The mortar of the “Leaning Tower” of Pisa: the product of a medieval technique for preparing high-strength mortars

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Abstract: Thirty mortar samples from the “Leaning Tower” of Pisa were examined. The specimens include mortars from both the first (1173-1178) and second (1272-1278) stages of Tower’s construction. The mineralogical, petrographical, chemical and physical data collected on the bulk mortar and its binder show that the famous “Leaning Tower” of Pisa was built through the constant use of a high-quality hydraulic mortar (average compressive strength about 16 N/mm²; average binder SiO₂ content about 29 %) as the binding agent for the “infill” masonry. Although a great deal of variability exists in the values of each measured property, even amongst samples from the same stage of construction, the averaged values for the foundations and the above-ground structures erected during the two distinct construction stages are highly uniform. The most conspicuous differences lie in the sand content and granulometry, which are respectively greatest and coarsest in the foundation mortars. Chemical and mineralogical data suggest that the Tower mortar was prepared by mixing slaked lime, obtained from an almost pure limestone, with sand from Arno and Serchio Rivers alluvium and a diatomaceous earth, probably quarried at Mt. Amiata, about 180 km to the south of Pisa. It is estimated that the construction of the Tower from the foundations to the top of the 7th storey (the belfry, added to the main structure only around 1365, is not considered here) required the use of about 1400 tons of slaked lime (assuming 60% water content), 1350 tons of sand and 400 tons of diatomite.

Key-words: “Leaning Tower of Pisa”, mortar, binder, lumps, hydraulic character, formulation procedure.

1. Introduction

The “Leaning Tower” of Pisa is a medieval eight-storey structure (total height: 58.36 m), made up of a hollow cylinder (external diameter: 15.5 m; height: 47.24 m), surrounded by 6 loggias (from the 2nd to the 7th storey) and topped by the belfry (= 8th storey; external diameter 12.7 m; height: 7.21 m). It rests on a ring-shaped foundation with an external diameter of 19.58 m and a height of 3.91 m. The masonry structure was constructed using the “infill” technique: two stone walls facing a concrete core made of stone fragments, gravel and sand, cemented with a lime mortar. The construction of the Tower began in 1173 and progressed steadily until about the middle of the 4th storey; in 1178 the work was suspended, to be resumed only a century later, in 1272. This second stage ended in 1278, at the top of the 7th storey. Only between 1360 and 1370 was the belfry finally added to the Tower. Full details on the historical, architectural and structural features of the monument, as well as the make up and mechanical properties of the subsoil is provided in the Report of Minister of Public Works (Ministero Lavori Pubblici, 1971).

In 1990 growing concern over the possibility of an almost instantaneous structural collapse of the Tower compelled the Italian Government to set up the “International Committee for Safeguarding the Leaning Tower of Pisa”. This Committee began its works by promoting a number of multidisciplinary studies in the fields of art history and restoration, structural and geotechnical engineering and so forth. In particular, the Committee deemed investigations of the masonry structure’s