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A NON-DESTRUCTIVE METHOD FOR FIXING PLACARDS WITH MASONRY STRUCTURES

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1. INTRODUCTION

The practise of fixing placards to masonry structures using steel nails – a method widely used in Malta – is destructive and causes irreversible damage to the building fabric, as well as having indisputable aesthetic impacts, especially problematic with culturally significant heritage buildings. With a superficial area of circa 316 km^2, Malta and its dependencies represent the smallest EU Member State and, at the same time, the nation state with the highest density of designated World Heritage sites. Its capital, Valletta, was also listed by UNESCO in its entirety as a World Heritage Site in 1980 [1]. It is one of the most concentrated heritage areas on the globe – 320 cultural monuments within an area of 55 ha.

2. GLOBIGERINA LIMESTONE FORMATION

2.1. Lithostratigraphy

This city is primarily constructed in Lower Globigerina Limestone (LGL). This limestone is composed of massively bedded, biodetrital limestone consisting of globigerinid planktonic foraminifera. In contrast with the upper part of this member, the lower part is coarser-grained and strongly bioturbated [2].

2.2. Petrophysical characteristics

Microphotographs illustrating the texture, cement fabric and pores of both LGL lithotypes show that the first-quality lithotype has well defined physico-mechanical interlocking (Figure 1a); its pore structure and fine-grained sparry calcite, which fills the inter-particle voids, cements most allochems. This interlocking physico-mechanical bond, pore structure and fine-grained cement account for its better durability compared to the second-quality lithotype.

3. THE ISSUE

Where nails have been used to fix something to the surface of a building, there are two options when the item is due to be detached: (i) remove the nail or (ii) drive it further in. The former case involves driving a cat's claw or hammer claw under the nail's head and levering it out. The latter case is more damaging in the long term, as additional stresses are generated due to corrosion of the nail.

Although nails have a narrow end, the pullout force (F_p) required to pluck them out of LGL generates a combination of tensile and shear stresses, resulting in a cone of the fabric being removed. F_p is directly proportional to the compressive strength of the limestone (σ_m) thus:

$$F_p = \sigma_m a_c \qquad (1)$$

where a_c is the surface area of the conic frustum.

The greater the pullout resistance, the greater the pullout force, resulting in a conic frustum with a larger surface area, resulting in greater irreversible damage to the fabric. Furthermore, given LGL's physico-mechanical characteristics of interlocking and the fine-grained sparry calcite cement (Figure 1a), the surface area of the conic frustum generated in the first-quality lithotype is greater than in second-grade limestone (Figure 1b). Therefore, more damage is caused to cultural heritage buildings predominantly constructed from the high-grade lithotype.

4. DESIGN PROPOSAL

The proposed design – the RR-Plug – is an anchor plug placed in a hole drilled in the mortar of bed and/or head joints and can be removed when required. The concept is based on Rawlbolt®. The RR-Plug is a removable and reusable stainless steel plug with an expanding sleeve, a ferrule with a built-in flange and an angle-tapered nut, the latter ensuring maximum expansion on tightening the bolt (Figure 2).

The drill bit is slightly larger than the shield of the plug (Figure 3a) and can therefore be loosely placed in the hole once it has been cleared of debris (Figure 3b). Once fully assembled, when the bolt and washer are tightened, the tapered nut is pulled towards the plug's shield via the bolt's thread; the angle-tapered nut does not lock in the shield on tightening. This expands the shield, securing the plug in its orifice (Figure 3c).

For extraction, the bolt is untightened (Figure 3d) and gently hammered in so that the nut angle moves away from the shield (Figure 3e). The purpose of the inbuilt flange is to minimize and absorb most of the stresses transmitted to the masonry in which the plug is set (when it needs to be gently hammered to extract it). On hammering, the flange helps minimise the damage to the surrounding fabric (the diameter of the flange, must be at least 3 times the diameter of the plug).

On hammering, the stress, σ, generated on the fabric is given by:

$$\sigma = F_h\, a^{-1} \qquad (2)$$

where F_h is the hammering force and a is the area on which the F_h is transmitted.

The surface area of (i) the flange (a_f), (ii) the mortar joint covered by the flange (a_m) and (iii) the drilled hole (a_h) are related as follows:

$$a_f = 0.25\, \Pi\, \phi_f^2 \qquad (3)$$

$$a_m \approx \phi_h\, \phi_f \qquad (4)$$

$$a_h = 0.25\, \Pi\, \phi_h^2 \qquad (5)$$

If the mortar is level with the masonry,

$$a = 0.25\, \Pi\, (\phi_f^2 - \phi_h^2) \qquad (6)$$

and hence,

$$\sigma = F_h\, [0.25\, \Pi\, (\phi_f^2 - \phi_h^2)]^{-1} \qquad (7)$$

If the mortar is recessed in the masonry,

$$a \approx \phi_f\, [0.25\, \Pi\, (\phi_f - \phi_h)] \qquad (8)$$

and hence,

$$\sigma \approx F_h\, [\phi_f\, (0.25\, \Pi\, \phi_f - \phi_h)]^{-1} \qquad (9)$$

Thus, in the case of Malta, if ϕ_h = 0.005 m and ϕ_f = 0.015 m, then the stress, σ, is over 50 % greater in recessed mortar than when the mortar is level with the masonry. Thus, it is recommended that prior to installation the mortar joint is rendered, with a reversible mix compatible with the existing fabric, to a relatively flat surface with the dimension stones in order to generate a uniformly distributed stress on the fabric when hammering.

After removing the bolt (Figure 3f) the hole must be thoroughly cleaned of any debris and infilled with a compatible mortar. Initially, the hole can be drilled using a portable electrical drill. If skillfully used, this kind of tool will cause less damage, but attention should be paid to the power of the drill. The principle is simple: the faster the rate of penetration, the more accurate the hole is likely to be [4].

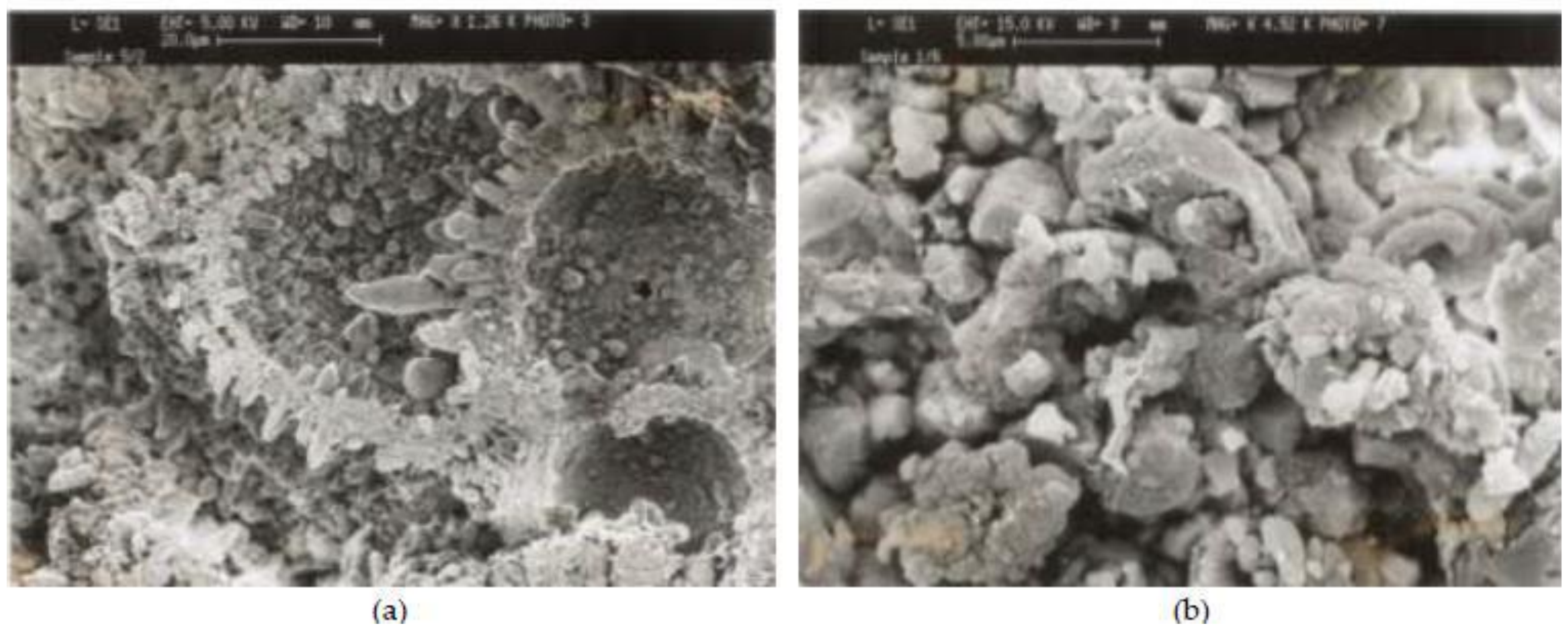

Figure 1 – SEM images illustrating the pore structure, physico-mechanical interlocking and fine-grained sparry calcite cement in (a) the first quality lithotype and (b) the second quality lithotype [3].

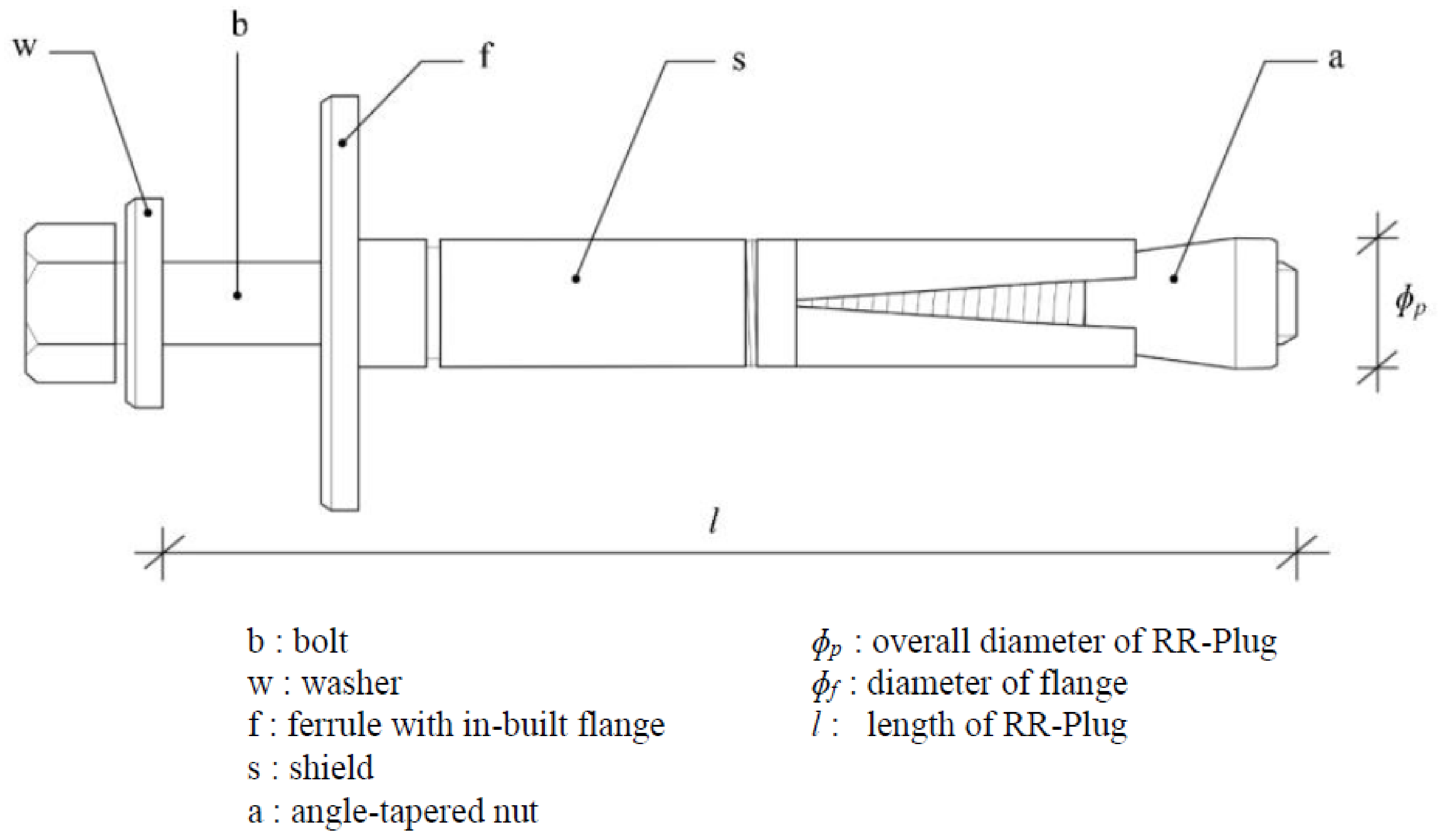

Figure 2 – Conceptual sketch of proposed design of RR Plug (not to scale). The RR Plug's main components include a bolt and washer, a shield (which includes a ferrule with a built in flange) and an angle tapered nut.

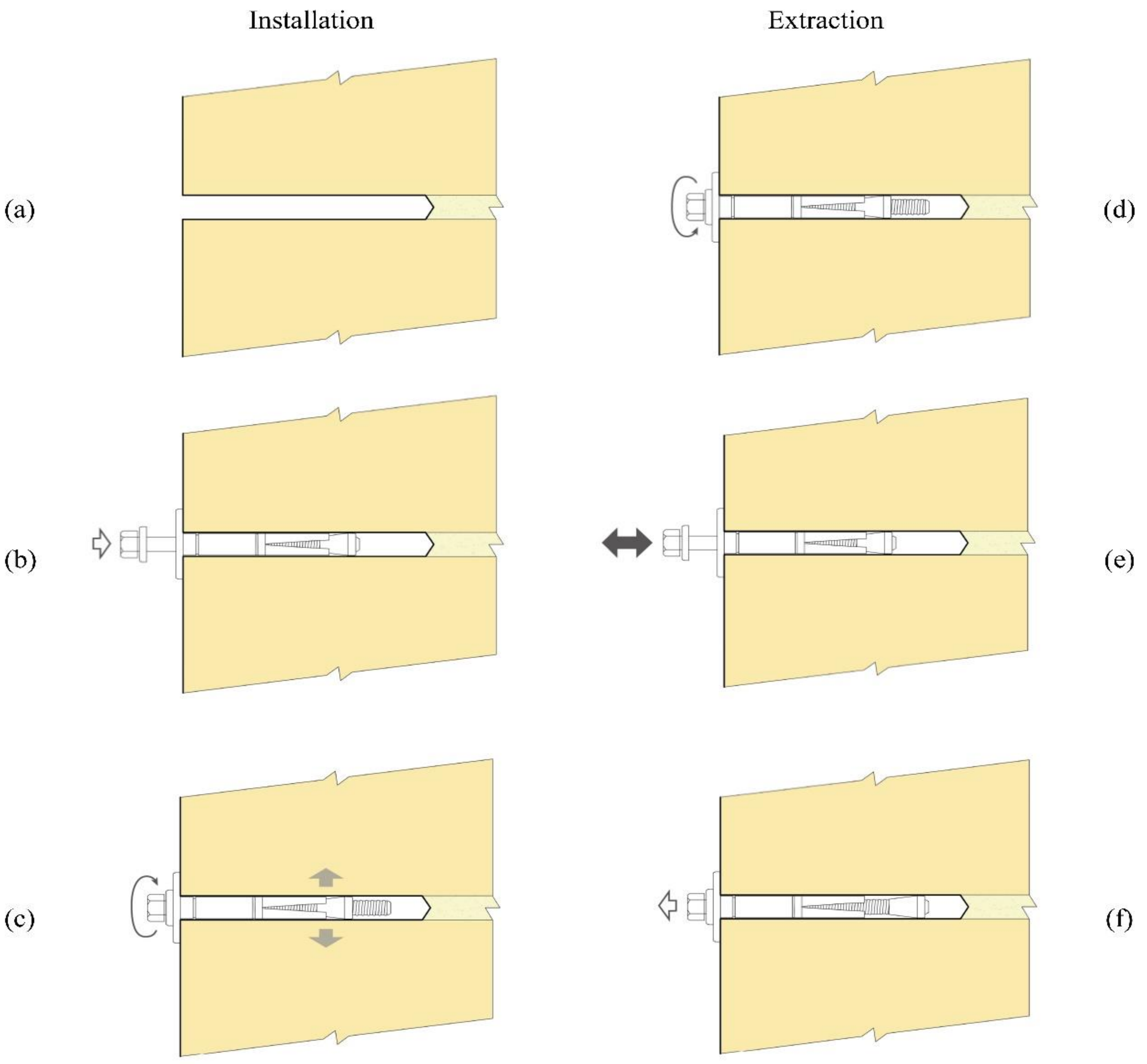

Figure 3 – Installation (a to c) and extraction (d to f) guides of a RR-Plug (conceptual; not to scale).

References:

[1] UNESCO 1980 *City of Valletta* (https://whc.unesco.org/en/list/131/, retrieved 14 August 2022).

[2] Baldassini N, Mazzei R, Foresi L M, Riforgiato F, Salvatorini G 2013 Calcareous plankton bio-chronostratigraphy of the Maltese Lower Globigerina Limestone member. *Acta Geol. Pol.* **63**: 105-135.

[3] Bianco L 2021 Geochemistry, mineralogy and textural properties of the Lower Globigerina Limestone Used in the built heritage. *Minerals* **11**(7): 740. https://doi.org/10.3390/min11070740

[4] Feilden B M 1982 *Conservation of Historic Buildings* (London: Butterworth Scientific).

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