Structural Engineering Documents

10

Matthias Haldimann
Andreas Luible
Mauro Overend

Structural Use of Glass

International Association for Bridge and Structural Engineering
Association Internationale des Ponts et Charpentes
Internationale Vereinigung für Brückenbau und Hochbau

IABSE
AIPC
IVBH

About the Authors:

Dr Matthias HALDIMANN is director of the project and management consulting department at Emch+Berger AG Bern, Switzerland. He received his doctoral degree from the Swiss Federal Institute of Technology (EPFL), where he investigated the fracture strength, modelling, testing and design of structural glass elements.

Dr Andreas LUIBLE is a senior façade engineer at Josef Gartner Switzerland AG, which is part of the Permasteelisa Group. He received his doctoral degree from the Swiss Federal Institute of Technology (EPFL), where he undertook research on the stability of load carrying glass elements.

Dr Mauro OVEREND is a lecturer in Building Engineering Design at the Department of Engineering, University of Cambridge, United Kingdom and a Fellow of Christ's College, where he leads research in structural glass and façade engineering. He received his doctoral degree from the University of Surrey, United Kingdom, where he carried out research on glass assemblies and the fracture strength of glass.

Structural Engineering Document

10

Matthias Haldimann
Andreas Luible
Mauro Overend

Structural Use of Glass

International Association for Bridge and Structural Engineering IABSE
Association Internationale des Ponts et Charpentes AIPC
Internationale Vereinigung für Brückenbau und Hochbau IVBH

ISBN 978-3-85748-119-2

Publisher:
IABSE-AIPC-IVBH
ETH Zürich
CH-8093 Zürich, Switzerland

Phone: Int. + 41-44-633 2647
Fax: Int. + 41-44-633 1241
E-mail: secretariat@iabse.org
Web: www.iabse.org

Preface

All common applications of architectural glass may be deemed as ‘structural’. A small glass pane in a traditional four-edge supported window frame must withstand self-weight, wind-induced pressures, thermal strains and occasional cleaning loads. Unsurprisingly there are several suitable guidelines and adequate rules of thumb that enable appropriate design of these traditional applications.

Recent architectural trends and technological developments have brought about unprecedented opportunities and major changes in the use of glass in buildings. These include the use of large area glass panels; the use of glass in areas traditionally reserved for other materials such as roofs, floors, staircases and partitions; a vast selection of improved glass products; a wide range of novel support and connection details including bolted glass. The consequence of these exciting applications is that glass is often subjected to onerous actions and complex states of stress. Furthermore the glass may now contribute to the integrity of the overall structure and the consequence of failure is considerably greater, such that the glass has a more ‘structural’ role than the small glass pane in the traditional four-edge supported window. In such applications the traditional rules of thumb are of little assistance as the simplifying assumptions embedded within them no longer hold true and cannot be extrapolated from the specific glass product and simple boundary conditions for which they were devised.

Structural engineers currently have a bewildering array of glass products and configurations to choose from and a wide range of normal and exceptional loading conditions to consider, but very few unified reference texts for undertaking these tasks. This book attempts to redress this issue by providing an overview of the recent developments in this field thereby providing a basis for the understanding of the structural performance and design of glass in buildings.

The book is primarily for structural engineers and researchers who have an interest in structural glass. It draws on topics from many specialist areas such as manufacturing, materials science, fracture mechanics, computational analysis, reliability and forensic engineering and is therefore also relevant to professionals in this field. The level is appropriate for senior undergraduates, post-graduate students, researchers and practising engineers.

The level of interest and the depth of knowledge will vary for instance between the general practising engineer who may be interested in gaining an overview of the general design considerations and specification of glass structures, to the researcher who may be interested in a specific fracture phenomenon in glass. This wide range of interest is accommodated by providing a mix of general and specialist chapters. Furthermore, the text is supplemented by tables of the relevant codes of practice and by an extensive list of references.

The first chapter provides a review of glass production, processing methods and glass products ranging from clear float glass to the more recent developments in switchable glazing. The chapter also provides both a useful listing of glass products as well as the underlying principles that affect the mechanical properties of glass. Chapter 2 provides general guidelines on the analysis and design of glass structures, including advice on actions on glass structures, structural analysis and computational modelling as well as post-breakage behaviour and requirements. Chapter 3 provides an answer to the elusive question 'What is the strength of glass?' by presenting an account of glass fracture mechanisms and formulating useful stochastic failure prediction models for a single flaw and for random surface flaw populations. The chapter also provides an overview of fundamental dynamic fracture mechanics which is useful in glass forensics. Chapter 4 presents a series of quick checks and rules of thumb that are useful for preliminary sizing of structural glass elements. This chapter also reviews the main standards and codes of practice used for the design of structural glass and provides a commentary on the strengths and shortcomings of these standards. Chapter 5 covers the exciting possibilities offered by loading glass in compression and the factors that affect buckling instability in glass. The chapter provides guidelines on the performance and structural design of glass elements that undergo column buckling, lateral torsional buckling and plate buckling. Chapter 6 provides recommendations on how the fracture mechanics formulations presented in the previous chapters may be deployed in practice. This chapter provides guidelines on how to overcome the limitations of laboratory testing and how to obtain statistically relevant and consistent data. Chapter 7 presents a review of connections and support fixings commonly used in glass structures and provides recommendations on good detailing. The chapter also provides useful sizing charts for bolted fixings and reviews the recent developments in enhanced mechanical fixings and adhesive connections. Chapter 8 reviews the current practice and standards used for the design-assisted-by-testing approach, which is particularly relevant for assessing post-breakage and impact performance. This chapter also includes practical advice for undertaking forensic engineering in glass structures.

This book therefore provides a snapshot of the recent developments in the structural use of glass in buildings and draws from the latest developments in practice and research. This was only possible thanks to the contributions from students and colleagues who have kindly donated their work or their time. Their contributions are gratefully acknowledged in the text and the references. The contents of this book have also been greatly enriched by the contributions of several glass experts, who have provided substantial input and advice on specific sections of this book. Their names are listed below and are also shown alongside the headings of the sections they contributed in.

Benjamin BEER	Werner Sobek Stuttgart, Germany
Lucio BLANDINI, Dr.	Werner Sobek Stuttgart, Germany
Mick EEKHOUT, Prof. Dr.	Octatube, Delft, The Netherlands
Christoph HAAS	Ernst Basler + Partner AG, Zürich, Switzerland
Iris MANIATIS, Dr.	University of the German Federal Armed Forces Munich, Germany
Jürgen NEUGEBAUER, Dr.	University of Applied Sciences, FH Joanneum, Graz, Austria
Jens SCHNEIDER, Prof. Dr.	Frankfurt University of Applied Sciences, Germany
Werner SOBEK, Prof. Dr.	Werner Sobek Stuttgart, Germany
Geralt SIEBERT, Prof. Dr.	University of the German Federal Armed Forces Munich, Germany
Ronald VISSER	Octatube, Delft, The Netherlands
Frank WELLERSHOFF, Dr.	Permasteelisa Central Europe GmbH, Würzburg, Germany

Finally a special word of thanks goes to the IABSE Structural Engineering Documents Editorial Board, especially to Geoff Taplin, and to their reviewers Chris Jofeh and Geralt Siebert, who kindly reviewed the drafts of this book and helped to improve it with their valuable feedback.

Berne, Basel and Nottingham/January 2008

Dr. Matthias Haldimann
Dr. Andreas Luible
Dr. Mauro Overend

Contents

Chapter

1 Material

This text has been compiled in collaboration with the following experts:
Prof. Dr. Jens Schneider

1.1 Production

1.1.1 Production of flat glass

Figure 1.1 gives an overview of the most common glass production processes, processing methods and glass products. The main production steps are always similar: melting at 1600–1800 °C, forming at 800–1600 °C and cooling at 100–800 °C.

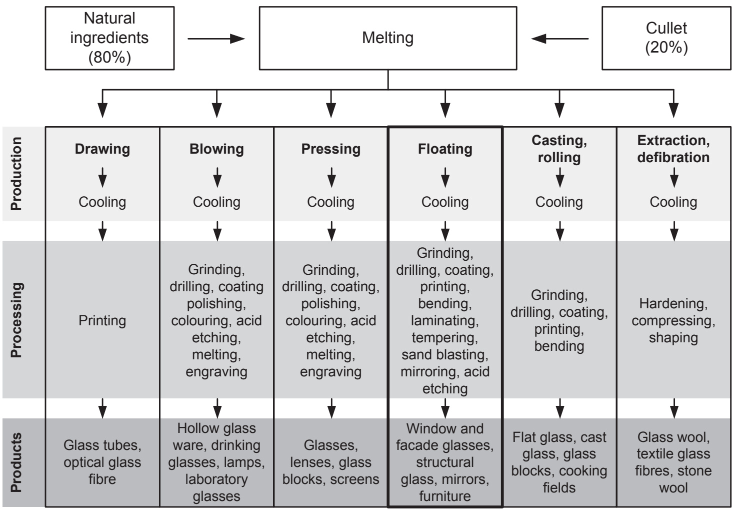

Figure 1.1: Glass production processes and products overview.

Chapter

2 General Design Guidelines

2.1 The design process

This text has been compiled in collaboration with the following experts:
Christoph HAAS

2.1.1 Particularities of glass structures

The overall design procedure for structural glass elements is not unlike other structural materials i. e. it is essentially an iterative process that relies on a combination of rules of thumb, more accurate analytical methods and prototype testing. The use of these three techniques varies throughout the design process. Quick, approximate methods are primarily used at early design stage to test alternative schemes and at a later stage for verifying the more accurate calculations; more accurate methods are employed during detailed design stages; prototype testing is used to verify the design prior to construction.

As with any structure, the designer should establish the fundamental performance requirements before starting any calculations. These requirements include the ultimate limit state that ensures adequate strength to withstand the anticipated actions, namely, material strength, overall structural stability (i. e. the structure is not a mechanism) and elastic stability (i. e. no flexural or lateral torsional buckling). Additional ultimate limit state performance requirements that are particularly relevant to glass deal with fail-safe concepts, ranging from criteria for overall structural robustness to requirements for the post-breakage structural behaviour of individual glass elements. Serviceability limit state requirements normally include limiting deflections and/or vibrations, movement tolerances and aesthetic criteria. It is understood that all the ultimate and serviceability limit states should be satisfied in order to ensure structural adequacy.

The standard elastic design method used with most construction materials is known as the maximum stress approach. In this approach the engineer sizes a structural element by ensuring that the maximum stresses caused by an action do not exceed the strength of a material at any position on that element. Most engineers therefore implement structural design from a few fundamental constants, the strength of the material being one of them.

Chapter

3 Fracture Strength of Glass Elements

3.1 Introduction

The aim of this chapter is to provide an in-depth understanding of the mechanisms of glass fracture that underpin subsequent chapters and should be used as the basis for structural design of glass.

The mechanical properties of glass stem from the molecular structure discussed in Chapter 1, which unlike most other construction materials, does not consist of a geometrically regular network of crystals, but of an irregular network of silicon and oxygen atoms with alkaline parts in between. The random molecular structure has no slip planes or dislocations to allow macroscopic plastic flow before fracture; consequently, glass is perfectly elastic at normal temperature and exhibits brittle fracture. This inability to yield plastically before fracture means that the fracture strength of glass is very sensitive to stress concentrations. Since surface flaws cause high stress concentrations, accurate characterization of the fracture strength of glass must incorporate the nature and behaviour of such flaws. To this end, Section 3.2 discusses the stress corrosion that causes existing surface flaws to grow slowly in size prior to failure, a phenomenon that is often referred to as 'sub-critical crack growth'. This section is also a prerequisite for subsequent sections.

Section 3.3 introduces quasi-static linear elastic fracture mechanics (LEFM) and provides a mathematical model for determining the fracture strength of glass. This model, called the 'lifetime prediction model', is derived from a mathematical description of a glass element's surface condition and of the growth and fracture of surface flaws through LEFM and probability theory. The equations that are provided in the lifetime prediction model can be used for predictive modelling and structural design. They take sub-critical crack growth, non-homogeneous, time-variant biaxial stress fields, arbitrary geometry and arbitrary stress histories into account. While the lifetime prediction model described herein is more complex than traditional semi-empirical models, it offers significant advantages that are discussed in this section.

Chapter

4 Current Standards, Guidelines and Design Methods

4.1 Introduction

The increasing use of glass as a load-bearing material has led to the development of a number of national and international design standards, draft standards, technical guidelines and recommendations. The aim of these documents is to arrive at an accurate value of allowable load or stress for an acceptable probability of failure in terms of the geometrical configuration of the glass (i. e. shape and support conditions) and the environmental parameters (loads and ambient conditions) by means of a few simple calculations.

These design methods do not cater for all types of glass configurations, loading, support and surface conditions. Most commonly, they are limited to glass elements of rectangular shape with continuous lateral support and to uniformly distributed out-of-plain loads. An in-depth analysis of the underlying assumptions in Section 4.5 reveals further limitations that the design methods fail to mention.

It is beyond the scope of this document to give an exhaustive overview of *all* national standards and design methods that exist in the field of glass. All the more, because many of them are based on simple theories, ignore geometrical non-linearity and the like. Although these methods are sufficiently accurate for rectangular window glazing with continuous lateral support, they should not be used for structural glass applications or for support and loading conditions that they do not cover. The standards and design methods discussed in the following have been chosen either because they are widely used or because they are of particular interest for structural glass design.

4.2 Rules of thumb

This text has been compiled in collaboration with the following experts:
Benjamin BEER

Accurate analysis and design methods are generally unattractive for manual computation and it is unrealistic to expect the engineer to perform laborious calculations throughout

Chapter

5

Design for Compressive In-plane Loads and Stability Problems

5.1 Introduction

The compressive strength of glass is significantly higher than its tensile strength [80, 169]. Experimental studies [242] demonstrated that it is possible to utilize the enormous compressive in-plane load carrying capacity of glass panels. This opens up new applications of glass panels in structures such as columns, transparent walls, beams, for fins to stiffen façade elements, for shear panels, and for applications where the glass is used in a similar way to steel, aluminum or timber [233, 339]. Owing to the high slenderness of structural glass elements made of thin glass plates, they are unstable and tend to fail. Every in-plane loaded glass element must, therefore, be checked against stability failure. Several established design methods exist for common structural materials (i. e. steel, timber), but these methods cannot be applied directly to glass, because the influence of production tolerances (thickness, variation in panel size) of the initial imperfections, of the brittle behaviour, and of the viscoelastic behaviour of laminated glass interlayers have to be specifically considered for glass. A substantial amount of fundamental research has been carried out in the past few years to investigate the stability behaviour of structural glass elements. Nevertheless, results are not yet implemented in existing design standards. Column buckling of glass elements was studied by Kutterer [234], Luible [243, 247], and Overend [268]. Fundamental research on lateral torsional buckling of glass beams was done by Belis [36], Holberndt [240], Kasper [224] and Luible [243, 245]. Research on glass plate buckling is a relatively new research field. First experimental and analytical studies were carried out by Englhardt [162], Luible [243] and Wellershoff [338, 339].

In the past, stability problems were described with bifurcation buckling models based on linear elastic stability theory. The bifurcation buckling theory assumes that a geometrically perfect elastic structural member that is subjected to an increasing load fails suddenly when a critical load is reached. This critical load depends only on the geometry, the loading conditions and the flexural stiffness of the element and may be determined by mathematical models (i. e. [325]) or by numerical approaches such as finite element analysis (FEA). Bifurcation buckling models are generally unable to describe the buckling

Chapter

6 Design Methods for Improved Accuracy and Flexibility

6.1 Introduction

As mentioned in Section 4.6, many of the shortcomings of current standards, guidelines and design methods can be addressed with the generalized lifetime prediction model that was discussed in Section 3.3. This chapter provides an outline of this approach by summarizing the recommendations of Haldimann [189]. For more details, the reader can refer to this document.

6.2 Surface condition modelling

The lifetime prediction model described in Section 3.3 offers two alternatives for modelling a glass element's surface condition: a *single surface flaw (SSF)* and a *random surface flaw population (RSFP)*.

For structural design, it is essential to know which of these models to use and when. The characteristics and particularities of these two surface condition models are, therefore, discussed in the ensuing text. On this basis, recommendations for design and testing are given in Section 6.3.

6.2.1 Single surface flaw model

The surface condition of as-received glass can be characterized accurately by an RSFP, i. e. a large number of flaws of random depth, location and orientation (cf. Section 3.3.5). If, however, a glass element's surface contains a single flaw (or a few flaws) that is substantially deeper than the many small flaws of the RSFP, its resistance is likely to be governed by this deep flaw because it will initiate failure.

If the surface condition of a glass element can be represented by a SSF, its lifetime can be predicted by simulating the growth of this flaw using the equations derived in Section 3.3.4. A glass element is acceptable if a design flaw does not fail during the service life when the element is exposed to the design action history. In order to determine the

Chapter

7 Glass Connections

7.1 Introduction

The traditional approach for dealing with connections between glass and other materials was to avoid direct contact between the glass and other harder materials thereby diverting loads or movement away from the glass. Although this sound engineering advice still holds true today, the past 25 years has seen an increasing architectural trend to maximize transparency when using glass. This trend can be traced through the chronological development of glass connections: from the linearly supported glazing associated with the curtain walls developed in the mid 20th century, to the patch plate friction fittings developed in the mid-1970s, to the bolted point supports developed in the 1980s and 1990s (*Figure 7.1*).

These developments show a gradual reduction in the size of the glass support and an increase in the magnitude and types of loads that are transmitted to the glass. In all

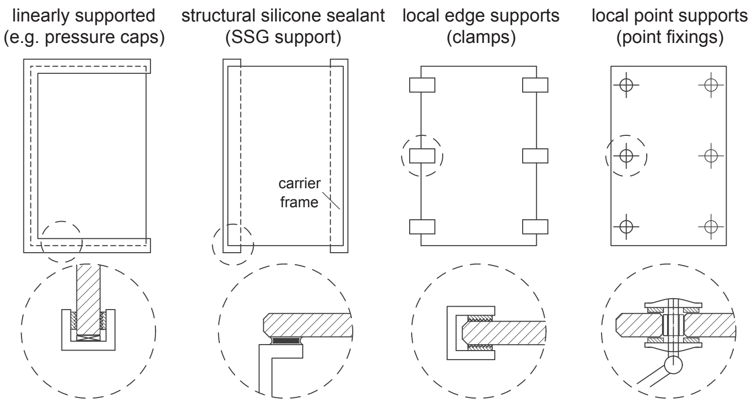

Figure 7.1: Summary of common glass support types.

Chapter

8 Special Topics

8.1 Design assisted by testing

This text has been compiled in collaboration with the following experts:
Benjamin BEER, Dr. Iris MANIATIS, Prof. Dr. Geralt SIEBERT

8.1.1 Introduction

Despite advances in the field of computational analysis, the design of complex glass structures cannot be based solely on numerical simulation. The reasons why full scale prototype testing remains an integral part of the design process of innovative glass structures, as well as the main issues that should be considered when testing glass elements, were discussed in Section 6.4.1.

Computational modelling, typically finite element models verified by rules of thumb, are required to predict the structural behaviour with an acceptable level of accuracy. The results from these calculations are often the basis for the first test prototype or specimen. Geometrical imperfections as well as tolerances should be taken into account to achieve a realistic test setup. A comparison between test results and the corresponding predicted values given by the model should be carried out. If major discrepancies are found, both the test setup and the model should be checked.

The fracture strength of heat-treated glass is the sum of the absolute value of the residual (compressive) surface stress and the inherent glass strength (see Section 3.3.2). Only the latter is influenced by subcritical crack growth and depends, therefore, on time and environmental conditions. The residual stress is constant. Consequently, results from experiments with heat-treated glass (heat-strengthened glass or fully tempered glass) in ambient conditions depend significantly less on time and environmental conditions than the results from tests on annealed glass.

General guidelines for design assisted by testing are given in the annexe of EN 1990:2002 [135]. The engineer must, however, bear in mind that this standard has not been specifically written for glass structures. Detailed reviews of the countless national standards, regional standards, building regulations and recommendations for

Appendix

A Notation, Abbreviations

A.1 General information

Variables are defined and explained on their first occurrence only. In case of doubt, readers should refer to the symbol list below. It gives a short description of the variables as well as references to the place where they are defined in the text.

Particularly unfamiliar or important terms are defined in the glossary (p. 183).

The present document follows current regulations on technical and scientific typesetting, in particular [211], [212], [214] and [213]. Accordingly, *italic* symbols are used only to denote those entities that may assume different values. These are typically physical or mathematical variables. Symbols, including subscripts and superscripts, which do not represent physical quantities or mathematical variables are set in upright roman characters. (Example: The exponent '*n*' (italic) in σ_n^n is a physical variable, while the index 'n' (roman) is an abbreviation for 'normal'.)

A.2 Generally used indices and superscripts

$\mathbb{X}_{\mathrm{I,\,II,\,III}}$	related to crack mode I, II or III
$\mathbb{X}_{\mathrm{adm}}$	admissible
$\mathbb{X}_{\mathrm{c}}$	critical
$\mathbb{X}_{\mathrm{d}}$	design level
$\mathbb{X}_{\mathrm{eff}}$	effective
$\mathbb{X}_{\mathrm{eq}}$	equivalent
$\mathbb{X}_{\mathrm{f}}$	failure, at failure, related to failure
$\mathbb{X}_{\mathrm{i}}$	initial
$\mathbb{X}_{\mathrm{inert}}$	in or for inert conditions
$\mathbb{X}_{i}$	i-th value, case or time period
$\mathbb{X}_{\mathrm{n}}$	normal, normalized, national
$\mathbb{X}_{\mathrm{test}}$	in laboratory testing, in laboratory conditions
$\sigma^{(i)}$	i-th value, case or time period (avoids σ_1 and σ_2, which are the principal stresses)
$\mathbb{X}^{(1)}$	related to a single crack
$\mathbb{X}^{(k)}$	related to k cracks

Appendix

B

Glossary of Terms

Action General term for all mechanical, physical, chemical and biological actions on a structure or a structural element, e. g. pressures, loads, forces, imposed displacements, constraints, temperature, humidity, chemical substances, bacteria and insects.

Action history The description of an action as a function of time.

Abhesive A material that resists adhesion; a film of coating applied to surfaces to prevent sticking, heat sealing, and so on, such as a parting agent or mold release agent.

Abrasion (general) The wearing away of a material surface by friction.

Abrasion (decorative glass) A method of shallow, decoration grinding using a diamond wheel.

Absolute humidity The weight of water vapour present in a unit of air.

Accelerated ageing Any set of test conditions designed to determine, in a short time, the result obtained under normal conditions of ageing. In accelerated ageing tests, the usual factors considered are heat, light, and oxygen, either separately or combined.

Accelerated weathering Machine-made means of duplicating or reproducing weather conditions. Such tests are particularly useful in comparing a series of products at the same time. No real correlation between test data and actual service is known for resins and rubbers used in many products.

Acid etching A process, manly used for glass decoration, where the glass surface is treated with hydrofluoric acid. Acid-etched glass has a distinctive, uniformly smooth and satin-like appearance.

Acoustical double glazing Two monolithic glass panels, set in a frame, with an air space between them.

Acrylate resins Polymerization products of certain esters of acrylic and methacrylic acid, such as methyl or ethyl acrylate. Possess great optical clarity and high degree of light transmission. Nearest approach to an organic glass.

Acrylic A group of thermoplastic resins or polymers formed by polymerizing the esters of acrylic acid.

Action intensity The magnitude of an action, e. g. a load intensity, a stress intensity or the magnitude of an imposed deformation. See also ‘load shape’.

Active solar heat gain Solar heat that passes through a material and is captured by mechanical means.

Adduct A chemical addition product.

Adhere That property of a sealant/compound which measures its ability to bond to the surface to which it is applied.

Adhesion The clinging or sticking of two material surfaces to each other. In rubber parlance, the strength of the bond or union between two rubber surfaces or plies, cured or uncured. The bond between a cured rubber surface and non-rubber surface, e.g., glass, metal, wood, or fabric.

Adhesion failure (1) The separation of the two surfaces with a force less than specified. (2) The separation of the two adjoining surfaces due to service conditions.

Adhesive setting Classifies the conditions to convert the adhesive from its packaged state to a more useful form.

Appendix

C Statistical Fundamentals

C.1 Statistical distribution functions

Table C.1: Continuous statistical distribution functions.

Type	PDF $f(x)$ CDF $F(x)$	Mean μ Variance σ^2
Normal	$f(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{1}{2}\left(\frac{x-\mu}{\sigma}\right)^2\right)$	$\mu = \mu$
	$F(x) = \int_{-\infty}^{x} f(x)\,\mathrm{d}x$	$\sigma^2 = \sigma^2$
Log-normal	$f(x) = \frac{1}{\zeta x\sqrt{2\pi}} \exp\left(-\frac{1}{2}\left(\frac{\ln x-\lambda}{\zeta}\right)^2\right)$	$\mu = \exp\left(\lambda + \frac{\zeta^2}{2}\right)$
	$F(x) = \int_{0}^{x} f(x)\,\mathrm{d}x$	$\sigma^2 = \mu^2\left(\exp(\zeta^2) - 1\right)$
Uniform	$f(x) = \frac{1}{b-a}$	$\mu = \frac{a+b}{2}$
	$F(x) = \frac{x-a}{b-a}$	$\sigma^2 = \frac{(b-a)^2}{12}$
Pareto	$f(x) = \frac{ab^a}{x^{a+1}}$	$\mu = \frac{ab}{a-1}$
	$F(x) = 1 - \left(\frac{b}{x}\right)^a$	$\sigma^2 = \frac{ab^2}{(a-1)^2(a-2)}$
Weibull	$f(x) = \frac{\beta}{\theta}\left(\frac{x}{\theta}\right)^{\beta-1} \cdot \exp\left(-\left(\frac{x}{\theta}\right)^{\beta}\right)$	$\mu = \theta \cdot \Gamma\left(1 + \frac{1}{\beta}\right)$
	$F(x) = 1 - \exp\left(-\left(\frac{x}{\theta}\right)^{\beta}\right)$	$\sigma^2 = \theta^2\left[\Gamma\left(1+\frac{2}{\beta}\right) - \Gamma^2\left(1+\frac{1}{\beta}\right)\right]$

References

[1] AAMA CW-13-85. *AAMA CW-13-85: Structural Sealant Glazing Systems*. American Architectural Manufacturers Association (AAMA), Schaumburg, USA, 1985.

[2] Abrams, M. B., Green, D. J. and Glass, S. J. Fracture behavior of engineered stress profile soda lime silicate glass. *Journal of Non-Crystalline Solids*, 321(1-2):10–19, 2003.

[3] Adams, R. and Harris, J. The influence of local geometry on the strength of adhesive joints. *International Journal of Adhesion & Adhesives*, 7(2):69–80, 1987.

[4] Adams, R. and Wale, W. *Structural adhesive joints in Engineering*. Elsevier, London, UK, 1984.

[5] Adams, R. D., Comyn, J. and Wake, W. C. *Structural Adhesive Joints in Engineering*. 2nd Edition. Chapman and Hall, London, 1997.

[6] Addington, M. and Schodek, D. *Smart Materials and Technologies in Architecture*. Architectural Press, 2004. ISBN 0750662255.

[7] Amstock, J. S. *Handbook of Glass in Construction*. McGraw-Hill, 1997. ISBN 0-070-01619-4.

[8] AS 1288-2006. *Glass in buildings – Selection and installation*. Australia, 2006.

[9] AS website. Angstrom Sciences website. 2006. URL http://www.angstromsciences.com/.

[10] ASCE GFI 1989. *Guidelines for Failure Investigation*. Technical Council on Forensic Engineering. American Society of Civil Engineers, 1989. ISBN 0872627365.

[11] ASTM C 1036-2001. *Standard Specification for Flat Glass*. American Society for Testing Materials, 2001.

[12] ASTM C 1048-04. *Standard Specification for Heat-Treated Flat Glass – Kind HS, Kind FT Coated and Uncoated Glass*. American Society for Testing Materials, 2004.

[13] ASTM C 1172-03. *Standard Specification for Laminated Architectural Flat Glass*. American Society for Testing Materials, 2003.

[14] ASTM C 1376-03. *Standard Specification for Pyrolytic and Vacuum Deposition Coatings on Flat Glass*. American Society for Testing Materials, 2003.

[15] ASTM C 1401-02. *Standard Guide for Structural Sealant Glazing*. American Society for Testing Materials, 2002.

[16] ASTM C 1422-99(2005). *Standard Specification for Chemically Strengthened Flat Glass*. American Society for Testing Materials, 2005.

[17] ASTM C 1464-06. *Standard Specification for Bent Glass*. American Society for Testing Materials, 2006.

[18] ASTM C 1503-01. *Standard Specification for Silvered Flat Glass Mirror*. American Society for Testing Materials, 2001.

[19] ASTM D 1002-05. *Standard test method for apparent shear strength of single-lap-joint adhesively bonded metal specimen by tension loading (metal-to-metal)*. American Society for Testing Materials, 2005.

[20] ASTM D 3528-96. *Standard test method for strength properties of double lap shear adhesive joints by tension loading*. American Society for Testing Materials, 1996.

[21] ASTM E 1300-03. *Standard Practice for Determining Load Resistance of Glass in Buildings*.

Index

You may order SED monographs, or get information on other IABSE publications, directly from:

IABSE, ETH Zürich, CH-8093 Zürich, Switzerland
Phone: +41-1-633 2647 Fax: +41-1-633 1241
e-mail: secretariat@iabse.org web: www.iabse.org
Order Form: www.iabse.org/publications/orderform

Structural Engineering Documents 10

Structural Use of Glass, by Matthias Haldimann, Andreas Luible, Mauro Overend

Published: May 2008; 215 pages; ISBN 3-85748-119-2

Structural Engineering Documents 9

Cable Vibrations in Cable-Stayed Bridges, by Elsa de Sa Caetano

Published: October 2007; 188 pages; ISBN 978-3-85748-115-4

Structural Engineering Documents 8

Use and Application of High - Performance Steels for Steel Structures,
by Hans-Peter Günther

Published: October 2005; 152 pages; ISBN 3-85748-113-7

Structural Engineering Documents 7

Use of Fibre Reinforced Polymers in Bridge Construction, by Thomas Keller

Published: August 2003; 131 pages; ISBN 3-85748-105-0

Structural Engineering Documents 6

Structural Bearings and Expansion Joints for Bridges, by Günter Ramberger

Published: May 2002; 89 pages; ISBN 3-85748-105-6

Structural Engineering Documents 5 - Revised Version

Introduction to Safety and Reliability of Structures, by Jörg Schneider

SED 5 revised version (2006) includes Variables Processor software, supporting the subjects treated ***free:*** educational version VaP 1.6;
one-year free trial: professional version VaP 2.2

Published: second edition 2006; 109 pages; ISBN 3-85748-093-6

Structural Engineering Documents

Objective:

To provide in-depth information to practicing stuctural engineers in reports of high scientific and technical standards on a wide range of structural engineering topics.

Topics:

Structural analysis and design, dynamic analysis, construction materials and methods, project management, structural monitoring, safety assessment, maintenance and repair, and computer applications.

Readership:

Practicing structural engineers, teachers, researchers and students at a university level, as well as representatives of owners, operators and builders.

Publisher:

The International Association for Bridge and Structural Engineering (IABSE) was founded as a non-profit scientific association in 1929. Today it has more than 3900 members in over 90 countries. IABSE's mission is to promote the exchange of knowledge and to advance the practice of structural engineering worldwide. IABSE organizes conferences and publishes the quarterly journal Structural Engineering International, as well as conference reports and other monographs, including the SED series. IABSE also presents annual awards for achievements in structural engineering.

For further Information:

IABSE-AIPC-IVBH
ETH Zürich
CH-8093 Zürich, Switzerland
Phone: Int. + 41-44-633 2647
Fax: Int. + 41-44-633 1241
E-mail: secretariat@iabse.org
Web: www.iabse.org

Structural Use of Glass

Recent architectural trends and technological developments have brought about unprecedented opportunities and exciting changes in the use of glass in buildings.

Structural engineers currently have a bewildering array of glass products and configurations to choose from and a wide range of normal and exceptional loading conditions to consider, but very few unified reference texts for undertaking these tasks. This book attempts to redress this issue by providing an overview of the recent developments in this field thereby providing a basis for the understanding of the structural performance and design of glass in buildings.

Each chapter draws on the latest developments in practice and research and contains contributions from various international glass experts. The mix of general and specialist content ranging from rules of thumb to fracture mechanics and novel applications to post-breakage performance make this book useful to practitioners and researchers. Furthermore, the text is supplemented by tables of the major codes of practice and by an extensive list of references.

The book is primarily for structural engineers and researchers who have an interest in structural glass. It will be used by senior undergraduates, post-graduate students, researchers and practicing engineers.