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Dynamic Behavior of a Historical Building

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Abstract Given the particular difficulty in classifying and defining the characteristics of the structural systems of historical buildings, especially when they are part of complex historical constructions, the vulnerability study efforts becomes significantly more difficult than the study of regular modern structural systems. Furthermore, old buildings may have been altered repeatedly over time, may be founded on older buildings that got buried over and could be connected one to the others. This will cause dynamic interactions with other buildings or sub-structures during an earthquake. Therefore, the particular architectural and structural history of each structure adds uncertainties in the assessment of its seismic vulnerability. In this paper the dynamic response of CEDRAV building, part of the historical centre of Cerreto di Spoleto (Italy), is analyzed, by means of the data recorded by several temporary deployments of velocimeters. The complexity in assessing seismic behavior of the historical built environments is pointed out and so the dynamic interaction with adjacent buildings.

Keywords: Historical building, cultural heritage, dynamic response, seismic behavior

Introduction

The structure of the CEDRAV building, in Cerreto di Spoleto, Italy, built in the 14th century and damaged during the Umbria-Marche 1997 seismic earthquake, is of stone masonry walls and is both horizontally and vertically irregular (Fig. 1). The geometric complexity, both in the plant and in elevation, has made impossible use automatic procedures to create the mesh model and a number of uncertainties have influenced the creation of the mathematical model (Clemente et al. 2007, Rinaldis et al. 2005). The original building suffered additions of several structures at different time. In fact a new part was added at the third level at the NE side, which consisted of a small church covered with a cross vault ceiling. Then two more buildings have been added: one rectangular building at the NE façade, composed by two rooms at second and third level, respectively, and one in the NW part, composed by one room at each level. Finally, CEDRAV is connected with a small masonry house, in its SW part. The connection was realized at the second and third levels, by means of a masonry arch and a floor, respectively, connected by means of masonry walls, which define a small room where the sensors were deployed. Recently, an elevator in the SW part of the Monastery has been built.

The Experimental Tests

As previously stated, a tool to have a first guess of the best sensors deployment is temporary array: velocimeters positioned as different configurations can be used. The configurations used to record the responses of CEDRAV building, using temporary deployment, are summarized in Table 1. For each configuration, different numbers of tests were carried out. Tests within any configuration are a function of the excitation system. For the purposes of this paper, it is enough to consider only data obtained using temporary deployments from tests in configurations 6 and 8 (Table 1). Furthermore, spectral analysis by means of power spectral density (PSD) and cross spectral density (CSD) analyses of recorded events and noise will be done to investigate the effectiveness of the arrays to recover the dynamic behavior of the CEDRAV building. Detailed analyses of the dynamic behavior of the building were carried out by using data from Configurations 1 and 2 (Rinaldis & al., 2004). As general remark, records at the top shows unusual long duration with particular low frequency content, not visible in the record on the basement, this is to be related to the closely-coupled torsional

-translational mode that causes beating phenomenon. Normally, such beating occurs when the system has low damping in addition to closely-coupled translational-torsional modes.

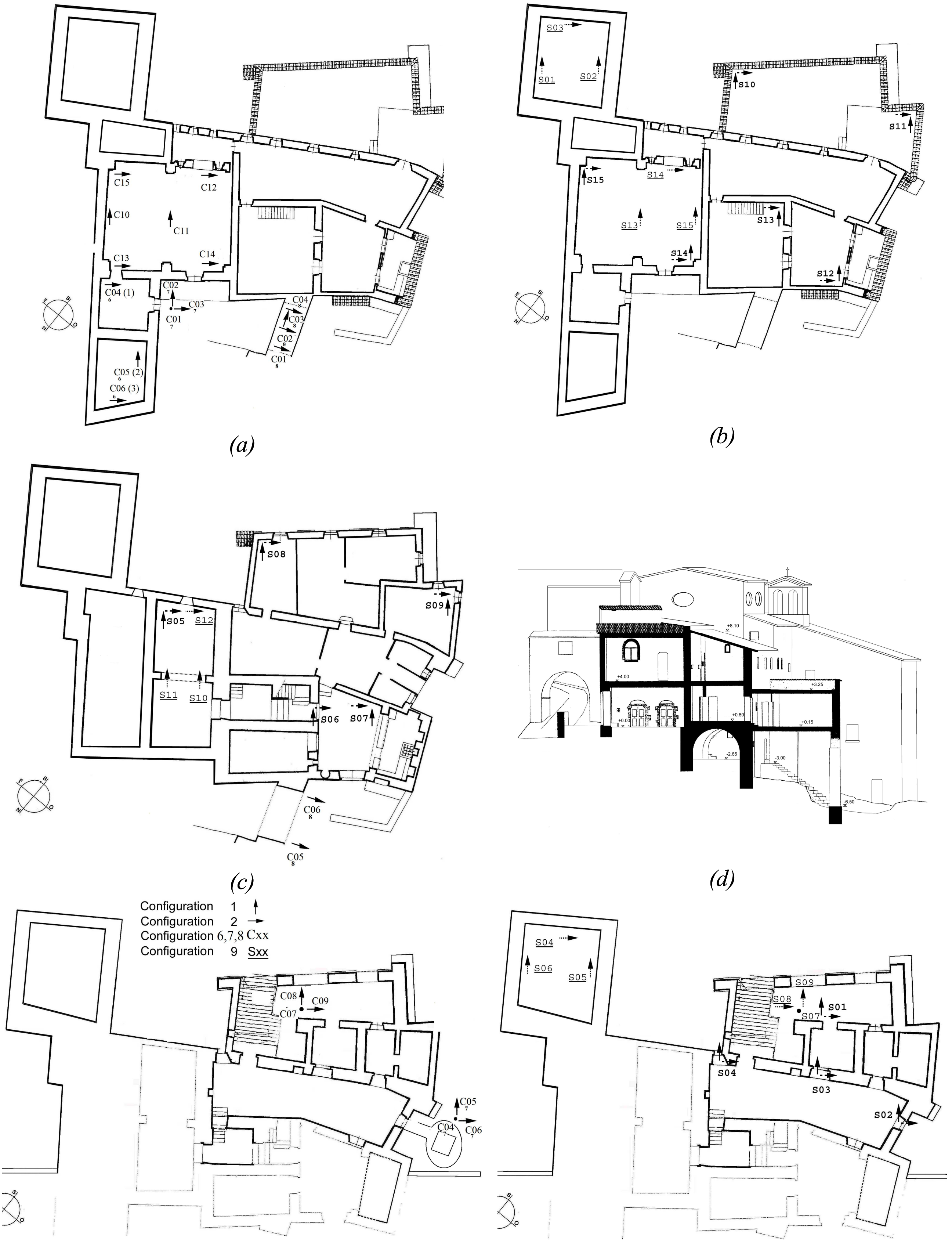


Figure 1: Sensor locations at level 3 (a-b), 2 (c) and 1 (e, f). () indicate position at the higher floor

Table 1: Temporary array: configurations and tests used in the analyses

Config.	*Note*	*Test Number*	*Input*
1	Only NS sensors in Fig. 1b-d are used	01÷05	Earthquake
		06	Ambient+Man-induced
		07	Ambient
2	Only EW sensors in Fig. 1b-d are used	08	Ambient
		09	Ambient +Man-induced
6	Sensors are on the floor of top level of the church and the neighbouring buildings	20	Earthquake
		21	Ambient
		22	Ambient +Man-induced
8		25	Ambient
		26	Ambient +Man-induced
		27÷34	Earthquake

Configuration 6. Configuration 6 has allowed the analysis of the interaction between the NE facade of the CEDRAV and the masonry building connected to the church. The interaction should involve the church as well and the building connected in the SE facade of CEDRAV. To simplify the analysis let's start to look at the time histories (TH), PSD and CSD of records of sensors deployed inside the above mentioned masonry building (Fig. 1a). Table 1 listed one recorded event only for this configuration (No. 20). TH show very small peaks, less than 0.04 mm/s, and very short durations (about 3-4 s, Fig. 2). PSD of recorded TH at all sensors (Figs. 2 and 3, S45W direction) in the attached building (first floor and basement) evidenced peaks at 6.2, 7.0 (very small), 8.0, 9.0 and 15.0 Hz, but the first one (6.2 Hz) is higher than the fourth one (9 Hz) in the sensors closer to the CEDRAV building (C01 and C04). Records from sensors far from the adjacent building show the opposite: peaks at 7.0 and 9.0 Hz are higher than peaks at 6.2 Hz. It is worth pointing out that PSD at sensors C15 (same wall as C13), C12 and C14 (far from the building in analysis) show peaks at 6.2 Hz higher than PSD of records of sensor C13, which is closer to C04. Then looking at the CSD (Fig. 4, C04-C06, C04-C13, C04-C15) it is possible to state that: peak at 6.2 Hz is associated to a mode involving the rectangular building motion and the church; the structure has its centre of rotation in level 2 with respect to a vertical axis positioned between C04 and C06. In fact sensors 04 and 06 are 150 degrees out of phase, and sensors C04-C13, C04-C15 and C13-C15 are in phase. If now comparison is made between PSD of C01, C03, C04 and C06, a common peak at 9.0 Hz is noticeable. Then CSD C01-C03 shows that this peak is associated to a torsional mode (180 degrees out of phase). This torsional mode is certainly due to the rectangular building since almost disappear in the C13-C15 CSD. Further analysis of records oriented S45E, seem to state that contribution to the mode at 9.0 Hz are noticeable and almost is phase (see CSD C02-C05); much more complicated seems, at that frequency, to be the motion respect to the wall instrumented by the sensor C10: in fact the rectangular building seems to be moving out of phase respect to that wall (see C05-C10 and C02-C10 CSDs).

Configuration 8. This configuration has been designed to study the interaction between NW part of the CEDRAV building and a structure connected to it by means of a masonry arch . In a preliminary study of this configuration peaks at the two frequencies, 6.0 Hz and 6.4 Hz, were found for event 11 (Rinaldis et al., 2007). Records from events 11 and 12 have been analyzed. Peaks in TH and PSD seem to indicate that records are of increasing energy (energy of event 11 < event 12). In particular, main peaks on the PSD of records obtained from sensor deployed on the masonry arch (C01, C02, C03 – Figs. 5c, 5d and 6a) at 6.4 Hz and 8.0 Hz on the CEDRAV's walls (C04), Further, the latter PSD shows values that are much two order lower, indicating that the CEDRAV wall, is practically not moving with reference to the masonry arch. CSD, phase and coherence of C01-C05, C02-C06 and C02-C05 give similar information: peaks at 6.0 and 6.4 Hz related to translational modes (phase factor equal to zero) and high coherence function. Instead, no evidence of peaks at those frequencies is found in CSD of C04-C06, and values of coherence is always much lower indicating that the CEDRAV wall, where sensors are deployed, is in practice not moving (Fig. 6a). In event 12 sensor C04 shows a component at lower frequency not apparent in the record of event 11. In fact, PSD of sensor C04 for event 12 shows a peak at 3.4 Hz not present in event 11 (see Figs. 5a and 5b,

respectively). At all the sensors (C01, C02, C03 and C04) peak at 7.8 Hz is the largest one. Peaks at 6.4 Hz are still evident but much smaller. The mode at 8.0 Hz is not clear. The mode at 3.4 Hz is instead torsional (Figs. 6a and 6b).

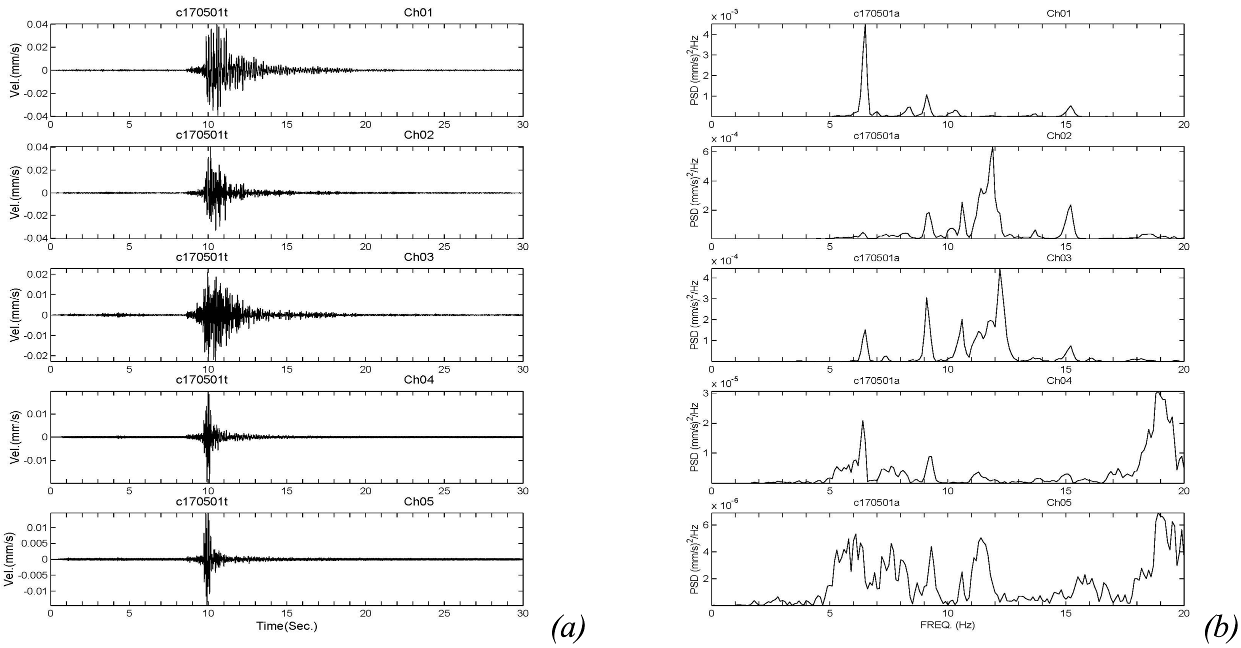


Figure 2: Configuration 6: TH, PSD of a recorded event in the S-E building

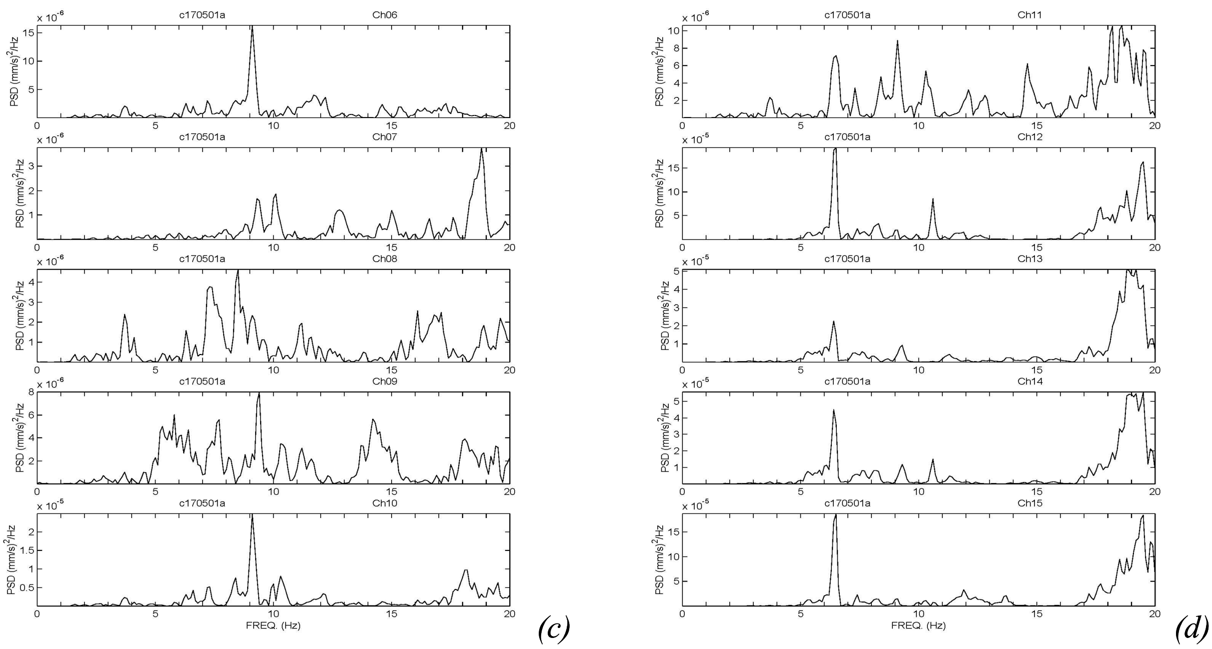
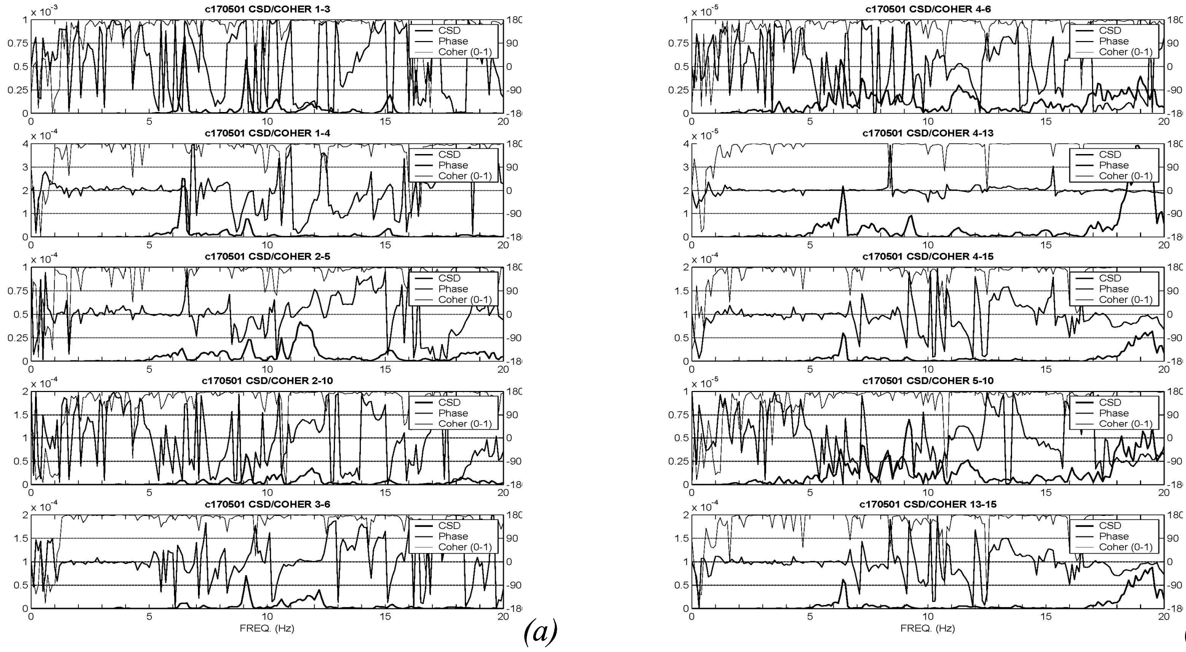


Figure 3: Configuration 6: PSD of a recorded event in the S-E building

Conclusions

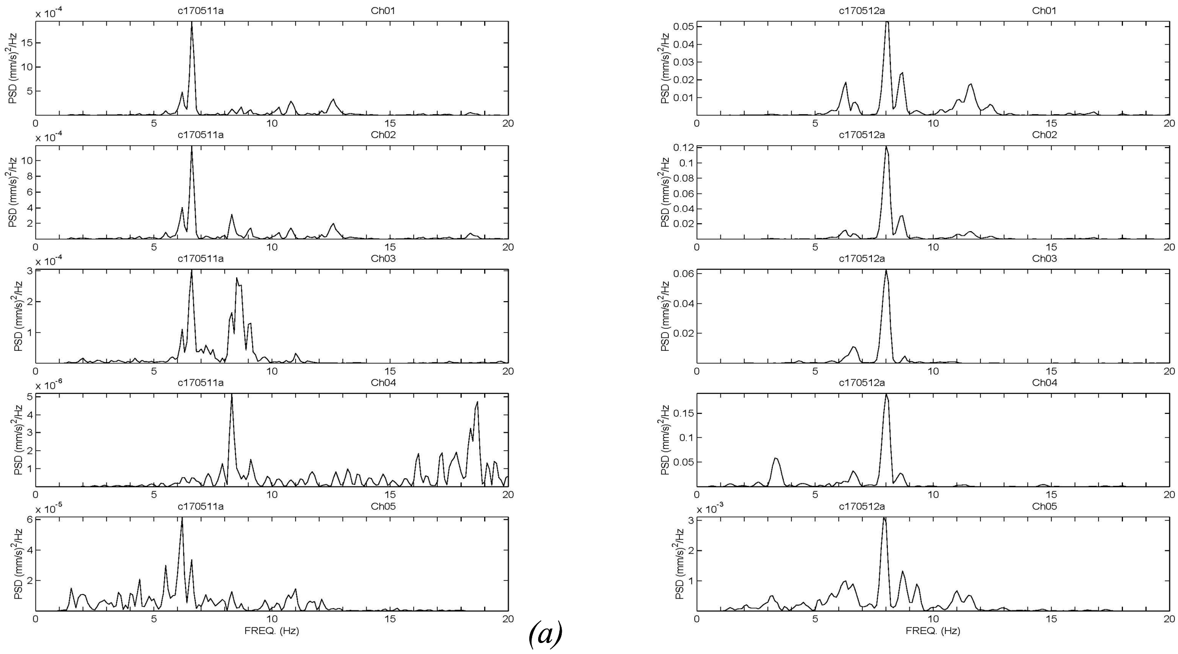
The dynamic characterization of the structure, using ambient and forced vibration tests, allowed to have very important information about the health status of the structure and to point out its main dynamic characteristics. The knowledge of the influence of building dynamic interaction in modifying the dynamic characteristics is of fundamental importance to characterize the mechanisms that underlie the damage time history. In the study of the CEDRAV building, records from temporary

arrays have been used for dynamic characterization of structures, excited by means of ambient or forced vibrations and weak seismic motion.



(a) *(b)*

Figure 4: Configuration 6: CSD of a recorded event in the S-E building



(a) *(b)*

Figure 5: Configuration 8: PSD of sensors 01-05

The analysis of the interaction between the NE facade of the CEDRAV and the masonry building connected to the church (Configuration 6) has pointed out a peak at 6.2 Hz associated to a mode involving the rectangular building motion and the church; the rotation centre at level 2 with reference to a vertical axis is positioned between C04 and C06; furthermore the analysis of records oriented S45E seems to state that contribution to the mode at 9.0 Hz are noticeable; the motion respect to the wall instrumented by the sensor C10 is much more complex at that frequency: in fact, the rectangular building motion is out of phase with reference to that wall.

The health status of the building seems to be quite good. The connections between the walls are effective except for those between the main block and the two adjacent smaller blocks. The structure

vulnerability is essentially related to the absence of rigid diaphragms between the walls, necessary to guarantee a suitable distribution of the seismic actions. The floors, in fact, are very flexible to satisfy this requirement. The strengthening of the building will regard essentially this aspect: the existing floors should be substituted by new rigid floors, especially the third and the fourth. The connection between the floors, old and new, and the walls must be realized. The input energy was very low: more evident non-linear effects could be observed in the case of seismic actions.

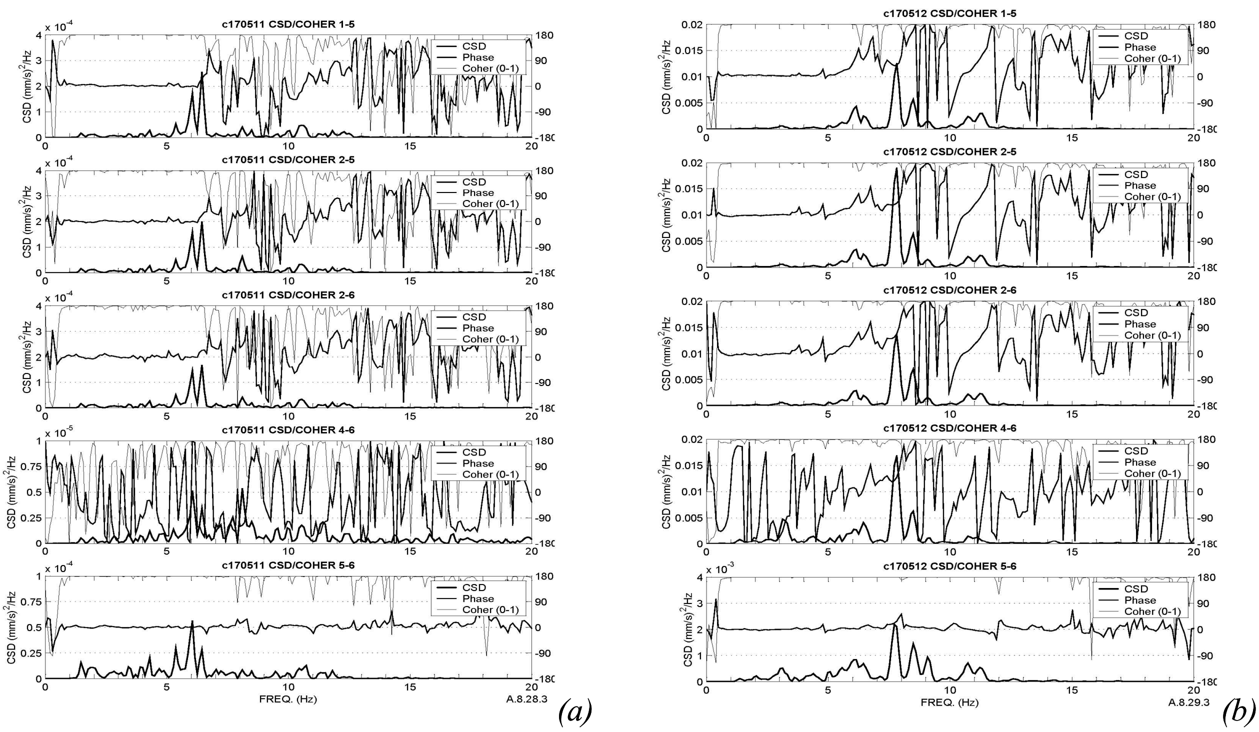


Figure 6: Configuration 8: PSD and CSD

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