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An approach to mullion deflection in stick system façade durability

TESI DI LAUREA MAGISTRALE IN BUILDING ENGINEERING FOR SUSTAINABILITY

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Abstract

The present master's thesis follows the development path of a computation tool focused on mullion deflection in stick systems curtain walls. Originating in an internship made by the student in the Milanese façade design office Faces Engineering, its purpose is to evaluate the maximum movement value of the frame for which the glazing safety is ensured, given building typologies and geometrical inputs differing of the firm's already existing calculation tools, especially regarding the glazing fixation types (standard, structurally clamped with profile or toggle) and the kind of setting blocks. Starting from the façade manufacturer Reynaer's database, and with the help of the literature review on this few documented subject, a theorical framework is identified and shapes the development of the calculation method. Having assessed hypothesis and elaboration principles, the workflow is then precisely detailed; a focus is made on the dimension changes of materials due to thermal variation. Finally, the tool is used in an actual project by Faces Engineering to evaluate its relevance and precision, going through a comparison with the effective design process leading to final considerations about the calculations' accuracy and its possible development.

Mullion deflection – stick system curtain wall – thermal dilatation – glass shimming – glazing fixation

1 Introduction

When arriving at the Politecnico di Milano to attend the Master *Building Engineering for Sustainability*, the student's main aim was to complete its training within the field of building structures – besides the international aspect of the program, that offered him lectures in both English and Italitan with a concern regarding global stakes – to gain the skills he was still lacking regarding its past curriculum (architectural and general engineering) and internships experiences (façade and acoustic design offices).

However, taking into account one of the other Master's specialties, the major exercise consisting in the thesis seemed to him to be a proper opportunity to deepen transversal approaches he already experienced, bridging its structural interest with the thematic of building envelopes. Thus, he planned to study possible interactions between building façade and structure.

Discovered through a scholar seminar presentation given by the engineers Lucilla Brambilla and Paolo Franco, Faces Engineering appeared as a relevant place to concretize such a project since the firm's work mostly deals with these two topics: façade and structural engineering. An internship in research and development (R&D), started in February 2026 and extended till the graduation period was the first condition of the present work.

Presentation of Faces Engineering

Faces Engineering features different poles, ranking from structural studies to BIM and façade studies, the collaborators from this latter being the ones with whom the student mostly interacted during his internship period and the connected thesis work.

The Milan-based company operates at the intersection of architecture and engineering, specializing in complex building envelopes and structural design; founded in 2014, it also features an office in London, gathering 40 collaborators. The firm provides technical consultancy and engineering services, ensuring that the aesthetic intent of a project is matched by technical feasibility, safety, and environmental performance. Among its projects, one can mention City Life's skyscrapers and City Wave, Unipol Tower, Galfa Tower, Gioia 22 (all these being in Milano) [1]. One of its mottos has been "working with the best"; indeed, some of Faces' main collaborators are worldwide-known architects such as Studio Libeskind, BIG, or Snøhetta.

The firm's approach is characterized by a multisectoral expertise and a focus on sustainability and innovation. Its works deal with integrating building physics, structural analysis, and material science, over all the conception and construction processes. Accordingly, the design of envelopes optimizes thermal performance and minimizes the carbon footprint of the building. Utilizing R&D to develop proprietary tools and workflows, such as the one developed during this internship, allows the company to go further the current boundaries of standard façade systems.

A consequent number of the employees come from the same master (*Building Engineering*, earlier version of the one already mentioned) and therefore share common knowledge and skills that they have developed further and specialized according to their position and tasks. During his stay in the office, the student has been guided by the engineer Xin Yue. She indicated to him the starting point, with the related documentation, and drew the guidelines and directions to follow. A part of the exchanges also occurred with Steve Alemanno (often working from Turin) and, to a lesser extent, with Paolo Franco.

After an initial time used to catch up with façade-related background (focusing on lectures from other Polimi's tracks, technical guidelines and standards), the actual calculation work began with the progressive implementation in form of an Excel worksheet. Its elaboration went step by step, doing regular controls and discussions with the tutors to check the accuracy regarding the assignment, the viability of the calculations, the relevance of some hypothesis and whenever needed, discuss and solve problems that might unavoidably occur.

After the end of the mandatory internship period, the student dedicated a growing part of his time to the preliminary researches then the redaction of this thesis, while parallelly pursuing the development of the calculation tool and modifying it according to its progressive theoretical discoveries and exchanges with tutors. The research and development methodology is integrally presented in the present report, although some modifications may still happen in the future to achieve the tool and deliver it definitely to Faces Engineering for its extensive use in projects.

2 Subject and scope

The work accomplished by the student consists in the development of a calculation tool focusing on the racking of glass panels in a stick system façade connected to movements of its frame.

Consisting in an Excel file, the tool aims at helping design process by determining the maximum authorized deflection of a mullion before the safety of the glazing may be compromised, starting from design and environmental parameters. Main inputs include the frame dimensions, the kind of glass used, and thermal data. Examples already exist of vertical deflection deriving from glass panels dimensions; in this context however, the workflow stipulated that also the glass panel had to be a calculated output (depending on the frame and glass edge cover fixation). Considering a variety of design cases (type of glass shimming and panel fixation), the tool had to provide coherent values that should later be used as a support for the engineer to statue on which solution would fit the best a precise project.

The principal material that has been used as a theoretical background for the calculator is a stick system façade catalog by Reynaers. The firm may be the only one that shared both precise structural details and mullion deflections values for separate typologies of case studies.

Initially, the student only re-built a coherent calculation model that, starting from the desired input, would give results matching the one of Reynaers – while discussing and challenging them along the process. It allowed to get a sure and robust nucleus for the tool to be expanded. The next steps dealt indeed with the broadening of the possible use conditions. By reformulating given hypothesis and formulas from the existing literature; by seeking for other problem dimensions (out of the database) to be also computed; and by taking into account the effects of the thermal dilatation.

2.1. Problem statement

2.1.1. Stick systems' movement accommodation

Glass curtain wall

The development of ever slimmer structural frames, characterized by increased flexibility of primary structures, growing spans and floor heights, parallelly to the implementation of bigger glass formats, led to an issue of having greater displacements of structural members while the ability of the glass enclosures to accommodate them is more limited [2]. This matter has not been precisely addressed yet, neither in the Eurocodes nor the existing normative such as EN 13830:2003.

Façade stick systems, especially for glass curtain walls, already featured little movement capacity, mostly relying on the clearance between the glass edges and the aluminum frame [3]; yet curtain walls problems (with destructive effects) may arise from insufficient movement accommodation. Said movement is generated from both out-of-the plan solicitations (wind action) and in-plane solicitations (especially earthquakes; the related behavior strictly depends on that of the principal structure [4],[5]). This last case is the one studied in this thesis, with the particularity that the initial movement of the façade is generated by the primary structure (vertical) deflection, e.g. under permanent loads – although this part of the problem is considered purely theorical and not explicated within the frame of this work.

In case of failure, curtain walls affect the main structure of the building and jeopardize pedestrians and occupants. Besides representing an obvious hazard, these eventual damages may cause sensitive economic losses. Both exigency on safety and economic viability motivate investigations about reliable methods to predict the behavior of these façade systems.

Most curtain wall problems occur because of incompatibility with the primary building frame, but also construction imperfections and inappropriate design. To ensure the serviceability and maintain the performance of the curtain wall, its designer must obtain the expected movement, in terms of dimensions and directions, from the building design engineer, these movements having to be used to design joints and clearances. However, a curtain wall will perform better in service than anticipated by calculation, due to inherent deflections and twists within the curtain wall components [3].

Glass panel serviceability

Glass curtain walls systems are still getting increasingly used in buildings, especially for mid and high-rise building [5], while glazing windows and façades constitute delicate and breakable elements within a building structure [6]. Even if glass and aluminum feature high strength to self-weight ratio and sustainable assets (corrosion-resistant, recyclable, reusable), glass components appear indeed as the most vulnerable components in a building envelope [7].

Glazing may be subject to different actions and solicitations, including dynamic loads (internal and external climate, wind, crowd, pedestrian traffic, pressure and negative-pressure wave, etc.), static loads (self-weight, imposed loads, snow, hydrostatic pressure, etc.), explosions, vibrations, accidental loads, various impacts and fire [8]. Considering sustainability (service life) and safety (breaking, risks of hurting persons or animals and damaging objects, fall, or social damage compromising a community or its activities) issues, glazing should be dimensioned to resist these solicitations or avoid critical situations.

Glazing failure

Glass-to-frame collision occurs as the aluminum frame deforms [9]. In-plane tests performed on full-size single glass units with aluminum frame allowed to identify the common chained mechanisms of damage: gaskets dislodging, glass crushing at corners, then cracking, and ultimately panels fall-out [5]. But even before, glass plates can cause significant plastic deformations of the aluminum frame where the contact happens [10].

The ability of joints to accommodate movement is mostly correlated to their joint’s dimensions – and, in absence of joints, to the ability of components and materials to change dimension without inducing unacceptably high stresses and loads. According to the CWCT, the key concept is then to isolate (from movement of the building envelope) materials that should remain unstressed, such as glass, using appropriate movement joints [11].

2.1.2. Study framework

The study focusing on stick system curtain walls, are excluded from this work [12]:

- unitized curtain walls
- point-fixed / point-supported curtain walls
- structural sealant glazing
- double-skin façade

The object of study being a standard stick system façade portion, are excluded from this work:

- windows
- doors
- portals (of garages)
- façade portions including openings automated systems and rotating external doors systems
- smoke and heat evacuation
- showcases

- façade having particular requirements (safety, intrusion or explosion resistance, buildings for public entertainment, banks, military buildings, etc.)
- elevators' envelope.

2.2. Definitions

2.2.1. Curtain wall

According to the UNI EN 13830, a curtain wall is a "part of the building envelope made of a framework usually consisting of horizontal and vertical profiles, connected together and anchored to the supporting structure of the building, and containing fixed and/or openable infills, which provides all the required functions of an internal or external wall or part thereof, but does not contribute to the load bearing or the stability of the structure of the building. Curtain walling is designed as a self-supporting construction which transmits dead-loads, imposed loads, environmental load (wind, snow, etc.) and seismic load to the main building structure" [13].

It is then a particular kind of external, non-bearing wall. Composed of repeated modular elements, usually manufactured then assembled on site, it ensures all the functions (and only them) of separation between exterior and interior [12].

Being non-structural elements, they only have to meet requirements related to safety, and do not contribute to stability [14]. The permanent load they have to carry is only composed of the façade components' self-weight. Acting forces consist of wind, explosion, earthquakes, thermal variation, opening of movable parts. Vertical members of a curtain wall system are usually supported on each storey's diaphragm members, so to smoothly transfer loads from the glass surface to the columns then from the columns to the diaphragm members through anchors and brackets [7].

2.2.2. Stick system

Façade stick systems consist in a carrier framework of site assembled components supporting glass, insulating glass units and infill panels [15]; the curtain wall frame and its components are installed and connected together piece by piece, from an exterior scaffolding. The order of assembly usually starts with mullions then transoms, spandrel panels and glazed parts.

Framed stick systems are typically designed using extruded aluminum components, although steel may also have been used in the past [6]. Mullion-to-transom joints are usually managed by aluminum shear blocks. The glazing can be either mechanically retained (typically by a perimetral pressure plate) or bonded (by at least a perimeter sealant).

With more than 60 years of presence on the market, these curtain walls have been characterized by an important product evolution, made possible by a strong adaptability of the system regarding transforming design expectancies and enhanced by their easy implementation (low costs, stockage simplicity and small implementing space required compared to other typologies) [12].

The main problem regarding stick system execution is the need for external scaffolding, as well as an elevated risk of bad sealing and tightness to external atmospheric agents. As for other building components, they require meticulous planning of delivery and quality control at every step of the execution.

Compared to other façade systems (e.g. unitized and semi-unitized, characterized by a highest production quality thanks to the assembly process in factory), stick curtain walls have a limited capacity to resist racking movement (mostly generated by seismic excitation [3]).

2.2.3. Frame components

Glass

Glass, or glazing, is a generic term covering glazed elements of various nature and composition [8]. Despite its prevalent mechanical use, and because of its relatively low tensile strength and brittle nature, glass poses challenges when overloaded [6]. The UNI 7697 distinguishes several types of glazing according to:

Application

- external: placed outside, or separating an outer environment from an inner environment
- internal: placed inside, or separating two internal environments

Assembly

- vertical: angle between the assembly surface and the vertical ≤ ±15°
- inclined: angle between the assembly surface and the vertical is in the interval ±15°÷±85°
- horizontal: angle between the assembly surface and the vertical ≥ ±85°

Others

- accessible: people may access it within planned used conditions
- non accessible: people may non access it within planned used conditions
- protected: when dispositions to eliminate fore sure any eventual risk of panel break have been adopted
- non protected: when there are none of the dispositions mentioned above

The present study focuses on external glazing, with vertical assembly, without specification about accessibility and protection.

Joint

Joints ensure connection and continuity between two separated elements or components, dealing with aesthetic as well as air, water, heat and noise tightness issues, eventually accommodating the building structure with the façade [12]. They may be open or sealed (with gaskets and sealant joints) [16]; in general, open joints perform well – although care is needed to ensure that adjacent panels do not impact on each other –, meanwhile sealed joints have to accommodate any relative movement of adjacent panels and should then be designed appropriately.

One of joints' purposes is to absorb movements, either structural, thermal, hygrometric, of one element or component with respect to another, helping to keep their integrity and guarantee their prestation. Some codes set minimum joint widths for this reason; for instance, in case of thermal dilatation, the ratio between the joint width and its depth is about 2/1 (maximum 3/1) [12].

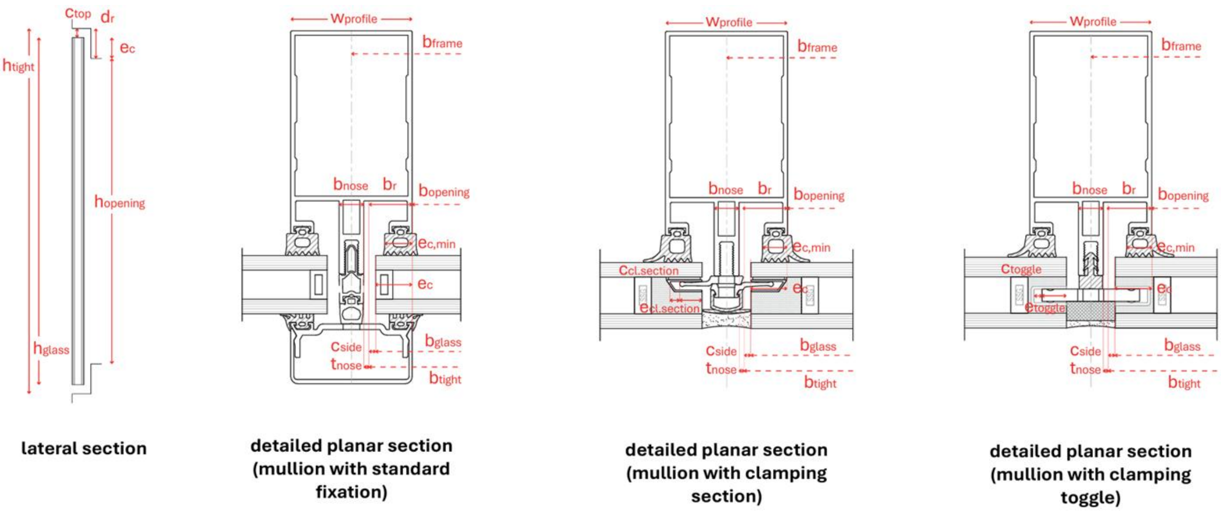

Figure 2.2—1: Localization of some of the geometrical boundaries for components of a stick system's frame (after CWCT's TN55 and Reynaers CW50-CW60 Catalog)

Clearance

Clearances are more particularly the empty parts of a joint located between a definite element and its neighbors (e.g. the edges of a glazing and of its frame, see "c_{side}" in Figure 2.2—1). While the term joint may be used generally and qualitatively talking about the building scale, this work will mostly deal with the term clearance since a part of the calculation deal with definite values of different kind of them, always related to a precise part of the detail design section.

(Glass) edge cover

This expression designates the part of glazing being gripped by the frame's gaskets (for the so-called "glass edge cover"; see "e_c" in Figure 2.2—1) and any other component (in the case of structurally clamped glazing, toggles and clamping profile also feature a corresponding edge cover). Though being a maintained area, the edge cover is expressed as the distance between the glazing edge and the limit of the gripped zone, expressed accordingly to a relative section.

2.2.4. Tolerance

An induced deviation is the permanent difference between a specified nominal value and the actual measured value due to manufacturing process and lack of absolute precision in human operation and instrumentation [17]. Tolerances define the limits of induced deviation for which allowance should be made in design and within which actual sizes are acceptable. Therefore, they describe how much variability is allowable.

Tolerances of both the supporting structure and the façade components will determine the final dimensions of any gaps or movement joints in the envelope and the movement accommodation at the fixings or brackets [11].

2.2.5. Racking

Racking is a displacement of the frame with rotation of the glass. Usually occurring under slab deflection, either uniform or differential, it is then distinct of simple elements deflection where only translation happens [2]. This study focuses on vertical racking, thus not considering the horizontal racking caused by building sway (e.g. under wind or seismic solicitation).

The process leading to vertical racking of glass panels can be summarized as follows:

- solicitations make the mullion deflect, so to say (vertically) translate. These forces may be mechanical (floor deflection under a given load) or thermal (dilatation and retractation of the frame in case of important temperature differences);
- the transom connected to the mullion starts to rotate;
- according to the type of shimming, the glazing may rotate as well (for bottom shimming) or stay straight (for side shimming) – yet in this last case, one cannot strictly speak about racking;
- movement is accommodated to the point where the glazing touches the frame; either because it rotated toward the mullion (bottom shimming) or because the upper transom rotated toward it (side shimming).

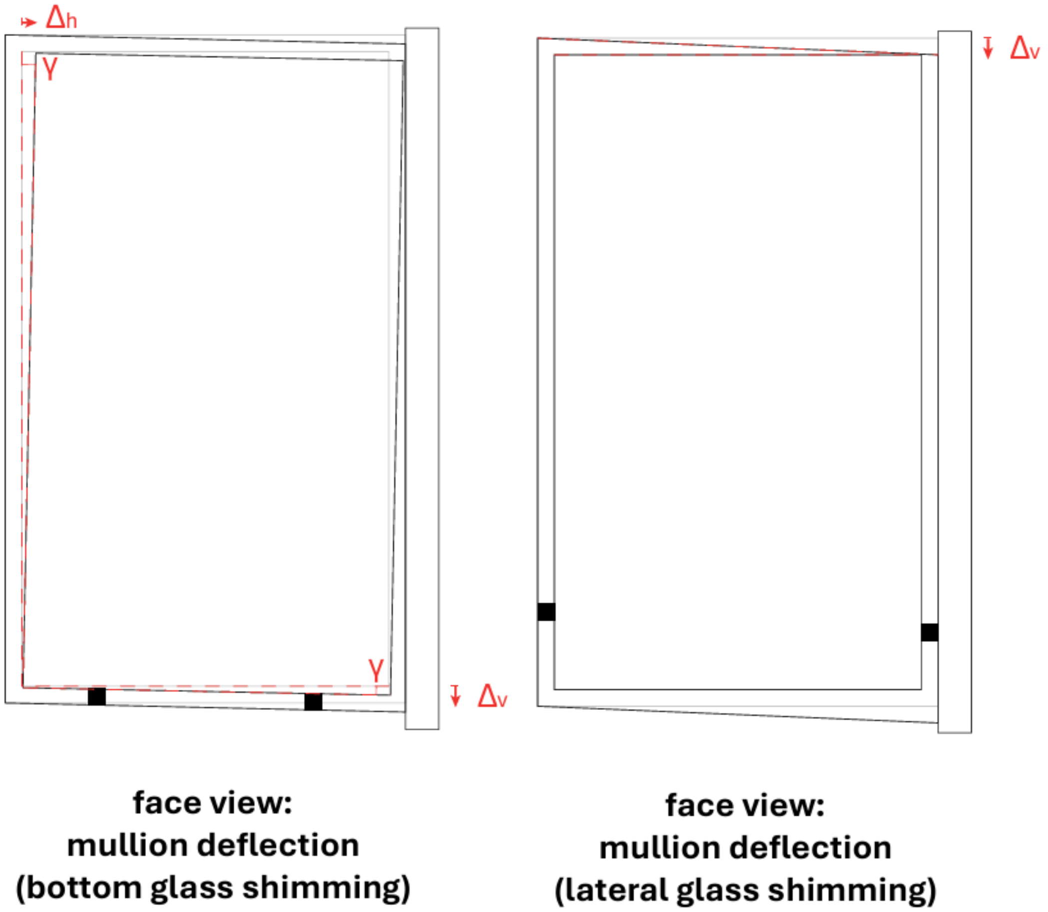

Figure 2.2—2: Mullion deflection for different glazing support (after CWCT's TN55 and Reynaers CW50-CW60 Catalog)

NB: it may occur for the type of shimming to be "mixed", with support blocks both at the bottom and on the side. In this case, the behavior is dominated by the side blocks that impeach rotation and the relevant typology should be side glass shimming.

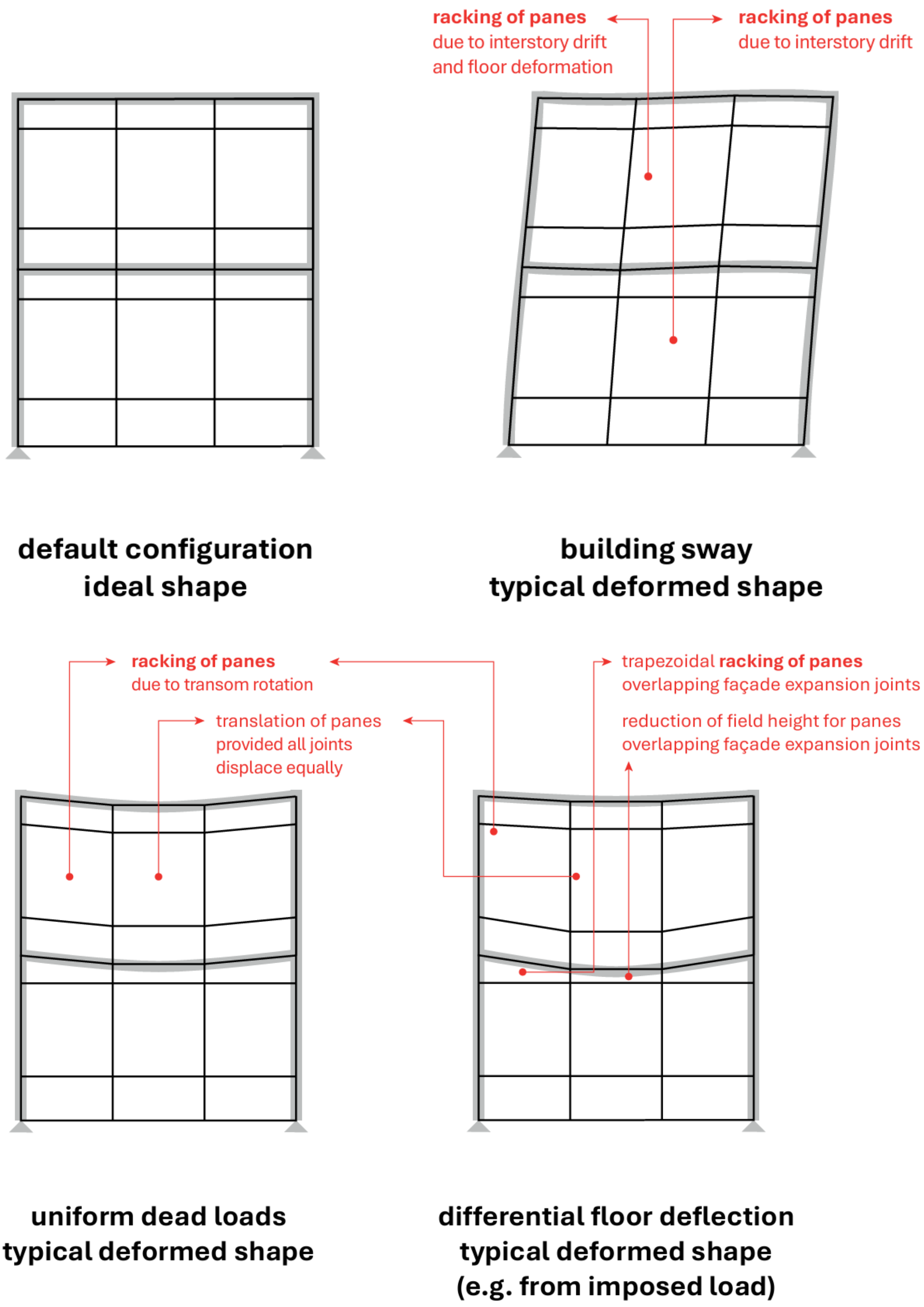

Figure 2.2—3: Identification of vertical racking cases among various types of building movement affecting the envelope (after Trifonov 2015)

3 State of the art

The following part will then introduce elements from the literature giving the theoretical ground for the R&D process and, consequently, for the present thesis. After having described how the information was found, the related documentation is contextualized and classified, highlighting the types of existing sources and their correlations. Then, the relevant current knowledge regarding the studied field is summarized, providing a sure, up-to-date foundation for the later work.

3.1. Preliminary retrieval

The available information comes from different kinds of sources of various origins. Materials and standards were provided in lectures of "advanced building envelope engineering – façade" and "innovation for building façades", some of them were also available in Faces database. Normative and builder's documentation were provided by Faces – since they served as departure materials – and are partially available online, on firm's websites. The academic papers come from manual retrieval of relevant references using Scopus, Lens Scholarly Search and ResearchGate.

Before going deeper in these precise documents, a small study has been conducted using the Google Trend tool evaluate the number of numeric searches regarding the studied subject. Given a searched term as an input, Google Trend furnishes graphs and tables summarizing this term's popularity online (with a variety of possible boundaries) and then, its relative importance.

This schematic retrieval started from "glass panels racking" and immediately related expressions which gave no significant results. It was then chosen to refer to the following terms/expression (from more general to more precise):

- building envelope
- (glass) curtain wall façade
- mullion

These terms were successively combined with the following subjects:

- movement accommodation
- racking
- deflection
- sway

There were no specified boundaries since the results are about the whole world for the total available period (from 2004 up to today) – plus, considering their low number (for most of the selected combinations), it would not be relevant to frame (for instance, geographically) this analysis leading to high discrepancies in the compared terms.

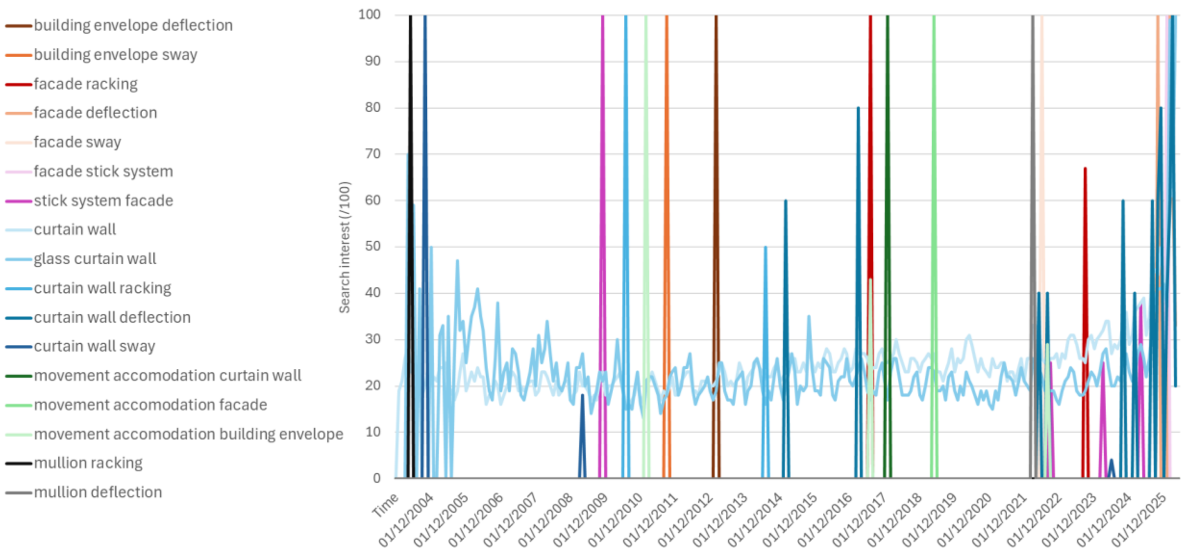

Figure 3.1—1: Web researches trends connected to racking of glass panels (source: Google Trends)

NB: How to read this graph. The y-axis displays the search interest according to a popularity index going from 0 to 100. 100 represents the absolute peak popularity for the searched term (at that moment, it hit its maximum share of total Google searches); 50 then means the term is half popular at that moment as it is at its peak. 0 means there was virtually no search interest (or not enough data to calculate a trend) [18].

Thus, the numerous high peaks at 100 express the existence of niche subjects that have been few dealt with. On the other hand, the low but quite regular results in the case of "curtain wall" and "glass curtain wall", the two most generic topics, highlight a continuous interest to this field, while we may almost distinguish a slow rise at the beginning of the 2020s. The only other combination of terms that seems to match this pattern, and feature more than a few isolated peaks of interest, is "curtain wall deflection".

This small synthesis then expresses how, despite being part a widely documented topic, the problem of glass panels racking remains relatively undocumented: only sporadic researches about scarcely connected aspects have been made.

3.2. Types of references

Sources about calculation of frame deflection for curtain walls emanate from both public and private actors. Researchers have been investigating the topic of curtain walls racking for the last thirty years, almost only within the frame of articles – describing both a theoretical field and some related experimentations. Besides them, the important ones are normative, with different geographical scales of application. The third most useful are guidelines edited by industrial operators. Finally, a specific category of industrial catalog has also been considered since it is the primary base for the Excel tool developed in parallel to this study.

3.2.1. Papers

Curtain wall technologies were mainly developed and spread during the last third of the 20th century. Being an innovative system, it took some decades before their long-term behavior, especially regarding the sustainability of the glass panels, was investigated [1] – probably pushed

[1] With the notable exceptions of the early works by Bouwkamp and Meehan about glass drift. [19] seems to be the foundation reference of this subject, quoted in a majority of the studied article.

by economic backslash and growing exigencies from contractors and authorities. The main aspect motivating the very first precise studies in this field is the seismic performance. Indeed, seismic racking may constrain the glass to touch the aluminum frame (leading to the development of tensions inside the panels, eventually up to breaking), but furthermore break the mullion-to-transom joint seals and allow water to ingress [3].

After significant earthquakes showed how vulnerable curtain walls might be regarding horizontal racking, papers started being edited about glass panels movement, trying to highlight the conditions in which maintaining the façade prestation. The first set of detailed works on this matter are the one conducted by Behr (with Minor, Norville, Brown, Belardi, and Culp)[2] and by Sucuoğlu and Vallabhan [20]. All of these, and the majority of the following ones, mostly focus on horizontal racking issues. Though providing an enriching reference framework, it does not give precise clue on vertical racking, and one has to wait for the 2010s to find mentions about this topic – initially mostly introduced in comparative studies as a minor interest case.

A second other main theme present in the bibliography is the behavior of curtain walls confronted by blast loads and explosions; along with seismic resistance, it became an increasing object of applications for both tests in labs and Finite Elements Methods (FEM). The first may include various protocols including shaking table (to assess the seismic performance of the systems[3]) test or in-plane racking test (to assess the drift capacity) [6]. The latter had to go through a development phase trying to connect empirical data with the computed results to assess the reliability of numerical models in predicting a curtain wall's behavior in these conditions. As for diverse engineering subjects, numerical methods grew in importance due to their ability to mitigate the financial burden associated with laboratory testing and to facilitate parametric studies involving diverse input variables. Finaly, lots of study do a review of existing regulation (especially those applied in specific countries) regarding movement accommodations and limitations for glazing façade panels.

As one can see, thus being part a developing topic, taking advantage of new technologies and processes, the precise problem of vertical racking in curtain walls remains few documented. Further information has to be found outside of the mere academic field.

3.2.2. Normative

For most topics, including continuous façade, different levels of standards may be identified: international/local, and general/material specific.

International standards

Usually linked to the International Standards Organization (ISO), the normative given at an international level are, nowadays in Italy, mostly coming from the European Union level (European Standards, EN). The main reference document in this category for the present study is then the:

- EN 13830 "Curtain walling – Product standard"

Specifying the requirements of curtain wall building envelope, aimed at providing resistance to atmospheric agent, energy economy, heat retention, and more connected to the case study, to safety in use (providing methods of testing, evaluation, calculation and related prestation criteria to ensure conformity) [13]. The document has then been re-elaborated by the UNI for the Italian context.

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[2] The latter of these being [10].

[3] Including serviceability concerns. For instance, Australia's and New Zealand's building construction codes require that a prototype should pass weather testing both before and after a simulated SLS seismic event [3].

UNI

The UNI normative from the *Ente Italiano di Normazione* statues on Italian specification. Since they were not all directly used in the present study but may be quoted as theoretical ground for some of the next sources (especially the guidelines mentioned in §3.2.3), the relevant standards have been listed here to provide the reader with some indications.

- UNI 6534: Vetrazioni in opere edilizie. Progettazione, materiali e posa in opera. Cap. 3.6.1
- UNI 8369-2:1987 - Edilizia. Pareti perimetrali verticali. Classificazione e terminologia, punto 2.6
- UNI EN 755-1 Alluminio e leghe di alluminio - Barre, tubi e profilati estrusi - Condizioni tecniche di fornitura e collaudo
- UNI EN 755-2 Alluminio e leghe di alluminio - Barre, tubi e profilati estrusi - Caratteristiche meccaniche
- UNI 11173 Serramenti esterni e facciate continue - Criteri di scelta delle caratteristiche prestazionali di permeabilità all'aria, tenuta all'acqua e resistenza al carico del vento
- UNI EN 13119 Facciate continue – Terminologia
- (UNI EN 13830 Facciate continue – Norma di prodotto)

NTC 2018

The study being grounded within the Italian context, one cannot avoid referring to the *Norme tecniche per le costruzioni* (technical normative for the constructions) in their 2018 update that provide all the methodological process to model and verify structures.

- DM 12/01/2018: Aggiornamento delle "Norme tecniche per le costruzioni"

During the tool development, they were mainly used to statue about the thermal dilatation issue (§3.5 *Azione della temperature* being the main reference for this work's §5.2 *Thermal dimension variation*) [21].

Eurocodes

For the last three decades, Eurocodes are the common framework used in structure calculation by most of European engineering entities – the Italian NTC partially relying on them. Though not directly used in this study, one can still refer to the following issues:

- EN 1990:2002: Eurocode - Basis of structural design
- EN 1993-1-1, Eurocode 3: Design of steel structures (Part 1-1: General rules and rules for buildings)
- EN 1999-1-1, Eurocode 9: Design of aluminum structures (Part 1-1: General structural rules)

3.2.3. Guidelines

Mostly issued by private actors, guidelines provide further, more specific, and problem-solving oriented theorical resource.

CWCT

Located in the UK, the Center for Window and Cladding Technology (CWCT) is an independent industry-funded publisher of standard, guidance and technical publications [22],[23]. Its standards are redacted under the supervision of architects, consultants, contractors and manufacturers. Expertise area of CWCT particularly feature curtain walling systems, covering loading and movement issues.

The very CWCT's documents used in this work mainly consist of so-called "technical notes" and "technical update", short documents synthesizing stakes and calculation methods for a specific matter:

- CWT Technical Note No. 20: Design of sealant joints

- CWT Technical Note No. 21: Tolerance, fit and appearance of cladding
- CWT Technical Note No. 30: Cladding of buildings subject to earthquakes18
- CWT Technical Note No. 55: Movement accommodation in building envelopes
- CWT Technical Note No. 56: Accommodation of structural movement
- CWT Technical Note No. 57: Cladding movement
- CWT Technical Update No. 18: Allowable deflections

UNICMI

The UNICMI (*Unione Nazionale delle Industrie delle Costruzioni Metalliche dell'Involucro e dei serramenti*, national union of envelope, windows and doors metal construction industries) is a consortium of Italian firms dealing with building envelope, structures and equipment – especially curtain walls and glazing [24]. It aims at updating and improving the technological and qualitative level of the sector's production, providing help and information to its members, producers' associations and other market actors. The UNICMI works indeed as an interface between them and the regulation authorities, also proposing specialized training.

The UNCSAAL (*Unione Nazionale Costruttori Serramenti Alluminio Acciaio Leghe*, National Union of Windows and Doors St Construction) is an inner UNICMI society whose purpose is to communicate about these last activities as well as develop resources for designers and constructors.

UX60 Guida alla posa in opera delle facciate continue

This document provides a peculiarly precise way of defining the curtain wall theoretical field, that has guided the following work (cf. §2.1.2 *Study framework*), especially in quoting main normative references, defining key concepts, distinguishing and providing tolerance values.

X83 Linee guide per la progettazione e la posa in opera delle facciate ventilate

Though focusing on ventilated (and opaque) façade, this document summarizes best practices for designing and installing façades (such as the need for controlled dilatation through the use of clamping guaranteeing sliding in one direction), also synthesizing limits value for project geometry and deformations.

3.2.4. Builder's documentation

The whole study is built on a few documents issued by the Belgian firm specialized in metalwork Reynaers Aluminum, identified by Faces Engineering consultants as their only example of numerical values calculated for mullion deflection.

Reynaers' Nomenclature

Reynaers' solutions names are built as a combination of the following elements:

- CW: concept wall
- 50 or 60: mullion width in mm
- HI: high insulation
- SC: structurally clamped

"CW50" meaning, for instance, that a standard fixation curtain wall with 50 mm thick profiles is considered.

Reynaers' catalogs

CW50-CW60

Within this catalog, the problem of racking is particularly addressed (§B.IV) [25]. In the related section, the manufacturer introduces an overview of the problem for stick façades and related hypothesis to compute the movement accommodation of its components. Especially, it provides a set of tables giving the mullion deflection values according to the glazing dimensions, completed by detailed dimensioned mullion sections.

Reynaers' explicitly quoted theorical framework is CWCT's Technical note 56. It insists on the accommodation of racking movement caused by floor deflection, stressing the role played in it by the edge clearance, as well as the importance of parameters such as proportions of the glazing unit [25].

Specific boundary conditions are hypothesized in order to ensure the prestation of the curtain wall. The minimum glass edge cover is set at 11 mm, and the tolerances are taken into account as a 2 mm margin around the mullion nose. Without further explanations, it may be assumed that these 2 mm group both tolerances for glazing production (usually 1 mm) and façade installation (1 mm). For structurally clamped glazing, a supplementary limit is introduced since the clamping edge cover should not be under 5 mm. The general idea in evaluating the mullion deflection is that it corresponds to the point right before collision happens between the glass and the frame (or the clamping element).

The various cases considered by Reynaers depend on parameters such as glass overlap, solution and use of toggle/clamping profile (for more details: cf. §B *Appendix*):

Table 3.2—1: List of tables given by Reynaers regarding mullion deflection

Reynaer's table	Profile width and type [mm]	Glass overlap [mm]	Glazing fixation
1	50	15	Standard
2	50 / 50-HI	13	Standard
3	60 / 60-HI	18	Standard
4	50-SC	15	Clamping profile
5	50-SC	13	Clamping profile
6	50-SC	15	Toggle
7	50-SC	13	Toggle
8	60-SC	20	Clamping profile
9	60-SC	20	Toggle

Everything that has been said so far is valid within the case of bottom glass shimming. Reynaer shortly considers the case of side glass shimming where the maximum allowed mullion deflection is much simpler to evaluate, since in a configuration where the glass panel remains totally vertical, it is equal to the clearance between the glass and the upper transom, taking the tolerances into account (in this case, -2 mm).

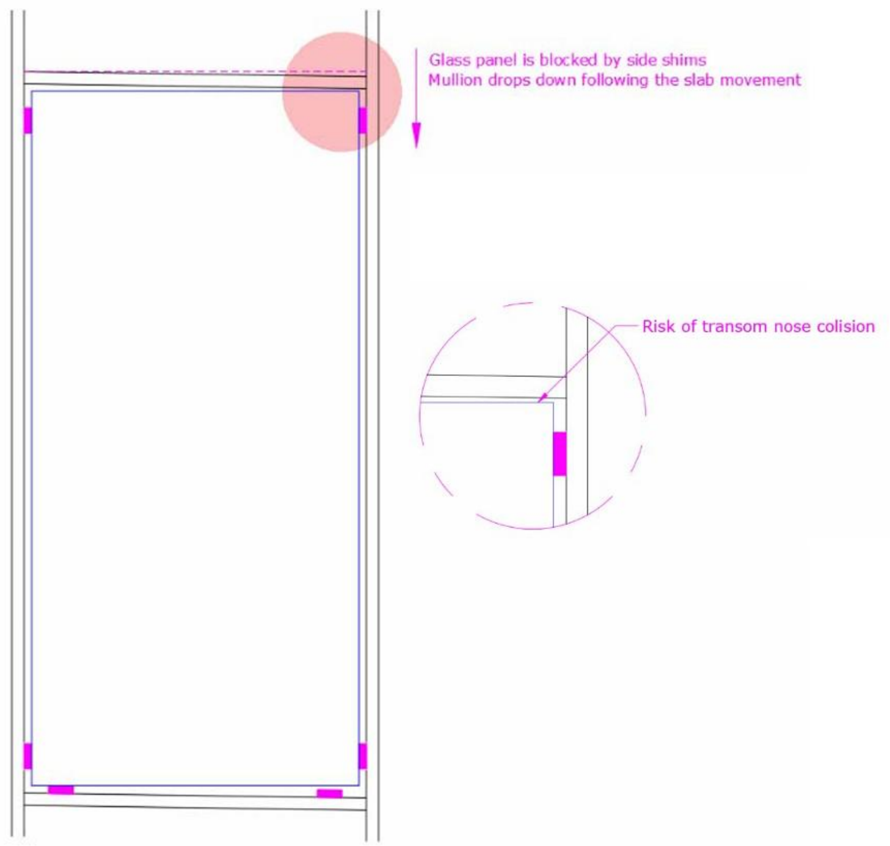

Figure 3.2—1: Reynaer's scheme: "racking" in side glass shimming configuration (source: CW50-CW60 § IV.2.3 Solution for more movement accommodation*)*

CW50-CW60

This second catalog features test configurations with details on façade fixation that were used to verify their products.

Details

.dwg catalogs are available on Reynaers' website and, regrouping the ensemble of technical solutions developed by the industrial (such as all its mullions, or fixing strips types), it provides a precious insight into the design solutions to be taken into account while developing a related calculation tool.

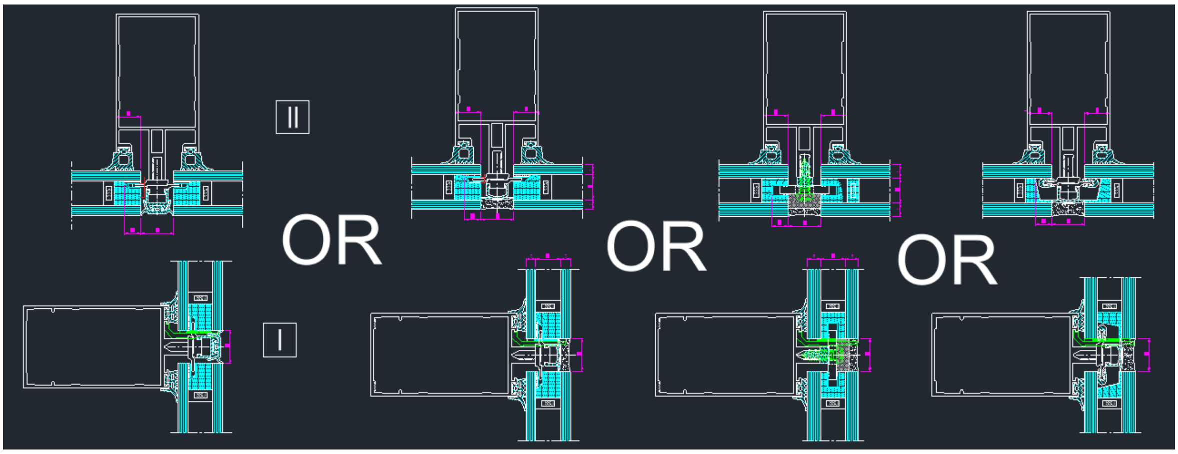

Figure 3.2—2: Example of mullion and transom connections for 50 mm profiles with structurally clamped glazing (source: cw_50_&_60_architect_overview.dwg)

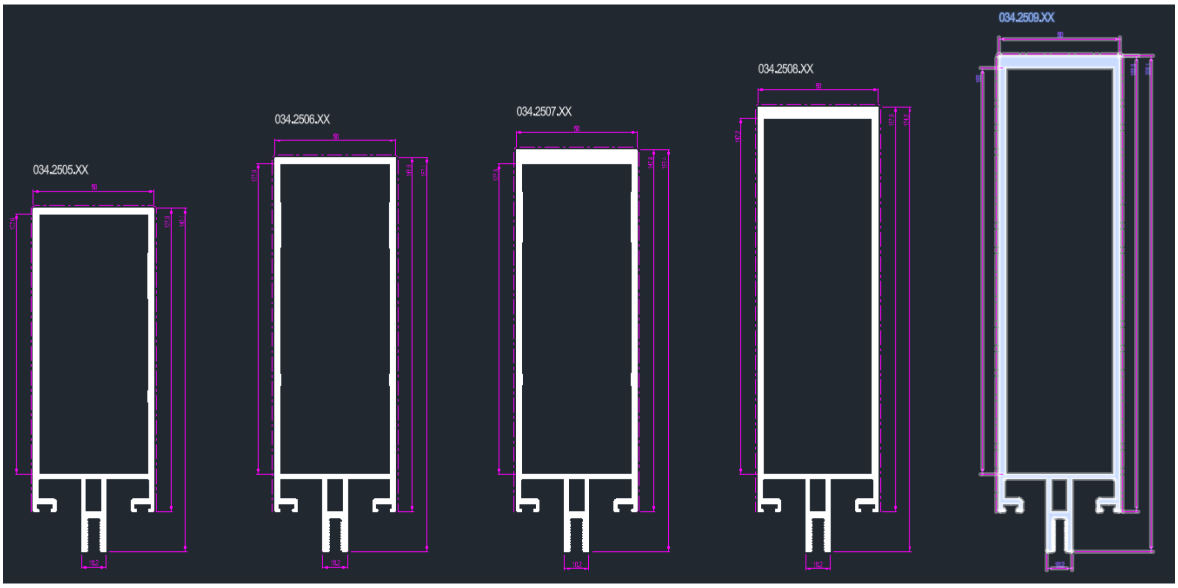

Figure 3.2—3: Example of detailed mullion sections for 50 mm profiles (source: cw_50_&_60_architect_overview.dwg)

Other firms' information

Other firms' documentation has been investigated, without providing further highlight to the specific case study, since variations between constructors endanger the coherency of the calculation tool. However, a quick retrieval may help confirm some details (e.g. the mullion nose standard width, being 10.2 mm for Reynaers, is 10 mm for Schüco and 11 mm for AluK and Wicona).

3.3. Existing theorical framework

Having investigated and classified all the relevant sources of the study, one can now consider all the information retrieved connected to mullion deflection and glazing racking issues.

3.3.1. Structural behavior of façades

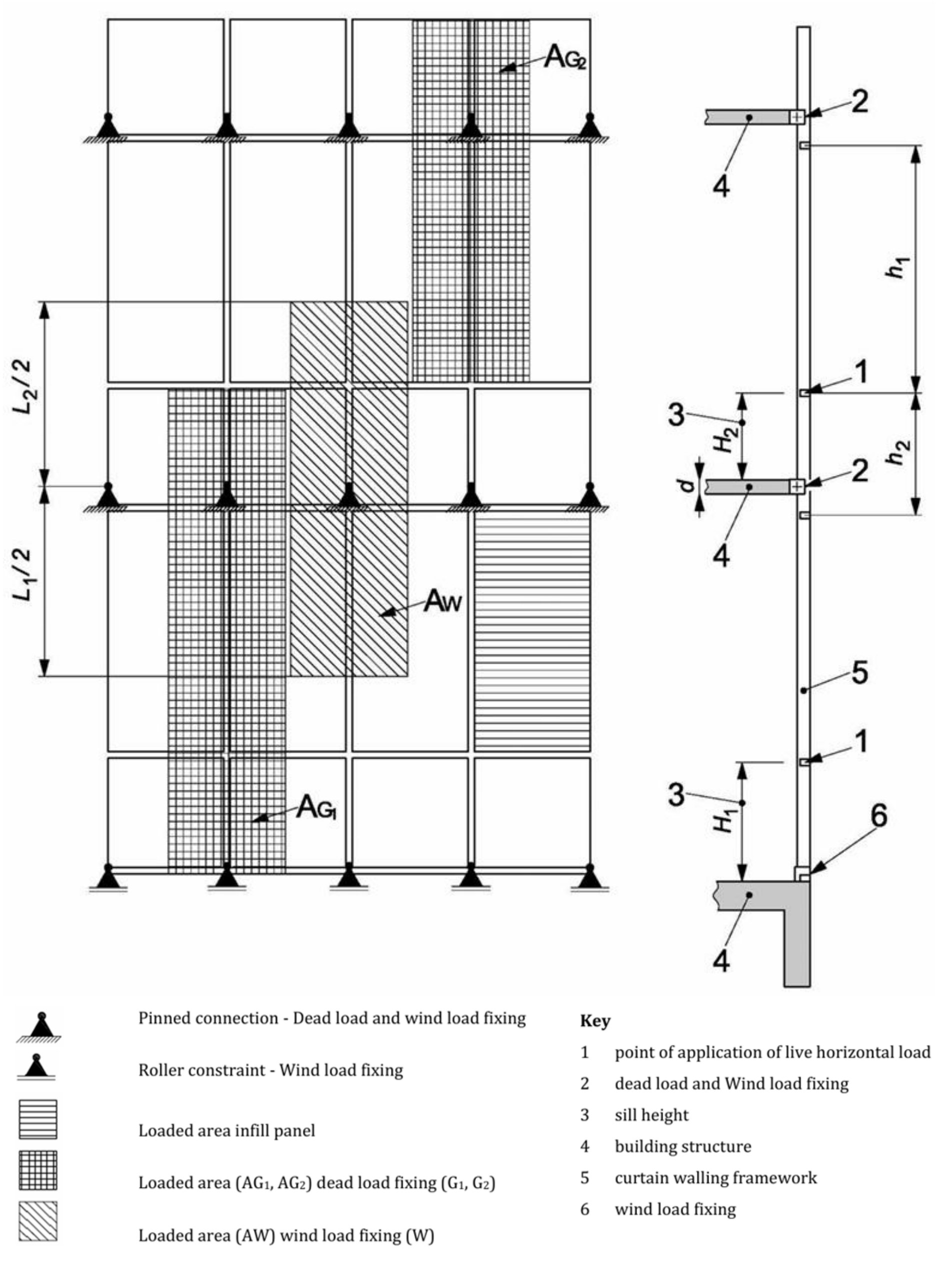

Figure 3.3—1: Curtain wall typical fixing and loaded area (source: UNI EN 13830:2020 A.1)

Façade mullions are modelled structurally as vertical beams anchored to the façade, usually at the level of a floor's slab, by the mean of a pin or a roller (depending of the connection type). For both of these cases, the vertical displacement is a degree of freedom.

Anchorage attachments play a significant role mostly influenced by factors like span lengths, temperature fluctuations, design loads and considerations for seismic or wind events and determining the size, shape and placement of attachment anchors. These attachments lead unavoidably to diverse responses during wind and seismic events, accommodating movements and rotations while maintaining flexibility [6]. Studies have also shown that a displacement applied to the curtain wall through certain fastener models may be dissipated and the stress not transmitted to other members [9].

As described earlier, the study did not focus on applied loads but on movement, supposedly provoked by slab deflection (cf. §2.2.5 *Racking*). Different movement modes, although they do not represent an actual issue on their own, may become critical when combined with others[4]; e.g. vertical racking of panes reduces the capacity of the envelope for accommodating interstorey drift [2].

3.3.2. Vertical racking

Considerable displacements of the primary bearing system of the building, caused by wind or earthquake, must be entirely followed by the glazed curtain wall. Huge racking forces occur during these displacements, compromising the integrity of connections between façade and bearing structure, disintegrating the sealants and eventually leading to the destruction of the entire wall. For these reasons, during designing curtain walls, a special attention must be paid to adequate connection design between the façade structure and main bearing system of the building [4].

Racking can be dealt with four kind of approaches: edge clearance (between the edge of the glass and the frame when fracture occurs as the glass undergoes in-plane deformation), rocking (exterior panels rotate to absorb the in-place deformation – during earthquakes, against the inter-story drift of the building), swaying (exterior panels' upper part can move horizontally) and structural silicone glazing [9].

Stick curtain walls accommodate movement mainly in their edge clearance (with or without rotation of the perimeter frame) as glass panes float within the frame after overcoming the friction between glass and gaskets (failure mechanism being typically edge damage or breakage of glass) [2]. Overall, the methodology proposed by CWCT almost only relies on said edge clearance to avoid glass to frame contact.

The displacement of glass panels subjected to in-plane loads can be seen as the sum of two components: rigid body rotation, until the contact between glass panel and frame, and diagonal compressive deformation after the contact happens [19]. However, a safe design should avoid said contact: it then represents a displacement limit not to overcome, replacing the problem as a mere rotation.

Assuming the dimensions of the frame components do not vary (the mullion and transom do not dilate nor contract, and the considered distance are still measured from axis to axis), the allowed rotation angle γ is the same on each side of the panel regarding its original position and can be characterized as follows [2]:

$$tg(\gamma) = \frac{\Delta_v}{b_{frame}} = \frac{\Delta_h}{h_{frame}} \ [-] \qquad (3.3.2\text{-}1)$$

The allowed lateral displacement is given by:

$$\Delta_h = c_{side} - t_c \ [mm] \qquad (3.3.2\text{-}2)$$

With:

- c_{side} the clearance on the side [mm]
- t_c the tolerance of the edge clearance [mm]

The allowed vertical displacement my then be calculated as:

$$\Delta_v = \frac{(c_{side} - t_c).b_{frame}}{(h_{frame} - 2c_{side})} \approx \frac{(c_{side} - t_c).b_{frame}}{h_{frame}} \ [mm] \qquad (3.3.2\text{-}3)$$

[4] Cf. Eurocode 0 for types combinations and their related coefficients Ψ.

NB: [2] provides a formula considering a slightly corrected measure of the frame height, that has been neglected here:

$$\left(h_{frame} - 2c_{side}\right) \approx h_{frame} \text{ since } h_{frame} \gg c_{side} \; [mm] \quad (3.3.2\text{-}4)$$

For tall and narrow panes, the capacity for vertical racking can be modified (and actually, in most of the cases, increased) using side blocks (for side glass shimming, instead of bottom glass shimming). The ultimate vertical displacement of the transoms then becomes:

$$\Delta_v = c - t_c (= \Delta_h) \; [mm] \quad (3.3.2\text{-}5)$$

However, according to [2], the use of side blocks may lead the glass pane to be subjected to diagonal compression from dead load, then reducing the capacity for horizontal racking.

Without rotation of the pane (typically for side glass shimming), displacement of the frame normally occurs under differential slab deflection if a pane overlaps a mullion expansion joint (expansion joints usually have greater movement capacity) [2]. Thus, the ultimate differential displacement of transom ends is:

$$\Delta_{h,transom} = c_{side} - t_c - \Delta_{h,transom} \; [mm] \quad (3.3.2\text{-}6)$$

With:

- c_{side} the clearance on the side [mm]
- t_c the tolerance of the edge clearance [mm]
- $\Delta_{h,transom}$ the transom deflection under dead load of glass [mm]

Typical indicated value for the tolerance of the edge clearance is 1.5 mm for capped systems. The value of the transom deflection should not exceed the minimum between 3 mm and l/500.

This way of modeling the problem is consistent with Reynaers' approach (cf. §3.2.4 *Builder's documentation*) that is still simpler, since it does not consider the impact of the dead load of glass. Yet these calculations tend to be conservative [3]; deviations exist between analytic approaches, widely used in Europe, and the actual movement capacities achievable in tests [2].

The approach supra represents a considerable progress regarding the previous limitations provided by the CWCT in 2007 [26]. Indeed, 50 mm wide transoms were directly assumed to accommodate floor differential vertical movement up to 4 mm, and 9 mm in the case 60 mm, precising that the exact movement accommodation may be less.

Note on unitized systems

Compared to stick system, unitized curtain walls have a greater capacity to accept large racking movement since, instead of the clearance, it is the joints between panels that deal with it. During earthquakes, unitized panels remain rectangular and rigid, and are able to rotate according to the said joints opening and closing. Glass components remain within their frame and do not have any forces due to structural movement imposed on them [3].

3.3.3. Façade and structural elements deflection

Structural movement is a combination of floor deflection, column shortening, wind sway, seismic sway, settlement and thermal movement; its effect is relative, not absolute [26]. Large floor spans are designed for serviceability and checked for acceptable strength; their deflection limits are given by structural codes. Building envelope, however, require tighter deflection limits. The actual deflection is often smaller than the calculated one. When giving an allowable deflection of slabs of L/250 [2], the Eurocodes does not specifically refer to glazed buildings and do not recommend allowable displacements for such [5].

Here are limits arrow values that can be put in comparison with the studied deflection [14],[27].

- For mullions: $\delta_{lim,mullion} = \frac{L}{200}$ with L the vertical span between two successive fixings ≤ 3000 mm; $5 + \frac{L}{200}$ for 3000 < L < 7500; $\frac{L}{250}$ for L ≥ 7500.
- For transoms: $\delta_{lim,transom,v} = \frac{L}{300}$ with L the horizontal span, in the case of vertical deflection due to elements weight (for deflection in the horizonal plane, $\delta_{lim,transom,h} = \frac{L}{100}$)

When combined aluminum profiles deflect less than the 1/200 limit, the shift of their components can be disregarded [28]. The given mullion limits are often considered for cases of frontal deflection due to wind loads [29].

Mullion shortening due to slab deflection

Mullion movement can be limited by the ability to seal the gap and the ability of the glazing opening to contract without contacting the glass. The considered distance in this case is:

$$\Delta_{h,mullion} = c_{top} - \Delta_{h,transom}\ [mm] \qquad (3.3.3\text{-}1)$$

With:

- c_{top} the edge clearance of the top rebate [mm]
- $\Delta_{h,transom}$ the transom deflection [mm]

The phenomenon of mullion shortening, as well as racking (and shear) of the wall, can be limited by the glass and infill panels [26].

3.3.4. Clearance

The edge clearance between the glass and the frame governs the ability of framing members in a stick curtain wall to move or deflect in plane without contacting the glass [26]. Thus, improvement of the movement accommodation of the building envelope may be achieved through the use of wider joints and/or wider framing member, smaller panels and/or more joints. However, at best the movement accommodation of a building envelope can only be varied by a factor of two before the appearance becomes radically different and a different method of construction may be required [11]. The clearance between glass and profile can be calculated as follows:

$$c = \frac{b_{frame} - b_{nose} - b_{glass}}{2} = \frac{b_{tight} - b_{glass}}{2} = b_r - e_c\ [mm] \qquad (3.3.4\text{-}1)$$

With:

- b_{frame} the frame width [mm]
- b_{nose} the profile nose width [mm]
- b_{glass} the glass panel width [mm]
- b_{tight} the tight size of the frame [mm]
- b_r the rebate depth [mm]

[5] Besides, Eurocode 2 allows designers of reinforced concrete structures to omit completely the calculation of vertical deflections if certain span to depth ratios are maintained – this not encouraging structural engineers to undertake complicated and time-consuming analysis to determine the movements form all individual load cases.

- e_c the edge cover

Since a minimum dimension of edge cover is required to accommodate gaskets or seals and transfer wind load from glass to frame, increasing the edge clearance means using a profile with greater rebate depth.

3.3.5. Tolerances

Design and building structure

The design of the facade and its anchors must take into account the structural tolerances, defined with respect to three axes [12]:

- X-axis: horizontal, within the plane of the facade, + towards the right.
- Y-axis: vertical, within the plane of the facade, + upwards.
- Z-axis: horizontal, perpendicular to the facade, + towards the interior of the building.

Tolerances generally refer to the significant points of interaction between the facade and the structure—specifically, points used for securing anchors, points that may cause physical interference, points that limit assembly clearance, or those that prevent the opening of windows and doors.

Any significant point of the structure interacting with the facade cannot deviate from its theoretical position by more than ± 25 mm along the three defined axes. Furthermore, the following more restrictive local tolerances apply (the first three are applicable not only to the axes and elevations of two successive structural elements but also to the distances between two significant points belonging to them):

- Center-to-center distance between two successive columns or load-bearing walls (X and Z): ± 20 mm
- Height between two successive floor slabs (Y): ± 20 mm
- Out-of-plumb between two successive floor slabs (Z): ± 20 mm
- Elevation difference between similar points on the same floor slab (Y): ± 10 mm
- Out-of-plumb between points of the same column (Z): ± 10 mm

Façade structure

The assembly tolerances of the curtain wall are much smaller than the structure's ones, taken into consideration throughout the use of joints (or clearances) allowing on-field adaptation then translation (vertical for mullions, horizontal for transoms) to accommodate loads cases and thermal movements [12].

Inserts may be positioned within the structure with the following tolerances:

- ± 10 mm parallel to the reference line
- ± 5 mm perpendicular to the reference line

Furthermore, the facade must satisfy aesthetic requirements for verticality and the alignment of continuous vertical and horizontal lines.

- Vertical Lines: Points must not deviate by more than ± 5 mm from the theoretical vertical line established by a plumb line (± 10 mm if the building has more than 10 floors; these values are doubled if facade installation begins before the structure of all floors is completed). Additionally, deviation must not exceed ±2 mm between points on the same floor (if height 3.5 m; otherwise ± 3 mm).
- Horizontal Lines: Points must not deviate from the theoretical horizontal level by more than ± 5 mm (± 2 mm between points on the same facade module).

Cladding

For the completed cladding, tolerances are generally required to achieve a satisfactory appearance, rather affected by relative positions of the visible cladding elements than absolute spatial position [17].

- Line ± 2 mm in any one storey height, or structural bay width, and ± 5 mm overall
- Level ± 2 mm in any one structural bay, and ± 5 mm overall
- Plumb ± 2 mm in any storey height, and ± 5 mm overall
- Plane ± 2 mm in any one storey height, or structural bay width, and ± 5 mm overall
- Widths of fixed joints should not vary by more than 10% of the minimum joint width
- Offsets at joints should not exceed 10% of the joint width in plane, or out of plane.

Calculation model

Dimensions of building components can be given as mean values, otherwise as maximum or minimum values [17]. In this case, a fitting component is described by its minimum value, and a fitted component by its maximum value, the joint between them having to be superior to the sum of the tolerances.

For instance, given an opening whose width is W with a tolerance of +2w/-0, a frame F +0/-2f and a joint J +/-j then:

$$W \geq F + (J - j) \text{ and } f + w \leq j \; [mm] \tag{3.3.5-1}$$

The mullion maximum length is equal to the interstorey height.

Besides minimum relevant distances between the profile and the wall, local regulation mechanisms have to comply with eventual verticality and coplanarity defects, for which a tolerance of around 1 cm is generally admitted for the installation [14].

3.3.6. Thermal movement

Dimensions variations of building elements due to thermal variations can be calculated as [30]:

$$\delta = \alpha \cdot \Delta t \cdot L_0 \; [mm] \tag{3.3.6-1}$$

$$L' = L_0 + \delta = L_0(1 + \alpha \cdot \Delta t) \; [mm] \tag{3.3.6-2}$$

With:

- $\delta \; (= \Delta L)$ the change of dimensions [mm]
- α the thermal coefficient of expansion [°C^{-1}]
- Δt the temperature change [°C]
- L_0 and L' the original and final length [mm]

Table 3.3—1: Thermal coefficient of expansion for some building envelope materials (source: NTC 2018)

Material	α [1/°C]
Aluminium	$2.40 \cdot 10^{-5}$
Glass	$9.00 \cdot 10^{-6}$
Lightweight concrete	$7.00 \cdot 10^{-6}$
Masonry	$3.00 \cdot 10^{-6}$
PVC	$7.00 \cdot 10^{-5}$
Steel	$1.20 \cdot 10^{-5}$
Steel-concrete composite structure	$1.20 \cdot 10^{-5}$
Structural concrete	$1.00 \cdot 10^{-5}$
Wood (orthogonal to the fibers)	$5.00 \cdot 10^{-5}$
Wood (parallel to the fibers)	$5.00 \cdot 10^{-6}$

For unrestrained components, bowing may occur, as well as dishing. Restrained thermal movements generate stress (equal to E·δ). However, these issues regard mostly the frame and their effect may be neglected when studying racking of glazing).

3.3.7. Glass shimming

Setting blocks used to maintain the glass panel's position inside the frame have to be more than 5 mm thick [12]. UNI 6534 provide indication about how to position them. Other requirements are:

- The report of the length of individual setting blocks (L) to pane surface area (S):
  $L\ [cm] = 2.5S\ [m^2]$ for elastomer or plastic blocks;
  $L\ [cm] = 1S\ [m^2]$ for hardwood blocks:
- The distance from the corner must be approximatively 1/10 of the length of the pane side for both operable sashes and fixed modules.
- The positioning has to be as provided in the shop drawings and design calculations (ensuring that resulting deformations do not exceed specified requirements).
- For Insulating Glass Units (IGU), the blocks must support both panes of glass.

Finally, some spacer blocks (location blocks) must be placed in correspondence with the setting blocks and, if necessary, at the center of the side.

3.3.8. Horizontal sway

The standard approach to horizontal in-plane racking shares common features with the problem of vertical racking, although it is much more developed, due to its specific interest in seismic resistance [13]. Similarly to vertical racking, the movement can be expressed as a function of the rotation angle and the interstorey height:

$$\Delta_h = h \cdot \tan(\gamma)\ [mm] \tag{3.3.8-1}$$

With:

- Δ_h the lateral displacement [mm]
- h the interstorey height [mm]
- γ the rotation angle between the initial and the deformed configuration of the frame mullion [°]

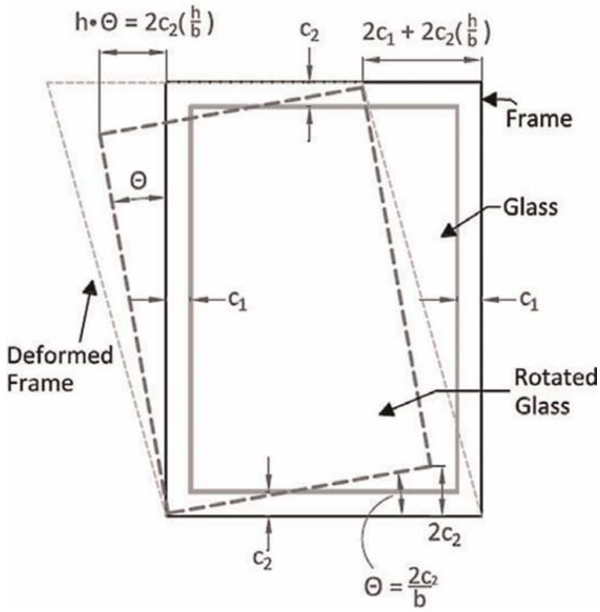

Figure 3.3—2: Illustration of geometric parameters to determine drift at initial glass-to-fame contact (source: Momeni et Bedon 2024)

Sway under seismic excitation

Earthquake movements occur according to a 3D spectrum, though when it comes to the study of a building frame, they often are simplified as sideways in one direction or inter storey drift [3]. When an exterior frame of a building deforms under the translational and/or torsional effects of ground excitation, it imposes similar deformations on the enclosed enveloping components which possess negligible lateral stiffness. Thus, window glass panels survive earthquakes as long as they cope with their supporting frame deformations [20].

In-plane deformation of window panels under horizontal shear takes place in two subsequent phases. First, the window frame deforms and the glass plate translates within the frame until they come in contact at tow opposite corners of the glass plate; this may be defined as the rigid body motion of the glass plate in the window frame, depending on the clearance between glass panel and the window frame – but also on the resiliency of the sealant material. Second, the glass plate further rotates until its opposite corners coincide with the adjacent frame corners.

The total lateral deformation of the window panel due to the rigid body motion of the glass panel in the window frame can be expressed in terms of their geometric characteristics:

$$\Delta_h = 2\mathrm{c}_{side}\left(1 + \frac{\mathrm{h}_{frame}}{\mathrm{b}_{frame}}\right)\ [mm] \qquad (3.3.8\text{-}2)$$

With:

- c_{side} the clearance on each side [mm]
- h_{frame} the height of the frame [mm]
- b_{frame} the width of the frame [mm]

This expression is only valid for windows panels having lateral drift capacity: i.e., their sealant is resilient enough and permits the relative motion of glass plates with respect to the window frame.

Horizontal movement accommodation

The movement accommodation is function of the edge clearance and of the inverse of the panels size (glazing and infills). Considering any sealant joints – combined with appropriate mullion to transom seals, and edge cover for gaskets – it then conditions serviceability performance [13].

A common test configuration consists in having a fixed base while movement is applied at the head of the curtain wall, as shown in Figure 3.3—3, the reverse approach also being acceptable (fixed head and movement applied at the base). For larger specimens of stick construction, the normative proposes a prototype configuration on two storeys (cf. Figure 3.3—4).

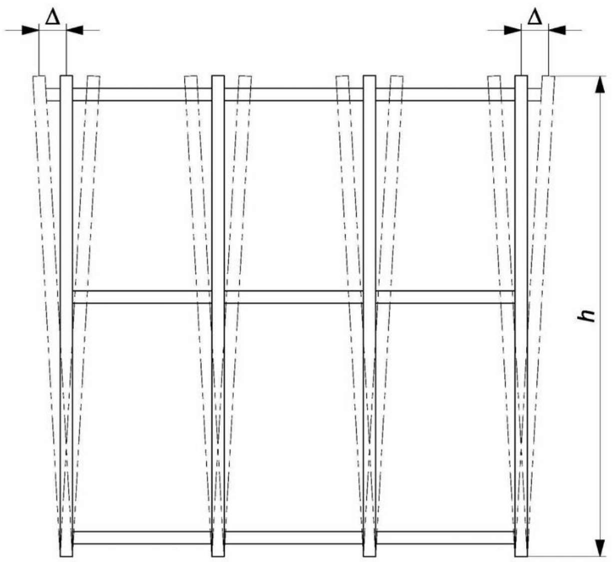

Figure 3.3—3: Seismic test specimen for stick construction one storey height (source: UNI EN 13830:2020 B.1)

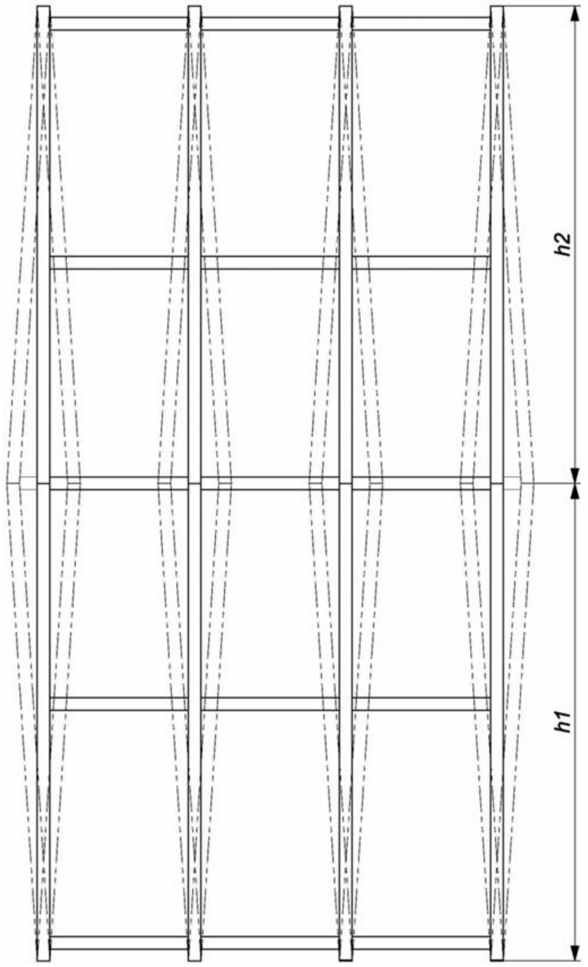

Figure 3.3—4: Seismic test specimen for stick construction two storeys height (source: UNI EN 13830:2020 B.2)

The reader may then see that, in the case of unitized systems, the approach remains similar, except for the measured deformation which value at each level has to be summed:

$$\Delta_{tot,1} = \Delta_1 \; [mm] \tag{3.3.8-3}$$

$$\Delta_{tot,2} = \Delta_1 + \Delta_2 \; [mm] \tag{3.3.8-4}$$

With:

- $\Delta_{tot,i}$ the lateral displacement at level i [mm]
- Δ_i the lateral displacement from level $i-1$ to i [mm]

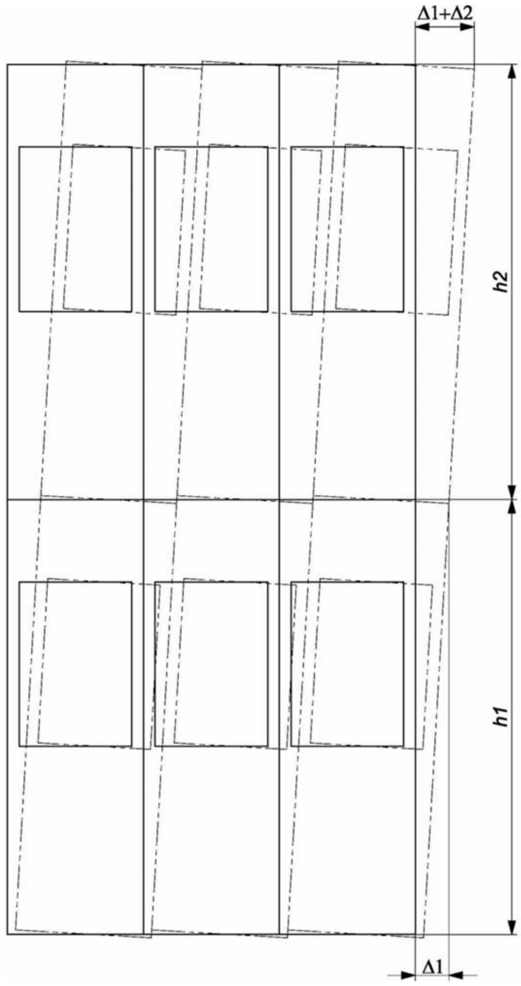

Figure 3.3—5: Seismic test specimen for unitized construction two storeys height (source: UNI EN 13830:2020 B.3)

Horizontal movement restriction

The American Society of Civil Engineers (ASCE) proposes the following approach to compute restrictions in case of drift of a considered glass curtain wall component[6]. This relative seismic displacement at initial glass-to frame contact (for rectangular panels) is [31]:

$$D_{clear} \geq 2c_1(1+\frac{h_p}{b_p}\frac{c_2}{c_1})\ [mm] \tag{3.3.8-5}$$

With:

- h_p the glass panel height [mm]
- b_p the glass panel width [mm]
- c_1 the side clearance [mm]
- c_2 the upper (and lower) clearance [mm]

[6] The verification criteria using this value being $D_{clear} \geq 1.25D_{pI}$ with the relative seismic displacement (drift) at of a considered glass curtain wall component $D_{pI} = D_p I_e$, where D_p is the relative seismic displacement that the component must be designed to accommodate, and I_e is the importance factor (1.00, 1.25, 1.50 for increasing importance) of the earthquake.

Normative values

The table below summarizes interstorey drift ratios (differential movement between adjacent floors) in various countries' codes.

Table 3.3—2: Comparison of old maximum drift ratios in several codes (source: Sucuoğlu et. Al 1997)

Code	Design limit state	Maximum drift ratio
Canada	Ultimate	0.02
CEB	Service	0.002-0.0025
ECCS	Service	0.003-0.006
Japan	Service	0.003-0.0083
New Zealand	Ultimate	H<15m: 0.02 H>30m: 0.015
NEHRP	Ultimate	0.015
UBC	Ultimate	T<0.7: 0.015 or 0.019 R_w T>0.7: 0.011 or 0.015 R_w

Drift ratios vary between 0.2 and 0.83% under service level design forces, and between 1.1 and 2% under ultimate design forces [20].

Further precisions can be given for other countries and cases. In Eurocode 8: the permissible interstorey drift ratio values for damage control in non-structural elements under various conditions (SLS and ULS): 0.5%, 0.75% and 1% for brittle nonstructural elements attached to the structure and for ductile non-structural elements or those integrated without obstructing structural deformation, respectively [3]·[32]. The New Zealand code NZS 1170.5 provides, as detailed limits, either 1/250 of the span (storey height) or twice the width of the glass clearance (width of the silicone adhesive bar inserted on each side of the glass panel) [6]. Japan defined its requirements by putting inter storey drift ratio limits of 1, 0.5 or 0.33% (severe, moderate and low earthquakes) In Corea: 1, 1.5 or 2% of the floor height / interstorey drift. In China, the in-plane peak-drift of the curtain wall has to be 3 times superior to the elastic deformation limit of the main structure

A comparison can be made with the way CWCT expressed the problem regarding glass to frame contact according to the frame's characteristics, precising that tighter limits might apply; limits to movement should then be checked with the cladding designer [26].

Table 3.3—3: CWCT interstorey drift limits (source: TN56)

	50 mm width frame [mm]	60 mm width frame [mm]
Storey height glass (no glass to frame contact)	5	10
Storey height glass (after rotation)	15	30

Intermediate transom (no glass to frame contact)	10	20
Intermediate transom (after rotation)	20	40

Accommodation systems

Various strategies can be identified for stick systems to deal with interstorey drift generated by earthquakes [4]:

- clearance and gap: when provided on each four sides of the panel, they facilitate prevention of corner and edge damage as a result of rotation and displacement; however, this solution alone is seldom sufficient;
- fitting and sealing of the glass with a gasket into the frame, so that glazing pockets are deep enough to allow the designed glass displacement (most frequently used in stick system curtain wall);
- additional seismic frame connected to the building frame, and moving in unison with it;
- friction damping connectors isolating the façade from the main structure and dissipating energy;
- Earthquake-Isolated Curtain Wall System (EICS) where façade components are decoupled both from upper and lower floor, featuring so-called "seismic decoupler joint" between each floor's mullion;
- round panel edge corners [33][7].

[7] Quoted in [4]. Corners being the point where damage and breakage of panels firstly occur, making them rounded allow greater rotations, increasing both serviceability and ultimate drift limit, reducing glass cracking as well as fallout of glass panes. Another advantage of this design is its potential retrofit application, movement accommodation strategies being way more complex to apply to existing buildings compared to newly built ones.

4 Hypothesis and structure of the tool

In this part is introduced the strategy used to model the problem, some specific hypothesis on which it relies and its way of working, while the following part *Detailed workflow* will break down its detailed structure.

4.1. Geometrical modeling

4.1.1. Frame configuration

The calculation tool only considers one cell of the stick system, since it represents an ideal case whose characteristics have to be relevant for the whole curtain wall extent. The extent of the aluminum frame gives the outer limits of the cell, with its boarders being fixed on the profiles' axis. Every dimension variation and component rotation will then happen within or according to this defined frame.

The simplified scheme can be considered as valid since any other component, not playing a structural role, has no impact on the overall behavior – for example, considering the significant difference between the elastic module of aluminum and polymers elements such as gaskets and thermal inlets (more than 20 times), their rigidity can be neglected [28].

4.1.2. Glass panels movement

When a movement of the structural frame occurs, cladding will either freely accommodate it or be subject to stresses eventually leading to breaking [16] (in the related models, panels are assumed to be rigid [3]). In-plane movement of the glazing should be accommodated by the rigid body slip and subsequent rotation of the glass in the enclosing window frame without stressing the panel [20]. Indeed, movement accommodation can be of 3 kinds: rotation (of storey height panels (Figure 4.1—1.a) or of smaller panels (Figure 4.1—1.b)), shear (Figure 4.1—1.c) or sliding (Figure 4.1—1.d. NB.).

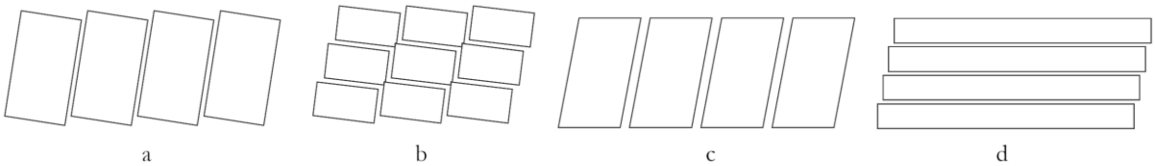

Figure 4.1—1: Panel movement (source: CWCT TN30 figure 2)

Since the purpose of façade design is to avoid breaking, the case of shear will not be considered. When dealing with a deformation of the frame due to mullion deflection, the movement accommodation will be a rotation in the case of bottom glass shimming and a sliding (vertical, though) in the case of side glass shimming (cf. §4.1.3 *Types of glass shimming*).

Rotation

If they are held between gaskets, glass and infill panels are able to slide within the frame until they are restrained by panel to frame contact (or by the glazing blocks). If they are mounted in a glazing rebate, small panels may be free to rotate.

Sliding

Also in the case of sliding, the height of the panels can be equal to the storey height – they may then feature sliding joints at each floor level, that do not fit within the frame the study.

4.1.3. Types of glass shimming

The bottom and side glass shimming considered by the tool only have an impact on how the glazing pane is considered. As already said for a similar case of mullion deflection, bottom glass shimming will lead to rotation and side glass shimming to sliding of the glazing. No other consideration, such as number, dimensions, and localization of the setting blocks (cf. §3.3.7 *Glass shimming*) decisively impacts the glass' behavior and thus has not been taken into account.

4.2. Dimension restrictions

Peculiar limits are imposed to the model provided by Reynaers.

4.2.1. Tolerances

As seen in the subject presentation above (cf. §2.2.4 *Tolerance*), deviation in dimensions (as well as material quality) of building components is unavoidable. Manufacturers usually provide reference values to help contractors and designer figure out the actual range of value for the dimensions the exemplars of a same product may feature.

The method used by Reynaers to account for tolerances consists in defining a "safety margin" against the nose of the mullion equal to 2 mm [25]. No further explanations are given about this result, and in the absence of it, one has to hypothesize a proper justification for it. Actually, façade building processes usually include two main tolerances categories. The first one, the product tolerance, accounts for potential discrepancies in the dimensions of manufactured components, and has a value of 1 mm. The second one, the installation tolerance, considers the unavoidable deviation happening when implementing any building element on a construction field, and also has a value of 1 mm. It was then assumed that the 2 mm tolerance given by Reynaers was a sum of these product and installation tolerances, working as a virtual damping space around the mullion nose (outermost limit of the glass edge clearance), allowing to deal with a worst key scenario where the glass panel would be 1 mm larger and the frame installed 1 mm shorter than it should by preventing the contact between them.

NB: for the case of structural clamping (both with clamping profile and toggle), an added note states that "to avoid collision between the glass unit and clamping profile/toggle, the glass unit must be produced 1 mm undersize to a tolerance of ±1 mm." However, thus relating to a similar problem as the one already existing in the standard case with the mullion nose, it does not appear in it, and is therefore not considered. Furthermore, while building the calculation file, it has been found that this indication was playing no role in the computation, thus stands only as a good practice reminder, but not an actual hypothesis.

4.2.2. Boundary conditions

According to the studied cases, boundary conditions of the problem have been provided by Reynaers – though without justification. Typically, the minimum glass edge cover is set at 11 mm; it is then assumed that this value coincides with geometrical characteristics of this manufacturer's products. Similarly, the minimum edge cover (for the case of structural clamping, both with clamping profile and toggle) given by Reynaers is 5 mm, meanwhile discussions with Faces Engineering consultants lead to consider a value of 4 mm. Although the relevance of knowing what the minimum grip for a glazing is, either regarding gaskets, clamping profile or toggle, appears clearly, in this case again no further justification is made.

4.3. Organization

4.3.1. Categories of inputs and outputs

Inputs from the user have to be implemented in the light blue cells. They are the actual parameters of the problem.

Hypothesis and tolerance can be found in the grey cells; though modifiable, they ought not to be. As seen in the previous paragraphs, most of the values used come directly from Reynaers' document or have been valuated according to them. In ulterior development processes, where the calculation tool might apply to curtain walls system from other constructors or featuring different specificities, these values might need to be changed in order to match these specifics constructor's new hypothesis.

Every calculated result appears in a green cell, while the layout emphasizes the importance of the final vertical deflection result regarding the other intermediary outputs.

4.3.2. Panels fixation

In Reynaers' documentation, three main types of glazing fixation are identified within the frame of the mullion deflection calculation – each one of them highlighted by structural details, schemes, and the results tables mentioned in §3.2.4 *Builder's documentation*:

Standard

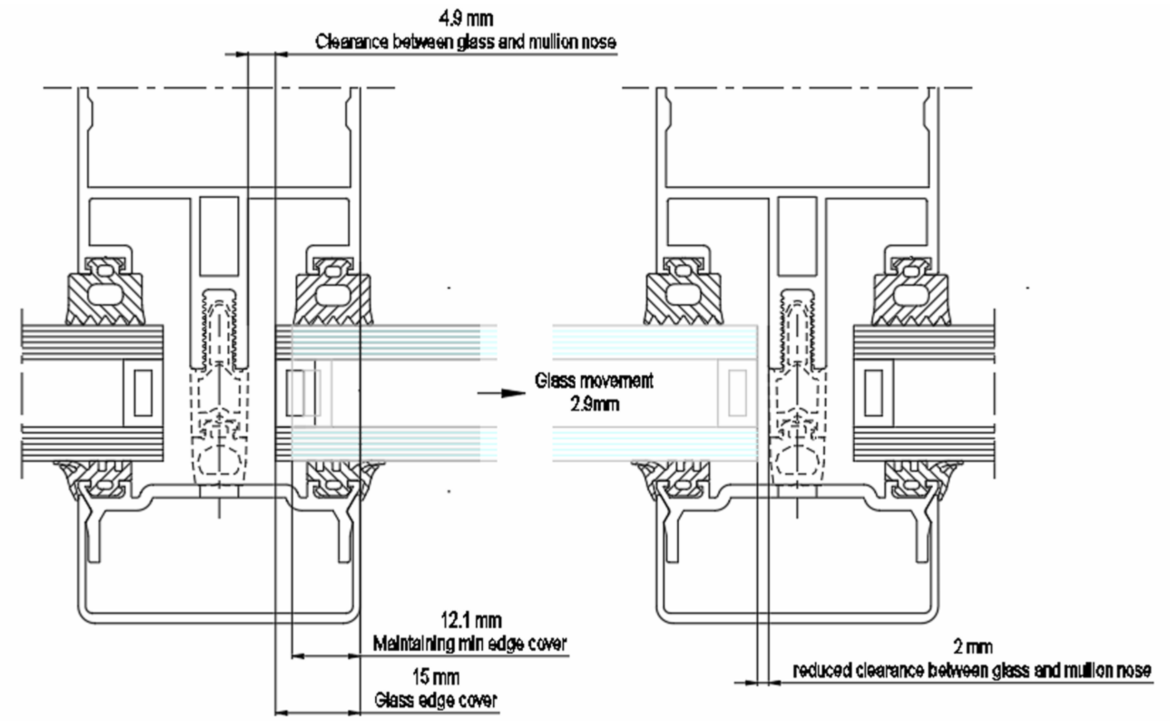

Figure 4.3—1: Standard fixation (CW 50, parameters for 15mm glass edge cover) (source: Reynaers CW50-CW60 figure 5)

Structural clamped with clamping profile

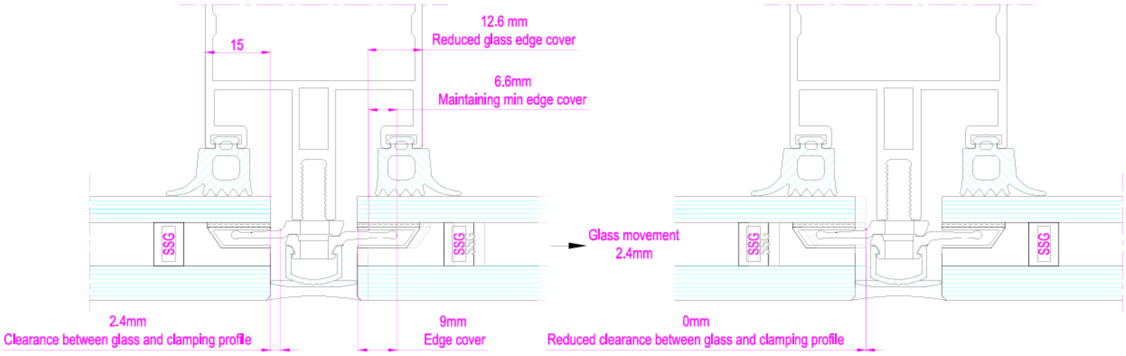

Figure 4.3—2: Clamping profile fixation (CW 50-SC, parameters for 15mm glass edge cover) (source: Reynaers CW50-CW60 figure 7)

Structural clamped with toggle

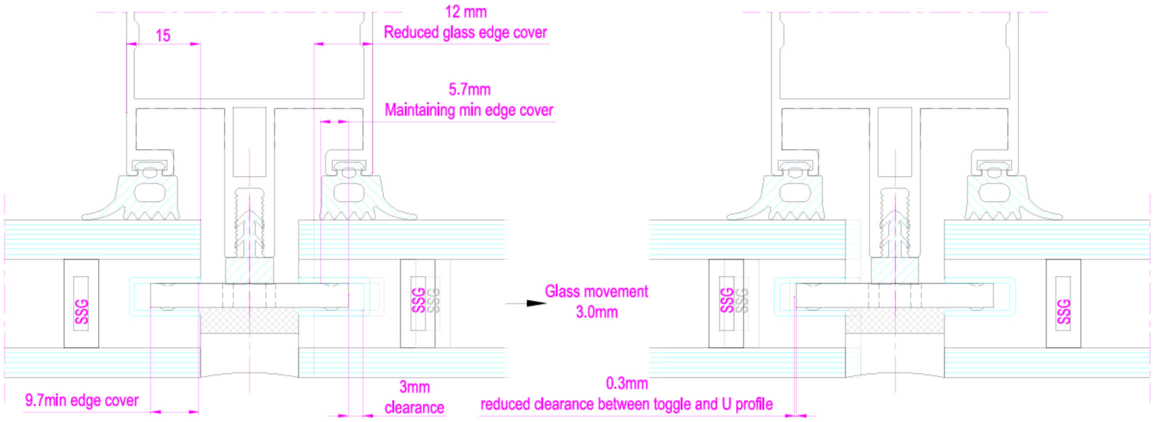

Figure 4.3—3: Toggle fixation (CW 50-SC, parameters for 15mm glass edge cover) (source: Reynaers CW50-CW60 figure 9)

4.3.3. Flowchart

Beneath appears a flow diagram synthetizing the whole calculation process before diving precisely into it.

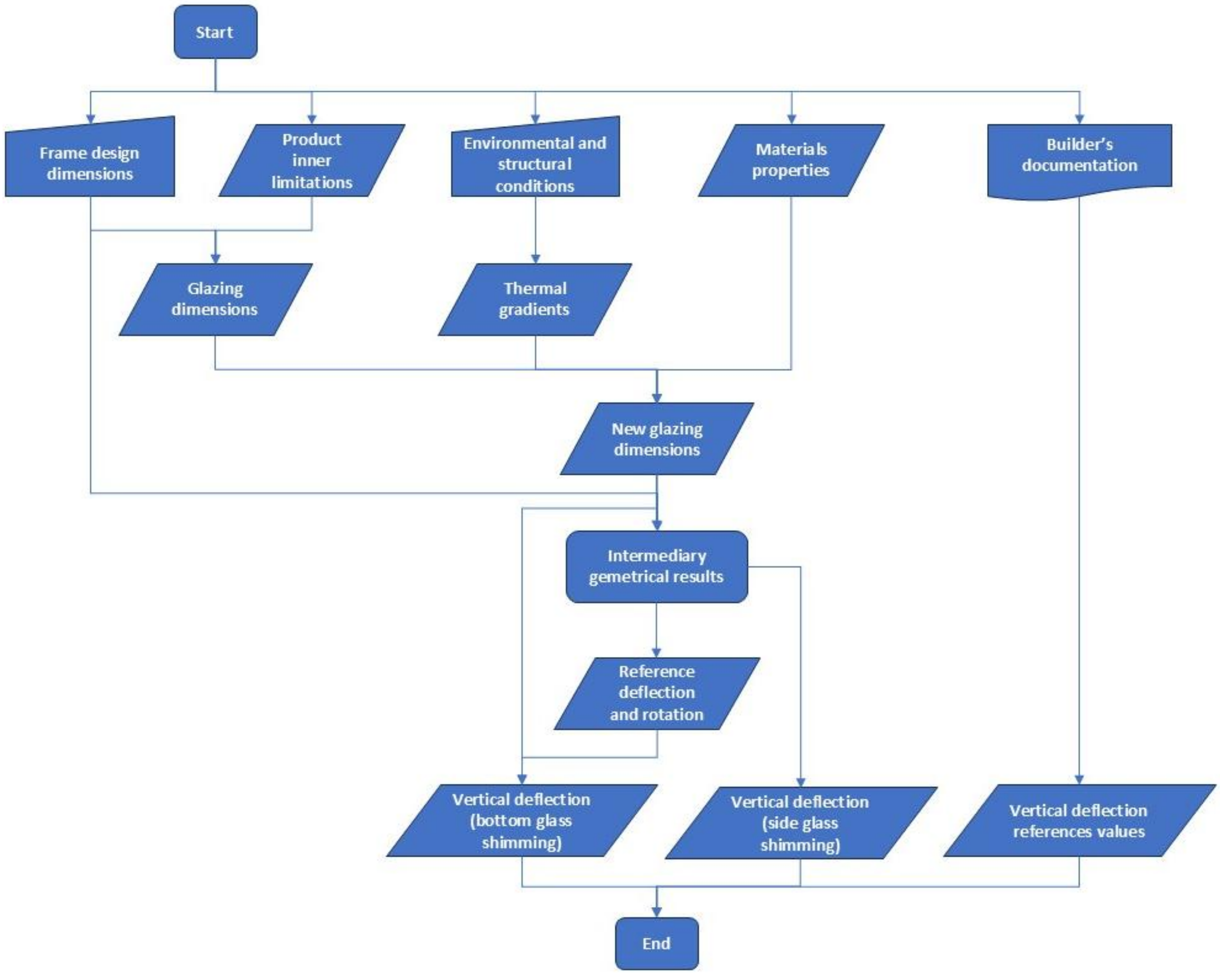

Figure 4.3—4: Calculation tool overall workflow

5 Detailed workflow

This part describes linearly each step of the calculation as it would be run by any user, displaying every calculation step in the file while highlighting further hypothesis and assumptions that guided the process's set up. Below is a comprehensive view of what the tool looks like (before simplifications, relevant for a common use).

	Standard				
					Pressure plate, silicone
Dimensions input	$w_{profile}$	Profile (mullion) width	**50.00**	mm	
	b_{frame}	Frame width (~transom length)	**520.00**	mm	Interaxis length
	h_{frame}	Frame height (mullion length)	**1020.00**	mm	
	e_c	Glass edge cover	**15.00**	mm	
	-	Production tolerance	**1.00**	mm	
	-	Installation tolerance	**1.00**	mm	
Hypothesis	t_{nose}	Total tolerance	2.00	mm	To avoid collision with mullion nose for standard glazing
	b_{nose}	Mullion nose (or thermal break width)	10.20	mm	Generally: Schüco=10mm, Reynaers=10.2mm, Wicona=11mm
	$e_{c,min}$	Minimum glass edge cover	11.00	mm	Reynaers hypothesis
Glass panel	b_{glass}	Glass panel width	**500.00**	mm	Data for [500; 3000] mm
	h_{glass}	Glass panel height	**1000.00**	mm	

Structure conditions	a_s	Reference altitude	138.00	m	
	T_0	Reference temperature	15.00	°C	
	T_{in}	Internal temperature	20.00	°C	
	-	Frame material	Aluminium	-	
	-	Panel material	Glass	-	
	-	Exposition	S-O	-	
	-	Surface tint	Dark	-	
Temperature variation	$T^{(+)}$	Temperature incrementation	42.00	°C	
	$T_{out,max}$	Max summer temperature	83.172	°C	
	$T_{out,min}$	Min winter temperature	-15.55	°C	
	T_{max}	Max mean temperature in envelope	51.59	°C	
	T_{min}	Min mean temperature in envelope	2.224	°C	
	$\Delta T_{u,max}$	Summer temperature difference	36.59	°C	
	$\Delta T_{u,min}$	Winter temperature difference	-12.78	°C	
Thermal dilatation coefficients	α_{frame}	Coeff. dilatation frame	2.40E-05	1/°C	
	α_{panel}	Coeff. dilatation panel	9.00E-06	1/°C	
Dilatation	$b_{frame,d}'$	Dilated frame width	**520.46**	mm	
	$h_{frame,d}'$	Dilated frame height	**1020.90**	mm	
	$b_{glass,d}'$	Dilated glass width	**500.44**	mm	
	$h_{glass,d}'$	Dilated glass height	**1000.88**	mm	
Contraction	$b_{frame,c}'$	Contracted frame width	**519.84**	mm	
	$h_{frame,c}'$	Contracted frame height	**1019.69**	mm	
	$b_{glass,c}'$	Contracted glass width	**499.85**	mm	
	$h_{glass,c}'$	Contracted glass height	**999.69**	mm	

SUMMER

Intermediary results	b_{tight}	Total allowable width btw. mullions	505.35	mm	Without tolerance
	$b_{opening}$	Window opening width	475.44	mm	Without tolerance
	h_{tight}	Total allowable height btw. mullions	1005.79	mm	Without tolerance
	$h_{opening}$	Window opening height	975.88	mm	Without tolerance
	e_c'	Reduced glass edge cover	12.09	mm	After movement
	c_{side}	Lateral clearance glass / profile nose	4.91	mm	Without tolerance
	c_{side}'	Reduced lateral clearance	2.00	mm	After movement
	c_{top}	Superior clearance glass / profile nose	4.91	mm	Without tolerance
	c_{top}'	Reduced superior clearance	2.00	mm	After movement
Glass panel rotation	Δ_h	Allowed lateral deflection	2.91	mm	Reference value for a square panel
	$\tan(\gamma)$	Corresponding tangent	2.91E-03	-	=Δh/h
	γ	Allowed glazing rotation angle	2.91E-03	rad	
			0.17	°	
Bottom glass shimming	Δ_v	**Allowed vertical deflection**	**1.45**	**mm**	For transom length = glaze width
		Reynaers value	*1.50*	*mm*	*Taken from CW50-60 - PP_AD089S51A01.pdf*
Side glass shimming	Δ_v	**Allowed vertical deflection**	**2.91**	**mm**	Clearance minus tolerances aligned with glazing sides
		Reynaers value	*2.90*	*mm*	

WINTER

Intermediary results	b_{tight}	Total allowable width btw. mullions	504.74	mm	Without tolerance
	$b_{opening}$	Window opening width	474.85	mm	Without tolerance
	h_{tight}	Total allowable height btw. mullions	1004.59	mm	Without tolerance
	$h_{opening}$	Window opening height	974.69	mm	Without tolerance
	e_c'	Reduced glass edge cover	12.09	mm	After movement
	c_{side}	Lateral clearance glass / profile nose	4.90	mm	Without tolerance
	c_{side}'	Reduced lateral clearance	2.00	mm	After movement
	c_{top}	Superior clearance glass / profile nose	4.90	mm	Without tolerance
	c_{top}'	Reduced superior clearance	2.00	mm	After movement
Glass panel rotation	Δ_h	Allowed lateral deflection	2.90	mm	Reference value for a square panel
	$\tan(\gamma)$	Corresponding tangent	2.90E-03	rad	=Δh/h
	γ	Allowed glazing rotation angle	2.90E-03	rad	
			0.17	°	
Bottom glass shimming	Δ_v	**Allowed vertical deflection**	**1.45**	**mm**	For transom length = glaze width
		Reynaers value	*1.50*	*mm*	*Taken from CW50-60 - PP_AD089S51A01.pdf*
Side glass shimming	Δ_v	**Allowed vertical deflection**	**2.90**	**mm**	Clearance minus tolerances aligned with glazing sides
		Reynaers value	*2.90*	*mm*	

Figure 5—4.3—1: View of the calculation tool (standard fixation case)

5.1. Determination of the dimensions

One of the main purposes of the calculation tool being use different inputs (in a way, reversed) than the one traditionally used (cf. §2 *Subject and scope*), the first part aims at determining the dimensions of the studied glass panel starting from the geometrical characteristics of the frame.

5.1.1. Frame dimension inputs

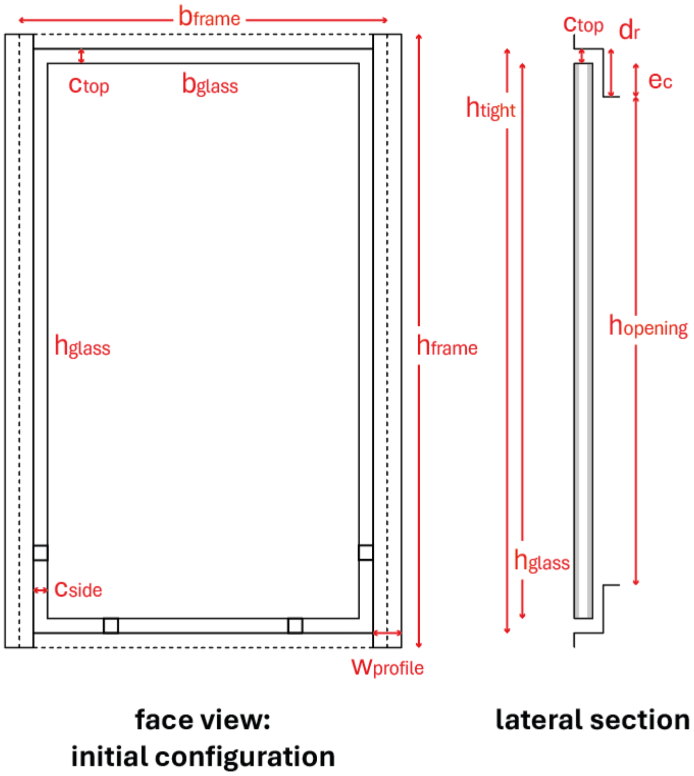

Figure 5.1—1: Frame geometrical parameters

Profile width w_p

Although also existing in I or T profiles, the study focuses on rectangular section, more particularly on two types of profile width corresponding to the standardized industrial dimension: either 50 or 60 mm wide. The other dimensions of the profile are not taken into account.

Frame width b_{frame}

Assimilated to "transom length" – actually, its true value is equal to the transom length plus (twice half of) the mullion width. Sets the outer horizontal limit of the studied rectangular module.

Frame height h_{frame}

Assimilated to "mullion length" – correct if one also assumes that the façade module is displayed on the whole storey height and that the mullion only runs on one storey. Sets the outer vertical limits of the studied rectangular module.

Glass edge cover e_c

From the Reynaers' documentation, only four values of glass edge cover were identified, thus justifying their implementation through a drop-down list [25]:

Table 5.1—1: Types of glazing from glass edge cover

Glass edge cover [mm]	Corresponding types of glazing
13	CW 50 CW 50-SC (clamping profile) CW 50-SC (toggle)
15	CW 50 CW 50-HI CW 50-SC (clamping profile) CW 50-SC (toggle)
18	CW 60 CW 60-HI
20	CW 60-SC (clamping profile) CW 60-SC (toggle)

In excel, the possible values are dependent on the type of glazing, leading to a reverse organization:

Table 5.1—2: Glass edge covers from type of glazing

Types of glazing	Corresponding glass edge cover [mm]
CW 50	13 15
CW 50-HI	15
CW 50-SC (clamping profile)	13 15
CW 50-SC (toggle)	13 15
CW 60	18
CW 60-HI	18
CW 60-SC (clamping profile)	20
CW 60-SC (toggle)	20

5.1.2. Modeling hypothesis

Tolerances

As explained in §3.2.4 *Builder's documentation*, Reynaers indicates a 2 mm tolerance to take into account around that has been split in two distinct tolerances of 1 mm to account for variability in production and installation.

Mullion nose or thermal break width

Since the study focuses on data provided by the Reynaers company, it has been decided to stick with their documentation in order to maintain coherency within the considered situations and their respective results. However, a comparison with data from some of the main other manufacturers allows to define more precisely the common range for a mullion nose width, stating upper and lower boundaries to this field.

Table 5.1—3: Mullion nose width comparison

Manufacturer	Mullion nose's common width [mm]
AluK	11.0
Reynaers	10.2
Schüco	10.0
Wicona	11.0

Since the same profile is used for both mullion and transom, the same mullion nose value is considered as well.

5.1.3. First intermediary output: glass panel dimensions

The value for the glazing unit width is such as:

$$b_{glass} = b_{frame} - \left(w_{profile} - 2 * e_c\right)\ [mm] \tag{5.1.3-1}$$

With:

- b_{frame} the frame width [mm]
- $w_{profile}$ the profile width (traditionally, either 50 or 60) [mm]
- e_c the glass edge cover [mm]

And similarly for the glazing height:

$$h_{glass} = h_{frame} - \left(w_{profile} - 2 * e_c\right)\ [mm] \tag{5.1.3-2}$$

With:

- h_{frame} the frame heigth [mm]

5.2. Thermal dimension variation

This part of the process has been led following the steps given by the NTC 2018 (§3.5 *Azioni della temperature*) [21], sticking to the process already developed by Faces Engineering in a previous calculation tool [34]. Because of the firm's location, and its importance regarding the construction sector in Italy, it has been decided to consistently locate the study in Milan, Lombardy.

5.2.1. Hypothesis

Considering that the scope of the developed tool is to compute the maximal allowed mullion deflection for diverse design scenarios, one has to take deal with the dimensional variation implied by temperature differences may impact the performance of the façade structural system. Since the calculated output is a length variation of slender elements (which length is much superior to their other dimensions), furthermore often located on the outer layer of the building envelope, other dimensions' variations are considered negligible.

The temperature gradient within the elements due to indoor and outdoor air temperature difference is simplified considering the mean value of the outdoor and indoor surface temperature of the profile. No isolation solution has been taken into account.

- Profile length >> width: we only consider the dilatation in the larger dimension
- External elements: linear temperature gradient in the profile thickness

5.2.2. Thermal parameters

Materials

The most common materials used in the composition of curtain walls frame are aluminum and glass, this latter considered with the properties given in §2.2.3 *Frame components*.

Note that aluminum can endure a thermal load variation of about 50°C (even 80 in the case of profiles with dark anodization and solar radiation absorption coefficients of about 0.8-0.9) [12].

Reference situation

The reference altitude a_s for Milan is 138 m. Values of reference and internal temperature T_0 and T_{in}, in absence of further specifications, may be respectively assumed equal to 15 and 20°C [21].

Two further parameters are provided that will influence mostly the summer thermal behavior: the façade exposition and its color responsible for a temperature increase.

Temperature values

The outside air temperature T_{out} may assume values in a range going from $T_{out,min}$ to $T_{out,max}$. Lombardy being classified in Zone I of the Italian regions, they are calculated from the following formulas:

$$T_{out,min} = -15 - \frac{4 \cdot a_s}{1000} \; [°C] \tag{5.2.2-1}$$

$$T_{out,max} = 42 - \frac{6 \cdot a_s}{1000} + T^{(+)} \; [°C] \tag{5.2.2-2}$$

With:

- a_s the reference altitude [m]
- $T^{(+)}$ the temperature incrementation due to exposition and color of the façade [°C]

The temperature in the envelope is then computed as a mean between outside and inside air temperature, such as:

$$T_{min} = \frac{T_{in} + T_{out,min}}{2} \; [°C] \quad (5.2.2\text{-}3)$$

$$T_{max} = \frac{T_{in} + T_{out,max}}{2} \; [°C] \quad (5.2.2\text{-}4)$$

Finally, the thermal gradient that is considered is:

$$\Delta T_{min} = T_{min} - T_0 [°C] \quad (5.2.2\text{-}5)$$

$$\Delta T_{max} = T_{max} - T_0 [°C] \quad (5.2.2\text{-}6)$$

Dimension variation

The formula to compute the dimension variation is then:

$$l' = l +\cdot \Delta l \; [mm] \quad (5.2.2\text{-}7)$$

$$\Delta l = l \cdot \alpha \cdot \Delta T \; [mm] \quad (5.2.2\text{-}8)$$

With:

- l the initial length of the element [mm]
- l' the final length of the element [mm]
- α the thermal dilatation coefficient [°C^{-1}]

Two cases haven then been considered: dilatation, related to the maximum values and the summer behavior, and contraction, related to the minimum values and the winter behavior; this distinction will be further explained. From the frame dimensions (b_{frame}, h_{frame}) and the calculated glazing dimensions (b_{glass}, h_{glass}), user then get height new values, four for each case ($b'_{frame,d}$, $h'_{frame,d}$, $b'_{glass,d}$, $h'_{glass,d}$ and $b'_{frame,c}$, $h'_{frame,c}$, $b'_{glass,c}$, $h'_{glass,c}$).

For the sake of simplicity, in the coming explanation of the calculation, generic dimensions index (independent from thermal dilatation) have been used.

NB: $\alpha_{aluminum} = 2.4 \cdot 10^{-5} > \alpha_{glass} = 9 \cdot 10^{-6}$ [°C^{-1}]

The coefficient of dilatation of the aluminum being higher than the glass', and considering a façade module displaying these two materials, in case of thermal dilatation the configuration to calculate the allowed vertical mullion deflection becomes safer; since the metal dilates more than the glass panel, the clearances and other inner dimensions will slightly grow. On the opposite, the most critical case is the thermal retractation: the frame will get smaller faster than the panel, leading to slightly smaller clearances.

5.3. Rotation and deflection

5.3.1. Standard glazing fixation

Clearance between glass and profile nose

$$c_{side} = \frac{b_{frame} - b_{glass} - b_{nose}}{2} \; [mm] \quad (5.3.1\text{-}1)$$

With:

- b_{frame} the frame width [mm]
- b_{glass} the glass panel width [mm]
- b_{nose} the profile nose width [mm]

Allowed glazing lateral movement reference value

Equal to the minimum (therefore most stringent) dimension between:

- the difference between the glass edge cover and its minimal possible value (hypothesized);
- the difference between clearance (glass and mullion nose) and its tolerances (hypothesized) taken into account.

$$\Delta_h = \min\,(e_c - e_{c,min};\, c_{side} - t_{nose})\ [mm] \tag{5.3.1-2}$$

With:

- e_c the glass edge cover [mm]
- $e_{c,min}$ the minimum glass edge cover [mm]
- c_{side} the clearance between glass and profile nose [mm]
- t_{nose} the tolerance applied around profile nose [mm]

Reduced profile nose clearance

$$c'_{side} = c_{side} - \Delta_h\ [mm] \tag{5.3.1-3}$$

With:

- c_{side} the clearance between glass and profile nose [mm]
- Δ_h the allowed lateral deflection [mm]

Reduced glass edge cover

Similarly, the reduced glass edge cover is calculated as:

$$e'_c = e_c - \Delta_h\ [mm] \tag{5.3.1-4}$$

With:

- e_c the glass edge cover [mm]
- Δ_h the allowed lateral deflection [mm]

Other internal reduced (post-rotation) dimensions are calculated the same way; the clearance and glass edge cover are explained here since their values are highlighted in Reynaers' details and were used to control the consistency of the calculation.

Final allowed vertical deflection

The rotation angle is approached by:

$$\tan(\gamma) = \frac{\Delta_h}{h_{glass}}[-] \tag{5.3.1-5}$$

Finally, the vertical deflection is given by:

$$\Delta_v = \tan\,(\gamma) \cdot b_{glass}\ [mm] \tag{5.3.1-6}$$

With:

- γ the rotation angle [rad]
- Δ_h the allowed lateral deflection [mm]
- b_{glass} and h_{glass} the width and height of the glazing [mm]; as said in §5.2.2 *Thermal parameters*, they will actually assume values equal to either, $b'_{glass,d}$, $h'_{glass,d}$ or $b'_{glass,c}$, $h'_{glass,c}$ to take into account the dimension variation due to temperature. Same remark applies for the following calculations.

5.3.2. Clamping profile fixation

Clamping edge cover

$$e_{c,clamping} = b_{fs,long} - \frac{b_{frame} - b_{glass}}{2} \; [mm] \qquad (5.3.2\text{-}1)$$

With:

- $b_{fs,long}$ the longest side of the fixing strip used in the clamping profile [mm]
- b_{glass} and h_{glass} the width and height of the glazing [mm]

Clearance between glass and profile nose

The calculation in the case of clamping profile fixation is the same as in the case of standard fixation (5.3.1-1).

Clerance between glass and clamping section

$$c_{cl,section} = b_{fs,eff} - e_{c,clamping} \; [mm] \qquad (5.3.2\text{-}2)$$

With:

- $b_{fs,eff}$ the longest side of the fixing strip used in the clamping profile [mm]
- $e_{c,clamping}$ the clamping edge cover |mm]

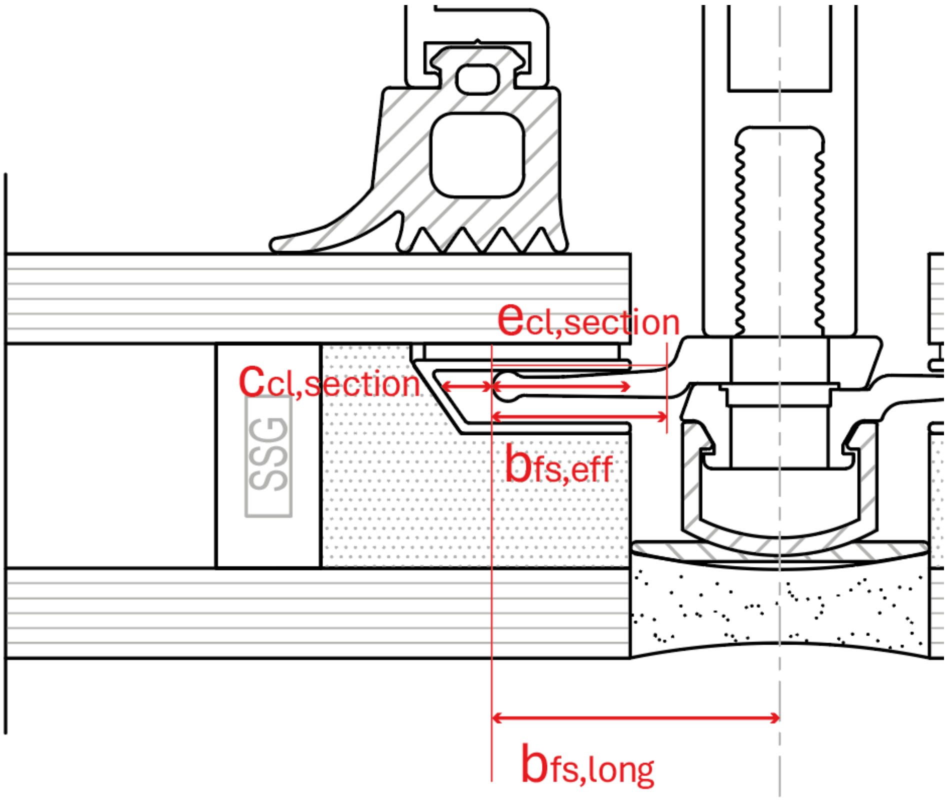

Figure 5.3—1: Detail of geometrical parameters for clamping section

Allowed glazing lateral movement reference value

Similarly to the standard fixation case, this value is equal to the minimum (therefore most stringent) dimension between two already known terms and a third one that has just been calculated:

- the difference between the glass edge cover and its minimal possible value (hypothesized)
- the difference between clearance (glass and mullion nose) and its tolerances (given by hypothesis) taken into account
- the clearance between glass and clamping section

$$\Delta_h = \min\left(e_c - e_{c,min};\ c_{side} - t_{nose}; c_{cl,section}\right)\ [mm] \qquad (5.3.2\text{-}3)$$

With:

- e_c the glass edge cover [mm]
- $e_{c,min}$ the minimum glass edge cover [mm]
- c_{side} the clearance between glass and profile nose [mm]
- t_{nose} the tolerance applied around profile nose [mm]
- $c_{cl,section}$ the clearance between glass and clamping section [mm]

Reduced profile nose clearance

The calculation in the case of clamping profile fixation is the same as in the case of standard fixation (5.3.1-3).

Reduced clamping clearance

$$c'_{cl,section} = c_{cl,section} - \Delta_h\ [mm] \qquad (5.3.2\text{-}4)$$

With:

- $c_{cl,section}$ the clearance between glass and clamping section [mm]
- Δ_h the allowed lateral deflection [mm]

Reduced glass edge cover

The calculation in the case of clamping profile fixation is the same as in the case of standard fixation (5.3.1-4).

Final allowed vertical deflection

The calculation in the case of clamping profile fixation is the same as in the case of standard fixation (5.3.1-5), (5.3.1-6).

5.3.3. Toggle fixation

Clamping edge cover

$$e_{c,toggle} = \frac{d_{toggle}}{2} - \left(\frac{w_{profile}}{2} - e_c\right) \; [mm] \qquad (5.3.3\text{-}1)$$

With:

- d_{toggle} the toggle diameter [mm]
- $w_{profile}$ the profile width (traditionally, either 50 or 60) [mm]
- e_c the glass edge cover [mm]

Clearance between glass and profile nose

The calculation in the case of toggle fixation is the same as in the case of standard fixation (5.3.1-1).

Clerance between glass and toggle

$$c_{toggle} = d_u - t_u - \frac{d_t - (b_{frame} - b_{glass})}{2} \; [mm] \qquad (5.3.3\text{-}2)$$

With:

- d_u the U-profile depth [mm]
- t_u the U-profile thickness [mm]
- d_t the toggle diameter [mm]
- b_{frame} the frame width [mm]
- b_{glass} the glass panel width [mm]

Allowed glazing lateral movement reference value

Similarly to the clamping profile fixation case, this value is equal to the minimum (therefore most stringent) dimension between:

- the difference between the glass edge cover and its minimal possible value (given by hypothesis)
- the difference between clearance (glass and mullion nose) and its tolerances (given by hypothesis) taken into account
- the clearance between glass and clamping section

$$\Delta_h = \min\left(e_c - e_{c,min};\; c_{side} - t_{nose}; c_{cl,toggle}\right) [mm] \qquad (5.3.3\text{-}3)$$

With:

- e_c the glass edge cover [mm]
- $e_{c,min}$ the minimum glass edge cover [mm]
- c_{side} the clearance between glass and profile nose [mm]
- t_{nose} the tolerance applied around profile nose [mm]
- $c_{cl,toggle}$ the clearance between glass and toggle [mm]

Reduced profile nose clearance

The calculation in the case of clamping profile fixation is the same as in the case of standard fixation (5.3.1-3).

Reduced clamping clearance

$$c'_{cl,toggle} = c_{cl,toggle} - \Delta_h \ [mm] \qquad (5.3.3\text{-}4)$$

With:

- $c_{cl,toggle}$ the clearance between glass and toggle [mm]
- Δ_h the allowed lateral deflection [mm]

Reduced glass edge cover

The calculation in the case of clamping profile fixation is the same as in the case of standard fixation (5.3.1-4).

Maintaining minimum edge cover

$$e'_{cl,toggle} = e_{cl,toggle} - \Delta_h \ [mm] \qquad (5.3.3\text{-}5)$$

With:

- $e_{cl,toggle}$ the clamping edge cover [mm]
- Δ_h the allowed lateral deflection [mm]

Final allowed vertical deflection

The calculation in the case of clamping profile fixation is the same as in the case of standard fixation (5.3.1-5), (5.3.1-6).

5.4. Side glass shimming

The determination of the allowed vertical deflection in the case of side glass shimming is much simpler; Reynaers directly provides examples value that actually correspond to the clearance between the glazing and the transom nose minus the related tolerances. Below are the corresponding steps to determine its value in all cases.

$$c_{top} = \frac{h_{frame} - h_{glass} - b_{nose}}{2} \ [mm] \qquad (5.3.3\text{-}1)$$

$$\Delta_v = c_{top} - t_{nose} \ [mm] \qquad (5.3.3\text{-}2)$$

With:

- c_{top} the clearance on top of the glazing (may be equal to c_{side}) [mm]
- h_{frame} the frame width [mm]
- h_{glass} the glass panel width [mm]

- b_{nose} the profile nose width [mm]
- t_{nose} the tolerance applied around profile nose [mm]

One can notice that this value is completely independent from the glazing rotation, and that compared to the use of bottom blocks only, its calculation is much more direct and simpler.

5.5. Comparison with builder's data

Having been built around Reynaers' value to obtain the formulas that has then been controlled using references from the state of the art, the very way of working of the file implies that there are (initially) no differences between the calculated ones and Reynaers'. However, some peculiar discrepancies have been observed, whose origin may be discussed.

Graphs and tables

Generally, numerical values given in the Reynaers figures are not precise enough to be fully trusted in each case. The final allowable movement is usually precise enough, also because one can then relate to the tables for control check. But for any other dimension (e.g., clearances before and after movement) some unfortunately rounded up values mess the understanding of the process.

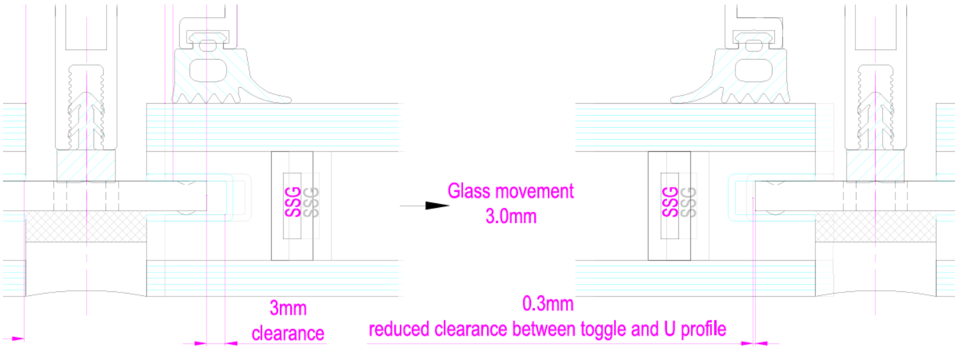

Figure 5.5—1: Example of a discrepancy in Reynaers schemes (toggle case with 15 mm glass edge cover. Source: CW50-60)

Following the discrepancy highlighted in Figure 5.5—1, Reynaers' tables 6 and 7 (cf. Appendix) feature calculated values that are more advantageous since they take into account all the clearance (3+0.3=3.3 mm instead of 3 mm).

Last point to consider: the number of chosen relevant digits is another cause of potential discrepancies (and, perhaps, the reason for the errors already discussed above). For instance, the clearance between glass and clamping profile for a clamping profile with a 15 mm glass edge cover is 2.45 mm, appearing 2.5 mm in Excel, meanwhile Reynaers give a value of 2.4 mm only.

Clamping profile case

On the same principle, a few differences may happen between calculation and results table. For instance, with Reynaers' table 5 (CW50-SC with 13 mm glass edge cover and clips 034.0176.00 + 034.0175.00): a 4.5 mm clearance calculated while the catalog gives 4.1 mm. This "error" may be caused by the curvature of the clamping profile which makes the exact contact point more uncertain – indeed, since geometrical values for U-profiles and clamping section come from simple measures in the manufacturer's dwg files, not only are they subjected to variations according to the considered reference points for the quotation, but also on the actual building aspects, their consideration requires levels of precisions that do not make sense for such projects.

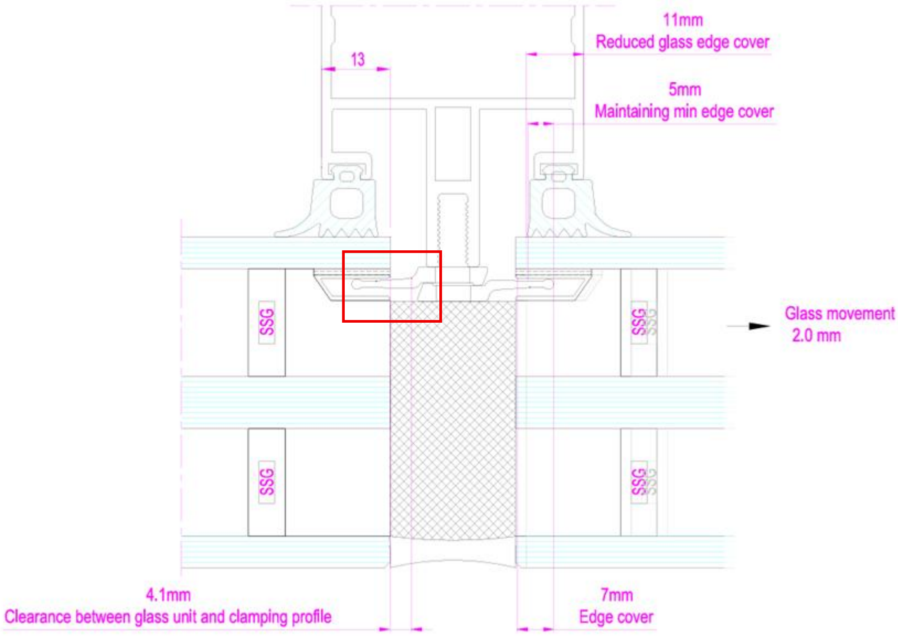

Figure 5.5—2: Example of a discrepancy in Reynaers schemes (clamping profile with 13 mm glass edge cover. Source: CW50-60)

Finally, two big kinds of errors have been encountered regarding the clamping section:

- In the first case, calculated clamping edge cover all were 0.25 mm bigger than Reynaers' values; potentially due to a different way of measuring the edge cover, or a supplementary untold hypothesis.
- Similarly, the clearance values were 0.20 mm higher than Reynaers'; once again, probably because of a specific way to consider the fixing strip side width.

During the development phase of the tool, adaptation terms were then implemented in the calculation process to catch up with Reynaers value during the overall consistency checks. Once this process was done, they were deleted, considering they would be obstacles to a comprehensive use of the file in future contexts.

Ulterior development phases

Finally, let us recall that Reynaers' calculations take place in an isothermal context. Since the purpose of the file is to consider the behavior under thermal solicitations, the continuous referring to the manufacturer's data does not make sense anymore. The reference values that are provided in the file may just be considered as purely indicative values, independent from the computed one. However, according to the context, it could be of good practice to consider ulterior checks in the cases where the calculated results strongly differ of Reynaers' ones – but this process becomes irrelevant as soon as detailed design parameters, such as some that will be discussed in the following part *Use in a real project* change the criticality of the dimensions in the frame.

6 Use in a real project

In order to evaluate the relevance and consistency of the developed calculation tool, it has been tested within the frame of an actual design project already finished. This part is based on a calculation relation by Faces engineering focusing on the static aspects of the façade. Highlighting and understanding the differences between this previous process and the developed tool, the goal is to assess its reliability.

6.1. Case study description

The considered project, by Faces Engineering, is an office building featuring a stick system façade, that is not introduced explicitly for confidentiality reasons. The glazing is fixed with toggles, and features setting blocks on the side (and at the bottom, but in any case in a sliding configuration and not a rotating one) [35].

Located in Milan, it displays its glass façade on six levels, with a diversity of configurations of modular elements and glazing panels. This evaluation will focus on the most common kind of panel such as the type depicted here in Figure 6.1—1.

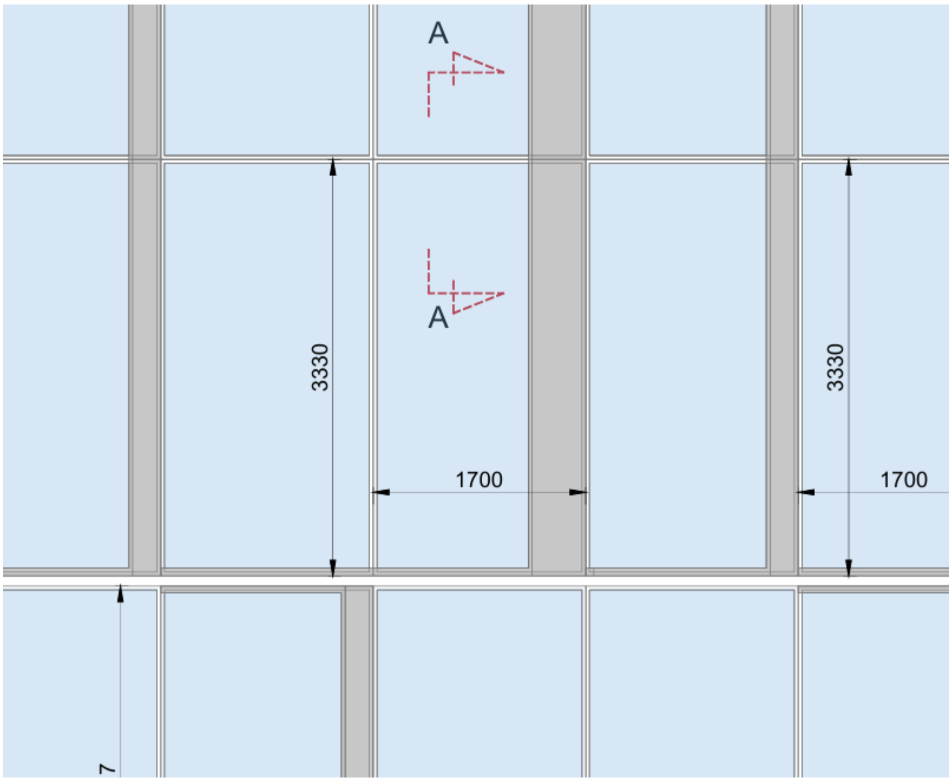

Figure 6.1—1: Individuation of a case study typical façade module (courtesy of Faces Engineering)

Below are reported the main design parameters involved in the mullion deflection calculation.

Table 6.1—1: Case study module relevant dimensions

Project parameters		Value [mm]
$w_{profile}$	Profile (mullion) width	60.00
b_{frame}	Frame width (~transom length)	1770.00
h_{frame}	Frame height (mullion length)	3300.00
e_c	Glass edge cover	20.00
t_{nose}	Total tolerance	2.50
b_{nose}	Mullion nose (or thermal break) width	10.00
d_{toggle}	Toggle diameter	38.00
d_u	U-profile depth	13.50
d_u	U-profile boundary thickness	1.50

Among the main differences between this case study's parameters and the Excel tool's ones, let us stress about a supplementary 0.5 mm tolerance used by Faces to account for the frame production variation (beside the variations in the glass panel production and the installation).

6.2. Comparison with Reynaers' framework

An initial calculation is made to be used as control sample; the scope of this step is, before further iterating, to get reference values while modifying as few parameters as possible in the existing file.

Table 6.2—1: Control sample regarding Reynaer's results

Parameters [mm]	Reynaers	Control 1	Control 2	Control 3	Faces
e_c	*18.00*	18.00	20.00	20.00	*20.00*
t_{nose}	*2.00*	2.00	2.00	2.50	*2.50*
$\Delta_{v,\text{ bottom glass shimming}}$	*1.57*	2.13	1.60	1.60	*(?) 2.20*
$\Delta_{v,\text{ side glass shimming}}$	***4.90***	**4.90**	**2.90**	**2.40**	***2.20***

The main problem regarding Reynaers' data, in this case (CW-60-SC with toggle, cf. Reynaers' table 9), is the lack of detailing in calculating the side glass shimming case, since it basically just considers the top clearance from whom the tolerances have been subtracted. Thus, going out of the very standard cases the manufacturer has considered, its values become irrelevant. Below are described three first iterations to simply approach the process displayed in the case study:

- Control 1: with the default glass edge cover of 18 mm, one can reach the exact same value of vertical deflection for side glass shimming (4.90 mm). However, the bottom glass shimming case gives a much less precise value (2.13 for 1.57 mm).
- Control 2: Changing the glass edge cover to match the 20 mm of Faces, the reverse occurs: the bottom glass shimming value grows closer to Reynaers (1.60 for 1.57 mm) meanwhile the side glass shimming one becomes too diverse (2.90 for 4.90 mm – obviously, since increasing the glass edge cover, by also increasing the panel dimension, changes the clearance).
- Control 3: Last preliminary iteration to evaluate the impact of the tolerances used by Faces; it makes the calculated value for side glass shimming get quite close to the final calculated in the case study (2.40 for 2.20 mm).

These steps, not taking into consideration any dimension variation due to thermal loads, cannot lead to precise results. However, they highlight the fact that Faces' process for the case study is widely different of the one implemented by Reynaers, stressing the need for more iterations, a more detailed list of references between the approach, and a clear comprehensive overview of both methodologies, eventually leading to their critics and reformulation.

6.3. Comparison with Faces' process

Considering various quantities and hypothesis differ between the calculation tool and the Faces' relation, an iteration of successive changes in the files have been made to best match the real project situation. In a first time, to assess that as much relevant parameters as possible are matching – considering the divergences between both processes. Second, to progressively implement them in an actually comparable situation.

6.3.1. Specific parameters retrieval

Regarding the thermal behavior, all useful parameters have been summarized in the following table. These values and the process to which they're bounded highly differ from the Italian normative. Indeed, the maxima come from [36], while the minima have been given by manufacturers; these limitations are mostly connected with the resistance of silicon joints to extreme temperatures.

Table 6.3—1: Reference temperatures [°C] given in Faces' report

Element	T_{prod}	T_{max}	T_{min}	ΔT_{summer}	ΔT_{winter}
Frame	25	60	-10	35	-35
Panel	25	80	-20	55	-45

Although featuring a potential higher temperature gradient, the summer behavior has not been explicitly considered. Indeed, as seen in §5.2.2 Thermal parameters, due to the lowest thermal variation for the glass, it is the contraction scenario that is the more stringent.

Notice that these values and temperature difference are widely different than the ones considered in the Excel tool; indeed, instead of considering environmental parameters, they consider the absolute values given for the components of the panel. Thus, this represents a consequent point of divergence between the two methods.

The calculation explicated in the Faces' report is the following:

$$c'_{top} = c_{top} + L\left(\alpha_{frame}\Delta T_{frame,winter} - \alpha_{glass}\Delta T_{glass,winter}\right) - \sum t \ [mm] \quad (6.3.1\text{-}1)$$

$$\Rightarrow 2.2 = 6 + L \cdot (2.4 \cdot 10^{-5} \cdot (-35) - 9 \cdot 10^{-6} \cdot (-45) - 2.5$$

$$\Rightarrow L = 3250\ mm$$

NB: this calculation is given here provided the student found a discrepancy in the calculation process and concluded that the frame dimension that was actually taken into account was 3250 mm instead of 3350.

6.3.2. Side glass shimming

Then, the actual comparison has to be made in accordance with all remaining design parameters, processing through iterative changes to reach a relevant final value.

Temperature gradient

The temperature taken into account recreates the environmental conditions of the façade, thus differs from the limits given by manufactures such as [35] indicated them. Considering the critical behavior for winter, the useful parameters are the following:

Table 6.3—2: Considered parameters for the thermal behavior

Temperature parameters		Value	Unit
a_s	Reference altitude	138.00	m
T_0	Reference temperature	15.00	°C
T_{in}	Internal temperature	25.00	°C
-	Frame material	Aluminum	-
-	Panel material	Glass	-
$\Delta T_{u,min}$	Winter temperature difference	-10.28	°C

NB: Orientation and color of the façade do not impact the winter results since they are only responsible for a positive temperature increase.

In Faces' report, the modelling hypothesis consider the panel and the frame as having similar dimensions, and only use the variation within the calculation. On the opposite, in the Excel tool, the panels dimensions are calculated, after thermal contraction, starting from the usual development parameters (frame dimensions, profile width and glass edge cover). So, in order to reach the design values of 3250×1750 mm, it has been implemented a 3270×1770 mm frame (slightly smaller and wider than the usual designed modules).

The allowed vertical deflection is then computed using the following values (according to the process already described in §5.3.3 *Toggle fixation* and 5.4 *Side glass shimming*), as well as the unaltered ones in Table 6.1—1: Case *study module relevant dimensions*:

Table 6.3—3: Parameters for the computation of the allowed vertical deflection

Calculation outputs		Value	Unit
$h_{frame,c}'$	Contracted frame height	3269.23	mm

$h_{glass,c}'$	Contracted glass height	3249.23	mm
c_{top}	Superior clearance glass / profile nose	5.01	mm
Δv	**Allowed vertical deflection**	**2.50**	**mm**

The final allowed vertical deflection value is then higher than the one give in Faces' report (2.50 > 2.20 mm), with a difference that seems hardly negligible: around 11%.

6.3.3. Bottom glass shimming

This case is hypothetically considered for information purpose – since the actual project is characterized by setting blocks both on the side and at the bottom of the panel. Without side glass shimming, bottom glass shimming allows the glazing panels to rotate (cf. 4.1.3 *Types of glass shimming*). Considering than the panels used in the project are rectangles with the height being the biggest dimension, for a given allowed lateral deflection, the related allowed vertical deflection will be smaller.

The reference value of lateral deflection for a square panel that has been calculated corresponds to the reduced clearance on the side, and thus equals the vertical glass deflection for pure sliding without rotation of the panel. From (5.3.3-3):

$$\Delta_h = c_{side} - t_{nose} = \Delta_{v,side\ glass\ shimming} = c_{top} - t_{nose} = 2.51\ [mm]$$

With:

- Δ_h the allowed lateral deflection [mm]
- c_{side} and c_{top} the tolerances on the side and on the top of the panel [mm]
- t_{nose} the total tolerance [mm].

From (5.3.1-5), (5.3.1-6), this leads once again to:

$$\Delta_v = \frac{\Delta_h}{h_{glass}} \cdot b_{glass} = 1.35\ [mm]$$

With:

- b_{glass} and h_{glass} the width and height of the glazing [mm]; as said in §5.2.2 *Thermal parameters*, they will actually assume values equal to either, $b'_{glass,d}$, $h'_{glass,d}$ or $b'_{glass,c}$, $h'_{glass,c}$ to take into account the dimension variation due to temperature. Same remark applies for the following calculations.

In this case, the allowable mullion deflection value is much smaller, because the geometry of the panel allows little rotation before reaching a critical point for safety.

6.4. Discussion

Modeling and hypothesis

As already discussed, Faces considered common dimensions for the module elements, and only used the length of the element to compute the differential thermal movement between glazing and frame. In this process, the dimensions of the glazing are not explicit (and thus, lost to the user); rather than a lack of precision, it illustrates a more synthetic formulation of the same problem. However, it may generate discrepancies regarding the configuration of the Excel tool, or difficulties in use that are hardly accountable or coherent.

For instance, considering a lateral clearance of 5 mm and a mullion nose of 10 mm width, the equation (5.3.1-1) allows to write:

$$b_{glass} = b_{frame} - 2 \cdot c_{side} - w_{profile} = b_{frame} - 20\ [mm]$$

Meanwhile the "computed" glazing dimension (since the frame dimension input has been modified to that the glass panels match the geometry in Faces' report), get from equations (5.1.3-1) and (5.1.3-2), features a 20 mm difference with the frame – thus, the values match. However, inherently to the workflow of the Excel tool, whose way of implementing the values is quite restricted, the user has to indirectly modify the most external parameters to modify the inner, dependent ones. This becomes a problem when, just like here, horizontal and vertical section feature different value for a corresponding parameter (e.g., the clearance) and thus the verification steps have to be pursued separately (since while verifying the vertical section, one may mess with the parameters of the horizontal and vice versa).

Supplementary design details

Below appear two detailed sections from the case study. The first one highlights another issue that might rise up in specific design: here, the toggle also features an outer ring that reduces the clearance between the glass and the mullion nose, from 5 mm to 2.7 mm. This typology of element is absent from Reynaers' data and structural details such as those displayed in previous part of this document; consequently, it was not considered in the case study verification, assuming the implementation of such a new parameter would modify far too deeply the structure of the workflow – also, one could consider than since 2.7 > 2.5 mm (the allowed lateral deflection) then this case still results verified. However, in future designs and uses of the tool, similar situation may rise and require a peculiar attention so that critical dimensions may be consequently adapted.

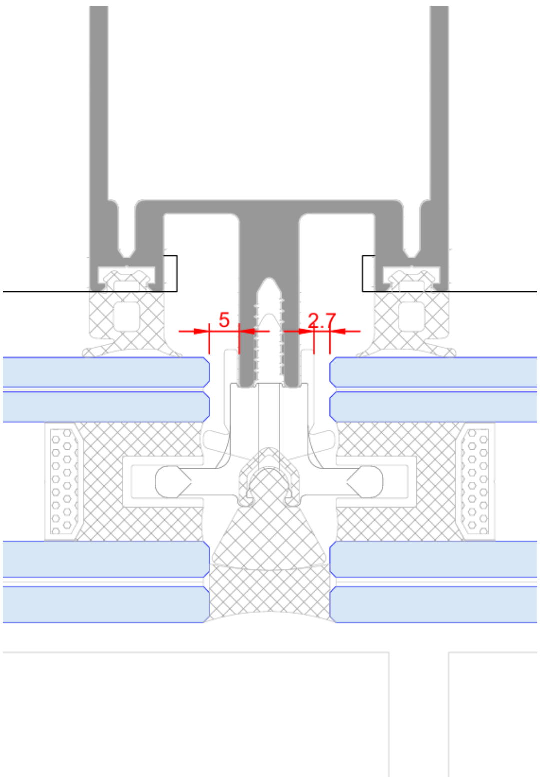

Figure 6.4—1: Planar section on the mullion (courtesy of Faces Engineering)

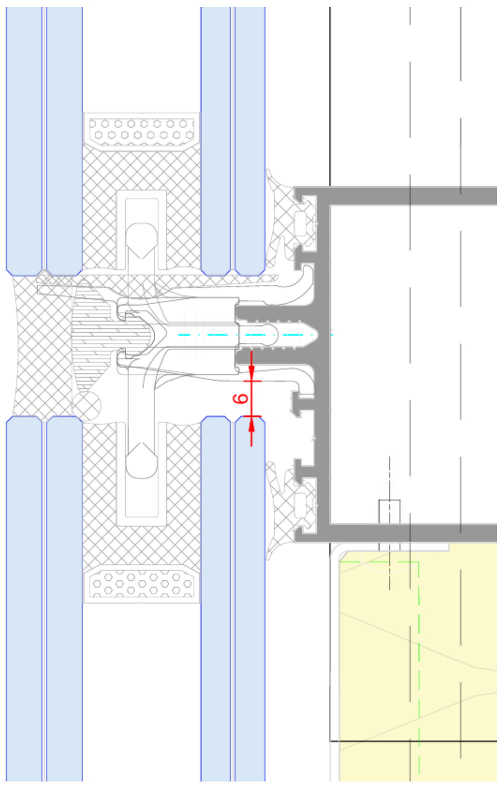

Figure 6.4—2: Vertical section on the mullion (courtesy of Faces Engineering)

Side glass shimming result

A specific word must be said on the side glass shimming, a configuration that relies almost only on top clearance (such as displayed in Figure 6.4—2: *Vertical section on the mullion* (courtesy of Faces Engineering)). It was demonstrated before that, with a similar geometrical configuration, Faces' approach was more conservative; indeed, the most critical value they got comes from a bigger temperature gradient (coming from the admissible values for material, and not from the environmental conditions). One can actually question the relevance of such a process, where the thermal dichotomy between the materials of the two components is assumed to provide the maximum temperature range, but without direct relationship with the actual climate and geographical location. This choice may be discussed, and influenced by factors such as manufacturers' data, contractor's exigencies and designers' preferences.

Coefficients used

A slight variation has also been identified regarding the value of the thermal coefficient used. All else being equal, using the aluminum thermal coefficient provided by the NTC 2018 ($2.4 \cdot 10^{-5}$) instead of the Faces' report one ($2.3 \cdot 10^{-5}$) in the equation (6.3.1-1) gives 1.42 mm instead of 1.31 mm, an 8% difference. Although, in reality, this may have almost no impact on a building field, it still alters the precision of the calculations and may make them less reliable.

Dilatation case

The dilatation was not merely considered in Faces' report for reasons already mentioned. It may legitimately be questioned that, since that the material for infill panels (typically: glass) are most likely to have a dilatation coefficient smaller than the frame (metals), this case should perhaps not be considered. One can hypothesize than, however, in some peculiar situations, the results of this part could have an informative value – but these minority cases have to be defined or identified.

Lessons learned

This range of tests provided useful information regarding the operation of the tool, its accessibility and relevance. For instance, its use highlighted the need for effectively independent parameters for the side and the top of the glazing.

Similarly, the consideration of numerous intermediary results (mostly geometrical secondary parameters), explicitly displayed in the calculation for precision concerns – and in order for the user to be able to follow more easily the computation steps –, resulted quite unpractical in a common use. It was then decided to hide or erase several of them to ensure more clarity in the Excel file.

Finally, it has been actually experimented than the hypothesis and framework used shall be carefully introduced and detailed since, even in such a simple geometrical problem, since they generate variable results and may blur the behaviors of the studied façade.

7 Conclusion

Arrived at the end of this work, here are summarized and synthetized the main aspects it dealt with.

Tool useability

It has been demonstrated how, and in which conditions, the Excel tool and its results are reliable. The initial workflow, grounded on Reynears' database, has been confirmed and deepened thanks to the review of the existing literature on this subject, ultimately leading to a more adaptive process. In a second time, its implementation within the frame of an actual project allowed to highlight the influence of its founding hypothesis as well as potential directions of betterment.

Thermal variation

Parallelly, the implementation of dimension variation under the influence of temperature made the previous results more concrete, bringing in the present tool processes that had been previously computed by Faces. However, this field may still be subject of ulterior discussions. For instance, the relevance of considering dilatation cases; since due to the dichotomy of behavior between the metallic frame and the infill panels, the worst key scenario occurs for winter behavior and contraction is most likely to create critical conditions for the safety of the frame. Similarly, the choice to base the thermal calculation on NTC's methodology may be challenged by the EOTA's [36]; the corresponding hypothesis to statue on would be whether the environmental conditions or the material characteristics play the most determining role in this specific problem.

Dealing with racking

An important part of the early work consisted in the evaluation of rotation occurring in racking. However, this phenomenon mostly relies on the absence of side glass shimming. It has been recalled than the use of side blocs to impeach rotation leads to better performance of the system: racking is always more critical (and more difficult to assess) than mere sliding considering the rotating glass problem. A legitimate question is then to what extent a design may take advantage in using only bottom blocks and let the possibility for the glazing to rotate since it represents a weakness in movement accommodation. This issue, connected to horizontal sway, would require a comparative approach for all kind of in-place façade movements.

Fulfillment of the task

What still has to be done, besides last control check, is mostly a aesthetical work to make the appearance of the tool more user-friendly. Moreover, some of the discussions mentioned above might still impact last changes. The placing process will then take place, ensuring every useful information is actually transmitted, serviceable and referenced for future uses.

Place of the thesis in the student's formation

Finally, this work allowed the student to dive more precisely in typical façade problems. Although not complex on a technical point of view, the convergence of many stakes in this subject (building typologies, thermal behavior, link with the primary structure, calculation processes) made it a proper way of getting more in touch with façade engineering. It also represented a comprehensive training in R&D tasks typical of design studios, thus an effective way of preparing his actual entrance in professional life.

A References

A.1. Bibliography

A.2. Index of terms

- a_s reference altitude [m]
- α thermal dilatation coefficient [°C^{-1}]
- b_{frame} frame width [mm]
- $b_{fs,eff}$ fixing strip effective width (clamping section case) [mm]
- $b_{fs,long}$ fixing strip longest side (clamping section case) [mm]
- $b_{fs,short}$ fixing strip shortest side (clamping section case) [mm]
- b_{glass} glass panel width [mm]
- b_{nose} profile nose width [mm]
- b_r rebate depth [mm]
- b_{tight} tight size of the frame [mm]
- $c_{cl,section}$ clearance between glass and clamping section [mm]
- $c'_{cl,section}$ reduced clearance between glass and clamping section [mm]
- $c_{cl,toggle}$ clearance between glass and toggle [mm]
- $c'_{cl,toggle}$ reduced clearance between glass and toggle [mm]
- c_{side} clearance between glass and profile nose [mm]
- c'_{side} reduced clearance between glass and profile nose [mm]
- d_{fs} clip diameter (clamping section case) [mm]
- d_t toggle diameter [mm]
- d_u U-profile depth [mm]
- Δ_h allowed glazing horizontal movement [mm]
- ΔT_{max} summer (positive) thermal gradient [°C]
- ΔT_{min} winter (negative) thermal gradient [°C]
- Δ_v allowed glazing vertical movement [mm]
- $e_{c,clamping}$ edge cover (clamping section case) [mm]
- e_c glass edge cover [mm]
- e'_c reduced glass edge cover [mm]
- $e_{c,min}$ minimum glass edge cover [mm]
- $e_{cl,section}$ clamping edge cover (clamping section case) [mm]
- $e_{cl,section,min}$ minimum clamping edge cover (clamping section case) [mm]
- $e_{cl,toggle}$ clamping edge cover (toggle case) [mm]
- $e_{cl,toggle,min}$ minimum clamping edge cover (toggle case) [mm]
- γ rotation angle [rad]
- h_{frame} frame height [mm]
- h_{glass} glass panel height [mm]
- l_{clip} clip length (clamping section case) [mm]
- $T^{(+)}$ temperature incrementation due to color and façade exposition [°C]
- T_0 reference temperature [°C]
- T_{in} internal temperature [°C]
- T_{max} maximum temperature in the envelope [°C]
- T_{min} minimum temperature in the envelope [°C]
- T_{out} outside temperature [°C]
- $T_{out,max}$ maximum outside temperature [°C]
- $T_{out,min}$ minimum outside temperature [°C]
- t_u U-profile thickness [mm]
- t_{nose} total tolerance (applied around profile nose) [mm]
- $w_{profile}$ profile width [mm]

B Appendix

B.1. Reynaers data tables

Synthesis of reference allowed mullion deflection values, with colors such as green < 2 mm, yellow < 4 mm, red < 6 mm, white > 6 mm.

Table B.1—1: Reynaers data 1 (source: CW50-60)

CW50

Allowable mullion differential movement for glass edge cover of 15mm [mm]

		Width glass panel [mm]																									
		50(	60(	70(	80(	90(	10(	11(	12(	13(	14(	15(	16(	17(	18(	19(	20(	21(	22(	23(	24(	25(	26(	27(	28(	29(	30(
Height glass panel [mm]	500	2.9	3.5	4.1	4.6	5.2	5.8	6.4	7	7.5	8.1	8.7	9.3	9.9	10.4	11	11.6	12.2	12.8	13.3	13.9	14.5	15.1	15.7	16.2	16.8	17.4
	600	2.4	2.9	3.4	3.9	4.4	4.8	5.3	5.8	6.3	6.8	7.3	7.7	8.2	8.7	9.2	9.7	10.2	10.6	11.1	11.6	12.1	12.6	13.1	13.5	14	14.5
	700	2.1	2.5	2.9	3.3	3.7	4.1	4.6	5	5.4	5.8	6.2	6.6	7	7.5	7.9	8.3	8.7	9.1	9.5	9.9	10.4	10.8	11.2	11.6	12	12.4
	800	1.8	2.2	2.5	2.9	3.3	3.6	4	4.4	4.7	5.1	5.4	5.8	6.2	6.5	6.9	7.3	7.6	8	8.3	8.7	9.1	9.4	9.8	10.2	10.5	10.9
	900	1.6	1.9	2.3	2.6	2.9	3.2	3.5	3.9	4.2	4.5	4.8	5.2	5.5	5.8	6.1	6.4	6.8	7.1	7.4	7.7	8.1	8.4	8.7	9	9.3	9.7
	1000	1.5	1.7	2	2.3	2.6	2.9	3.2	3.5	3.8	4.1	4.4	4.6	4.9	5.2	5.5	5.8	6.1	6.4	6.7	7	7.3	7.5	7.8	8.1	8.4	8.7
	1100	1.3	1.6	1.8	2.1	2.4	2.6	2.9	3.2	3.4	3.7	4	4.2	4.5	4.7	5	5.3	5.5	5.8	6.1	6.3	6.6	6.9	7.1	7.4	7.6	7.9
	1200	1.2	1.5	1.7	1.9	2.2	2.4	2.7	2.9	3.1	3.4	3.6	3.9	4.1	4.4	4.6	4.8	5.1	5.3	5.6	5.8	6	6.3	6.5	6.8	7	7.3
	1300	1.1	1.3	1.6	1.8	2	2.2	2.5	2.7	2.9	3.1	3.3	3.6	3.8	4	4.2	4.5	4.7	4.9	5.1	5.4	5.6	5.8	6	6.2	6.5	6.7
	1400	1	1.2	1.5	1.7	1.9	2.1	2.3	2.5	2.7	2.9	3.1	3.3	3.5	3.7	3.9	4.1	4.4	4.6	4.8	5	5.2	5.4	5.6	5.8	6	6.2
	1500	1	1.2	1.4	1.5	1.7	1.9	2.1	2.3	2.5	2.7	2.9	3.1	3.3	3.5	3.7	3.9	4.1	4.3	4.4	4.6	4.8	5	5.2	5.4	5.6	5.8
	1600	0.9	1.1	1.3	1.5	1.6	1.8	2	2.2	2.4	2.5	2.7	2.9	3.1	3.3	3.4	3.6	3.8	4	4.2	4.4	4.5	4.7	4.9	5.1	5.3	5.4
	1700	0.9	1	1.2	1.4	1.5	1.7	1.9	2	2.2	2.4	2.6	2.7	2.9	3.1	3.2	3.4	3.6	3.8	3.9	4.1	4.3	4.4	4.6	4.8	4.9	5.1
	1800	0.8	1	1.1	1.3	1.5	1.6	1.8	1.9	2.1	2.3	2.4	2.6	2.7	2.9	3.1	3.2	3.4	3.5	3.7	3.9	4	4.2	4.4	4.5	4.7	4.8
	1900	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8	2	2.1	2.3	2.4	2.6	2.8	2.9	3.1	3.2	3.4	3.5	3.7	3.8	4	4.1	4.3	4.4	4.6
	2000	0.7	0.9	1	1.2	1.3	1.5	1.6	1.7	1.9	2	2.2	2.3	2.5	2.6	2.8	2.9	3	3.2	3.3	3.5	3.6	3.8	3.9	4.1	4.2	4.4
	2100	0.7	0.8	1	1.1	1.2	1.4	1.5	1.7	1.8	1.9	2.1	2.2	2.3	2.5	2.6	2.8	2.9	3	3.2	3.3	3.5	3.6	3.7	3.9	4	4.1
	2200	0.7	0.8	0.9	1.1	1.2	1.3	1.5	1.6	1.7	1.8	2	2.1	2.2	2.4	2.5	2.6	2.8	2.9	3	3.2	3.3	3.4	3.6	3.7	3.8	4
	2300	0.6	0.8	0.9	1	1.1	1.3	1.4	1.5	1.6	1.8	1.9	2	2.1	2.3	2.4	2.5	2.6	2.8	2.9	3	3.2	3.3	3.4	3.5	3.7	3.8
	2400	0.6	0.7	0.8	1	1.1	1.2	1.3	1.5	1.6	1.7	1.8	1.9	2.1	2.2	2.3	2.4	2.5	2.7	2.8	2.9	3	3.1	3.3	3.4	3.5	3.6
	2500	0.6	0.7	0.8	0.9	1	1.1	1.3	1.4	1.5	1.6	1.7	1.9	2	2.1	2.2	2.3	2.4	2.6	2.7	2.8	2.9	3	3.1	3.2	3.4	3.5
	2600	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.5	2.6	2.7	2.8	2.9	3	3.1	3.2	3.3
	2700	0.5	0.6	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3	3.1	3.2
	2800	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.5	1.5	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3	3.1
	2900	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3
	3000	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.5	1.6	1.8	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
	3100	0.5	0.6	0.7	0.8	0.9	1	1.1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.4	2.5	2.6	2.7	2.8
	3200	0.5	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.4	2.5	2.6	2.7
	3300	0.4	0.5	0.6	0.7	0.8	0.9	1	1.1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.5	2.6
	3400	0.4	0.5	0.6	0.7	0.8	0.9	0.9	1	1.1	1.2	1.3	1.4	1.5	1.5	1.6	1.7	1.8	1.9	2	2.1	2.1	2.2	2.3	2.4	2.5	2.6
	3500	0.4	0.5	0.6	0.7	0.8	0.8	0.9	1	1.1	1.2	1.3	1.3	1.4	1.5	1.6	1.6	1.7	1.8	1.9	2	2.1	2.1	2.2	2.3	2.4	2.5

Table B.1—2: Reynaers data 2 (source: CW50-60)

CW50/CW50-HI

Allowable mullion differential movement for glass edge cover of 13mm [mm]

Height glass panel [mm]	Width glass panel [mm]																									
	50(	**60(**	**70(**	**80(**	**90(**	**10(**	**11(**	**12(**	**13(**	**14(**	**15(**	**16(**	**17(**	**18(**	**19(**	**20(**	**21(**	**22(**	**23(**	**24(**	**25(**	**26(**	**27(**	**28(**	**29(**	**30(**
500	2	2.4	2.8	3.2	3.6	4	4.4	4.8	5.2	5.6	6	6.4	6.8	7.2	7.6	8	8.4	8.8	9.2	9.6	10	10.4	10.8	11.2	11.6	12
600	1.7	2	2.3	2.7	3	3.3	3.7	4	4.3	4.7	5	5.3	5.7	6	6.3	6.7	7	7.3	7.7	8	8.3	8.7	9	9.3	9.7	10
700	1.4	1.7	2	2.3	2.6	2.9	3.1	3.4	3.7	4	4.3	4.6	4.9	5.1	5.4	5.7	6	6.3	6.6	6.9	7.1	7.4	7.7	8	8.3	8.6
800	1.3	1.5	1.8	2	2.3	2.5	2.8	3	3.3	3.5	3.8	4	4.3	4.5	4.8	5	5.3	5.5	5.8	6	6.3	6.5	6.8	7	7.3	7.5
900	1.1	1.3	1.6	1.8	2	2.2	2.4	2.7	2.9	3.1	3.3	3.6	3.8	4	4.2	4.4	4.7	4.9	5.1	5.3	5.6	5.8	6	6.2	6.4	6.7
1000	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	5	5.2	5.4	5.6	5.8	6
1100	0.9	1.1	1.3	1.5	1.6	1.8	2	2.2	2.4	2.5	2.7	2.9	3.1	3.3	3.5	3.6	3.8	4	4.2	4.4	4.5	4.7	4.9	5.1	5.3	5.5
1200	0.8	1	1.2	1.3	1.5	1.7	1.8	2	2.2	2.3	2.5	2.7	2.8	3	3.2	3.3	3.5	3.7	3.8	4	4.2	4.3	4.5	4.7	4.8	5
1300	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8	2	2.2	2.3	2.5	2.6	2.8	2.9	3.1	3.2	3.4	3.5	3.7	3.8	4	4.2	4.3	4.5	4.6
1400	0.7	0.9	1	1.1	1.3	1.4	1.6	1.7	1.9	2	2.1	2.3	2.4	2.6	2.7	2.9	3	3.1	3.3	3.4	3.6	3.7	3.9	4	4.1	4.3
1500	0.7	0.8	0.9	1.1	1.2	1.3	1.5	1.6	1.7	1.9	2	2.1	2.3	2.4	2.5	2.7	2.8	2.9	3.1	3.2	3.3	3.5	3.6	3.7	3.9	4
1600	0.6	0.8	0.9	1	1.1	1.3	1.4	1.5	1.6	1.8	1.9	2	2.1	2.3	2.4	2.5	2.6	2.8	2.9	3	3.1	3.3	3.4	3.5	3.6	3.8
1700	0.6	0.7	0.8	0.9	1.1	1.2	1.3	1.4	1.5	1.6	1.8	1.9	2	2.1	2.2	2.4	2.5	2.6	2.7	2.8	2.9	3.1	3.2	3.3	3.4	3.5
1800	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.6	2.7	2.8	2.9	3	3.1	3.2	3.3
1900	0.5	0.6	0.7	0.8	0.9	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.1	3.2
2000	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3
2100	0.5	0.6	0.7	0.8	0.9	1	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
2200	0.5	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.5	2.6	2.7
2300	0.4	0.5	0.6	0.7	0.8	0.9	1	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.7	1.8	1.9	2	2.1	2.2	2.3	2.3	2.4	2.5	2.6
2400	0.4	0.5	0.6	0.7	0.8	0.8	0.9	1	1.1	1.2	1.3	1.3	1.4	1.5	1.6	1.7	1.8	1.8	1.9	2	2.1	2.2	2.3	2.3	2.4	2.5
2500	0.4	0.5	0.6	0.6	0.7	0.8	0.9	1	1	1.1	1.2	1.3	1.4	1.4	1.5	1.6	1.7	1.8	1.8	1.9	2	2.1	2.2	2.2	2.3	2.4
2600	0.4	0.5	0.5	0.6	0.7	0.8	0.8	0.9	1	1.1	1.2	1.2	1.3	1.4	1.5	1.5	1.6	1.7	1.8	1.8	1.9	2	2.1	2.2	2.2	2.3
2700	0.4	0.4	0.5	0.6	0.7	0.7	0.8	0.9	1	1	1.1	1.2	1.3	1.3	1.4	1.5	1.6	1.6	1.7	1.8	1.9	1.9	2	2.1	2.1	2.2
2800	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.9	0.9	1	1.1	1.1	1.2	1.3	1.4	1.4	1.5	1.6	1.6	1.7	1.8	1.9	1.9	2	2.1	2.1
2900	0.3	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1	1	1.1	1.2	1.2	1.3	1.4	1.4	1.5	1.6	1.7	1.7	1.8	1.9	1.9	2	2.1
3000	0.3	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.9	0.9	1	1.1	1.1	1.2	1.3	1.3	1.4	1.5	1.5	1.6	1.7	1.7	1.8	1.9	1.9	2
3100	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1	1	1.1	1.2	1.2	1.3	1.4	1.4	1.5	1.5	1.6	1.7	1.7	1.8	1.9	1.9
3200	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	0.9	1	1.1	1.1	1.2	1.3	1.3	1.4	1.4	1.5	1.6	1.6	1.7	1.8	1.8	1.9
3300	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.8	0.9	1	1	1.1	1.2	1.2	1.3	1.3	1.4	1.5	1.5	1.6	1.6	1.7	1.8	1.8
3400	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.8	0.8	0.9	0.9	1	1.1	1.1	1.2	1.2	1.3	1.4	1.4	1.5	1.5	1.6	1.6	1.7	1.8
3500	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.9	0.9	1	1	1.1	1.1	1.2	1.3	1.3	1.4	1.4	1.5	1.5	1.6	1.7	1.7

Table B.1—3: Reynaers data 3 (source: CW50-60)

CW60/CW60-HI

Allowable mullion differential movement for glass edge cover of 18mm [mm]

Height glass panel [mm]	Width glass panel [mm]																									
	50(	**60(**	**70(**	**80(**	**90(**	**10(**	**11(**	**12(**	**13(**	**14(**	**15(**	**16(**	**17(**	**18(**	**19(**	**20(**	**21(**	**22(**	**23(**	**24(**	**25(**	**26(**	**27(**	**28(**	**29(**	**30(**
500	**4.9**	5.9	6.9	7.8	8.8	9.8	10.8	11.8	12.7	13.7	14.7	15.7	16.7	17.6	18.6	19.6	20.6	21.6	22.5	23.5	24.5	25.5	26.5	27.4	28.4	29.4
600	4.1	4.9	5.7	6.5	7.4	8.2	9	9.8	10.6	11.4	12.3	13.1	13.9	14.7	15.5	16.3	17.2	18	18.8	19.6	20.4	21.2	22.1	22.9	23.7	24.5
700	3.5	4.2	4.9	5.6	6.3	7	7.7	8.4	9.1	9.8	10.5	11.2	11.9	12.6	13.3	14	14.7	15.4	16.1	16.8	17.5	18.2	18.9	19.6	20.3	21
800	3.1	3.7	4.3	4.9	5.5	6.1	6.7	7.4	8	8.6	9.2	9.8	10.4	11	11.6	12.3	12.9	13.5	14.1	14.7	15.3	15.9	16.5	17.2	17.8	18.4
900	2.7	3.3	3.8	4.4	4.9	5.4	6	6.5	7.1	7.6	8.2	8.7	9.3	9.8	10.3	10.9	11.4	12	12.5	13.1	13.6	14.2	14.7	15.2	15.8	16.3
1000	2.5	2.9	3.4	3.9	4.4	4.9	5.4	5.9	6.4	6.9	7.4	7.8	8.3	8.8	9.3	9.8	10.3	10.8	11.3	11.8	12.3	12.7	13.2	13.7	14.2	14.7
1100	2.2	2.7	3.1	3.6	4	4.5	4.9	5.3	5.8	6.2	6.7	7.1	7.6	8	8.5	8.9	9.4	9.8	10.2	10.7	11.1	11.6	12	12.5	12.9	13.4
1200	2	2.5	2.9	3.3	3.7	4.1	4.5	4.9	5.3	5.7	6.1	6.5	6.9	7.4	7.8	8.2	8.6	9	9.4	9.8	10.2	10.6	11	11.4	11.8	12.3
1300	1.9	2.3	2.6	3	3.4	3.8	4.1	4.5	4.9	5.3	5.7	6	6.4	6.8	7.2	7.5	7.9	8.3	8.7	9	9.4	9.8	10.2	10.6	10.9	11.3
1400	1.8	2.1	2.5	2.8	3.2	3.5	3.9	4.2	4.6	4.9	5.3	5.6	6	6.3	6.7	7	7.4	7.7	8.1	8.4	8.8	9.1	9.5	9.8	10.2	10.5
1500	1.6	2	2.3	2.6	2.9	3.3	3.6	3.9	4.2	4.6	4.9	5.2	5.6	5.9	6.2	6.5	6.9	7.2	7.5	7.8	8.2	8.5	8.8	9.1	9.5	9.8
1600	1.5	1.8	2.1	2.5	2.8	3.1	3.4	3.7	4	4.3	4.6	4.9	5.2	5.5	5.8	6.1	6.4	6.7	7	7.4	7.7	8	8.3	8.6	8.9	9.2
1700	1.4	1.7	2	2.3	2.6	2.9	3.2	3.5	3.7	4	4.3	4.6	4.9	5.2	5.5	5.8	6.1	6.3	6.6	6.9	7.2	7.5	7.8	8.1	8.4	8.6
1800	1.4	1.6	1.9	2.2	2.5	2.7	3	3.3	3.5	3.8	4.1	4.4	4.6	4.9	5.2	5.4	5.7	6	6.3	6.5	6.8	7.1	7.4	7.6	7.9	8.2
1900	1.3	1.5	1.8	2.1	2.3	2.6	2.8	3.1	3.4	3.6	3.9	4.1	4.4	4.6	4.9	5.2	5.4	5.7	5.9	6.2	6.4	6.7	7	7.2	7.5	7.7
2000	1.2	1.5	1.7	2	2.2	2.5	2.7	2.9	3.2	3.4	3.7	3.9	4.2	4.4	4.7	4.9	5.1	5.4	5.6	5.9	6.1	6.4	6.6	6.9	7.1	7.4
2100	1.2	1.4	1.6	1.9	2.1	2.3	2.6	2.8	3	3.3	3.5	3.7	4	4.2	4.4	4.7	4.9	5.1	5.4	5.6	5.8	6.1	6.3	6.5	6.8	7
2200	1.1	1.3	1.6	1.8	2	2.2	2.5	2.7	2.9	3.1	3.3	3.6	3.8	4	4.2	4.5	4.7	4.9	5.1	5.3	5.6	5.8	6	6.2	6.5	6.7
2300	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.3	4.5	4.7	4.9	5.1	5.3	5.5	5.8	6	6.2	6.4
2400	1	1.2	1.4	1.6	1.8	2	2.2	2.5	2.7	2.9	3.1	3.3	3.5	3.7	3.9	4.1	4.3	4.5	4.7	4.9	5.1	5.3	5.5	5.7	5.9	6.1
2500	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.5	2.7	2.9	3.1	3.3	3.5	3.7	3.9	4.1	4.3	4.5	4.7	4.9	5.1	5.3	5.5	5.7	5.9
2600	0.9	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.5	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.3	4.5	4.7	4.9	5.1	5.3	5.5	5.7
2700	0.9	1.1	1.3	1.5	1.6	1.8	2	2.2	2.4	2.5	2.7	2.9	3.1	3.3	3.4	3.6	3.8	4	4.2	4.4	4.5	4.7	4.9	5.1	5.3	5.4
2800	0.9	1.1	1.2	1.4	1.6	1.7	1.9	2.1	2.3	2.5	2.6	2.8	3	3.2	3.3	3.5	3.7	3.9	4	4.2	4.4	4.6	4.7	4.9	5.1	5.3
2900	0.8	1	1.2	1.4	1.5	1.7	1.9	2	2.2	2.4	2.5	2.7	2.9	3	3.2	3.4	3.5	3.7	3.9	4.1	4.2	4.4	4.6	4.7	4.9	5.1
3000	0.8	1	1.1	1.3	1.5	1.6	1.8	2	2.1	2.3	2.5	2.6	2.8	2.9	3.1	3.3	3.4	3.6	3.8	3.9	4.1	4.3	4.4	4.6	4.7	4.9
3100	0.8	0.9	1.1	1.3	1.4	1.6	1.7	1.9	2.1	2.2	2.4	2.5	2.7	2.8	3	3.2	3.3	3.5	3.6	3.8	4	4.1	4.3	4.4	4.6	4.7
3200	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8	2	2.1	2.3	2.5	2.6	2.8	2.9	3.1	3.2	3.4	3.5	3.7	3.8	4	4.1	4.3	4.4	4.6
3300	0.7	0.9	1	1.2	1.3	1.5	1.6	1.8	1.9	2.1	2.2	2.4	2.5	2.7	2.8	3	3.1	3.3	3.4	3.6	3.7	3.9	4	4.2	4.3	4.5
3400	0.7	0.9	1	1.2	1.3	1.4	1.6	1.7	1.9	2	2.2	2.3	2.5	2.6	2.7	2.9	3	3.2	3.3	3.5	3.6	3.7	3.9	4	4.2	4.3
3500	0.7	0.8	1	1.1	1.3	1.4	1.5	1.7	1.8	2	2.1	2.2	2.4	2.5	2.7	2.8	2.9	3.1	3.2	3.4	3.5	3.6	3.8	3.9	4.1	4.2

Table B.1—4: Reynaers data 4 (source: CW50-60)

CW50-SC Clamping profile with 0.34.0176.00+034.0175.00
Allowable mullion differential movement for glass edge cover of 15mm [mm]

Height glass panel [mm]	Width glass panel [mm]																									
	50(	60(	70(	80(	90(	10(	11(	12(	13(	14(	15(	16(	17(	18(	19(	20(	21(	22(	23(	24(	25(	26(	27(	28(	29(	30(
500	2.4	2.9	3.4	3.8	4.3	4.8	5.3	5.8	6.2	6.7	7.2	7.7	8.2	8.6	9.1	9.6	10.1	10.6	11	11.5	12	12.5	13	13.4	13.9	14.4
600	2	2.4	2.8	3.2	3.6	4	4.4	4.8	5.2	5.6	6	6.4	6.8	7.2	7.6	8	8.4	8.8	9.2	9.6	10	10.4	10.8	11.2	11.6	12
700	1.7	2.1	2.4	2.7	3.1	3.4	3.8	4.1	4.5	4.8	5.1	5.5	5.8	6.2	6.5	6.9	7.2	7.5	7.9	8.2	8.6	8.9	9.3	9.6	9.9	10.3
800	1.5	1.8	2.1	2.4	2.7	3	3.3	3.6	3.9	4.2	4.5	4.8	5.1	5.4	5.7	6	6.3	6.6	6.9	7.2	7.5	7.8	8.1	8.4	8.7	9
900	1.3	1.6	1.9	2.1	2.4	2.7	2.9	3.2	3.5	3.7	4	4.3	4.5	4.8	5.1	5.3	5.6	5.9	6.1	6.4	6.7	6.9	7.2	7.5	7.7	8
1000	1.2	1.4	1.7	1.9	2.2	2.4	2.6	2.9	3.1	3.4	3.6	3.8	4.1	4.3	4.6	4.8	5	5.3	5.5	5.8	6	6.2	6.5	6.7	7	7.2
1100	1.1	1.3	1.5	1.7	2	2.2	2.4	2.6	2.8	3.1	3.3	3.5	3.7	3.9	4.1	4.4	4.6	4.8	5	5.2	5.5	5.7	5.9	6.1	6.3	6.5
1200	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	5	5.2	5.4	5.6	5.8	6
1300	0.9	1.1	1.3	1.5	1.7	1.8	2	2.2	2.4	2.6	2.8	3	3.1	3.3	3.5	3.7	3.9	4.1	4.2	4.4	4.6	4.8	5	5.2	5.4	5.5
1400	0.9	1	1.2	1.4	1.5	1.7	1.9	2.1	2.2	2.4	2.6	2.7	2.9	3.1	3.3	3.4	3.6	3.8	3.9	4.1	4.3	4.5	4.6	4.8	5	5.1
1500	0.8	1	1.1	1.3	1.4	1.6	1.8	1.9	2.1	2.2	2.4	2.6	2.7	2.9	3	3.2	3.4	3.5	3.7	3.8	4	4.2	4.3	4.5	4.6	4.8
1600	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8	2	2.1	2.3	2.4	2.6	2.7	2.9	3	3.2	3.3	3.5	3.6	3.8	3.9	4.1	4.2	4.4	4.5
1700	0.7	0.8	1	1.1	1.3	1.4	1.6	1.7	1.8	2	2.1	2.3	2.4	2.5	2.7	2.8	3	3.1	3.2	3.4	3.5	3.7	3.8	4	4.1	4.2
1800	0.7	0.8	0.9	1.1	1.2	1.3	1.5	1.6	1.7	1.9	2	2.1	2.3	2.4	2.5	2.7	2.8	2.9	3.1	3.2	3.3	3.5	3.6	3.7	3.9	4
1900	0.6	0.8	0.9	1	1.1	1.3	1.4	1.5	1.6	1.8	1.9	2	2.1	2.3	2.4	2.5	2.7	2.8	2.9	3	3.2	3.3	3.4	3.5	3.7	3.8
2000	0.6	0.7	0.8	1	1.1	1.2	1.3	1.4	1.6	1.7	1.8	1.9	2	2.2	2.3	2.4	2.5	2.6	2.8	2.9	3	3.1	3.2	3.4	3.5	3.6
2100	0.6	0.7	0.8	0.9	1	1.1	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.9	3	3.1	3.2	3.3	3.4
2200	0.5	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.1	3.2	3.3
2300	0.5	0.6	0.7	0.8	0.9	1	1.1	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3	3.1
2400	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3
2500	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
2600	0.5	0.6	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8
2700	0.4	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7
2800	0.4	0.5	0.6	0.7	0.8	0.9	0.9	1	1.1	1.2	1.3	1.4	1.5	1.5	1.6	1.7	1.8	1.9	2	2.1	2.1	2.2	2.3	2.4	2.5	2.6
2900	0.4	0.5	0.6	0.7	0.7	0.8	0.9	1	1.1	1.2	1.2	1.3	1.4	1.5	1.6	1.7	1.7	1.8	1.9	2	2.1	2.2	2.2	2.3	2.4	2.5
3000	0.4	0.5	0.6	0.6	0.7	0.8	0.9	1	1	1.1	1.2	1.3	1.4	1.4	1.5	1.6	1.7	1.8	1.8	1.9	2	2.1	2.2	2.3	2.3	2.4
3100	0.4	0.5	0.5	0.6	0.7	0.8	0.9	0.9	1	1.1	1.2	1.2	1.3	1.4	1.5	1.5	1.6	1.7	1.8	1.9	1.9	2	2.1	2.2	2.2	2.3
3200	0.4	0.5	0.5	0.6	0.7	0.8	0.8	0.9	1	1.1	1.1	1.2	1.3	1.4	1.4	1.5	1.6	1.7	1.7	1.8	1.9	2	2	2.1	2.2	2.3
3300	0.4	0.4	0.5	0.6	0.7	0.7	0.8	0.9	0.9	1	1.1	1.2	1.2	1.3	1.4	1.5	1.5	1.6	1.7	1.8	1.8	1.9	2	2	2.1	2.2
3400	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1	1.1	1.1	1.2	1.3	1.3	1.4	1.5	1.6	1.6	1.7	1.8	1.8	1.9	2	2	2.1
3500	0.3	0.4	0.5	0.5	0.6	0.7	0.8	0.8	0.9	1	1	1.1	1.2	1.2	1.3	1.4	1.4	1.5	1.6	1.7	1.7	1.8	1.9	1.9	2	2.1

Table B.1—5: Reynaers data 5 (source: CW50-60)

CW50-SC Clamping profile with 0.34.0176.00+034.0175.00
Allowable mullion differential movement for glass edge cover of 13mm [mm]

Height glass panel [mm]	Width glass panel [mm]																									
	50(	60(	70(	80(	90(	10(	11(	12(	13(	14(	15(	16(	17(	18(	19(	20(	21(	22(	23(	24(	25(	26(	27(	28(	29(	30(
500	2	2.4	2.8	3.2	3.6	4	4.4	4.8	5.2	5.6	6	6.4	6.8	7.2	7.6	8	8.4	8.8	9.2	9.6	10	10.4	10.8	11.2	11.6	12
600	1.7	2	2.3	2.7	3	3.3	3.7	4	4.3	4.7	5	5.3	5.7	6	6.3	6.7	7	7.3	7.7	8	8.3	8.7	9	9.3	9.7	10
700	1.4	1.7	2	2.3	2.6	2.9	3.1	3.4	3.7	4	4.3	4.6	4.9	5.1	5.4	5.7	6	6.3	6.6	6.9	7.1	7.4	7.7	8	8.3	8.6
800	1.3	1.5	1.8	2	2.3	2.5	2.8	3	3.3	3.5	3.8	4	4.3	4.5	4.8	5	5.3	5.5	5.8	6	6.3	6.5	6.8	7	7.3	7.5
900	1.1	1.3	1.6	1.8	2	2.2	2.4	2.7	2.9	3.1	3.3	3.6	3.8	4	4.2	4.4	4.7	4.9	5.1	5.3	5.6	5.8	6	6.2	6.4	6.7
1000	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	5	5.2	5.4	5.6	5.8	6
1100	0.9	1.1	1.3	1.5	1.6	1.8	2	2.2	2.4	2.5	2.7	2.9	3.1	3.3	3.5	3.6	3.8	4	4.2	4.4	4.5	4.7	4.9	5.1	5.3	5.5
1200	0.8	1	1.2	1.3	1.5	1.7	1.8	2	2.2	2.3	2.5	2.7	2.8	3	3.2	3.3	3.5	3.7	3.8	4	4.2	4.3	4.5	4.7	4.8	5
1300	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8	2	2.2	2.3	2.5	2.6	2.8	2.9	3.1	3.2	3.4	3.5	3.7	3.8	4	4.2	4.3	4.5	4.6
1400	0.7	0.9	1	1.1	1.3	1.4	1.6	1.7	1.9	2	2.1	2.3	2.4	2.6	2.7	2.9	3	3.1	3.3	3.4	3.6	3.7	3.9	4	4.1	4.3
1500	0.7	0.8	0.9	1.1	1.2	1.3	1.5	1.6	1.7	1.9	2	2.1	2.3	2.4	2.5	2.7	2.8	2.9	3.1	3.2	3.3	3.5	3.6	3.7	3.9	4
1600	0.6	0.8	0.9	1	1.1	1.3	1.4	1.5	1.6	1.8	1.9	2	2.1	2.3	2.4	2.5	2.6	2.8	2.9	3	3.1	3.3	3.4	3.5	3.6	3.8
1700	0.6	0.7	0.8	0.9	1.1	1.2	1.3	1.4	1.5	1.6	1.8	1.9	2	2.1	2.2	2.4	2.5	2.6	2.7	2.8	2.9	3.1	3.2	3.3	3.4	3.5
1800	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.6	2.7	2.8	2.9	3	3.1	3.2	3.3
1900	0.5	0.6	0.7	0.8	0.9	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.1	3.2
2000	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3
2100	0.5	0.6	0.7	0.8	0.9	1	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
2200	0.5	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.5	2.6	2.7
2300	0.4	0.5	0.6	0.7	0.8	0.9	1	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.7	1.8	1.9	2	2.1	2.2	2.3	2.3	2.4	2.5	2.6
2400	0.4	0.5	0.6	0.7	0.8	0.8	0.9	1	1.1	1.2	1.3	1.3	1.4	1.5	1.6	1.7	1.8	1.8	1.9	2	2.1	2.2	2.3	2.3	2.4	2.5
2500	0.4	0.5	0.6	0.6	0.7	0.8	0.9	1	1	1.1	1.2	1.3	1.4	1.4	1.5	1.6	1.7	1.8	1.8	1.9	2	2.1	2.2	2.2	2.3	2.4
2600	0.4	0.5	0.5	0.6	0.7	0.8	0.8	0.9	1	1.1	1.2	1.2	1.3	1.4	1.5	1.5	1.6	1.7	1.8	1.8	1.9	2	2.1	2.2	2.2	2.3
2700	0.4	0.4	0.5	0.6	0.7	0.7	0.8	0.9	1	1	1.1	1.2	1.3	1.3	1.4	1.5	1.6	1.6	1.7	1.8	1.9	1.9	2	2.1	2.1	2.2
2800	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.9	0.9	1	1.1	1.1	1.2	1.3	1.4	1.4	1.5	1.6	1.6	1.7	1.8	1.9	1.9	2	2.1	2.1
2900	0.3	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1	1	1.1	1.2	1.2	1.3	1.4	1.4	1.5	1.6	1.7	1.7	1.8	1.9	1.9	2	2.1
3000	0.3	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.9	0.9	1	1.1	1.1	1.2	1.3	1.3	1.4	1.5	1.5	1.6	1.7	1.7	1.8	1.9	1.9	2
3100	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1	1	1.1	1.2	1.2	1.3	1.4	1.4	1.5	1.5	1.6	1.7	1.7	1.8	1.9	1.9
3200	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	0.9	1	1.1	1.1	1.2	1.3	1.3	1.4	1.4	1.5	1.6	1.6	1.7	1.8	1.8	1.9
3300	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.8	0.9	1	1	1.1	1.2	1.2	1.3	1.3	1.4	1.5	1.5	1.6	1.6	1.7	1.8	1.8
3400	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.8	0.8	0.9	0.9	1	1.1	1.1	1.2	1.2	1.3	1.4	1.4	1.5	1.5	1.6	1.6	1.7	1.8
3500	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.9	0.9	1	1	1.1	1.1	1.2	1.3	1.3	1.4	1.4	1.5	1.5	1.6	1.7	1.7

Table B.1—6: Reynaers data 6 (source: CW50-60)

CW50-SC Toggle with 073.5916.00

Allowable mullion differential movement for glass edge cover of 15mm [mm]

	Width glass panel [mm]																									
Height glass panel [mm]	50(	60(	70(	80(	90(	10(	11(	12(	13(	14(	15(	16(	17(	18(	19(	20(	21(	22(	23(	24(	25(	26(	27(	28(	29(	30(
500	3	3.6	4.2	4.8	5.4	6	6.6	7.2	7.8	8.4	9	9.6	10.2	10.8	11.4	12	12.6	13.2	13.8	14.4	15	15.6	16.2	16.8	17.4	18
600	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
700	2.1	2.6	3	3.4	3.9	4.3	4.7	5.1	5.6	6	6.4	6.9	7.3	7.7	8.1	8.6	9	9.4	9.9	10.3	10.7	11.1	11.6	12	12.4	12.9
800	1.9	2.3	2.6	3	3.4	3.8	4.1	4.5	4.9	5.3	5.6	6	6.4	6.8	7.1	7.5	7.9	8.3	8.6	9	9.4	9.8	10.1	10.5	10.9	11.3
900	1.7	2	2.3	2.7	3	3.3	3.7	4	4.3	4.7	5	5.3	5.7	6	6.3	6.7	7	7.3	7.7	8	8.3	8.7	9	9.3	9.7	10
1000	1.5	1.8	2.1	2.4	2.7	3	3.3	3.6	3.9	4.2	4.5	4.8	5.1	5.4	5.7	6	6.3	6.6	6.9	7.2	7.5	7.8	8.1	8.4	8.7	9
1100	1.4	1.6	1.9	2.2	2.5	2.7	3	3.3	3.5	3.8	4.1	4.4	4.6	4.9	5.2	5.5	5.7	6	6.3	6.5	6.8	7.1	7.4	7.6	7.9	8.2
1200	1.3	1.5	1.8	2	2.3	2.5	2.8	3	3.3	3.5	3.8	4	4.3	4.5	4.8	5	5.3	5.5	5.8	6	6.3	6.5	6.8	7	7.3	7.5
1300	1.2	1.4	1.6	1.8	2.1	2.3	2.5	2.8	3	3.2	3.5	3.7	3.9	4.2	4.4	4.6	4.8	5.1	5.3	5.5	5.8	6	6.2	6.5	6.7	6.9
1400	1.1	1.3	1.5	1.7	1.9	2.1	2.4	2.6	2.8	3	3.2	3.4	3.6	3.9	4.1	4.3	4.5	4.7	4.9	5.1	5.4	5.6	5.8	6	6.2	6.4
1500	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	5	5.2	5.4	5.6	5.8	6
1600	0.9	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	3.9	4.1	4.3	4.5	4.7	4.9	5.1	5.3	5.4	5.6
1700	0.9	1.1	1.2	1.4	1.6	1.8	1.9	2.1	2.3	2.5	2.6	2.8	3	3.2	3.4	3.5	3.7	3.9	4.1	4.2	4.4	4.6	4.8	4.9	5.1	5.3
1800	0.8	1	1.2	1.3	1.5	1.7	1.8	2	2.2	2.3	2.5	2.7	2.8	3	3.2	3.3	3.5	3.7	3.8	4	4.2	4.3	4.5	4.7	4.8	5
1900	0.8	0.9	1.1	1.3	1.4	1.6	1.7	1.9	2.1	2.2	2.4	2.5	2.7	2.8	3	3.2	3.3	3.5	3.6	3.8	3.9	4.1	4.3	4.4	4.6	4.7
2000	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8	2	2.1	2.3	2.4	2.6	2.7	2.9	3	3.2	3.3	3.5	3.6	3.8	3.9	4.1	4.2	4.4	4.5
2100	0.7	0.9	1	1.1	1.3	1.4	1.6	1.7	1.9	2	2.1	2.3	2.4	2.6	2.7	2.9	3	3.1	3.3	3.4	3.6	3.7	3.9	4	4.1	4.3
2200	0.7	0.8	1	1.1	1.2	1.4	1.5	1.6	1.8	1.9	2	2.2	2.3	2.5	2.6	2.7	2.9	3	3.1	3.3	3.4	3.5	3.7	3.8	4	4.1
2300	0.7	0.8	0.9	1	1.2	1.3	1.4	1.6	1.7	1.8	2	2.1	2.2	2.3	2.5	2.6	2.7	2.9	3	3.1	3.3	3.4	3.5	3.7	3.8	3.9
2400	0.6	0.8	0.9	1	1.1	1.3	1.4	1.5	1.6	1.8	1.9	2	2.1	2.3	2.4	2.5	2.6	2.8	2.9	3	3.1	3.3	3.4	3.5	3.6	3.8
2500	0.6	0.7	0.8	1	1.1	1.2	1.3	1.4	1.6	1.7	1.8	1.9	2	2.2	2.3	2.4	2.5	2.6	2.8	2.9	3	3.1	3.2	3.4	3.5	3.6
2600	0.6	0.7	0.8	0.9	1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	2	2.1	2.2	2.3	2.4	2.5	2.7	2.8	2.9	3	3.1	3.2	3.3	3.5
2700	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.6	2.7	2.8	2.9	3	3.1	3.2	3.3
2800	0.5	0.6	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3	3.1	3.2
2900	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3	3.1
3000	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3
3100	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
3200	0.5	0.6	0.7	0.8	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.3	2.4	2.5	2.6	2.7	2.8
3300	0.5	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.5	2.6	2.7
3400	0.4	0.5	0.6	0.7	0.8	0.9	1	1.1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.6
3500	0.4	0.5	0.6	0.7	0.8	0.9	0.9	1	1.1	1.2	1.3	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6

Table B.1—7: Reynaers data 7 (source: CW50-60)

CW50-SC Togglε with 073.5916.00

Allowable mullion differential movement for glass edge cover of 13mm [mm]

	Width glass panel [mm]																									
Height glass panel [mm]	50(	60(	70(	80(	90(	10(	11(	12(	13(	14(	15(	16(	17(	18(	19(	20(	21(	22(	23(	24(	25(	26(	27(	28(	29(	30(
500	2	2.4	2.8	3.2	3.6	4	4.4	4.8	5.2	5.6	6	6.4	6.8	7.2	7.6	8	8.4	8.8	9.2	9.6	10	10.4	10.8	11.2	11.6	12
600	1.7	2	2.3	2.7	3	3.3	3.7	4	4.3	4.7	5	5.3	5.7	6	6.3	6.7	7	7.3	7.7	8	8.3	8.7	9	9.3	9.7	10
700	1.4	1.7	2	2.3	2.6	2.9	3.1	3.4	3.7	4	4.3	4.6	4.9	5.1	5.4	5.7	6	6.3	6.6	6.9	7.1	7.4	7.7	8	8.3	8.6
800	1.3	1.5	1.8	2	2.3	2.5	2.8	3	3.3	3.5	3.8	4	4.3	4.5	4.8	5	5.3	5.5	5.8	6	6.3	6.5	6.8	7	7.3	7.5
900	1.1	1.3	1.6	1.8	2	2.2	2.4	2.7	2.9	3.1	3.3	3.6	3.8	4	4.2	4.4	4.7	4.9	5.1	5.3	5.6	5.8	6	6.2	6.4	6.7
1000	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	5	5.2	5.4	5.6	5.8	6
1100	0.9	1.1	1.3	1.5	1.6	1.8	2	2.2	2.4	2.5	2.7	2.9	3.1	3.3	3.5	3.6	3.8	4	4.2	4.4	4.5	4.7	4.9	5.1	5.3	5.5
1200	0.8	1	1.2	1.3	1.5	1.7	1.8	2	2.2	2.3	2.5	2.7	2.8	3	3.2	3.3	3.5	3.7	3.8	4	4.2	4.3	4.5	4.7	4.8	5
1300	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8	2	2.2	2.3	2.5	2.6	2.8	2.9	3.1	3.2	3.4	3.5	3.7	3.8	4	4.2	4.3	4.5	4.6
1400	0.7	0.9	1	1.1	1.3	1.4	1.6	1.7	1.9	2	2.1	2.3	2.4	2.6	2.7	2.9	3	3.1	3.3	3.4	3.6	3.7	3.9	4	4.1	4.3
1500	0.7	0.8	0.9	1.1	1.2	1.3	1.5	1.6	1.7	1.9	2	2.1	2.3	2.4	2.5	2.7	2.8	2.9	3.1	3.2	3.3	3.5	3.6	3.7	3.9	4
1600	0.6	0.8	0.9	1	1.1	1.3	1.4	1.5	1.6	1.8	1.9	2	2.1	2.3	2.4	2.5	2.6	2.8	2.9	3	3.1	3.3	3.4	3.5	3.6	3.8
1700	0.6	0.7	0.8	0.9	1.1	1.2	1.3	1.4	1.5	1.6	1.8	1.9	2	2.1	2.2	2.4	2.5	2.6	2.7	2.8	2.9	3.1	3.2	3.3	3.4	3.5
1800	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.6	2.7	2.8	2.9	3	3.1	3.2	3.3
1900	0.5	0.6	0.7	0.8	0.9	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.1	3.2
2000	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3
2100	0.5	0.6	0.7	0.8	0.9	1	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
2200	0.5	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.5	2.6	2.7
2300	0.4	0.5	0.6	0.7	0.8	0.9	1	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.7	1.8	1.9	2	2.1	2.2	2.3	2.3	2.4	2.5	2.6
2400	0.4	0.5	0.6	0.7	0.8	0.8	0.9	1	1.1	1.2	1.3	1.3	1.4	1.5	1.6	1.7	1.8	1.8	1.9	2	2.1	2.2	2.3	2.3	2.4	2.5
2500	0.4	0.5	0.6	0.6	0.7	0.8	0.9	1	1	1.1	1.2	1.3	1.4	1.4	1.5	1.6	1.7	1.8	1.8	1.9	2	2.1	2.2	2.2	2.3	2.4
2600	0.4	0.5	0.5	0.6	0.7	0.8	0.8	0.9	1	1.1	1.2	1.2	1.3	1.4	1.5	1.5	1.6	1.7	1.8	1.8	1.9	2	2.1	2.2	2.2	2.3
2700	0.4	0.4	0.5	0.6	0.7	0.7	0.8	0.9	1	1	1.1	1.2	1.3	1.3	1.4	1.5	1.6	1.6	1.7	1.8	1.9	1.9	2	2.1	2.1	2.2
2800	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.9	0.9	1	1.1	1.1	1.2	1.3	1.4	1.4	1.5	1.6	1.6	1.7	1.8	1.9	1.9	2	2.1	2.1
2900	0.3	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1	1	1.1	1.2	1.2	1.3	1.4	1.4	1.5	1.6	1.7	1.7	1.8	1.9	1.9	2	2.1
3000	0.3	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.9	0.9	1	1.1	1.1	1.2	1.3	1.3	1.4	1.5	1.5	1.6	1.7	1.7	1.8	1.9	1.9	2
3100	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1	1	1.1	1.2	1.2	1.3	1.4	1.4	1.5	1.5	1.6	1.7	1.7	1.8	1.9	1.9
3200	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	0.9	1	1.1	1.1	1.2	1.3	1.3	1.4	1.4	1.5	1.6	1.6	1.7	1.8	1.8	1.9
3300	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.8	0.9	1	1	1.1	1.2	1.2	1.3	1.3	1.4	1.5	1.5	1.6	1.6	1.7	1.8	1.8
3400	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.8	0.8	0.9	0.9	1	1.1	1.1	1.2	1.2	1.3	1.4	1.4	1.5	1.5	1.6	1.6	1.7	1.8
3500	0.3	0.3	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.9	0.9	1	1	1.1	1.1	1.2	1.3	1.3	1.4	1.4	1.5	1.5	1.6	1.7	1.7

Table B.1—8: Reynaers data 8 (source: CW50-60)

CW60-SC Clam| with 0.34.0176.00+034.0175.00
Allowable mullion differential movement [mm]

Width glass panel [mm]

Height glass panel [mm]	50(	60(	70(	80(	90(	10(	11(	12(	13(	14(	15(	16(	17(	18(	19(	20(	21(	22(	23(	24(	25(	26(	27(	28(	29(	30(
500	2.4	2.9	3.4	3.8	4.3	4.8	5.3	5.8	6.2	6.7	7.2	7.7	8.2	8.6	9.1	9.6	10.1	10.6	11	11.5	12	12.5	13	13.4	13.9	14.4
600	2	2.4	2.8	3.2	3.6	4	4.4	4.8	5.2	5.6	6	6.4	6.8	7.2	7.6	8	8.4	8.8	9.2	9.6	10	10.4	10.8	11.2	11.6	12
700	1.7	2.1	2.4	2.7	3.1	3.4	3.8	4.1	4.5	4.8	5.1	5.5	5.8	6.2	6.5	6.9	7.2	7.5	7.9	8.2	8.6	8.9	9.3	9.6	9.9	10.3
800	1.5	1.8	2.1	2.4	2.7	3	3.3	3.6	3.9	4.2	4.5	4.8	5.1	5.4	5.7	6	6.3	6.6	6.9	7.2	7.5	7.8	8.1	8.4	8.7	9
900	1.3	1.6	1.9	2.1	2.4	2.7	2.9	3.2	3.5	3.7	4	4.3	4.5	4.8	5.1	5.3	5.6	5.9	6.1	6.4	6.7	6.9	7.2	7.5	7.7	8
1000	1.2	1.4	1.7	1.9	2.2	2.4	2.6	2.9	3.1	3.4	3.6	3.8	4.1	4.3	4.6	4.8	5	5.3	5.5	5.8	6	6.2	6.5	6.7	7	7.2
1100	1.1	1.3	1.5	1.7	2	2.2	2.4	2.6	2.8	3.1	3.3	3.5	3.7	3.9	4.1	4.4	4.6	4.8	5	5.2	5.5	5.7	5.9	6.1	6.3	6.5
1200	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	5	5.2	5.4	5.6	5.8	6
1300	0.9	1.1	1.3	1.5	1.7	1.8	2	2.2	2.4	2.6	2.8	3	3.1	3.3	3.5	3.7	3.9	4.1	4.2	4.4	4.6	4.8	5	5.2	5.4	5.5
1400	0.9	1	1.2	1.4	1.5	1.7	1.9	2.1	2.2	2.4	2.6	2.7	2.9	3.1	3.3	3.4	3.6	3.8	3.9	4.1	4.3	4.5	4.6	4.8	5	5.1
1500	0.8	1	1.1	1.3	1.4	1.6	1.8	1.9	2.1	2.2	2.4	2.6	2.7	2.9	3	3.2	3.4	3.5	3.7	3.8	4	4.2	4.3	4.5	4.6	4.8
1600	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8	2	2.1	2.3	2.4	2.6	2.7	2.9	3	3.2	3.3	3.5	3.6	3.8	3.9	4.1	4.2	4.4	4.5
1700	0.7	0.8	1	1.1	1.3	1.4	1.6	1.7	1.8	2	2.1	2.3	2.4	2.5	2.7	2.8	3	3.1	3.2	3.4	3.5	3.7	3.8	4	4.1	4.2
1800	0.7	0.8	0.9	1.1	1.2	1.3	1.5	1.6	1.7	1.9	2	2.1	2.3	2.4	2.5	2.7	2.8	2.9	3.1	3.2	3.3	3.5	3.6	3.7	3.9	4
1900	0.6	0.8	0.9	1	1.1	1.3	1.4	1.5	1.6	1.8	1.9	2	2.1	2.3	2.4	2.5	2.7	2.8	2.9	3	3.2	3.3	3.4	3.5	3.7	3.8
2000	0.6	0.7	0.8	1	1.1	1.2	1.3	1.4	1.6	1.7	1.8	1.9	2	2.2	2.3	2.4	2.5	2.6	2.8	2.9	3	3.1	3.2	3.4	3.5	3.6
2100	0.6	0.7	0.8	0.9	1	1.1	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.9	3	3.1	3.2	3.3	3.4
2200	0.5	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.1	3.2	3.3
2300	0.5	0.6	0.7	0.8	0.9	1	1.1	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3	3.1
2400	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3
2500	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
2600	0.5	0.6	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8
2700	0.4	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7
2800	0.4	0.5	0.6	0.7	0.8	0.9	0.9	1	1.1	1.2	1.3	1.4	1.5	1.5	1.6	1.7	1.8	1.9	2	2.1	2.1	2.2	2.3	2.4	2.5	2.6
2900	0.4	0.5	0.6	0.7	0.7	0.8	0.9	1	1.1	1.2	1.2	1.3	1.4	1.5	1.6	1.7	1.7	1.8	1.9	2	2.1	2.2	2.2	2.3	2.4	2.5
3000	0.4	0.5	0.6	0.6	0.7	0.8	0.9	1	1	1.1	1.2	1.3	1.4	1.4	1.5	1.6	1.7	1.8	1.8	1.9	2	2.1	2.2	2.3	2.3	2.4
3100	0.4	0.5	0.5	0.6	0.7	0.8	0.9	0.9	1	1.1	1.2	1.2	1.3	1.4	1.5	1.5	1.6	1.7	1.8	1.9	1.9	2	2.1	2.2	2.2	2.3
3200	0.4	0.5	0.5	0.6	0.7	0.8	0.8	0.9	1	1.1	1.1	1.2	1.3	1.4	1.4	1.5	1.6	1.7	1.7	1.8	1.9	2	2	2.1	2.2	2.3
3300	0.4	0.4	0.5	0.6	0.7	0.7	0.8	0.9	0.9	1	1.1	1.2	1.2	1.3	1.4	1.5	1.5	1.6	1.7	1.8	1.8	1.9	2	2	2.1	2.2
3400	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1	1.1	1.1	1.2	1.3	1.3	1.4	1.5	1.6	1.6	1.7	1.8	1.8	1.9	2	2	2.1
3500	0.3	0.4	0.5	0.5	0.6	0.7	0.8	0.8	0.9	1	1	1.1	1.2	1.2	1.3	1.4	1.4	1.5	1.6	1.7	1.7	1.8	1.9	1.9	2	2.1

Table B.1—9: Reynaers data 9 (source: CW50-60)

CW60-SC Toggl with 073.5916.00
Allowable mullion differential movement [mm]

Width glass panel [mm]

Height glass panel [mm]	50(	60(	70(	80(	90(	10(	11(	12(	13(	14(	15(	16(	17(	18(	19(	20(	21(	22(	23(	24(	25(	26(	27(	28(	29(	30(
500	3	3.6	4.2	4.8	5.4	6	6.6	7.2	7.8	8.4	9	9.6	10.2	10.8	11.4	12	12.6	13.2	13.8	14.4	15	15.6	16.2	16.8	17.4	18
600	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12	12.5	13	13.5	14	14.5	15
700	2.1	2.6	3	3.4	3.9	4.3	4.7	5.1	5.6	6	6.4	6.9	7.3	7.7	8.1	8.6	9	9.4	9.9	10.3	10.7	11.1	11.6	12	12.4	12.9
800	1.9	2.3	2.6	3	3.4	3.8	4.1	4.5	4.9	5.3	5.6	6	6.4	6.8	7.1	7.5	7.9	8.3	8.6	9	9.4	9.8	10.1	10.5	10.9	11.3
900	1.7	2	2.3	2.7	3	3.3	3.7	4	4.3	4.7	5	5.3	5.7	6	6.3	6.7	7	7.3	7.7	8	8.3	8.7	9	9.3	9.7	10
1000	1.5	1.8	2.1	2.4	2.7	3	3.3	3.6	3.9	4.2	4.5	4.8	5.1	5.4	5.7	6	6.3	6.6	6.9	7.2	7.5	7.8	8.1	8.4	8.7	9
1100	1.4	1.6	1.9	2.2	2.5	2.7	3	3.3	3.5	3.8	4.1	4.4	4.6	4.9	5.2	5.5	5.7	6	6.3	6.5	6.8	7.1	7.4	7.6	7.9	8.2
1200	1.3	1.5	1.8	2	2.3	2.5	2.8	3	3.3	3.5	3.8	4	4.3	4.5	4.8	5	5.3	5.5	5.8	6	6.3	6.5	6.8	7	7.3	7.5
1300	1.2	1.4	1.6	1.8	2.1	2.3	2.5	2.8	3	3.2	3.5	3.7	3.9	4.2	4.4	4.6	4.8	5.1	5.3	5.5	5.8	6	6.2	6.5	6.7	6.9
1400	1.1	1.3	1.5	1.7	1.9	2.1	2.4	2.6	2.8	3	3.2	3.4	3.6	3.9	4.1	4.3	4.5	4.7	4.9	5.1	5.4	5.6	5.8	6	6.2	6.4
1500	1	1.2	1.4	1.6	1.8	2	2.2	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	4	4.2	4.4	4.6	4.8	5	5.2	5.4	5.6	5.8	6
1600	0.9	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.4	2.6	2.8	3	3.2	3.4	3.6	3.8	3.9	4.1	4.3	4.5	4.7	4.9	5.1	5.3	5.4	5.6
1700	0.9	1.1	1.2	1.4	1.6	1.8	1.9	2.1	2.3	2.5	2.6	2.8	3	3.2	3.4	3.5	3.7	3.9	4.1	4.2	4.4	4.6	4.8	4.9	5.1	5.3
1800	0.8	1	1.2	1.3	1.5	1.7	1.8	2	2.2	2.3	2.5	2.7	2.8	3	3.2	3.3	3.5	3.7	3.8	4	4.2	4.3	4.5	4.7	4.8	5
1900	0.8	0.9	1.1	1.3	1.4	1.6	1.7	1.9	2.1	2.2	2.4	2.5	2.7	2.8	3	3.2	3.3	3.5	3.6	3.8	3.9	4.1	4.3	4.4	4.6	4.7
2000	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8	2	2.1	2.3	2.4	2.6	2.7	2.9	3	3.2	3.3	3.5	3.6	3.8	3.9	4.1	4.2	4.4	4.5
2100	0.7	0.9	1	1.1	1.3	1.4	1.6	1.7	1.9	2	2.1	2.3	2.4	2.6	2.7	2.9	3	3.1	3.3	3.4	3.6	3.7	3.9	4	4.1	4.3
2200	0.7	0.8	1	1.1	1.2	1.4	1.5	1.6	1.8	1.9	2	2.2	2.3	2.5	2.6	2.7	2.9	3	3.1	3.3	3.4	3.5	3.7	3.8	4	4.1
2300	0.7	0.8	0.9	1	1.2	1.3	1.4	1.6	1.7	1.8	2	2.1	2.2	2.3	2.5	2.6	2.7	2.9	3	3.1	3.3	3.4	3.5	3.7	3.8	3.9
2400	0.6	0.8	0.9	1	1.1	1.3	1.4	1.5	1.6	1.8	1.9	2	2.1	2.3	2.4	2.5	2.6	2.8	2.9	3	3.1	3.3	3.4	3.5	3.6	3.8
2500	0.6	0.7	0.8	1	1.1	1.2	1.3	1.4	1.6	1.7	1.8	1.9	2	2.2	2.3	2.4	2.5	2.6	2.8	2.9	3	3.1	3.2	3.4	3.5	3.6
2600	0.6	0.7	0.8	0.9	1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	2	2.1	2.2	2.3	2.4	2.5	2.7	2.8	2.9	3	3.1	3.2	3.3	3.5
2700	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.6	2.7	2.8	2.9	3	3.1	3.2	3.3
2800	0.5	0.6	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3	3.1	3.2
2900	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3	3.1
3000	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3
3100	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9
3200	0.5	0.6	0.7	0.8	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.3	2.4	2.5	2.6	2.7	2.8
3300	0.5	0.5	0.6	0.7	0.8	0.9	1	1.1	1.2	1.3	1.4	1.5	1.5	1.6	1.7	1.8	1.9	2	2.1	2.2	2.3	2.4	2.5	2.5	2.6	2.7
3400	0.4	0.5	0.6	0.7	0.8	0.9	1	1.1	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6	2.6
3500	0.4	0.5	0.6	0.7	0.8	0.9	0.9	1	1.1	1.2	1.3	1.3	1.4	1.5	1.6	1.7	1.8	1.9	1.9	2	2.1	2.2	2.3	2.4	2.5	2.6