THE USE OF GLASS AS STRUCTURAL MATERIAL

Alexandros TOLIS, Structural Engineer, U.Th.
MSc ADERS N.T.U.A.

ABSTRACT

In the last decade there was a dramatic increase in the use of structural glass due to the rising interest among architects and improvements in technology. The obvious reason for choosing glass is that it is translucent and resistant to the effects of erosion.

This work aims to gather information relating to the use of the material and mainly to give the reader the impetus for deeper engagement with the object.

Grounded in the literature describes the experience gained from design and manufacture of glass construction, but because of the large scale of the issue mainly is limited to glass panes.

BRIEF HISTORY

It is believed that around 3500 BC people began to make glass, especially strings of beads. Such objects have been found in Egypt and Eastern Mesopotamia. Glass vessels appeared in the sixteenth century BC followed glass jars. The next breakthrough for the glass was glassblowing somewhere between 27 BC and 14 AD. The discovery was made by Syrian craftsmen. The Romans first began to use glass for artistic purposes with the discovery of clear glass in Alexandria about 100 AD, placing in significant buildings glass windows, although they had poor quality. From the eleventh century, new ways developed of creating glass sheets, when small rectangular pieces of glass joined together with pieces of wire creating the first windows. The glass continued to be fine material to the late Middle Ages. The promotion of glass in modern times was made by the Pilkington brothers in Britain (1959) and since then widely used. Today, large pieces of high quality glass produced reliably and cheaply

Paris Louvre

Paris Louvre

INTRODUCTION

For centuries, the use of glass in buildings was substantially limited in displays and windows. The aesthetic benefits and current trends of contemporary architecture seek to extend the use on a truly new areas. Meanwhile last decades there was a continuous improvement in technology of production, allowing glass elements to carry larger loads and thus may play a more significant role.

The structural design of such elements, nevertheless, remains problematic. Nowadays design methods suffer from characteristic weaknesses and are not applicable, at present, in general conditions but limited to specific cases such as rectangular structures for uniform lateral loads, constant loads and loads independent of time. Also standard parameters created, combine the many natural features together and depend on the experiments from which they arise. The design methods contain inconsistencies and does not give realistic results in specific cases where different models produce different results, and many researchers have expressed serious doubts regarding the suitability of common glass. The lack of confidence in advanced glass models, the lack of a common design method and the precision of experiments are issues that create barriers to greater implementation.

The chain design - production - manufacturing - quality control can be achieved reliably when there are well-established standards of general application. In relation to the design of structural glass, at present, there are no international standards for application in detail and thus requires knowledge of engineering combined with the characteristics and properties of the material to be retrieved, on the basis of published papers and research results.

The design of projects should take into account that glass failure is brittle and is the result of cracks development in the surface, even under static loadings. The behavior of elements of glass depends significantly on the surface condition, because of process remaining stresses, weather conditions and the prehistory of loading. The failure is always under tensile stresses. A key element in design is the redundancy resistance to sudden failure of a glass component or sheet that can occur as a result of a impact load or local failure due to poor glass immixture but also to avoid a disproportionate collapse, as a result of a local failure. By applying appropriate safety factors, and using composite glass in critical structural members, the glass can be designed to be safe under operating loads as well as at failure.

GLASS TYPES

The glass is made by fusing silica sand, which is the main ingredient, one or more fluxes and one or more stabilizers. If stabilizer is not used, then the glass becomes brittle and weathered by water. The common glass is made by fusing sand (SiO_2 - 73,7%), sodium carbonate (commonly Soda, Na_2CO_3 - 16%), potassium oxide (K_2O - 0,5%) as fluxes, and calcium carbonate (commonly limestone ($CaCO_3$ - 5,2%) magnesium carbonate ($MgCO_3$ - 3,6%) and aluminum oxide (Al_2O_3 - 1%) as stabilizers. Depending on the type and amount of stabilizers and fluxes are taken and the various types of glass.

Basic types

Common Glass (Soda-lime glass): Prepared using flux of sodium oxide (12-18%) and stabilization of calcium oxide (5-12%). Some other oxides can participate for coloring. The common glass is inexpensive to manufacture and has optical and physical properties suitable for construction of common objects such as glass sheets and household utensils (cups, bottles, food containers). Because it is not porous, it holds no substance and it is easily cleaned. It does not reacts with aqueous solutions or oils and fats, so it does not alter the composition of food and taste or smell. It is also biologically inert and so unaffected by the presence of bacteria or fungi. The common glass is also opaque to visible radiation with wavelengths shorter than 400 nm. This makes it suitable for use in glass windows.

Lead Glass: This glass is prepared by the replacement of sodium oxide from potassium oxide and by calcium oxide from lead oxide (PbO). The content of PbO can be as high as 30%, but the glass containing up to 24% PbO is classified as crystal. It has high durability, the objects are extremely glossy and has a high refractive index. The last two properties make it particularly suitable material for making ornaments and (expensive) household articles, such as glasses, vases, etc. Lead is poisonous material, but because it's atoms are completely trapped in the molecular structure of glass, is absolutely no harm to human health. However, it is still sensitive to temperature changes and can easily break by them. Because of its high refraction is used in manufacturing optical instruments (e.g. lenses). A special form of this type of glass, containing PbO in approximately 65%, is used for the manufacture of special protective glass sheets, because lead absorbs the harmful radiation contained in sunlight

Boron Glass: It is well known under the brand name "Pyrex". The composition is based in silica (70-80%), boron oxide B_2O_3 (7-13%) and small amounts of alkali oxides (4-8% Na_2O and K_2O, and 2-7% aluminum oxide Al_2O_3). The presence of boron and the small amount of alkali glass make it resistant to sudden temperature changes and more infusible. Used in the manufacture of laboratory instruments and appliances, packaging of medical products, high performance lamps (i.e. floodlights) and for household applications (utensils Pyrex, which does not break during cooking). Also shows a low coefficient of expansion, which gives more precise measurements in the experiments.

Glass fibers: Made from various types of glass in form of a thread with multiple uses. The common glass provides threads suitable for the construction of insulation (glass-wool), while boron gives glass fibers from which manufactured textile structures used to support construction of plastic, such as helmets, small boats, car bodies, pipes, etc. and is known by trade name Fiberglass. A more recent application of glass fibers is the manufacture of optical fiber used to transmit light signals, bypassing the straightness of light transmission. Used for endoscopy organs in living organisms, managing signals from road signs and rail traffic and the construction of special instruments such as sonar, hydrophone, etc. The optical fibers are also used in telecommunication technology. By its use, applications such as telephony, computer networks and the Internet (broadband), met substantial growth.

Special types

Aluminum Glass: Contains approximately 20% aluminum oxide, small amounts of boron and magnesium oxides, but very small percentage of alkali oxides. The glass of this type is highly heat-resistant and used in a combustion chambers, in glasses of high temperatures measuring instruments and in halogen lamps, where the temperature of this glass can be up to 750^oC.

Alkali - Barium Glass: Without this type of glass, using a monitor for computers and televisions would be dangerous. The CRT monitor, by way of operation, produces very dangerous radiation (X rays) absorbed by this type of glass, which contains other than lead oxide at a low rate, barium oxide (BaO) and strontium (SrO)

Ceramic glass: It is glass with the participation of aluminum oxides and lithium to its composition and, because of its heat resistance, has found application as a transparent refractory material in furnace doors, mirrors of telescopes, vitrification tiles, in spacecrafts, but also in household appliances (glass ceramic cooking hobs, etc.).

Optical Glasses: There is no firm recommendation, but this varies each time depending on the type required. It is encountered in the manufacture of eyewear and sunglasses, in devices such as cameras, video cameras and microscopes (manufacture of lenses) and precision devices (optical navigation instruments, mirrors, telescopes, etc.).

COMMON GLASS

From those types described above, structural interest is on common glass. Common glass is divided in flat glass (or float glass) and that for the packaging (bottles etc). These two types differ:

- in the manufacturing process. The flat glass produced by infusion over a molten tin (from which the name float), so to give a uniform thickness and flat surface.
- in the chemical composition. The flat glass has a higher content of magnesium oxide (MgO) and sodium carbonate (Na_2CO_3) and lower content of quartz sand (SiO_2), calcium oxide (CaO) and aluminum oxide (Al_2O_3).

The viscosity of glass increases rapidly with temperature. The glass transition from a solid elastic body to a fluid form is very quick. At this temperature (555°C) is given the term transition temperature or annealing point.

Annealed glass

This glass is after a process of elimination of internal stresses developed within the crystalline structure. In this, glass is heated to the annealing point and then cooled under control. This process is very important for its durability and comes before the rest of processing.

The annealed glass is produced in standard thicknesses of 3, 4, 6, 8, 10, 12, 15, 19 and 25 mm in sheets of maximum dimension $3.0x6.0m^2$ but it is possible to produce and dimensions such as $3.2x8.0m^2$.

The resistance of glass under permanent stress tends to deteriorate with time, due to chemical corrosion in the micro-cracks created in the surface, by the action of water which enlarges the cracks. Nevertheless there is a limit stress (about 7Mpa) below which the effect is not significant.

Another phenomenon, in which the annealed glass is sensitive, is the thermal shock. Thermal shock is caused by temperature differences that exist at various points on the surface of sheet of glass (e.g. part in shadow and part in direct sunlight) which develop internal stresses that result in cracking. As a critical temperature is found to be the 33^oC. Where this phenomenon is important, then the glass should be specified as tempered.

Tempered glass

Having completed the planned treatment (cutting, polishing, drilling, etc.), the annealed glass is restored by reheating to 650°C and then rapid cooling of the surface with a carefully controlled manner. This process prestress (Figure 1) the outer surface thereby increasing the strength of this glass in tension. The level of residual stress depends mainly on the rate of cooling and there are basically two grades:

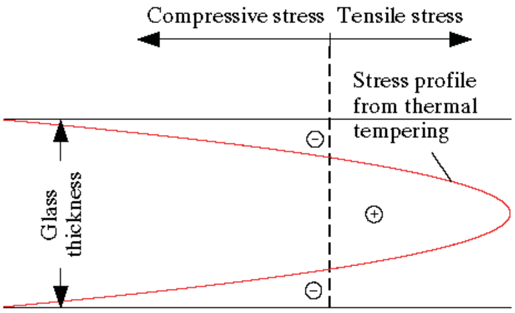


Figure 1: Residual stresses after cooling [6].

Toughened glass, which is usually prescribed with a residual surface tension at minimum 100Mpa. All thicknesses of annealed glass produced, with the exception of 25mm which is difficult to achieve a residual stress on the threshold of 100Mpa. The maximum sheet dimensions depend on the equipment of factories and are usually 2.14x4.5m^2 although it may be found to 3.0x6.0m^2.

Heat strengthened glass, usually prescribed with residual surface tension between 40-50Mpa. It is produced of the thicknesses of annealed glass but with a maximum thickness of 12mm.

In hardened glasses there is risk of random fragmentation due to the sulfur content in nickel. The fracture is caused by the hardening process, due to the rapid cooling of glass surface, which changes the crystalline structure of nickel sulphide.

This phenomenon, however, does not apply to heat-strengthened glass because of the declined cooling. To minimize the aforementioned risk, toughened glass undergoes heat soaking after hardening at a temperature of approximately 280°C.

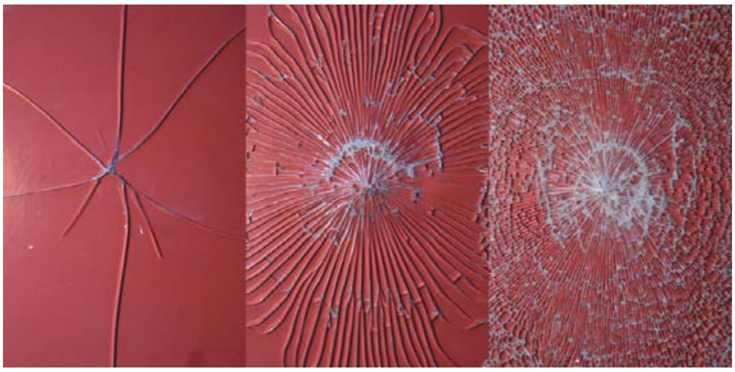


Figure 2: Form of glass breakage. From left, annealed , heat strengthened, toughened [6].

Hardened glass (Figure 2) has the tendency to break into small cubic segments, rather than large and sharp angle pieces, which minimizes the risk of injury or death. Finally, another feature is that, due to stress concentration that exists at the edges, can break by impact to the edges

Laminated glass.

It consists of sheets of glass attached with adhesive, which is designed to keep themselves attached and create shear interaction. As such materials are used in Polyvinyl butyral (PVB), polyurethane or liquid resin during infusion.

The design of thickness of composite glass depends on the type of loading (permanent or live) and the temperature. Main problem is the variability of the shear modulus of the binder by the temperature and time history of loading.

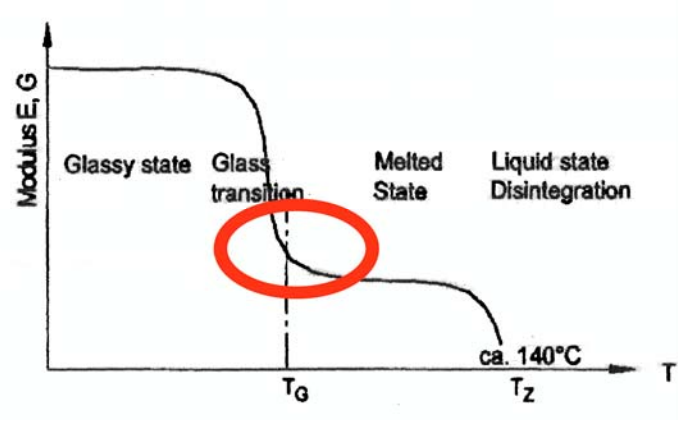


Figure 3: Variation of elastic and shear modulus of PVB, by temperature change [1].

Although the shear modulus of the binder at low temperatures and short term loads may be at values comparable to those of glass (about 100Mpa), high temperatures and permanent loads can greatly reduce it.

The curve of Figure 3 refers to the change in E and G modulus by the temperature for the PVB material. The point at which the curve shows a sharp slope is between 15 and 20^{o}C [1].

DESIGN OF STRUCTURAL GLASS

The theoretical glass resistance is dictated by the consistency of molecular bonds of silicon and oxygen. For common glass (soda-lime) the theoretical cohesive force is σ_{coh} = 20 GPa but this is several hundred times greater than the actual resistance. It has been shown that all the resistance characteristics of glass have been explained to the imperfections on the surface and the edges. So the tensile strength depends on these flaws, which have come either during construction or during the placement. In the production of flat glass such defects occur across the surface along a length of *a* <10μm. Impacts during the placement, scratches or minor collisions with other objects cause defects in the order of 100μm. The tensile force imposed on the glass is concentrated at the edges of these defects under the form of increased tensile stress. If the cohesive force in the region σ_{coh} is exceeded then the atoms split up and the crack grows. This type of mechanism leads to forming brittle failure.

Apart from the presence and distribution of defects on the surface, the strength of glass depends on environmental conditions. This feature requires attention during design because, unlike other materials, the spread of resistance is great and can be increased further during the life of the material.

The fundamental theory for the failure criterion given by Griffith in 1920 is based on an energy balance by which the crack will grow, in an element under tension, at a point where the crack increase releases more energy than it is required for the creation of new cracks

Paris, Avenue des Champs Elysees

We define the concentration factor as:

$$K_I = Y \cdot \sigma_t \cdot \sqrt{a} \ ,$$

where σ_t is the tension stress, under centrally imposed tension force, that is defined without the presence of cracking, α is the length of the crack and Y the analogy factor that depends from the shape of crack, the ratio of its length to thickness of the element and the position of crack in the tension area. The factor Y has been found experimentally to be equal 1.77 for a crack in the center of the width of the tensile region and 1.99 when at its edge.

The determination of the critical concentration factor K_{IC} is done when at the previous relationship $K_I = K_{IC}$ and the correlation is made with the stress at failure σ_f. Then:

$$\sigma_f = \frac{K_{IC}}{Y \cdot \sqrt{a}}$$

This factor K_{IC} has found to varies between the values of 0.72 and 0.82 MPa $m^{-1/2}$ and an accepted value is 0.75 MPa $m^{-1/2}$.

In the previous equation has been assumed that the crack edge is sharp (i.e. the radius of curvature is zero). But assuming that the radius is not zero then:

$$\sigma_f = \sigma_{coh} \frac{\sqrt{\rho}}{2\sqrt{\alpha}}$$

It is obvious that by increasing the radius, the resistance increases. According to Lawn and others, the minimum radius is found from the next formula

$$\rho_{\min} = \left(\frac{2\cdot K_{IC}}{Y\cdot \sigma_{coh}}\right)^2$$

Applying the values K_{IC}=0.75 MPa $m^{-1/2}$, σ_{coh}= 20000 MPa and Y=1.99 the minimum radius is p_{min}=1.4 nm. This value is four time the length of the bond Si-O-Si that is 0.32nm long.

Sometimes the size of critical flaws is determined by the failure surface after fracture. The measurement requires very high precision that can only be achieved by electron microscopes.

When brittle materials like glass, carved from other hard materials, cracks are eventually created by these notches. Since the failure of the glass begins by surface imperfections in size of some microns, the failure may be caused by contact with tiny but tough particles. The air contains dust, which largely consists of small particles of quartz that is hard enough to be able to carve all materials except the diamond. Typically if considered a piece of quartz with a radius of 1mm on the surface of glass, the critical load to be carved is only 0.5N (Derby 1992). It is very common these particles to collect on surfaces of materials and even more to be trapped between two surfaces in contact, then this critical load is easily get over. So at the direct contact of glass with the metal frame, that surrounds it, the tiny particles carve the glass, instead of the metal surface, and the failure begins. Therefore, the contact between glass and metal should be prevented by placing material with lower modulus (e.g. rubber), between the surfaces of glass - metal

Although glass is characterized as a chemically neutral material and corrosion resistance is actually very sensitive to failure due to corrosion under tension, caused by the water. This phenomenon, often referred to as static fatigue, is the reason for failure of glass under long term tensile stresses

The process of glass breaking is divided into the following parts:

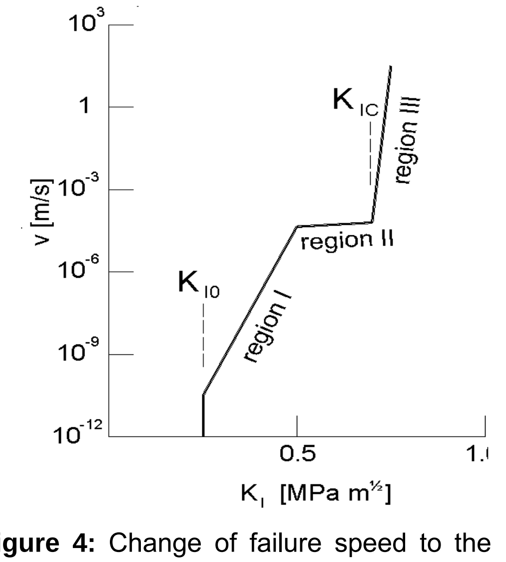


Figure 4: Change of failure speed to the rate of factor K_I [3].

- The crack is caused at the surface of the glass during production or placement.
- Tensile stresses develop at the crack. If the concentration factor K_I > K_{I0} (K_{I0} = (20-30)% K_{IC}, (area I at figure 4) the crack begins to grow due to static fatigue, caused by chemical reaction . $Si_2O + H_2O \rightarrow 2SiOH$, thus releasing the link (Figure 4).
- As soon as the limit of diffusion (zone II in Figure 4) passed, the crack is growing at an extraordi-

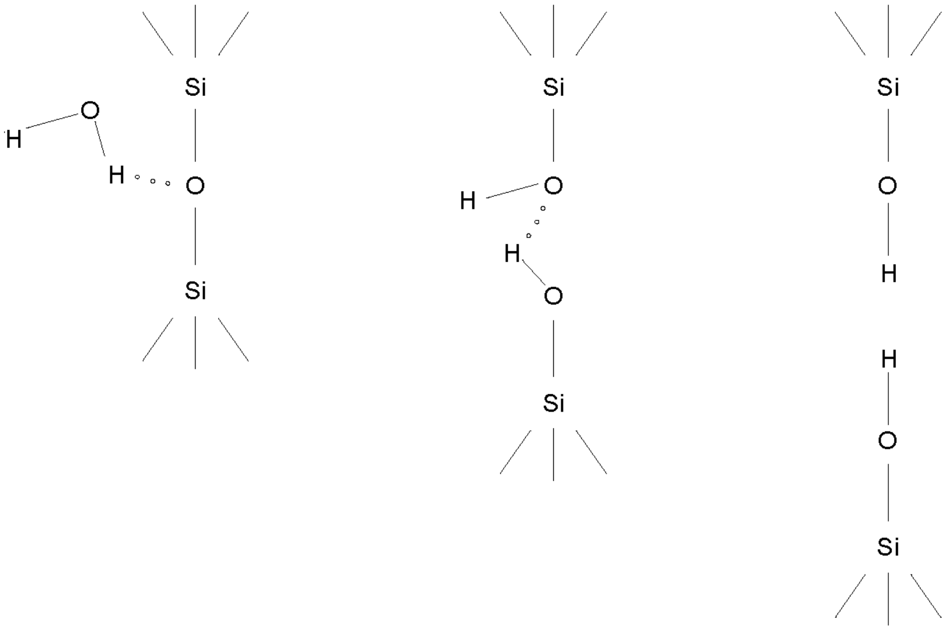


Figure 5: Schematic process of destroying the bond of quartz sand by the action of water (from left to right) [3].

nary rate while K_I increases. At this point the failure rate is already high and the Ki increases very rapidly until it reaches the critical value K_{IC}.

- When the concentration ratio equals the critical $K_I = K_{IC}$ is the crack propagation speed increases dramatically leading directly to fracture. If the crack has room to grow may the speed reaches the value v_{max}=1500 m/s. When this speed is achieved, the crack is divided into smaller ones growing at slower speeds.
- If the stress level is high at the outset or defects are large in size, the concentration factor is equated immediately with the critical $K_I = K_{IC}$ just after loading. In this case the resistance of glass, in short-term load, is exceeded and the glass shatters instantly without any warning

As already seen, from the above process and figure 4, it is possible to provide some level of loading which will result in a slow crack propagation, for the duration of loading, resulting in a predictable, in time, utility of the material. It is also obvious that long term loads (e.g. permanent loads) should be treated differently than those shorter loading time (e.g. snow) or almost instantaneous application such as wind

DESIGN BASED ON THE NEW EUROPEAN DRAFT prEN 13474

Since 1999 CEN created a draft of the European standard 13474 for the calculation of the glass window panes which consists of three parts, part one is dealing with general provisions for calculating, part two calculation for a uniform loading and part three loading with linear loads. Although this standard should have been finalized (for normal standard application) at the time of writing this text has been withdrawn for corrections.

The design according to this model code consists of the following steps:

- The determination of the design strength, which is a function of the loaded area, load duration and of the partial safety factors specified in the standard
- The determination of loads under their respective Eurocodes (e.g. EN 1991-1-4 Action on structures - General actions - Wind Action, etc).
- The determination of maximum stress and deflection. Note here that due to the very small thickness which the glass has, in relation to the displacement (multiple of the half thickness of the section), issues are created for large deformations (geometrical non-linear behavior). For this reason, the draft of code, provides an easy way for certain types of loadings, to determine the stress and deflection nonlinearly.
- The determination of an equivalent stress which takes into account of the reduced probability of failure when the maximum stress is limited in extent.

Analytically:

Determination of the design strength

The determination of the design strength due to static tension, on common glass, is given by the formula:

$$f_{g,d} = k_{\mathrm{mod}} \frac{f_{g,k}}{\gamma_m \cdot k_A} \cdot \gamma_n$$, where:

- k_{mod} = 0.72 for wind loading, 0.36 for snow and 0.27 for permanent loads
- $f_{g,k}$ = 45 Mpa (EN 572)
- γ_m =1.8
- $K_A = A^{1/\beta}$, shape coefficient
- γ_n country depended factor, normally equal to 1.0

For tempered glass this formula becomes:

$$f_{g,d} = \left(\frac{f_{b,k} - f_{g,k}}{\gamma_V} + k_{\mathrm{mod}} \cdot \frac{f_{g,k}}{\gamma_m \cdot k_A} \right) \cdot \gamma_n$$, where:

- $f_{b,k}$ = 120 Mpa (EN 12150) for toughened glass
- $f_{b,k}$ = 70 Mpa (EN 1863) for heat-strengthened glass
- γ_v = 2.3

It is noted that the values of $f_{g,k}$ and $f_{b,k}$ are for loading duration of 1,5 sec and therefore it is necessary to correct using factor k_{mod}.

Determination of maximum stress

Maximum stress is given by:

$$\sigma_{\max} = k_1 \cdot \left(\frac{a}{t}\right)^2 \cdot q_d \text{ , where:}$$

- a, the length of the shorter side of glass pane,
- t pane thickness,
- q_d design load and
- k_1 coefficient according to diagram 1
- p^* Reduced load rate, with $p^* = \left(\frac{a}{t}\right)^4 \cdot \frac{q_d}{E}$,
- E=70000 MPa modulus of elasticity.

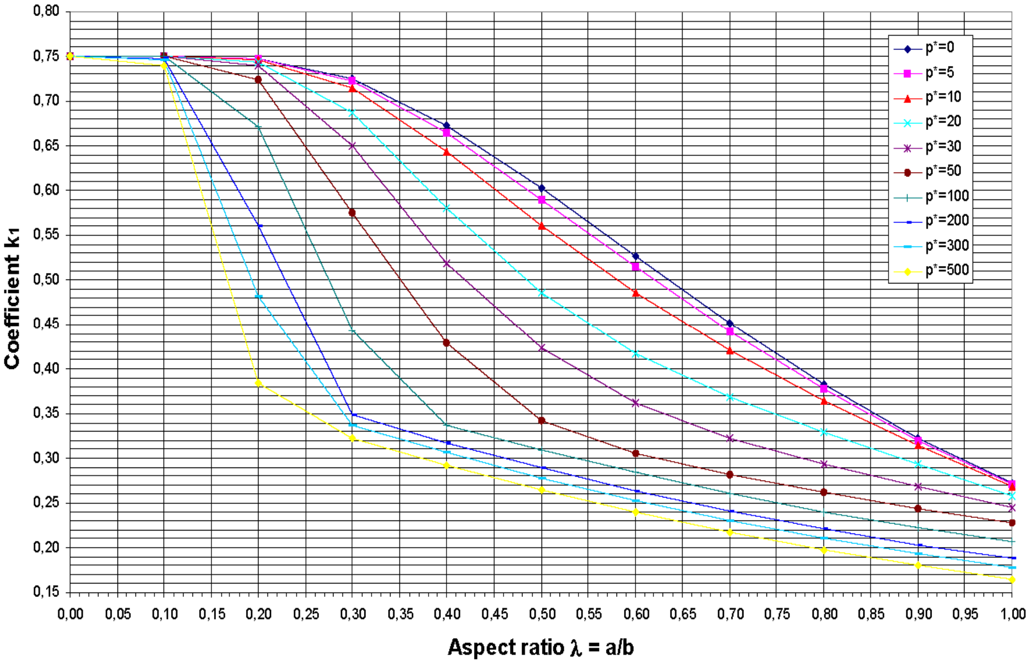


Diagram 1: Calculation of the coefficient k_1 in relation to the pane sides aspect ratio λ and the reduced load ratio p^* [3].

The above formula for orthogonal panes supported on two sides becomes:

$$\sigma_{\max} = 0.75 \cdot \left(\frac{L}{t}\right)^2 \cdot q_d \text{ ,with L equal to span length.}$$

Determination of equivalent (effective) stress.

Once the tensile strength of glass depends on the distribution and size of surface imperfections, it can be shown that the distribution of stresses affect the strength design. For example, if the tensile stresses are developed evenly across the surface, the probability of failure is greater than if the tensile stresses of that tension has been applied to a smaller part.

To take this into account we can use, in order to control resistance, instead of the maximum stresses the effective tension stress σ_{ef}. As "effective" is meant an average weighted value of the principal tensile stress determined in a manner analogous to the coefficient k_A. Through the effective stress the probability of failure, caused by the actual distribution of stress, is equalized with the one that could have been developed across surface of the glass.

The effective tension is calculated as follows:

$$\sigma_{ef} = \left[\frac{1}{A} \cdot \iint \sigma_{\mathrm{I}}{}^{\beta} dxdy\right]^{\frac{1}{\beta}}$$, where:

- A the surface area
- σ_I principal stress at point (x, y)
- β=25 constant.

A graphical method, for immediate calculation, is given In the draft of the code, as explained in the following. Calculate:

$\sigma_{ef} = k_2 \cdot \left(\frac{a}{t}\right)^2 \cdot q_d$, where k_2 is a coefficient to the following diagram. All other variables as before.

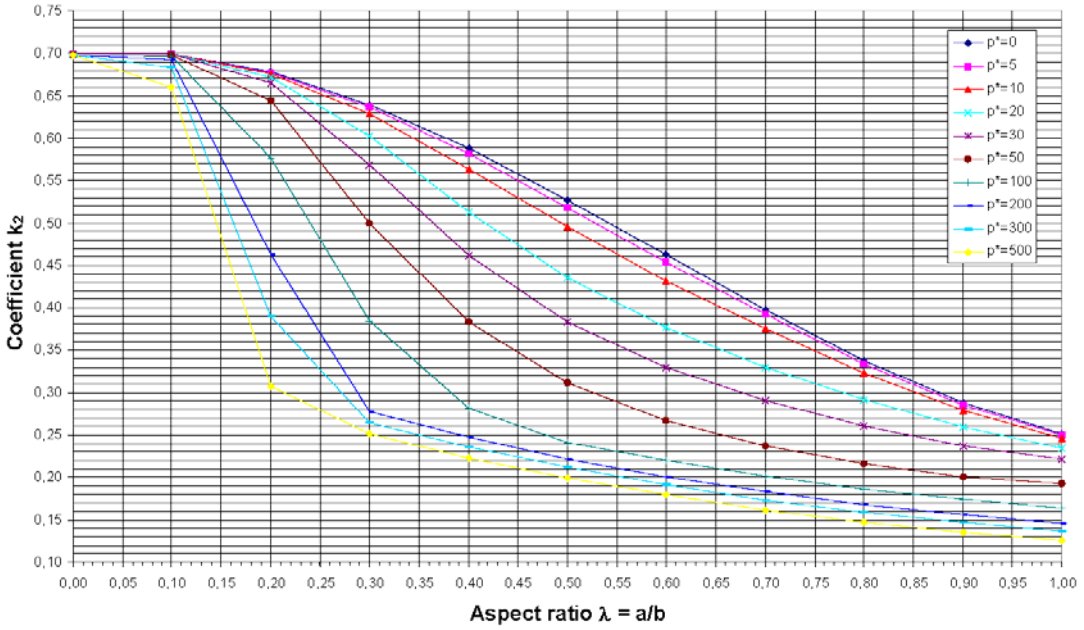


Diagram 2: Calculation of coefficient k_2 in relation to the pane sides aspect ratio λ and the reduced load ratio p^* [3].

The above formula for orthogonal panes supported on two sides becomes:

$$\sigma_{\max} = 0.699 \cdot \left(\frac{L}{t}\right)^2 \cdot q_d$$

Determination of maximum displacement

The following formula calculates the maximum bending displacement δ_{max} of glass panes supported on four sides:

$$\delta_{\max} = k_4 \cdot \frac{L^4}{t^3} \cdot \frac{q_k}{E}$$, where:

- q_k the nominal (SLS) load,
- k_4 coefficient determined as in the case of maximum stress but now p^* is calculated by q_k

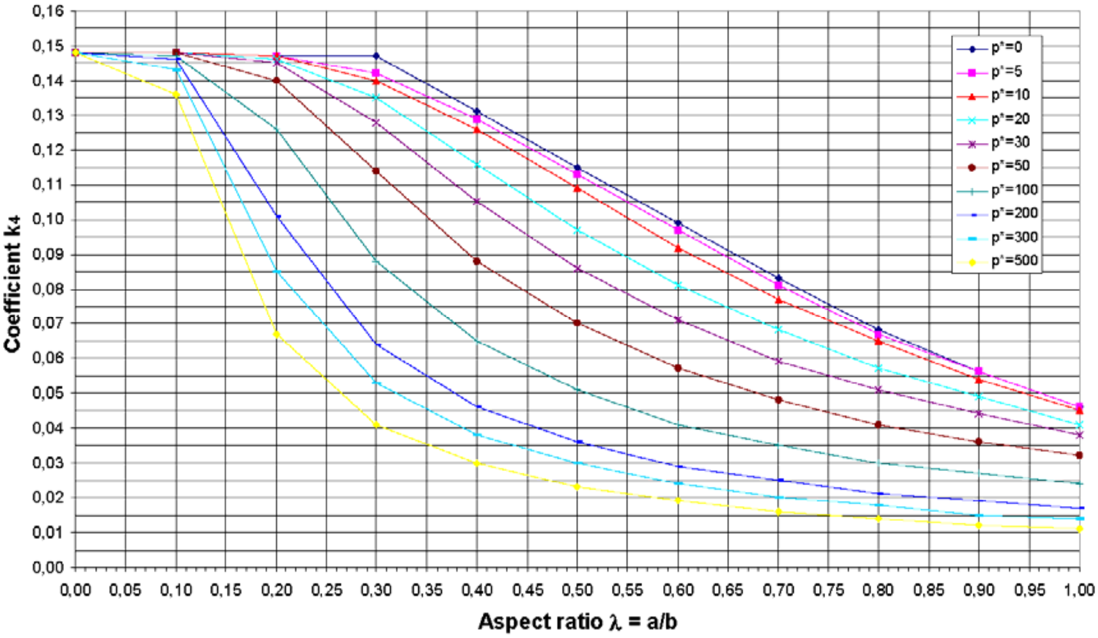


Diagram 3: Calculation of coefficient k_4 in relation to the pane sides aspect ratio λ and the reduced load ratio p^* (calculated using q_k) [3].

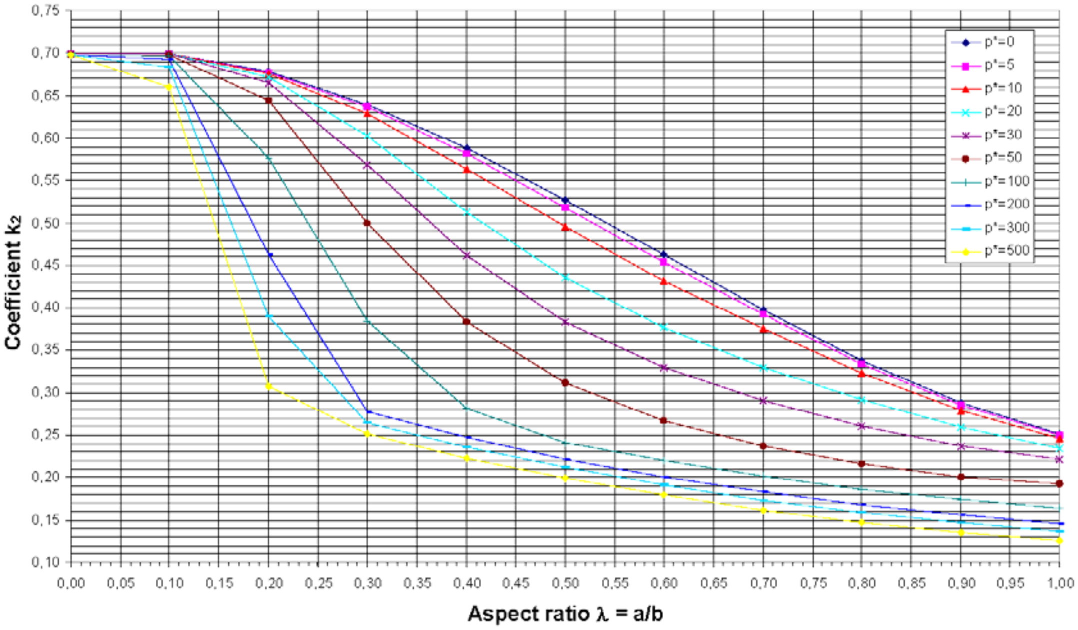


Diagram 2: Calculation of coefficient k_2 in relation to the pane sides aspect ratio λ and the reduced load ratio p^* [3].

The above formula for orthogonal panes supported on two sides becomes:

$$\delta_{\max} = 0.148 \cdot \frac{L^4}{t^3} \cdot \frac{q_k}{E}$$

The draft standard does not specify a limit for the maximum deflection. Instead it states that the limits should applied in light of other applicable standards or regulations. The variety, however, of limits to various documents is significant. Customary, however, can be used for common glasses the limit of δ_{max} =a/125, where "a" is the shorter side of the pane to be designed.

Temperature difference

Brief mention is made for temperature difference loading between surfaces of the glass. Differences of about 10°C have been observed in a standard glass (i.e. uncoated) but some coatings may rise larger differences. The equation that gives the extreme stress is:

$$\sigma_{\mathrm{T}} = \mathrm{E} \cdot \alpha \cdot \Delta\mathrm{T} \ .$$

If apply, in this equation, the glass constants (E=70000Mpa, $\alpha=9.0\mathrm{x}10^{-6}(^{o}\mathrm{C})^{-1}$) then:

$$\frac{\sigma_{\mathrm{T}}}{\Delta\mathrm{T}} = 0.63 \cdot \frac{Mpa}{^{o}C}$$

Following finite element analyses, this formula is found to be pretty accurate, actually slightly overestimating $\sigma_{T.}$ Correcting coefficient to be used with temperature is k_{mod}=0.36

Loading combinations

On the basis of the above, calculation of a glass component combining loads of different duration shows that there is no basis for comparison, since the resistance is not the same. It is proposed to use the following equation:

$\sum_i \left[\frac{\sigma_{ef,i}}{\sigma_{g,d,i}} \right] \leq 1$, where in place of σ_{efx} can be used the σ_{max}.

These stresses have been calculated taking into account non-linearity and normally cannot be combined but the sum will be located on the side of safety. The latter is evidenced by the fact that stresses calculated separately give less cumulative effect of geometric nonlinearity than of the sum but geometric nonlinearity is favorable for stress results (see diagrams for calculating coefficients k).

LAMINATED (COMPOSITE) GLASS

In critical places, glazing can pose security issues for persons injury. If for example a shed is covered by glass, then a question can be posed of what would happen if glass brake, for reasons not related to the loading. Such reasons could be the impact with an object that fell from above or accidental damage by nickel sulphide impurities etc. The fitting of tempered glass does not fully correct the problem because although the glass finally breaks into small parts there is the possibility of falling of an entire section from height on people, causing injuries or even death.

In such cases a redundant composite glazing can be applied. The loads on the basis of which will the system be designed should take into account the risk of such a case. These loads can vary from permanent loads on glass (extreme case) to the full design load of the system (perhaps an extreme case again).

What should be underlined here is that the composite action caused by the adhering layer (e.g. PVB) is not complete because the shear modulus of the material is greatly influenced by temperature, creep and aging from UV rays. It is clear that the permanent loads or those with long duration, should be distributed to each consisting part in proportion to the their inertia (cube of the thickness), thus completely ignoring composite action. It should also be taken into account the likelihood of extreme loads in high temperatures. But perhaps, the lack of composite action in momentary or accidental loads, is excessive and should be considered as partly composite action. For example, the Canadian standard (CAN / CGS 12.20-M89, Structural design of glass for buildings) requires, in order to take into account the composite action of glass, for the wind forces temperatures less than 70F (21^0C).

Obviously, as composite glass cannot be considered the insulating glass (double glazed) that, because of the air-tight gap, require a special consideration. Briefly are indicated, the change of external air pressure (due to Meteorology reasons or altitude difference) than that at the time of sealing, the temperature change, the load transfer from one glass to another through the air gap etc.

RECOGNITION

This text is based in large part to the references [3] and [2]. Considerable assistance in providing references found by my father and colleague, Dimitris Tolis.

REFERENCES

[1] University of Florence: Department of civil engineering Anna Bati, Maurizio Orlando, Ostilio Spadaccini, Paolo Spinelli «Use of Laminated Safety Glass plates under compression: application to the design of an arch pedestrian bridge» International Symposium on the Application of Architectural Glass (ISAAG) Munich, Germany 2006

[2] Philip Wilson, Gennady Vasilchenko-Malishev, «The design and construction of all glass structures», International Association for Shell and Spatial Structures (IASS), Paris 2006.

[3] Aki Vuolio, «Structural behaviour of glass structures in facades», Helsinki University of Technology Laboratory of Steel Structures Publications 27, Espoo, October 2003

[4] Leonardo Lani, «Progretto di elementi in vetro structturale secondo la norma EN 13474-3 (CEN/TC129/WG8)», Dipartimento Ingegneria Strutturale, Facoltà Ingegneria, Università di PISA.

[5] Matthias Haldimann, «Fracture strength of structural glass elements – analytical and numerical modelling, testing and design», THÈSE NO 3671 (2006), ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE, 13 décembre 2006

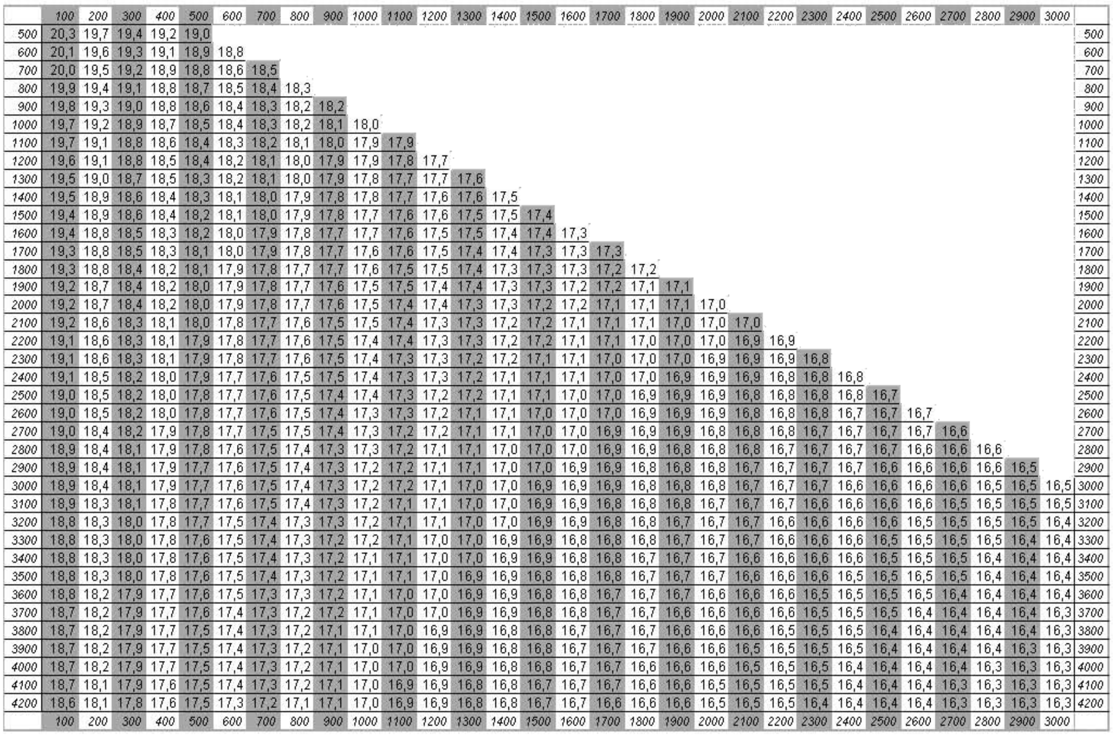
[6] M. Overent, S. Gaetano, M. Haldimann, «Diagnostic interpretation of glass failure», Structural Engineering International 2/2007

[7] Wikipedia Wikipedia – The Free Encyclopedia 2008. URL http://en.wikipedia.org/

APPENDIX A

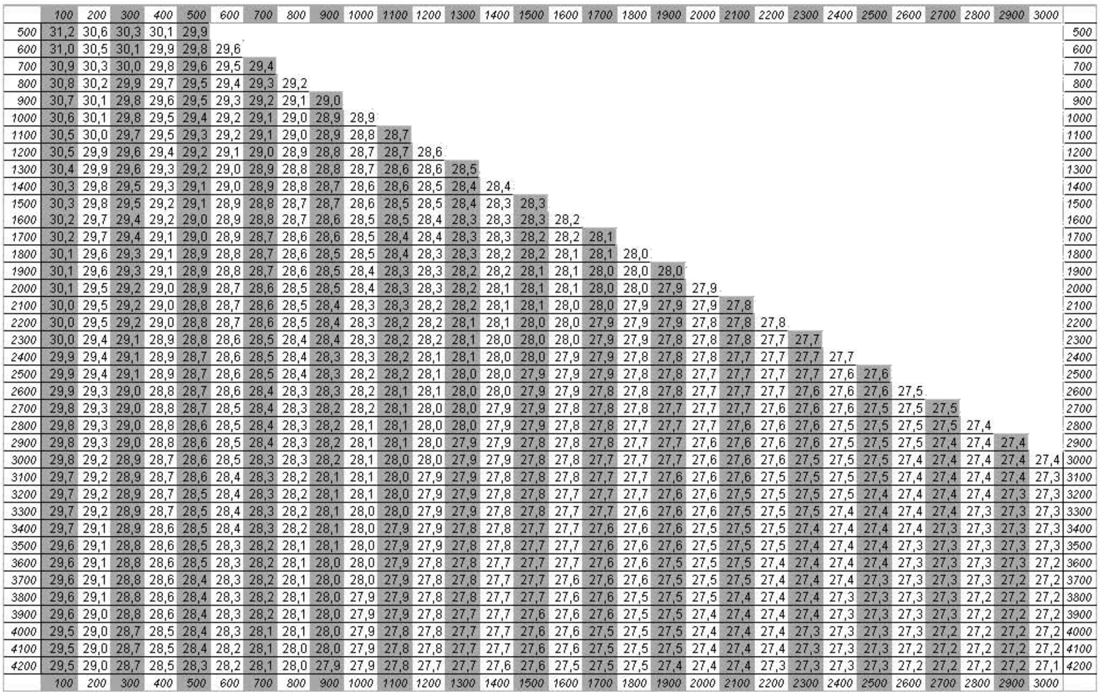
Tables for calculating the design strength in prEN 13474-1 (1999) for loadings short-term limit [3].

Select the dimensions "a" (columns) "b" (lines), must be a>b, and at the intersection, read the design stress



	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900	3000	
500	20,3	19,7	19,4	19,2	19,0																										500
600	20,1	19,6	19,3	19,1	18,9	18,8																									600
700	20,0	19,5	19,2	18,9	18,8	18,6	18,5																								700
800	19,9	19,4	19,1	18,8	18,7	18,5	18,4	18,3																							800
900	19,8	19,3	19,0	18,8	18,6	18,4	18,3	18,2	18,2																						900
1000	19,7	19,2	18,9	18,7	18,5	18,4	18,3	18,2	18,1	18,0																					1000
1100	19,7	19,1	18,8	18,6	18,4	18,3	18,2	18,1	18,0	17,9	17,9																				1100
1200	19,6	19,1	18,8	18,5	18,4	18,2	18,1	18,0	17,9	17,9	17,8	17,7																			1200
1300	19,5	19,0	18,7	18,5	18,3	18,2	18,1	18,0	17,9	17,8	17,7	17,7	17,6																		1300
1400	19,5	18,9	18,6	18,4	18,3	18,1	18,0	17,9	17,8	17,8	17,7	17,6	17,6	17,5																	1400
1500	19,4	18,9	18,6	18,4	18,2	18,1	18,0	17,9	17,8	17,7	17,6	17,6	17,5	17,5	17,4																1500
1600	19,4	18,8	18,5	18,3	18,2	18,0	17,9	17,8	17,7	17,7	17,6	17,5	17,5	17,4	17,4	17,3															1600
1700	19,3	18,8	18,5	18,3	18,1	18,0	17,9	17,8	17,7	17,6	17,6	17,5	17,4	17,4	17,3	17,3	17,3														1700
1800	19,3	18,8	18,4	18,2	18,1	17,9	17,8	17,7	17,7	17,6	17,5	17,5	17,4	17,3	17,3	17,3	17,2	17,2													1800
1900	19,2	18,7	18,4	18,2	18,0	17,9	17,8	17,7	17,6	17,5	17,5	17,4	17,4	17,3	17,3	17,2	17,2	17,1	17,1												1900
2000	19,2	18,7	18,4	18,2	18,0	17,9	17,8	17,7	17,6	17,5	17,4	17,4	17,3	17,3	17,2	17,2	17,1	17,1	17,1	17,0											2000
2100	19,2	18,6	18,3	18,1	18,0	17,8	17,7	17,6	17,5	17,5	17,4	17,3	17,3	17,2	17,2	17,1	17,1	17,1	17,0	17,0	17,0										2100
2200	19,1	18,6	18,3	18,1	17,9	17,8	17,7	17,6	17,5	17,4	17,4	17,3	17,3	17,2	17,2	17,1	17,1	17,0	17,0	17,0	16,9	16,9									2200
2300	19,1	18,6	18,3	18,1	17,9	17,8	17,7	17,6	17,5	17,4	17,3	17,3	17,2	17,2	17,1	17,1	17,0	17,0	17,0	16,9	16,9	16,9	16,8								2300
2400	19,1	18,5	18,2	18,0	17,9	17,7	17,6	17,5	17,5	17,4	17,3	17,3	17,2	17,1	17,1	17,1	17,0	17,0	16,9	16,9	16,9	16,8	16,8	16,8							2400
2500	19,0	18,5	18,2	18,0	17,8	17,7	17,6	17,5	17,4	17,4	17,3	17,2	17,2	17,1	17,1	17,0	17,0	16,9	16,9	16,9	16,8	16,8	16,8	16,8	16,7						2500
2600	19,0	18,5	18,2	18,0	17,8	17,7	17,6	17,5	17,4	17,3	17,3	17,2	17,1	17,1	17,0	17,0	17,0	16,9	16,9	16,9	16,8	16,8	16,8	16,7	16,7	16,7					2600
2700	19,0	18,4	18,2	17,9	17,8	17,7	17,5	17,5	17,4	17,3	17,2	17,2	17,1	17,1	17,0	17,0	16,9	16,9	16,9	16,8	16,8	16,8	16,7	16,7	16,7	16,7	16,6				2700
2800	18,9	18,4	18,1	17,9	17,8	17,6	17,5	17,4	17,3	17,3	17,2	17,1	17,1	17,0	17,0	17,0	16,9	16,9	16,8	16,8	16,8	16,7	16,7	16,7	16,7	16,6	16,6	16,6			2800
2900	18,9	18,4	18,1	17,9	17,7	17,6	17,5	17,4	17,3	17,2	17,2	17,1	17,1	17,0	17,0	16,9	16,9	16,8	16,8	16,8	16,7	16,7	16,7	16,7	16,6	16,6	16,6	16,6	16,5		2900
3000	18,9	18,4	18,1	17,9	17,7	17,6	17,5	17,4	17,3	17,2	17,2	17,1	17,0	17,0	16,9	16,9	16,9	16,8	16,8	16,8	16,7	16,7	16,7	16,6	16,6	16,6	16,6	16,5	16,5	16,5	3000
3100	18,9	18,3	18,1	17,8	17,7	17,6	17,5	17,4	17,3	17,2	17,1	17,1	17,0	17,0	16,9	16,9	16,8	16,8	16,8	16,7	16,7	16,7	16,6	16,6	16,6	16,6	16,5	16,5	16,5	16,5	3100
3200	18,8	18,3	18,0	17,8	17,7	17,5	17,4	17,3	17,3	17,2	17,1	17,1	17,0	17,0	16,9	16,9	16,8	16,8	16,7	16,7	16,7	16,6	16,6	16,6	16,6	16,5	16,5	16,5	16,5	16,4	3200
3300	18,8	18,3	18,0	17,8	17,6	17,5	17,4	17,3	17,2	17,2	17,1	17,0	17,0	16,9	16,9	16,8	16,8	16,8	16,7	16,7	16,7	16,6	16,6	16,6	16,5	16,5	16,5	16,5	16,4	16,4	3300
3400	18,8	18,3	18,0	17,8	17,6	17,5	17,4	17,3	17,2	17,1	17,1	17,0	17,0	16,9	16,9	16,8	16,8	16,7	16,7	16,7	16,6	16,6	16,6	16,6	16,5	16,5	16,5	16,4	16,4	16,4	3400
3500	18,8	18,3	18,0	17,8	17,6	17,5	17,4	17,3	17,2	17,1	17,1	17,0	16,9	16,9	16,8	16,8	16,8	16,7	16,7	16,7	16,6	16,6	16,6	16,5	16,5	16,5	16,5	16,4	16,4	16,4	3500
3600	18,8	18,2	17,9	17,7	17,6	17,5	17,3	17,3	17,2	17,1	17,0	17,0	16,9	16,9	16,8	16,8	16,7	16,7	16,7	16,6	16,6	16,6	16,5	16,5	16,5	16,5	16,4	16,4	16,4	16,4	3600
3700	18,7	18,2	17,9	17,7	17,6	17,4	17,3	17,2	17,2	17,1	17,0	17,0	16,9	16,9	16,8	16,8	16,7	16,7	16,6	16,6	16,6	16,6	16,5	16,5	16,5	16,4	16,4	16,4	16,4	16,3	3700
3800	18,7	18,2	17,9	17,7	17,5	17,4	17,3	17,2	17,1	17,1	17,0	16,9	16,9	16,8	16,8	16,7	16,7	16,7	16,6	16,6	16,6	16,5	16,5	16,5	16,4	16,4	16,4	16,4	16,4	16,3	3800
3900	18,7	18,2	17,9	17,7	17,5	17,4	17,3	17,2	17,1	17,0	17,0	16,9	16,9	16,8	16,8	16,7	16,7	16,7	16,6	16,6	16,5	16,5	16,5	16,5	16,4	16,4	16,4	16,4	16,3	16,3	3900
4000	18,7	18,2	17,9	17,7	17,5	17,4	17,3	17,2	17,1	17,0	17,0	16,9	16,9	16,8	16,8	16,7	16,7	16,6	16,6	16,6	16,5	16,5	16,5	16,4	16,4	16,4	16,4	16,3	16,3	16,3	4000
4100	18,7	18,1	17,9	17,6	17,5	17,4	17,3	17,2	17,1	17,0	16,9	16,9	16,8	16,8	16,7	16,7	16,7	16,6	16,6	16,5	16,5	16,5	16,5	16,4	16,4	16,4	16,3	16,3	16,3	16,3	4100
4200	18,6	18,1	17,8	17,6	17,5	17,3	17,2	17,1	17,1	17,0	16,9	16,9	16,8	16,8	16,7	16,7	16,6	16,6	16,6	16,5	16,5	16,5	16,4	16,4	16,4	16,4	16,3	16,3	16,3	16,3	4200
	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900	3000	

Table A-1: Common glass short term loading (k_{mod}=0.72)



	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900	3000	
500	31,2	30,6	30,3	30,1	29,9																										500
600	31,0	30,5	30,1	29,9	29,8	29,6																									600
700	30,9	30,3	30,0	29,8	29,6	29,5	29,4																								700
800	30,8	30,2	29,9	29,7	29,5	29,4	29,3	29,2																							800
900	30,7	30,1	29,8	29,6	29,5	29,3	29,2	29,1	29,0																						900
1000	30,6	30,1	29,8	29,5	29,4	29,2	29,1	29,0	28,9	28,9																					1000
1100	30,5	30,0	29,7	29,5	29,3	29,2	29,1	29,0	28,9	28,8	28,7																				1100
1200	30,5	29,9	29,6	29,4	29,2	29,1	29,0	28,9	28,8	28,7	28,7	28,6																			1200
1300	30,4	29,9	29,6	29,3	29,2	29,0	28,9	28,8	28,8	28,7	28,6	28,6	28,5																		1300
1400	30,3	29,8	29,5	29,3	29,1	29,0	28,9	28,8	28,7	28,6	28,6	28,5	28,4	28,4																	1400
1500	30,3	29,8	29,5	29,2	29,1	28,9	28,8	28,7	28,7	28,6	28,5	28,5	28,4	28,3	28,3																1500
1600	30,2	29,7	29,4	29,2	29,0	28,9	28,8	28,7	28,6	28,5	28,5	28,4	28,3	28,3	28,3	28,2															1600
1700	30,2	29,7	29,4	29,1	29,0	28,9	28,7	28,6	28,6	28,5	28,4	28,4	28,3	28,3	28,2	28,2	28,1														1700
1800	30,1	29,6	29,3	29,1	28,9	28,8	28,7	28,6	28,5	28,5	28,4	28,3	28,3	28,2	28,2	28,1	28,1	28,0													1800
1900	30,1	29,6	29,3	29,1	28,9	28,8	28,7	28,6	28,5	28,4	28,3	28,3	28,2	28,2	28,1	28,1	28,0	28,0	28,0												1900
2000	30,1	29,5	29,2	29,0	28,9	28,7	28,6	28,5	28,5	28,4	28,3	28,3	28,2	28,1	28,1	28,1	28,0	28,0	27,9	27,9											2000
2100	30,0	29,5	29,2	29,0	28,8	28,7	28,6	28,5	28,4	28,3	28,3	28,2	28,2	28,1	28,1	28,0	28,0	27,9	27,9	27,9	27,8										2100
2200	30,0	29,5	29,2	29,0	28,8	28,7	28,6	28,5	28,4	28,3	28,2	28,2	28,1	28,1	28,0	28,0	27,9	27,9	27,9	27,8	27,8	27,8									2200
2300	30,0	29,4	29,1	28,9	28,8	28,6	28,5	28,4	28,4	28,3	28,2	28,2	28,1	28,0	28,0	28,0	27,9	27,9	27,8	27,8	27,8	27,7	27,7								2300
2400	29,9	29,4	29,1	28,9	28,7	28,6	28,5	28,4	28,3	28,3	28,2	28,1	28,1	28,0	28,0	27,9	27,9	27,8	27,8	27,8	27,7	27,7	27,7	27,7							2400
2500	29,9	29,4	29,1	28,9	28,7	28,6	28,5	28,4	28,3	28,2	28,2	28,1	28,0	28,0	27,9	27,9	27,9	27,8	27,8	27,7	27,7	27,7	27,7	27,6	27,6						2500
2600	29,9	29,3	29,0	28,8	28,7	28,6	28,4	28,3	28,3	28,2	28,1	28,1	28,0	28,0	27,9	27,9	27,8	27,8	27,8	27,7	27,7	27,7	27,6	27,6	27,6	27,5					2600
2700	29,8	29,3	29,0	28,8	28,7	28,5	28,4	28,3	28,2	28,2	28,1	28,0	28,0	27,9	27,9	27,8	27,8	27,8	27,7	27,7	27,7	27,6	27,6	27,6	27,5	27,5	27,5				2700
2800	29,8	29,3	29,0	28,8	28,6	28,5	28,4	28,3	28,2	28,1	28,1	28,0	28,0	27,9	27,9	27,8	27,8	27,7	27,7	27,7	27,6	27,6	27,6	27,5	27,5	27,5	27,5	27,4			2800
2900	29,8	29,3	29,0	28,8	28,6	28,5	28,4	28,3	28,2	28,1	28,1	28,0	27,9	27,9	27,8	27,8	27,8	27,7	27,7	27,6	27,6	27,6	27,6	27,5	27,5	27,5	27,4	27,4	27,4		2900
3000	29,8	29,2	28,9	28,7	28,6	28,5	28,3	28,3	28,2	28,1	28,0	28,0	27,9	27,9	27,8	27,8	27,7	27,7	27,7	27,6	27,6	27,6	27,5	27,5	27,5	27,4	27,4	27,4	27,4	27,4	3000
3100	29,7	29,2	28,9	28,7	28,6	28,4	28,3	28,2	28,1	28,1	28,0	27,9	27,9	27,8	27,8	27,8	27,7	27,7	27,6	27,6	27,6	27,5	27,5	27,5	27,5	27,4	27,4	27,4	27,4	27,3	3100
3200	29,7	29,2	28,9	28,7	28,5	28,4	28,3	28,2	28,1	28,1	28,0	27,9	27,9	27,8	27,8	27,7	27,7	27,7	27,6	27,6	27,5	27,5	27,5	27,5	27,4	27,4	27,4	27,4	27,3	27,3	3200
3300	29,7	29,2	28,9	28,7	28,5	28,4	28,3	28,2	28,1	28,0	28,0	27,9	27,9	27,8	27,8	27,7	27,7	27,6	27,6	27,6	27,5	27,5	27,5	27,4	27,4	27,4	27,4	27,3	27,3	27,3	3300
3400	29,7	29,1	28,9	28,6	28,5	28,4	28,3	28,2	28,1	28,0	27,9	27,9	27,8	27,8	27,7	27,7	27,6	27,6	27,6	27,5	27,5	27,5	27,4	27,4	27,4	27,4	27,3	27,3	27,3	27,3	3400
3500	29,6	29,1	28,8	28,6	28,5	28,3	28,2	28,1	28,1	28,0	27,9	27,9	27,8	27,8	27,7	27,7	27,6	27,6	27,6	27,5	27,5	27,5	27,4	27,4	27,4	27,3	27,3	27,3	27,3	27,3	3500
3600	29,6	29,1	28,8	28,6	28,5	28,3	28,2	28,1	28,0	28,0	27,9	27,8	27,8	27,7	27,7	27,7	27,6	27,6	27,5	27,5	27,5	27,4	27,4	27,4	27,4	27,3	27,3	27,3	27,3	27,2	3600
3700	29,6	29,1	28,8	28,6	28,4	28,3	28,2	28,1	28,0	28,0	27,9	27,8	27,8	27,7	27,7	27,6	27,6	27,6	27,5	27,5	27,5	27,4	27,4	27,4	27,3	27,3	27,3	27,3	27,2	27,2	3700
3800	29,6	29,1	28,8	28,6	28,4	28,3	28,2	28,1	28,0	27,9	27,9	27,8	27,8	27,7	27,7	27,6	27,6	27,5	27,5	27,5	27,4	27,4	27,4	27,3	27,3	27,3	27,3	27,2	27,2	27,2	3800
3900	29,6	29,0	28,8	28,6	28,4	28,3	28,2	28,1	28,0	27,9	27,9	27,8	27,7	27,7	27,6	27,6	27,6	27,5	27,5	27,4	27,4	27,4	27,4	27,3	27,3	27,3	27,3	27,2	27,2	27,2	3900
4000	29,5	29,0	28,7	28,5	28,4	28,3	28,1	28,1	28,0	27,9	27,8	27,8	27,7	27,7	27,6	27,6	27,5	27,5	27,5	27,4	27,4	27,4	27,3	27,3	27,3	27,3	27,2	27,2	27,2	27,2	4000
4100	29,5	29,0	28,7	28,5	28,4	28,2	28,1	28,0	28,0	27,9	27,8	27,8	27,7	27,7	27,6	27,6	27,5	27,5	27,5	27,4	27,4	27,4	27,3	27,3	27,3	27,2	27,2	27,2	27,2	27,2	4100
4200	29,5	29,0	28,7	28,5	28,3	28,2	28,1	28,0	27,9	27,9	27,8	27,7	27,7	27,6	27,6	27,5	27,5	27,5	27,4	27,4	27,4	27,3	27,3	27,3	27,3	27,2	27,2	27,2	27,2	27,1	4200
	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900	3000	

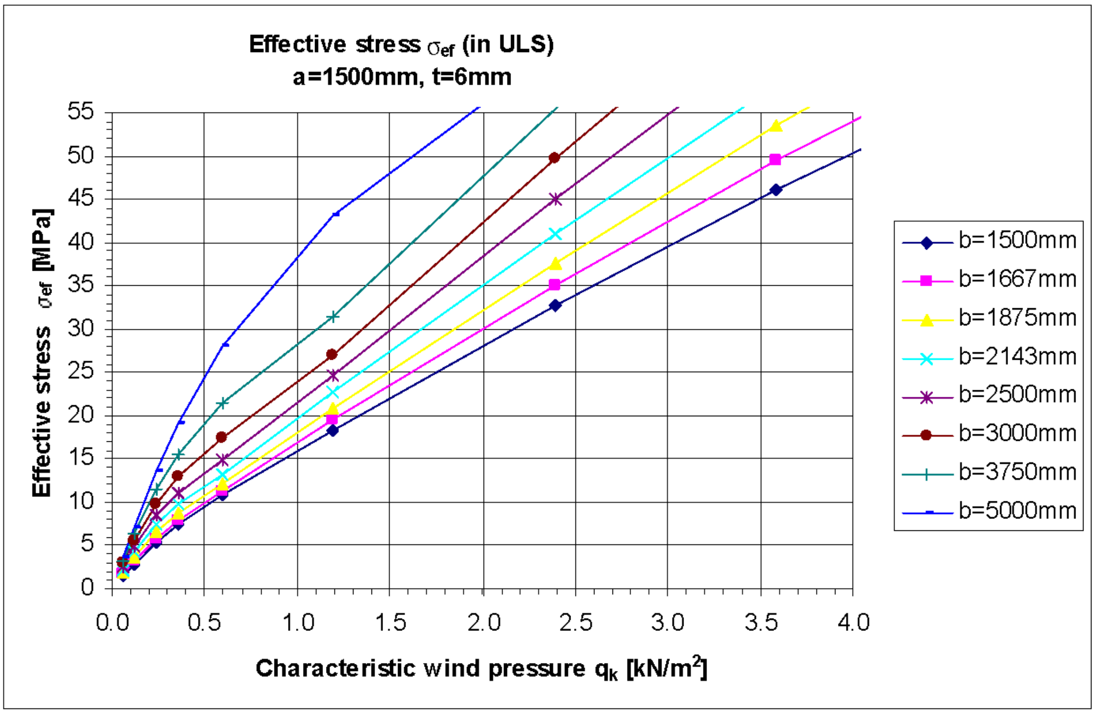
Table A-2: Heat strengthened glass, short term loading (k_{mod}=0.72)

	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900	3000	
500	52,9	52,3	52,0	51,8	51,6																										500
600	52,8	52,2	51,9	51,7	51,5	51,4																									600
700	52,6	52,1	51,8	51,5	51,4	51,2	51,1																								700
800	52,5	52,0	51,7	51,4	51,3	51,1	51,0	50,9																							800
900	52,4	51,9	51,6	51,4	51,2	51,1	50,9	50,8	50,8																						900
1000	52,3	51,8	51,5	51,3	51,1	51,0	50,9	50,8	50,7	50,6																					1000
1100	52,3	51,7	51,4	51,2	51,0	50,9	50,8	50,7	50,6	50,5	50,5																				1100
1200	52,2	51,7	51,4	51,1	51,0	50,8	50,7	50,6	50,6	50,5	50,4	50,3																			1200
1300	52,1	51,6	51,3	51,1	50,9	50,8	50,7	50,6	50,5	50,4	50,4	50,3	50,2																		1300
1400	52,1	51,5	51,2	51,0	50,9	50,7	50,6	50,5	50,4	50,4	50,3	50,2	50,2	50,1																	1400
1500	52,0	51,5	51,2	51,0	50,8	50,7	50,6	50,5	50,4	50,3	50,3	50,2	50,1	50,1	50,0																1500
1600	52,0	51,4	51,1	50,9	50,8	50,6	50,5	50,4	50,3	50,3	50,2	50,1	50,1	50,0	50,0	49,9															1600
1700	51,9	51,4	51,1	50,9	50,7	50,6	50,5	50,4	50,3	50,2	50,2	50,1	50,0	50,0	49,9	49,9	49,9														1700
1800	51,9	51,4	51,1	50,8	50,7	50,6	50,4	50,3	50,3	50,2	50,1	50,1	50,0	50,0	49,9	49,9	49,8	49,8													1800
1900	51,8	51,3	51,0	50,8	50,6	50,5	50,4	50,3	50,2	50,2	50,1	50,0	50,0	49,9	49,9	49,8	49,8	49,7	49,7												1900
2000	51,8	51,3	51,0	50,8	50,6	50,5	50,4	50,3	50,2	50,1	50,0	50,0	49,9	49,9	49,8	49,8	49,7	49,7	49,7	49,6											2000
2100	51,8	51,2	50,9	50,7	50,6	50,4	50,3	50,2	50,2	50,1	50,0	50,0	49,9	49,8	49,8	49,8	49,7	49,7	49,6	49,6	49,6										2100
2200	51,7	51,2	50,9	50,7	50,5	50,4	50,3	50,2	50,1	50,0	50,0	49,9	49,9	49,8	49,8	49,7	49,7	49,6	49,6	49,6	49,5	49,5									2200
2300	51,7	51,2	50,9	50,7	50,5	50,4	50,3	50,2	50,1	50,0	50,0	49,9	49,8	49,8	49,7	49,7	49,7	49,6	49,6	49,5	49,5	49,5	49,4								2300
2400	51,7	51,1	50,8	50,6	50,5	50,3	50,2	50,1	50,1	50,0	49,9	49,9	49,8	49,8	49,7	49,7	49,6	49,6	49,5	49,5	49,5	49,4	49,4	49,4							2400
2500	51,6	51,1	50,8	50,6	50,4	50,3	50,2	50,1	50,0	50,0	49,9	49,8	49,8	49,7	49,7	49,6	49,6	49,6	49,5	49,5	49,5	49,4	49,4	49,4	49,3						2500
2600	51,6	51,1	50,8	50,6	50,4	50,3	50,2	50,1	50,0	49,9	49,9	49,8	49,8	49,7	49,7	49,6	49,6	49,5	49,5	49,5	49,4	49,4	49,4	49,3	49,3	49,3					2600
2700	51,6	51,1	50,8	50,6	50,4	50,3	50,2	50,1	50,0	49,9	49,8	49,8	49,7	49,7	49,6	49,6	49,5	49,5	49,5	49,4	49,4	49,4	49,3	49,3	49,3	49,3	49,2				2700
2800	51,5	51,0	50,7	50,5	50,4	50,2	50,1	50,0	50,0	49,9	49,8	49,8	49,7	49,7	49,6	49,6	49,5	49,5	49,4	49,4	49,4	49,3	49,3	49,3	49,3	49,2	49,2	49,2			2800
2900	51,5	51,0	50,7	50,5	50,3	50,2	50,1	50,0	49,9	49,9	49,8	49,7	49,7	49,6	49,6	49,5	49,5	49,5	49,4	49,4	49,4	49,3	49,3	49,3	49,2	49,2	49,2	49,2	49,1		2900
3000	51,5	51,0	50,7	50,5	50,3	50,2	50,1	50,0	49,9	49,8	49,8	49,7	49,7	49,6	49,6	49,5	49,5	49,4	49,4	49,4	49,3	49,3	49,3	49,2	49,2	49,2	49,2	49,1	49,1	49,1	3000
3100	51,5	51,0	50,7	50,5	50,3	50,2	50,1	50,0	49,9	49,8	49,7	49,7	49,6	49,6	49,5	49,5	49,5	49,4	49,4	49,3	49,3	49,3	49,2	49,2	49,2	49,2	49,1	49,1	49,1	49,1	3100
3200	51,4	50,9	50,6	50,4	50,3	50,1	50,0	49,9	49,9	49,8	49,7	49,7	49,6	49,6	49,5	49,5	49,4	49,4	49,4	49,3	49,3	49,3	49,2	49,2	49,2	49,1	49,1	49,1	49,1	49,1	3200
3300	51,4	50,9	50,6	50,4	50,3	50,1	50,0	49,9	49,8	49,8	49,7	49,6	49,6	49,5	49,5	49,4	49,4	49,4	49,3	49,3	49,3	49,2	49,2	49,2	49,2	49,1	49,1	49,1	49,1	49,0	3300
3400	51,4	50,9	50,6	50,4	50,2	50,1	50,0	49,9	49,8	49,7	49,7	49,6	49,6	49,5	49,5	49,4	49,4	49,4	49,3	49,3	49,2	49,2	49,2	49,2	49,1	49,1	49,1	49,1	49,0	49,0	3400
3500	51,4	50,9	50,6	50,4	50,2	50,1	50,0	49,9	49,8	49,7	49,7	49,6	49,6	49,5	49,5	49,4	49,4	49,3	49,3	49,3	49,2	49,2	49,2	49,1	49,1	49,1	49,1	49,0	49,0	49,0	3500
3600	51,4	50,8	50,6	50,3	50,2	50,1	50,0	49,9	49,8	49,7	49,6	49,6	49,5	49,5	49,4	49,4	49,4	49,3	49,3	49,2	49,2	49,2	49,1	49,1	49,1	49,1	49,0	49,0	49,0	49,0	3600
3700	51,3	50,8	50,5	50,3	50,2	50,0	49,9	49,8	49,8	49,7	49,6	49,6	49,5	49,5	49,4	49,4	49,3	49,3	49,3	49,2	49,2	49,2	49,1	49,1	49,1	49,1	49,0	49,0	49,0	49,0	3700
3800	51,3	50,8	50,5	50,3	50,2	50,0	49,9	49,8	49,7	49,7	49,6	49,5	49,5	49,4	49,4	49,4	49,3	49,3	49,2	49,2	49,2	49,1	49,1	49,1	49,1	49,0	49,0	49,0	49,0	48,9	3800
3900	51,3	50,8	50,5	50,3	50,1	50,0	49,9	49,8	49,7	49,7	49,6	49,5	49,5	49,4	49,4	49,3	49,3	49,3	49,2	49,2	49,2	49,1	49,1	49,1	49,0	49,0	49,0	49,0	48,9	48,9	3900
4000	51,3	50,8	50,5	50,3	50,1	50,0	49,9	49,8	49,7	49,6	49,6	49,5	49,5	49,4	49,4	49,3	49,3	49,2	49,2	49,2	49,1	49,1	49,1	49,1	49,0	49,0	49,0	49,0	48,9	48,9	4000
4100	51,3	50,8	50,5	50,3	50,1	50,0	49,9	49,8	49,7	49,6	49,6	49,5	49,4	49,4	49,3	49,3	49,3	49,2	49,2	49,2	49,1	49,1	49,1	49,0	49,0	49,0	49,0	48,9	48,9	48,9	4100
4200	51,2	50,7	50,4	50,2	50,1	50,0	49,8	49,8	49,7	49,6	49,5	49,5	49,4	49,4	49,3	49,3	49,2	49,2	49,2	49,1	49,1	49,1	49,0	49,0	49,0	49,0	48,9	48,9	48,9	48,9	4200
	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700	1800	1900	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900	3000	

Table A-3: Toughened glass, short term loading (k_{mod}=0.72)

APPENDIX B

Diagrams to pre-estimate glass panes to prEN 13474-2(2000) [3]..



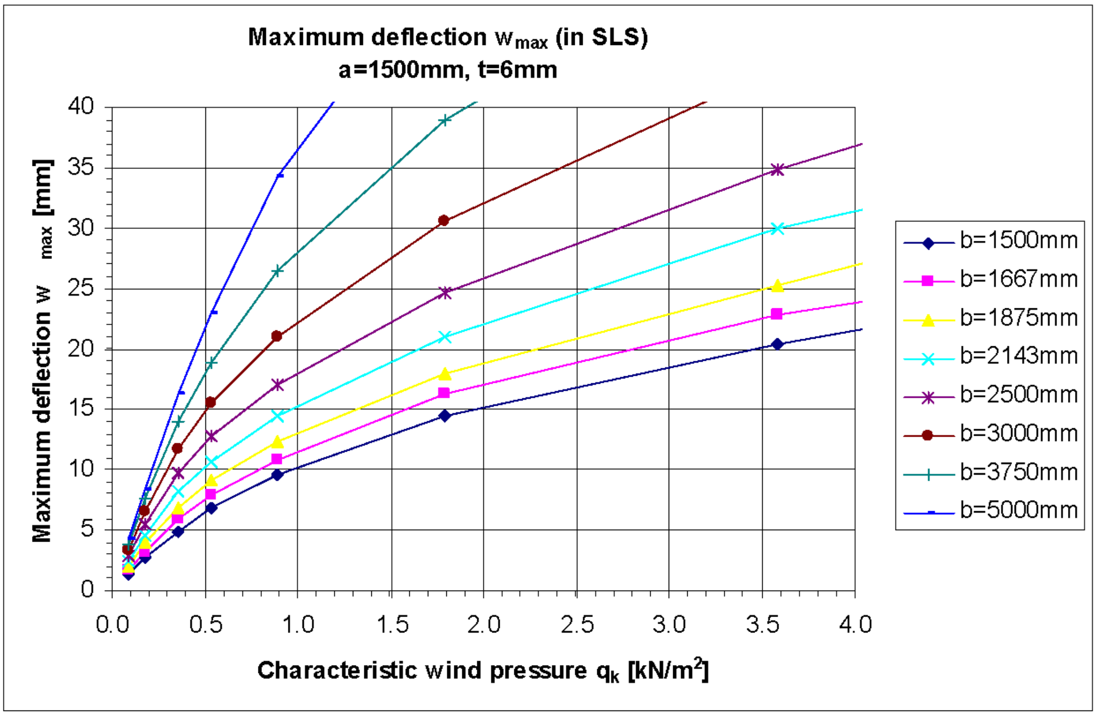
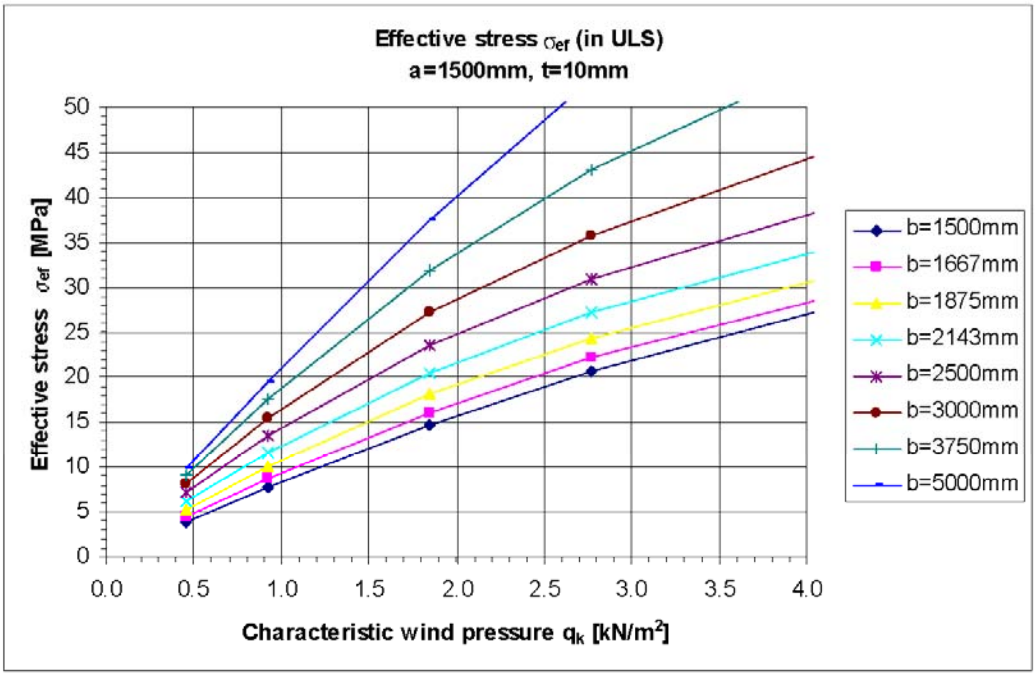


Diagram B-1: Orthogonal panes with side length a=1500mm and thickness t=6mm, supported all around, in function with dimension b and nominal wind pressure $q_{k.}$ Top diagram ULS active stress, bottom diagram SLS maximum displacement.



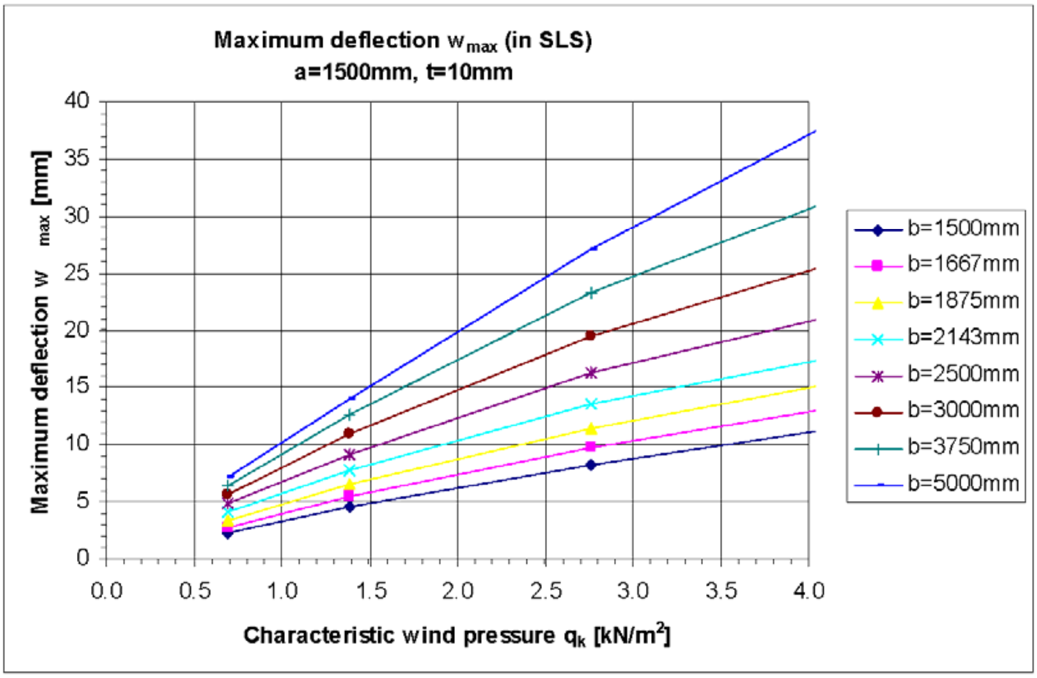
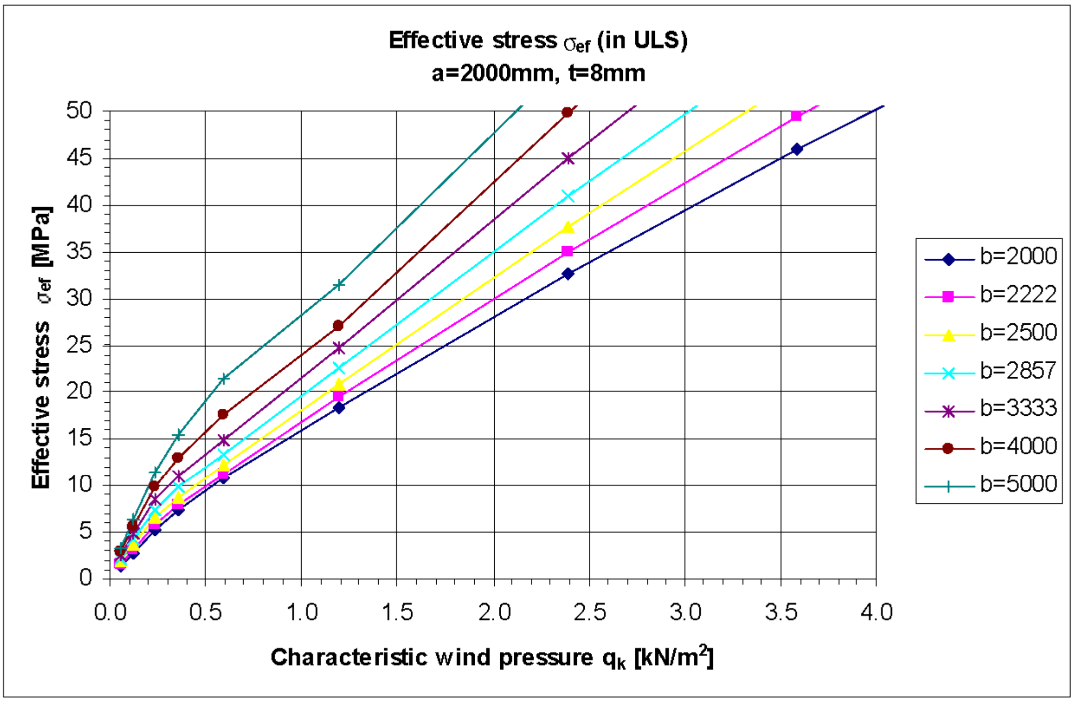


Diagram B-2: Orthogonal panes with side length a=1500mm and thickness t=10mm, supported all around, in function with dimension b and nominal wind pressure $q_{k.}$ Top diagram ULS active stress, bottom diagram SLS maximum displacement.



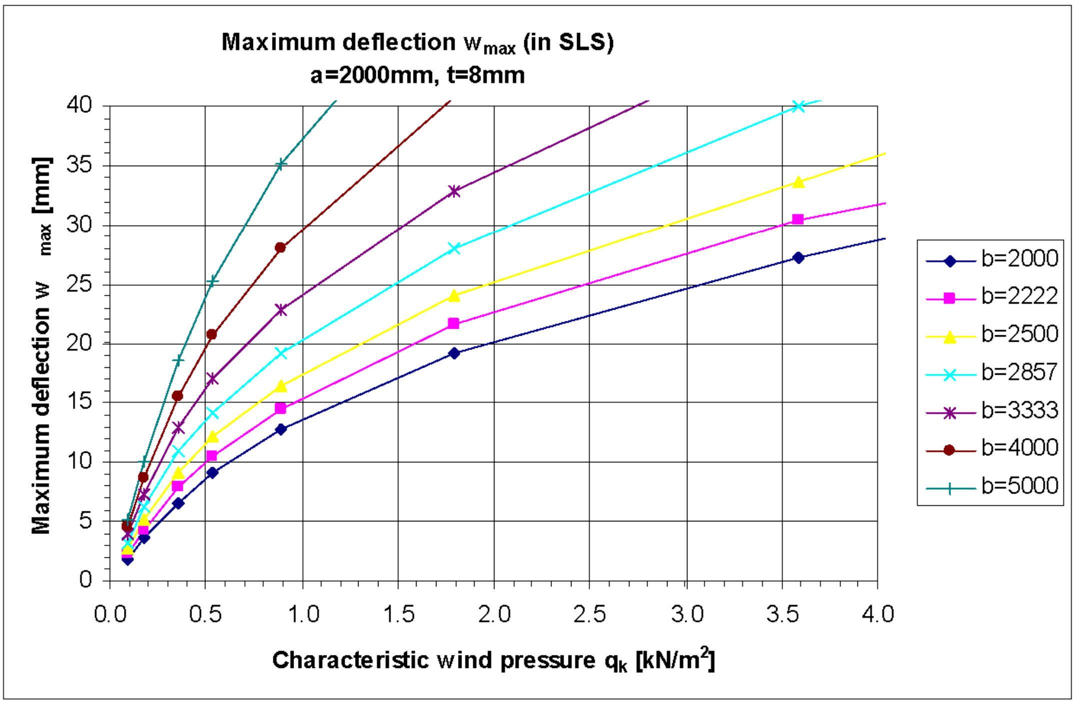
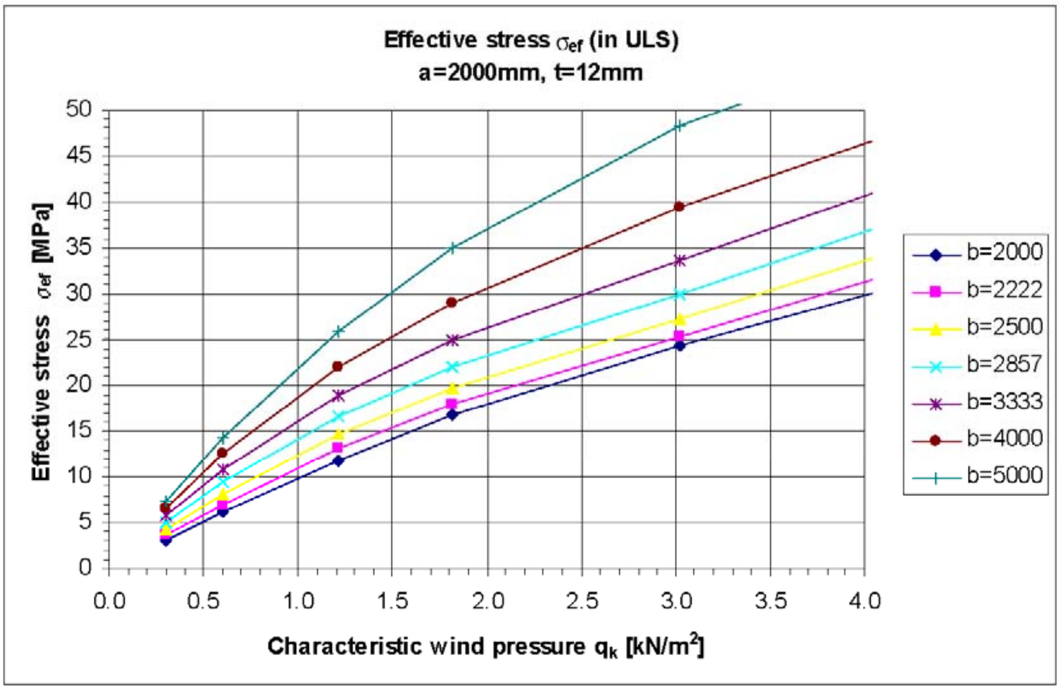


Diagram B-3: Orthogonal panes with side length a=2000mm and thickness t=8mm, supported all around, in function with dimension b and nominal wind pressure $q_{k.}$ Top diagram ULS active stress, bottom diagram SLS maximum displacement.



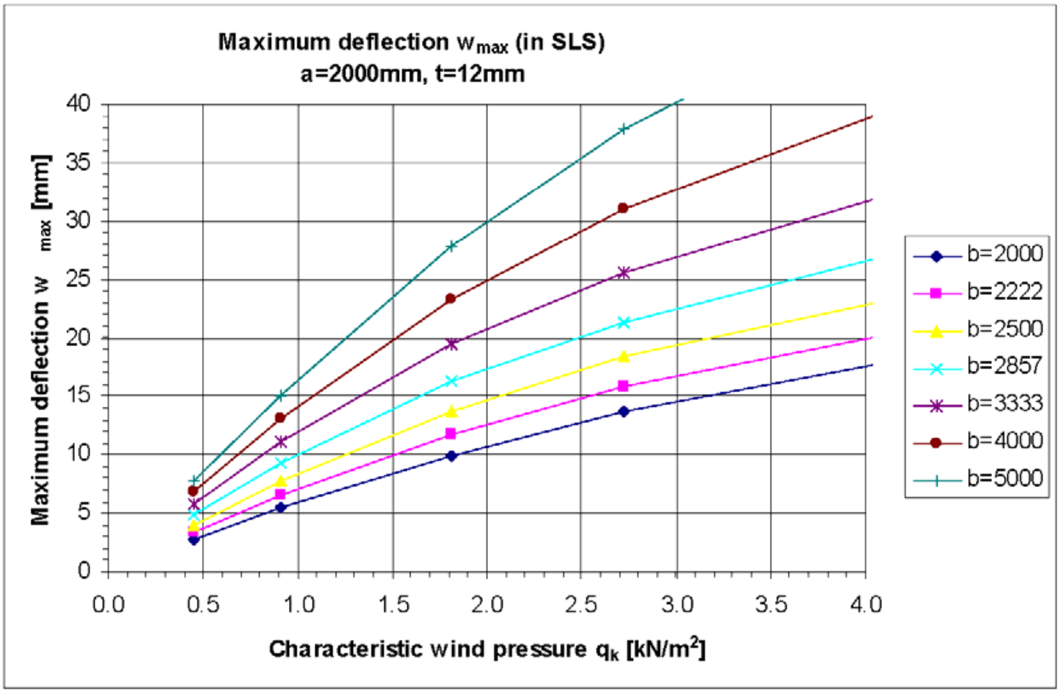
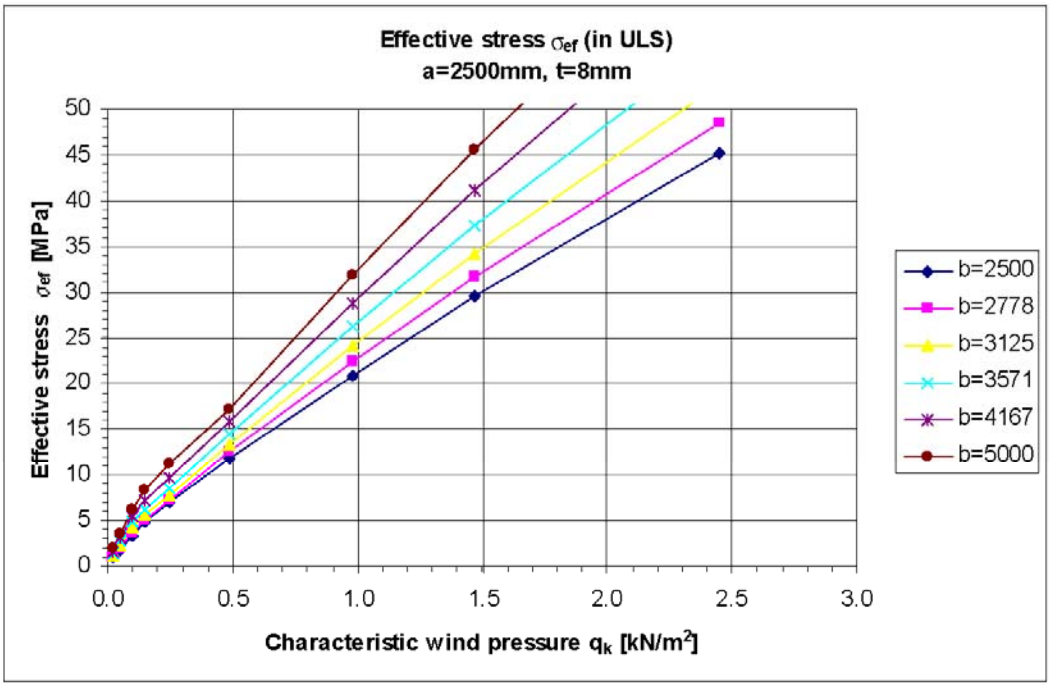


Diagram B-4: Orthogonal panes with side length a=2000mm and thickness t=12mm, supported all around, in function with dimension b and nominal wind pressure $q_{k.}$ Top diagram ULS active stress, bottom diagram SLS maximum displacement.



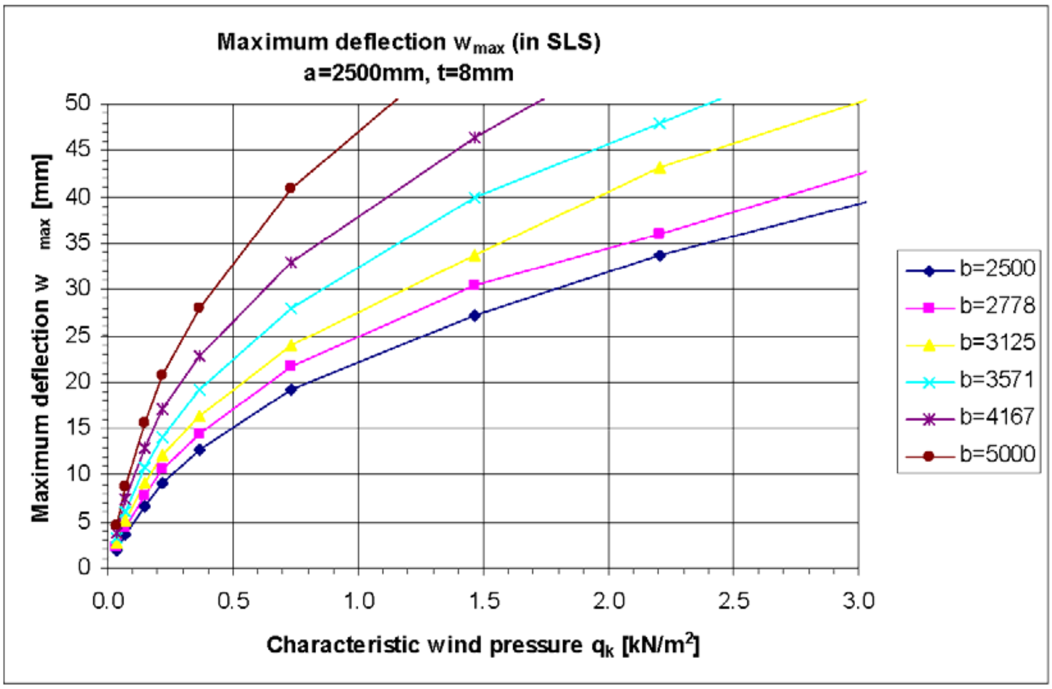
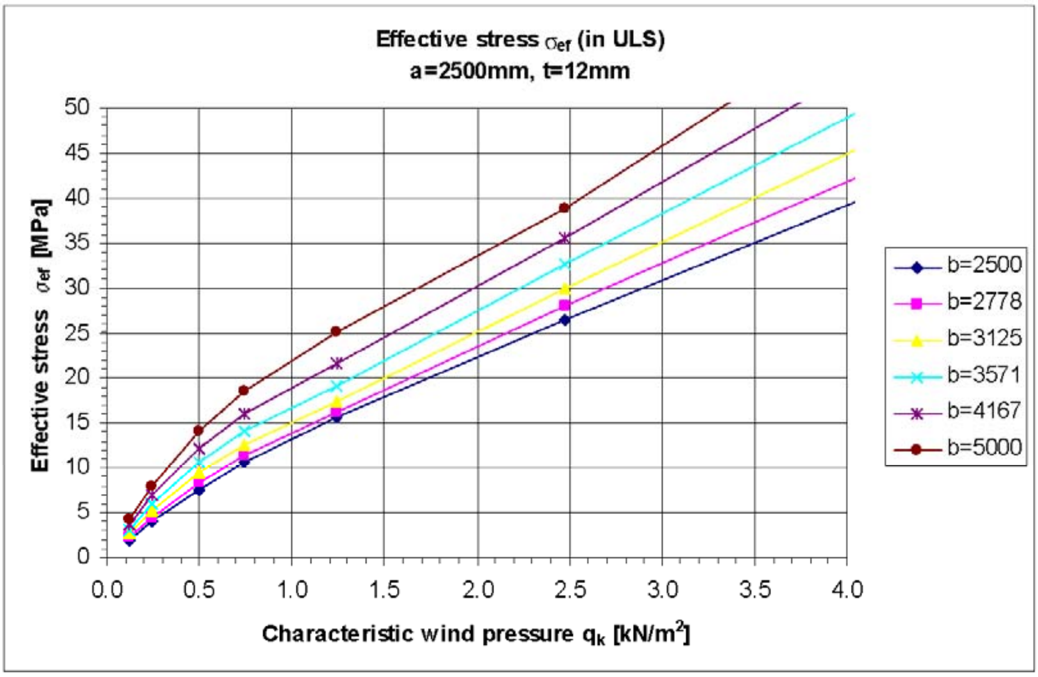


Diagram B-5: Orthogonal panes with side length a=2500mm and thickness t=8mm, supported all around, in function with dimension b and nominal wind pressure $q_{k.}$ Top diagram ULS active stress, bottom diagram SLS maximum displacement.



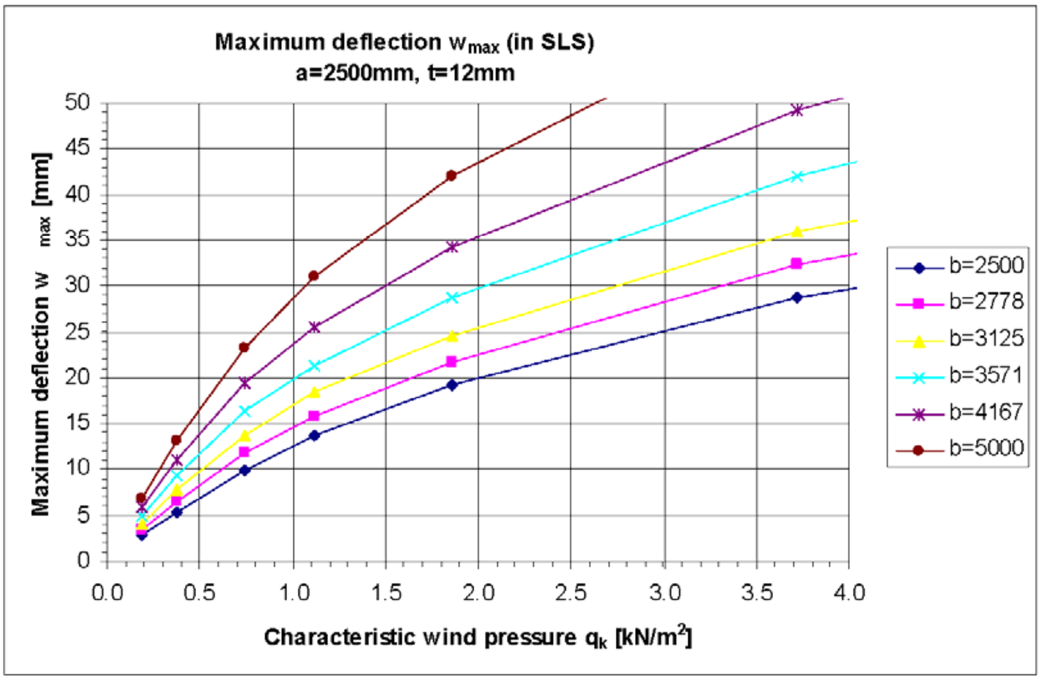
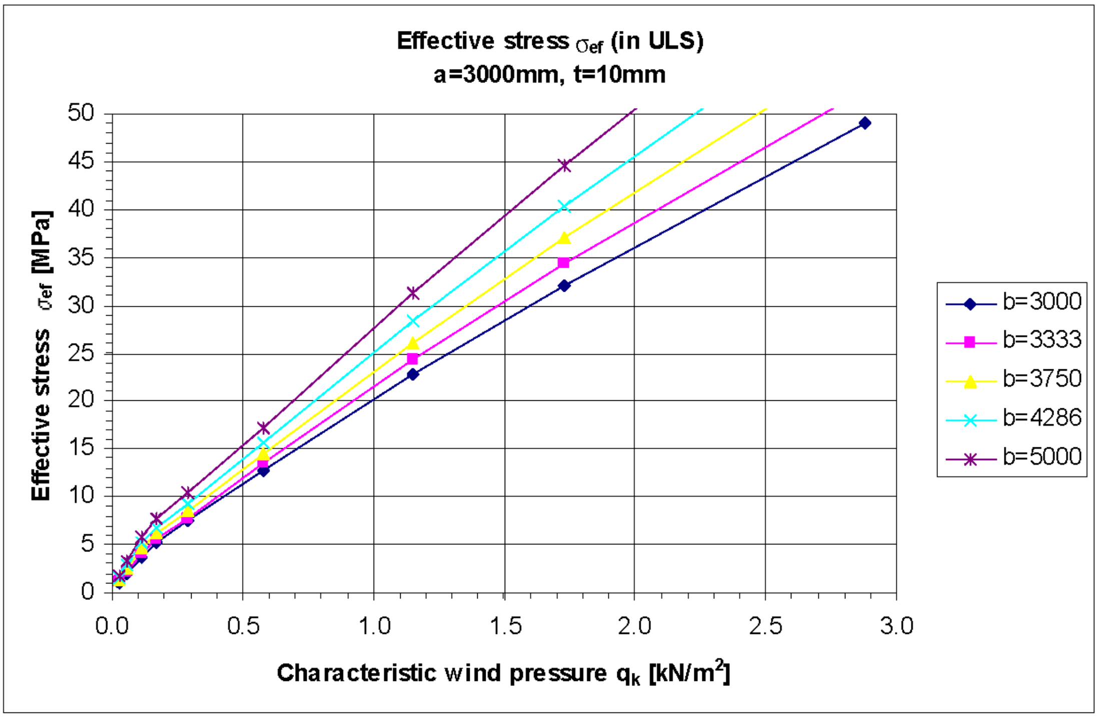


Diagram B-6: Orthogonal panes with side length a=12500mm and thickness t=12mm, supported all around, in function with dimension b and nominal wind pressure $q_{k.}$ Top diagram ULS active stress, bottom diagram SLS maximum displacement.



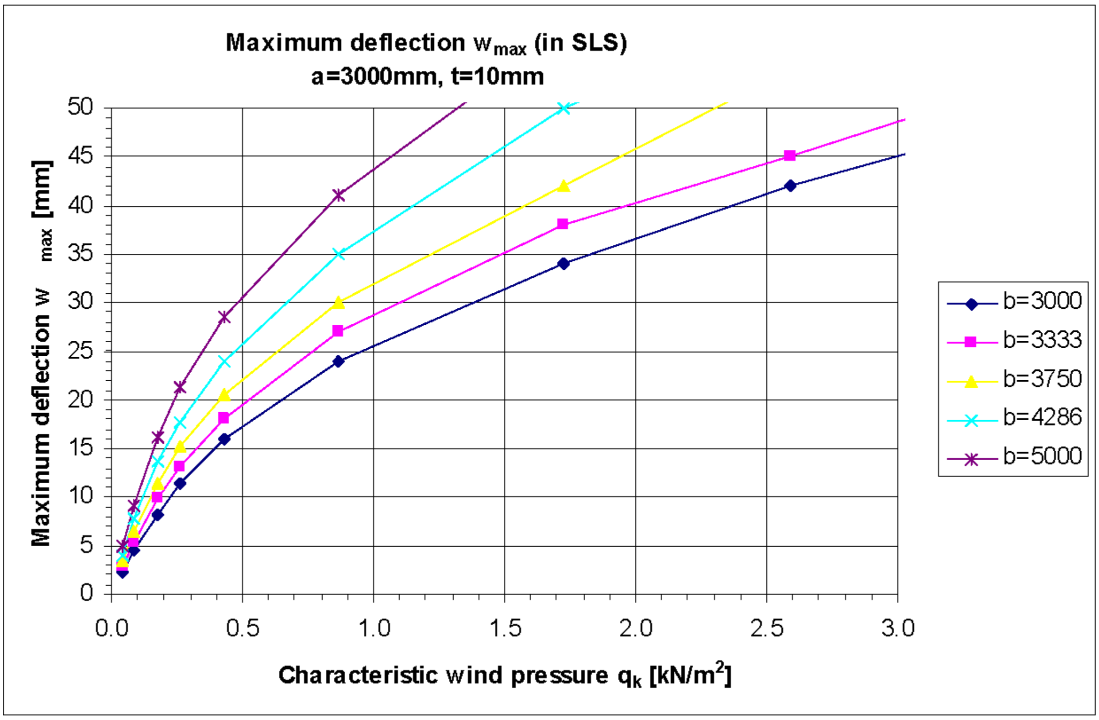
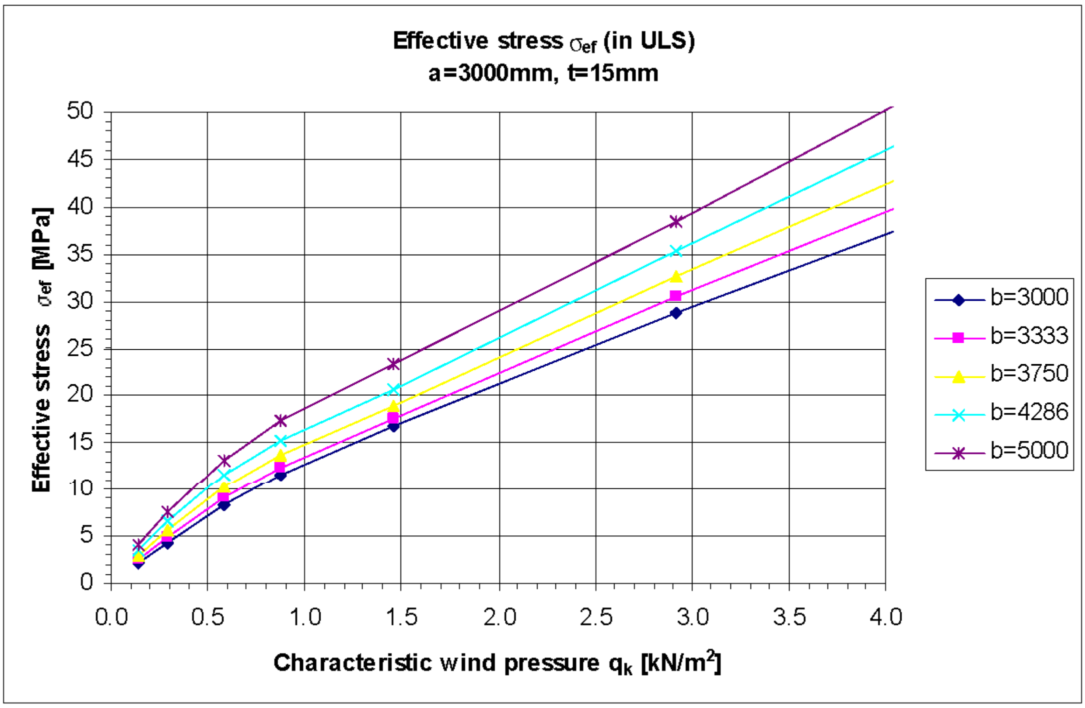


Diagram B-7: Orthogonal panes with side length a=3000mm and thickness t=10mm, supported all around, in function with dimension b and nominal wind pressure q_k. Top diagram ULS active stress, bottom diagram SLS maximum displacement.



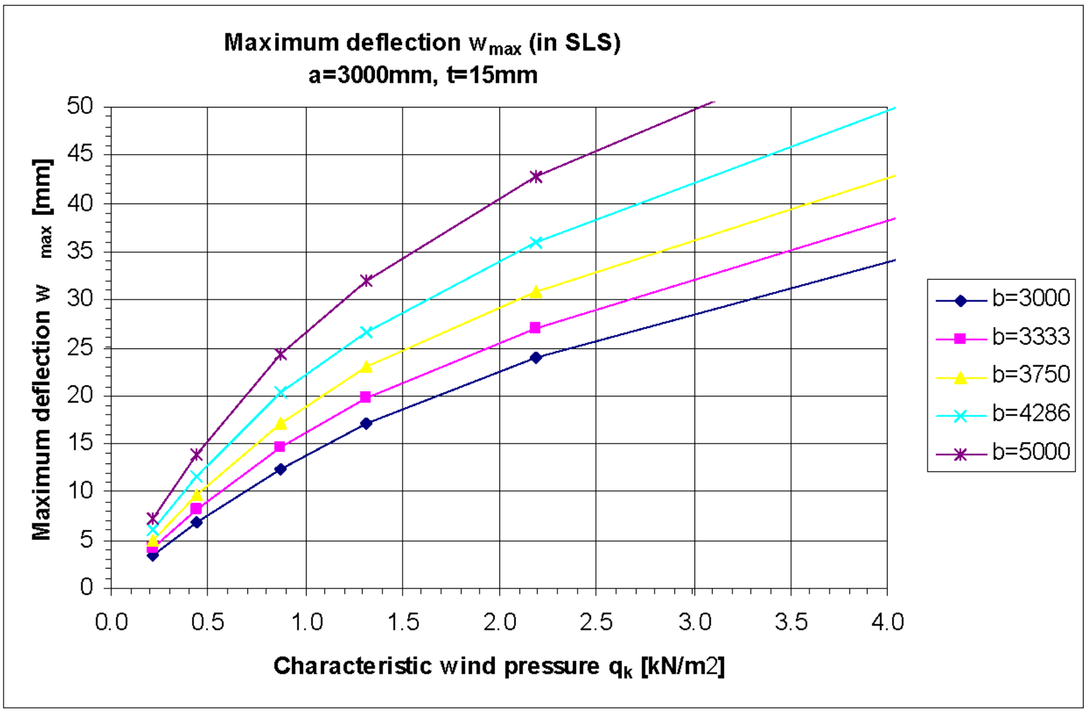


Diagram B-8: Orthogonal panes with side length a=3000mm and thickness t=15mm, supported all around, in function with dimension b and nominal wind pressure $q_{k.}$ Top diagram ULS active stress, bottom diagram SLS maximum displacement.