Optimizing of the Geometrical Accuracy of Windows and External Doors

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Abstract. Geometric accuracy of building structures is an important part of the quality of construction work. Within the technical standards, it is assumed that the designer determines the functional geometrical parameters of building structures by calculation. The functional geometrical parameters are to be determined primarily for critical elements, i.e. for structures whose geometrical accuracy is important for structures that require high precision or are subject to functional requirements. If, for any reason, the designer fails to perform the calculation of the functional geometric parameters, the designer may use the recommended values of the geometric parameters given by the technical standards. The assumption is that the designers incorporate these geometrical deviations in the planning of spatial parameters of building structures, which should ensure that the minimum dimensional requirements for finished structures are met. The problem may arise in the implementation phase when the contractors follow the technical standards for the execution of individual parts of building structures. At present, when we adopt European technical standards, the system of technical standards is not interrelated and there may be situations where the standard requirements for the geometric accuracy of successive structures will differ significantly or will not be determined at all. These differences could lead to the fact, that the designer considered the design documentation with a margin for geometrical deviations for finished structures, with specified geometric accuracy requirements and required dimensions will not be met. One of these constructions are windows and exterior doors. Therefore, it is necessary to pay attention to the determination of the basic geometric accuracy requirements and to define procedures for the fulfilment of these basic requirements in all related operations.

1. Introduction
Geometrical accuracy should be taken into account when making construction openings, as in other parts of building structures. Each construction opening should have permissible geometric deviations of dimensions it can reach. These deviations should be set in such a way, that the filling, for which the opening was designed, can be subsequently incorporated into the opening. One of the structures that is very sensitive to the dimensions of the building opening are windows and exterior doors that need certain requirements for the dimensions of the building opening so that they can perform their function correctly even after being built into the building. In the construction phase, the accuracy of the installation of windows and external doors in the building opening may be influenced primarily by the following factors:

- Geometric accuracy of the construction opening.
• Geometric accuracy of the product being built into the construction opening.
• Placement accuracy of the product being built into the construction opening.

During the acceptance of installed windows and doors, the following parameters are checked (from the investor's point of view):
• The actual size of the window, which should correspond to the projected size and which may be affected by the geometric accuracy of the construction opening.
• Accuracy of the installation of window and balcony doors horizontally and vertically on the facade.
• Accuracy of fitting windows and balcony doors within the construction opening.

If the permissible geometrical parameters of the dimensions of the construction openings and the installation of windows are not stipulated in the project or workshop documentation, contract of work, they are assessed according to the requirements of valid technical standards. The standards should specify the maximum permissible deviations from the designed values for the geometrical parameters of the construction openings and fitted windows.

2. Requirements for geometric accuracy of construction openings according to the implementation standards for individual structures
Geometric parameters of building openings can be assessed according to standards for individual construction structures in which these openings are located (Table 1, 2). Geometric parameters of building openings for windows and external doors can also be assessed according to the technical standard [1], which specifies the requirements for the installation of construction openings fillings (among other things, the requirements for geometric parameters of the construction opening and the parameters of built-in products).

| Geometric parameter | Windows and external doors | Concrete structures | Masonry structures | Timber structures |
|---------------------|-----------------------------|--------------------|-------------------|------------------|
| Dimensions of the construction opening | | | | |
| with untreated surface | | | | |
| ±12 mm for | ±10 mm for | ±25 mm<sup>a</sup> | NDF | According to construction documentation |
| L ≤ 3 m | L ≤ 3 m | | | |
| ±16 mm for | ±12 mm for | | | |
| 3 m > L ≤ 6 m | 3 m > L ≤ 6 m | | | |

NDF – not defined
<sup>a</sup> The deviation value also applies to the location of the opening in the concrete construction.
Table 2. Comparison of geometric accuracy requirements for rectangularity of construction openings according to technical standards for the most commonly used building structures with requirements for geometric accuracy of openings for windows and external doors

| Geometric parameter | Windows and external doors | Concrete structures | Masonry structures | Timber structures |
|---------------------|-----------------------------|---------------------|-------------------|------------------|
| Rectangularity of the construction opening | 6 mm for $L \leq 1\,\text{m}^a$ | NDF | NDF | According to construction documentation |
| | 8 mm for $1 \,\text{m} < L \leq 3\,\text{m}^a$ | | | |
| | 12 mm for $3 < L \leq 6\,\text{m}^a$ | | | |

NDF – not defined

$^a$ The deviation is determined by measuring the diagonals and subtracting the values from each other, comparing the difference to the values given in this table.

At first sight, it is clear that the requirements of individual technical standards differ considerably and that there is no uniform solution. The problem of technical standards for individual structures is that they focus on the accuracy of building openings in general (without taking into account the functional requirements of the structures to be fitted in the opening) or do not address them at all.

Technical standard [1] for windows and external doors addresses requirements for a building opening in terms of the functionality of openings filling. The requirements are based on the German technical standard [2], the validity of which applies to both structural works and finishing.

The requirements in the technical standard for concrete structures [3] are set in such a way that the static properties of the structure are not violated if they are observed. This means that if these requirements are exceeded, a structural analysis assessment should be performed. At the same time, it is stated in the technical standard [3] that if there are stricter requirements for geometric accuracy, the performance of concrete structures should follow these stricter requirements. So, in the case of openings for windows and external doors in concrete structures, stricter requirements according to technical standard for windows and external doors may be required. For concrete structures, it is necessary to check above all the observance of the dimensions in order to keep the minimum reinforcement coverage.

Requirements in the technical standard for masonry structures [4] are set very generally, in addition, it is necessary to take into account the manufacturing variations of masonry elements. The requirements of the windows and external doors technical standard can be applied to masonry constructions provided that it is a part of masonry work also finishing off the jamb before the installation of windows into the opening. Requirements for timber structures should be set according to construction documentation [5].

3. Requirements for geometric accuracy of installed windows and external doors according to technical standards

Requirements for deviations of windows and external doors should be laid down in the technical standards of individual products (Table 3).
Table 3. Comparison of requirements for deviations of dimensions of windows and external doors

| Geometric parameter               | Windows and external doors | Timber windows | Aluminium windows | PVC-U profiles for the fabrication of windows and doors |
|-----------------------------------|----------------------------|----------------|-------------------|--------------------------------------------------------|
| Height and width of basic dimensions | ±2 mm                    | ±1 mm          | Refers to an invalid technical standard | Only deviations of profile width and thickness are solved. |
| Height and width of casement      | NDF                       | 3 mm           |                   |                                                        |
| Rectangularity of casing and casement | 4 mm                     |                |                   |                                                        |

NDF – not defined

At present, it is only possible to require compliance with the prescribed technical standard deviations of the wooden windows [6]. There are no normative requirements for aluminium and plastic windows [7].

The absence of technical requirements for window and external door dimensional deviations can in certain cases, pose major problems in fitting them into the construction opening.

In practice, there have already been situations where the investor required accurate installation of windows on the façade, in a vertical and horizontal plane with a deviation up to 5 mm. During the measurement, the contractor found that in some cases, the windows on one side are mounted exactly in the vertical plane, but on the other side, the deviation differs by more than 5 mm. In the end, it became clear, that the deviations of the production dimensions of the windows were the cause. The windows fitting had to be rearranged to meet the investor's requirements.

Setting uniform technical requirements for deviations of product dimensions (e.g. according to technical standard for wooden windows) could thus prevent such problems in the future.

4. Product fitting accuracy requirement

The requirements for the accuracy of product installation are set out as follows [1]:

- The maximum deviation of the flatness of the frame profile (deflection of the frame profile to the longitudinal axis) of the built-in product is 3 mm for length and width up to 2 m and 5 mm for length and width over 2 m. It does not concern the deflection of frame profiles, which may arise due to the thermal expansion of the profiles, provided that this deflection does not affect the functionality and durability of the product.
- The maximum deviation in the vertical and horizontal position of the frame of the built-in product for the length up to 3 m is 2 mm per 1 m, but maximum 3 mm.
- The maximum frame rectangularity deviation (diagonal length difference) is 3 mm for windows and doors up to 1.5 m wide and 2.2 m height, and 5 mm for windows and doors width over 1.5 m and height over 2.2 m.

Within the requirements for the installation of windows and external doors, deviations of verticality, flatness and rectangularity of windows and external doors are addressed. In practice, we meet other investor requirements on construction sites. These are mainly the following two parameters:

- Horizontal and vertical position of the plane of windows and balcony assemblies, which are placed one above the other on the facade.
- Position of the window within the window opening relative to the outer plane of the finished façade (the depth of the window within the window opening affects the width of the external and internal window sill).
The position of windows and balcony doors on the facade will to some extent, be influenced by the position of the construction opening. Geometric accuracy of the position of the construction opening is solved only in the technical standard for concrete structures [3] where it can be ± 25mm, other standards do not address this parameter. Surprisingly, this parameter is not addressed by the German technical standard [2] also.

The deviation of the relative position of the windows on the facade, which are placed in a plane above or next to each other, as well as the deviation of the position of the window within the construction opening, is not addressed in any technical standards or other regulations. In some cases, however, it is strongly required by the investor. In such case, the contractor shall establish a deviation, which he will be able to observe.

The deviation of the relative position of the windows on the facade and the deviation of the position of the window within the construction opening should be determined based on the following parameters:

- Accuracy of setting out - will depend on the accuracy of the measuring instrument (the measuring instrument deviation should be within ± 2 mm to ± 3 mm, the total setting deviation including mounting mark should not exceed ± 5 mm),
- Accuracy of mounting the window on the mounting mark (deviation up to ± 2mm can be achieved),
- Deviations of window production dimensions (the frame height and width) should not exceed ± 2mm.

Considering the above parameters, I recommend setting the requirements as follows (Figure 1):

- The deviation of the relative position of the windows on the facade placed one above the other and next to each other should not exceed 10 mm, in cases where the investor will require very high fitting accuracy, the requirement for 7 mm can be tightened.
- The deviation of the window position within the construction opening should not exceed ± 7mm, in cases where high fitting accuracy is required, the requirement can be tightened to ± 5mm.

The graph below (Figure 2) shows an example of a completed apartment building project that very precise fitting of windows and external doors can be achieved in cases where an exact placement of windows in the plane above and next to one another is required by the investor.
6. Recommended deviations of geometric accuracy of construction openings

Based on the requirements of technical standards and practical experience, I recommend setting requirements for geometric accuracy of construction openings according to the following principles (Table 4-6).

For lift building openings, the requirements are specified in the lift technical documentation (usually a requirement of ± 10 mm for position and size).

For the position of windows on the facade, the requirement is ± 25 mm, and the distance between two adjacent windows, both vertically and horizontally, should not exceed 10 mm.
For the position of the window within the building opening as a requirement of ±7 mm, the deviation is related to the outer face of the facade without surface treatment (ETICS, etc.).

6. Conclusions
In the case of construction openings, it is always necessary to discuss the requirements for their implementation with the designer and investor in advance. It is necessary to clarify according to which technical standards the geometrical parameters of construction openings (dimensions, rectangularity, flatness of jamb, etc.) will be assessed. Especially in the case of openings in concrete structures, it is necessary to draw attention to the difference between the requirements of technical standards for geometric parameters of dimensions.

In preparation, it is necessary to compensate the unevenness of the jamb of the construction openings before the installation of windows and external doors with increased consumption of material and time for the compensation of the unevenness and the costs of the works to be included in the costs and claims of the constructor towards the investor.

At the same time, it is necessary to strive for improved or stricter geometric parameters for construction openings, so that it is easier to meet the required functional requirements for the windows and external doors and thus reduce any additional costs associated with claims.

References
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[2] DIN 18202 “Tolerances in building construction – Buildings”. Deutsches Institut für Normung e.V, 2013. (in Deutsch).
[3] ČSN EN 13 670 „Execution of concrete structures”. Czech office for standards, metrology and testing, 2010 (in Czech).
[4] ČSN EN 1996-2 “Eurocode 6: Design of masonry structures - Part 2: Design considerations, selection of materials and execution of masonry”. Czech Standard Institute, 2007 (in Czech).
[5] ČSN 73 2810+Z1 “Timber structures; construction”. ČNI, 2000 (in Czech).
[6] ČSN 74 6101+Z1 “Timber windows – Basic regulations”. Czech office for standards, metrology and testing, 2015 (in Czech).
[7] ČSN EN 12608-1 “Unplasticized poly(vinyl chloride) (PVC-U) profiles for the fabrication of windows and doors – Classification, requirements and test methods – Part 1: Non-coated PVC-U profiles with light coloured surfaces”. Czech office for standards, metrology and testing, 2017 (in Czech).