NONDESTRUCTIVE TEST FOR STRUCTURAL REHABILITATION. THE CASES OF DEVIL'S AND S. DONATO'S MASONRY BRIDGES IN VENICE

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Abstract: As much known the use of nondestructive test as a methodology to better understand the technical choices more opportune in the field of structural reinforcement and restoration, represents by now a good way for monument and historical manufactured.
This research shows the first results on non destructive tests carried out on two masonry bridges in venetian islands Torcello and Murano, named respectively Devil's bridge and realised approximately in XII century, and S. Donato bridge's, in the XVII century. For both bridges nondestructive test (NDT) connected to destructive test (DT) to evaluate the compressive strength of the brick and the homogeneity/compactness of the masonry has been realised.

Introduction: The aim of this research regards the evaluation of mechanical characteristics of masonry (brick and mortar) and its homogeneity in the cases of two historical masonry bridge situated in venetian islands Torcello and Murano.
For both type of structures named respectively Devil's (in Torcello) and S. Donato's (in Murano) bridge this study shows the first results on non destructive test carried out to evaluate the structural behaviour. In both case we have the arch static scheme, the test has been ordered from venetian municipality in view of the structural restoration with appropriate reinforcement or employment of the new material with the same mechanical characteristics.
For NDT the penetrometer to measure the energy released per each hole in the masonry and the Fourier analysis setup were employed; the first instrument gives results on mechanical performance of mortar and brick (also with DT to deduce the curve of calibration between DT and NDT results); with Fourier setup (sonic test type) the information on the homogeneity of the masonry and on the possible presence of empty inside were expected.
Also the endoscopy has been utilised in critical cross sections of masonry vaults, to understand the effective stratigraphy of structure.
For a structural view point, the study also give prominence to the interaction between the geometry of the structure and the mechanical characteristics of masonry, especially in the case which the structure is very old and the materials (masonry and brick) show low values of mechanical performance.
The type of test employed - sonic test - is by now one of more reliable choice to understand in situ the effective performance of structure without destructive test, (1), (2), especially in presence of historical monument/structure, (3), (4), this not only for global performance of masonry but also for the mechanical characteristics of the materials, (5), (6). Besides many works already available in literature give some information of this non destructive procedure, (7), (8).
For each bridge the research shows also the crack pattern, the presence of local damage and the general situation for static view point, with the evaluation of effective stiffness degree of boundary condition. The research shows the first results with Fourier analysis device sonic test. Figure 1, 2 shows the dimensions, geometry, material and one view for S. Donato Bridge; figure 3, 4 shows the same thing for Devil bridge. Figure 5 and 6 illustrate for both bridges the crack pattern with presence of local damage.

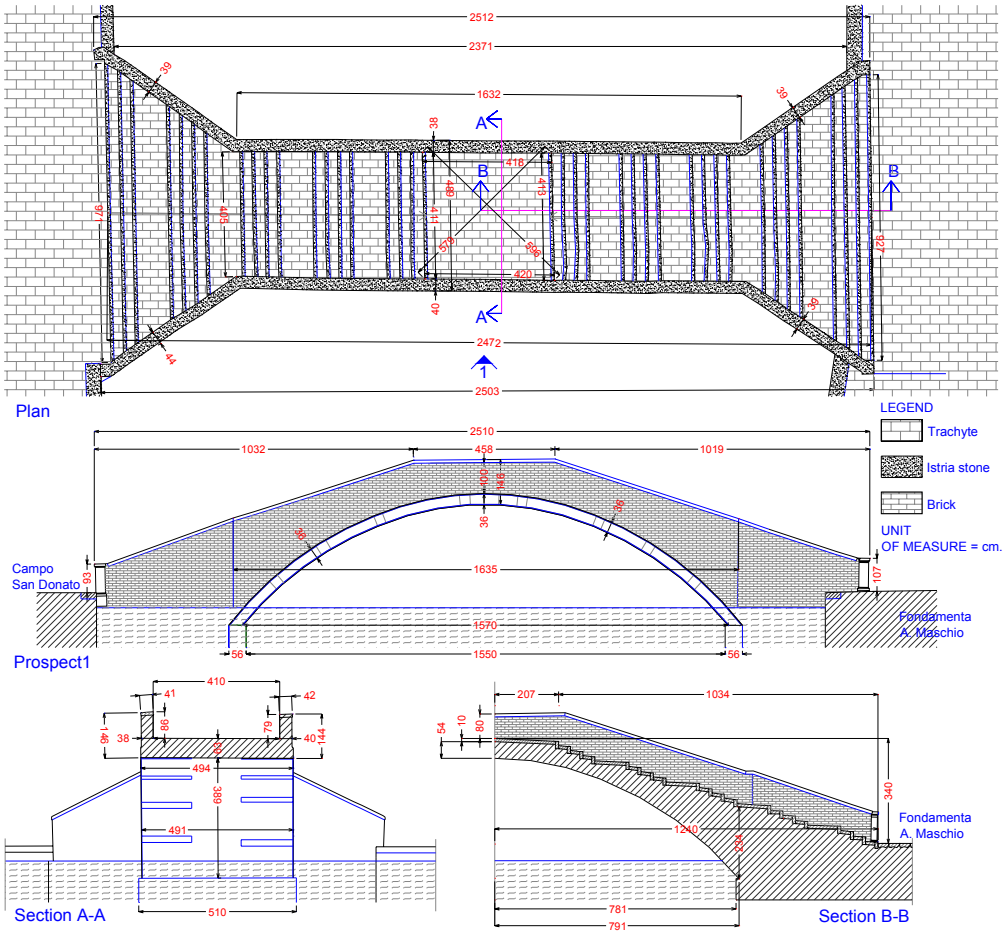

Figure 1 - plan, sections, prospect 1

Figure 2 - view SOUTH

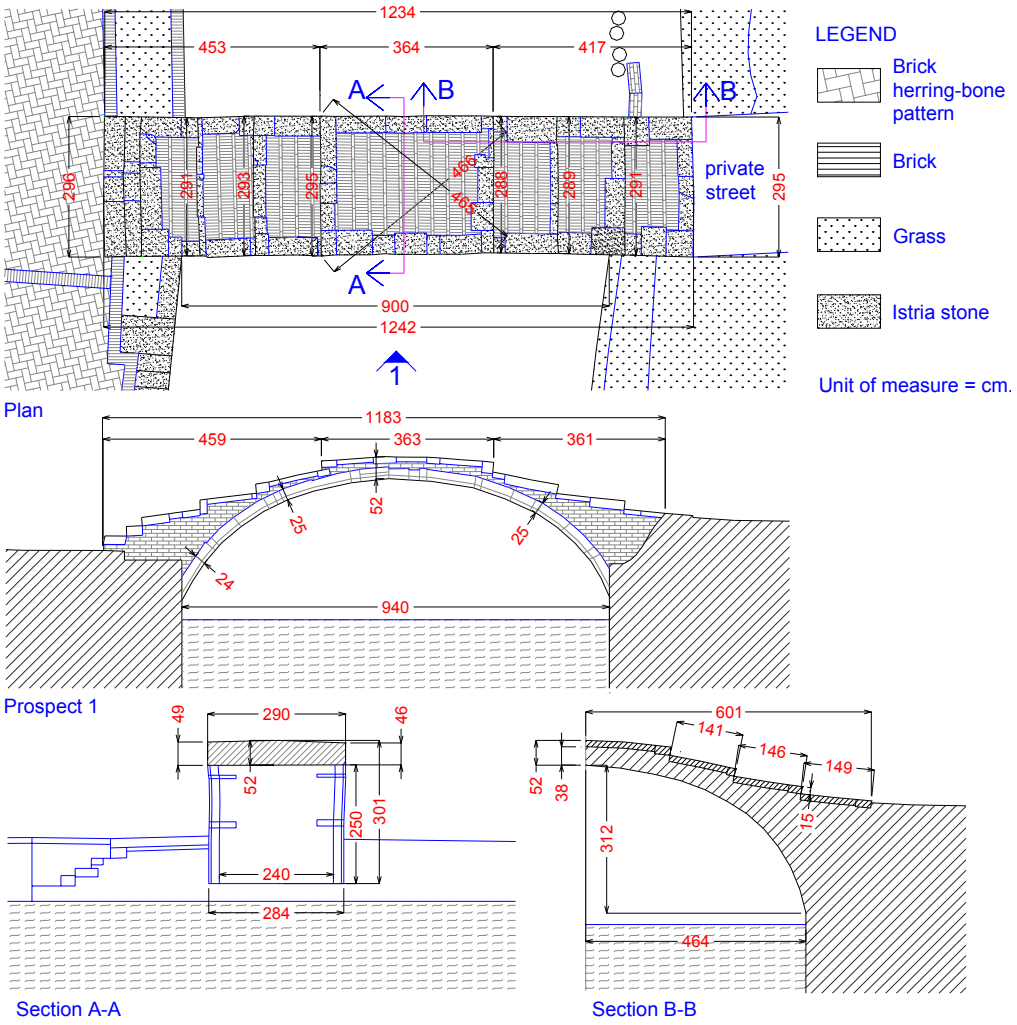

Figure 3 - plan, sections, prospect 1

Figure 4 - view WEST

Figure 5 – Detail of local damage of Devil bridge

Figure 6 – Detail of local damage of S. Donato bridge

Results: The Fourier analysis device gives many information on velocity of sonic wave induced by hammer and measured through the masonry by accelerometer. In this way by Fourier's series and fast Fourier transform algoritm the is also possible to determine the frequency and thus the energy dissipated, see respectively equation (1) and (2), (3).

$$F(t) = a_0 + \Sigma_{(n=1 \text{ to inf.})}[a_n \cos n\omega t + b_n \sin n\omega t] \qquad (1)$$

with,
$F(t)$ = periodic function
$\omega = 2\pi/T$ = frequency
T= period of function
a_0, a_n, b_n = Fourier coefficients

and for fast Fourier transform we have

$$A(k) = \Sigma_{(n=0 \text{ to } N-1)}\, D(n)\, e^{-j2\pi nk/N} \qquad (2)$$

with the associated inverse equal to

$$D(n) = \Sigma_{(k=0 \text{ to } N-1)}\, A(k)\, e^{+j2\pi nk/N} \qquad (3)$$

with,
n,k = dimensionless indices, 'n' refers to time increments, 'k' to frequency increments

In the case of Devil's bridge the dynamic identification is very interesting because there is not the parapets (see Figure 4) and consequently the evaluation of static and homogeneity of the masonry vault deck is not influenced by the presence of the other structural elements.
Figures 7 and 8 show respectively the distance-velocity and the energy dissipated-velocity diagrams for Devil's bridge. Tables 1 and 2 show in both axis x-y the velocity of sonic wave and the percentage of energy released.

Distance (cm)	**Time to wave sonic transit** (μs)	**Velocity** (m/sec)	**Energy retained (%)**	**Energy Released (%)**
860	19360	440	0.041	99.96
860	14120	610	0.098	99.90

Table 1- Devil's Bridge. Sonic test on the total longitudinal axis (y)

Point	**Transversal dimension of bridge** (cm)	**Time to wave sonic transit** (μs)	**Velocity** (m/sec)	**Energy retained (%)**	**Energy Released(%)**
1	200	6697,5	300	0.35	99.6
2	/	6717,5	300	0.26	99.7
3	/	6277,0	320	0.35	99.6
4	/	6017,4	330	0.35	99.6
5	/	4717,7	420	0.34	99.7
6	/	6700,0	300	0.74	99.2
7	/	6777,0	300	0.37	99.6
8	/	5797,6	340	0.41	99.6
9	/	5582,5	360	0.47	99.5
10	/	5017,5	400	0.64	99.3
11	/	3597,5	550	0.35	99.6
12	/	5057,0	400	0.31	99.7
13	/	5217,5	380	0.36	99.6

Table 2- Devil's Bridge. Sonic test on the longitudinal axis (x)

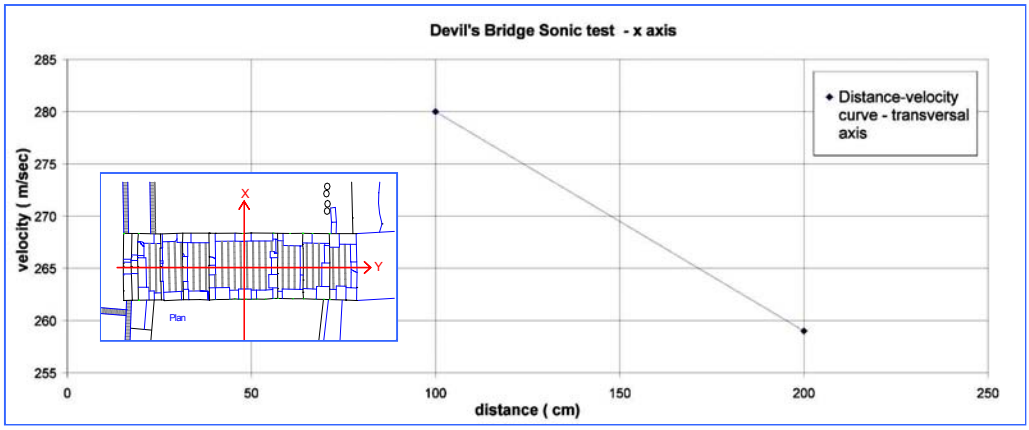

Figure 7 – Devil's Bridge Sonic test – x axis

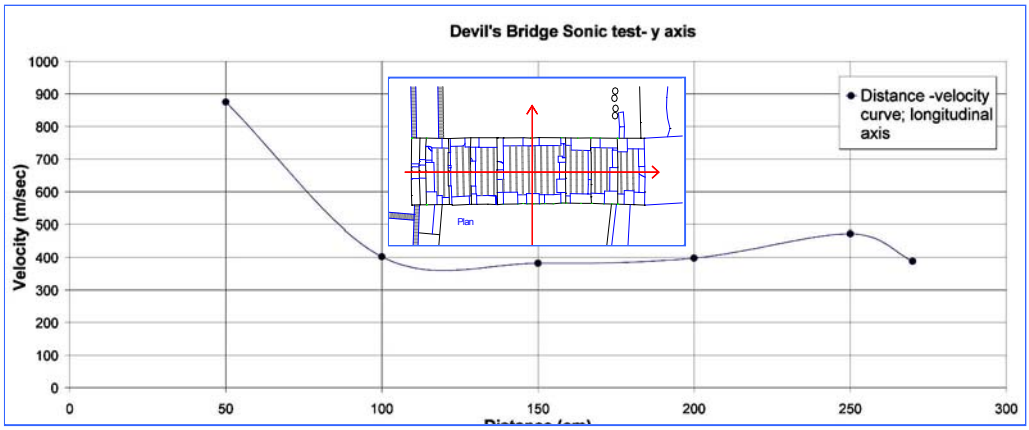

Figure 8 – Devil's Bridge Sonic test – y axis

Conclusions: The main findings of this study, for the Devil's bridge, are summarized as follows:
a) the level of velocity sonic wave came approximately from 400 to 600 m/sec and is strongly lower than the average value for a good quality masonry (even if old) that came from 1800 to 2000 m/sec.;
b) the sonic wave velocity shows also that in the x direction the homogeneity of deck vault is lower than the y axis. This aspect is obviously influenced by the position of the brick and by the presence of cracks;
c) if we consider the very low value of thickness of the vault and the low level of homogeneity of the masonry, we can conclude that even if in presence of very old bridges and of the global deterioration of mechanical performance of masonry, the arch static scheme plays a very important rule for structural view point;
d) The results showed in Table 1 give prominence that along the total longitudinal length of the bridge the level of energy retained is almost null;
e) The results in Table 2 show the good quality of results (for statistically view point) in term of value of wave velocity, even if this value is strongly influenced by the presence of longitudinal cracks present in the vault.
f) Generally speaking, this research is still in progress, the next step will consider the calibration between NDT and DT for both bridges.

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