# Software Requirements Specification for GlassBR

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## Contents

# 1 Reference Material

This section records information for easy reference.

## 1.1 Table of Units

Throughout this document SI (Système International d'Unités) is employed as the unit system. In addition to the basic units, several derived units are used as described below. For each unit, the symbol is given followed by a description of the unit and its name.

| **Symbol** | **Description** | **SI** |
|---|---|---|
| Pa | pressure | Pascal |
| N | force | Newton |

## 1.2 Table of Symbols

The table that follows summarizes the symbols used in this document along with their units. The symbols are listed in alphabetical order.

| Symbol | Unit | Description |
|---|---|---|
| $a$ | mm | Plate length (long dimension) |
| $B$ | unitless | Risk function |
| $b$ | mm | Plate width (short dimension) |
| $d_{\mathrm{max}}$ | mm | Maximum value for one of the dimensions of the glass plate |
| $d_{\mathrm{min}}$ | mm | Minimum value for one of the dimensions of the glass plate |
| $E$ | kPa | Modulus of elasticity of glass |
| $g$ | unitless | Glass type, $g \in \{\mathrm{AN}, \mathrm{HS}, \mathrm{FT}\}$ |
| $h$ | mm | Actual thickness |
| is_safe1 | unitless | Variable that is assigned true when calculated probability is less than tolerable probability |
| is_safe2 | unitless | Variable that is assigned true when load resistance (capacity) is greater than load (demand) |
| $J$ | unitless | Stress distribution factor (Function) |
| $J_{\mathrm{tol}}$ | unitless | Stress distribution factor (Function) based on $P_{b_{\mathrm{tol}}}$ |
| $k$ | $\mathrm{N}^{-7}\mathrm{m}^{12}$ | Surface flaw parameter |
| $m$ | $\mathrm{N}^{-7}\mathrm{m}^{12}$ | Surface flaw parameter |
| $P_b$ | unitless | Probability of breakage |
| $P_{b_{\mathrm{tol}}}$ | unitless | Tolerable probability of breakage |
| $q$ | kPa | Applied load (demand) |
| $\hat{q}$ | unitless | Dimensionless load |
| $\hat{q}_{\mathrm{tol}}$ | unitless | Tolerable load |
| SD | m | Stand off distance which is represented in coordinates $(\mathrm{SD}_x, \mathrm{SD}_y, \mathrm{SD}_z)$ |
| $\mathrm{SD}_{\mathrm{max}}$ | m | Maximum stand off distance permissible for input |
| $\mathrm{SD}_{\mathrm{min}}$ | m | Minimum stand off distance permissible for input |
| $\mathrm{SD}_{\mathrm{x}}$ | m | Stand off distance (x-component) |
| $\mathrm{SD}_{\mathrm{y}}$ | m | Stand off distance (y-component) |
| $\mathrm{SD}_{\mathrm{z}}$ | m | Stand off distance (z-component) |
| $t$ | mm | Nominal thickness |
| | | $t \in \{2.5, 2.7, 3.0, 4.0, 5.0, 6.0, 8.0, 10.0, 12.0, 16.0, 19.0, 22.0\}$ |
| $t_d$ | second | Duration of load |
| $w$ | kg | Charge weight |
| $w_{\mathrm{max}}$ | kg | Maximum permissible input charge weight |
| $w_{\mathrm{min}}$ | kg | Minimum permissible input charge weight |
| $w_{\mathrm{TNT}}$ | kg | Explosive Mass in equivalent weight of TNT |

### 1.3 Abbreviations and Acronyms

| Abbreviation | Full Form |
|---|---|
| AN | Annealed Glass |
| AR | Aspect Ratio |
| $AR_{max}$ | Maximum Aspect Ratio |
| FT | Fully Tempered Glass |
| GTF | Glass Type Factor |
| HS | Heat Strengthened |
| IG | Insulating Glass |
| LDF | Load Distribution Factor |
| LG | Laminated Glass |
| LR | Load Resistance |
| LSF | Load Share Factor |
| N/A | Not Applicable |
| NFL | Non-Factored load |
| TNT | TNT (Trinitrotoluene) equivalent factor |

## 2 Introduction

Software is helpful to efficiently and correctly predict the blast risk involved with the glass slab. The blast under consideration is any type of man-made explosion. The software, herein called GlassBR, aims to predict the blast risk involved with the glass slab using an intuitive interface.

The following section provides an overview of the Software Requirements Specification (SRS) for GlassBR. This section explains the purpose the document, the scope of the system, the organization of the document, and the characteristics of the intended reader.

### 2.1 Purpose of Document

The main purpose of this document is to predict whether a given glass slab is likely to resist a specified blast. The goals and theoretical models used in the GlassBR code are provided, with an emphasis on explicitly identifying assumptions and unambiguous definitions. This document is intended to be used as a reference to provide all information necessary to understand and verify the analysis. The SRS is abstract because the contents say *what* problem is being solved, but not *how* to solve it.

This document will be used as a starting point for subsequent development phases, including writing the design specification and the software verification and validation plan. The design document will show how the requirements are to be realized, including decisions on the numerical algorithms and programming environment. The verification and validation plan will show the steps that will be used to increase confidence in the software documentation and the implementation. Although the SRS fits in a series of documents that follow the so-called waterfall model, the actual development process is not constrained in any way. Even when the waterfall model is not followed, as Parnas and Clements point out [1], the most logical way to present the documentation is still to "fake" a rational design process.

## 2.2 Scope of Requirements

The scope of the requirements includes getting all input parameters related to the glass slab and also the parameters related to blast type. Given the input, GlassBR is intended to use the data and predict whether the glass slab is safe to use or not.

## 2.3 Characteristics of Intended Reader

Reviewers of this documentation should have a strong knowledge in theory behind glass breakage and blast risk. The reviewers should also have an understanding of second year calculus, structural mechanics, and computer applications in civil engineering. In addition, reviewers should be familiar with the applicable standards for constructions using glass [2, 3, 4]. The users of GlassBR can have a lower level of expertise, as explained in Section 4.2.

## 2.4 Organization of Document

The organization of this document follows the template for an SRS for scientific computing software proposed by [5] and [6], with some aspects taken from Volere template 16 [7]. The presentation follows the standard pattern of presenting goals, theories, definitions, and assumptions. For readers who would like a more bottom up approach, they can start reading the data definitions in Section 6.2.4 and trace back to find any additional information they require.

The goal statements are refined to the theoretical models, and theoretical models to the instance models. The data definitions are used to support the definitions of the different models.

# 3 Stakeholders

This section describes the stakeholders: the people who have an interest in the product.

## 3.1 The Client

The client for GlassBR is a company named Entuitive. It is developed by Dr. Manuel Campidelli. The client has the final say on acceptance of the product.

## 3.2 The Customer

The customers are the end users of GlassBR.

# 4 General System Description

This section provides general information about the system including identifying the interfaces between the system and its environment (system context), describing the user characteristics and listing the system constraints.

## 4.1 System Context

Figure 1 shows the system context. A circle represents an external entity outside the software, the user in this case. A rectangle represents the software system itself (GlassBR). Arrows are used to show the data flow between the system and its environment.

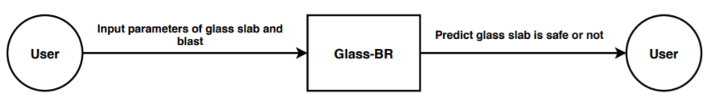


Figure 1: System Context

The interaction between the product and the user is through a user interface. The responsibilities of the user and the system are as follows:

- User Responsibilities:
  - Provide the input data related to the glass slab and the blast type, ensuring no errors in the data entry
  - Ensure that consistent units are used for input variables

- Ensure required software assumptions (Section 6.2.1) are appropriate for any particular problem input to the software

- GlassBR Responsibilities:
  - Detect data type mismatch, such as a string of characters input instead of a floating point number
  - Determine if the inputs satisfy the required physical and software constraints
  - Predict whether the glass slab is safe to use or not.

## 4.2 User Characteristics

- The end user of GlassBR is expected to have completed at least the equivalent of the second year of an undergraduate degree in civil or structural engineering.
- The end user is expected to have an understanding of theory behind glass breakage and blast risk.
- The end user is expected to have basic computer literacy to handle the software.

## 4.3 System Constraints

N/A

# 5 Scope of the Project

This section presents the scope of the project. It describes the expected use of GlassBR as well as the inputs and outputs of each action. The use cases are input and output, which defines the action of getting the input and displaying the output.

## 5.1 Product Use Case Table

| Actor | Input and Output |
|---|---|
| User | Characteristics of the glass slab and of the blast. Details in Section 5.2 |
| GlassBR | Whether or not the glass slab is safe for the calculated load and supporting calculated values |

Table 1: Use Case Table

## 5.2 Individual Product Use Cases

The user provides the inputs to GlassBR for use within the analysis. There are two main classes of inputs: glass geometry and blast type. The glass geometry based inputs include the glass type and dimensions of the glass plane. The blast type input includes parameters like weight of charge, TNT equivalent factor, and stand off distance from the point of explosion. These parameters describe charge weight and stand off blast. Another input the user gives is the tolerable value of probability of breakage. GlassBR outputs if the glass slab will be safe by comparing whether capacity is greater than demand. Capacity is the load resistance calculated and demand is the requirement which is the 3 second duration equivalent pressure. The second condition is to check whether the calculated probability ($P_b$) is less than the tolerable probability ($P_{btol}$) which is obtained from the user as an input. If both conditions return true, then it's shown that the glass slab is safe to use, else if both return false, then the glass slab is considered unsafe. All the supporting calculated values are also displayed as output.

# 6 Specific System Description

This section first presents the problem description, which gives a high-level view of the problem to be solved. This is followed by the solution characteristics specification, which presents the assumptions, theories and definitions.

## 6.1 Problem Description

A system is needed to efficiently and correctly predict the blast risk involved with the glass. GlassBR is a computer program developed to interpret the inputs to give out the outputs which predict whether the glass slab can withstand the blast under the given conditions.

### 6.1.1 Terminology and Definitions

This subsection provides a list of terms that are used in the subsequent sections and their meaning, with the purpose of reducing ambiguity and making it easier to correctly understand the requirements. All of the terms are extracted from [2].

1. *Aspect Ratio (AR)* - The ratio of the long dimension of the glass to the short dimension of the glass. For glass supported on four sides, the aspect ratio is always equal to or greater than 1.0. For glass supported on three sides, the ratio of the length of one of the supported edges perpendicular to the free edge, to the length of the free edge, is equal to or greater than 0.5.

2. *Glass breakage* - The fracture or breakage of any lite or ply in monolithic, laminated, or insulating glass.

3. *Lite* - Pieces of glass that are cut, prepared, and used to create the window or door.

4. *Glass Types:*

   (a) *Annealed (AN) glass* - A flat, monolithic, glass lite which has uniform thickness where the residual surface stresses are almost zero, as defined in [3].

   (b) *Fully tempered (FT) glass* - A flat, monolithic, glass lite of uniform thickness that has been subjected to a special heat treatment process where the residual surface compression is not less than 69 MPa (10 000 psi) or the edge compression not less than 67 MPa (9700 psi) as defined in [4].

   (c) *Heat strengthened (HS) glass* - A flat, monolithic, glass lite of uniform thickness that has been subjected to a special heat treatment process where the residual surface compression is not less than 24 MPa (3500 psi) or greater than 52 MPa (7500 psi) as defined in [4].

5. *Glass type factor (GTF)* - A multiplying factor for adjusting the LR of different glass types, that is, AN, HS, or FT in monolithic glass, LG (Laminated Glass), or IG (Insulating Glass) constructions.

6. *Lateral* - Perpendicular to the glass surface.

7. *Load* - A uniformly distributed lateral pressure.

   (a) *Specified design load* - The magnitude in kPa (psf), type (for example, wind or snow) and duration of the load given by the specifying authority.

   (b) *Load resistance (LR)* - The uniform lateral load that a glass construction can sustain based upon a given probability of breakage and load duration as defined in [2].

   (c) *Long duration load* - Any load lasting approximately 30 days.

   (d) *Non-factored load (NFL)* - Three second duration uniform load associated with a probability of breakage less than or equal to 8 lites per 1000 for monolithic AN glass.

   (e) *Glass weight load* - The dead load component of the glass weight.

   (f) *Short duration load* - Any load lasting 3 seconds or less.

8. *Load share factor (LSF)* - A multiplying factor derived from the load sharing between the double glazing, of equal or different thicknesses and types (including the layered behaviour of LG under long duration loads), in a sealed IG unit.

9. *Probability of breakage ($P_b$)* - The fraction of glass lites or plies that would break at the first occurrence of a specified load and duration, typically expressed in lites per 1000 [3].

10. *Specifying authority* - The design professional responsible for interpreting applicable regulations of authorities having jurisdiction and considering appropriate site specific factors to determine the appropriate values used to calculate the specified design load, and furnishing other information required to perform this practice.

11. *Blast resistant glazing* - Glazing that provides protection against air blast pressure generated by explosions.

12. *Equivalent TNT charge mass* - Mass of TNT placed on the ground in a hemisphere that represents the design explosive threat.

13. *Stand off distance (SD)* - The distance from the glazing surface to the centroid of a hemispherical high explosive charge.

#### 6.1.2 Physical System Description

The physical system of GlassBR, as shown in Figure 2 includes the following elements:

PS1: The glass slab.

PS2: The point of explosion. Where the bomb, or any man-made explosive, is located. The stand off distance is the distance between the point of explosion and the glass.

#### 6.1.3 Goal Statements

Given the dimensions of the glass plane, glass type, the characteristics of the explosion, and the tolerable probability of breakage, the goal statements are:

GS1: Analyze and predict whether the glass slab under consideration will be able to withstand the explosion of a certain degree which is calculated based on user input.

### 6.2 Solution Characteristics Specification

This section explains all the assumptions considered and the theoretical models which are supported by the data definitions.

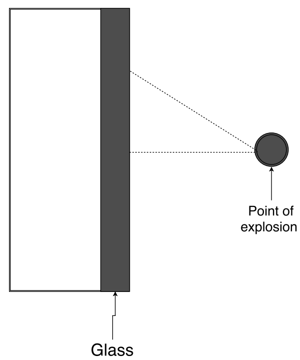


Figure 2: The physical system

### 6.2.1 Assumptions

This section simplifies the original problem and helps in developing the theoretical model by filling in the missing information for the physical system. The numbers given in the square brackets refer to the data definition, or the instance model, in which the respective assumption is used.

A1: The standard E1300-09a for calculation applies only to monolithic, laminated, or insulating glass constructions of rectangular shape with continuous lateral support along one, two, three, or four edges. This practice assumes that (1) the supported glass edges for two, three, and four-sided support conditions are simply supported and free to slip in plane; (2) glass supported on two sides acts as a simply supported beam and (3) glass supported on one side acts as a cantilever.

A2: This practice does not apply to any form of wired, patterned, etched, sandblasted, drilled, notched, or grooved glass with surface and edge treatments that alter the glass strength.

A3: This system only considers the external explosion scenario for its calculations.

A4: Standard values used for calculation in GlassBR are:

(a) $m = 7$

(b) $k = 2.86 \times 10^{-53}$ N$^{-7}$m$^{12}$

(c) $E = 7.17 \times 10^{7}$ kPa

(d) $t_d = 3$ s

[IM1, DD3, DD5, DD7, DD9]

A5: Glass under consideration is assumed to be a single lite; hence, the value of LSF is equal to 1 for all calculations in GlassBR. [IM2, DD7]

A6: Boundary conditions for the glass slab are assumed to be 4-sided support for all calculations. [IM1]

A7: The response type considered in GlassBR is flexural. [IM1]

A8: With reference to A4, the value of load distribution factor (LDF) is a constant in GlassBR. [DD3]

#### 6.2.2 Theoretical Models

| Number | T1 |
|---|---|
| Label | **Safety Requirement-1** |
| Equation | $\text{is\_safe1} = P_b < P_{b_{\text{tol}}}$ |
| Description | If is_safe1 = True, the glass is considered safe. is_safe1 and is_safe2 (from T2) are either both True or both False.<br>$P_b$ is the probability of breakage, as calculated in IM1<br>$P_{b_{\text{tol}}}$ is the tolerable probability entered by the user |
| Source | [2] |
| Ref. By | T2 |

| | |
|---|---|
| Number | T2 |
| Label | **Safety Requirement-2** |
| Equation | is_safe2 = LR $> q$ |
| Description | If is_safe2 = True, the glass is considered to be safe. is_safe1 (from T1) and is_safe2 are either both True or both False.<br>LR is the Load Resistance (also called capacity), as defined in IM2<br>$q$ (also referred as the demand) is the 3 second equivalent pressure, as defined in IM3 |
| Source | [2] |
| Ref. By | T1 |

### 6.2.3 General Definitions

There are no general definitions.

### 6.2.4 Data Definitions

This section collects and defines all the data needed to build the instance models.

| Number | DD1 |
|---|---|
| Label | **Risk of Failure (B)** |
| Equation | $B = \frac{k}{(\frac{a}{1000} \times \frac{b}{1000})^{m-1}}((E \times 1000)(\frac{h}{1000})^2)^m \times \text{LDF} \times e^J$ |
| Description | $B$ is the risk of failure<br><br>$m, k$ are the surface flaw parameters<br><br>$a$, $b$ are dimensions of the plate, where $(a > b)$<br><br>$E$ is the modulus of elasticity<br><br>$h$ is the true thickness, which is based on the nominal thickness as shown in DD2<br><br>LDF is the Load Duration Factor, as defined in DD3<br><br>$J$ is the stress distribution factor, as defined in DD4 |
| Source | [2] |
| Ref. By | IM1 |

| Number | DD2 |
| --- | --- |
| Label | **Minimum Thickness ($h$) from Nominal Thickness ($t$)** |
| Equation | $h = h(t)$ |
| Description | $h$ is a function that maps from the nominal thickness ($t$) to the minimum thickness, as follows: $h(t) \equiv (t = 2.5 \Rightarrow 2.16 \mid t = 2.7 \Rightarrow 2.59 \mid t = 3.0 \Rightarrow 2.92 \mid t = 4.0 \Rightarrow 3.78 \mid t = 5.0 \Rightarrow 4.57 \mid t = 6.0 \Rightarrow 5.56 \mid t = 8.0 \Rightarrow 7.42 \mid t = 10.0 \Rightarrow 9.02 \mid t = 12.0 \Rightarrow 11.91 \mid t = 16.0 \Rightarrow 15.09 \mid t = 19.0 \Rightarrow 18.26 \mid t = 22.0 \Rightarrow 21.44)$ |
| Source | [2] |
| Ref. By | IM1, DD9, DD7, DD5 |

| Number | DD3 |
| --- | --- |
| Label | **Load Duration Factor (LDF)** |
| Equation | $\mathrm{LDF} = (\frac{t_d}{60})^{m/16}$ |
| Description | $t_d$ is the duration of the load<br>$m$ is a surface flaw parameter |
| Source | [2] |
| Ref. By | IM1, DD9 |

| Number | DD4 |
|---|---|
| Label | **Stress Distribution Factor** $(J)$ |
| Symbols | $J = J(\hat{q}, \text{AR})$ |
| Description | $J$ is the stress distribution factor, which is obtained by interpolating from the data shown in Figure 8<br><br>$\hat{q}$ is the dimensionless load defined in DD7<br><br>AR is the Aspect Ratio DD11 |
| Source | [2] |
| Ref. By | IM1 |

| Number | DD5 |
|---|---|
| Label | **Non-Factored Load** |
| Equations | $\text{NFL} = \frac{\hat{q}_{\text{tol}} E h^4}{(ab)^2}$ |
| Description | $E$ is the modulus of elasticity<br><br>$a$, $b$ are the dimensions of the plate where $(a > b)$<br><br>$h$ is the true thickness, which is based on the nominal thickness as shown in DD2<br><br>$\hat{q}_{\text{tol}}$ is the tolerable load defined in DD8 |
| Source | [2] |
| Ref. By | IM2 |

| Number | DD6 |
|---|---|
| Label | **Glass Type Factor (GTF)** |
| Equation | $\mathrm{GTF} = \mathrm{GTF}(g)$ |
| Description | GTF is a function that maps from the glass type ($g$) to a real number, as follows:<br>$\mathrm{GTF}(g) \equiv (g = \mathrm{AN} \Rightarrow 1.0 \vert g = \mathrm{FT} \Rightarrow 4.0 \vert g = \mathrm{HS} \Rightarrow 2.0)$<br>AN is annealed glass<br>FT is fully tempered glass<br>HS is heat strengthened glass |
| Source | [2] |
| Ref. By | DD7, IM2 |

| Number | DD7 |
|---|---|
| Label | **Dimensionless Load ($\hat{q}$)** |
| Equation | $\hat{q} = \frac{q(ab)^2}{Eh^4 GTF}$ |
| Description | $q$ is the 3 second equivalent pressure, as given in IM3<br>$a$, $b$ are dimensions of the plate, where $(a > b)$<br>$E$ is the modulus of elasticity<br>$h$ is the true thickness, which is based on the nominal thickness as shown in DD2<br>GTF is the Glass Type Factor, as given by DD6 |
| Source | [2] |
| Ref. By | DD4 |

| Number | DD8 |
|---|---|
| Label | **Tolerable Load ($\hat{q}_{\text{tol}}$)** |
| Equations | $\hat{q}_{\text{tol}} = \hat{q}_{\text{tol}}(J_{\text{tol}}, \text{AR})$ |
| Description | $\hat{q}_{\text{tol}}$ is the tolerable load which is obtained from Figure 8 using $J_{\text{tol}}$ and Aspect Ratio AR (DD11) as parameters using interpolation. Calculation of $J_{\text{tol}}$ is defined in DD9. |
| Source | [2] |
| Ref. By | DD5 |

| Number | DD9 |
|---|---|
| Label | **Tolerable Stress Distribution Factor ($J_{\text{tol}}$)** |
| Symbols | $J_{\text{tol}} = \ln[\ln(\frac{1}{1-P_{b_{\text{tol}}}})\frac{(\frac{a}{1000}\times\frac{b}{1000})^{m-1}}{k((E\times 1000)(\frac{h}{1000})^2)^m \text{LDF}}]$ |
| Description | $J_{\text{tol}}$ is the stress distribution factor calculated with reference to $P_{b_{\text{tol}}}$<br><br>$a$, $b$ are dimensions of the plate where $(a > b)$<br><br>$h$ is the true thickness, which is based on the nominal thickness as shown in DD2<br><br>$m$, $k$ are the surface flaw parameters<br><br>LDF is the Load Duration Factor, as defined by DD3<br><br>$E$ is the modulus of elasticity<br><br>$P_{b_{\text{tol}}}$ is the tolerable probability entered by the user |
| Source | [2] |
| Ref. By | DD8 |

| Number | DD10 |
|---|---|
| Label | **Stand off Distance (SD)** |
| Equations | $\mathrm{SD} = \sqrt{{\mathrm{SD}_x}^2 + {\mathrm{SD}_y}^2 + {\mathrm{SD}_z}^2}$ |
| Description | SD is the stand off distance and $(\mathrm{SD}_x, \mathrm{SD}_y, \mathrm{SD}_z)$ are the coordinates for this position |
| Source | [2] |
| Ref. By | IM3 |

| Number | DD11 |
|---|---|
| Label | **Aspect Ratio (AR)** |
| Equations | $\mathrm{AR} = a/b$ |
| Description | AR is the Aspect Ratio and $a$, $b$ are dimensions of the plate where $(a \geq b)$ |
| Source | [2] |
| Ref. By | DD4, DD8 |

### 6.2.5 Instance Models

| Number | IM1 |
|---|---|
| Label | **Probability of Glass Breakage** |
| Equation | $P_b = 1 - e^{-B}$ |
| Description | $P_b$ is the calculated probability of breakage<br>$B$ is the risk of failure, as defined in DD1 |
| Source | [2] |
| Ref. By | T1 |

| | |
|---|---|
| Number | IM2 |
| Label | **Calculation of Capacity (LR)** |
| Equation | $\mathrm{LR} = \mathrm{NFL} \times \mathrm{GTF} \times \mathrm{LSF}$ |
| Description | LR is the Load Resistance, which is also called capacity<br>NFL is the Non-Factored Load, as defined in DD5<br>GTF is the Glass Type Factor, as given by DD6<br>LSF is the Load Share Factor |
| Source | [2] |
| Ref. By | T2 |

| | |
|---|---|
| Number | IM3 |
| Label | **Calculation of Demand ($q$)** |
| Equation | $q = q(w_{\mathrm{TNT}}, \mathrm{SD})$ |
| Description | $q$, or demand, is the 3 second equivalent pressure obtained from the Figure 7 by interpolation using stand off distance (SD) and $w_{\mathrm{TNT}}$ as parameters<br>$w_{\mathrm{TNT}}$ is defined as $w_{\mathrm{TNT}} = w \times \mathrm{TNT}$<br>$w$ is the charge weight<br>TNT is the TNT equivalent factor<br>SD is the stand off distance (DD10) |
| Source | [2] |
| Ref. By | T2, DD7 |

### 6.2.6 Data Constraints

Table 2 shows the data constraints on the input variables. The column of physical constraints gives the physical limitations on the range of values that can be taken by the variable. The constraints are conservative, to give the user of the model the flexibility to experiment with unusual situations. The column of typical values is intended to provide a feel for a common scenario. The uncertainty column provides an estimate of the confidence with which the physical quantities can be measured. This information would be part of the input if one were performing an uncertainty quantification exercise. Table 7 gives the values of the specification parameters used in Table 2. $\mathrm{AR}_{\max}$ refers to the maximum aspect ratio for the plate of glass.

Table 2: Input Variables

| Var | Physical Cons | Software Constraints | Typical Value | Uncertainty |
|---|---|---|---|---|
| $a$ | $a > 0 \land \mathrm{AR} \geq 1$ | $d_{\min} \leq a \leq d_{\max} \land \mathrm{AR} < \mathrm{AR}_{\max}$ | 1500 mm | 10% |
| $b$ | $b > 0 \land b < a$ | $d_{\min} \leq b \leq d_{\max} \land \mathrm{AR} < \mathrm{AR}_{\max}$ | 1200 mm | 10% |
| $P_{b_{\mathrm{tol}}}$ | $0 < P_{b_{\mathrm{tol}}} < 1$ | – | 0.008 | 0.1% |
| $w$ | $w \geq 0$ | $w_{\min} < w < w_{\max}$ | 42 kg | 10% |
| TNT | $\mathrm{TNT} > 0$ | – | 1 | 10% |
| SD | $\mathrm{SD} > 0$ | $\mathrm{SD}_{\min} < \mathrm{SD} < \mathrm{SD}_{\max}$ | 45 m | 10% |

Note: The values for $d_{\min}$ and $d_{\max}$ are obtained from Figure 3 and the GLASS_BR_0_40b.xslm which can be found in the Reference directory. The value for $\mathrm{AR}_{\max}$ is obtained from Figure 8 and the GLASS_BR_0_40b.xslm. The values for $w_{\min}$, $w_{\max}$, $\mathrm{SD}_{\min}$ and $\mathrm{SD}_{\max}$ are obtained from Figure 7 and the GLASS_BR_0_40b.xslm.

Table 3 shows the constraints that must be satisfied by the output.

Table 3: Output Variables

| Var | Physical Constraints |
|---|---|
| $P_b$ | $0 < P_b < 1$ |

# 7 Requirements

## 7.1 Functional Requirements

The following section provides the functional requirements, the business tasks that the software is expected to complete.

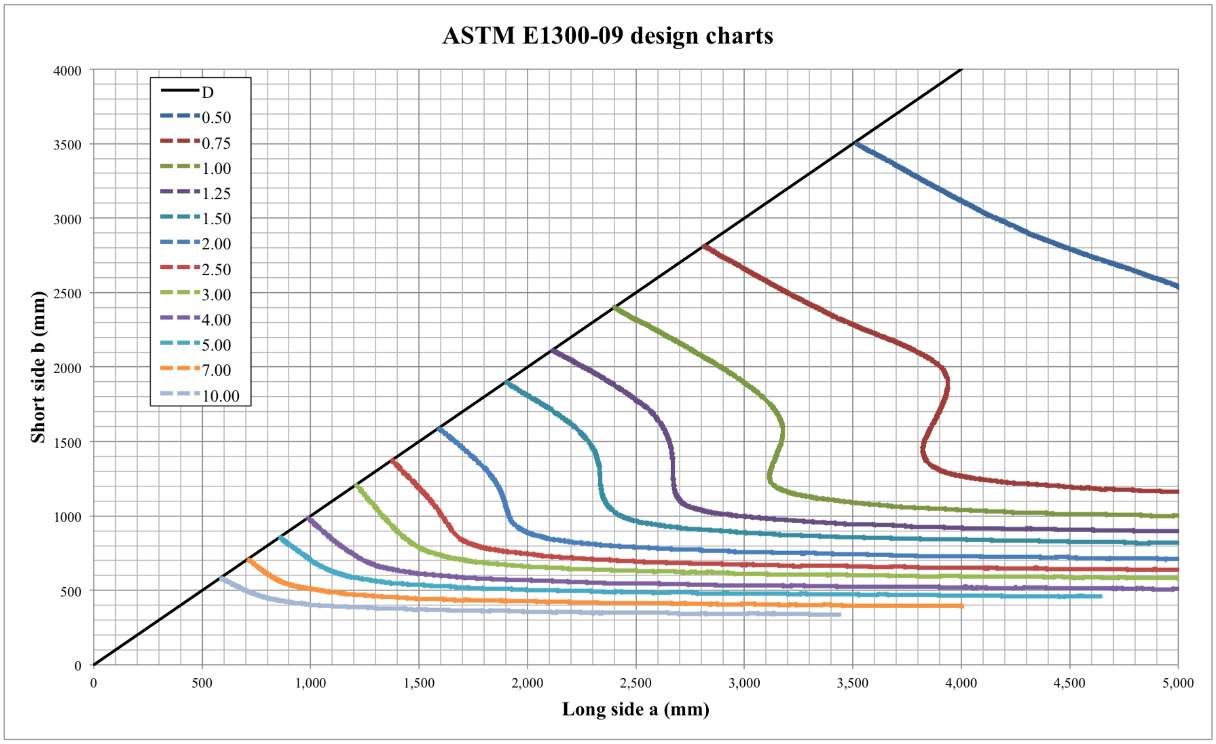


Figure 3: Long side (a) versus Short side (b)

R1: Input the following quantities, which define the glass dimensions, type of glass, tolerable probability of failure and the characteristics of the blast:

| symbol | unit | description |
|---|---|---|
| $a$ | mm | Length of the glass slab |
| $b$ | mm | Breadth of the glass slab |
| $g$ | unitless | Glass Type, $g \in \{\mathrm{AN}, \mathrm{HS}, \mathrm{GT}\}$ |
| $P_{b_{\mathrm{tol}}}$ | unitless | Tolerable probability |
| $\mathrm{SD}_x$ | m | Stand off distance ($x$-component) |
| $\mathrm{SD}_y$ | m | Stand off distance ($y$-component) |
| $\mathrm{SD}_z$ | m | Stand off distance ($z$-component) |
| $t$ | mm | Nominal thickness of the glass slab, $t \in \{2.5, 2.7, 3.0, 4.0, 5.0, 6.0, 8.0, 10.0, 12.0, 16.0, 19.0, 22.0\}$ |
| TNT | unitless | TNT equivalent factor |
| $w$ | kg | Charge weight |

R2: The system shall set the known values as follows:

- $m$, $k$, $E$, $t_d$ following A4
- LDF from DD3
- LSF following A5
- $h$ from DD2
- GTF from DD6
- SD from DD10
- AR from DD11

R3: The system shall check the entered input values to ensure that they do not exceed the data constraints mentioned in 6.2.6. If any of the input parameters is out of bounds, an error message is displayed and the calculations stop.

R4: Output the input quantities from R1 and the known quantities from R2.

R5: If is_safe1 $\wedge$ is_safe2 (from T1 and T2) output the message “For the given input parameters, the glass is considered safe.” If the condition is false, then output the message “For the given input parameters, the glass is NOT considered safe.”

R6: Output the following quantities:

- Probability of breakage ($P_b$) (IM1)

- Risk of failure ($B$) (DD1)
- Load resistance (LR) (IM2)
- Applied load (demand) ($q$) (IM3)
- Stress distribution factor ($J$) (DD4)
- Non-factored load (NFL) (DD5)
- Dimensionless load ($\hat{q}$) (DD7)
- Tolerable load ($\hat{q}_{\text{tol}}$) (DD8)
- Stress distribution factor based on $P_b$ ($J_{\text{tol}}$) (DD9)

### 7.2 Nonfunctional Requirements

Given the small size, and relative simplicity, of this problem, performance is not a priority. Any reasonable implementation will be very quick and use minimal storage. Rather than performance, the priority nonfunctional requirements are correctness, verifiability, understandability, reusability, maintainability and portability.

## 8 Likely Changes

LC1: A3 - The system currently only calculates for external blast risk. In the future calculations can be added for the internal blast risk.

LC2: A4, A8 - Currently the values for $m$, $k$ and $E$ are assumed to be the same for all glass. In the future these values can be changed to variable inputs.

LC3: A5 - The software may be changed to accommodate more than a single lite.

LC4: A6 - The software may be changed to accommodate more boundary conditions than 4-sided support.

LC5: A7 - The software may be changed to consider more than just flexure of the glass.

## 9 Unlikely Changes

UC1: The goal of the system is to predict whether the glass slab under consideration can withstand an explosion of a certain degree.

UC2: A2 requires that the glass is not altered in any way. Therefore, this cannot be used on altered glass.

# 10 Traceability Matrices and Graphs

The purpose of the traceability matrices is to provide easy references on what has to be additionally modified if a certain component is changed. Every time a component is changed, the items in the column of that component that are marked with an "X" should be modified as well. Table 4 shows the dependencies of theoretical models, data definitions, and instance models with each other. Table 5 shows the dependencies of requirements on theoretical models, instance models, data definitions and data constraints. Table 6 shows the dependencies of theoretical models, data definitions, instance models, likely changes and requirements on the assumptions.

| | T1 | T2 | IM1 | IM2 | IM3 | DD1 | DD2 | DD3 | DD4 | DD5 | DD6 | DD7 | DD8 | DD9 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T1 | | X | X | | | | | | | | | | | |
| T2 | X | | | X | X | | | | | | | | | |
| IM1 | | | | | | X | X | X | X | | | | | |
| IM2 | | | | | | | | | | X | X | | | |
| IM3 | | | | | | | | | | | | | | |
| DD1 | | | | | | | | | | | | | | |
| DD2 | | | | | | | | | | | | | | |
| DD3 | | | | | | | | | | | | | | |
| DD4 | | | | | | | | | | | | X | | |
| DD5 | | | | | | | X | | | | | | X | |
| DD6 | | | | | | | | | | | | | | |
| DD7 | | | | | X | | X | | | | X | | | |
| DD8 | | | | | | | | | | | | | | X |
| DD9 | | | | | | | X | X | | | | | | |

Table 4: Traceability Matrix Showing the Connections Between Items of Different Sections

| | T1 | T2 | IM1 | IM2 | IM3 | DD1 | DD2 | DD3 | DD4 | DD5 | DD6 | DD7 | DD8 | DD9 | 6.2.6 | R1 | R2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R1 | | | | | | | | | | | | | | | | | |
| R2 | | | | | | | | | | | | | | | | | |
| R3 | | | | | | | | | | | | | | | X | | |
| R4 | | | | | | | | | | | | | | | | X | X |
| R5 | X | X | | | | | | | | | | | | | | | |
| R6 | | | X | X | X | | X | X | X | X | X | X | X | X | | | |

Table 5: Traceability Matrix Showing the Connections Between Requirements and Other Items.

| | A1 | A2 | A3 | A4 | A5 | A6 | A7 | A8 |
|---|---|---|---|---|---|---|---|---|
| T1 | | | | | | | | |
| T2 | | | | | | | | |
| IM1 | | | | X | | X | X | |
| IM2 | | | | | X | | | |
| IM3 | | | | | | | | |
| DD1 | | | | | | | | |
| DD2 | | | | | | | | |
| DD3 | | | | X | | | | X |
| DD4 | | | | | | | | |
| DD5 | | | | X | | | | |
| DD6 | | | | | | | | |
| DD7 | | | | | X | | | |
| DD8 | | | | | | | | |
| DD9 | | | | X | | | | |
| LC1 | | | X | | | | | |
| LC2 | | | | X | | | | X |
| LC3 | | | | | X | | | |
| LC4 | | | | | | X | | |
| LC5 | | | | | | | X | |
| R1 | | | | | | | | |
| R2 | | | | X | X | | | X |
| R3 | | | | | | | | |
| R4 | | | | | | | | |
| R5 | | | | | | | | |
| R6 | | | | | | | | |

Table 6: Traceability Matrix Showing the Connections Between Assumptions and Other Items

The purpose of the traceability graphs is also to provide easy references on what has to be additionally modified if a certain component is changed. The arrows in the graphs represent dependencies. The component at the tail of an arrow is depended on by the component at the head of that arrow. Therefore, if a component is changed, the components that it points to should also be changed. Figure 4 shows the dependencies of theoretical models, data definitions, instance models on each other. Figure 5 shows the dependencies of requirements on theoretical models, instance models, data definitions and data constraints. Figure 6 shows the dependencies of theoretical models, instance models, data definitions, requirements and likely changes on assumptions.

NOTE: Building a tool to automatically generate the graphical representation of the matrix by scanning the labels and reference can be future work.

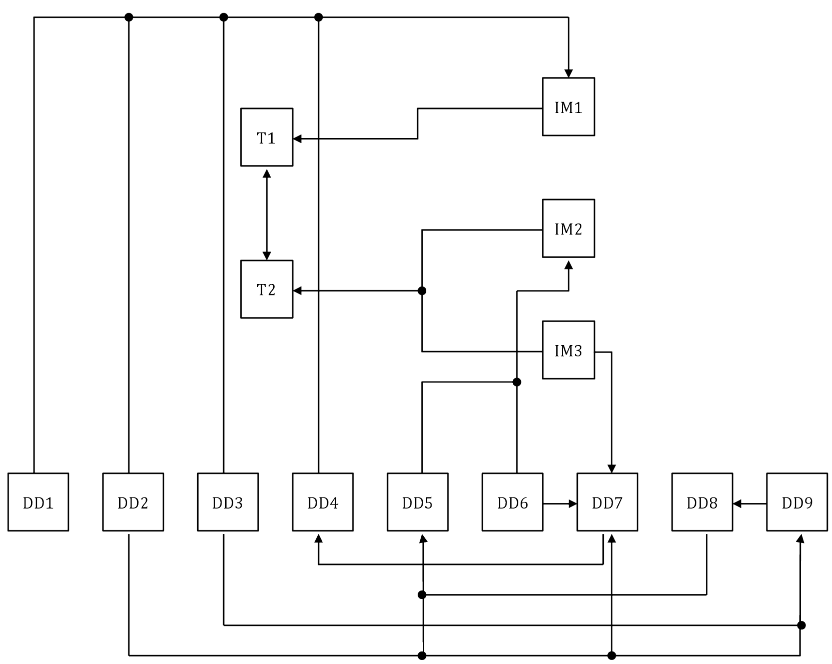


Figure 4: Traceability Graph Showing the Connections Between Items of Different Sections.

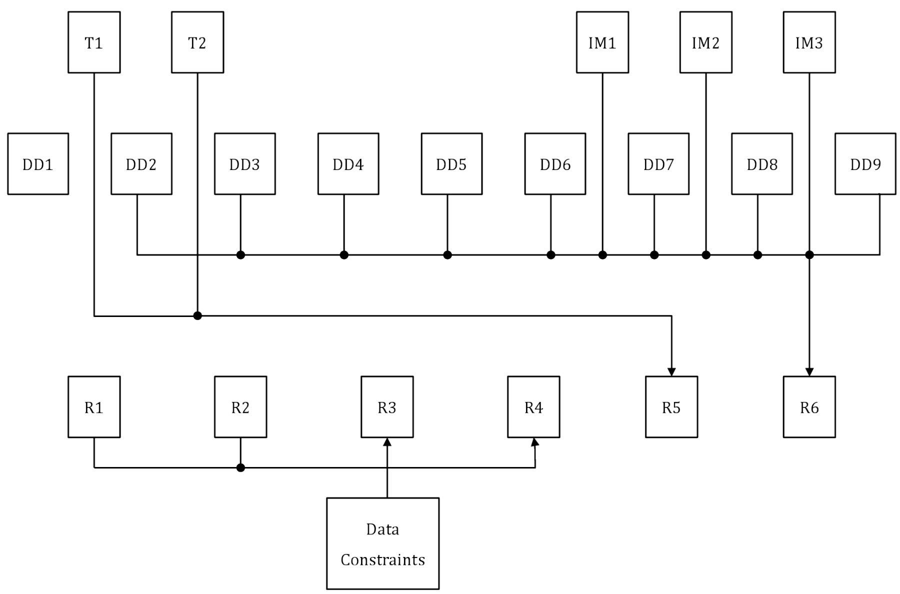


Figure 5: Traceability Graph Showing the Connections Between Requirements and Other Items.

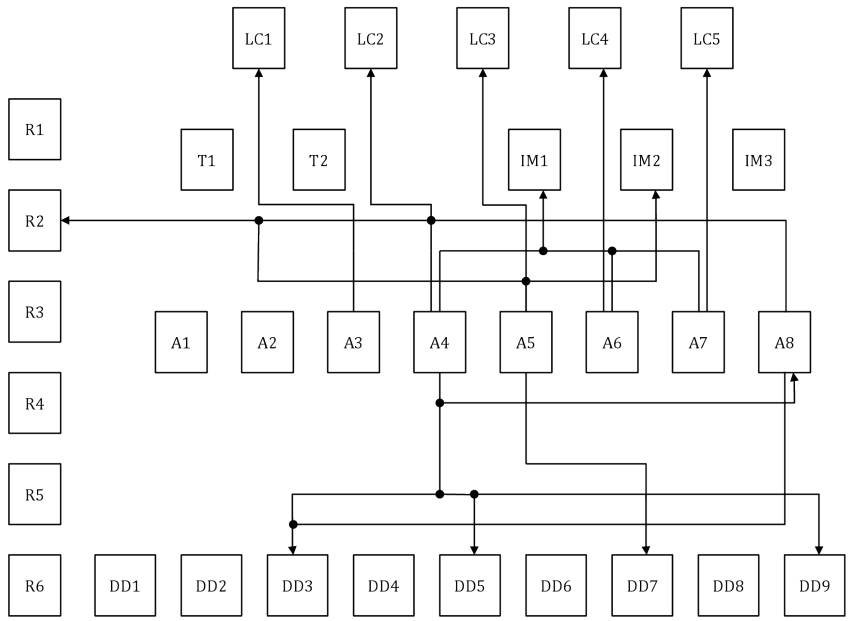


Figure 6: Traceability Graph Showing the Connections Between Assumptions and Other Items.

# 11 Values of Auxiliary Constants

This section contains the standard values that are used for calculations in GlassBR.

| Symbol | Description | Value | Unit |
|---|---|---|---|
| $m$ | surface flaw parameter | 7 | $\frac{\mathrm{m}^{12}}{\mathrm{N}^{7}}$ |
| $k$ | surface flaw parameter | $(2.86)\,10^{-53}$ | $\frac{\mathrm{m}^{12}}{\mathrm{N}^{7}}$ |
| $E$ | modulus of elasticity of glass | $(7.17)\,10^{7}$ | Pa |
| $t_d$ | duration of load | 3 | s |

| | | | |
|---|---|---|---|
| LSF | load share factor | 1 | Unitless |
| $d_{max}$ | maximum value for one of the dimensions of the glass plate | 5.0 | m |
| $d_{min}$ | minimum value for one of the dimensions of the glass plate | 0.1 | m |
| $\text{AR}_{max}$ | maximum aspect ratio | 5.0 | Unitless |
| $w_{max}$ | maximum permissible input charge weight | 910.0 | kg |
| $w_{min}$ | minimum permissible input charge weight | 4.5 | kg |
| $\text{SD}_{max}$ | maximum stand off distance permissible for input | 130.0 | m |
| $\text{SD}_{min}$ | minimum stand off distance permissible for input | 6.0 | m |

Table 7: Auxiliary Constants

# 12 References


[1] D. L. Parnas and P. Clements, "A rational design process: How and why to fake it," *IEEE Transactions on Software Engineering*, vol. 12, no. 2, pp. 251–257, February 1986.

[2] ASTM, "Standard practice for determining load resistance of glass in buildings," Standard E1300-09a, 2009.

[3] ASTM, "Standard specification for flat glass," 2016.

[4] ASTM, "Standard specification for heat-strengthened and fully tempered flat glass," 2012.

[5] N. Koothoor, "A document drive approach to certifying scientific computing software," Master's thesis, McMaster University, Hamilton, Ontario, Canada, 2013.

[6] W. S. Smith and L. Lai, "A new requirements template for scientific computing," in *Proceedings of the First International Workshop on Situational Requirements Engineering Processes – Methods, Techniques and Tools to Support Situation-Specific Requirements Engineering Processes, SREP'05* (J. Ralyté, P. Ȧgerfalk, and N. Kraiem, eds.), (Paris, France), pp. 107–121, In conjunction with 13th IEEE International Requirements Engineering Conference, 2005.

[7] S. Robertson and J. Robertson, *Mastering the Requirements Process*, ch. Volere Requirements Specification Template, pp. 353–391. New York, NY, USA: ACM Press/Addison-Wesley Publishing Co, 1999.

# 13 Appendix

This appendix holds the graphs (Figure 7 and Figure 8) used for interpolating values needed in the models.

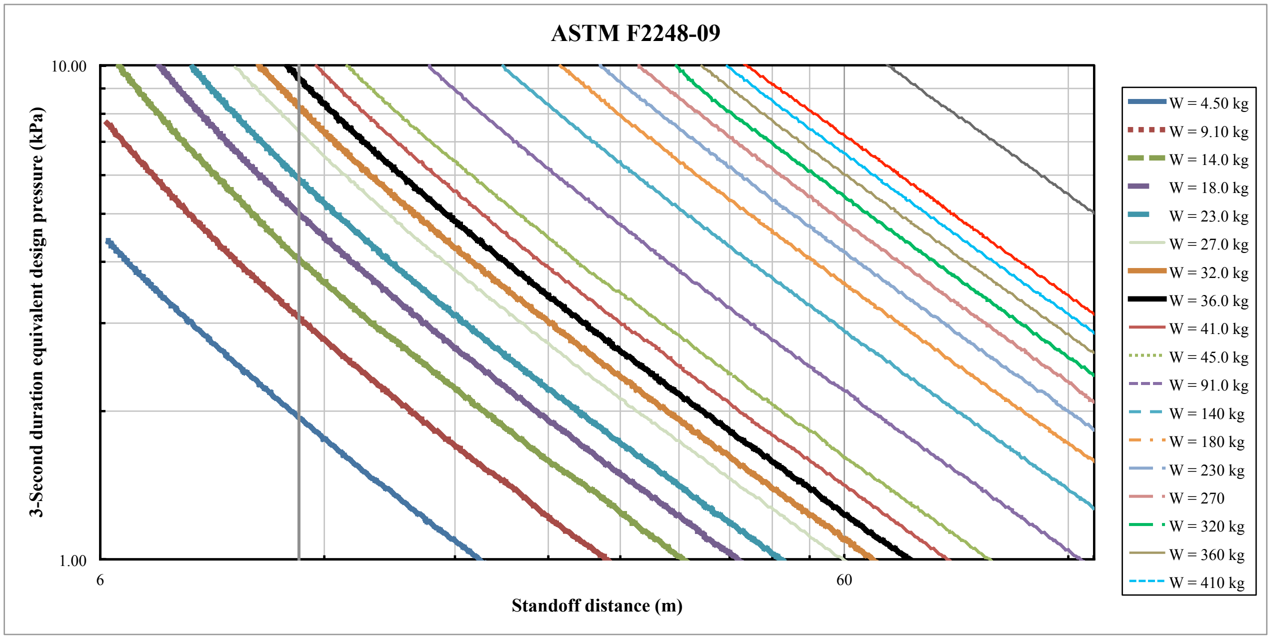


Figure 7: 3 second equivalent pressure ($q$) versus Stand off distance (SD) versus charge weight ($w$)

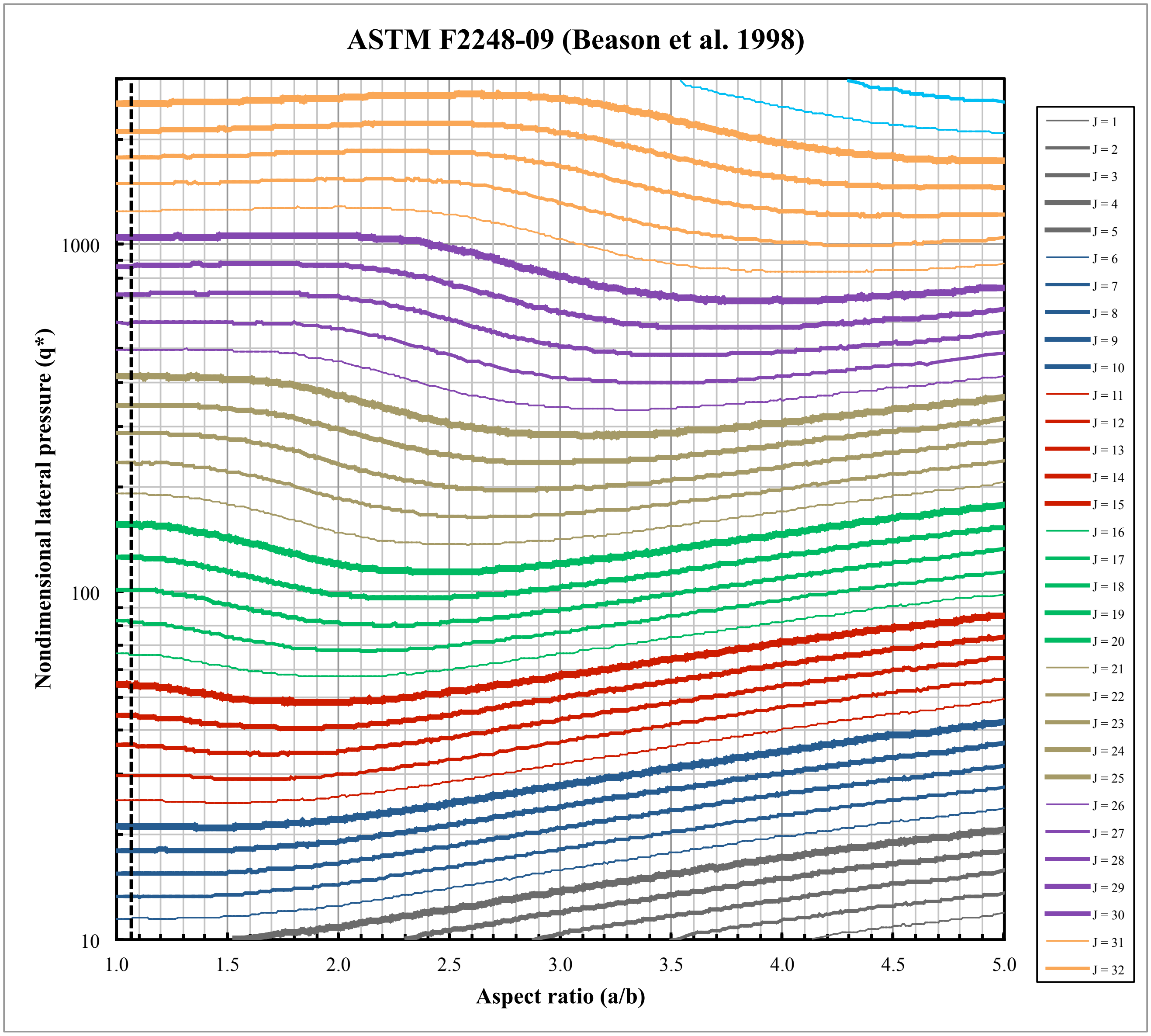


Figure 8: Non dimensional lateral load ($\hat{q}$) versus Aspect ratio versus Stress distribution factor (J)