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Technical recommendations for fixing of façades in seismic zones

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Abstract

Just like load-bearing structures, façades must also be able to safely transfer loads resulting from earthquakes. Although they are defined as non-structural elements in the current standards, façades represent a significant risk in the event of failure. Falling parts of façades can cause considerable injury to people, but even after an earthquake, fallen elements block access and escape routes, thus blocking important rescue and emergency services. In particular, heavy façades - those with a deadload of more than 100 kg/m² - pose an increased risk. The following paper deals especially with anchorages for these heavy façades, i.e. consisting of masonry, natural stone or concrete. As the fixings form the link between the two systems (façade/ load bearing structure) they have to be dimensioned adequately. Whether the fixings should be designed as ductile or rigid also has to be examined; this influences the interaction and the bearing behaviour significantly. Up to now, several experimental examinations have been made. Large scale tests such as shake table tests as well as detailed component tests were carried out to compare rigid and ductile (load) bearing behaviour of fixings for heavy façades. These tests have shown that it is possible to reach a sufficient level of safety by adequately strengthening the existing fixing systems. In general, new methods for modelling the behaviour of heavy façades during earthquakes need to be developed. Results from shake table tests and other experimental examinations support this technical approach. Suitable recommendations are discussed in this paper, the technical background is explained and the experiment results are illustrated.

Key words: seismic, façade systems, anchorages and fixings, non-structural elements, testing methods

1 Introduction

Building façades have two main tasks: as an envelope they are part of the aesthetic design of the building and part of the thermal insulation. In order to ensure that the physics of the building is effectively influenced, façades consist not only of external cladding, but also of a corresponding insulation layer and additional ventilation. The corresponding task of the fastening elements is therefore to safely introduce loads into the building structure and to ensure sufficient space for all necessary components. Especially for "heavy" façades, i.e. façades with a dead load of more than 100 kg/m², such as brickwork, natural stone cladding or concrete panels, fastening structures must bear high point loads across large wall cavities. Fixings are fastening products, including anchor bolts, welded connections and mechanical fasteners. Depending on the importance of the fastener arrangement in question, fixings are classified into different categories of construction. Generally, façades and their fixings are classified similarly to non-structural wall elements, i.e. as architectural components or elements, but must nevertheless be designed to withstand seismic events in order to prevent injury to persons during an earthquake and to ensure free escape routes after an earthquake [1].

2 Façade anchors and their application

2.1 General

Façades need to be weather tight and durable to ensure they are suitable for use. Many façade materials are in use today and three common ones are discussed below.

2.2 Concrete facades

Concrete façade panels are installed after the substructure has been erected. They usually consist of prefabricated elements whose surface can be made visually appealing by special treatments. The following inserts are required for their handling and installation:
- Transport anchors for moving the panels during manufacture and transport and for lifting the panels to their final position.
- Bearing supports to carry vertical loads.
- Spacers for adjusting panels and for transferring horizontal loads.
- Pins for aligning and connecting the plates.

In contrast to these panels, sandwich elements consist of a carrier layer and a facade layer, which are produced simultaneously. Normally, the exposed concrete is first introduced into the formwork. To do this, the reinforcement is inserted into the prepared formwork and anchors and tie rods or support pins are inserted. The concrete is then poured evenly into the formwork and compacted. A thermal insulation layer is then applied to the concrete using anchors. Once the reinforcement of the load-bearing layer is connected to the anchors, the concrete is poured into the formwork. Examples of both types of panel are shown in Fig. 1.

Figure 1. a) Concrete façade panels; b) Sandwich facade panels

2.3 Natural stone facades

This type of façade consists of at least 30mm thick stone panels which are fixed to the building with special anchors or channel substructures, Fig. 2. The panels are fixed to the anchors themselves using either special anchors or special bolts, according to DIN 18516-3 (2018), and the fixings must be adjustable for precise alignment of the façade panel [2].

Figure 2. a) Natural stone façade; b) Supporting construction

2.4 Brickwork facades

Brickwork façades, as shown in Fig. 3a, can be masoned during the erection of the supporting construction or can be attached later. The façade layer consists of masonry at a set distance (cavity) from the supporting structure, so that the bricks are supported either with steel angles or, in the case of larger cavities, with brackets and angles (Fig 3b).

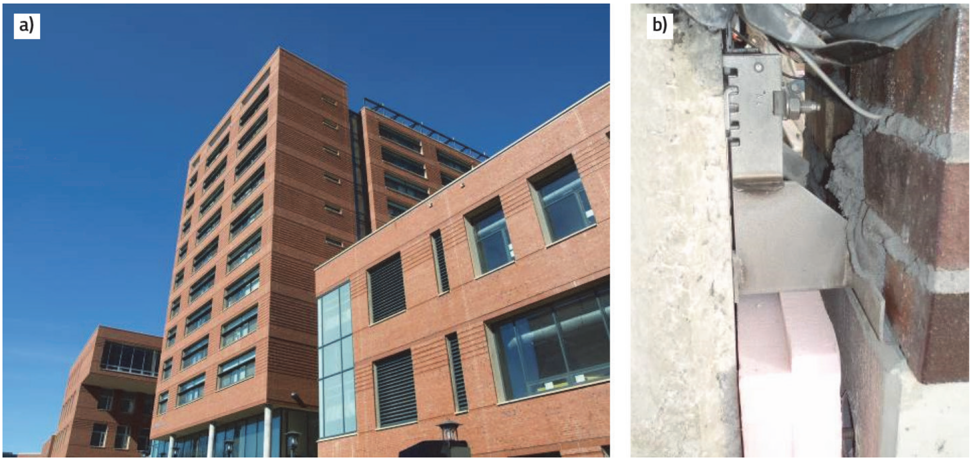

Figure 3. a) Brickwork façade; b) Supporting construction

The brackets and angles provide vertical support to the masonry and are attached to the structure with suitable fasteners such as anchor pins or anchor channels. Horizontal loads must be supported separately by special horizontal ties, such as cavity wall ties or masonry ties [3].

3 Bearing behaviour of façade anchors

3.1 Static resistance

In the static load case, horizontal loads perpendicular to the wall plane, such as wind, must be taken into account in addition to the dead weight of the facing brickwork layer. Horizontal forces parallel to the plane of the façade can usually be neglected to avoid constraining forces.

Façade support anchors take on the dead load of the façade layer and transfer this load to the load-bearing layer. Restraint anchors ensure the distance between the two wall layers is maintained and take the loads perpendicular to the wall plane. They also transfer them safely to the load-bearing layer. Serviceability is achieved by complying with the maximum deflections.

3.2 Seismic resistance

Whereas the design of façade fixings generally only takes into account static loads such as dead loads, wind loads and constraint forces, in countries with seismic hazards it is necessary to include the effects of earthquakes as well. In the event of an earthquake, this is intended to ensure escape routes are kept clear and personal injury is prevented. Earthquake standards usually designate façades as non-load-bearing components and allow for a simplified design to account for additional static equivalent loads from earthquakes. Their effect is to be assumed in the most unfavourable horizontal direction. These loads must be absorbed safely and at the same time without loss of flexibility.

Common façade anchors designed for the static load case act like a pendulum that is loaded and stabilized by the dead load of the facing layer. They usually offer possibilities to compensate for on-site tolerances, but are not able to absorb horizontal loads, especially in the façade plane, without corresponding deflections. Brickwork façades are supported by brackets or angles, for example. These create a line bearing, but do not provide horizontal support.

In the seismic load case, horizontal loads occur both perpendicular to, and in the plane of, the façade and accordingly the horizontal deflections must be restricted to the serviceability limits, which often requires additional bearings. This can be achieved by extending the static façade concept with supplementary fixings or strengthening the existing supports with additional horizontal bearings.

3.3 Providing the required resistance

As already mentioned in chapter 2, the fastening systems of the respective façade types consist of several components. These anchors should be arranged in such a way that constraints are avoided as far as possible. Nevertheless, a safe load transfer into the supporting structure must be ensured, especially in the design of the anchorage to absorb the seismic loads.

This interaction of different anchors, which act in different load directions and have different stiffnesses, can often become relatively complicated, so that a perfect static calculation is not possible. For anchorages in existing structures, the load-bearing capacity of the anchors in the supporting material must also be assessed. Well accepted design rules are given in [4], which is finally published in 2019.

Therefore the identification and assessment of a suitable seismic concept and it's resistance should usually be performed by tests. The test method – especially if the tests have to be carried out on site – can have a major impact on the project schedule and construction time. It is therefore essential that they are included in the planning phase and that they are planned and carried out properly.

4 Design concept

As mentioned previously, façades are classified as non-structural elements, i.e. they are not regarded as load-bearing components. Nevertheless, they have to withstand loads resulting from earthquakes because their failure can result in a considerable potential risk. In most cases, the failure of a façade construction can cause significant personal injury, as well as blocking important escape and rescue routes due to the fallen material. Therefore, according to EN 1998-1 [1], the non-structural components and also their connections and attachments or anchorages must be verified for the earthquake design situation. The effects of the seismic action may be determined according to [1] by applying to the non-structural element a horizontal force F_a which is defined as follows:

$$F_a = \left(S_a \cdot W_a \cdot \gamma_a\right) / q_a \tag{1}$$

The seismic coefficient S_a may be calculated using the following expression:

$$S_a = \alpha \cdot S \cdot \left[3\left(1+\frac{z}{H}\right) / (1+\left(1-\frac{T_a}{T_1}\right)^2) - 0{,}5 \right] \tag{2}$$

The input values for a correct determination of the load F_a are:
W_a - Mass of the element
H - Height of the building
z - Height of the centre of mass of the facade element
γ_a - Importance factor of the element / the building
q_a - Behaviour factor
α - Local ground motion
S - Local soil factor
T_a - set to $z^{2/3}$
T_1 - set to $H^{2/3}$

In relation to the verifications for façades, this means that a building façade should first be divided into individual areas. Each area – as long as it is sufficiently separated from other areas by joints – can be considered separately with regard to the action F_a. When dividing the façade, it ought to be noted that the areas should have as simple, symmetrical shapes as possible; corners, offsets and particularly slender areas should be avoided. Several anchor types are available to absorb the static equivalent load F_a, which can be used depending on the requirements, such as load size, ductility requirements or conditions of the structure itself. In general, a distinction can be made between anchors acting at local points and anchors distributed over a wide area.

These anchors must be assessed in advance with regard to their force and deformation. This deformation behaviour should be taken into account during planning, as it can have an influence on the joints and adjoining building components.
Special attention must be paid to the fact that the fulcrum of the anchor forces should coincide with the centre of mass of the façade area. If this is not the case, the façade element could move uncontrollably in different directions and result in rotating, rocking or tilting. These movements could cause further impact, especially in the anchors responsible for the vertical loads, as well as causing damage that could otherwise be avoided. An example of a façade, split into sections with a seismic anchor layout is shown in Fig. 4 and Fig. 5, see also [5].

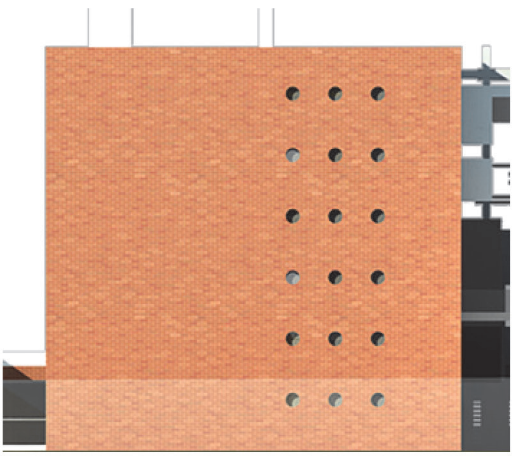

Figure 4. Facade elevation

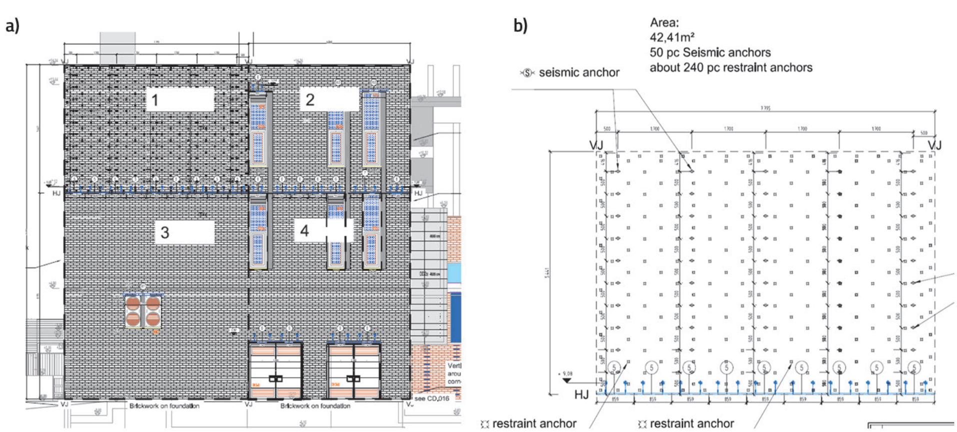

Figure 5.) Division into sections; b) Spacing of seismic anchors per section

Such a conscientious planning of the anchoring concept can prevent damage and avoid failure of the non-structural elements. It must be carried out individually for each building – and for each façade surface – taking into account the specific boundary conditions resulting from the importance of the building as well as the behaviour factor, the local ground motion and the local soil factor.
This is the reason why a universal, all-purpose earthquake anchor cannot exist.
A safe and efficient design of a building façade must always adhere to this design concept. The suitability of the anchors can be calculated if necessary, but as a rule experimental proof is essential.

5 Conclusion

Examples are given for each construction method of "heavy" facades, i.e. for masonry, natural stone and concrete facades. Each material requires different supporting elements but, due to their very nature, all of the façades impose high loads onto their fastening and support systems. Even though façades are defined as non-structural elements, they must be designed to withstand earthquakes to prevent personal injury during an earthquake and to ensure free escape routes after an earthquake. During the design process, seismic forces have to be added to ensure the fixings have sufficient resistance. These forces can either be calculated or determined in tests. They act in a horizontal or vertical direction and shall be applied in the most unfavorable way. For a load direction for which a fastening has already been allowed, the seismic load is added. For a load direction that was not considered in the original design, a separate fastener must be included. This usually means that a seismic load component is added to the support system that carries the vertical weight, but additional anchors must be installed parallel to the façade plane. Equations to determine the horizontal force, F_a, are shown and an appropriate design concept is discussed.

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