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Original article

The construction of a street never opened to traffic. The extraordinary discovery of pavement engineering in vicolo dei Balconi of Pompeii

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ABSTRACT

A significant portion not yet investigated in the Regio V of the ancient city of Pompeii is currently the subject of the most remarkable excavation in the post-World War II period. These activities relate to a triangular area, the so-called "wedge", which is placed between the houses of Nozze d'Argento and Marco Lucrezio Frontone. Besides the astonishment and scientific emotions resulting from the finding of magnificent frescoed and well preserved *thermopolium*, dwellings and balconies, also a feeling of extreme interest in the pavement engineering arose due to a further one of a kind discovery. The Somma-Vesuvium volcanic eruption of 79 AD buried a narrow alley, i.e. vicolo dei Balconi, during the construction of its stone pavement, in which the laying of compact lava stone flags was interrupted about halfway from north to south. The eruption and the following superimposition of lapilli, ash and pumice blankets has therefore maintained in a state of perfect documental conservation the whole area, preserving the new laid flagstones still showing the original surface finishing and the preparatory subgrade. Thus, this historical and archeological source becomes a priceless engineering evidence describing some of the design and construction techniques used by the Romans at Pompeii. The excavated area has been analyzed following a cross-disciplinary approach, adopting several minimally intrusive or non-destructive techniques and instruments belonging to different branches of science to capture some specific aspects. Specifically, the alley has been initially surveyed with a terrestrial laser scanner (TLS) device to build an accurate layout model of the worksite. Although the TLS survey provided an invaluable source of information for the street structures documentation, specific stone paving elements were also analyzed using close range photogrammetry techniques and their friction properties have been measured exploiting the potential of a modern road engineering device, i.e. a skid resistance tester, also known as the British pendulum tester (BPT). The consistency analysis of the subgrade structure and homogeneity in the unpaved section involved the use of two dynamic procedures, i.e. a penetrometric (dynamic cone penetrometer - DCP) and a deflectometric (light weight deflectometer - LWD) test. Besides, some design and urban planning considerations have been drawn from the analysis of the relationships between the finished structures and the pavement construction site according to the lines of the existing curbs, the thresholds of access to the dwellings and the placement of enigmatic prismatic blocks arranged in trenches, probably intended as a useful target points for the stonemasons or temporary pedestrian passage. In a wider reading a succession of paving works (and not repaving) using stone elements in this part of the city starting from the *Cardo* via del Vesuvio (from west to east) is recognizable.

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1. Introduction

Approximately 270 years after the first explorations of the ruins of Pompeii (1748), the most remarkable excavation in the post-World War II has involved a significant portion not yet investigated in the Regio V of the ancient city. This site is part of the largest stabilization intervention of the excavation fronts aimed at re-shaping and re-profiling them to avoid the hazards of hydrogeological instability on the already unearthed buildings and structures [1]. These works were made possible by the Grande Progetto Pompei (Great Pompeii Project), i.e. a conservation and restoration program launched in 2012 and largely underwritten by the European Union [2]. The ongoing activities relate to a triangular area of about 1400 m^2, the so-called "wedge", which is placed between the houses of Nozze d'Argento (Insula 2) and Marco Lucrezio Frontone (Insula 4) (Fig. 1) [3].

The excavation of the wedge has brought to light unexpected treasures, emotions and very important knowledge for the history of the Roman colony. Particularly rich in surprises has been the discovery and reveal of a narrow alley, i.e. vicolo dei Balconi, which connects the vicolo delle Nozze d'Argento and a section of the superior *Decumanus* via di Nola [4]. Architectures and decorations of magnificent dwellings of the alley, especially of the casa del Giardino with the superb frescoes of the *triclinium* and the painted porch with fourth Pompeian style decorations and casa di Giove/Orione with first Pompeian style wall paintings and two extraordinary Egyptian-inspired mosaics, an outstanding decorated and perfectly preserved *thermopolium* (commercial establishment where drinks and hot food were served) and four balconies, from which the alley derives its name, have been emerged [5,6]. Specifically, some houses were already finished and inhabited, where skeletons and precious and daily life objects (jewels, coins, tools and furnishings) have been found, whereas others were under refurbishment, still showing rough and not re-plastered façades [7]. Besides the astonishment and scientific emotions of researchers and archaeologists from all over the world resulting from such findings, also a feeling of extreme interest in the pavement engineering arose due to a further one of a kind discovery. In fact, the Somma-Vesuvium volcanic eruption of 79 AD buried vicolo dei Balconi during the construction of the stone pavement, in which the process of virgin flags laying was interrupted about halfway from north to south through its development (Fig. 2). This alley is therefore the image of how Pompeii found in the last years, that is a great criticality state, resulting not only from the impressive 62 AD earthquake but also from the seismic activity that probably preceded already from the previous summer the 79 AD Plinian eruption, to which was sought to remedy with continuous maintenance and rehabilitation works [4,8].

The pavement of vicolo dei Balconi can be synthetically described as a succession of three clearly distinguishable states of progress. A first part in the northern section up to the intersection with vicolo delle Nozze d'Argento, in which the stone elements although appear in good conditions show signs of wear from traffic. The second section proceeding towards the south in the direction of via di Nola was newly paved, testifying the progress of the construction site. In the last section, where the works have been stopped, only the subgrade is actually visible, describing a particularly interesting configuration that captures a specific moment of the paving process. The dramatic circumstance of the eruption and of the following superimposition of lapilli, ash and pumice blankets has maintained in a state of immobility and of perfect documental preservation an extremely particular technical case, that is a virgin natural stone paving where it is possible to recognize a surface layer never opened to traffic and thus still having the finishing characteristics just like conceived and realized by the Roman stonemasons [9]. Since set aside new stone elements has not been found in close proximity to the pavement construction site, works could be carried out on site piece by piece or with greater probability following specific times and progresses also driven by the completion of the related vertical structures.

2. Research aim

The excavated area of vicolo dei Balconi has been investigated following a cross-disciplinary approach, adopting several non-destructive instruments and methods belonging to different branches of science to capture some specific aspects. Road engineering, geotechnical and photogrammetric procedures were used to further understand some of the design and construction techniques used by the Romans at Pompeii, enriching the knowledge of the site and the progress of archeological research. Starting from an accurate visual inspection and an advanced laser scanner survey, some detailed analyses have been carried out to study the surface texture of the paving stones and the subgrade consistency in the unpaved section. Besides, some design and urban planning considerations have been drawn from the analysis of the relationships between the finished structures and the pavement construction site.

3. 3D model creation from laser scanner data

The alley and the crossing with via di Nola have been initially surveyed with a Leica RTC360 terrestrial laser scanner (TLS), capable of acquiring up to 2 million points per seconds with an operative range up to 130 m and a nominal accuracy of ca. 3 mm at 20 m. The instrument is equipped with a 36 Mpixel camera system which captures a co-registered high resolution panoramic (spherical) image just after the point cloud acquisition. The total extent of the two streets (i.e., vicolo dei Balconi and via di Nola from vicolo dei Balconi to vicolo di Cecilio Giocondo) required 42 different scan stations, acquiring overall an impressive more than one billion data point cloud. The specialized survey returns an accurate layout of the worksite, with the new constructed pavement surface that departs from the pre-existing one of vicolo delle Nozze d'Argento at the junction, where the *thermopolium* represents a refreshment stand.

4. Observations on the surface texture of the paving stones

The pavement elements in the Regio V are pyroclastic deposits of Somma-Vesuvius volcanic complex derived from the eruptive activity occurred from 19,000 to 10,000 BC [10]. This compact lava stone has a holocrystalline porphyritic texture with a fundamental hypidiomorphic micro-granular paste and more than 50% of sialic phenocrysts that are clearly visible to the naked eye. The minerals of the matrix and phenocrysts are mainly leucite, i.e. coarse (3 mm) roundish whitish idiomorphic individuals, plagioclase feldspar (bytownite), i.e. calcium-rich variety with medium to dark gray color and triclinic crystal system, augite, i.e. short and stubby (2 mm length and 5–6 mm width) prismatic crystals having dark green to black color and vitreous luster, and olivine, i.e. fine ($<$ 1 mm) irregular glassy light-green to dark green grains [11,12]. On the basis of this mineralogical composition, several authors have proposed a proper classification. Nicotera [13] ranked this type of rock as an ottanjanite using the triangular diagram of general classification and nomenclature of plutonic rocks according to the mineral content; Cinque [14], in the light of new investigations on the lava products of the Pompeian hill, defines it as an orvietite quarried around the ancient city area, while Kastenmeier et al. [10] suggested that this lava is included in the latite/tephriphonolite fields in the total

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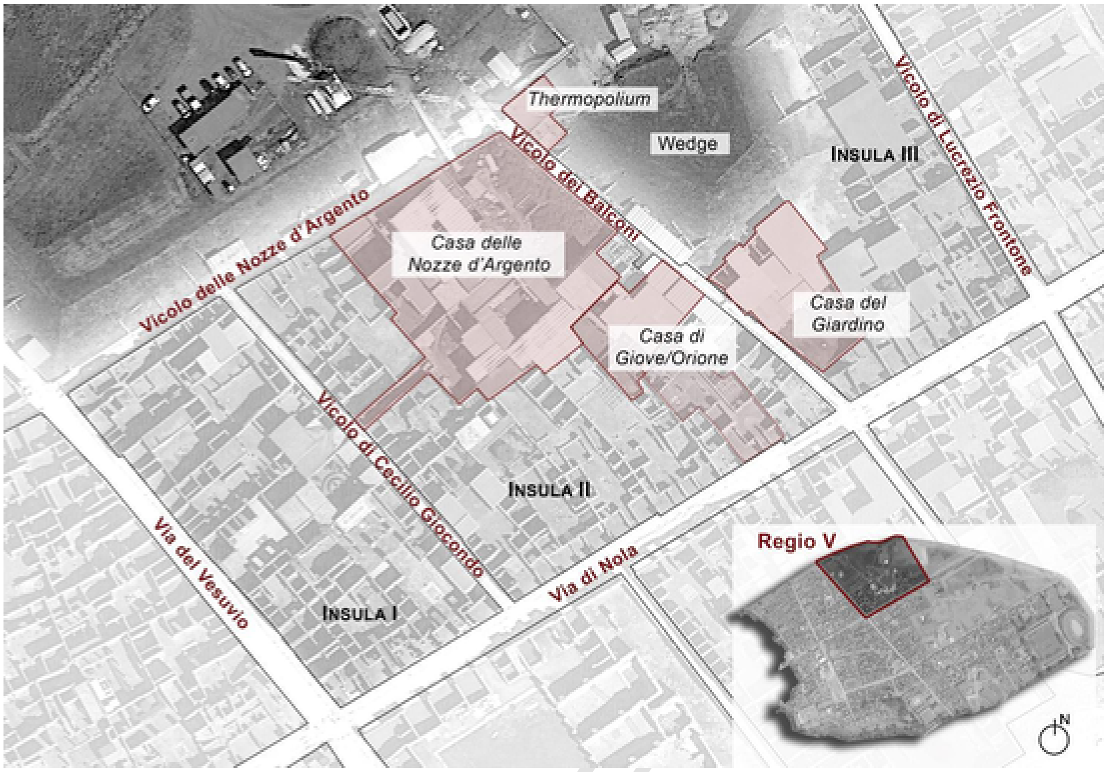


Fig. 1. Pompeii area under investigation (Regio V, Insula 2 and 3).

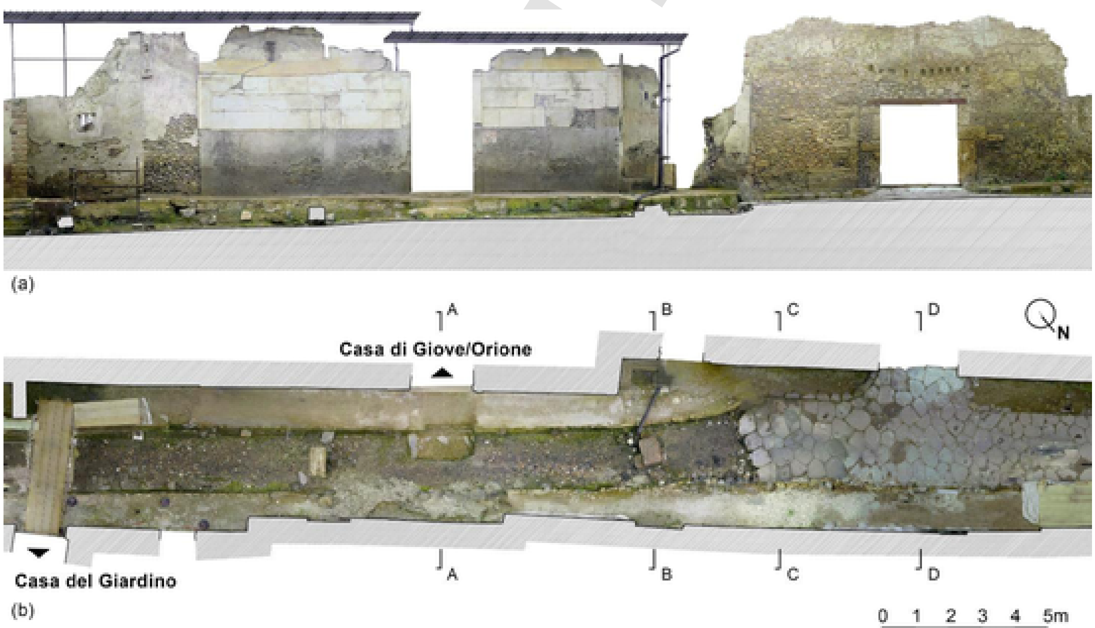


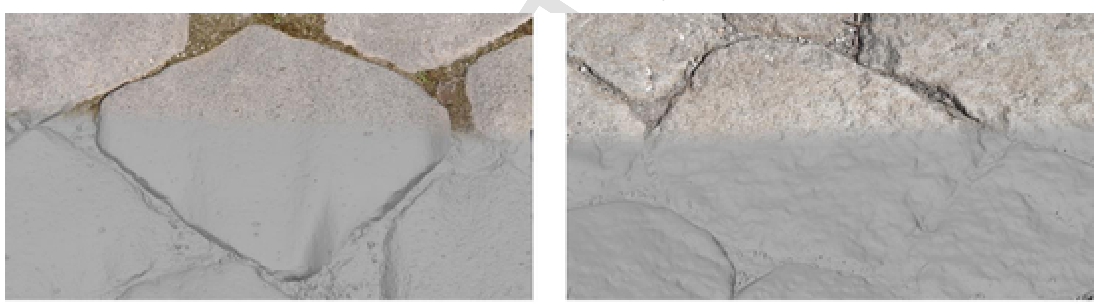
Fig. 2. Central section of vicolo dei Balconi: west front (a) and plan (b).

alkali-silica (TAS) diagram, which is based upon the relationships between the combined alkali and silica content.

Pavement is made by large, irregular and polygonal flagstones with a specifically dressed upper face and a roughly broken lower one. The handmade surface finishing consists of a succession of depressed and raised portions obtained from skilled stonemasons by using grooving chisels or punches and a mallet ("puntillo" technique). The final result substantially depends on the drafting and etching degree, from the picked or pointed finish and fine tooling, passing through the rough sparrow-pecked, to the punched dressing and rough tooling, in which the effect of the reliefs is gradually increasing [15–17].

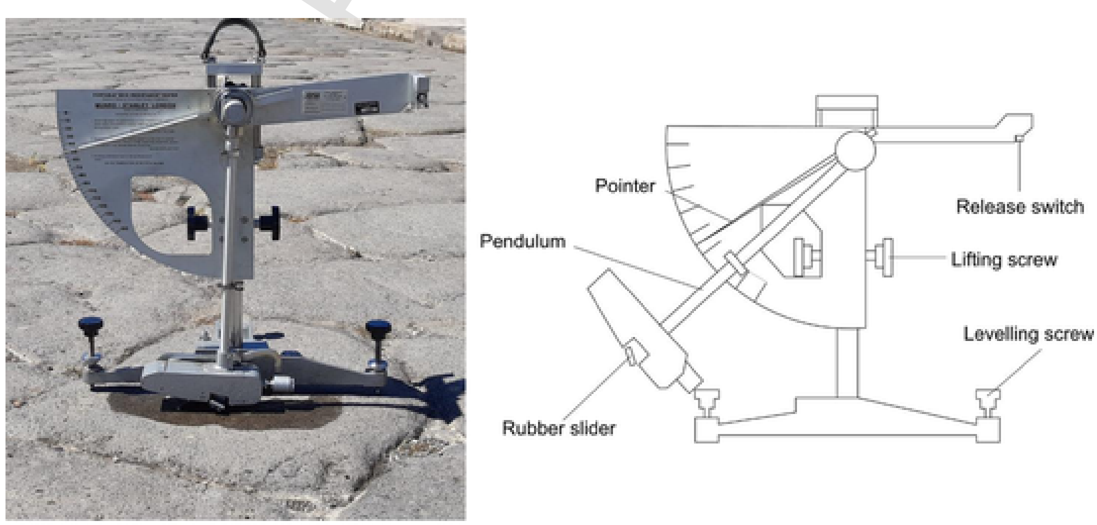
Although the TLS survey provided an invaluable source of information for the street structures documentation (i.e. cross- and horizontal sections, pavement layout, etc.), specific stone paving elements were surveyed also using close range photogrammetry techniques, in order to obtain higher resolutions and accuracies to evaluate their fine surface characteristics. Thus, a Nikon D3X high-resolution digital camera with 35 and 50 mm Nikkor optics was used [18]. For every single analyzed flagstone (along with its surrounding elements) a photogrammetric block with at least 12 convergent images, with an average camera-to-object distance of ca. 110 cm (resulting in an average ground sampling distance (GSD) of ca. 0.2 mm/pixel) has been acquired. The estimated precision of the photogrammetric reconstruction, although influenced by the actual texture characteristics of the stone element, is approximately 0.3 mm along the vertical direction, which allows to highlight several block surface features (e.g. roughness, defects, etc.…) on a very fine-detailed level. The evidence of the distinct macro-texture, determined by different wearing actions, is explicitly recognizable by the proximity of the pre-existing elements of vicolo delle Nozze d'Argento (Fig. 3a) and the newly installed flags of vicolo dei Balconi (Fig. 3b), which do not show any signs or marks of previous use. The general wear and tear, including rutting, of vicolo delle Nozze d'Argento paving flags extend to the full development of the alley. These traces together with the fact that several properties had wide openings towards this alley, which connected the *Cardo* (via del Vesuvio) to the *thermopolium* (an activity generally located at crowded crossroads) would indicate that vicolo delle Nozze d'Argento was a preferential traffic route. The excavations conducted in the Regio V Insula 1 within the Swedish Pompeii Project [19] discovered the presence of wheel ruts in the packed earth surface of the older street level, demonstrating that this alley was unpaved at least in a first phase of urban development [8]. Moreover, it is interesting to note that also the paving stones of vicolo di Cecilio Giocondo, i.e. the first western parallel to vicolo dei Balconi, resulted to be substantially unaffected with the clearly visible original surface finishing.

For the first time at this heritage site, a test aimed at measuring the friction properties of the paving stones surface, which are closely related to their micro-texture, has been carried out exploiting the potential of a modern road engineering device. Specifically, the Munro Stanley skid resistance tester, also known as the British pendulum tester (BPT) was selected (Fig. 4). BPT is a dynamic impact-type instrument which measures the pavement skid resistance, in terms of pendulum test value (PTV), based on the energy loss, i.e. the return height of the pendulum arm when its slider edge is propelled at low speed over a test surface. The measurements were carried out using a large TRL(55) rubber slider (76 mm x 25.4 mm x 6.35 mm), which is a codified reference reported in the EN 13036–4 standard for the measurement of slip/skid resistance of a surface and in the EN 14231 standard specifically intended for natural stones. Some authors, studying some functional aspects of historic stone pavements, have however proposed alternative and not standardized materials (wood, leather and steel) for coating the slider to better simulate ancient footwear and wagon or cart rims [20]. The measurements were performed on different flagstones swinging the pendulum along the street axis orientation, with small tolerated deviations sometimes required to assure the maintenance of the rubber slider contact over the specified sliding length on a fine textured surface. Each stone element was brushed to remove loose particles and thoroughly sprayed, as well as the slider, with water before each pendulum swing (wet condition procedure). Twelve stone elements (labelled using the letter from A to L) were tested, selecting six flagstones in the newly paved section and six in the northern area of vicolo dei Balconi (close to the intersection with vicolo delle Nozze d'Argento). The mean of five consecutive swings on each flagstone described its PTV. Since temperature can affect rubber resilience, slight adjustments to the recorded readings have been made depending on the pavement temperature. Starting from these corrected values, the PTV referred to the two kinds of flagstones (new laid and previously placed) was calculated as the



(a) (b)

Fig. 3. 3D models of the paving stones in via delle Nozze d'Argento (a) and vicolo dei Balconi (b). In each figure, textured and solid model is provided.



(a) (b)

Fig. 4. Skid resistance test.

mean on the six elements. The results have shown an almost perfectly coincident skid resistance between new laid and worn stone elements, showing in both cases values equal to 47 ± 2 (mean ± standard deviation). This behavior is probably justified by the mineralogical and holocrystalline nature of the igneous rock: the polishing has affected the surface macro-roughness, leaving the micro-roughness essentially unaltered. PT values for stones are not independent of the surface finishing (polished, pointed, blasted or flamed) and the polishing action (vehicular or pedestrian traffic). Some studies reported that different types of igneous rocks adopted in urban stone pavements, showed slight reductions (~5%) in PT values as a result of polishing effects under traffic in the field or caused by accelerated procedures in laboratory [21,22].

5. Remarks on the layout of the road construction site and possible progress of work criteria

The street section of vicolo dei Balconi provides the arrangements of curbs using large stone blocks, resulting in a sidewalk level rather high compared to the original laying surface or to the specifically prepared one. The worksite area between the new paved completed section and the southern junction with via di Nola has currently a preparatory subgrade consisting of an apparently pre-existing altered *glarea* [23], in which three prismatic stone blocks are placed on a provisional bed of coarse stones. These blocks seem to represent targets in the paving progress, perhaps useful for the alignment of the future finished surface as well as for the easier temporary alley crossing for pedestrians and workers (masons) (Fig. 5). The longitudinal profile highlights an essential regularity between the sidewalk level (existing curb) and the paved surface (about 230 mm) both along the eastern and western sides (Fig. 6).

Assuming that the top of the blocks, placed approximately at the center of the construction site, constitutes the project alignment and that final stone paved surface linearly varies between them, a consistency with the trend of the base course (probably the previous *glarea*) and the ideal line of the curbs under reconstruction from vicolo delle Nozze d'Argento is noted. This consistency is observed both in the west and east side, where also emerged the compatibility with the entrance (inaccessible at the eruption) to the casa di Giove/Orione, which is now served by a ramp from the base layer (or existing residual *glareata strata*) to the sidewalk. The impossibility of direct access to this house from vicolo dei Balconi is a reasonable testimony of how it was probably inhabited only in the garden sector and in that connected to the building facing to via di Nola, while the other parts were under renovation works: almost all furniture was found gathered in few rooms [1].

6. Assessments to evaluate the subgrade of the paving street

As above mentioned, the clear interruption during the paving progress is configured as a temporary waiting situation for following works. Stone elements, more specifically referred using the term *silex* due to the hardness of the rock, are laid on a subgrade course consisting of the lower layer of the trench defined by the side curbstones. This surface constitutes at present the bottom of the archeological excavation and thus the limit of the degree of knowledge. To increase this level, concerning in particular the preparation techniques of Romans for road and street construction, an investigation for the characterization of the ground below the stone pavement surface (defined in modern road engineering as subgrade) was performed by means of specific procedures, probably never applied in archeological sites. The interest is mainly oriented towards the analysis of the subgrade consistency, the understanding of its structure in one or more layers and the hypothetical assessment of the constituent materials having different composition or compaction degree and of the possible presence of soils or granular mixtures improved by hydraulic binders, only based on a response to mechanical inputs.

The consistency analysis of the subgrade homogeneity in the unpaved section, i.e. the alley section in which the construction works have been interrupted by the volcanic eruption, involved the use of two minimally intrusive or non-destructive dynamic procedures, i.e. a pen-

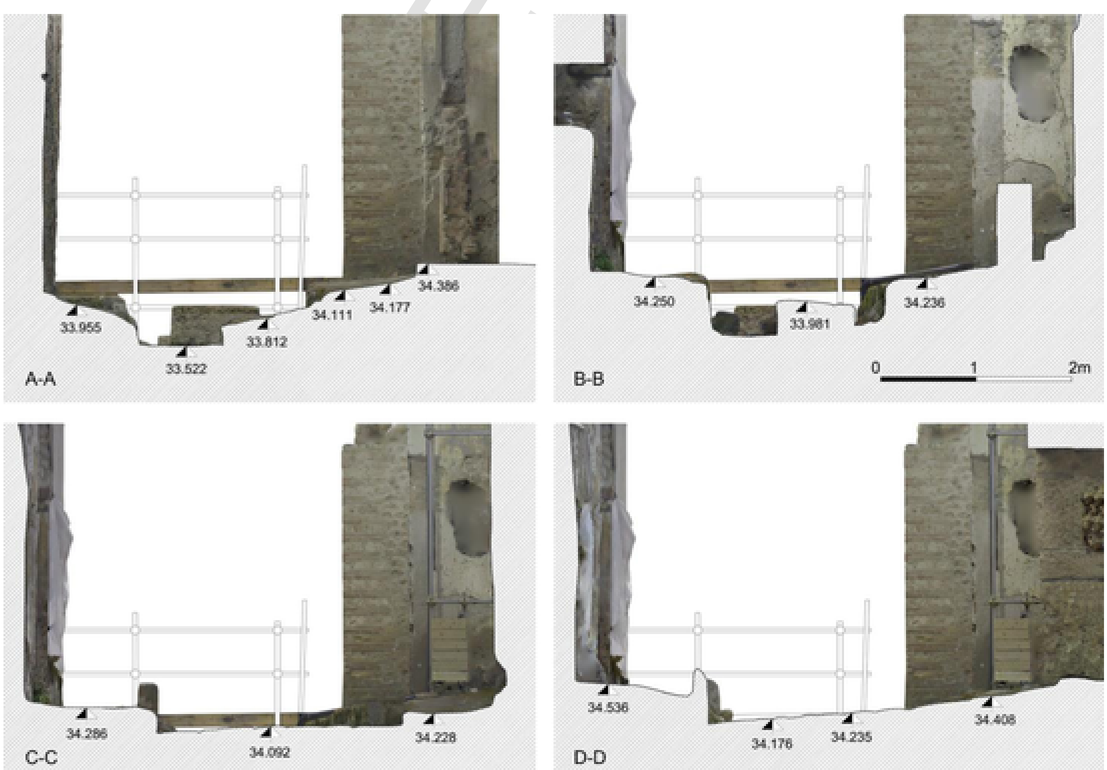


Fig. 5. Cross sections of vicolo dei Balconi (reported in Fig. 2).

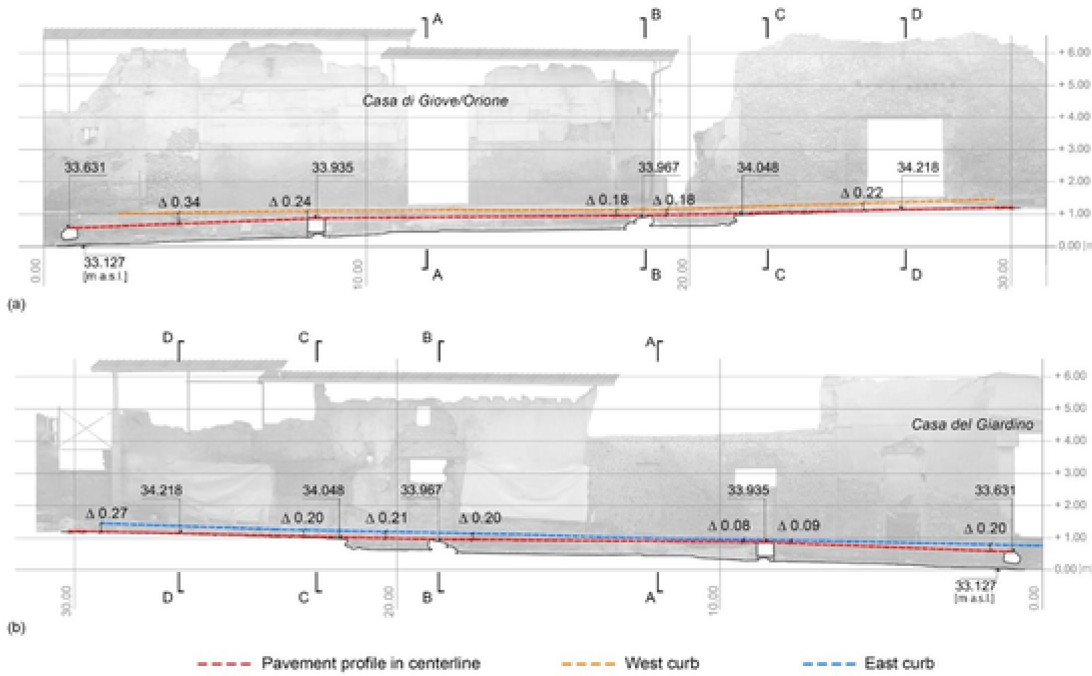


Fig. 6. Curb and pavement longitudinal profile: west (a) and east (b) side.

etrometric and a deflectometric test. Specifically, four survey points were identified: two suitable locations were selected between the last laid paving stones and the first prismatic stone block (constructive target or temporary stepping stone) and the other two downstream (south direction) of this monolithic element (Fig. 7).

In situ penetration tests are widely used in geotechnical, foundation, road and railroad substructure engineering for site investigation in support of structural analysis and design study [24]. Among the available equipment, the dynamic cone penetrometer (DCP) was adopted in this study (Fig. 8a). It consists of a 16 mm diameter steel drive rod with a replaceable cone tip having an included angle of 60° and a diameter at the base of 20 mm, an 8 kg hammer, a couple assembly and a handle (Fig. 8b). The test is performed by releasing the hammer from a selected drop height (575 mm) and measuring the cone penetration depth per blow. The slope of the curve, which displays the relationship between the penetration depth and the blows number define the dynamic cone penetration index (DCPI) in mm/blow.

By way of example, the trend of penetration depth versus the number of blows referred to the position 2 is shown in Fig. 9. The layers' thickness as well as the slope of the lines representing the DCPI can be determined by interpolating the measured data with linear regressions. Several correlations that link the DCPI with various pavement design parameters, including California Bearing Ratio (CBR), shear strength or elastic, resilient and back-calculated modulus, are actually available. The material type of each pavement layer was determined using the correlation $CBR = \frac{292}{DCPI^{1.12}}$ (ASTM D6951/D6951M–18 standard), with the exception of L_0 (lean clay soil) for which the relationship $CBR = \frac{1}{(0.017019\ DCPI)^2}$ was adopted. The most superficial part of the analyzed area (L_0 layer in Fig. 9) consists of organic soil, which is justified by the fact that the paving interruption has created a step which is now a receptacle for earthy materials carried by rainwater. The material type that composes the various layers was estimated analyzing the CBR values derived from the Unified Soil Classification System (USCS) [25]. The L_1 layer (thickness of about 145 mm) probably consists of well graded (GW) or silty sandy gravel (GM). The L_2 is possibly composed of uniformly gravelly sand (SW) or clayey sand (SC), without having how-

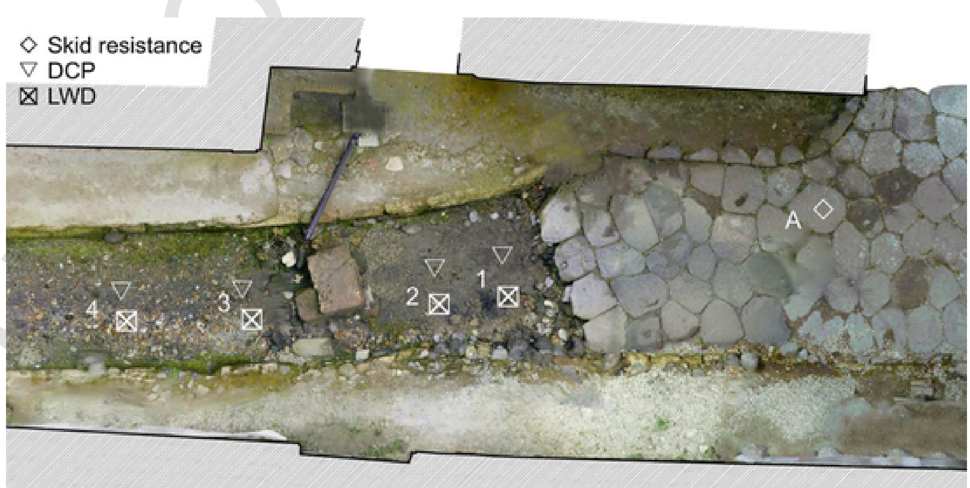


Fig. 7. Positioning of survey points.

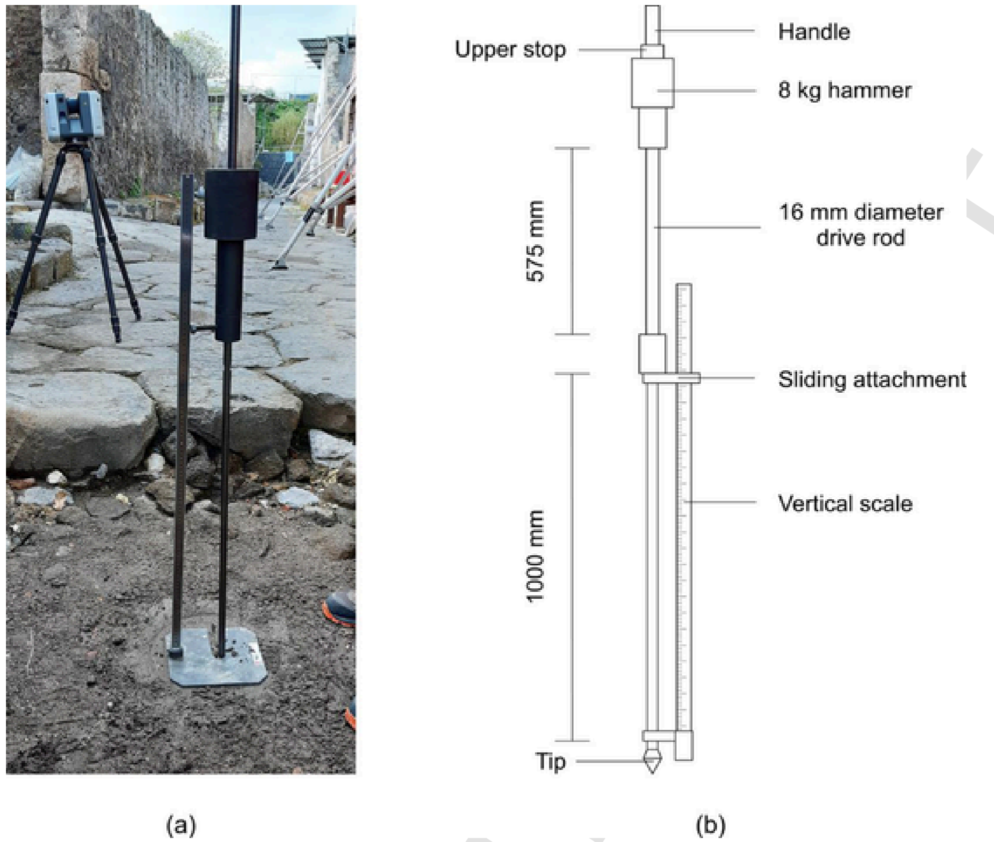


Fig. 8. Dynamic cone penetration test.

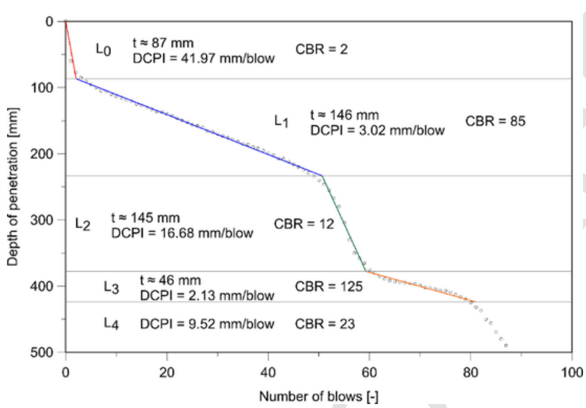


Fig. 9. Penetration depth vs number of blow at point 2.

ever at the moment any possibility of exact and detailed confirmation weather this is its true nature or represents the deposit of debris derived from anthropogenic interventions. The third layer (L_3) could again consists of well graded gravel (GW) of high consistency; the operator/author, according to his feeling, does not exclude the possibility that this material may have a weak bound structure due to presence of hydraulic binder or have developed heat-induced bonding. Given the decision shared with the archaeologists of the Superintendence to limit at present the number of tests and their depth (~500 mm) in this area of the Regio V, few considerations and assumptions on the L_4 layer, which however seems similar to L_2, can be drawn.

Besides, light weight deflectrometer (LWD) test, also known as light falling weight deflectometer or dynamic plate load test, was performed. It is a portable device, light enough to be moved and operated by one person, which is used to measure the in-situ modulus of subgrade and unbound pavement layers [26,27]. In LWD a mass is dropped from a certain height generating a load impulse; the force is transmitted to the ground through a circular plate. The applied loads are measured by a load cell while the surface deflections at the center of the plate are measured by a geophone or accelerometer. A Dynatest 3031 portable light weight deflectometer was used in this investigation (Fig. 10a). A mass of 10 kg was dropped from 84 cm generating a load impulse; the fall height has been chosen so as to have a stress level of about 100 kPa. The force is transmitted to the ground through a circular plate having a diameter of 300 mm. The applied loads are measured by a load cell while the surface deflections at the center of the plate are measured by a geophone. In addition to the central device, the instrument was equipped with two additional geophones capable of determining the deflections at 350 and 550 mm from the center of the plate. The surface modulus (E_0) was estimated using the Boussinesq elastic half-space theory $E_0 = \frac{f(1-\nu^2)\sigma_0 a}{d_0}$ in which f is the factor for stress distribution (2 for uniform distributions and π/2 for the rigid case), ν is the Poisson's ratio, σ_0 is the stress under the plate, a is the radius of the plate and d_0 is the central deflection. Fig. 10 shows the test set-up, the geometry of the instrument with the falling weight and the loading plate and the different orientations of the three geophones (one of which is on axis with the point of fall) with the responses in terms of deflections deduced from the acceleration measurements.

Combining the deflection responses measured with the LWD test and the layer thicknesses estimated from the DCP findings, a back-analysis procedure was applied to determine the subgrade material stiffness. The most significant course in the considered section is L_1 (due to its consistency and thickness inferred from the DCP test). Thus, a three-layer pavement structure has been assumed in the analysis. The first layer corresponds to L_0, the second one to L_1 while the third one (L_S) is composed by a system formed by L_2, L_3 and L_4 layers. The latter assumption turns out to be simplified but at the same time more correct, since L_3 is configured as a thin (46 mm) interlayer within in a thick soil

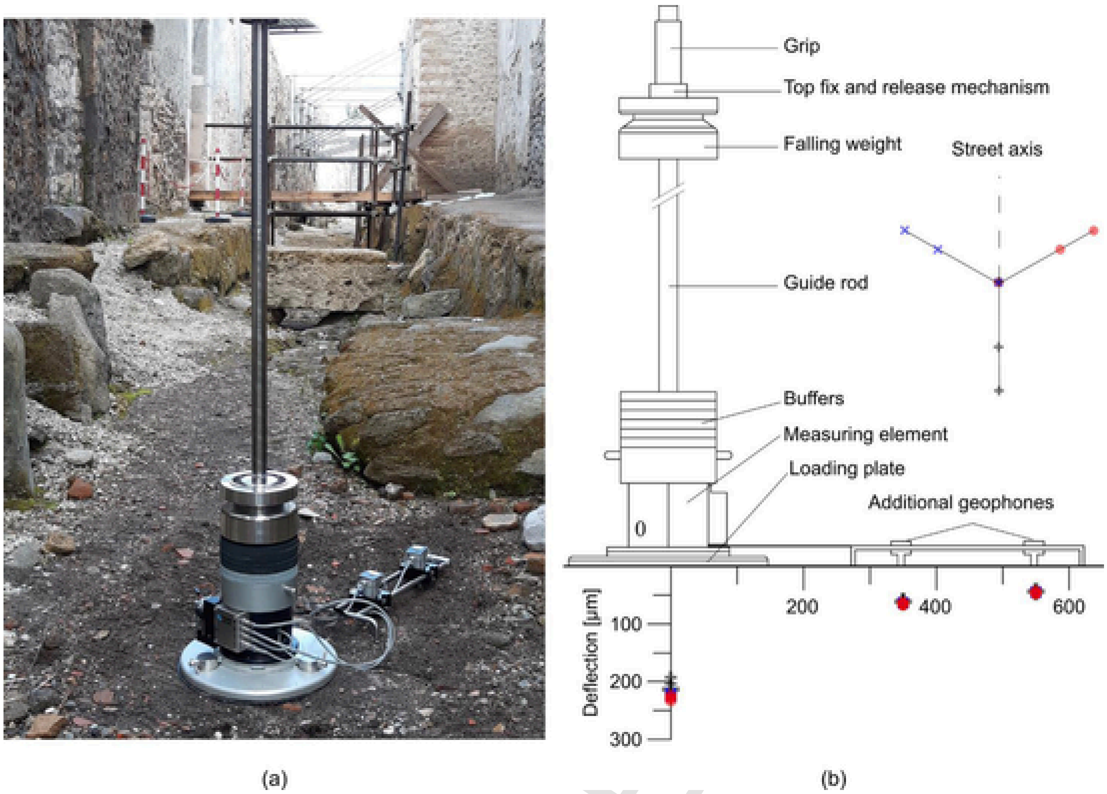


Fig. 10. Light weight deflectometer test: Experimental setup (a) and deflectometric results at point 2 (b).

course (L_2 and L_4) that exhibits uniform strength (similar slope in the penetration depth vs number of blows graph). The back-analysis results referred to the survey point 2 are represented in the Table 1. L_0 is difficult to interpret since, as already stated above, it is rich of earthy materials most likely unrelated to the subgrade structure carried by rainwater. A comparison with the elastic modulus values calculated from LWD test and those derived from the DCP test measurements was performed. Specifically, the CBR data were related to the stiffness modulus (E_{CBR}), also known in the literature as resilient or elastic modulus [28,29], according to the Eq. (1) suggested by the Transportation and Road Research Laboratory [30]:

$$E_{CBR} = 17.6\ CBR^{0.64} \tag{1}$$

The CBR of L_1 layer (Fig. 9) was directly used, while the equivalent CBR of L_S was obtained starting from the weighted average (over each layer thickness) of the three DCPI values (Table 1).

Both methods used in roadway and geotechnical applications have provided very similar information for determining the type and stiffness of subgrade material.

7. Conclusions

The extraordinary emotions produced by the discoveries of well-preserved buildings and their magnificent decorations at the vicolo dei Balconi may overshadow what, in a more complex deductive and interpretative key, has itself a great value in pavement engineering. The stopping of the street paving activity, which have led to the installation of newly laid and undisturbed paving stones never opened to traffic, allows to photograph a rather rare situation, if not unique, which is extremely interesting to further understand some of the design and construction techniques used by the Romans at Pompeii.

The use, for the first time, of light minimally intrusive (dynamic cone penetrometer) or non-destructive (terrestrial laser scanner, British pendulum tester, light weight deflectometer) surveying techniques derived from methodologies currently adopted for the monitoring of modern road pavements offers an original contribution to the great field of study and scientific research. These technical procedures have allowed to describe some functional aspects of the paved surface (skid/slip resistance and surface texture of flagstones) and to formulate hypotheses about the consistency and structure of the layers below. The reading of the flagstones macro-texture (close range photogrammetry) highlighted the missing or not significant effect of traffic in vicolo dei Balconi compared to vicolo delle Nozze d'Argento, with similarities that suggests a constructive temporal continuity with the paving of the western parallel vicolo di Cecilio Giocondo. This circumstance can possibly be interpreted in the perspective of urban re-development interventions that could be involving the streets of the Regio V in the period preceding the volcanic eruption of 79 AD. In a wider reading, a succession of paving works (and not repaving) using lava stone elements of the northern lateral alleys of via di Nola starting from via del Vesuvio (from west to east) is recognizable. This assumption is based on the typological analogy between the new laid stone pavement of vicolo dei Balconi and that of vicolo di Cecilio Giocondo and the conformation of the stabilized rammed earth path of the subsequent eastern parallel vicolo di Lucrezio Frontone. The analysis of the relationships between the built-up area and the street construction site can be mutually interpreted according to the lines of the existing curbs, the thresholds of access to the dwellings and the placement of enigmatic prismatic blocks arranged in trenches, probably intended as a useful target points for the stonemasons or temporary pedestrian passage. The subgrade of vicolo dei Balconi, that was intended to be covered by the paving stones, is struc-

Table 1
Elastic modulus of subgrade: comparison between LWD and DCP tests (survey point 2).

Layer	E (back analysis) [MPa]	E_{CBR} (TRRL [30]) [MPa]
L_1	300	301
L_S	100	111

turally traceable to the sediment of an existing earthen path or an old *glaera*. The thin interlayer, inferred from the DPC findings, can be currently read as a hard crust of an older pavement/substrate or an in situ soil densification by thermal or mechanical actions or perhaps more likely due to the presence of hydraulic binders. Performing a deeper investigation through micro-coring or small excavation combined with sampling of the removed material could assist to verify the correctness of these interpretative readings.

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