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THE CASE OF THE KILLER "BUBBOLA"

One of the issues which remained unresolved during the latest meeting in Ravello, specifically concerned with questions raised following the visit to Calitri, was that of how to define certain architectural episodes and building processes in relation to their vulnerability to earthquakes. I myself considered a question of substance: how vulnerable to earthquakes were architectural models devised in non-earthquake areas (or without regard for the earthquake risk) and then transferred to areas which did have an earthquake risk? I think I can begin to answer this using an object I picked up in the castle in Calitri: a "bubbola" or "carusiello" (the term more commonly used in Campania). This is a lump of terracotta, with a single hole for firing, used as a rule for ceiling vaults. Several people died when the roof vault of a church in Calitri made from these "bubbole" collapsed after the 1980 earthquake. The cylindrical form of the Calitri "bubbola" suggests to me that this very special material might be responsible for the collapse, or at least a contributory factor.

The use of hollow clay materials for the construction of strong but light roofs goes back to the classical tradition. I think the most famous example of it is the cupola of the Pantheon. The method itself is too widespread and too tried and tested to be open to question. I did, however, have the chance to verify its capabilities directly (which is not, of course, easy).

In Calabria, Crotone to be precise, I saw that in a vault made of this same material the "bubbole" were not cylindrical but slightly tapered and longer than those in Calitri. So why this use of similar materials but with a different shape?

The way in which these two types of "bubbole" were used was probably not fundamentally different. They were placed on the arches in parallel, staggered rows. The interstices caused by their circular form (cylinder or cone) were filled with liquid mortar. Once the centering was removed the structure could support considerable loads and cover extremely large spaces. The procedure is not radically different from that used in the stone vaults of antiquity. The result is a combination of extreme lightness and strength.

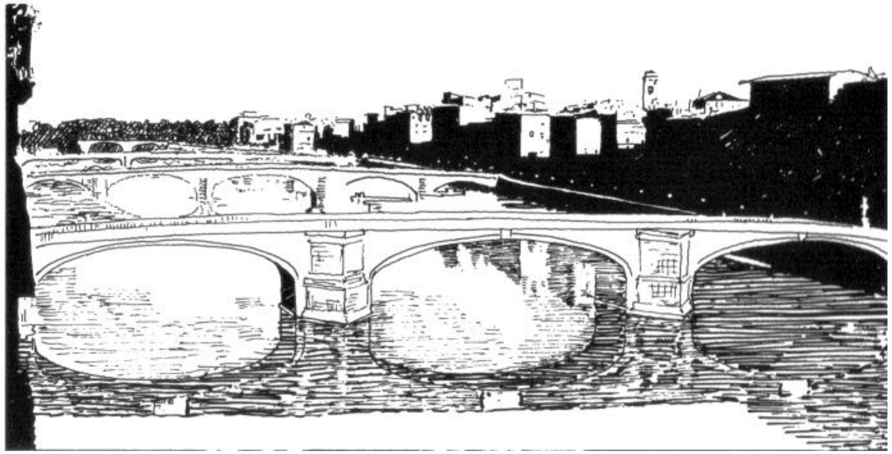
In this case the mortar merely fills the empty gaps, whilst the resistance to compression (and thus to load) is provided by the mass of "bubbole" pressing one against the other. This means that the importance of the quality of the mortar and its resistance to external agents is only relative as regards maintaining the static equilibrium. That may change, however, if the structure is subjected to compression stresses (slow upthrust, or sudden events like an earthquake), when the form of the "bubbola" (cylinder or cone) becomes critical.

The result differs firstly in terms of the shape of the vault. The Calabrian "bubbola" has a shape which effectively dictates the curve of the vault.

Its conical shape imposes a semi-circular or only slightly surbased arch. The section of the vault is thus modeled by the "bubbola" itself.

The cylindrical "bubbola", however, has a (geometrical) limit of alignment on a plane surface. This means that it allows all kinds of curves, by varying the angle of convergence between one "bubbola" and the next. This is a system which has been widely tested in other types of construction, shaping arches with whole bricks laid on edge. In this case the quality of the mortar used is important, because it is this which determines the behaviour of the thicknesses which maintain the tension of the arch. If the mortar cannot withstand the compression and crumbles for any reason, the structure's static base is compromised. It should be said, though, that certain types of vault, such as the polycentric vault, virtually have to use the cylindrical "bubbola".

A propos of the polycentric arch or vault, I will quote as an example the Holy Trinity Bridge of Bartolomeo Ammannati in Florence (1567-70), which is a famous example, if not the prototype, of this feature. It will be seen that the polycentric arch has a twofold advantage. It is lower than the semi-circular arch because the radius of its curve is longer in the central part, so that it can have a wider span without being too high, which is important for a bridge. Moreover, compared to a surbased arch, the lateral thrust on it is less, due to the very short curve radius at the two ends at the top of the imposts, because the structure reacts like a semi-circular arch. In a bridge the latter characteristic is not too



important, given the powerful counter-thrust exerted on its abutments, but it is most important in a building.

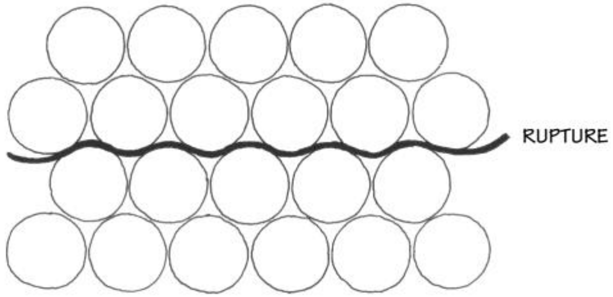
This type of arch is regularly found replacing the segmental arch, especially from the 17th century onwards, when passageways had to be covered without raising the floors (e.g. entrances to craftsmen's shops, carriage entrances, etc.). Inside, the polycentric section allows load-bearing vaults to be built without losing too much ceiling clearance. Its preferred use is as a false ceiling since it lends itself well to decoration.

But back to our subject. For the reasons I have briefly outlined, the polycentric arch was widespread for at least three centuries, because of its robustness. But the cultural context in which it evolved does not lead us to suppose that it was adopted purely for reasons of earthquake resistance. So let us say that it is part of the general history of architecture, and leave it at that.

In areas where a polycentric section is used in conjunction with a traditional material such as the "carusiello", this allows the construction of very light and very strong load-bearing roof vaults with a markedly surbased section. However, for the reasons stated above, it means that the cylindrical "bubbola" must perforce be used in preference to the conical one. The (variable) curve of the vault will thus entirely depend not on the shape of the "bubbola" but on the mortar thicknesses between one cylinder and the next.

There are of course several types of mortar, just as there are different ways of mixing it and more than one type of "bubbola".

But in general the mortar with the greatest tensile and compressive strength is clay-based. At the points where the cylinders touch, the mortar is far thinner, to the point of being virtually non-existent, at least at the lower end. This causes a kind of original rupture line which follows the line of the joins.

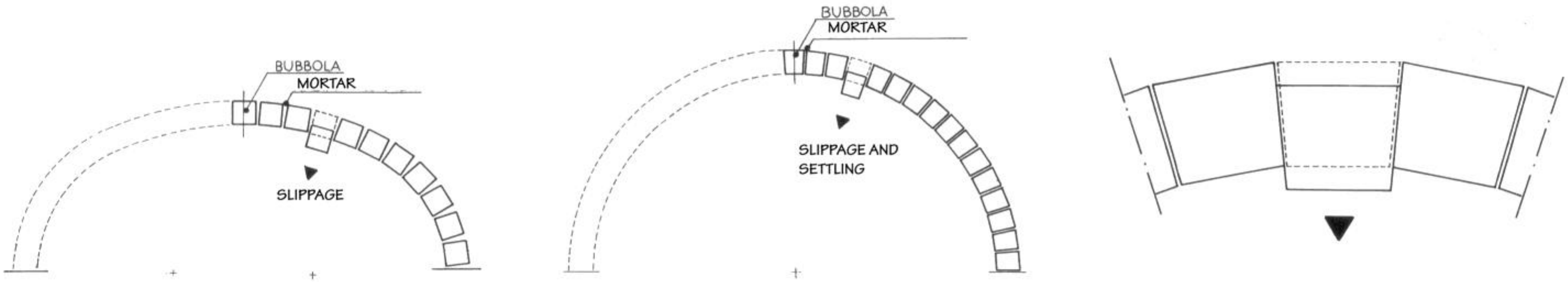


This break may appear when the load-bearing walls move apart as a result of slow upthrust by the masonry or (of direct concern to us here) of the so-called "artichoke effect" in the event of an earthquake. This effect may be aggravated by the presence of a structure which exerts thrust, such as a vault. Mortar is a friable material. During the inevitable downward slippage of weights which occurs when walls move apart, mortar joins break down and the equilibrium of the structure is destroyed. The counter-thrust which comes into play during this episode makes the crumbling worse rather than preventing it.

As I said before, the "bubbola" has greater tensile and compressive strength and does not crumble, except under extreme stress. However, in this case the cylindrical "bubbola" behaves in a neutral manner, because the static equilibrium of the vault depends solely on how the layers of mortar are arranged. Consequently it cannot stop it from collapsing when the mortar starts to crumble.

The same is not true of the conical "bubbola". One can imagine that any downward slippage may, in this case, resettle at a different level because of the resistance offered by the "bubbola" which, given its shape, reacts like a wedge. It is possible, in an earthquake, that a rearrangement of this kind (albeit temporary and very unstable) may save the structure from immediate collapse.

I do not mean to say by this that the collapse of the church roof in Calitri was



necessarily due to the cylindrical shape of the "carusielli" used in it. If anyone were to postulate that theory I would probably be the first to recommend a degree of caution. I have used this comparison of the two "bubbole" as my starting point for a more general exposé of ideas which may stimulate us to approach our systematic analysis of the historical documentation we are currently examining from an angle which I outline below.

The question raised at the previous meeting and left partially unresolved was the degree of vulnerability of buildings exposed to the risk of earthquakes. I am considering not individual buildings, but architecture as a whole. Ultimately the question is this: where should protection begin when there is a major risk of collapse? Or conversely, which kind of construction offers the best chance of withstanding an earthquake and thus deserves to be preserved unchanged?

Our two types of "bubbola" (from Calabria and Avellino) can be regarded as illustrative of two different situations. The cylindrical "bubbola" is, in our considered opinion, the result of an architectural culture which was widespread but certainly not dictated by seismic considerations. The conical "bubbola", however, may be evidence of a culture which was aware of the earthquake risk and thus gave preference to a building material which was already familiar rather than to newer and more functional solutions (polycentric section).

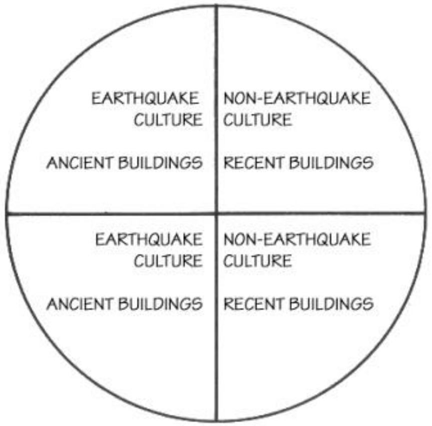
So we can speak (still broadly) of the Calabrian "bubbola" as reflecting an "earthquake culture" and that of Avellino as reflecting a "non-earthquake culture". This distinction leads us to two types of consideration which we shall compare with another distinction with which we concerned ourselves at our last meeting.

We said on that occasion that time operates a kind of natural selection, especially in the case of vernacular architecture. Where earthquakes are endemic, that is to say where they are a fact of life for the population, a system of action and reaction develops which is readily identifiable in ordinary housing, which receives more frequent renovation than larger and grander buildings. In effect, an earthquake puts the various methods of construction directly to the test. Those methods which prove their worth are adopted for use in new building work, whilst the others disappear naturally or are replaced in older buildings by the tried and tested methods. Thus old buildings are themselves proof of their ability to withstand earthquakes and thus of an earthquake culture.

This reasoning can also be applied to the choice of sites. If they could avoid it, people did not rebuild in places where the earthquake had been particularly devastating, but moved elsewhere. Calitri is an example of this, because the unstable zone remained unbuilt on until recently. The case of San Lorenzello and Cerreto Sannita is even more significant: the one was damaged but inhabitable, whilst the other, three kilometres away, was destroyed by the 1688 earthquake altogether. It thus makes sense that one village is still on its original site whilst the other was moved to an area theoretically safer from these dangers. And there is no dearth in earthquake zones of cases of whole villages moving away.

In short, the survival of old buildings is proof enough of their resistance.

Construction forms, methods and materials and the sites chosen for construction are factors worthy of consideration in any research on earthquake safety. One might add that the natural selection I alluded to earlier is important because it is not theoretical and general, but specific and verifiable. It applies to any building anywhere and thus fills in the gaps left when we discuss the difference between transmission of seismic waves through the ground at the surface and at depth.

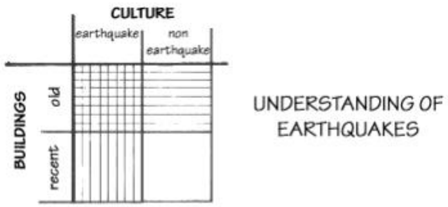


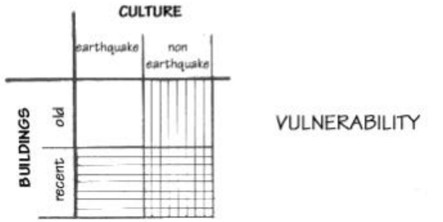
If we juxtapose the binomials of "old buildings/recent buildings" and "earthquake culture/non-earthquake culture", we get four sections which answer the two questions we were asking: where is the level of vulnerability greatest? And, conversely, where should we concentrate our protective endeavours in order to preserve existing evidence of local knowledge of earthquake resistance?

This diagram suggests that recent buildings reflecting a non-earthquake culture constitute the greatest risk (and are thus most in need of protective measures), whilst older buildings belonging to an earthquake culture require the utmost attention to preserve them because they provide us with valuable information. Supposing that there is a basis of truth to this diagram it may be used to define criteria which can answer another question: given this plethora of problems, where should we begin?

But the diagram is not enough. It should be said straight away, in order not to raise false hopes, that it is not easy at this stage of our research to identify and pick out values with which to validate the model presented here. Italy, in particular is lacking in an archaeological tradition that operates without predetermined goals.

When archaeology is primarily or even exclusively "classical" there are no systematic studies which allow us to analyse, in the same terms, buildings which are different and which have attracted interest of a different kind and often on a different scale. It will take at least two centuries of research to bring studies of vernacular architecture to the same level as those of "grand" architecture.





Even today, vernacular architecture remains the poor relation in treatises on the history of architecture. But in the absence of any significant literature on the subject and archives of descriptive sources, it can only be studied using the archaeological approach. In a country like Italy, where most of the digging is done by "treasure-hunters" rather than archaeologists, it is easy to see why the idea that all vernacular architecture should be included under the umbrella of archaeological research is wishful thinking to say the least. And yet it would appear that this is the direction which will have to be followed if we want precise and reliable results.

Eco-historical research is fundamental because the history of human settlements, studied over a long period, helps to determine which types of ground, which structures, which types of architecture have proved their worth in withstanding earthquakes in their region.

But when we embark on a study of the reasons for this phenomenon, it is not enough just to look at the general history of architecture, construction methods and architectural forms. We also have to study the materials which were used, one by one, where they came from, the purpose for which buildings were designed, how they were altered and especially how they were altered for the worse: credible results can be obtained from this if we use an archaeological method which is applied on a large scale but is nevertheless rigorous.

And we should not forget that this approach is essential to anyone concerned with seismic risk. The choice of values traditional in classical archaeology cannot be applied to the research work which we have in mind.

ì If I may conclude with a little joke which will, I hope, convince some of my archaeologist friends and colleagues who are a little reluctant to extend the traditional frontiers of their discipline, I would add that if an earthquake strikes a region it is very unlikely to adhere to the selection criteria of Johann Joachim Winckelmann!