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Large yachts — Strength, weathertightness and watertightness of glazed openings —

Part 1: Design criteria, materials, framing and testing of independent glazed openings

Grands yachts — Résistance, étanchéité aux intempéries et étanchéité à l'eau des ouvertures vitrées —

Partie 1: Critères de conception, matériaux, encadrement et essais des ouvertures vitrées indépendantes

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

ISO draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at www.iso.org/patents. ISO shall not be held responsible for identifying any or all such patent rights.

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 8, *Ships and marine technology*, Subcommittee SC 12, *Ships and marine technology — Large yachts*.

This second edition cancels and replaces the first edition (ISO 11336-1:2012), which has been technically revised.

The main changes are as follows:

— the Scope has been expanded to include length, number of passengers and glazing materials;

— the design pressure model has been parameterized and adapted to cover larger yachts;

— more advanced scantling calculation methods have been added;

— a new approach on robustness of superstructure and hull glazing has been added;

— Annex H has been replaced with information on the main changes since the first edition;

— Annexes I and J have been added.

A list of all parts in the ISO 11336 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Large yachts — Strength, weathertightness and watertightness of glazed openings —

Part 1: Design criteria, materials, framing and testing of independent glazed openings

1 Scope

This document specifies technical requirements for independent glazed openings on large yachts, taking into account navigation conditions, the location of the opening and the materials, framing and testing.

Large yachts are yachts with length of the hull, L_H, higher or equal to 24 m, used for sport or pleasure and commercial operations.

This document is suitable for the design of glazed openings on all large yachts. However, where yachts carry more than 12 passengers, the additional requirements (set by the appropriate marine administration) for fire integrity and damage stability are outside the scope of this standard.

The opening and the associated closing appliances considered in this document are only those that are above the deepest waterline (dsw) and are critical for the ship integrity related to weathertightness and watertightness, i.e. those that can lead to ingress of water in the hull in case of rupture, dislocation or loss of the pane or its mounting. This document is related and limited to independent glazed openings in which the pane is supported solely by simple linear support at the edges. Glazing in which the rotation at the edges is constrained more than it would be by a single bond line is not covered by this document. This document, excluding annexes, is limited to glazing of any shape, which is simply supported along all edges. Horizontally positioned glazing is excluded.

NOTE This document is based on the experience of ship window and glass manufacturers, shipbuilders and authorities who apply to ships the regulations of SOLAS, as amended[7], and of the International Convention of Load Lines, as amended[6], noting the provisions by the SOLAS Protocol of 1988, Article 8, as agreed by the appropriate Marine Administration, and on the experience gained with application of the Large Commercial Yacht Code and the REG Yacht Code[16].

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 178, *Plastics — Determination of flexural properties*

ISO 1751, *Ships and marine technology — Ships' side scuttles*

ISO 3903, *Ships and marine technology — Ships' ordinary rectangular windows*

ISO 5797, *Ships and marine technology — Windows and side scuttles for fire-resistant constructions*

ISO 6345, *Shipbuilding and marine structures — Windows and side scuttles — Vocabulary*

ISO 12543-1, *Glass in building — Laminated glass and laminated safety glass — Part 1: Vocabulary and description of component parts*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

ISO 21005, *Ships and marine technology — Thermally toughened safety glass panes for windows and side scuttles*

ISO 6721-10, *Plastics — Determination of dynamic mechanical properties — Part 10: Complex shear viscosity using a parallel-plate oscillatory rheometer*

EN 1288-3, *Glass in building — Determination of the bending strength of glass — Part 3: Test with specimen supported at two points (four point bending)*

EN 1990:2008, *Eurocode — Basis of structural design*

EN 12150-1:2000, *Glass in building — Thermally toughened soda lime silicate safety glass — Part 1: Definition and description*

EN 12337-1, *Glass in building — Chemically toughened soda lime silicate safety glass — Part 1: Definition and description*

EN 13195-1, *Aluminium and aluminium alloys. Specifications for wrought and cast products for marine applications (shipbuilding, marine and offshore)*

EN 16612, *Glass in building. Determination of the lateral load resistance of glass panes by calculation*

ISO 29584, *Glass in building — Pendulum impact testing and classification of safety glass*

ISO 11336-2, *Large yachts — Strength, weathertightness and watertightness of glazed openings — Part 2: Glazed opening integrated into adjacent structure (elastically bonded to bulkhead or shell) design criteria, structural support, installation and testing*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 6345 and the following apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
glazed opening
opening in the hull, *superstructure* (3.26) or deckhouse of a ship structure to be fitted with a transparent or translucent material

3.2
independent glazed opening
glazed opening (3.1) where the mechanical behaviour of the *pane* (3.5) can be considered independent from adjacent structure because the pane is mounted in such a way that it is isolated from deformations of the supporting structure, and the only loads on the pane are lateral pressure and effect of gravity and inertia

3.3
not independent glazed opening
glazed opening (3.1) where the mechanical behaviour of the *pane* (3.5) cannot be considered independent from adjacent structure, e.g. pane bonded directly into a seat in such a way that it is carrying in-plane loads or is subjected to out-of-plane deformations of the supporting structure

3.4
appliance
device made of a *pane* (3.5) and a fixing system, used to cover an opening in the hull, *superstructure* (3.26) or deckhouse

3.5
pane
sheet of material fixed within or to a supporting structure

3.6
glazing
transparent or translucent *pane* (3.5)

3.7
unsupported dimensions
clear dimensions between the supports bearing the *pane* (3.5)

Note 1 to entry: See Annex A.

3.8
deadlight
secondary watertight closure fitted to a *glazed opening* (3.1) and which is fitted on the inside of the vessel

3.9
storm shutter
portable protective closure fitted to a *glazed opening* (3.1) and which is fitted on the outside (weatherside) of the vessel

3.10
flag administration
government of the state whose flag the yacht flies

3.11
certifying authority
flag administration (3.10) or organization to whom the flag administration delegates certifying authority

3.12
service
description of the service limitations for which a yacht is assessed to be suitable

3.13
commercial operation
operation for commercial use, involving yachts carrying no cargo and generally not more than 12 passengers or not needing to comply with passenger ship requirements

3.14
pleasure operation
operation involving private yachts not engaged in trade

3.15
operational range
range for which a yacht is assessed to be suitable

Note 1 to entry: For unrestricted range yachts, the operational range is the extended distance from safe haven where conditions experienced can exceed wind force 8 (Beaufort scale), excluding extreme conditions.

Note 2 to entry: For intermediate range yachts, the operational range is a distance of not more than 200 nautical miles from a safe haven.

Note 3 to entry: For a short range yacht, the operational range is a distance of not more than 60 nautical miles from a safe haven.

3.16
freeboard deck
uppermost complete deck exposed to weather and sea, which has permanent means of closing all openings in the weather part thereof, and below which all openings in the sides of the ship are fitted with permanent means of watertight closing

Note 1 to entry: At the decision of the owner and subject to the approval of the administration, a lower deck can be designated as a freeboard deck, provided it is a complete and permanent deck continuous in a fore and aft direction at least between the machinery space and peak bulkheads and continuous athwart-ships.

3.17
standard superstructure height
h_{std}
height parameter expressed in meters (m) which is used for the calculation of the design load

Note 1 to entry: For vessels up to 75 m load line length, the height is taken as 1,8 m.

Note 2 to entry: For vessels over 125 m load line length, the height is taken as 2,3 m.

Note 3 to entry: For vessels of intermediate lengths, the height is obtained by linear interpolation.

3.18
load line length
L
96 % of the total length on a waterline at 85 % of the least moulded depth measured from the top of the keel, or as the length from the fore side of the stem to the axis of the rudder stock on that waterline, if that is greater

Note 1 to entry: For ships without a rudder stock, the length, L, is taken as 96 % of the waterline at 85 % of the least moulded depth.

3.19
limits in glazed openings
maximum size of *glazed openings* (3.1) below a line 0,05 times ship length, measured from dsw (deepest seagoing waterline) or less than $L/4$ aft of a line drawn at the intersection of the 0,05 L and the stem, and below a line drawn at 0,05 L +h_{std}, not exceeding 0,85 m^2

Note 1 to entry: See Figure 1.

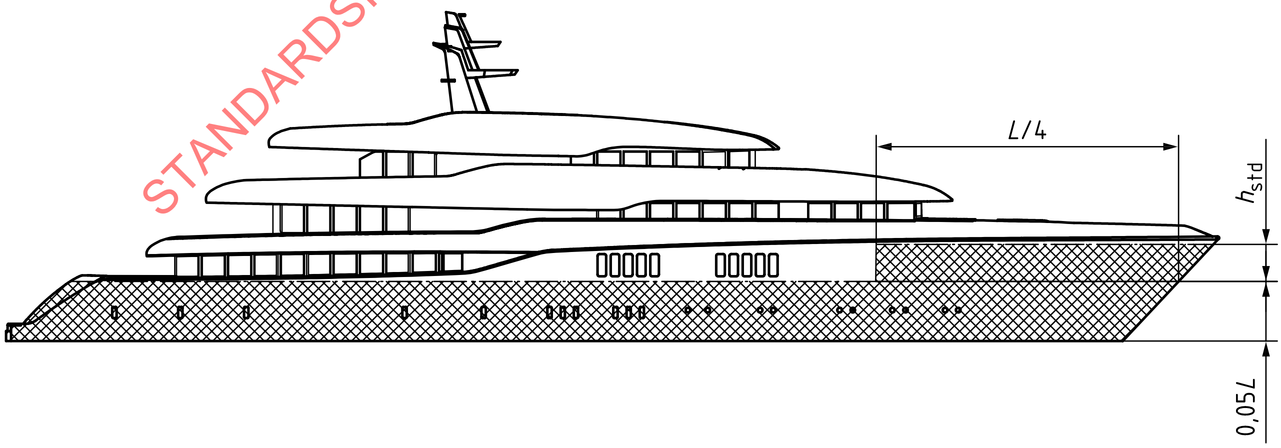


Figure 1 — Area in which glazed openings are limited to 0,85 m^2

3.20
large yacht
yachts in use for sport or *pleasure* (3.14) and *commercial operations* (3.13), with a length of the hull, $L_{H,}$ higher or equal to 24 m

Note 1 to entry: The length of the hull, L_H is measured according to ISO 8666.

3.21
weathertightness
capacity to prevent that, in any sea conditions, water will penetrate into the ship

Note 1 to entry: This definition has been adapted from the term “weathertight” taken from the International Convention on Load Lines (ICLL), Annex I, Regulation 3 (12). This is interpreted generally as indicating that weathertightness is required from the exterior only, as opposed to *watertightness* (3.22), indicating the ability to withstand from both inside and outside.

3.22
watertightness
capacity of an appliance to prevent the passage of water through the structure in any direction under a head of water for which the surrounding structure is designed

3.23
strength
capacity of a structure to maintain full structural integrity under the action of loads

3.24
design loads
external hydrostatic loads according to which glazed openings strength is assessed

3.25
hull
part of the yacht within the envelope of the side shell and decks taken into account for the assignment of freeboard and for stability evaluation

3.26
superstructure
decked structure on the freeboard deck, extending from side to side of the yacht or with side plating not being inboard of the shell plating more than 4 % of the yacht breadth

[SOURCE: ICLL 1966, Regulation 3, 10 (a), modified — “ship” replaced with “yacht”.]

3.27
deckhouse
structure enclosing a space that is normally accessible and used for accommodation or service and that does not qualify as a *superstructure* (3.26) and that can be positioned on the freeboard deck, and/or the tiers above

3.28
wheelhouse
control position occupied by the officer of the watch

3.29
glass ply
plate made of an inorganic non-crystalline solid exhibiting a glass transition behaviour

3.30
thermally toughened safety glass
glass where strength increase is obtained by a thermal treatment resulting in the introduction of permanent compression stress on both sides of its cross section

3.31
chemically toughened glass
glass where strength increase is obtained by chemical treatment resulting in the introduction of permanent compression stress on both sides of its cross section

3.32
monolithic pane
monolithic construction
glazing (3.6) consisting of one ply of glass

3.33
laminated glass
multi-layer *pane* (3.5) made of glass plies, plastic plies or other *glazing* (3.6) materials, which are kept together by suitable plastic adhesive films or curable resins

3.34
safety glass
monolithic thermally toughened glass, fully tempered, or *laminated glass* (3.33) built from thermally or chemically toughened *panes* (3.5)

3.35
insulating glazing unit
IGU
window *panes* (3.5) (usually glass) separated by a gas-filled space to reduce heat transfer across a part of the vessel envelope

Note 1 to entry: Insulating *glazing* (3.6) units consist of two or more window panes.

Note 2 to entry: A window with insulating glass is commonly known as double glazing or a double-paned window, triple glazing or a triple-paned window, or quadruple glazing or a quadruple-paned window, depending on how many panes of glass are used in its construction.

3.36
depth of compression layer
glass case depth
l_{CD}
depth measured from the surface to the inner cross section point where compression stress is zero, when a *glass ply* (3.29) is toughened by the introduction of permanent compression stress on both sides of its cross section

3.37
glass surface compression
S_C
value of compression stress taken at the surface, when a *glass ply* (3.29) is toughened by the introduction of permanent compression stress on both sides of its cross section

3.38
plastic ply
rigid plate, made of a polymeric material, where “rigid” means that the plastic material has a modulus of elasticity in flexure or, if not applicable, then in tension, greater than 700 MPa

3.39
interlayer
laminating adhesive material that holds together the plies of a laminated *glazing* (3.6)

Note 1 to entry: It can be a thermoplastic adhesive film or a curable resin.

3.40
characteristic failure strength
σ_C
ultimate flexural strength of *glass pane* (3.41) or *plastic material* (3.42)

3.41
glass pane
ultimate flexural strength at rupture of glass measured, on a statistical basis, in a flexural testing arrangement with a defined method of data reduction taking in account statistical dispersion

3.42
plastic material
ultimate flexural strength at rupture or flexural strength at yield, whichever is lower

Note 1 to entry: The choice between the value at rupture or at yield depends on the mechanical characteristics of the plastic material; as a general indication brittle plastic material breaks before yielding without apparent plastic deformation while non-brittle plastic material yields before breaking.

3.43
main structural section
monolithic or laminated *pane* (3.5) construction that meets strength requirements

Note 1 to entry: to entry The strength requirements are specified in 5.2.

3.44
additional functional plies
additional glass or plastic plies or *panes* (3.5) not included in the frame that can be coupled to the main structural section, do not have structural functionalities and do not affect structural functionality of the main structural section

Note 1 to entry: The flexural modulus/flexural strength, E/σ_c, is substantially less (50 %) than that of the main structural section.

3.45
deepest seagoing waterline
dsw
assigned waterline for commercial yachts or the deepest seagoing waterline for private yachts

3.46
superstructure type A
superstructure (3.26) not considered buoyant in the stability calculations

3.47
superstructure type B
superstructure (3.26) considered buoyant in the stability calculations

3.48
aft perpendicular
position of the aft end of the *deepest seagoing waterline* (3.45)

4 Symbols and abbreviated terms

p_D	design pressure following from the location on board the ship
p_{DE}	design pressure for engineering the glass panels
p_{D0}	base design pressure
p_{ULS}	ultimate limit state pressure - $p_{ULS} = \gamma \cdot p_{DE}$.
a	factor relating to location and vessel length
b	factor based on longitudinal location
f	factor based on vessel length

c	factor based on width of superstructure or deckhouse
h	height of centre of pane from dsw
h_0	height above the waterline where design pressure equals p_{D0}
h_{std}	standard superstructure height
I_s	shear collaboration factor in laminated glazing
k_s	service factor
L_H	length of the hull
L	load line length
L_p	length between perpendiculars on summer load waterline
x	distance of centre of pane or storm shutter from aft perpendicular
t_O	basic pane thickness
a_P	unsupported long side of a rectangular pane or “equivalent long side” of a pane
b_P	unsupported short side of a rectangular pane or “equivalent short side” of a pane
β_S	pane aspect-ratio coefficient for stress
β_D	pane aspect-ratio coefficient for deflection
σ_A	allowable design flexural stress of the material
d	diameter of a circular glazed opening
σ_C	characteristic breaking strength of a material or laminate
γ	design factor
t_a	actual pane thickness
t_{min}	minimum pane thickness
$t_{p1}, t_{p2}, ..., t_{pn}$	ply thicknesses of a laminated pane
$t_{eq,j}$	equivalent thickness of each ply of the laminate
t_{eq}	equivalent thickness of laminated construction
t_{Lam}	physical thickness of a laminate
δ_{max}	maximum pane deflection
M	pane stiffness
l_{CD}	depth of compression layer
S_C	glass surface compression
N	number of test specimens
n	number of independent plies

σ_i	breaking stress for each test specimen when tested according to EN 1288-3 for glass or ISO 178 for brittle plastic materials; stress at yield for each test specimen when tested according to ISO 178 for non-brittle plastic materials
σ_{av}	average breaking stress or yield stress, whichever is applicable
s_x	standard deviation
C_V	coefficient of variation
K_n	statistic coefficient corresponding to lower half of the 90 % confidence limit
E	Young's modulus
ν	Poisson's ratio
Z	section modulus
ICLL 1966	International Convention on Load Line 1966, as amended
IACS	International Association of Class Societies
TTG	thermally toughened safety glass
CTG	chemically toughened glass
IGU	insulating glazing units
PMMA	Poly(methyl methacrylate)
PC	Polycarbonate
dsw	deepest seagoing waterline
FRP	fibre reinforced plastics

5 Design criteria

5.1 General

Other international standards, for example, those dealing with stability, buoyancy, weathertight or watertight integrity, can have restrictions on the position of appliances which are outside the scope of this document. However, it is expected that the builder or user ensures that the appliances comply with other relevant international standards.

It is also possible that national authorities have additional requirements differing from those of this document. Individual statutory regulations of flag administrations for commercial yachts can apply. For example, where yachts are complying with the published "Conditions of Assignment" of the International Convention on Load Line, 1966, as amended[6], the maximum size of a glazed opening below the freeboard deck or in enclosed superstructures is 0,16 m^2.

5.2 Strength

The strength of glazed openings and associated appliances shall meet the requirements of this document, ISO 3903 or ISO 1751, depending on the type of glazed opening. For the scope of this document, strength is considered only with reference to local loads, that is, external hydrostatic loads coming from weather and sea conditions. Strength requirements are fulfilled according to any of the following criteria:

— where the glazed opening type is covered by an existing relevant international standard, such as ISO 3903 or ISO 1751, for ship's windows and ship's portlights respectively;

— where the pane thickness is calculated according to the method outlined in 5.6, and the glass is flat or convex towards the load action direction, the strength requirements of the frame are according to an existing relevant international standard such as ISO 3903 or ISO 1751;

— when the pane has been tested according to the hydrostatic test procedure outlined in 7.3.

External hydrostatic loads (design loads) shall be the only loads considered for strength requirement fulfilment according to this document. For a particular application, other requirements and criteria can be relevant and can apply.

Strength requirements for monolithic and laminated constructions shall be fulfilled only for the main structural section. Additional functional plies or panes are plies that are not intended to fulfil strength requirements. Furthermore, they shall not take part in the structural validation of the appliance or in the hydrostatic test outlined in 7.3. Such plies or panes shall not adversely affect the strength of the main structural section.

According to qualification by hydrostatic test, any changes to the glazing materials or any change to the cross-section or larger dimensions of the glazing shall require re-testing. For tolerances, see 7.3.2.

5.3 Watertightness

The appliance shall be designed and mounted to prevent ingress of water into the yacht according to any of the following criteria:

— where the appliance type is covered by an existing relevant international standard;

— where the pane thickness is calculated in accordance with the methods outlined in 5.6. The pane is clamped with a rubber gasket or bonded in the frame with the bonding joint in compression. The strength requirements of the frame are according to ISO 1751 or ISO 3902, depending on their type;

— when tested according to the hydrostatic test procedure outlined in 7.3.

Any changes to the glazing materials or any change to the cross-section or larger dimensions of the glazing shall require re-testing. For tolerances, see 7.3.2.

5.4 Weathertightness

The weathertightness requirements shall be fulfilled by performing a hose test in the final installation on board. The hose test consists of hosing the appliance along its perimeter (width of 100 mm) by means of at least 12,0 mm nominal size hose held at a distance of not more than 1,5 m from the appliance. A static water pressure (with no water flow) of 200 kPa shall be used and the free height of water from the hose with stream directed upwards of shall be not less than 10 m.

The hosing shall last at least three minutes, uniformly applied around the periphery for each appliance. No water shall be detected on the inner side of the appliance.

5.5 Design loads

5.5.1 Design pressure for glazed openings in end bulkheads of superstructures and deckhouses on or above the freeboard deck

This design pressure shall also be applied to storm shutters and deadlights in the exposed bulkheads of superstructures and deckhouses, on and above the freeboard deck.

The design pressure formula in IACS UR S 3[8], is adapted to Formulae (3) to (5) to give design pressures p_D for glazed openings and storm shutters in the end bulkheads of superstructures, the end bulkheads and side bulkheads of deckhouses on or above the freeboard deck.

The design pressure, p_D, depends on the position on the vessel and the orientation of the opening. It is a component of the design pressure for engineering, p_{DE}, (see 5.6), which includes factors for robustness. Potential consequences of failure and this pressure, $p_{DE,}$ shall be used for design of the scantlings of the glazing.

The following apply to Formulae (1) to (8) for the determination of the design pressure use the following definitions:

y is the transverse distance from centreline;

b_2 is the half beam of vessel;

ϕ is the orientation angle of the window (see Figure 3).

The determination of design pressure requires a preliminary calculation of the base design pressure, p_{D0} (kN/m^2) according to Formula (1):

$$p_{D0} = (1 + f_{PD0}) \cdot \max\left(15; 12{,}5 + \frac{L}{20}\right) \quad (1)$$

where

p_{D0} is the base design pressure expressed in (kN/m^2);

f_{PD0} is the position factor of the glazed opening (non-dimensional);

and where the factors are determined using Formula (2) (see Figure 2):

$$f_{PD0} = f_h \cdot \max(f_{dir}; f_b) \quad (2)$$

where

$f_h = 1$ when the centre of the window is up to 1,5 m above the main deck (see Figure 2);

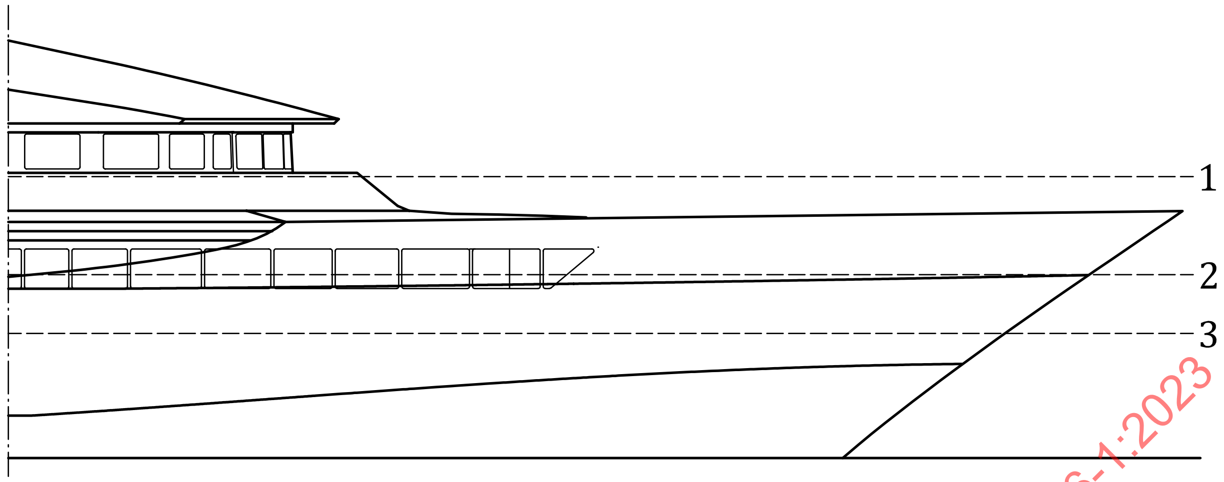
$f_h = 0$ when the centre of the window is 4,0 m or more above the main deck (see Figure 2) intermediate values of f_h by linear interpolation;

$f_b = 1$ when $y/b_2 = 1$;

$f_b = 0$ when $y/b_2 < 0{,}85$; intermediate values of f_b by linear interpolation;

$f_{dir} = -\cos(\phi)$ when $\phi > 90°$;

$f_{dir} = 0$ otherwise.



Key

1 4 m above the main deck

2 1,5 m above main deck

3 main deck

NOTE The main deck forms the top closure of the buoyant volume of the ship. It is usually the deck to which the depth is measured.

Figure 2 — Coefficient f_h definition

Design pressure, p_D (expressed in kN/m²), shall be not less than given by Formulae (3), (4) and (5):

If $h < h_0$ then: $p_D = 10{,}05 \cdot a \cdot k_s \cdot (b \cdot f - h) \cdot c$ (3)

If $h \geq h_0$ then: $p_D = p_{D0} - 2{,}27 \cdot (h - h_0)$ (4)

In no case p_D shall be less than

$$p_D = 3{,}5 \cdot (1 + f_{dir}) \quad (5)$$

h_0 in Formulae (3) and (4) is the height above the waterline where design pressure equals p_{D0}, that is:

$$h_0 = b \cdot f - \frac{p_{D0}}{(10{,}05 \cdot a \cdot k_s \cdot c)} \quad (6)$$

The design pressures given in IACS UR S 3[8] are also included in ISO 5779 and BS MA 25[9].

The factor relating to location, orientation and vessel length, a, introduced in Formula (3) can be defined in Formula (7):

$$a = x_1 \cdot \left(\frac{L}{100} \right) + x_2 \quad (7)$$

where

$$x_1 = \sqrt{\left[x_{1,x} \cdot \cos(\phi)\right]^2 + \left[x_{1,y} \cdot \sin(\phi)\right]^2} \; ; x_2 = \sqrt{\left[x_{2,x} \cdot \cos(\phi)\right]^2 + \left[x_{2,y} \cdot \sin(\phi)\right]^2} \quad (8)$$

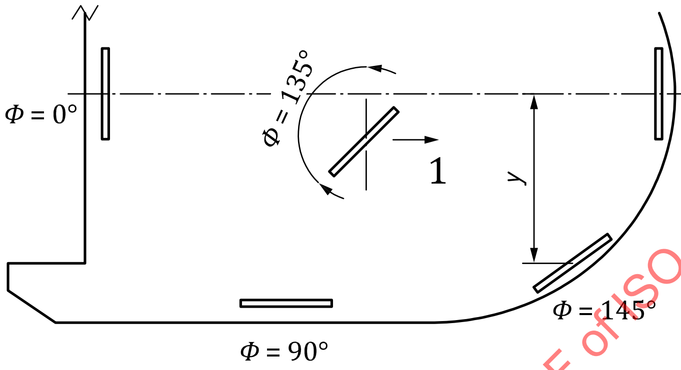
ϕ is the orientation angle - direction of projection of the average normal of the pane in the horizontal plane (see Figure 3), in degrees;

= 180° for forward facing;

= 90° for side facing;

= 0° for aft facing.

$x_{1,x}$ and $x_{2,x}$ are reported in Table 1 while $x_{1,y}$ and $x_{2,y}$ are in Table 2.



Key

1 forward

ϕ orientation angle of the window

y transverse distance from centreline

Figure 3 — Definition of the orientation angle

Table 1 — $x_{1,x}$ and $x_{2,x}$ coefficients

Position	**Orientation**	$x_{1,x}$	$x_{2,x}$
Aft facing	Where ϕ < 90 °	$x_{1,aft}$	$x_{2,aft}$
Forward facing	otherwise	$x_{1,front}$	$x_{2,front}$
Position code	**Height**	$x_{1,front}$	$x_{2,front}$
F1	Up to 1,5 m above the deck	0,83	2,0
F2	At 4 m above the deck	0,83	1,0
F3	At 6,5 m and more above the deck	0,66	0,5
	Location	$x_{1,aft}$	$x_{2,aft}$
A1	Where x/L < 0,25	0,1	0,60
A2	Where x/L > = 0,75	0,1	0,30
NOTE For intermediate positions between F1-F3 and F3 and A1-A2, values of $x_{1,aft}$ and $x_{2,aft}$ are determined via linear interpolation.			

Table 2 — $x_{1,y}$ and $x_{2,y}$ coefficients

Position code	**Location**	$x_{1,y}$	$x_{2,y}$
S1	y/b_2 = 1,0	$x_{1,front}$	$x_{2,front}$
S2	y/b_2 < = 0,8	0,1	0,30
NOTE For intermediate positions between S1 and S2, values of $x_{1,y}$ and $x_{2,y}$ are determined via linear interpolation.			

The remaining symbols for Formulae (3) to (6) are:

k_s – service factor

= 1,00 for unrestricted range yacht,

= 0,85 for intermediate range yacht,

= 0,75 for short range yacht;

f – factor based on vessel length, given in Table 3;

b – factor based on longitudinal location, given in Table 4;

c – correction for position relative to ship's side

= 0,85 where the pane is set inboard from the ship's side by 10 % or more of the ship's beam.

= 1,0 elsewhere;

For intermediate positions, *c* is determined by linear interpolation.

Table 3 — Values of *f*

Length *L* m	24	30	40	50	60	70	80	90	100	120	140	200	300
Factor *f*	1,18	1,72	2,57	3,36	4,09	4,76	5,38	5,94	6,45	7,33	8.04	9,34	10,0
NOTE Approximation: f = 0,428 4$(L/100)^3$ - 3,686 5$(L/100)^2$ + 10,951$(L/100)$ - 1,244.													

Table 4 — Values of *b*

x/*L*	*b*	*x*/*L*	*b*
0,00	1,41	0,50	1,01
0,10	1,25	0,60	1,07
0,20	1,13	0,70	1,19
0,30	1,05	0,80	1,38
0,40	1,01	0,90	1,62
0,45	1,00	1,00	1,93
NOTE Approximation: b = 2,626* $(x/L)^2$ -2,156* (x/L) + 1,436.			

5.5.2 Design pressure for glazed openings and deadlights in the side shell

Glazed openings and deadlight design pressures shall be as given in Table 5. The design of glazed openings shall include consideration of the strength of the deadlights and their means of attachment to the hull structure.

Table 5 — Design pressures for glazed hull openings and deadlights

L m	Motor yachts kN/m^2		Cruising sailing yachts kN/m^2	
	hull	Superstructure type B	hull	Superstructure type B
24	70	35	70	35
30	70	35	70	35
40	70	35	70	35
50	70	35	83	42
60	76	38	96	48
70	84	42	109	55
80	91	46	To be taken in accordance with ISO 5780, with minimum pressures being those in this table for a 70 m sailing yacht. Intermediate values by linear interpolation.	
90	98	49		
100	108	52		
> 100	To be taken in accordance with ISO 5780, with minimum pressures being those in this table for a 100 m motor yacht.			
NOTE The values in this table are design pressures for glazed hull openings and deadlights between the dsw and uppermost continuous deck, and for superstructures type B.				

5.6 Scantling determination of panes

5.6.1 General

Scantling formulae given in Formulae (10) and (11) are for panes in independent glazed openings supported on their full perimeter, mechanically independent from the adjacent structure.

Scantlings of panes in not independent glazed openings cannot be determined using Formulae (10) and (11).

Formula (10) is valid for rectangular panes; for circular panes see Formula (11).

Dimensions of clear opening for panes are defined in Annex A. For panes having shapes different from a rectangle or a circle, the approximations of Annex A shall be used to determine the "equivalent" unsupported dimensions.

The scantlings of the panes shall be determined using the design pressure for engineering $p_{DE,}$ using Formula (9):

$$p_{DE} = f_E \cdot p_D \tag{9}$$

where:

p_D is the design pressure determined in 5.5;

f_E is a factor for robustness:

f_E = 1,5 where glazing thickness is enhanced as an equivalent for providing 'storm shutters' (see Clause 8).

f_E = 1,0 elsewhere.

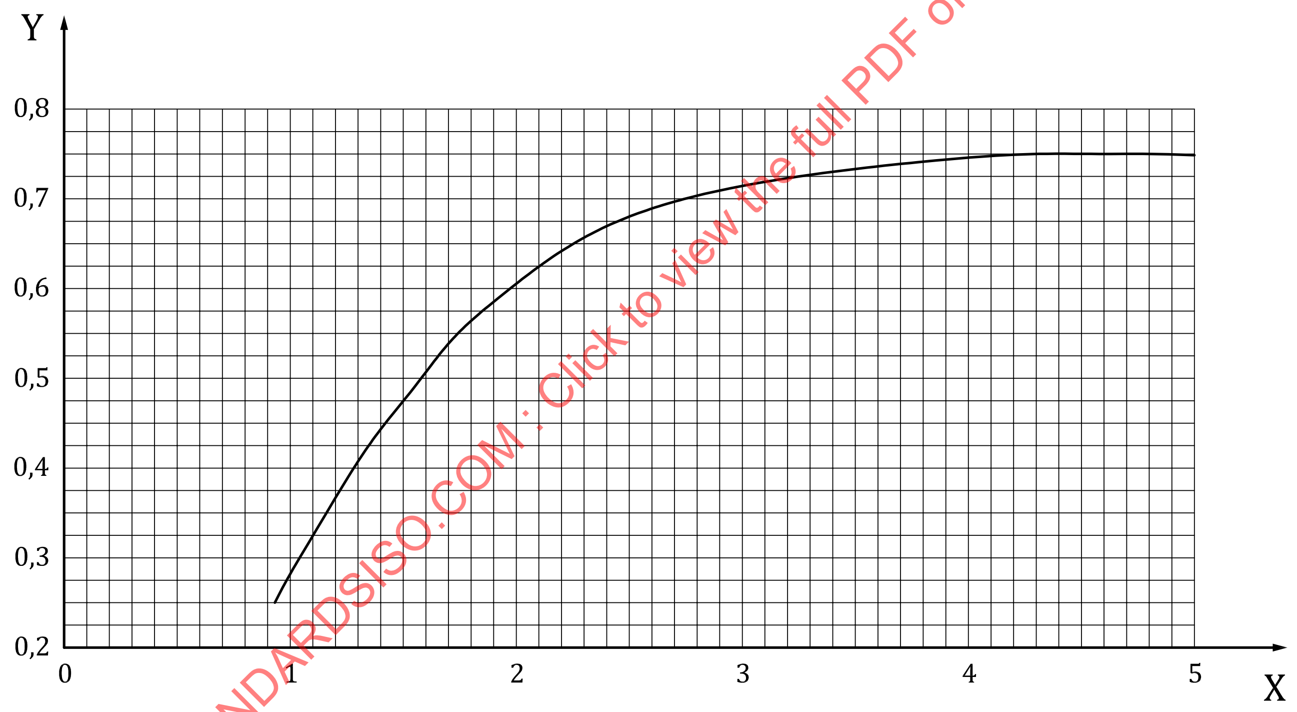
5.6.2 Basic pane thickness , t_0 , for rectangular or rectangular equivalent glazed openings

Basic pane thickness, t_0, is calculated as

$$t_0 = b_P \cdot \sqrt{\frac{\beta \cdot p_{DE}}{1\,000 \cdot \sigma_A}} \tag{10}$$

where

- t_0 is the basic pane thickness (mm);
- b_P is the clear opening short side of a rectangular pane or “equivalent short side” of a pane (mm);
- β is the pane aspect-ratio coefficient (see Figure 4 and Table 7 for panes simply supported on 4 sides);
- p_{DE} is the design pressure used for engineering (kN/m²);
- σ_A is the allowable design flexural stress of the material (see 5.6.4) (N/mm²).



Key

X aspect ratio, equal to a_p/b_p

Y pane aspect ratio coefficient, β

Figure 4 — Pane aspect ratio coefficient — β (X = a_p/b_p) for 4 sides simply supported panes

5.6.3 Basic pane thickness, t_0, for circular or circular equivalent glazed openings

Basic pane thickness t_0 is calculated as

$$t_0 = 0{,}5 \cdot d \cdot \sqrt{\frac{1{,}21 \cdot p_{DE}}{1\,000 \cdot \sigma_A}} \tag{11}$$

where

t_0 is the basic pane thickness (mm);

d is the clear opening diameter or the equivalent diameter of the glazed opening (mm);

p_{DE} is the design pressure used for engineering (kN/m^2);

σ_A is the allowable design flexural stress of the material (N/mm^2).

See Annex C for further information.

5.6.4 Design flexural stress of material, σ_A

Design flexural stress of material, σ_A, is evaluated from the values of the characteristic failure strength, σ_C, of the material and the relevant design factor, γ, according to Formula (12):

$$\sigma_A = \frac{\sigma_C}{\gamma} \quad (12).$$

The values of characteristic failure strength of the pane material are the manufacturer's stated values.

Glass materials shall be tested in accordance with EN 1288-3. Plastic materials shall be tested in accordance with ISO 178.

The acceptable values are given in Table 6. Values represent the lower confidence interval evaluated by the *t*-Student distribution at 90 % probability.

For the characteristic failure strength values expressed in Table 6 which are achieved to qualify glazing materials, materials with lower characteristic failure strength are not allowed.

Table 6 — Mechanical properties of materials, design factor and nominal design stress

Material	Abbreviated term	Characteristic failure strength σ_C N/mm^2		Design factor γ [a]	Reference standard (ISO – EN)
		Minimum [b]	Maximum		
Polymethyl methacrylate Polycarbonate	PMMA PC	90		3,5	ISO 178
Heat strengthened glass	HSG	70		3,0	EN 1863-1
Thermally toughened safety glass[c]	TTG	120	160	3,0[c]	EN 12150-1
Chemically toughened glass					
From soda lime silicate glass	CTG	150	300	3,75	EN 12337-1
From Lithium/Sodium Aluminium Silicate	CTG-LAS-SAS	150	300	3,75	

[a] For mixed constructions the higher design factor shall be used, unless stress per ply is determined via finite element calculations or laminate theory.

[b] Minimum industry standard. This is also the default value, to be used if no other data is available.

[c] Results in design stress 120/3 = 40 MPa consistent with traditional maritime standards.

5.6.5 Selection of monolithic pane thickness

The value of the pane thickness, t_a, expressed in millimetres, to be used in case of monolithic construction, shall be the higher of the following:

— the basic pane thickness, t_0, calculated in Formula (10) or (11) as applicable;

— the minimum pane thickness, t_{min}, in accordance with ISO 1751, ISO 3903 or ISO 21005, when glazing design is based on any of these standards.

With commercially available panes, the actual thickness is selected as the first upper integer.

5.6.6 Selection of laminated pane thickness

Laminated constructions can be considered:

a) laminates with plies of the same material (type A), and

EXAMPLE 1 Glass ply/interlayer/glass ply.

EXAMPLE 2 Plastic ply/interlayer/plastic ply.

NOTE In Example 2, the “plastic” layer always consists of the same material. Examples of type (A) are: Acrylic/interlayer/acrylic or Polycarbonate/interlayer/polycarbonate. It is not type (A) if the construction is: Acrylic/interlayer/polycarbonate.

b) laminates with plies of different materials (type B).

EXAMPLE 3 Glass ply/interlayer/plastic ply.

EXAMPLE 4 Glass ply/interlayer/plastic ply/interlayer/glass ply.

EXAMPLE 5 Acrylic ply/interlayer/polycarbonate ply.

5.6.7 Type (A) laminates — Laminates with plies of the same material

5.6.7.1 Independent plies

When the mechanical properties of the interlayer material (the laminating adhesive material) are not known, the plies of the laminated glazing shall be considered as mechanically independent.

The equivalent thickness of type (A) laminates made of n independent plies of thicknesses: t_1, t_2, ..., t_n, shall be calculated and compared with the basic thickness, t_0, calculated according to 5.6.1.

The equivalent thickness of n independent plies shall be calculated as follows. The thickness of one ply of the laminate is indicated generically as t_j, where the index j is ranging from 1 to n.

For each ply of the laminate a partial equivalent thickness, $t_{eq,j}$, is calculated as Formula (13)

$$t_{eq,j} = \sqrt{\frac{\sum_{i=1}^{n} t_i^3}{t_j}} \quad j = 1,n \tag{13}$$

and the equivalent thickness of the laminate t_{eq} shall be the minimum of the n $t_{eq,j}$ values, as shown in Formula (14):

$$t_{eq} = \min\left[t_{eq,j}\right]; j = 1,n \tag{14}$$

The laminate construction is accepted when it results $t_{eq} \geq t_0$.

5.6.7.2 Collaborating plies

When the mechanical properties of the interlayer are known in terms of shear modulus, G (N/mm^2), at 25 °C for 10 s duration load, the equivalent thickness shall be calculated using Formulae (15) to (21).

For glass panels with other types of support, the equivalent thickness (if any) shall either be determined by direct calculation (e.g. FEM or analytical approaches where applicable) or the plies shall be considered as independent and calculated as per 5.6.7.1.

For interlayer materials, the shear modulus value at 25 °C for short time duration load of 10 s shall be selected, considering the declared value by the interlayer material manufacturer. In the case this value is not known, the plies shall be considered independent and Formulae (13) and (14) shall be used. The shear modulus value declared by the manufacturer shall be determined in accordance with ISO 6721-10.

The preliminary calculations are:

$$h_s = 0,5 \cdot (t_1 + t_2) + t_1 \tag{15}$$

$$t_{s;2} = \frac{h_s \cdot t_2}{t_1 + t_2} ; t_{s;1} = \frac{h_s \cdot t_1}{t_1 + t_2} \tag{16}$$

$$I_s = t_1 \cdot t_{s;2}^2 + t_2 \cdot t_{s;1}^2 \tag{17}$$

where

t_1 is the ply thickness (mm);

t_2 is the ply thickness (mm);

t_l is the interlayer thickness (mm).

Shear transfer coefficient evaluation (for independent plies Γ = 0, for full collaborating plies as "monolithic" behaviour Γ = 1) can be calculated with Formula (18)

$$\Gamma = \frac{1}{1 + 9,6 \cdot \frac{E}{G} \cdot \frac{I_s}{h_s^2} \frac{t_l}{a^2}} \tag{18}$$

where

a for 4 side supported panels: shortest clear opening dimension of the glazing laminate (mm);

E Young's modulus of the ply (N/mm²);

G shear modulus of the interlayer at 25 °C and load duration 10 s (N/mm²).

The equivalent thicknesses evaluation for deflection is

$$t_{\text{eq;w}} = \sqrt[3]{\left(t_1^3 + t_2^3 + 12 \cdot \Gamma \cdot I_s\right)} \tag{19}$$

and for strength

$$t_{1\text{ef};\sigma} = \sqrt{\frac{t_{\text{eq;w}}^3}{t_1 + 2 \cdot \Gamma \cdot t_{s;2}}} ; t_{2\text{ef};\sigma} = \sqrt{\frac{t_{\text{eq;w}}^3}{t_2 + 2 \cdot \Gamma \cdot t_{s;1}}} . \tag{20}$$

Equivalent thickness shall be selected as

$$t_{\text{eq}} = \min\left(t_{1\text{ef};\sigma}, t_{2\text{ef};\sigma}\right) \tag{21}$$

In case of multiple (more than two plies) laminates, the calculation shall be iterated.

The iteration shall start from the outer ply (the one directly loaded by water pressure) and end with the inner ply. See Annex E for examples.

The laminate construction is accepted when it results $t_{\text{eq}} \geq t_0$.

5.6.7.3 Type (B) laminates — Laminates with plies of different materials

When the laminate construction is of type (B), the plies of the laminated glazing shall be considered as mechanically independent. The equivalent thickness of n independent plies of different materials shall be calculated as follows. The thickness of one ply of the laminate is indicated generically as t_j and its Young's modulus as E_j where the index j is ranging from 1 to n.

For each ply of the laminate a partial equivalent thickness, $t_{\text{eq},j}$, is calculated using Formula (22)

$$t_{\text{eq};j} = \sqrt{\frac{\sum_{i=1}^{n} E_i \cdot t_i^3}{E_j \cdot t_j}} \qquad j = 1,n \tag{22}$$

and the equivalent thickness of the laminate, t_{eq}, shall be the minimum of the n $t_{\text{eq},j}$ values, as shown in Formula (23):

$$t_{\text{eq}} = \min\left(t_{\text{eq},j}\right) \qquad j = 1,n \tag{23}$$

See Annex F for examples.

The laminate construction is accepted when it results $t_{\text{eq}} \geq t_0$.

t_0 shall be calculated for the same material type corresponding to the material for which minimum value of $t_{\text{eq},j}$ is selected.

5.6.7.4 Selection of laminates thickness by flexural testing

The flexural strength of a laminate sample shall be taken as equal to the bending load at the moment of first ply failure.

The flexural strength of a multiply laminate of physical thickness, t_{Lam}, can be determined as characteristic flexural strength by a four-point bending strength test according to the method described in EN 1288-3, as outlined in 7.2.1.

The measured characteristic flexural strength value is strictly to be referred to the actual cross-section of the tested laminated pane.

The characteristic flexural strength of the laminate divided by the design factor of glass shall be considered as the allowable design flexural stress of the laminate.

Formulae (10) and (11) may be used to calculate the basic pane thickness, t_0, resulting from design pressure, geometry of the laminated pane and its allowable flexural strength.

The physical thickness of the laminate, t_{Lam}, shall be compared with the calculated t_0 and it is accepted when $t_{Lam} \geq t_0$

5.6.7.5 Selection of laminates thickness by nonlinear analytic methods

As an alternative to the methods in 5.6.7.1 to 5.6.7.5, monolithic and laminate thickness can be selected on the basis of analytic methods for the assessment of plates under large deflection.

The method used shall be validated for the size and stiffness of the panel. See EN 16612 for an example of validation.

The laminate can be accepted if the calculated bending stress does not exceed the characteristic failure strength (σ_C) for a pressure $p_{ULS} = \gamma \cdot p_{DE}$.

5.6.7.6 Selection of laminates thickness by direct calculation (Finite Element Method)

As an alternative to the methods in 5.6.7.1 to 5.6.7.5, monolithic and laminate thickness can be selected on the basis of Finite Element Method (FEM) calculations. Annex I provides further details on this subject.

The FE model can be either representative mid-plane for (equivalent) monolithic, mid-plane per ply, or full solid.

Principal stress is calculated per-ply according to laminate theory.

The laminate can be accepted if the principal stress does not exceed the CFS for a pressure $p_{ULS} = \gamma \cdot p_{DE}$.

5.6.8 Insulating glazing unit panes determination

5.6.8.1 General

Insulating glazing units (IGUs) considered in this document are standard ones according to EN 1279. IGUs do not deal with any special designs of spacer.

5.6.8.2 and 5.6.8.3 provide detail on the additional considerations for application on board a vessel:

— persistence of weathertight/watertight integrity;

— resistance to motions and inertia loads.

Under a lateral pressure load, the deflection of the outside pane compresses the gas in the cavity, which leads to a degree of load sharing between the panes. For large IGUs, this load sharing can be significant, and can be taken into account subject to the criteria in 5.6.8.2 and 5.6.8.3.

Where load sharing is taken into account, the IGUs shall be qualified by computation in accordance with established methods as in EN 16612. Hydrostatic pressure test according to 7.3 performed on the complete appliance can be used as verification of the computation method.

5.6.8.2 Stepped IGU

In stepped IGU, one of the panes is supported by the framing or bonding while the other pane is held only by the spacer, in tension. In this case, the supported pane of the IGU shall be selected according to 5.6.2 if monolithic, or 5.6.3 if laminated using the relevant design pressure loads from 5.5.

Mounting of the supported pane shall be as per 6.1.

The supported pane shall be of a laminated cross-section, meeting the criteria for residual strength classification 1B1 in accordance with ISO 29584.

The effect of unsupported panes located on the pressure side of the supported pane may optionally be taken into account for the evaluation of the structural cross-section. The effect of unsupported panes location on the non-pressure side, where the contribution would be via tension on the spacer, shall be ignored in the evaluation of the cross-section.

5.6.8.3 Unstepped IGU

In unstepped IGU which is mounted according to options 1, 2, 5 or 6 in Figures 6 to 8, all panes can be considered supported by the framing structure.

An unstepped IGU shall not be applied in a side B position unless either:

— it is mounted via 5 or 6 in 6.1, in which case the integrity of the unit does not depend on the tensile properties of the spacer, or

— the outer pane is ignored in the determination.

5.6.9 Strength requirements of fire-resistant glazing

The strength requirement for fire-resistant glazing shall be fulfilled by evaluating the construction in accordance with ISO 5797.

5.6.10 Glazing effective as fall protection

Where the lower edge of the clear opening for the glazing is less than 1,0 m above the walking surface and the glazing is in a location where protection from overboard fall is required by ICLL Regulation 25[6], additional requirements for strength and robustness shall be fulfilled. This is done in order to ensure that a level of protection equivalent to ICLL Regulation 25 criteria is achieved at all times.

For the purpose of this document, designs complying with the criteria of CEN/TS 19100:2021, but with the personnel loads with the loads enhanced by 50 % to account for the motions of the ship, can be considered to meet the requirements of ICLL Regulation 25.

For IGUs, the supported pane and panes inward of the supported pane shall be considered.

5.6.11 Deflection

5.6.11.1 Maximum deflection

The maximum deflection detailed in this subclause relates purely to the structural performance of the glazing and its attachment method to the yacht, under the design loads detailed in 5.5. This relationship specifically does not account for deflections under vessel accelerations, wind loads or induced cyclic vibrations. These can be of relevance on large windows on decks found well above the waterline, where the lower design pressure leads to a relatively thin cross-section.

The structural glazing shall meet the deflection criterion shown in Formula (24)

$$\delta_{all} = \frac{a_P}{50} \tag{24}$$

where

δ_{all} is the allowable pane deflection, expressed in mm;

a_p is the clear opening long side of a rectangular pane or "equivalent long side" of a pane, expressed in mm. For the purpose of this deflection criteria, it shall not be taken more than 1,4 times of b_p (shorter side) In this last case a_p shall be taken as b_p·1,4.

5.6.11.2 Determination of deflection

The maximum deflection of the structural pane either monolithic, laminated or stepped IGU shall be determined by calculation.

The deflection of a pane can be calculated according to Formula (25):

$$\delta_{max} = \alpha \frac{P_{DE} \cdot b_P^4}{1\,000 \cdot M} \quad (25)$$

where

δ_{max} is the maximum deflection of a pane, expressed in mm;

α is the pane aspect-ratio deflection coefficient (see Table 7);

P_{DE} is the engineering design pressure (see 5.5), expressed in kN/m^2;

b_P is the unsupported short side of a rectangular pane or "equivalent short side" of a pane, expressed in mm;

M is the pane stiffness , which shall be calculated in accordance with Annex B.

Table 7 — Coefficients α and β versus aspect ratio for four sides simply supported panes

Aspect ratio a_p/b_p	α	β
1,0	0,004 06	0,287 4
1,1	0,004 85	0,332 4
1,2	0,005 64	0,376 2
1,3	0,006 38	0,416 4
1,4	0,007 05	0,453 0
1,5	0,007 72	0,487 2
1,6	0,008 30	0,517 2
1,7	0,008 83	0,544 8
1,8	0,009 31	0,568 8
1,9	0,009 74	0,591 0
2,0	0,010 13	0,610 2
3,0	0,012 23	0,713 4
4,0	0,012 82	0,741 0
5,0	0,012 97	0,747 6
∞	0,013 02	0,750 0

NOTE The values in Table 7 can be approximated with sufficient accuracy for 1,0 < = a_p/b_p < = 6 via:

α = −4E-05 $(a_p/b_p)^4$ + 0,000 8 $(a_p/b_p)^3$ – 0,005 8 $(a_p/b_p)^2$ + 0,018 4 (a_p/b_p) – 0,009 4

β = −0,002 8 $(a_p/b_p)^4$ + 0,050 3 $(a_p/b_p)^3$ – 0,342 $(a_p/b_p)^2$ + 1,039 7 (a_p/b_p) – 0,459 2

Where $\delta_{max} > \delta_{all}$ further calculation with more advanced methods (nonlinear analytic or FEM) can be used to verify compliance with 5.6.7.1. See also Annex I.

6 Framing

6.1 General

Glazed openings are generally framed if the they are designed to be independent from loads of the adjacent structure. The framing shall provide a safe and secure fixing of the glazing. The glazing shall either be clamped with elastomer gaskets or bonded and additionally secured with an elastomer gasket between the glazing and retaining frame, or bonded at both sides. Framing concept types are represented in Figures 5, 6 and 7. The sketches are not to scale and shall be considered as a concept arrangement.

Bonding shall be in accordance with the definitions provided in ISO 11336-2.

6.2 Framing types

a) Type 1 **b) Type 2**

Key

1 inside

2 outside

3 bonding

4 seal

Figure 5 — Framing types 1 and 2

a) Type 3 b) Type 4

Key

1 inside
2 outside
3 bonding
4 seal

Figure 6 — Framing types 3 and 4

a) Option 5 b) Option 6

Key

1 inside
2 outside
3 rubber gasket

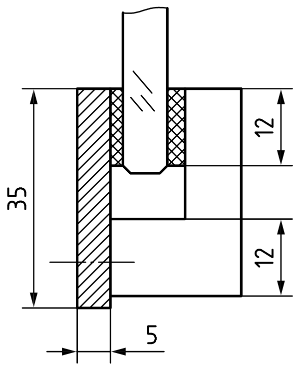
Figure 7 — Framing types 5 and 6

6.3 Framing dimensions

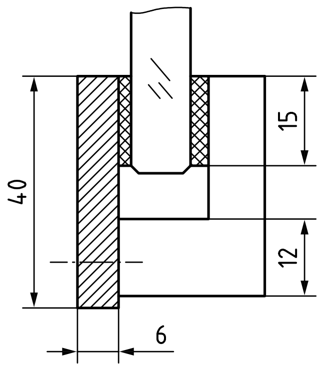
6.3.1 General

The dimensions indicated in Figure 8 shall be considered as minimum dimensions. Chamfered edge or other preparations (i.e. bullnose) of the glass edge shall not be included in the width of overlap indicated in Figure 8. The direct contact between frame and glazing shall be avoided.

Dimensions in millimetres



a) Glazed opening clear view ≤1,00 m^2



b) Glazed opening clear view ≤2,50 m^2

Figure 8 — Minimum dimensions

6.3.2 Clear view of >0,45 m^2 up to 1 m^2

Glazed openings with smaller dimensions are covered by existing international standards, such as ISO 3903. Elastomer gaskets shall have the following characteristics: Shore A 50-70, width ≥12 mm, thickness outside 2 mm to 6 mm (not in compression), thickness inside 2 mm to 4 mm (not in compression). The gaskets shall be properly secured against dislocation (i.e. gluing, positive fit). The distance between the frame and glass shall not be less than 5 mm.

6.3.3 Clear view of >1 m^2 up to 2,5 m^2

For glazed openings with a clear view of >1 m^2 up to 2,5 m^2, elastomer gaskets shall have the following characteristics: Shore A 55-70, width ≥15 mm, thickness outside 4 mm to 6 mm (not in compression), thickness inside 2 mm to 4 mm (not in compression). The distance between the frame and glass shall not be less than 7 mm.

Windows which are fitted in such a way that the adhesive is under tension load are not permitted in or below areas 1, 2, and 3 (see Figure 10 and Figure 11).

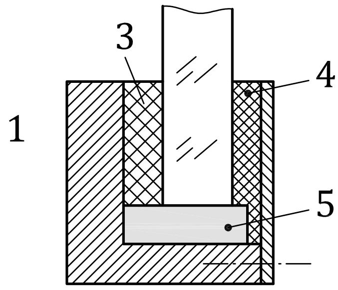
All load transmitting elements in the load path between the glazing and the adjacent bulkhead structure shall generally be metal and shall be based on the glazing design pressure and a design factor of 1 on the yield strength of the material.

6.3.4 Clear view >2,5 m^2

Glazed openings with a clear view exceeding the 2,50 m^2 shall be considered on case by case basis.

6.4 Support pads

Support of the glass mass and secure positioning within the frame shall be achieved by support pads with comparable elastic properties comparable to those of the elastomeric gasket or the bonding material. The arrangement of support pads is shown in Figure 9. The compatibility of materials between support pad and bonding shall be ensured.



Key

1 inside
2 outside
3 bonding
4 elastomer gasket
5 support pad

Figure 9 — Support pads

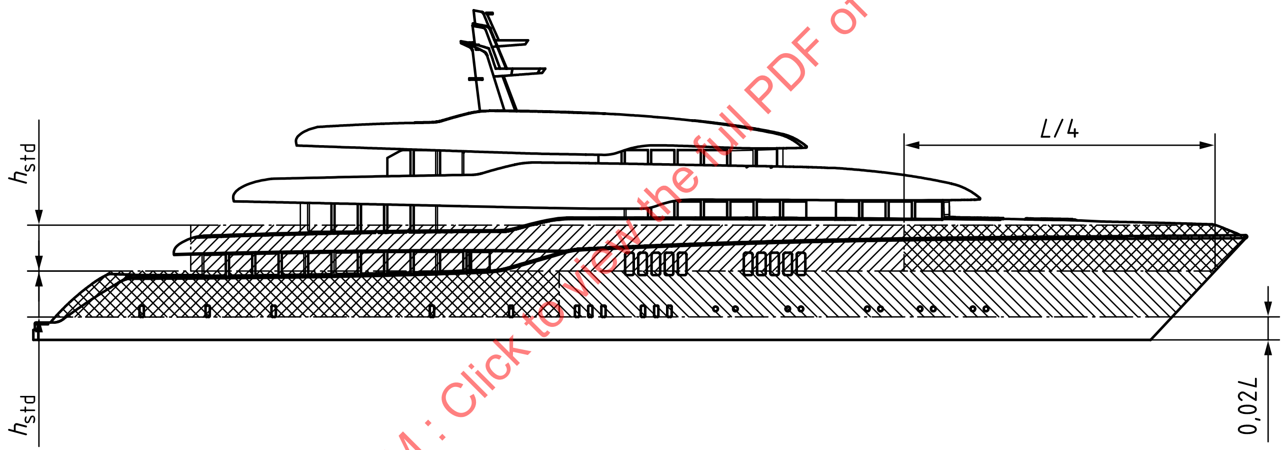


Figure 10 — Areas of typical motor yacht

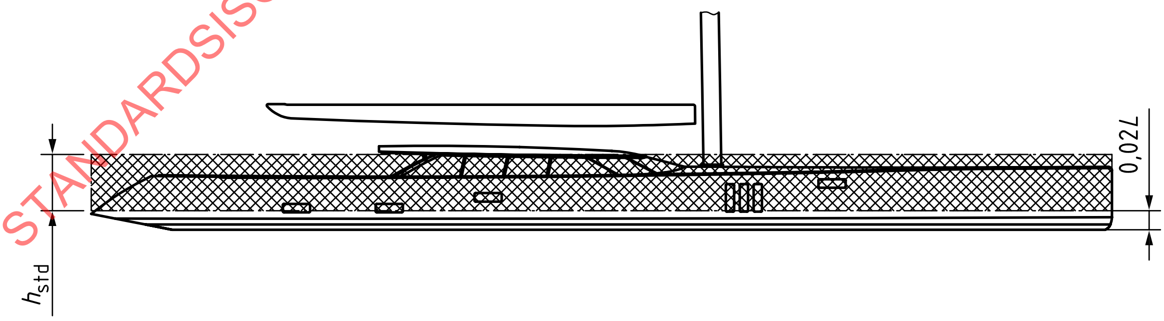


Figure 11 — Areas of typical sailing yacht

6.5 Material requirements for the framing

All materials used shall be in compliance with or equivalent to ISO 3903 or ISO 1751. The strength of metal frames shall ensure under the window design pressures that the yield strength of the material is not exceeded. Non-metallic frames are outside the scope of this document.

Bolts generally should be of stainless steel with a minimum grade 50. The bolt material shall be compatible both in terms of strength and corrosion with the frame. The supplier shall ensure that the mechanical properties are achieved and valid documentation shall be provided.

Bolts shall have at least M6 and shall fulfil the general requirements for the thread/screwed-in depth for the used frame material. The maximum allowable pitch of the bolts shall not exceed 75 mm, in accordance with ISO 3903 (Heavy type E).

Deviating materials i.e. larger bolts or bolts with a higher grade and smaller screw pitch can be used to meet the respective requirements. They shall be specified by the manufacturer and approved by the certifying authority.

7 Materials

7.1 General

Clause 7 identifies the glazing materials that can be used within the scope of this document. This clause also shows testing methods for the qualification of these materials for use with this document.

NOTE See Clause 5 for the testing methods for the characteristic failure strength of pane materials and the selection of laminates by flexural testing.

7.2 Materials selection

7.2.1 General

Panes shall be made of glazing materials defined in Table 6.

Other materials of comparable strength and stiffness to those cited in Table 6, may be considered.

7.2.2 Glass

7.2.2.1 Restrictions of usage for monolithic construction

— Only toughened safety glass meeting the requirements of the fragmentation test outlined in EN 12150-1:2000, Clause 8 shall be used.

— For laminated construction, the glazing shall meet the requirements outlined in ISO 12543-1.

— In wheelhouse glazing, for both front and sides positions, laminated safety glass shall be used.

  — Coating (hard or soft) shall not influence the strength of the glass.

7.2.2.2 Chemically toughened glass

7.2.2.2.1 General

Chemically toughened glass (CTG) shall meet the requirements outlined in EN 12337-1. For marine applications, CTG is not covered by existing international standards. For this reason, it shall be qualified as a structural material according to 7.2.2.2.2.

The following characteristics shall be declared by the glass ply manufacturer for structural qualification:

— depth of compression layer, l_{CD} (µm);

— surface compression, S_C (N/mm^2);

— characteristic failure strength, σ_C (N/mm^2).

The glass ply manufacturer is also responsible for the production conformity to the declared values.

7.2.2.2.2 Qualification by the characteristic failure strength

CTG shall be qualified by its characteristic failure strength, σ_C, value.

For this purpose, the glass ply manufacturer shall declare its characteristic failure strength, σ_C (N/mm2), in accordance with EN 1990:2008, Annex D, and determined by mechanical tests according to 7.3.1.

Acceptable values to comply with this document are listed in Table 6.

This structural qualification does not take into consideration the effects coming from surface abrasion resulting during pane service life. These effects can introduce additional requirements on the strengthening characteristics. Such additional requirements can be considered and introduced by recognized organizations and authorities.

7.2.3 Rigid plastic materials

7.2.3.1 Restrictions of usage

Values for characteristic failure strength and mechanical properties of rigid plastic panes shall comply with those shown in Table 6. The usage shall be restricted within the minimum strain values that are for PMMA ε < 0,6 % and for PC ε < 0,6 %. Plastic panes (monolithic) or plies (laminated) shall be used in accordance with the indications of material manufacturers, both in terms of chemical compatibility with other materials (adhesives, sealants, gaskets) and application conditions (with special attention to exposure to outdoor environment).

7.2.3.2 Interlayers

In laminated glazing, thermoplastic adhesive films or thermosetting curable resins may be used as adhesive materials to bond glass or plastic plies together.

Interlayer materials shall be used in accordance with the indications of the material manufacturer, in terms of chemical compatibility with other materials (glass, plastic plies, sealants, gaskets), application conditions (with special attention to exposure to outdoor environment) and laminated glazing manufacturing. The glazing manufacturer is responsible for following indications, precautions and manufacturing methods approved by the interlayer material manufacturer.

In the computations on laminated glazing, the shear modulus G (MPa) of an interlayer shall be taken as the value declared by the manufacturer for 25 °C at a load duration of 10 s. In cases where there is no declaration, the plies shall be considered as mechanically independent.

If a value is available only for Young's modulus, E (MPa), a shear modulus may be assumed as $G = E/3$.

7.3 Testing of materials

7.3.1 General

This is limited only to tests for structural qualification of glazing materials. Other qualification tests are not included here and shall be performed according to international standards relevant to the specific material, as shown in Table 6.

7.3.2 Glass

Characteristic flexural strength of glass materials shall be determined by the flexural four-point bending test, in accordance with EN 1288-3.

The characteristic failure strength, σ_C, shall be determined by mechanical tests as in Formulae (26), (27) and (28):

$$\sigma_{av} = \frac{1}{N} \cdot \sum_{i=1}^{N} \sigma_i \tag{26}$$

$$s_x = \sqrt{\frac{\sum_{i=1}^{N} (\sigma_i - \sigma_{av})^2}{N-1}} \tag{27}$$

$$\sigma_c = \sigma_{av} \cdot (1 - K_n \cdot C_V) \tag{28}$$

where

N is the number of test specimens (at least 10);

σ_i is the breaking stress, expressed in MPa, for each test specimen tested according to EN 1288-3;

σ_{av} is the average value;

s_x is the standard deviation;

C_V is the coefficient of variation; $C_V = \frac{s_x}{\sigma_{av}}$

K_n is the statistic coefficient corresponding to 90 % confidence limit. This value depends on the number of test specimens, N, according to the t-Student statistical distribution (see Annex D).

7.3.3 Rigid plastic materials

Characteristic failure strength, σ_C, for rigid plastic materials shall be determined by the flexural three-point bending test in accordance with ISO 178. Data reduction shall be performed as indicated in Formulae (26), (27) and (28).

7.4 Testing of appliances

7.4.1 Test procedure for hydrostatic structural testing of marine windows system

This procedure establishes an experimental method for proof testing of marine glazed openings system to assess their strength and watertightness characteristics. The test shall be performed on the complete glazed opening assembly including the fixing system. The glazed opening system has two main components:

— glazing;

— edge fixing system (clamping, framing, bonding or any mechanical/chemical method to fix the glazing on the ship structures).

When the glazing cross-section is already qualified according to 5.6, the hydrostatic test shall be understood to be a qualification test of the fixing system and the hydrostatic test shall be performed on one sample.

When the glazing cross-section cannot be qualified, the hydrostatic test shall be understood to be a qualification test on the complete system (glazing and fixing) and the test shall be performed on not less than three samples. The result is expressed by considering the maximum pressure achieved in each test without failure, as the average of the three results minus two times the standard deviation.

The results shall be evaluated considering the minimum pressure achieved out of the three tests, with structural integrity of the glazing (no breakages) and no fixing failures and full water tightness.

7.4.2 Motivations

Motivations for testing glazed opening systems are:

— innovative materials or construction systems which are introduced and not considered in existing international standards;

— edge fixing by any method not included in existing international standards;

— strength and water tightness characteristics of the glazed opening systems which cannot be predicted from calculations.

7.4.3 Testing plan and expected outcome

Any testing shall be covered by a testing plan clearly stating what the test is expected to validate and a computational prediction of the outcome with a validity range. Variations shall be investigated. When the results differ significantly from the computational results, re-evaluation of the computation and/or re-testing shall be carried out to clear the differences.

7.4.4 Apparatus

7.4.4.1 Testing assembly

The test shall be carried out using a testing basin which ensures the water tightness up to the requested test pressure. The basin shall show the real assembly situation on board, using identical or equivalent materials and dimensions.

The filling water piping and the basin pressure measuring piping shall be separated.

While filling the basin with water, ensure that air trapping is eliminated or at least minimized.

The supporting structure of the tested window system shall be stiff enough to prevent edge deflection which will influence the test results.

7.4.4.2 Measuring instruments

The responsibility of test operators is to run tests with calibrated measuring instruments, meeting metrological criteria in terms of reference to the International System of Units, accuracy and repeatability.

7.4.4.3 Sample

The tested sample shall be representative of the glazed opening construction and installation on board. A drawing of sample construction and fixing shall be provided and included in the test documentation.

7.4.4.4 Test procedure

The test shall be carried out by laboratories or institutions which meet the requirements of ISO/IEC 17025. Alternatively, window manufacturers fulfilling the equivalent minimum standard may perform such tests.

The test shall be carried out as follows.

Procedure (A):

a) Dimensions of all main components (basin and glazed opening) shall be checked and recorded.

b) Measuring instruments gauges shall be calibrated.

c) Engineering design test pressure, p_{DE} (kN/m^2), shall be established according to 5.5.

Chamber pressure shall be raised up to p_{DE} and maintained for at least 300 s. The pressure in the test chamber shall be raised up to design factor times the engineering design load pressure ($\gamma \cdot p_{DE}$) (see Table 5).

Three unloading/loading cycles (see Figure 12) shall be performed within the pressure range from $1 \cdot p_{DE}$ to $\gamma \cdot p_{DE}$ starting at below $1/2\ \gamma \cdot p_{DE}$ and going to $\gamma \cdot p_{DE}$.

d) Central deflection shall be measured and recorded up to the design pressure. The basin pressure shall be measured and recorded continuously during the test.

e) Any event such as loss of water tightness (from the glazing or from the fixing system) or glass plies breakage shall be recorded by the test operators with the relevant test pressure.

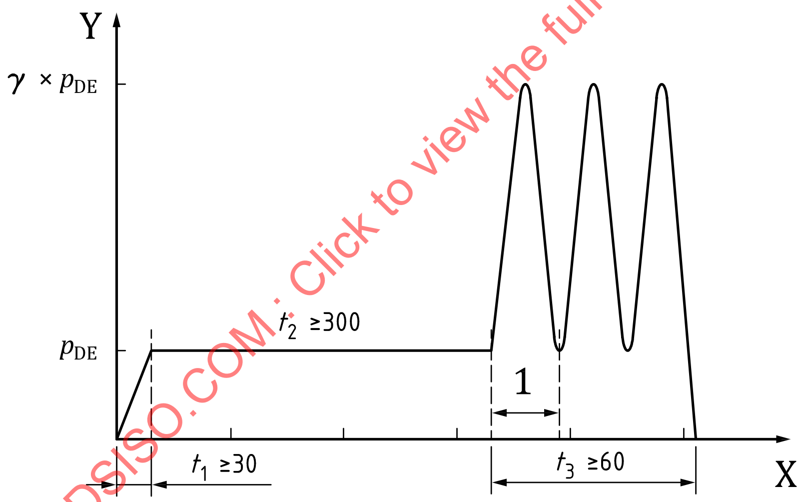
f) Unless otherwise specified and if possible, the sample shall be taken to final collapse.

Procedure (B):

Preliminary operations included in procedure (A) [namely a), b) and c)] shall be completed.

The pressure cycle shall be as shown in Figure 13: cyclic phase, hold phase and final rise to test pressure.

Operations requested for procedure (A) [namely d), e) and f)] shall be completed.



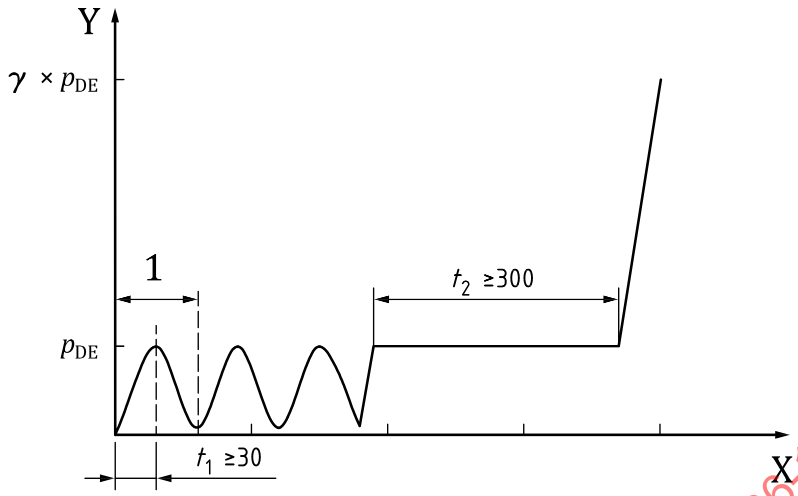
Key

X time (s)

Y pressure (kPa)

1 loading/unloading cycle

Figure 12 — Water pressure vs. time for test procedure (A)



Key

X time (s)

Y pressure (kPa)

1 loading/unloading cycle

Figure 13 — Water pressure vs. time for test procedure (B)

Chamber pressure shall be raised up to p_{DE} and three unloading/loading cycles shall be performed within the pressure range from unloaded to p_{DE}. Then, the pressure should be maintained for at least 300 s. Finally, the water pressure shall be raised up to γ times the design load pressure (see Table 5).

7.4.5 Acceptance criteria

The test is passed if the system withstands the design factor times p_{DE} load pressure without failure of any part of the system and if the watertightness is maintained. Engineering design pressure shall be reached in not less than 30 s for both procedure (A) and (B) and the three unloading/loading cycles for procedure (A) shall be performed in not less than 60 s. Provided that the fixing system is maintained in terms of construction details, geometrical dimensions and materials, and that the pane cross-section is identical, test acceptance may be extended to any glazed opening with lower requirements regarding strength (engineering design pressure p_{DE}) and size.

Tolerances for size extension are limited to a maximum of 5 % of each individual clear length of the glazing.

7.4.6 Test report

The test report shall contain at least the following information:

a) reference to this standard, including year of publication, and this clause;

b) date and location of the test;

c) window sample engineering documentation (drawings and description of glazing and fixing system);

d) when the test is a type approval test, production documents are provided identifying the production controls performed during sample manufacturing;

e) description of the measuring instruments;

f) description of the test conditions: engineering design pressure test, p_{DE}, description of testing chamber and of hydraulic circuits;

g) test procedure selection;

h) test results: maximum pressure achieved in the test, pressure rate to reach engineering design pressure from the beginning of the test, waiting time at engineering design pressure, watertightness failures and locations, glazing plies breakage events and related pressure values, other relevant events related to strength and watertightness of the window; recorded deflections and correlation with expected results;

i) names of the people witnessing the test and institution(s) they represent;

j) test operators and their qualification in terms of test responsibilities and institution responsibilities;

k) bonding methods and qualification of the bonding personnel;

l) any deviations from the procedure;

m) any unusual features observed.

8 Storm shutters and deadlights

8.1 General

The purpose of a storm shutter is to protect the glass against impact by debris or other objects and to provide resistance against extreme green sea loads and limit the ingress of water in case of breakage of the glazed openings.

The purpose of a deadlight is to provide a means to maintain the watertight integrity of the buoyancy volume in case of breakage of the glass or leakage of the glass mounting. It is a secondary barrier against ingress of water.

Alternative arrangements to storm shutters and deadlights are generally subject to the approval of the certifying authority.

8.2 Storm shutters

8.2.1 General practice

As a minimum, storm shutters or alternative arrangements to increase robustness shall be provided for openings located in side bulkheads at a height (h) above the waterline less than $(0{,}02L + h_{STD})$m, and in front bulkheads at a height above the waterline less than $(0{,}02L + 2 \cdot h_{STD})$m.

Further details on the backgrounds of the storm shutter requirements can be found in Annex G. Alternative arrangements to storm shutters are generally subject to the approval of the certifying authority (see G.2.)

Storm shutters shall be fitted externally on the bulkhead.

8.2.2 Glazed equivalents to providing storm shutters

The criteria in this subclause are based on yachts that either:

— comply with requirements for residual damage stability as formulated in the REG Yacht Code[16], or

— are restricted to short range operation.

To be considered as an acceptable equivalent for a traditional monolithic glazing with storm shutter, the glazing shall:

a) be designed, in the intact condition to a pressure not less than the engineering design pressure p_{DE} according to 5.5;

b) be of laminated construction;

c) be designed to withstand, after failure of any single one of the plies, the design pressure p_D with a design factor γ of 1,0 (see ISO 11336-3:2019, 4.2.2);

d) not show more than moderate loss of tightness (see ISO 11336-3:2019, 4.2.2) for the period needed for the crew to detect the failure and to take action to stop cascading damage and mitigate the consequences.

8.2.3 Construction of storm shutters

The construction shall comply with the quality standards and material testing as required for the structure of the bulkhead in which the storm shutter is located.

8.2.4 Design pressures and design flexural stresses

Design pressures shall be the same as required for windows in accordance with 5.5.

Design flexural stress for aluminium constructions shall be taken as the yield strength of 0,2 % proof stress.

Design flexural stresses shall take into account the un-welded or as-welded yield strength, depending on whether the construction is welded or extruded, as specified in EN 13195-1.

For FRP, a factor of safety to failure of 1,6 shall be achieved.

8.2.5 Structural model

Plating shall be considered simply supported at the edges of the window and between stiffeners.

Stiffeners shall be considered simply supported.

Stiffeners shall be checked for bending strength, shear strength, and tripping.

Support from mullions shall be considered using a grillage approach provided the bending stiffness (EI) of the mullions and the bulkhead supporting structure are considered in the grillage calculation.

8.2.6 Scantlings

8.2.6.1 General

Scantlings of storm shutters may be determined by direct calculation.

8.2.6.2 Structural detail

Stiffeners shall be arranged such that they can take the design loads and adequately transmit them to the surrounding yacht structure.

Storm shutter shall suitably overlap all around.

8.2.6.3 Metal construction

Stiffeners shall be sniped at their ends and stopped 15 mm from the storm shutter plate edge. The snipe shall be not less than 1 in 3 and shall start at 50 mm overlap of the stiffener onto the bulkhead structure.

Welding of stiffener to plating may be intermittent. Welding shall be full return at the end of stiffeners of not less than 100 mm.

8.2.6.4 FRP construction

FRP stiffeners, where fitted, shall be laminated or bonded to the storm shutter plate.

The spacing between the glass pane and the storm shutter shall be larger than the maximum deflection of the storm shutter under design load.

8.2.7 Attachment to bulkhead

The storm shutters shall be effectively attached to the bulkhead e.g. by bolted connections or by fitting into retaining bars.

In selecting the materials for the means of securing, the effects of corrosion between dissimilar metals shall be considered.

Bolt diameter shall be at least M12, spacing maximum 500 mm; alternative arrangements shall be approved by the certifying authority.

Where bolts and plate are of different materials, shear stress and bearing stress shall be designed to consider the different material mechanical properties.

8.3 Robustness of protection of hull openings

8.3.1 General practice

8.3.1.1 General

Deadlights or equivalent secondary barriers shall be provided to glazed openings in the side shell to prevent the ingress of water if the exposed glazing is fractured or damaged.

Deadlights shall generally be permanently attached if located in the buoyant areas of the ship (the hull). Portable deadlights are subject to the acceptance of the Administration.

8.3.1.2 Material for deadlights

Deadlights shall be made from either:

— marine grade aluminium alloy, steel or bronze, or

— composite material as used for hull construction.

Metal shall be of a ductile type with elongation to breakage not less than 6 %.

Other materials shall be ductile, acceptable for hull construction and approved by the certifying authority.

8.3.1.3 Design pressure and design flexural stresses for deadlights

Deadlights shall be dimensioned such that when loaded by the design pressure the yield stress is not exceeded.

The deadlight shall be designed considering the same design pressure as required for the glazing. When subjected to this pressure, the stress in the deadlight and all load bearing fittings shall not exceed the yield stress.

For circular openings up to 450 mm in diameter, the deadlight and all associated hinge pins, securing devices and fittings, can also be taken according to ISO 1751.

8.3.2 Equivalent secondary barriers

Other types of secondary barriers can be used at the discretion of the Flag administration. This secondary barrier can take the form of secondary glazing. Application is subject to the following:

a) The yacht is designed to have residual floatation and stability according to the REG Yacht Code[16] or equivalent, if the compartment protected by the glazing is flooded.

b) The secondary barrier is mounted permanently to the supporting structure.

c) Failure of any single component of the whole closing appliance shall never lead to loss of the watertight integrity. The bonding is a component.

d) The robustness of the secondary barrier shall be demonstrated as in 8.3.5.

8.3.3 Testing

a) Adequacy of deadlights and equivalent secondary barrier arrangements shall be demonstrated by prototype testing.

b) The aim of the testing is to ensure water-tightness is maintained or, for hinged or portable deadlights, at least restored when the outside pressure is reduced.

c) Test conditions and support of the deadlight or secondary barrier shall reflect the situation as mounted on board. The barrier and its mounting can be tested in a horizontal or vertical position as required by the testing method.

d) Testing considers resistance against a specific action. Demonstration of capability to resist that particular action does not constitute or imply capability to resist other actions that can affect the integrity.

8.3.4 Testing of metal or composite deadlights

The deadlights in the mounted position shall be tested for water tightness using a design pressure of 42 % of the design pressure, p_D.

The deadlights in the mounted position shall be tested for strength at a test pressure, p_D. After the test, any permanent deformation shall not be more than 1 % (0,01 times) the smaller dimension of the clear opening. This test may be replaced by computations. Equivalent strength can be assumed if the calculated bending stress does not exceed the minimal certified failure stress of the material. The failure stress shall be taken as the yield stress, 0,2 % proof stress, or first ply failure of the material for steel, aluminium alloy and composite material, respectively.

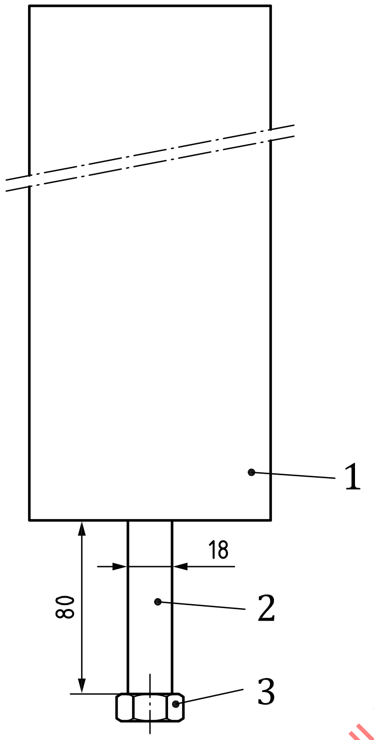
8.3.5 Testing of equivalent glazing deadlight

8.3.5.1 General

The impact test shall be able to deliver an impact energy of 1 800 J at a terminal velocity in a range of 5 m/s to 10 m/s.

The concept arrangement of the impactor is illustrated in Figure 14. The impactor head shall be arranged in such a way to present a hexagonal bolt, head M12, steel grade 8.8 (key reference 3 in Figure 14). Under the bolt head a steel spacer (key reference 2), with a length of 80 mm, an outer diameter of 18 mm, and inner diameter of 12,5 mm, shall be provided to ensure penetration is achieved before the main body (key reference 1) of the impactor reaches the surface of the glass.

Dimensions in millimetres



Key

1 impactor body

2 steel spacer

3 hexagonal bolt head

Figure 14 — Impactor arrangement

After the impact test, the sample shall be hydrostatically tested to prove water tightness with water at a pressure of 75 kPa, with the pressure from the external side. See Annex J for further details on how to conduct qualification testing of an equivalent deadlight.

8.3.5.2 Acceptance criteria

As a result of the impact tests, no full penetration is allowed on 3 representative samples. Full penetration is defined when, after the impact, a passing-through hole is formed with a diameter of 25 mm or more.

After reaching the maximum test pressure, this shall be maintained for at least five minutes. Leakage from the glazed surface and from the fixing joints/elements shall be recorded. Leakage is allowed at maximum pressure with an overall limit of 2,5 litres within the five minutes of pressure hold.

Acceptance is based on the same construction cross-section, both in terms of mechanical properties of materials and thickness, and the same fixing arrangements.

Acceptance criteria are established according to the following two methods:

— Method A: The three tested samples shall have clear opening dimensions representing different aspect ratio in the range of the clear opening dimensions specified by the designer or manufacturer. Consideration shall be given to limits in glazed openings. A typical range is:

  — 400 mm by 400 mm (aspect ratio = 1)

  — 1 100 mm by 800 mm (aspect ratio = 1,4)

— 1 100 mm by 400 mm (aspect ratio = 2,75)

All samples shall have the same laminate setup.

Each sample shall be subject to the impact test followed by a hydrostatic test at 75 kPa minimum pressure. All other dimensions within the limits of the chosen range shall be considered acceptable.

— Method B: Where dimensions of the equivalent glazing deadlight are not covered by method A, an individual test is considered. The test shall be performed on three samples with clear opening dimensions representing the window and glazing specified by the designer or manufacturer. Consideration shall be given to limits in glazed openings. All samples shall have the same laminate setup and construction.

Each sample shall be subject to the impact test followed by a hydrostatic test at 75 kPa minimum pressure. In this case, results cannot be extended to other dimensions different from the tested ones.

For circular equivalent glazing, deadlight qualification method B shall be followed.

8.3.5.3 Test report

The test report shall contain at minimum the following information:

a) a reference to this document (document reference number, title, year of publication);

b) date of the test, location, names of the observers;

c) selected Method (A or B) for qualification;

d) description and construction drawing of the tested framed assembly specifying the glazing cross-section in terms of materials, thicknesses and strengthening characteristics as requested by this document and fixing conditions. Unsupported dimensions of the tested equivalent deadlight shall be reported;

e) description of the impacting conditions: impactor weight and impacting head description, impact energy and terminal velocity of the impactor at the impact point, impact point at sample surface;

f) description of the main recorded evidence after impact (e.g. how many glass plies have been broken, full or partial impactor penetration);

g) hydrostatic test maximum pressure and hold time;

h) recorded evidence after hydrostatic test, any leakage (litres/minute) or further structural failure;

i) any deviations from the procedure;

j) any unusual features observed.

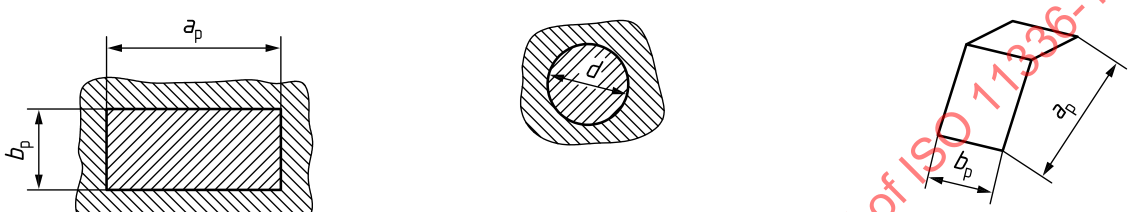
8.4 Owner's manual

Guidance shall be included in the operating manual on the sea state at which storm shutters and deadlights shall be fitted, and upon maintenance and inspection of the storm shutters and deadlights and their means of securing.

Annex A
(normative)

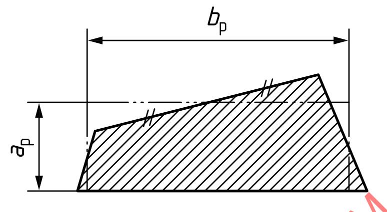
Unsupported pane dimensions

For rectangular pane, the small and large unsupported dimensions are b_p and a_p respectively, as shown in Figure A.1 a). For a folded pane, the small and large unsupported dimensions are b_p and a_p respectively, as shown in Figure A.1 c). For a circular plate, the unsupported diameter is d, as shown in Figure A.1 b). For non-rectangular or non-circular plate shapes, use “equivalent” dimensions of a rectangular or circular plate, having an area equal to the plate being considered (see Figure A.2).



a) Rectangle **b) Circle** **c) Folded pane**

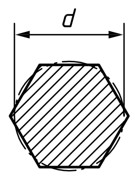
Figure A.1 — Unsupported pane dimensions



$b_p = A/a_p$

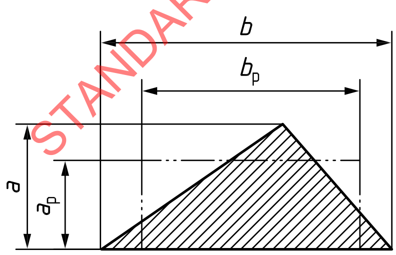
A = area of pane in mm^2

a) Quadrangle



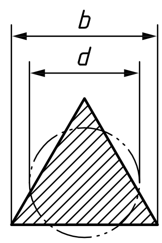
$d = \sqrt{\frac{4}{\pi} A}$

b) Polygon



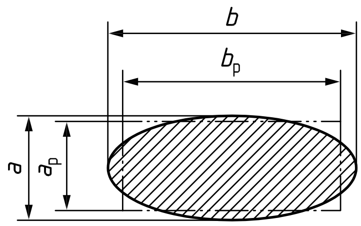
$a_p = 2a/3$; $b_p = 3b/4$

c) Triangle



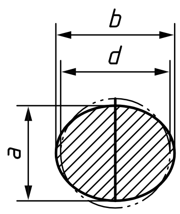
$d = 3b/4$

d) Equilateral triangle



$a_p = 0{,}87a$; $b_p = 0{,}87b$

e) Flat ellipse



$d = \sqrt{ab}$

f) Round ellipse

Figure A.2 — Equivalent dimensions

Annex B
(normative)

Calculation of the stiffness of a pane

For a monolithic pane of physical or equivalent thickness t_w, expressed in mm, the calculation of its stiffness, M, expressed in Nmm, shall be performed on the basis of the knowledge of its mechanical characteristics, as shown in Formula (B.1).

$$M = \frac{E \cdot t_w^3}{12 \cdot (1 - \nu^2)} \quad \text{(B.1)}$$

where

E is the Young's modulus, expressed in N/mm²;

ν is the Poisson's ratio;

t_w is the effective thickness for bending (see Table B.2).

Values of E and ν can be found in Table B.1. Other values may be used for Young's modulus and Poisson's ratio if declared by the material manufacturer.

Table B.1 — Mechanical properties of materials

Material	Acronym	Young's modulus E N/mm²	Poisson's ratio ν
Polymethylmethacrylate	PMMA	3 300	0,37
Polycarbonate	PC	2 300	0,38
Glass	TTG/CTG	70 000	0,23

Table B.2 — Effective thickness for bending

Cross-section	Effective thickness for bending mm
Monolithic	physical thickness
Independent plies	$t_w = \sqrt[3]{t_1^3 + t_2^3 + .. + t_n^3}$
Laminate type A (no collaboration)	$t_{eq;w}$
Laminate type B (with collaboration)	t_{eq}

Annex C
(informative)

Scantling formula

The scantling formula given in Formulae (10) and (11) comes from Formula (C.1):

$$t_0 = b \cdot \sqrt{\frac{\beta \cdot p_D}{\sigma_A}} \quad \text{(C.1)}$$

where

t_0 is the basic pane thickness, expressed in mm;

b is the short side of a rectangular pane or “equivalent short side” of a pane, expressed in mm;

β is the pane aspect-ratio coefficient;

p_D is the basic design pressure, expressed in kN/m^2;

σ_A is the allowable design flexural stress of the material, expressed in N/mm^2.

This Formula has been rearranged to be expressed in more practical units kN/m^2 and N/mm^2 as given in Formulae (10) and (11).

Formula (C.1) is derived from linear plate theory and is strictly valid for small deflection of the pane (less than $t_0/2$). A more accurate structural analysis may be based on nonlinear FEM calculation. Nevertheless, this simplified linear approach has been found to be consistent and conservative for scantling determination of plates when comparing results of hydrostatic tests with the more accurate nonlinear FEM calculations.

Annex D
(informative)

Statistical coefficient K_n and worked example

The statistic coefficient (K_n) introduced in 7.3.2 corresponding to 90 % confidence limit depends on the number of test specimens, N, according to the t-Student statistical distribution. In Table D.1, the K_n is reported as a function of the number of test specimens for a confidence limit of 90 %.

Table D.1 — K_n vs. number of tested specimens at 90 % confidence limit

Number of tested specimens	K_n
10	1,833
11	1,812
12	1,796
13	1,782
14	1,771
15	1,761
20	1,729
25	1,711
30	1,699
40	1,685
60	1,671
100	1,660
∞	1,645

A worked example is shown below.

Considering 12 strength tests sampling 12 individuals from a production lot, the average value, and standard deviation are:

$$C_V = \frac{s_x}{\sigma_{av}} = \frac{20}{210} = 0{,}0952$$

σ_C, characteristic failure strength is

$$\sigma_c = \sigma_{av} \cdot (1 - K_n \cdot C_V) = 210 \cdot (1 - 1{,}796 \cdot 0{,}0952) = 174 \text{ MPa}$$

where

σ_{av} is the average = 210 MPa;

s_x is the standard deviation = 20 MPa;

setting a probability level of 90 %, the value of K_n can be read from Table D.1

K_n = 1,796.

Annex E
(informative)

Worked examples of equivalent thickness calculationfor Type A laminates

E.1 Example 1 — Independent plies case

Construction cross-section:

— Glass 8 mm / 1,5 mm interlayer / glass 10 mm / 1,5 mm interlayer / glass 8 mm

Table E.1 illustrates an example calculation for independent plies case.

Table E.1 — Example of calculation for independent plies case

t mm	t^3 mm^3	$t_{eq,j} = [\Sigma(t^3)/t]^{1/2}$ mm
8	512	15,9
10	1 000	14,2
8	512	15,9

t_{eq} = 14,2 mm

In Table E.1, the t column indicates individual glass thicknesses of the laminate; the t^3 column indicates their cubes and the $t_{eq,j}$ column indicates the individual equivalent thickness of each glass layer of the laminate. The selected value of equivalent thickness t_{eq} is the minimum of this last column.

E.2 Example 2 — Collaborating plies case (symmetrical construction)

Construction cross-section:

— Glass 8 mm/ 1,52 mm Polyvinylbutyral (PVB) interlayer/ glass 8 mm

— Glazing short dimension: 1 000 mm

— E(Glass) = 70 000 MPa

— G(PVB) = 1,6 MPa

Table E.2 illustrates an example calculation for a collaborating plies case with symmetric construction.

Table E.2 — Example of calculation for collaborating plies case (symmetric construction)

Shear transfer coefficient Γ	**Equivalent thickness deflection** $t_{eq;w}$ mm	**Equivalent thickness stress — Ply 1** $t_{1ef;\sigma}$ mm	**Equivalent thickness stress — Ply 2** $t_{2ef;\sigma}$ mm
0,281	13,1	14,5	14,5

t_{eq} = 14,5 mm

In Table E.2, the $t_{eq,W}$ column indicates individual glass thickness for deflection; the $t_{1ef;}$ and $t_{2ef;\sigma}$ columns indicate equivalent thickness of each glass for stress. The selected value of equivalent thickness t_{eq} is the minimum of the two glasses. The same information applies to Tables E.3, E.4 and E.5.

E.3 Example 3 — Collaborating plies case (asymmetrical construction)

Construction cross-section:

— Glass 12 mm / 1,52 mm PVB interlayer / glass 8 mm

— Glazing short dimension: 1 000 mm

— E(Glass) = 70 000 MPa

— G(PVB) = 1,6 MPa

Table E.3 illustrates an example calculation for a collaborating plies case with asymmetrical construction.

Table E.3 — Example of calculation for collaborating plies case (asymmetrical construction)

Shear transfer coefficient Γ	Equivalent thickness deflection $t_{eq;w}$ mm	Equivalent thickness stress — Ply 1 $t_{1ef;\sigma}$ mm	Equivalent thickness stress — Ply 2 $t_{2ef;\sigma}$ mm
0,246	16,0	17,0	19,0

t_{eq} = 17,0 mm

E.4 Example 4 — Collaborating plies case (three plies iteration case)

Construction cross-section, defined from pressure side to inside:

— Glass 8 mm / 1,52 mm PVB interlayer / glass 10 mm / 1,52 mm PVB interlayer / glass 10 mm

— Glazing short dimension: 1 000 mm

— E(Glass) = 70 000 MPa

— G(PVB) = 1,6 MPa

First iteration, combining the two plies adjacent to the pressure side of the panel:

— Glass 8 mm / 1,52 mm PVB interlayer / glass 10 mm.

Tables E.4 and E.5 illustrate examples of calculations for a case with three collaborating plies. This case involves an iteration.

Table E.4 — Example of calculation for collaborating plies case (three plies iteration case) — First iteration

Shear transfer coeff. Γ	Equivalent thickness deflection $t_{eq;w}$ mm	Equivalent thickness stress — Ply 1 $t_{1ef;\sigma}$ mm	Equivalent thickness stress — Ply 2 $t_{2ef;\sigma}$ mm
0,261	14,5	16,6	15,7

t_{eq} (first iteration) = 15,7 mm

Second iteration:

