSTANBUL ŞUBESİ
2017 YILI (ŞB-1) MESLEK İÇİ EĞİTİM SEMİNERLERİ

CAMIN YAPILARDA KULLANIMI VE HESAP ESASLARI

04.05.2017 Karaköy



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CAMIN YAPILARDA KULLANIMI VE HESAP ESASLARI

- CAM ELEMANLARIN DAYANIMINI BELİRLEMEK İÇİN BİR HESAP YÖNTEMİ VAR MIDIR?
- HESAP ESASLARINI İÇEREN ULUSLARARASI BİR ŞARTNAME MEVCUT MUDUR?
- CAM İÇİN BİR HESAP YÖNTEMİ VARSA CAM SİSTEMLERDE DAYANIM HESABINI KİM YAPMALI?
- BİNA CEPHE CAMLARININ KIRILMAMASI İÇİN GÖRELİ KAT ÖTELEMESİ NE OLMALIDIR?
- UYGUN CAM SEÇİMİNİ ETKİLEYEN FAKTÖRLER NELERDİR?
- CAMIN KIRILMA SONRASI PERFORMANSI ARTTIRILABİLİR Mİ?
- CAMIN KIRILMA DAYANIMI KAÇ MPa'DIR?

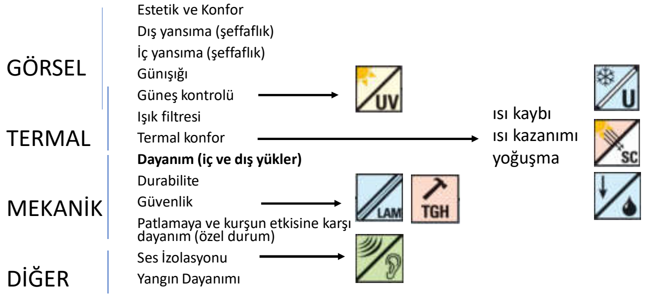
CAMIN YAPILARDA KULLANIMI VE HESAP ESASLARI

GÖRSEL

YERDEN ONLARCA METRE YÜKSEKLİKTE CAM DÖŞEMELİ BİR KÖPRÜDE NE KADAR GÜVENDE OLABİLİRSİNİZ?

CAMIN YAPILARDA KULLANIMI

Cam seçimini etkileyen faktörler



GÖRSEL
- Estetik ve Konfor
- Dış yansıma (şeffaflık)
- İç yansıma (şeffaflık)
- Günışığı
- Güneş kontrolü

TERMAL
- Işık filtresi
- Termal konfor

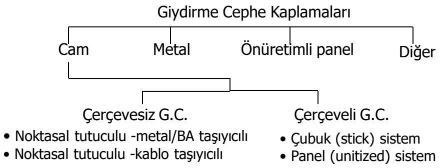
MEKANİK
- **Dayanım (iç ve dış yükler)**
- Durabilite
- Güvenlik
- Patlamaya ve kurşun etkisine karşı dayanım (özel durum)

DİĞER
- Ses İzolasyonu
- Yangın Dayanımı

ısı kaybı
ısı kazanımı
yoğuşma

CAMIN YAPILARDA KULLANIMI

KAPLAMA ELEMANI



Giydirme Cephe Kaplamaları

Cam — Metal — Önüretimli panel — Diğer

Çerçevesiz G.C.
- Noktasal tutuculu -metal/BA taşıyıcılı
- Noktasal tutuculu -kablo taşıyıcılı

Çerçeveli G.C.
- Çubuk (stick) sistem
- Panel (unitized) sistem

TAŞIYICI ELEMAN

- kiriş, kolon, plak (plate), levha (membrane), kabuk (shell)

CAMIN YAPILARDA KULLANIMI

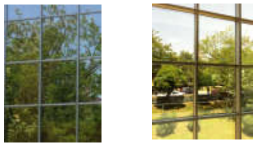
DOLGU ELEMANI

CAMIN YAPILARDA KULLANIMI

DOLGU ELEMANI

Çerçeveli G.C.

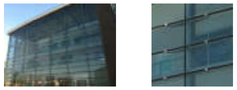
Çubuk (stick) sistem



Panel (unitized) sistem

Çerçevesiz G.C.

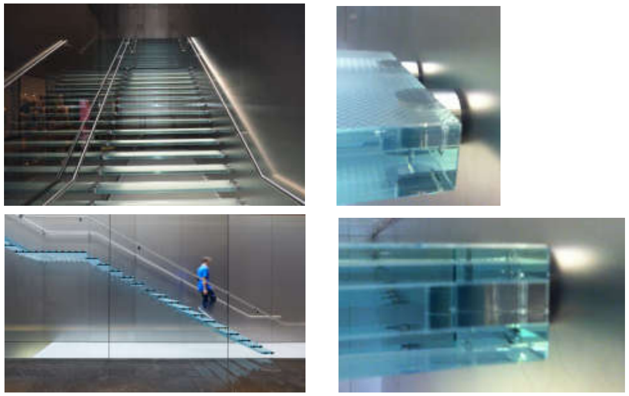
Noktasal tutuculu -metal/BA taşıyıcılı



Noktasal tutuculu -kablo taşıyıcılı

CAMIN YAPILARDA KULLANIMI

TAŞIYICI ELEMAN

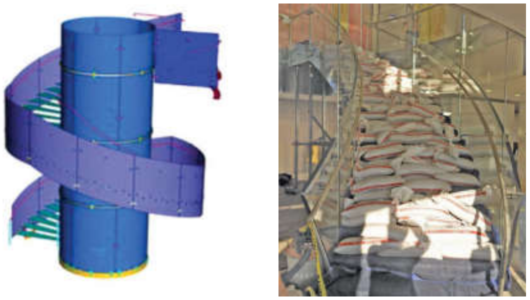


CAMIN YAPILARDA KULLANIMI

TAŞIYICI ELEMAN

CAMIN YAPILARDA KULLANIMI

TAŞIYICI ELEMAN



CAMIN YAPILARDA KULLANIMI

TAŞIYICI ELEMAN

CAMIN YAPILARDA KULLANIMI

TAŞIYICI ELEMAN

HESAP ESASLARI

1. MALZEME VE ÜRÜN ÖZELLİKLERİ
2. TEMEL TASARIM İLKELERİ
3. İKİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI
4. BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

HESAP ESASLARI

1-MALZEME VE ÜRÜN ÖZELLİKLERİ

*[1]

Soda-kireç-silikat camı tipik karışımı (TS EN 572-1)

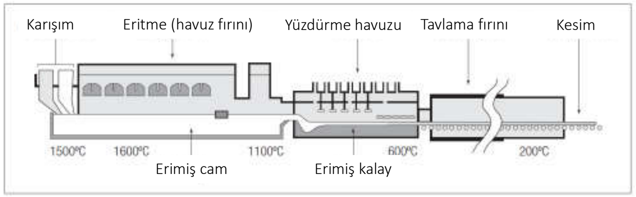
Malzeme	Formül	Karışım Yüzdesi
Silikat	SiO_2	69-74%
Kireç	CaO	5-14%
Soda	Na_2O	10-16%
Magnezyum oksit	MgO	0-6%
Alüminyum oksit	AL_2O_3	0-3%

EN 572-2 Yüzdürme (float) cam
EN 572-3 Parlatılmış telli cam
EN 572-4 Çekme düz cam
EN 572-5 Desenli cam
EN 572-6 Desenli telli cam
EN 572-7 Telli veya telsiz kanal şekilli cam
EN 572-8 Piyasaya arz boyutları ve son kesim boyutları
EN 572-9 Uygunluk değerlendirilmesi/mamul standardı

HESAP ESASLARI

1-MALZEME VE ÜRÜN ÖZELLİKLERİ

Günümüzde kullanılan cam biçimlendirme yöntemlerinden float (yüzdürme) yöntemi



Nominal kalınlık: 2, 3, 4, 5, 6, 8, 10, 12, 15, 19 (25*) mm
Standard plaka boyutu: 6 m x 3.21 m
Standard dışı plaka 25m (Çin)

HESAP ESASLARI

1-MALZEME VE ÜRÜN ÖZELLİKLERİ

GÖRSEL

FLOAT CAM ÜRETİMİ

HESAP ESASLARI

1-MALZEME VE ÜRÜN ÖZELLİKLERİ

İmalat Toleransları TS EN 12150-1

∗[2]

- boy *2 – 4 mm*
- gönye *2 – 4 mm*
- float cam kalınlığı – *tabloya bakınız*
- *delik çapı 0,5 mm*
- *delik konumu 0,5 – 2 mm*

Nominal kalınlık (mm)	Tolerans (mm)
2 - 6 mm	*± 0,2 mm*
8 - 12 mm	*± 0,3 mm*
15 mm	*± 0,5 mm*
19 - 25 mm	*± 1,0 mm*

HESAP ESASLARI

1-MALZEME VE ÜRÜN ÖZELLİKLERİ

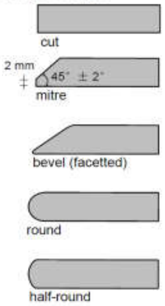
Kenar Kalitesi TS EN 12150-1

∗[2]

KENAR KALİTESİ

- *İşlenmemiş, kesim: keskin kenarlı*
- *Çapağı alınmış: keskin kenarları kırılmış ya da taşlama ile*
- *Kaba traşlanmış kenarlı*
- *Düzgün traşlanmış kenarlı*
- *Parlatılmış kenarlı*

KENAR ŞEKLİ



Kenar işleminin dayanıma etkisi için bkz. Maria Lindqvist PhD. 2013 [21]

HESAP ESASLARI

1-MALZEME VE ÜRÜN ÖZELLİKLERİ

Kenar Kalitesi TS EN 12150-1

KENAR KALİTESİ

İşlenmemiş, kesim: keskin kenarlı

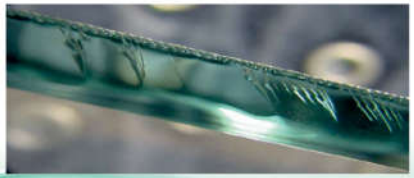
Çapağı alınmış: keskin kenarları kırılmış ya da taşlama ile

Kaba traşlanmış kenarlı

Düzgün traşlanmış kenarlı

Parlatılmış kenarlı

Şekil 2. Düzgün bir kesim ve koparma



Şekil 3. Kötü bir kesim ve koparma

HESAP ESASLARI

1-MALZEME VE ÜRÜN ÖZELLİKLERİ

Kenar Kalitesi TS EN 12150-1

Şekil 4. Kötü bir zımpara

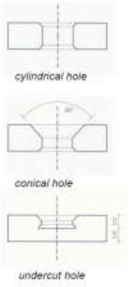
Şekil 5. İyi bir Rodaj örneği

Şekil 6. Soğutmada kırılmaya yol açabilen hata örnekleri

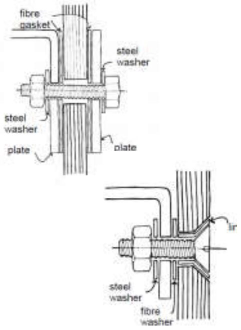
HESAP ESASLARI

1-MALZEME VE ÜRÜN ÖZELLİKLERİ

Delik delme




water cutting



Fotoğraf Kaynağı: Sustainable Constructions under Natural Hazards and Catastrophic Events 520121-1-2011-1-CZ-ERA MUNDUS-EMMC

HESAP ESASLARI

1-MALZEME VE ÜRÜN ÖZELLİKLERİ

Delik delme (GENEL KURALLAR)

Delik çapı cam kalınlığından büyük olmalı
Delikten kenara temiz mesafe en az cam kalınlığının iki katı olmalı
Delikten köşeye temiz mesafe en az cam kalınlığının altı katı olmalı

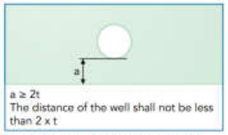


Fig. 7: Position of hole relative to edge

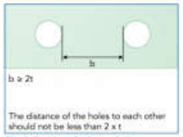


Fig. 8: Position of adjacent holes

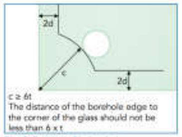


Fig. 9: Position of hole relative to corner

Fotoğraf Kaynağı: Guardian GlassTime, Standards, guidelines, tips

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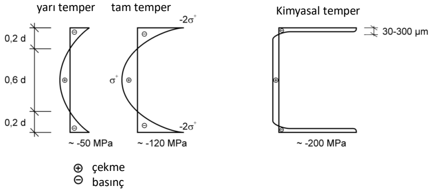
HESAP ESASLARI

1-MALZEME VE ÜRÜN ÖZELLİKLERİ

Camın Dayanımının Arttırılması

Eğilme dayanımlarına göre camların sınıflandırılması:

- tavlanmış cam (annealed) fb,k=45Mpa
- yarı temper cam (half tempered, heat strengthened) fb,k=70Mpa
- tam temper cam (fully tempered, thermally toughned) fb,k=120Mpa
- kimyasal temperli cam (chemically strengthened) fb,k=150Mpa



HESAP ESASLARI

1-MALZEME VE ÜRÜN ÖZELLİKLERİ

Camın Dayanımının Arttırılması

GÖRSEL
KİMYASAL TEMPERLİ CAM DENEYİ-1

HESAP ESASLARI

1-MALZEME VE ÜRÜN ÖZELLİKLERİ

Camın Dayanımının Arttırılması

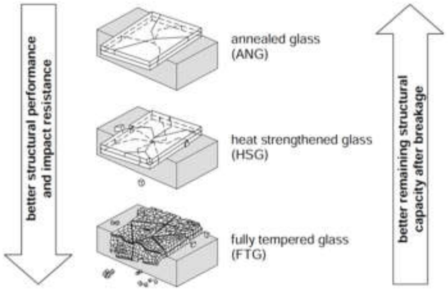
GÖRSEL
KİMYASAL TEMPERLİ CAM DENEYİ-2

HESAP ESASLARI

1-MALZEME VE ÜRÜN ÖZELLİKLERİ

Camların kırılma tipleri

*[3]



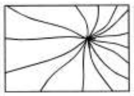
HESAP ESASLARI

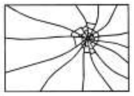
1-MALZEME VE ÜRÜN ÖZELLİKLERİ

Camda Kırılma Sebepleri

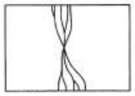
*[3]

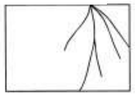

termal kırılma

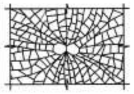

Sert cisim çapması

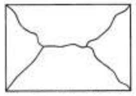

yumşak cisim çapması

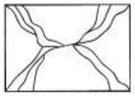

2 kenarı tutulu cam, düşük yük etkisi


2 kenarı tutulu cam, yüksek yük etkisi


Kenarda sert nokta


Nikel sülfür kalıntıları


4 kenarı tutulu cam, düşük yük etkisi

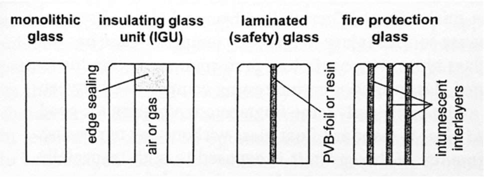

4 kenarı tutulu cam, yüksek yük etkisi

HESAP ESASLARI

1-MALZEME VE ÜRÜN ÖZELLİKLERİ

Cam Üniteleri

*[3]



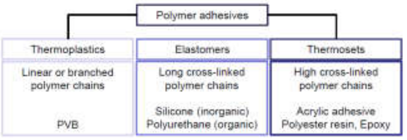
HESAP ESASLARI

1-MALZEME VE ÜRÜN ÖZELLİKLERİ

∗[4]

Ara katman tipleri

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



Thermoplastics: Relatively weak intermolecular forces hold molecules together in a thermoplastic. The material softens when exposed to heat, but returns to its original condition when cooled. Can be repeatedly softened by heating and then solidified by cooling, for improved performance. (linear and slightly branched polymers)
Elastomers: Rubbery polymers that can be stretched easily to several times their unstretched length and which rapidly return to their original dimensions. (cross-linked with low cross-link density)
Termosets: Solidify or "set" irreversibly when heated and further heating cannot reshape the material. (3D networked polymers with high degree of cross-linking)

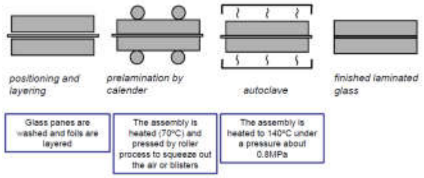
HESAP ESASLARI

1-MALZEME VE ÜRÜN ÖZELLİKLERİ

∗[4]

Ara katman tipleri

Polyvinyl butyral (PVB)



Glass panes are washed and foils are layered

The assembly is heated (70°C) and pressed by roller process to squeeze out the air or blisters

The assembly is heated to 140°C under a pressure about 0.8MPa

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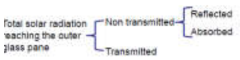
HESAP ESASLARI

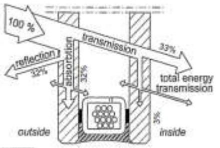
1-MALZEME VE ÜRÜN ÖZELLİKLERİ

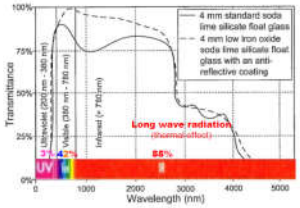
∗[4]

Isı Cam

Glass has very high transparency within the visible range of wavelengths (λ = 380-750 nm).







Most energy from solar radiation is contained in the IR long wave radiation (55%). Therefore, the strategy for solar protection is to block as much IR as possible without reducing the transmittance in the visible spectrum.

4

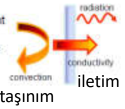
HESAP ESASLARI

1-MALZEME VE ÜRÜN ÖZELLİKLERİ

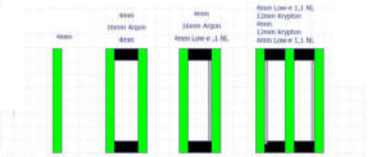
∗[4]

Isı Cam

In order to reduce coefficient U the thermal resistance of the glass element has to be increased.



It is not possible to change the convection properties but conductivity can be reduced by adding air space elements (preferably with a heavy gas: lower thermal conductivity) and heat transfer by radiation can be reduced by low emissivity coatings.

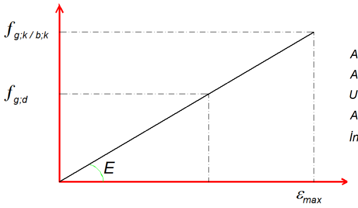


U thermal transmittance	5,8 W/m²K	3,0 W/m²K	1,2 W/m²K	0,5 W/m²K
tv light transmittance	90 %	81 %	79 %	67 %
g energy transmittance	86 %	77 %	65 % (#3)	51 %

HESAP ESASLARI

2-TEMEL TASARIM İLKELERİ

Dayanım



Avrupa	*prEN13474-1/2 1999 Design of Glass Panes*
Almanya	*TRLV:1998, TRAV:2003 ve DIN18008:2011*
USA	*ASTM E 1300 / GANA 2004*
Avusturalya	*AS1288*
İngiltere	*BS 6262-3:2005*

$f_{g;d}$	*: etkin emniyet gerilmesi (allowable effective stress for the design)*	
$f_{g;k\,/\,b;k}$	*: karakteristik test dayanımı (characteristic value of the test strength)*	
E	*: elastisite modülü (modulus of elasticity)*	*=7000kN/cm^2*
G	*: kayma modülü (shear modulus)*	*=2900 kN/cm^2*
ν	*: poisson oranı (Poisson's Ratio)*	*=0,20*
α	*: ısıl genleşme katsayısı (coef. of linear th. exp.*	*=0,000012 1/C°*
ρ	*: birim kütle (unit mass)*	*=2500 kg/m^3*

∗[1,5]

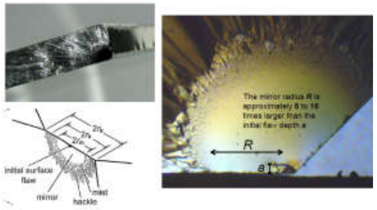
HESAP ESASLARI

2-TEMEL TASARIM İLKELERİ

∗[4]

Dayanım

Camın teorik çekme gerilmesi 5000~8000MPa arasındadır. Ancak yüzey kusurları sebebiyle gerçek dayanımı çok daha düşüktür. Cam sünek bir malzeme olmadığı için yüzeyindeki üretim ve işlenme sebebiyle mevcut çatlaklardaki büyük gerilme yığılmaları tekrar dağılıma uğrayamaz. Bu sebeple tavlanmış camın eğilme dayanımı 30~80MPa arasındadır



HESAP ESASLARI

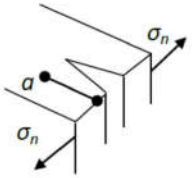
2-TEMEL TASARIM İLKELERİ

∗[4]

Dayanım

There is stress magnification near the tip of a crack.

The stress intensity factor K_I: elastic stress intensity near a crack tip. Provides a means to characterize the material in terms of its fracture toughness.



$$K_I = Y.\sigma_n.\sqrt{\pi.a}$$

K_I	: stress intensity factor	[MPa.m$^{0.5}$]
Y	: geometry factor	[-]
σ_n	: stress normal to the flaw's plane	[MPa]
a	: flaw depth	[m]

Instantaneous failure of glass occurs when the elastic stress intensity K_I, due to tensile stress at the tip of a crack, reaches or exceeds a critical value. This critical value is a material constant known as the fracture toughness or the critical stress intensity factor K_{IC}.

HESAP ESASLARI

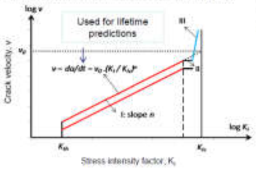
2-TEMEL TASARIM İLKELERİ

∗[4]

Dayanım

The growth of a surface flaw depends on the properties of the flaw and the glass, the stress history and the relationship between crack velocity and stress intensity.

The crack velocity scales with the kinetics of the chemical equation for the stress corrosion (region I).



n, v_0 - crack velocity parameters for structural design n=16 is reasonable and v_0 =6mm²/s should be conservative

K_{IC} – Fracture toughness (material constant = 0.75 Mpa m$^{0.5}$ for SLSG))

K_{th} – Threshold below which no crack growth occurs = 0.55 Mpa m$^{0.5}$ for SLSG

In region III, close to K_{IC} v is independent of the environment and approaches a characteristic propagation speed very rapidly (≈ 1500m/s).

In region II the kinetics of the chemical reaction at the crack tip are no longer controlled by the activation of the chemical process but by the supply rate of water (water rate can't keep up when the crack speed increases very fast)

For usual conditions, only region I (extremely slow sub-critical crack growth) is relevant for determining the design life of a glass element.

Parameters affecting the relation between v and stress intensity facroe K_I:

Humidity, temperature, PH value.

Loading rate (if it is too fast the water supply suffer a shortage and the stress corrosion is slow down).

Chemical composition of glass (affects all the parameters in sub critical crack growth).

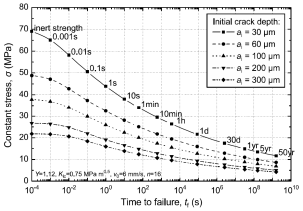
HESAP ESASLARI

2-TEMEL TASARIM İLKELERİ

Dayanım

Cam dayanımı birçok etkene bağlıdır: ∗[4,6,7]

- yüzey durumu (çatlakların boyutları)
- imalat yüzeyi (alt, üst): erimiş kalay ve hava tarafındaki yüzeyler üretildiğinde farklı dayanım gösterir ancak zamanla bu fark azalır.
- yüzey alanı
- yükleme süresi
- çevresel koşullar

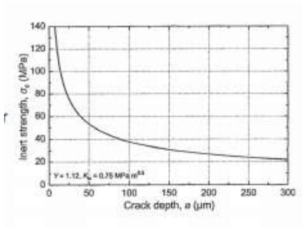


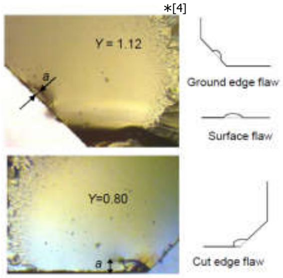
HESAP ESASLARI

2-TEMEL TASARIM İLKELERİ

Dayanım

∗[4]





$$f_{inert} = \frac{0.75}{Y.\sqrt{\pi.a_c}} \text{MPa}$$

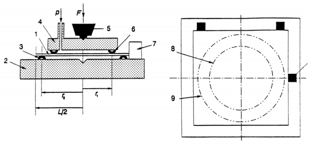
Stress causing failure of a crack of depth a_c (a_c: critical flaw depth)

Resistance of a crack to instantaneous failure (not triggered by sub critical crack growth)

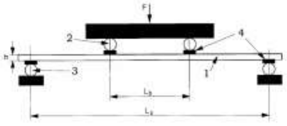
HESAP ESASLARI

2-TEMEL TASARIM İLKELERİ

Dayanım Testleri EN1288 ∗[8]



Çift halka deneyi



Dört nokta eğilmesi deneyi

1 Deney numunesi
2 Eğme silindiri
3 Destek silindiri
4 Kauçuk yastıklar

L_s = (200 ± 1) mm

L_s = (1000 ± 2) mm

HESAP ESASLARI

2-TEMEL TASARIM İLKELERİ

Tasarımda Dikkate Alınan Dayanım

∗[5]

$$f_{R,d} = k_{mod} \frac{f_{R,k}}{\gamma_m k_A} \gamma_n$$

prEN13474

Table 6: Modification factor k_{mod}

Duration of action	Loading example	k_{mod}
short	wind	0,72
medium	snow	0,36
	climate (for insulating glass units)	0,36
permanent	self-weight	0,27
	altitude (for insulating glass units)	0,27

Glass product	γ_m		γ_v Thermally toughened Heat soaked thermally toughened Heat strengthened		γ_v Chemically strengthened	
	Ultimate limit state	Serviceability limit state	Ultimate limit state	Serviceability limit state	Ultimate limit state	Serviceability limit state
Float glass	1,8	1,0	2,3	1,5	2,3	1,5

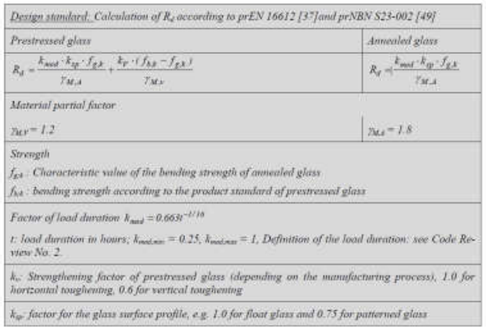
Glass product		Uniformly distributed load duration					
Glass Type	Processing	Short duration loads Wind loads		Medium duration loads Snow loads, Climatic loads		Permanent loads Self-weight loads, Altitude loads	
		Ultimate limit state	Serviceability limit state	Ultimate limit state	Serviceability limit state	Ultimate limit state	Serviceability limit state
Float glass and sheet glass	annealed	17.0	30.7	8.5	15.3	6.4	11.5
	heat strengthened	27.9	47.3	19.4	32.0	17.3	28.2
	thermally toughened	49.6	80.7	41.1	65.3	39.0	61.5
	chemically strengthened	62.7	100.7	54.2	85.3	52.0	81.5

HESAP ESASLARI

2-TEMEL TASARIM İLKELERİ

Tasarımda Dikkate Alınan Dayanım

∗[9]



Design standard: Calculation of R_d according to prEN 16612 [37]and prNBN S23-002 [49]	
Prestressed glass	*Annealed glass*
$R_d = \frac{k_{mod} \cdot k_{sp} \cdot f_{g,k}}{\gamma_{M,A}} + \frac{k_V \cdot (f_{b,k} - f_{g,k})}{\gamma_{M,v}}$	$R_d = \frac{k_{mod} \cdot k_{sp} \cdot f_{g,k}}{\gamma_{M,A}}$
Material partial factor $\gamma_{M,V} = 1.2$	$\gamma_{M,A} = 1.8$
Strength $f_{g,k}$: *Characteristic value of the bending strength of annealed glass* $f_{b,k}$: *bending strength according to the product standard of prestressed glass*	
Factor of load duration $k_{mod} = 0.663t^{-1/16}$ *t: load duration in hours;* $k_{mod,min} = 0.25$, $k_{mod,max} = 1$, *Definition of the load duration: see Code Review No. 2.*	
k_v*: Strengthening factor of prestressed glass (depending on the manufacturing process), 1.0 for horizontal toughening, 0.6 for vertical toughening*	
k_{sp}*: factor for the glass surface profile, e.g. 1.0 for float glass and 0.75 for patterned glass*	

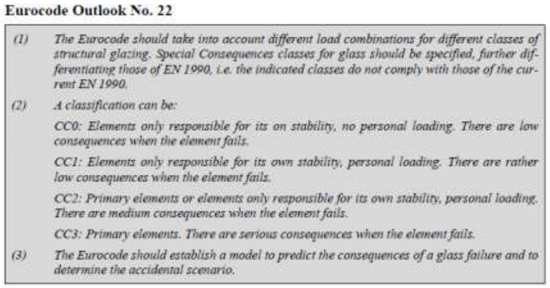
prEN16612

HESAP ESASLARI

2-TEMEL TASARIM İLKELERİ

Tasarımda Dikkate Alınan Dayanım

∗[10]



Eurocode Outlook No. 22

(1) *The Eurocode should take into account different load combinations for different classes of structural glazing. Special Consequences classes for glass should be specified, further differentiating those of EN 1990, i.e. the indicated classes do not comply with those of the current EN 1990.*

(2) *A classification can be:*

CC0: Elements only responsible for its on stability, no personal loading. There are low consequences when the element fails.

CC1: Elements only responsible for its own stability, personal loading. There are rather low consequences when the element fails.

CC2: Primary elements or elements only responsible for its own stability, personal loading. There are medium consequences when the element fails.

CC3: Primary elements. There are serious consequences when the element fails.

(3) *The Eurocode should establish a model to predict the consequences of a glass failure and to determine the accidental scenario.*

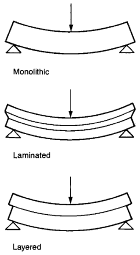
HESAP ESASLARI

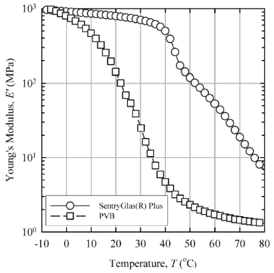
2-TEMEL TASARIM İLKELERİ

Ara katmanlı camlar – lamine camlar

∗[11]

Lamine camlarda ara katman olarak en çok kullanılan PVB viskoelastik bir malzemedir. Kayma modülü sıcaklık ve yükün etkime süresine göre farklılık gösterir. Kayma modülü ne kadar yüksekse iki camım kompozit çalışma etkisi o kadar artar.





HESAP ESASLARI

2-TEMEL TASARIM İLKELERİ

Ara katmanlı camlar – lamine camlar

∗[10]

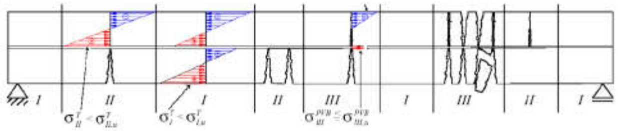


Figure 5-4 Resistance mechanisms in the post glass breakage phase [178]

HESAP ESASLARI

2-TEMEL TASARIM İLKELERİ

Yükler

∗[12]

Cephe sistemlerinin direnç göstermesi gereken yükler aşağıda özetlenmiştir (EN 13830):

- zati yükler (EN 1991-1-1)
- hareketli yükler (EN 1991-1-1)
- kar yükleri, (EN 1991-1-3)
- rüzgar yükleri (EN 1991-1-4)
- deprem yükleri (EN 1998-1, TDY Denk 2.21)
- çarpma yükleri (EN 12600)
- bina hareketleri ve ısıl yükler
- diğer yükler (patlama, termal gerilmeler)

HESAP ESASLARI

2-TEMEL TASARIM İLKELERİ

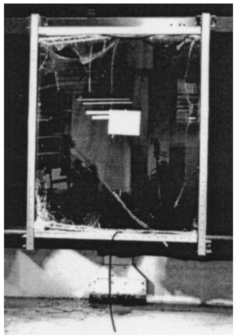
Yükler

∗[13]

DEPREM YÜKLERİ

Mimari camların yeterli bir deprem performansı göstermesini hedeflemenin iki önemli sebebi:

- İnsanların düşen camlardan dolayı yaralanmasını veya can kayıplarını önlemek
- Binanın servis dışı kalmasından ve tamirattan dolayı oluşacak maliyeti düşürmek



HESAP ESASLARI

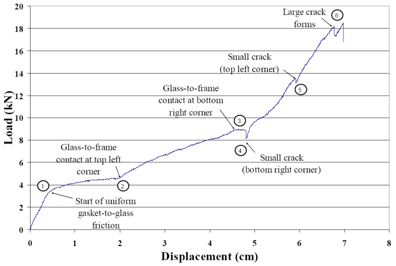
2-TEMEL TASARIM İLKELERİ

Yükler

DEPREM YÜKLERİ

∗[14]

- 0.01 cm/s statik yük altında yük-deplasman ilişkisi



HESAP ESASLARI

2-TEMEL TASARIM İLKELERİ

Yükler

DEPREM YÜKLERİ

Çerçeveli cam giydirme cephelerde, cam düzlemine dik (rüzgar yükü gibi) deprem yüklerinin yanı sıra -kat ötelenmesinden kaynaklanan- cam düzlemi içinde etkiler de oluşur.

- Cephelerde düzlem içi ve düzlem dışı deprem yükleri

$$f_e = 0.5\, A_o\, I\, w_e \left(1 + 2\frac{H_i}{H_N}\right)$$

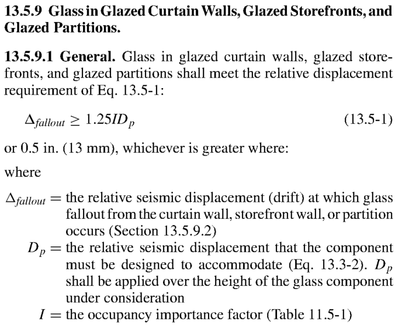
∗[15] Denklem 2.21

HESAP ESASLARI

2-TEMEL TASARIM İLKELERİ

Yükler

DEPREM YÜKLERİ ASCE7-05’e göre [16]



13.5.9 Glass in Glazed Curtain Walls, Glazed Storefronts, and Glazed Partitions.

13.5.9.1 General. Glass in glazed curtain walls, glazed storefronts, and glazed partitions shall meet the relative displacement requirement of Eq. 13.5-1:

$$\Delta_{fallout} \geq 1.25 I D_p \qquad (13.5\text{-}1)$$

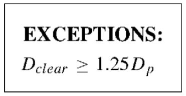
or 0.5 in. (13 mm), whichever is greater where:

where

$\Delta_{fallout}$ = the relative seismic displacement (drift) at which glass fallout from the curtain wall, storefront wall, or partition occurs (Section 13.5.9.2)

D_p = the relative seismic displacement that the component must be designed to accommodate (Eq. 13.3-2). D_p shall be applied over the height of the glass component under consideration

I = the occupancy importance factor (Table 11.5-1)



EXCEPTIONS:

$$D_{clear} \geq 1.25 D_p$$

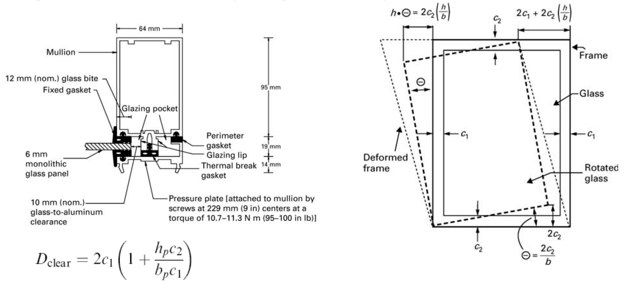
HESAP ESASLARI

2-TEMEL TASARIM İLKELERİ

Yükler

DEPREM YÜKLERİ

- Cephelerde düzlem içi deplasman şartları:



$$D_{\rm clear} = 2c_1\left(1 + \frac{h_p c_2}{b_p c_1}\right)$$

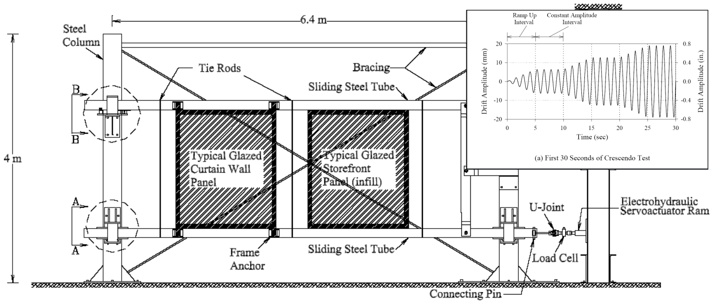
∗[17]

HESAP ESASLARI

2-TEMEL TASARIM İLKELERİ

Yükler

DEPREM YÜKLERİ (AAMA 501.6-09) [18]



HESAP ESASLARI

2-TEMEL TASARIM İLKELERİ

Yükler

DEPREM YÜKLERİ

%2.50 drift

GÖRSEL

DEPREM DENEYİ-1

HESAP ESASLARI

2-TEMEL TASARIM İLKELERİ

Yükler

DEPREM YÜKLERİ

GÖRSEL

DEPREM DENEYİ-2

HESAP ESASLARI

2-TEMEL TASARIM İLKELERİ

Yükler

DEPREM YÜKLERİ

GÖRSEL

DEPREM DENEYİ-3

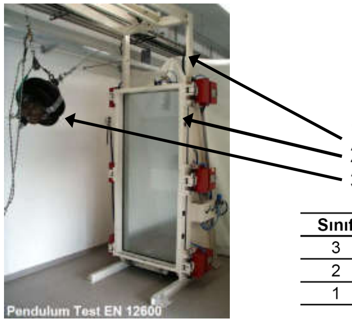
HESAP ESASLARI

2-TEMEL TASARIM İLKELERİ

Yükler

[19]

ÇARPMA YÜKLERİ (TS EN 12600'e göre)



1 Ana çerçeve
2 Tutturma çerçevesi
3 Darbe uygulayıcı

Sınıf	Düşme yüksekliği, mm
3	190
2	450
1	1200

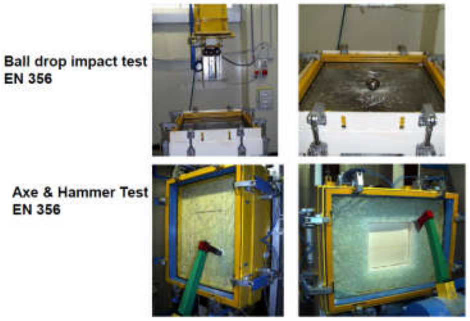
HESAP ESASLARI

2-TEMEL TASARIM İLKELERİ

Yükler

[20]

DARBE YÜKLERİ (TS EN 356'ya göre)



HESAP ESASLARI

2-TEMEL TASARIM İLKELERİ

Performans Kriterleri

EN 13830 *[12]

5.7 Wind load resistance

The curtain walling kit shall be tested in accordance with EN 12179. Under the imposed wind loads only the maximum frontal deflection (d) of the curtain walling's framing members shall not exceed the following limits:

- d ≤ L /200, if L ≤ 3000 mm;
- d ≤ 5 mm + L /300, if 3000 mm < L < 7500 mm;
- d ≤ L /250, if L ≥ 7500 mm.

when measured between the points of support or anchorage to the building's structure (L).

In addition, the permissible deflection limits of the infill (e.g. IGU, stone, etc.) shall be taken into account.

NOTE Guidance on the combinations of different loads is given in Annex C.

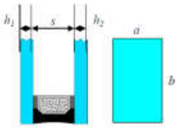
HESAP ESASLARI

3-İKİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

Isı Camlar

[4,5]

In case of double glazing, with panes of thickness h_1 and h_2, the distribution of external uniformly distributed loads (e.g. wind, snow, self weight) is essentially determined by the distribution of the stiffness of the panes, that is:



$$\delta_1 = \frac{h_1^3}{h_1^3 + h_2^3}$$

$$\delta_2 = \frac{h_2^3}{h_1^3 + h_2^3} = 1 - \delta_1$$

Additionally, the distribution of external loads is determined by the insulating unit factor φ.

$$\varphi = \frac{1}{1 + (a/a^*)^4}$$

The length "a" gives the actual dimension of the unit (e.g. in a rectangular unit the length of the short edge) while "a^*" is the characteristic length of the unit, depending on the thickness of the glass panes (h_1 and h_2) the gas space (s), and the shape of the unit (λ).

$$a^* = 28,9 \cdot \left(\frac{s \cdot h_1^3 \cdot h_2^3}{(h_1^3 + h_2^3) \cdot k_5} \right)^{0,25}$$

HESAP ESASLARI

3-İKİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

Isı Camlar

[5]

Coefficient k_5 for calculation of the volume change

Linear interpolation apply.

For small deflections (linear theory) p*=0 may be considered.

L4 Insulated glass units

λ=a/b	p* (internal initial pressurization)									
	0	5	10	20	30	50	100	200	300	500
1,0	0,019	0,019	0,019	0,018	0,017	0,015	0,011	0,008	0,007	0,005
0,9	0,024	0,024	0,023	0,022	0,020	0,017	0,013	0,009	0,007	0,006
0,8	0,029	0,029	0,028	0,026	0,023	0,020	0,015	0,010	0,008	0,007
0,7	0,035	0,035	0,034	0,031	0,028	0,023	0,017	0,012	0,010	0,008
0,6	0,042	0,042	0,040	0,037	0,033	0,027	0,020	0,014	0,012	0,009
0,5	0,050	0,050	0,048	0,044	0,040	0,033	0,025	0,018	0,014	0,011
0,4	0,059	0,058	0,057	0,053	0,049	0,042	0,031	0,022	0,018	0,014
0,3	0,068	0,067	0,066	0,064	0,061	0,054	0,042	0,031	0,025	0,020
0,2	0,077	0,077	0,076	0,076	0,074	0,071	0,062	0,048	0,040	0,031
0,1	0,086	0,086	0,086	0,086	0,086	0,085	0,084	0,081	0,077	0,068
0	0,095	0,095	0,095	0,095	0,095	0,095	0,095	0,095	0,095	0,095

HESAP ESASLARI

3-İKİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

Isı Camlar

										W-GLASS		LİNEER			
PROBLEM	GEOMETRİ	A(mm)	B(mm)	Açı(°)	Dış cam (mm)	Hava boşluğu (mm)	İç cam (mm)	Yük (kN/m²)	Gerilme hesabı için yük çarpanı	Sehim (mm)	Gerilme (Mpa)	Sehim (mm)	Gerilme (Mpa)	Sehim fark	Gerilme fark
B-1	DİKDÖRTGEN	2000	1000	90	6	-	-	0.5	1.5	3.72	11.88	3.81	12.56	-0.02	-0.06
B-2	DİKDÖRTGEN	2000	1000	90	6	-	-	1	1.5	7.31	21.29	7.61	25.12	-0.04	-0.18
B-3	DİKDÖRTGEN	2000	1000	90	6	-	-	2	1.5	12.53	34.28	15.32	50.23	-0.22	-0.47

HESAP ESASLARI

3-İKİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

Isı Camlar

										W-GLASS		LİNEAR			
PROBLEM	GEOMETRİ	A(mm)	B(mm)	Açı(^{o})	Dış cam (mm)	Hava boşluğu (mm)	İç cam (mm)	Yük (kN/m^2)	Gerilme hesabı için yük çarpanı	Sehim (mm)	Gerilme (Mpa)	Sehim (mm)	Gerilme (Mpa)	Sehim fark	Gerilme fark
B-1	DİKDÖRTGEN	2000	1000	90	6	16	6	0.5	1.5	1.93	6.31	1.95	6.43	-0.01	-0.02
B-2	DİKDÖRTGEN	2000	1000	90	6	16	6	1	1.5	3.81	12.14	3.9	12.27	-0.02	-0.01
B-3	DİKDÖRTGEN	2000	1000	90	6	16	6	2	1.5	7.27	21.67	7.79	25.7	-0.07	-0.19

HESAP ESASLARI

3-İKİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

Isı Camlar

[4,5]

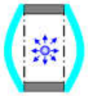
Internal pressure transmits the external loads (e.g. wind on pane 1) from one pane to the next ("Coupling Effect")

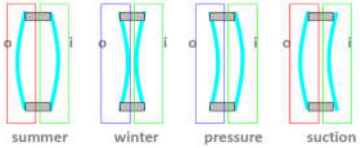
External load	Part of the external load carried by pane 1	Part of the external load carried by pane 2
F_{e1} acting on pane 1	$(1-\varphi)\cdot\delta_2\cdot F_{d1}$	$(\delta_1+\varphi\cdot\delta_2)\cdot F_{d1}$
F_{e2} acting on pane 2	$(1-\varphi)\cdot\delta_1\cdot F_{d2}$	$(\varphi\cdot\delta_1+\delta_2)\cdot F_{d2}$

The internal loads, given by the isochore pressure, are reduced by a factor proportional to the relative flexibility of the panes.

Internal load	Part of the internal load carried by pane 1	Part of the internal load carried by pane 2
Isochore pressure Dp	$\pm\ \varphi\cdot\Delta p$	$\pm\ \varphi\cdot\Delta p$

"Climatic Load"

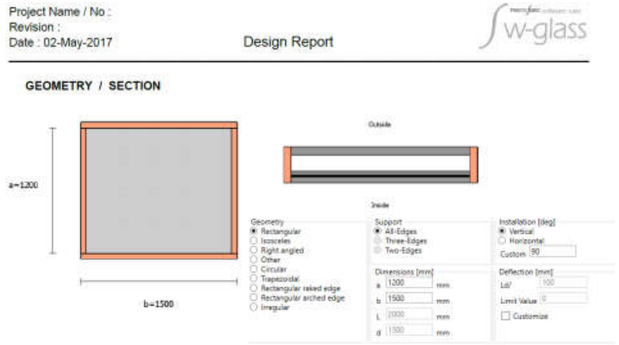




HESAP ESASLARI

3-İKİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

Isı Camlar - Örnek



Project Name / No :
Revision :
Date : 02-May-2017

Design Report

GEOMETRY / SECTION

Geometry
● Rectangular
○ Isosceles
○ Right angled
○ Other
○ Circular
○ Trapezoidal
○ Rectangular raked edge
○ Rectangular arched edge
○ Irregular

Support
● All-Edges
○ Three-Edges
○ Two-Edges

Installation [deg]
● Vertical
○ Horizontal
Custom 90

Dimensions [mm]
a 1200 mm
b 1500 mm
L 2000 mm
d 1500 mm

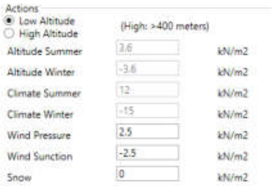
Deflection [mm]
L/d/ 100
Limit Value 0
☐ Customize

HESAP ESASLARI

3-İKİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

Isı Camlar - Örnek

SYSTEM-INFO
DESIGN CODE :prEN 13474
GEOMETRY :Rectangular
PANE COUNT : 2
SUPPORT :All-Edges
DIMENSION (a) :1200 (mm)
DIMENSION (b) :1500 (mm)
SLOPE ANGLE: 90 (deg) VERTICAL
DEFLECTION LIMIT : L(smallest)/100



Actions
● Low Altitude
○ High Altitude
(High: >400 meters)
Altitude Summer 3.6 kN/m2
Altitude Winter -3.6 kN/m2
Climate Summer 12 kN/m2
Climate Winter -15 kN/m2
Wind Pressure 2.5 kN/m2
Wind Sunction -2.5 kN/m2
Snow 0 kN/m2

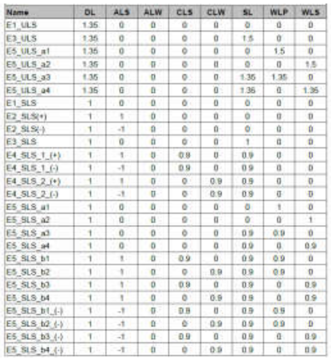
SECTION INFO (from Outside to Inside)

Thickness [mm]	Type	Material	Prestressing
8	Glass	Float Glass	Thermally Toughened
16	Cavity		
4	Glass	Float Glass	NonPrestressed Annealed
1.52	PVB		
6	Glass	Float Glass	NonPrestressed Annealed

HESAP ESASLARI

3-İKİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

Isı Camlar - Örnek



Name	DL	ALS	ALW	CLS	CLW	SL	WLP	WLS
E1_ULS	1.35	0	0	0	0	0	0	0
E3_ULS	1.35	0	0	0	0	1.5	0	0
E5_ULS_a1	1.35	0	0	0	0	0	1.5	0
E5_ULS_a2	1.35	0	0	0	0	0	0	1.5
E5_ULS_a3	1.35	0	0	0	0	1.35	1.35	0
E5_ULS_a4	1.35	0	0	0	0	1.35	0	1.35
E1_SLS	1	0	0	0	0	0	0	0
E2_SLS(+)	1	1	0	0	0	0	0	0
E2_SLS(-)	1	-1	0	0	0	0	0	0
E3_SLS	1	0	0	0	0	1	0	0
E4_SLS_1_(+)	1	1	0	0.9	0	0.9	0	0
E4_SLS_1_(-)	1	-1	0	0.9	0	0.9	0	0
E4_SLS_2_(+)	1	1	0	0	0.9	0.9	0	0
E4_SLS_2_(-)	1	-1	0	0	0.9	0.9	0	0
E5_SLS_a1	1	0	0	0	0	0	1	0
E5_SLS_a2	1	0	0	0	0	0	0	1
E5_SLS_a3	1	0	0	0	0	0.9	0.9	0
E5_SLS_a4	1	0	0	0	0	0.9	0	0.9
E5_SLS_b1	1	1	0	0.9	0	0.9	0.9	0
E5_SLS_b2	1	1	0	0	0.9	0.9	0.9	0
E5_SLS_b3	1	1	0	0.9	0	0.9	0	0.9
E5_SLS_b4	1	1	0	0	0.9	0.9	0	0.9
E5_SLS_b1_(-)	1	-1	0	0.9	0	0.9	0.9	0
E5_SLS_b2_(-)	1	-1	0	0	0.9	0.9	0.9	0
E5_SLS_b3_(-)	1	-1	0	0.9	0	0.9	0	0.9
E5_SLS_b4_(-)	1	-1	0	0	0.9	0.9	0	0.9

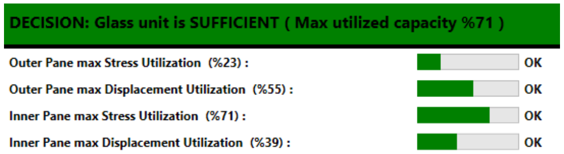
prEN 13474

DL:Dead Load
SL:Snow Load
ALS:Altitude Summer
ALW:Altitude Winter
CLS:Climate Summer
CLW:Climate Winter
WLP:Wind Load Pressure
WLS:Wind Load Sunction
SLS:Servicebility Limit State
ULS:Ultimate Limit State

HESAP ESASLARI

3-İKİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

Isı Camlar - Örnek



DECISION: Glass unit is SUFFICIENT (Max utilized capacity %71)

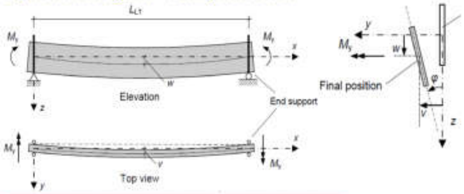
Outer Pane max Stress Utilization (%23) :	🟩	**OK**
Outer Pane max Displacement Utilization (%55) :	🟩	**OK**
Inner Pane max Stress Utilization (%71) :	🟩	**OK**
Inner Pane max Displacement Utilization (%39) :	🟩	**OK**

macrostatic

HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

KİRİŞLER **A) Monolithic glass – Analytical model** [4]



$$M_{CR} = C_1 \frac{\pi^2 EI_z}{L^2}\left[\sqrt{(C_2 z_a)^2 + \frac{GI_t L^2}{\pi^2 EI_z}} + C_2 z_a\right]$$

Critical LTB Moment

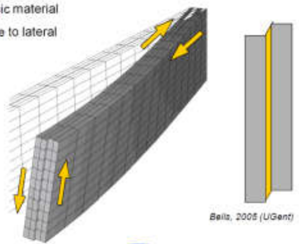
- *C_i, z_a …take into account different boundary conditions, different bending moment, distance between the centre of gravity and the load point*
- *LTB formulas for steel are valid, e.g. EC3*

HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

KİRİŞLER **B) Laminated glass – Analytical model** [4]

- No homogene, isotropic material
- Shear deformation due to lateral bending & torsion



Belis, 2005 (UGent)

Critical LTB Moment

$$M_{CR} = C_1 \frac{\pi^2 (E_g I_z)_{eff}}{L^2}\left[\sqrt{(C_2 z_a)^2 + \frac{(GI_t)_{eff} L^2}{\pi^2 (E_g I_z)_{eff}}} + C_2 z_a\right]$$

HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

HİBRİT KİRİŞLER

[4]

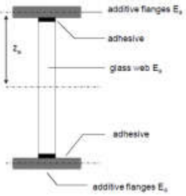
Möhler's method for steel-glass beam

- **Effective moment of inertia**

$$I_{y,eff} = \underbrace{2 \cdot I_a}_{\text{flanges}} + \underbrace{\frac{E_g}{E_a} \cdot I_g}_{\text{web}} + \underbrace{2 \cdot \gamma \cdot A_a \cdot z_a^2}_{\text{flanges}}$$

stiffness ratio

efficiency factor



$$\gamma = \frac{1}{1+k} \qquad k = \pi^2 \cdot \frac{E_a \cdot A_a}{L^2 \cdot K_K}$$

Stiffness of glued connection:

$$K_K = G_K \cdot \frac{b_k}{t_k}$$

shear modulus of adhesive

66

HESAP ESASLARI

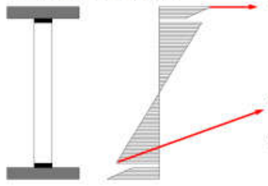
4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

HİBRİT KİRİŞLER

[4]

Möhler's method for steel-glass beam

- **Evaluation of stresses**



Edge of the steel flange

$$\sigma_{r1a} = \pm \frac{M_y}{I_{y,eff}} \cdot \left(\gamma \cdot z_a + \frac{t_f}{2} \right)$$

Edge of the glass web

$$\sigma_{r2} = \pm \frac{M_y}{I_{y,eff}} \cdot \frac{h_w}{2} \cdot \frac{E_g}{E_a}$$

Vertical deflection of the beam

$$\delta = \frac{5}{384} \cdot \frac{q \cdot L^4}{E_a \cdot I_{y,eff}}$$

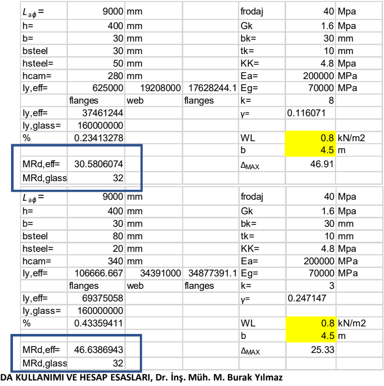
Shear stress in glued connection

$$\tau = \frac{Q \cdot \gamma \cdot z_a \cdot A_a}{I_{y,eff} \cdot b_k}$$

HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

HİBRİT KİRİŞLER



$L_{a\phi}$=	9000	mm		frodaj	40	Mpa
h=	400	mm		Gk	1.6	Mpa
b=	30	mm		bk=	30	mm
bsteel	30	mm		tk=	10	mm
hsteel=	50	mm		KK=	4.8	Mpa
hcam=	280	mm		Ea=	200000	MPa
Iy,eff=	625000	19208000	17628244.1	Eg=	70000	MPa
	flanges	web	flanges	k=	8	
Iy,eff=	37461244			γ=	0.116071	
Iy,glass=	160000000					
%	0.23413278			WL	0.8	kN/m2
				b	4.5	m
MRd,eff=	30.5806074			Δ_{MAX}	46.91	
MRd,glass	32					
$L_{a\phi}$=	9000	mm		frodaj	40	Mpa
h=	400	mm		Gk	1.6	Mpa
b=	30	mm		bk=	30	mm
bsteel	80	mm		tk=	10	mm
hsteel=	20	mm		KK=	4.8	Mpa
hcam=	340	mm		Ea=	200000	MPa
Iy,eff=	106666.667	34391000	34877391.1	Eg=	70000	MPa
	flanges	web	flanges	k=	3	
Iy,eff=	69375058			γ=	0.247147	
Iy,glass=	160000000					
%	0.43359411			WL	0.8	kN/m2
				b	4.5	m
MRd,eff=	46.6386943			Δ_{MAX}	25.33	
MRd,glass	32					

Hibrit kirişlerde çelik başlıkların gövdeden geniş olması durumu eğilme kapasitesi ve rijitliği arttırmaktadır.

HESAP ESASLARI

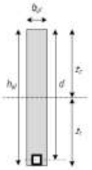
4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

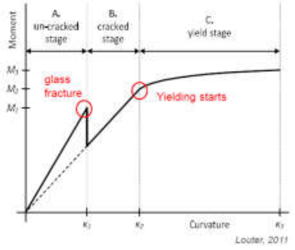
HİBRİT KİRİŞLER

[4]

Analytical model of reinforced glass beams

- Analogy with reinforced concrete
- Full interaction between glass and reinforcement is assumed.
- Three stages are distuingished:
  - **A. Un-cracked stage**
  - **B. Cracked stage**
  - **C. Yield stage**





Louter, 2011

HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

HİBRİT KİRİŞLER

[4]

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4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

TASARIM VERİLERİ

[22]

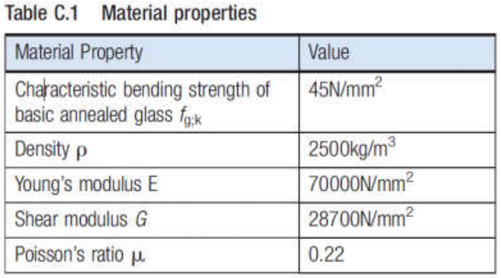

Table C.1 Material properties

Material Property	Value
Characteristic bending strength of basic annealed glass $f_{g;k}$	$45N/mm^2$
Density ρ	$2500kg/m^3$
Young's modulus E	$70000N/mm^2$
Shear modulus *G*	$28700N/mm^2$
Poisson's ratio μ	0.22

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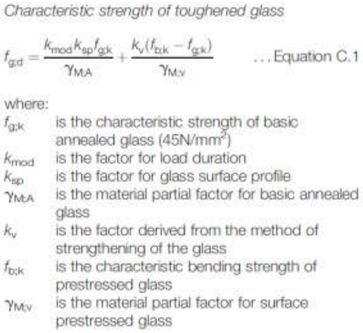
4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

TASARIM VERİLERİ

[22]



Characteristic strength of toughened glass

$$f_{g;d} = \frac{k_{mod} k_{sp} f_{g;k}}{\gamma_{M;A}} + \frac{k_v (f_{b;k} - f_{g;k})}{\gamma_{M;v}} \quad \ldots \text{Equation C.1}$$

where:

$f_{g;k}$	is the characteristic strength of basic annealed glass ($45N/mm^2$)
k_{mod}	is the factor for load duration
k_{sp}	is the factor for glass surface profile
$\gamma_{M;A}$	is the material partial factor for basic annealed glass
k_v	is the factor derived from the method of strengthening of the glass
$f_{b;k}$	is the characteristic bending strength of prestressed glass
$\gamma_{M;v}$	is the material partial factor for surface prestressed glass

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4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

TASARIM VERİLERİ

[22]

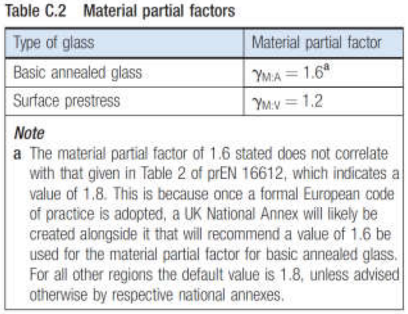


Table C.2 Material partial factors

Type of glass	Material partial factor
Basic annealed glass	$\gamma_{M;A} = 1.6^a$
Surface prestress	$\gamma_{M;v} = 1.2$

Note

a The material partial factor of 1.6 stated does not correlate with that given in Table 2 of prEN 16612, which indicates a value of 1.8. This is because once a formal European code of practice is adopted, a UK National Annex will likely be created alongside it that will recommend a value of 1.6 be used for the material partial factor for basic annealed glass. For all other regions the default value is 1.8, unless advised otherwise by respective national annexes.

HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

TASARIM VERİLERİ

[22]

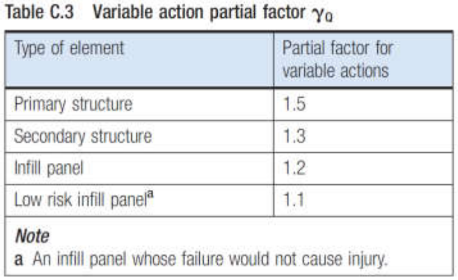


Table C.3 Variable action partial factor γ_Q

Type of element	Partial factor for variable actions
Primary structure	1.5
Secondary structure	1.3
Infill panel	1.2
Low risk infill panel[a]	1.1

Note

a An infill panel whose failure would not cause injury.

HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

TASARIM VERİLERİ

[22]

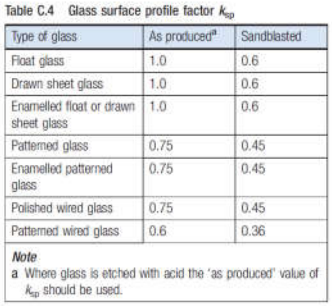


Table C.4 Glass surface profile factor k_{sp}

Type of glass	As produced[a]	Sandblasted
Float glass	1.0	0.6
Drawn sheet glass	1.0	0.6
Enamelled float or drawn sheet glass	1.0	0.6
Patterned glass	0.75	0.45
Enamelled patterned glass	0.75	0.45
Polished wired glass	0.75	0.45
Patterned wired glass	0.6	0.36

Note

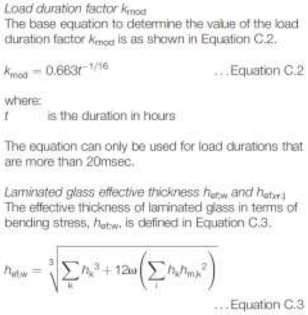
a Where glass is etched with acid the 'as produced' value of k_{sp} should be used.

HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

TASARIM VERİLERİ

[22]



Load duration factor k_{mod}

The base equation to determine the value of the load duration factor k_{mod} is as shown in Equation C.2.

$$k_{mod} = 0.663t^{-1/16} \qquad \text{...Equation C.2}$$

where:

t is the duration in hours

The equation can only be used for load durations that are more than 20msec.

Laminated glass effective thickness $h_{ef;w}$ and $h_{ef;\sigma;j}$

The effective thickness of laminated glass in terms of bending stress, $h_{ef;w}$, is defined in Equation C.3.

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

...Equation C.3

HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

TASARIM VERİLERİ

[22]

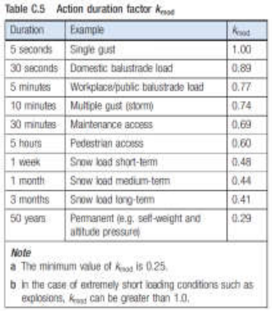


Table C.5 Action duration factor k_{mod}

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

Note

a The minimum value of k_{mod} is 0.25.

b In the case of extremely short loading conditions such as explosions, k_{mod} can be greater than 1.0.

HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

TASARIM VERİLERİ

[22]

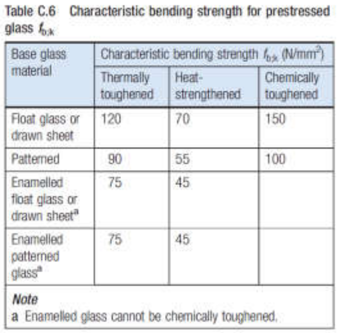


Table C.6 Characteristic bending strength for prestressed glass $f_{b;k}$

Base glass material	Characteristic bending strength $f_{b;k}$ (N/mm²)		
	Thermally toughened	Heat-strengthened	Chemically toughened
Float glass or drawn sheet	120	70	150
Patterned	90	55	100
Enamelled float glass or drawn sheet[a]	75	45	
Enamelled patterned glass[a]	75	45	

Note

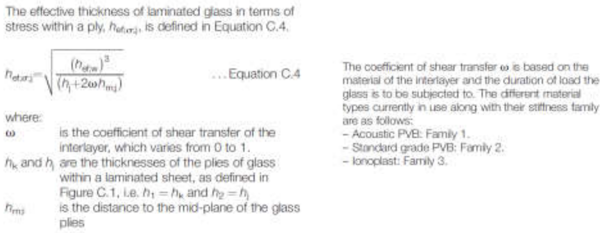
a Enamelled glass cannot be chemically toughened.

HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

TASARIM VERİLERİ

[22]



The effective thickness of laminated glass in terms of stress within a ply, $h_{ef;\sigma;j}$, is defined in Equation C.4.

$$h_{ef;\sigma;j} = \sqrt{\frac{(h_{ef;w})^3}{(h_j + 2\omega h_{m;j})}} \qquad \text{...Equation C.4}$$

where:

ω is the coefficient of shear transfer of the interlayer, which varies from 0 to 1.

h_k and h_j are the thicknesses of the plies of glass within a laminated sheet, as defined in Figure C.1, i.e. $h_1 = h_k$ and $h_2 = h_j$

$h_{m;j}$ is the distance to the mid-plane of the glass plies

The coefficient of shear transfer ω is based on the material of the interlayer and the duration of load the glass is to be subjected to. The different material types currently in use along with their stiffness family are as follows:

- Acoustic PVB: Family 1.
- Standard grade PVB: Family 2.
- Ionoplast: Family 3.

HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

TASARIM VERİLERİ

[22]

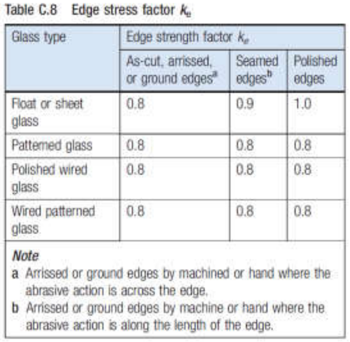


Table C.8 Edge stress factor k_e

Glass type	Edge strength factor k_e		
	As-cut, arrissed, or ground edges[a]	Seamed edges[b]	Polished edges
Float or sheet glass	0.8	0.9	1.0
Patterned glass	0.8	0.8	0.8
Polished wired glass	0.8	0.8	0.8
Wired patterned glass	0.8	0.8	0.8

Note

a Arrissed or ground edges by machined or hand where the abrasive action is across the edge.

b Arrissed or ground edges by machine or hand where the abrasive action is along the length of the edge.

HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

TASARIM VERİLERİ

[22]

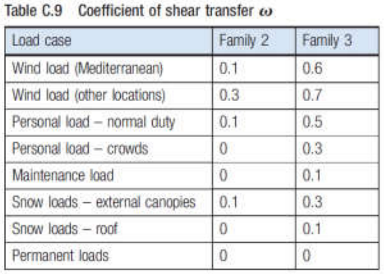


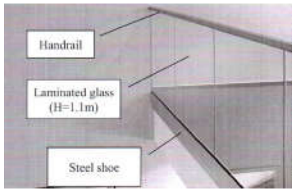
Table C.9 Coefficient of shear transfer ω

Load case	Family 2	Family 3
Wind load (Mediterranean)	0.1	0.6
Wind load (other locations)	0.3	0.7
Personal load – normal duty	0.1	0.5
Personal load – crowds	0	0.3
Maintenance load	0	0.1
Snow loads – external canopies	0.1	0.3
Snow loads – roof	0	0.1
Permanent loads	0	0

HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

ÇÖZÜMLÜ PROBLEMLER – CAM KORKULUK



Loading

$q := 1kN \quad \gamma_F := 1.5$

$h := 1.1m \quad M := q \cdot h \cdot \gamma_F = 1.65 \cdot kN \cdot m$

Glass strength

$f_{gk} := 45MPa \quad f_{bk} := 120MPa \quad E := 70GPa$

$k_{mod} := 0.89 \quad k_{sp} := 1.0 \quad k_v := 1$

$\gamma_{MA} := 1.8 \quad \gamma_{Mv} := 1.2$

$$f_{g.d} := \left[\frac{k_{mod} \cdot k_{sp} \cdot f_{gk}}{\gamma_{MA}} + \frac{k_v \cdot (f_{bk} - f_{gk})}{\gamma_{Mv}}\right] = 84.75 \cdot MPa$$

HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

ÇÖZÜMLÜ PROBLEMLER – CAM KORKULUK

Let's assume 2x10mm fully toughened glass (PVB - family 2)

$h_1 := 10mm \quad h_2 := h_1 \quad \omega := 0.1$ (personal load - normal duty)

$$h_{eff.w} := \sqrt[3]{h_1^3 + h_2^3 + 12 \cdot \omega \left[2 \cdot h_1 \cdot (0.5 \cdot 1.52mm + 0.5 \cdot h_1)^2\right]} = 14.088 \cdot mm$$

$$h_{eff.\sigma} := \sqrt{\frac{h_{eff.w}^3}{\left[h_1 + 2 \cdot \omega \cdot (0.5 \cdot 1.52mm + 0.5 \cdot h_1)\right]}} = 15.835 \cdot mm$$

Stress check

$W := \frac{1m \cdot h_{eff.\sigma}^2}{6} = 41.79 \cdot cm^3 \quad \sigma := \frac{M}{W} = 39.483 \cdot MPa \ .<. \quad f_{g.d} = 84.75 \cdot MPa$ OK

Deflection check

$I := \frac{1m \cdot h_{eff.w}^3}{12} = 23.302 \cdot cm^4 \quad \delta := \frac{q \cdot h^3}{3 \cdot E \cdot I} = 27.2 \cdot mm \ .<. \quad \delta_{max} := \frac{h}{65} = 16.923 \cdot mm$ NOT OK

HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

ÇÖZÜMLÜ PROBLEMLER – CAM KORKULUK

Let's assume 2x12mm fully toughened glass (PVB - family 2)

$h_1 := 12mm \quad h_2 := h_1 \quad \omega := 0.1$ (personal load - normal duty)

$$h_{eff.w} := \sqrt[3]{h_1^3 + h_2^3 + 12 \cdot \omega \left[2 \cdot h_1 \cdot (0.5 \cdot 1.52mm + 0.5 \cdot h_1)^2\right]} = 16.836 \cdot mm$$

$$h_{eff.\sigma} := \sqrt{\frac{h_{eff.w}^3}{\left[h_1 + 2 \cdot \omega \cdot (0.5 \cdot 1.52mm + 0.5 \cdot h_1)\right]}} = 18.905 \cdot mm$$

Stress check

$W := \frac{1m \cdot h_{eff.\sigma}^2}{6} = 63.254 \cdot cm^3 \quad \sigma := \frac{M}{W} = 26.085 \cdot MPa \ .<. \quad f_{g.d} = 84.75 \cdot MPa$ OK

Deflection check

$I := \frac{1m \cdot h_{eff.w}^3}{12} = 49.844 \cdot cm^4 \quad \delta := \frac{q \cdot h^3}{3 \cdot E \cdot I} = 12.716 \cdot mi \ .<. \quad \delta_{max} := \frac{h}{65} = 16.923 \cdot mm$ OK

HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

ÇÖZÜMLÜ PROBLEMLER – CAM KORKULUK

Post-failure check (one ply broken)

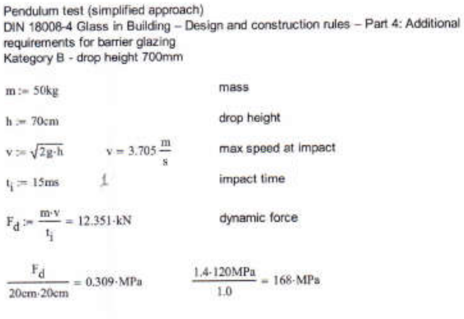
$\gamma_F := 1.0 \quad M := q \cdot h \cdot \gamma_F = 1.1 \cdot kN \cdot m$

$$h_1 := \begin{pmatrix} 8 \\ 10 \\ 12 \end{pmatrix} mm \quad W := \frac{1m \cdot h_1^2}{6} \quad \frac{M}{W} = \begin{pmatrix} 103.125 \\ 66 \\ 45.833 \end{pmatrix} \cdot MPa \quad f_{g.d} = 84.75 \cdot MPa$$

HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

ÇÖZÜMLÜ PROBLEMLER – CAM KORKULUK



Pendulum test (simplified approach)
DIN 18008-4 Glass in Building – Design and construction rules – Part 4: Additional requirements for barrier glazing
Kategory B - drop height 700mm

$m := 50kg$ mass

$h := 70cm$ drop height

$v := \sqrt{2g \cdot h}$ $v = 3.705 \frac{m}{s}$ max speed at impact

$t_i := 15ms$ impact time

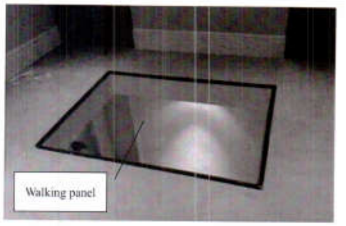
$F_d := \frac{m \cdot v}{t_i} = 12.351 \cdot kN$ dynamic force

$$\frac{F_d}{20cm \cdot 20cm} = 0.309 \cdot MPa \qquad \frac{1.4 \cdot 120MPa}{1.0} = 168 \cdot MPa$$

HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

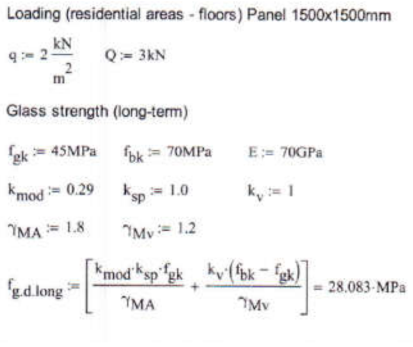
ÇÖZÜMLÜ PROBLEMLER – CAM DÖŞEME



HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

ÇÖZÜMLÜ PROBLEMLER – CAM DÖŞEME



Loading (residential areas - floors) Panel 1500x1500mm

$q := 2 \frac{kN}{m^2}$ $Q := 3kN$

Glass strength (long-term)

$f_{gk} := 45MPa$ $f_{bk} := 70MPa$ $E := 70GPa$

$k_{mod} := 0.29$ $k_{sp} := 1.0$ $k_v := 1$

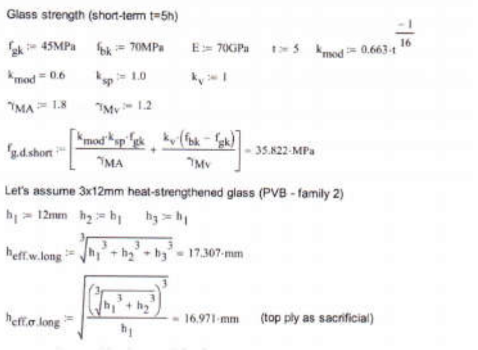
$\gamma_{MA} := 1.8$ $\gamma_{Mv} := 1.2$

$$f_{g.d.long} := \left[\frac{k_{mod} \cdot k_{sp} \cdot f_{gk}}{\gamma_{MA}} + \frac{k_v \cdot (f_{bk} - f_{gk})}{\gamma_{Mv}} \right] = 28.083 \cdot MPa$$

HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

ÇÖZÜMLÜ PROBLEMLER – CAM DÖŞEME



Glass strength (short-term t=5h)

$f_{gk} := 45MPa$ $f_{bk} := 70MPa$ $E := 70GPa$ $t := 5$ $k_{mod} := 0.663 \cdot t^{\frac{-1}{16}}$

$k_{mod} = 0.6$ $k_{sp} := 1.0$ $k_v := 1$

$\gamma_{MA} := 1.8$ $\gamma_{Mv} := 1.2$

$$f_{g.d.short} := \left[\frac{k_{mod} \cdot k_{sp} \cdot f_{gk}}{\gamma_{MA}} + \frac{k_v \cdot (f_{bk} - f_{gk})}{\gamma_{Mv}} \right] = 35.822 \cdot MPa$$

Let's assume 3x12mm heat-strengthened glass (PVB - family 2)

$h_1 := 12mm$ $h_2 := h_1$ $h_3 := h_1$

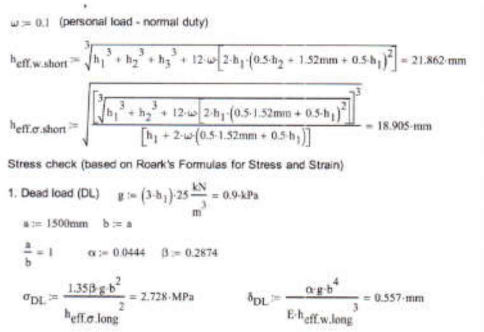
$$h_{eff.w.long} := \sqrt[3]{h_1^3 + h_2^3 + h_3^3} = 17.307 \cdot mm$$

$$h_{eff.\sigma.long} := \sqrt{\frac{\left(\sqrt[3]{h_1^3 + h_2^3}\right)^3}{h_1}} = 16.971 \cdot mm \quad \text{(top ply as sacrificial)}$$

HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

ÇÖZÜMLÜ PROBLEMLER – CAM DÖŞEME



$\omega := 0.1$ (personal load - normal duty)

$$h_{eff.w.short} := \sqrt[3]{h_1^3 + h_2^3 + h_3^3 + 12\cdot\omega\left[2\cdot h_1\cdot\left(0.5\cdot h_2 + 1.52mm + 0.5\cdot h_1\right)^2\right]} = 21.862\cdot mm$$

$$h_{eff.\sigma.short} := \sqrt{\frac{\left[\sqrt[3]{h_1^3 + h_2^3 + 12\cdot\omega\left[2\cdot h_1\cdot\left(0.5\cdot 1.52mm + 0.5\cdot h_1\right)^2\right]}\right]^3}{\left[h_1 + 2\cdot\omega\cdot\left(0.5\cdot 1.52mm + 0.5\cdot h_1\right)\right]}} = 18.905\cdot mm$$

Stress check (based on Roark's Formulas for Stress and Strain)

1. Dead load (DL) $g := \left(3\cdot h_1\right)\cdot 25\frac{kN}{m^3} = 0.9\cdot kPa$

$a := 1500mm \quad b := a$

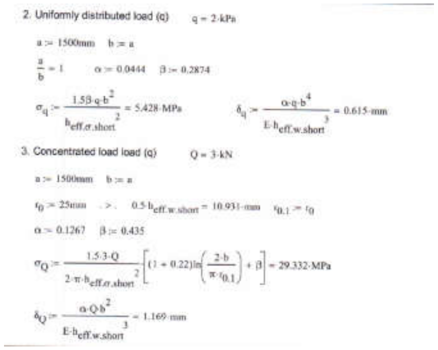
$\frac{a}{b} = 1 \qquad \alpha := 0.0444 \quad \beta := 0.2874$

$$\sigma_{DL} := \frac{1.35\beta\cdot g\cdot b^2}{h_{eff.\sigma.long}^2} = 2.728\cdot MPa \qquad \delta_{DL} := \frac{\alpha\cdot g\cdot b^4}{E\cdot h_{eff.w.long}^3} = 0.557\cdot mm$$

HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

ÇÖZÜMLÜ PROBLEMLER – CAM DÖŞEME



2. Uniformly distributed load (q) $q = 2\cdot kPa$

$a := 1500mm \quad b := a$

$\frac{a}{b} = 1 \qquad \alpha := 0.0444 \quad \beta := 0.2874$

$$\sigma_q := \frac{1.5\beta\cdot q\cdot b^2}{h_{eff.\sigma.short}^2} = 5.428\cdot MPa \qquad \delta_q := \frac{\alpha\cdot q\cdot b^4}{E\cdot h_{eff.w.short}^3} = 0.615\cdot mm$$

3. Concentrated load load (q) $Q = 3\cdot kN$

$a := 1500mm \quad b := a$

$r_0 := 25mm \quad .>. \quad 0.5\cdot h_{eff.w.short} = 10.931\cdot mm \quad r_{0.1} := r_0$

$\alpha := 0.1267 \quad \beta := 0.435$

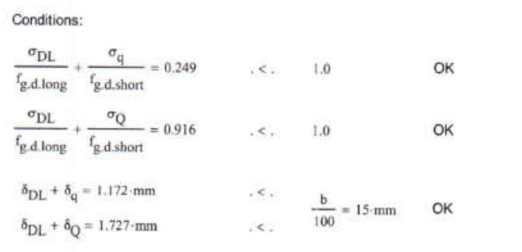
$$\sigma_Q := \frac{1.5\cdot 3\cdot Q}{2\cdot\pi\cdot h_{eff.\sigma.short}^2}\left[(1 + 0.22)\ln\left(\frac{2\cdot b}{\pi\cdot r_{0.1}}\right) + \beta\right] = 29.332\cdot MPa$$

$$\delta_Q := \frac{\alpha\cdot Q\cdot b^2}{E\cdot h_{eff.w.short}^3} = 1.169\cdot mm$$

HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

ÇÖZÜMLÜ PROBLEMLER – CAM DÖŞEME



Conditions:

$\frac{\sigma_{DL}}{f_{g.d.long}} + \frac{\sigma_q}{f_{g.d.short}} = 0.249 \quad .<. \quad 1.0 \qquad$ OK

$\frac{\sigma_{DL}}{f_{g.d.long}} + \frac{\sigma_Q}{f_{g.d.short}} = 0.916 \quad .<. \quad 1.0 \qquad$ OK

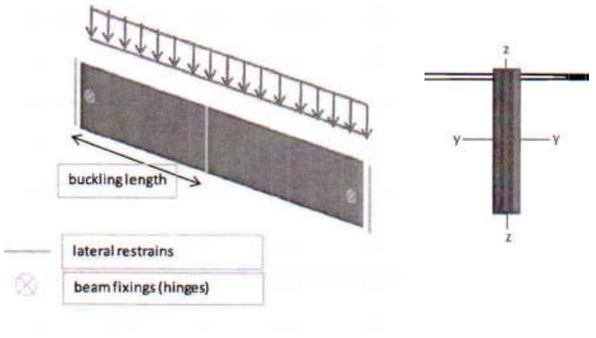
$\delta_{DL} + \delta_q = 1.172\cdot mm \quad .<.$

$\delta_{DL} + \delta_Q = 1.727\cdot mm \quad .<. \quad \frac{b}{100} = 15\cdot mm \qquad$ OK

HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

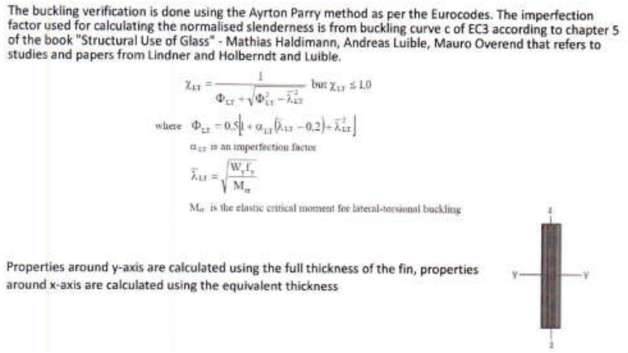
ÇÖZÜMLÜ PROBLEMLER – CAM KİRİŞ



HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

ÇÖZÜMLÜ PROBLEMLER – CAM KİRİŞ



The buckling verification is done using the Ayrton Parry method as per the Eurocodes. The imperfection factor used for calculating the normalised slenderness is from buckling curve c of EC3 according to chapter 5 of the book "Structural Use of Glass" - Mathias Haldimann, Andreas Luible, Mauro Overend that refers to studies and papers from Lindner and Holberndt and Luible.

$$\chi_{LT} = \frac{1}{\Phi_{LT} + \sqrt{\Phi_{LT}^2 - \bar{\lambda}_{LT}^2}} \quad \text{but } \chi_{LT} \leq 1{,}0$$

where $\Phi_{LT} = 0{,}5\left[1 + \alpha_{LT}\left(\bar{\lambda}_{LT} - 0{,}2\right) + \bar{\lambda}_{LT}^2\right]$

α_{LT} is an imperfection factor

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_y f_y}{M_{cr}}}$$

M_{cr} is the elastic critical moment for lateral-torsional buckling

Properties around y-axis are calculated using the full thickness of the fin, properties around x-axis are calculated using the equivalent thickness

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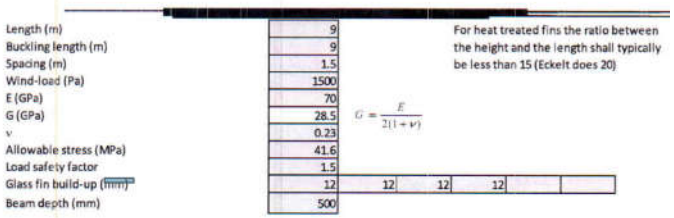
HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

ÇÖZÜMLÜ PROBLEMLER – CAM KİRİŞ



Length (m)	9					
Buckling length (m)	9					
Spacing (m)	1.5					
Wind-load (Pa)	1500					
E (GPa)	70					
G (GPa)	28.5					
v	0.23					
Allowable stress (MPa)	41.6					
Load safety factor	1.5					
Glass fin build-up (mm)	12	12	12	12		
Beam depth (mm)	500					

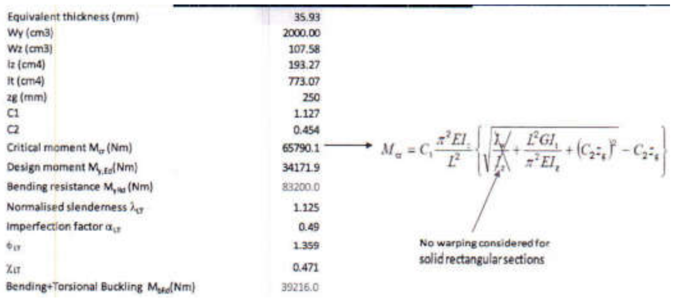
$$G = \frac{E}{2(1+\nu)}$$

For heat treated fins the ratio between the height and the length shall typically be less than 15 (Eckelt does 20)

HESAP ESASLARI

4-BİRİNCİL CAM ELEMANLARIN BOYUTLANDIRILMASI

ÇÖZÜMLÜ PROBLEMLER – CAM KİRİŞ



Equivalent thickness (mm)	35.93
Wy (cm3)	2000.00
Wz (cm3)	107.58
Iz (cm4)	193.27
It (cm4)	773.07
zg (mm)	250
C1	1.127
C2	0.454
Critical moment M_{cr} (Nm)	65790.1
Design moment $M_{y,Ed}$(Nm)	34171.9
Bending resistance M_{yRd} (Nm)	83200.0
Normalised slenderness λ_{LT}	1.125
Imperfection factor α_{LT}	0.49
ϕ_{LT}	1.359
χ_{LT}	0.471
Bending+Torsional Buckling M_{bRd}(Nm)	39216.0

$$\xrightarrow{} \quad M_{cr} = C_1 \frac{\pi^2 EI_z}{L^2}\left\{\sqrt{\cancel{\frac{I_w}{I_z}} + \frac{L^2 GI_t}{\pi^2 EI_z} + \left(C_2 z_g\right)^2} - C_2 z_g\right\}$$

No warping considered for solid rectangular sections

TEŞEKKÜRLER

- Sunuma yorum ve katkıları için CWG Danışmanlık'tan **Sn. Salih Sekban**'a teşekkürlerimizi sunuyoruz.
- Isıcamlar için paylaştıkları yazılım doğrulama örnek çözümleri sebebiyle MACROSTATIC'e teşekkür ederiz.

Kaynaklar

[1] TS EN 572-1 Cam yapılarda kullanılan temel soda kireç silikat cam ürünler kısım 1: Tarifler ve genel fiziksel ve mekanik özellikler

[2] TS EN 12150-1 Cam- Yapılarda kullanılan- Termal olarak temperlenmiş, soda kireç silikat emniyet camı- Bölüm 1: Tarifler- Açıklamalar

[3] Haldimann, M., Luible, A., Overend., *Structural Use of Glass*, IABSE, Switzerland ,2008

[4] COST European Erasmus Mundus Master Course Sustainable Constructions under Natural Hazards and Catastrophic Events, CTU in Prague, Ders Notları

[5] prEN 13474-1(1999)/2(2000) Design of Glass Panes

[6] Overend et al., "Diagnostic Interpretation of Glass Failure" Structural Engineering International 2/2007

[7] TS EN 1288-1:2003 Cam - Yapılarda kullanılan – Eğilme Mukavemetinin Tayini - Bölüm 1: Camla ilgili deneylerin esasları

[8] TS EN 1288-1:2003 Cam - Yapılarda kullanılan – Eğilme Mukavemetinin Tayini - Bölüm 1: Camla ilgili deneylerin esasları

Kaynaklar

[9] prEN16612 Glass In Building - Determination Of The Load Resistance Of Glass Panes By Calculation And Testing;

[10] Guidance for European Structural Design of Glass Components, 2014, JRC

[11] Zemanova A. Et al., "Simple Numerical Model of Laminated Glass Beams" Acta Polytechnica Vol. 48 No. 6/2008

[12] TS EN 13830:2005 Giydirme Cepheler-Mamul Standardı

[13] Memari, Ali, et al., "Seismic Behavior of Cırtain Walls Containing Insulating Glass Units" *Journal of Architectural Engineering*, ASCE

[14] Memari, Ali, et al., "Static Finite Element Analysis of Architectural Glass Curtian Walls Under in-plane Loads and and Corresponding Full-Scale Test." *Structural Engineering and Mechnahics,* 25(4), 365-382

[15] *DBYBHY 2007*

[16] ASCE7-05 Minimum Design Loads for Buildings and Other Structures, ASCE STANDARD

[17] *Architectural Glass to Resist Seismic and Extreme Climatic Events.* Woodhead Publishing in Materials, UK, 2009

Kaynaklar

[18] AAMA 501.6-09 "Recommended Dynamic Test Method for Determining the Seismic Drift Causing Glass Fallout from a Wall System" American Architectural Manufacturers Association

[19] TS EN 12600:2004 Cam - Yapılarda kullanılan – Sarkaç deneyi – Düz cam için çarpma deneyi ve sınıflandırma

[20] TS EN 356 Emniyet camları-Yapılarda kullanılan-Deneme ve sınıflandırma

[21] Maria Lindqvist PhD. 2013. «Structural Glass Strength Prediction Based on Edge Flaw Characterization» ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

[22] Structural Use of Glass in Buildings (2nd Edition)