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Damage to Brick Veneer Due to the Combination of Prefabricated Units and Traditional Masonry

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ABSTRACT

The construction of veneer facades has significantly changed in recent years. In the past, the area of veneer surpassed that of the windows, and the brickwork above the openings was supported by masonry arches. Veneer was unmistakably considered part of the masonry construction and was executed by skilled masons. Today, due to demands for views, lighting, and accessibility, window areas often exceed masonry. As a result, facing masonry has developed into a precast masonry construction, combining traditional masonry with precast concrete units or thin brick masonry veneer panels.

Those 'composite veneer walls' can lead to damage, especially in the anchoring of precast elements. In construction practice, supports designed for facing lintels are used, but they are unsuitable for bearing larger elements. The connection between traditional masonry and larger precast components is not governed by established standards. Additional challenges arise when traditional masonry is placed atop precast elements. In practice, there are also interface issues between masonry and precast concrete work and the planning of anchors and fastenings. Due to different expansion behaviors between masonry and concrete, movement joints and sealing tapes must also be given special consideration. The paper provides an overview of precast masonry construction and gives guidance on damage prevention.

KEYWORDS

veneer, prefabricated units, construction, concrete units and traditional masonry, masonry veneer panels, damage prevention.

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INTRODUCTION

Considering possible damage, this paper focuses on the latest development of masonry veneer walls, changing into ‘composite veneer walls’ as a combination of precast concrete products and handcrafted veneer panels. Fig. 1 illustrates the evolution of masonry exterior wall types in Central Europe, highlighting the increasing integration of ancillary components over time. Before the 1920s, masonry exterior walls in residential and industrial buildings were constructed as either single-leaf or double-leaf load-bearing walls. Segmental arches were incorporated to distribute loads above door and window openings, with thrust forces contained within the load-bearing wall's cross-section.

To achieve cost-effective construction, cavity walls emerged as a common building method after the First World War. (Fig. 1). As a result of material savings, cavity walls were expected to maintain the same functionality as single-leaf walls. This particularly concerned the protection against driving rain. Cavity walls consist of two parallel single-leaf walls, effectively tied together with headers or wall ties and with an air space inside. Wall ties and steel lintels were integrated as main ancillary components.

In response to the post-Second World War housing shortage, Germany introduced standardized masonry wall thicknesses in the 1950s for residential buildings up to six stories tall and 10.5 meters wide. They were based on standard DIN 4106:1953 [1]. The specified wall thicknesses were considering requirements for sound- and thermal-insulation. Result was a step back, to single- or double-leaf load-bearing exterior walls (Fig. 1): Brick lintels were used again, because steel ancillary components were hardly available in the 1950s. These were manufactured as traditional jack arches to integrate small rectangular windows that were available at that time. Again, arch thrust was covered within the section of the exterior load-bearing wall.

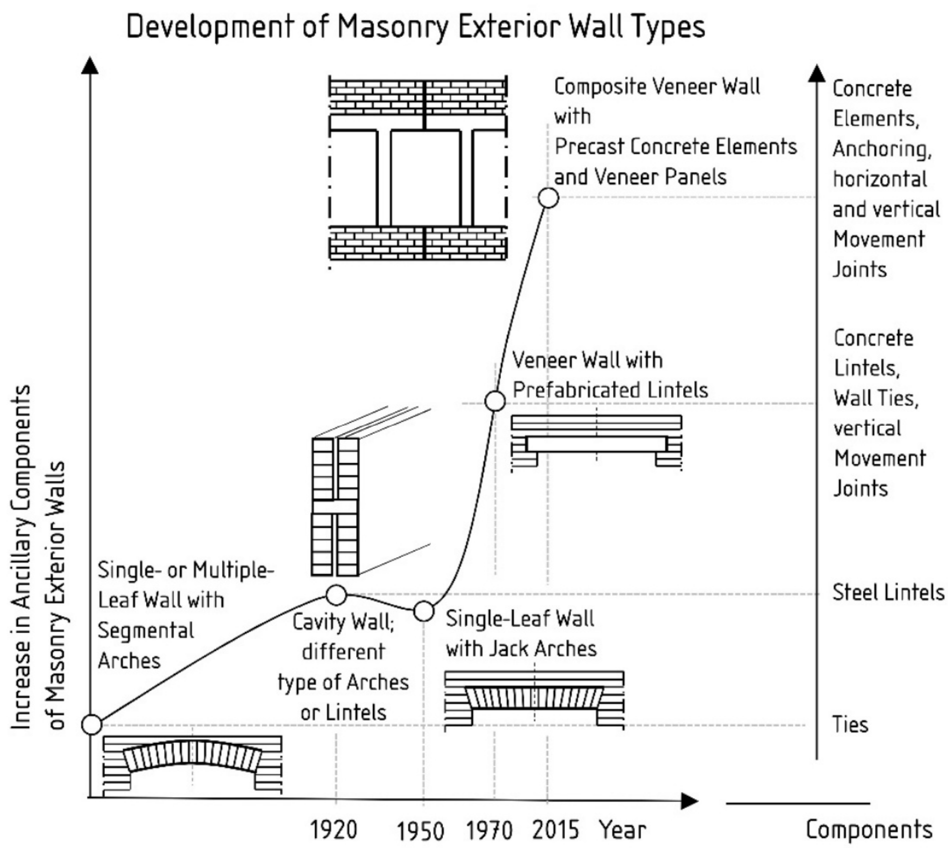

Figure 1: Development of Masonry Exterior Wall Types

In the 1970s, growing demands for thermal insulation prompted a revival of cavity walls as veneer walls (Fig. 1). This initiated the functional separation of the two parallel walls (see Fig. 2), a standard practice that continues today with Eurocode 6 (‘EC 6’): EC 6 defines masonry veneer as a wall, used as a facing, but not bonded or contributing to the resistance of the backing wall or framed structure [2].

Fig. 2 from [3] illustrates the fundamental construction principles of masonry veneer walls for residential buildings in Central Europe since the 1990s. The load-bearing backing wall is built using solid masonry units, such as calcium silicate blocks, while the non-load-bearing facing veneer wall is constructed from brick. The veneer serves primarily as a weather barrier and supports only its own weight. Consequently, brackets, lintels, and even supports for external sunshades must be anchored to the load-bearing backing wall. Traditional jack arches are not incorporated into the facing veneer wall, as their thrust forces cannot be accommodated within the veneer structure. The cavity is filled with multi-layered thermal insulation material and defines the system boundary of heat transfer. A small air gap is required for bricklaying.

The veneer wall is secured to the backing wall using standardized stainless-steel ties. To accommodate thermal and moisture movement, creep, and deflection, impregnated sealing tapes have been introduced as a new ancillary component, primarily for vertical movement joints. As an alternative for lintels, brackets and their fixings to the backing wall are used as ancillary component. Standardized brackets are comprising an individual support for two adjacent masonry units [4]. They are usually made of stainless steel. Since then, various types of brackets, joist hangers and fixings were developed, which are not regulated with standards, but by general building authority approvals.

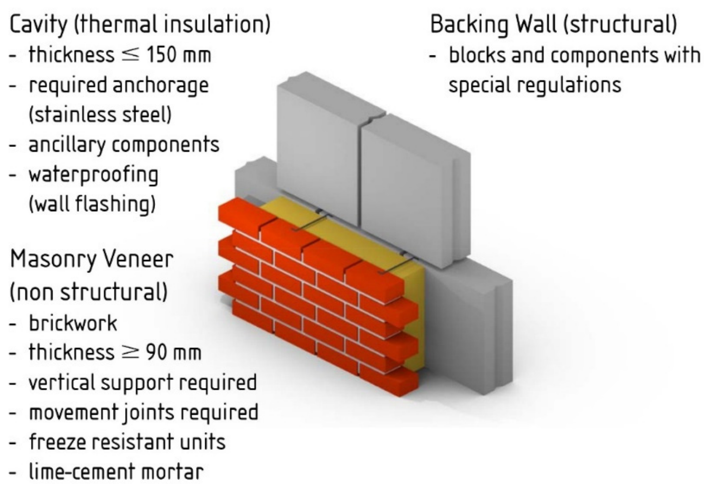

Figure 2: Construction principle of masonry veneer walls according to Eurocode 6, from [3]. The masonry veneer wall does not contribute to bearing the building loads.

In the 2010s lintels were increasingly replaced with precast concrete products (Fig. 1). Fig. 3 shows an example of a thin brick masonry veneer panel as a precast concrete element with detailing. It is used to connect the retaining wall of an underground garage to the above-ground masonry veneer. For this application, precast concrete elements are particularly suitable, as the structural strength of the thermal insulation in the cavity of a masonry veneer wall would require sufficient compressive strength to cover earth pressure. This transition detail is not regulated with EC 6. The transition is prone to thermal bridging and requires engineering expertise. Additionally, brackets may be necessary for structural support.

During the last years, precast concrete products with thin brick layers are increasingly being used within facing veneer walls. A report on prefabricated prestressed thin brick masonry veneer panels has been recently given by [5]. Composite veneer walls, combining traditional masonry veneer panels with larger precast concrete elements, represent the latest wall type and are not covered by existing standards (Fig. 1). Both, precast concrete linear structural elements and precast concrete panels, with or without thin-layer bricks, are combined with handcrafted brick veneer panels. This wall type is prone to damage, as standard masonry brackets may be insufficient to support the combined weight and structure of the masonry veneer and precast concrete elements.

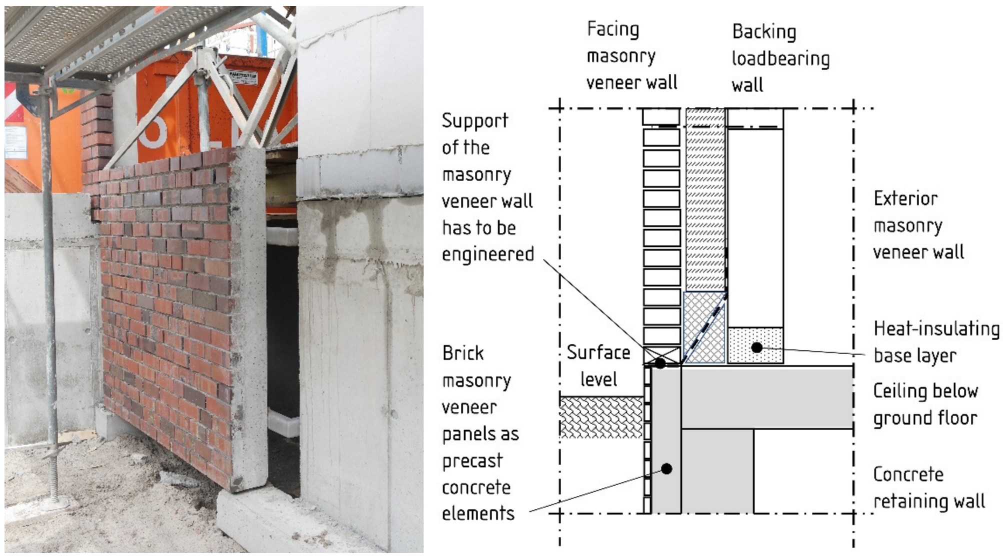

Figure 3: Precast concrete element with a thin brick veneer layer to connect the retaining wall of an underground garage to the above-ground masonry veneer (left). This transition detail (right) is not regulated by EC 6 and has to be engineered

COMPOSITE VENEER WALLS

Composite veneer walls (Fig. 4) are prone to building defects, caused by design flaws and execution errors, because they are not fully covered by the existing standards, resulting in a regulatory gap that requires individual evaluation. The handling of load-bearing precast concrete elements as part of exterior walls is standard practice for structural engineers. In contrast, the combination of non-load-bearing, handcrafted brick veneer panels and supporting precast concrete components into an overall non-load-bearing veneer wall is less common. So far, it was restricted to the use of lintels supporting load over openings, structural supports (Fig. 5) and the transition between rising masonry and underground retaining walls (Fig.3).

Fig. 5 is intended to explain the difference between the standard construction practice of using precast concrete elements within masonry exterior walls and composite veneer walls, like in Fig. 4. It shows a precast concrete support with thin brick veneer layer structure, as delivered to the construction site on the left, and installed as load-bearing support on the right. In contrast, composite veneer walls like shown in Fig. 4, are a hybrid construction type, combining a precast concrete façade and a masonry veneer wall. The difference is, that the load-bearing element in Fig. 5 has a clearly defined function as a support and is not supplemented with masonry on-site. In contrast, the T-shaped precast reinforced concrete elements in Figure 4 are large lintel-like components that are manually supplemented with masonry and work together as masonry veneer. Above the centrally positioned T-shaped element in Fig. 4, step-like cracks have developed, possibly due to improper support of the beam-like elements and the resulting deformations.

Figure 4: Composite veneer wall, made of T-shaped precast concrete elements framing the windows and supporting a handcrafted non-loadbearing masonry veneer wall

Figure 5: Standard construction practice with veneer walls; precast concrete element with thin brick veneer layer, as delivered to the construction site (left), and installed as load-bearing support (right)

Composite veneer walls integrate lintels - which were previously limited to spanning openings - as load-bearing precast concrete elements into the veneer wall (Fig. 4). The regulations of EC 6 are concerning double-leaf walls and masonry veneer and can only be applied to the masonry sections. The precast reinforced concrete elements must be evaluated independently as a precast concrete façade, e.g. following [6]. Hereby, fastening technology is particularly critical, as planners often lack experience in this area. The only available European standard for fastenings governs their design for use in concrete [7]. The design of anchors in masonry is regulated by European Technical Reports. Most relevant are EOTA TR 029 [8], TR 054 [9] and TR 064 [10].

Due to the different properties and load-bearing behavior of the façade sections made of precast reinforced concrete elements and handcrafted masonry veneer, these two distinct areas must be completely separated by appropriate movement joints. The resistance of masonry veneer walls to rain penetration depends significantly on the quality of waterproofing and sealing of the movement joints. Therefore, an increasing number of movement joints negatively affects the watertightness of veneer walls, thereby limiting one of their most important functions. Moreover, movement joints are less durable than masonry and require additional maintenance intervals.

SUPPORT OF VENEER WALLS

Veneer walls require a sufficiently load-bearing and low-deformation support, preferably on a shared foundation with the load-bearing backing wall. Following German National Annex to EC 6 [11], the veneer wall must typically be fully supported along its entire length. In cases of interrupted support (e.g., on brackets), all bricks must be supported on both sides at the support level. Brackets or lintels are used to support the veneer wall over openings. Since the veneer wall is non-load-bearing, support structures must be anchored to the load-bearing backing wall. Support structures that can no longer be inspected after installation must be made of materials that are permanently corrosion-resistant and either standardized for the application or approved by building authorities.

To support non-load-bearing veneer walls, lintels must be fastened to the load-bearing structure, typically using joist hangers. A joist hanger is a device for supporting a joist, beam, truss or rafter on a masonry wall via fixing bolts or screws [4]. Anchoring to load-bearing reinforced concrete components is achieved through ‘face fixing' with screws or fastening bolts (Fig. 6). Alternatively, the ‘joint fixing type’ might be applied. It is supporting a joist, beam, truss or rafter on a masonry wall by direct loading via a flange which is embedded in a mortar joint [4]. The essential load-bearing characteristics of beam supports must be specified in the declaration of performance [12]. This also applies to the requirements for fasteners and anchoring [4].

Support on lintels like shown in Fig. 6, is less load-resistant and less resistant to deformation compared to support on a shared foundation with the load-bearing backing wall. The anchoring points of the joist hangers must be measured with great precision, which is often challenging in practice when scaffolding is already in place or when balcony slabs or facade projections are present. Therefore, in the example shown in Fig. 6, no drilling work was performed. Instead, anchoring rails were embedded into the formwork during concrete casting at the site, which requires precise engineering planning. The mechanical anchoring in embedded corrosion-free rails achieves relatively high stiffness. Additionally, the connection allows for certain adjustments to ensure optimal force transmission. In contrast, bonded anchors are less error-resistant, for example, if minimum temperatures are not maintained during injection anchoring, or if the base material deviates from the approvals for the type of anchorage used.

Figure 6: Corner connection of two prefabricated concrete lintels with thin brick veneer layer, adjustable corrosion-resistant joint hangers type 'face fixing' and wall ties, anchored in a reinforced concrete beam that is embedded within the backing masonry wall

STRUCTURAL EFFECT OF LINTELS VS. PRECAST CONCRETE ELEMENTS

In construction and planning practice, the distinction between a lintel for masonry [13] and a precast concrete element might be difficult. Linear components spanning clear openings greater than 4.5 m in masonry walls and linear components intended for use independently in a structural role (e.g. beams) are not covered by [13]. Both are uncommon in masonry veneer walls. Large spans of more than 4.5 m occur only in special cases for supporting veneer masonry. In these cases, precast concrete products are used, which must be assessed e.g. based on [6] or [15]. Any components that are not linear, such as the T-shaped elements in Fig. 4, must be designed as precast concrete elements, as they take on additional loads, such as from wind, and have a frame-like load-bearing effect.

Possible damage of composite veneer walls is shown in Fig. 7. The reinforced concrete precast elements in the area of window openings in Fig. 7 are not lintels in the sense of a linear component. These are not ancillary components for masonry, as they do not complement the veneer wall by supporting masonry above openings. Instead, they form independent vertical structural elements between the windows as frame-like precast concrete components. Their material properties differ from those of masonry. Unlike the compression-loaded masonry, the frame elements transfer bending, which must be considered when evaluating their load-bearing capacity. Therefore, they cannot be considered part of the masonry veneer wall in terms of [11].

With more than two support points with joist hangers, the frame-like reinforced concrete precast element in Fig. 7 is based on a statically indeterminate system. This means that a uniform load distribution across all bracket anchors cannot be assumed. The actual load distribution depends on the stiffness of the connections and, therefore, on the execution and possible assembly tolerances. As a result of the statically indeterminate support or wind forces, the cracks visible in the figure have occurred. Elements made of reinforced concrete precast components in the veneer wall, as shown in Fig. 7, which differ from masonry lintels [13], must be designed using methods outside those required for masonry.

Figure 7: Detail of a composite veneer wall in the area of a window with shear cracks, likely due to statically indeterminate support. The rising veneer wall was build up directly and should have been separated by a horizontal movement joint.

Furthermore, the veneer wall in Fig. 7 was built up directly on the reinforced concrete precast element. This does not conform to [13], as the reinforced concrete precast component is not a lintel. Therefore, the requirements for designing the joist hangers at the specified positions are not met. Since the T-shaped reinforced concrete precast components have to be designed as a frame element of a reinforced concrete façade, a separation between the two façade areas - veneer wall and precast reinforced concrete façade - through movement joints is required. Veneer wall and reinforced concrete precast components must be supported independently and separated by a horizontal movement joint.

Movement Joints and Thermal and Moisture Expansion

In composite veneer walls, movement joints are required to separate the exterior concrete precast elements from the masonry veneer. Both sections serve the same purpose as the outer shell of the exterior wall and must collectively meet the technical requirements. These relate to: mechanical impacts, tolerances, weathering, driving rain, temperature fluctuations, light and moisture exposure, compatibility with adjacent materials, long-term elasticity of the component joints, and fire behavior.

From the structural engineering perspective, the shared support of the two sections of the composite veneer wall is basically possible. However, it is crucial to ensure that no force-locked connection is created between the concrete precast elements and the veneer wall segments. All movement joints between the different façade areas must securely prevent any force-locked connection. Therefore, the joint sealant must not be bridged by foreign bodies during or after installation. In particular, it must not be contaminated by mortar residue. Even one local disruption can lead to unintended force transfer and subsequent damage, such as crack formation due to unintended load transfer.

Building expansion joints must be considered separately. Within the composite veneer wall sections, the structural rules of the respective construction method, reinforced concrete precast elements and masonry veneer wall apply.

The final value of the moisture expansion of brick masonry is the subject of ongoing research. According to [2], it can range from -0.2 to +1.0 mm/m. For the design of brick masonry with brick sizes smaller than (length/width/height) = 240/115/113 mm and standard masonry mortar, the limit value of -0.2 mm/m applies in Germany. The moisture-induced expansions of concrete are typically smaller, depending on its composition, and less shrinkage occurs. Therefore, for composite veneer walls, movement joints are also important to prevent cracks caused by moisture effects, which could impair functionality and durability. The impact of the different hygroscopic deformations of the two components, reinforced concrete precast elements and masonry veneer, in composite veneer walls requires further scientific investigation.

CONCLUSIONS

The paper summarizes the evolution of masonry exterior wall types in Central Europe and reports on the latest developments in the construction of masonry veneer, considering possible damage. The expanding integration of ancillary components and the general increase in window areas resulted into the development of precast masonry construction, that combines traditional masonry with precast concrete units or thin brick masonry veneer panels. With this type of 'composite veneer wall', basic design principles of masonry veneer walls or traditional 'cavity walls' are still applied: The exterior masonry veneer wall, is used as a facing, but not contributing to the resistance of the backing wall or framed structure.

Unlike conventional masonry veneer, 'composite veneer walls' integrate lintel-like load-bearing elements, which were previously limited to spanning smaller window openings, as load-bearing precast concrete frame elements into the facing masonry, for example, to enclose increasingly larger window openings. This type of construction is prone to error, such as when connections designed for lintels are used for larger frame-like elements. Lintels are purely linear elements with lengths of up to 4.5 m, onto which the facing shell can be directly built, creating an integrated wall. In contrast, the design of large frame-like elements must account for wind loads, potential statically indeterminate systems, and the suitability of connection methods, as these factors can lead to cracks and deformations if not properly addressed.

The anchoring of large frame-like precast concrete elements as part of facing shells requires a high level of precision, both in the execution of the anchoring and in the surveying of the anchoring points. Surveying is often challenging, particularly when scaffolding, balconies, or façade offsets obstruct the line of sight. Furthermore, all connections between masonry and reinforced concrete components must be separated by permanently elastic movement joints. Masonry veneer must not be built directly onto the frame elements to prevent damage caused by differing thermal or hygroscopic deformations.

Furthermore, it must be verified whether anchoring elements designed for lintels can also be used for larger precast reinforced concrete elements. The increased number of movement joints required by the two façade components - masonry and precast concrete elements - creates weak points in terms of resistance to driving rain, potentially compromising the durability of the masonry veneer. In summary, the combination of reinforced concrete elements and masonry must be carefully planned to avoid damage. This construction method is not covered by the standards for masonry veneer walls.

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