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Dynamic Identification of Detachment Conditions on Prehispanic Mural Paintings in Central Mexico

Juan Carlos Araiza Garaygordóbil, Hermann Rocha Escalante, Agustín Orduña Bustamante
University of Colima, Civil Engineering School México.

ABSTRACT: According to archaeological evidence, mural paintings in the prehispanic site of *Cacaxtla* are original from 650-900 A.C. The murals were discovered recently (in the 70's) and have suffered a strong degradation since then. The mural paints consist in a decorated layer supported in an adobe wall. During the last years, a strong degradation of the paintings was observed, probably due to atmospheric aggressions. Some segments of mural are detached of the wall in different degrees. Due to the high artistic value off the paintings, a non-destructive technique was required to identify the connectivity condition between the decorated layer and the supporting adobe walls. A grid of dynamic testing under forced vibration was applied in few hundreds of segments of the mural. Energy dissipation time and natural frequencies were used to identify the attachment levels. A clear trend was observed when the results were graphically organized. Dynamic information was useful to characterize the detachment degree and to prepare a restoration project.

1 INTRODUCTION

Cacaxtla is one of the mayor archaeological sites in central Mexico. Prehispanic mural painting is one of the elements that makes the site particularly interesting. The *grand-basement*, as the archaeologists know it, is a superposition of different layers corresponding to different time periods. The construction method was based on a new city for every new governor constructed above the previous one. All the buildings were partially demolished and filled in order to create a new platform for the new city. Al least seven layers have been clearly identified by the local archaeologists.

In this process of renovation, some decorated buildings were covered with filling, and the mural painting inside were relatively well preserved for eleven to fourteen centuries. However, on the last few decades, some of the paintings were reopened to atmospheric aggression and a serious deterioration process has been recorded (Fig. 1). The mural paintings are a thin plaster layer directly supported on an adobe wall. The main damage is associated to a differential strain between the constitutive materials (adobe and plaster) generating detachments and local collapses of the decorated surface (Fig. 2).

In this participation, an experimental technique applied to identify the detachments levels is described. Two different murals were tested, known as *Ranas* and *Rojo.* The murals were divided into columns and rows and every 20x20cm segment was dynamically characterized. The first natural frequency was used as a parameter in order to identify the continuity or detachment condition. Few hundred of dynamic tests were carried out, and at the end, a particular frequency was defined for every segment. The same procedure was conducted under laboratory controlled conditions in a partially-connected mural made of acrylic.


Figure 1 : Typical damage in one of the murals.


Figure 2 : Typical detachment of a segment.

The promising perspective of vibration-based health monitoring is not new. It has inspired many researchers all over the world. A detailed survey of the technical literature associated to dynamic testing was presented by Richardson (1980). Doebling et al. surveyed and classified the literature on dynamic identification in a report published by Los Alamos National Laboratory (1996). Several doctoral dissertations that address damage detection and related issues have recently been published. Each dissertation contains a literature survey and a development of the theory relevant to its scope. These dissertations include Casas (1988), Rytter (1993), Hemez (1993), Kaouk (1993), Doebling (1995), Peeters (2000) and Araiza (2003). Mottershead and Friswell (1993) present a survey of the literature related to dynamic finite element model (FEM) updating, which has been used extensively for structural damage detection. However, dynamic testing for identification of detachments in mural painting is a novel application.

2 FIELD TESTS

2.1 Method

As described above, a series of dynamic tests were developed on every 20x20 cm. segment of the murals. A ceramic accelerometer was manually attached to the wall (Fig. 3) and a slight impact was applied next to the accelerometer with a rubber hummer. A sampling ratio of 10,000 points per second was used. The time response was recorded for three seconds. Four or five impacts were recorded in this time (Fig. 4). Afterwards, a Fast Fourier Transformed (FFT) was used to identify natural frequencies associates to the studied segment of the mural. The FFT was applied only to a section of the time signal, were the vibration was clearly associated to the impact. The test was performed several times until a clear frequency was identified after several repetitions.

Figure 3 : Dynamic characterization process.

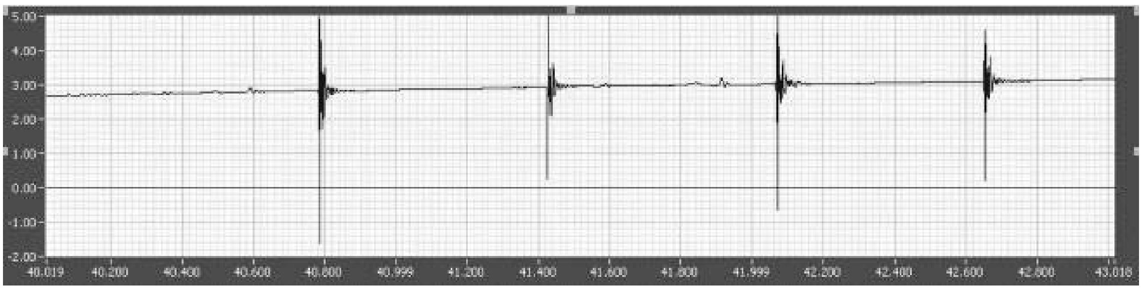

Figure 4 : Typical time domain response of a segment under four impacts.

2.2 Results

A contour diagram of iso-frequencies was created to identify the trends and to create an hypotheses of the location of detachments. It was expected that for a low frequency certain level of detachment could be expected. Actually, a clear trend was observed, for segments that showed either high or low frequencies. A group of segment showed a first natural frequency between 180-250 Hz and were considered detached. Anther group of segments presented a first natural frequency greater than 350 Hz, and was considered as attached. In Figs. 6 and 8, the lighter color represents lower frequencies and probably detached conditions. Darker color shows a higher frequency and likely a better attachment level.

Figure 5 : General view of the *Rojo* mural.

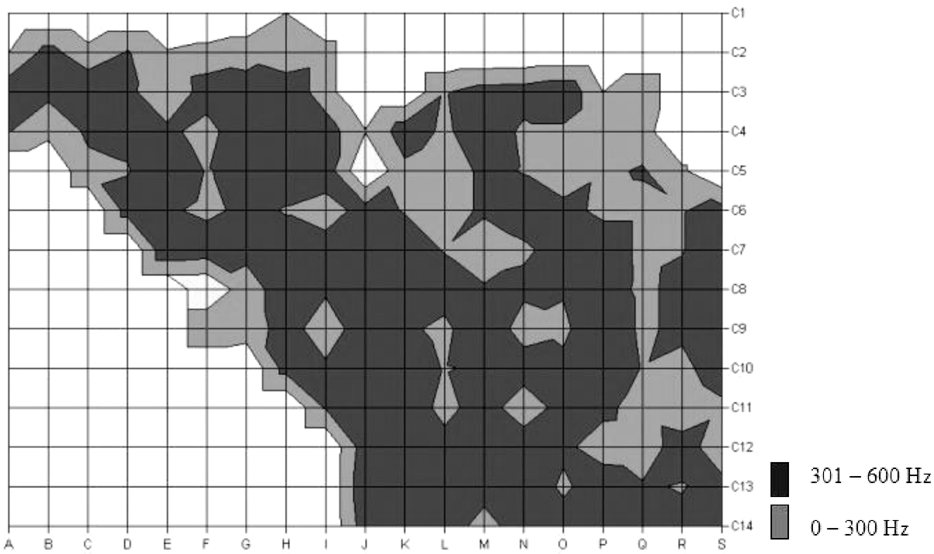

Figure 6 : Iso-frequency contour diagram of the *Rojo* mural.

For the particular case of the mural known as *Rojo*, there is a patter of detachments mainly in the region next to the stairs (Fig. 5) and in the upper part, were the differential movements of the Adobe seem to be more important.

Figure 7 : General view of the *Ranas* mural.

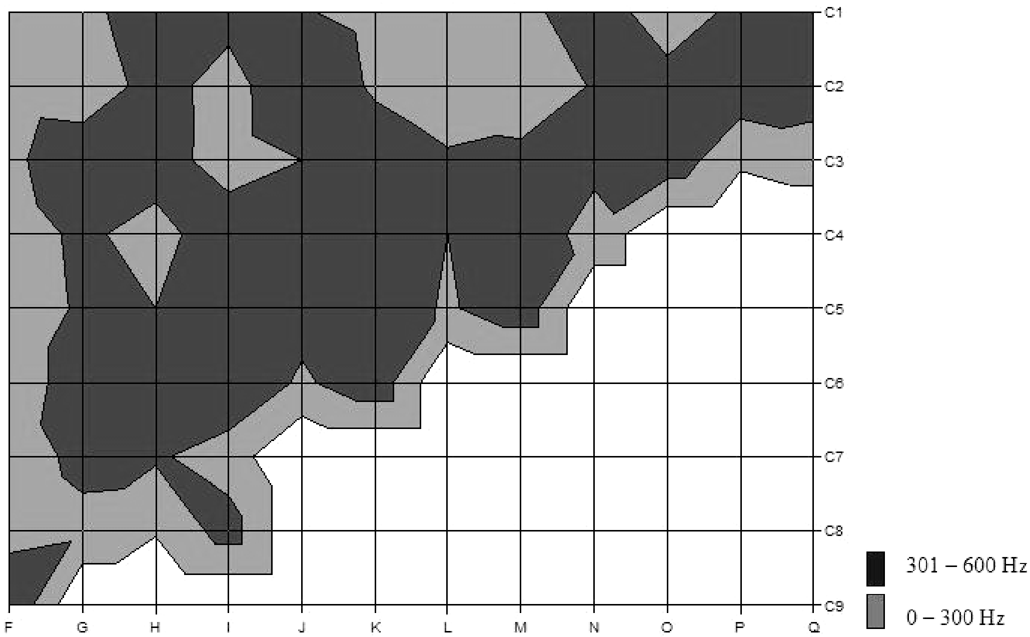

Figure 8 : Iso- frequency contour diagram of the *Ranas* mural.

In the case of the mural known as *Ranas*, the structural condition appears once again with some detachments adjacent to the stairs and to the upper part. It is worth mentioning that the stairs block is independent and shows a constructive joint on the contact with the mural (Fig. 7).

3 LABORATORY TESTS

3.1 Method

In order to validate the test data obtained in the mural, an artificial mural with induced detachments was constructed and tested. The mural was made of a 9 mm thick acrylic layer, attached partially to a concrete wall with glue (Fig. 9). The detached parts of the mural were separated 3mm of the concrete wall. The mural was divided into columns and rows and every 10x10 cm segment was dynamically tested. A ceramic accelerometer was again manually attached to the wall (Fig. 10) and a slight impact was applied next to the accelerometer with a rubber hummer. A sampling ratio of 10,000 points per second was used. The time response was recorded for three seconds. Four or five impacts were recorded in this time. Afterwards, a Fast Fourier Transformed (FFT) was used to identify natural frequencies associates to the studied segment of the mural. The FFT was applied using the same criteria of fieldworks.

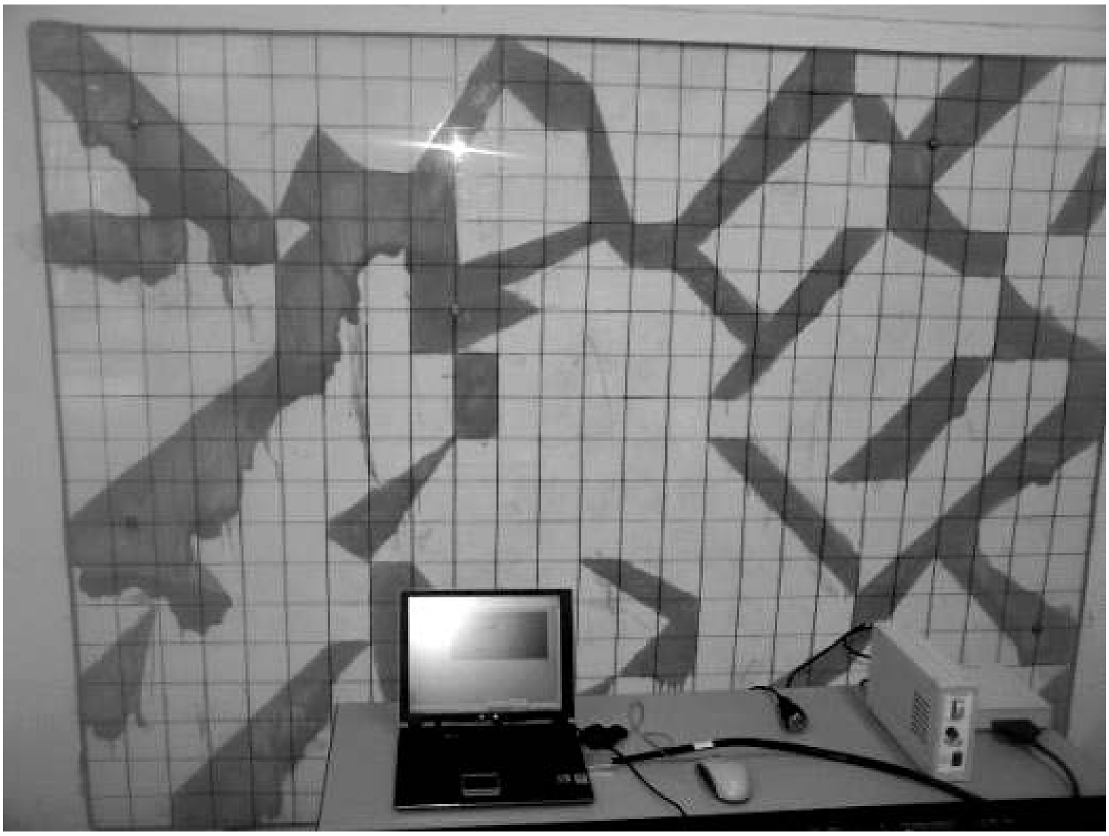

Figure 9 : Laboratory validation of the technique.

Figure 10 : Detail of dynamic testing of the laboratory specimen.

3.2 Results

A contour diagram of iso-frequencies was again created to identify the trends and to create a hypotheses of the location of detachments. It was expected that for a low frequency certain level of detachment could be expected. Once again, a clear trend was observed, for segments that showed either high or low frequencies. A group of segment showed a first natural frequency between 180-250 Hz and were considered detached. Anther group of segments presented a first natural frequency greater than 300 Hz, and was considered as attached. In Fig. 11, the lighter colour represents lower frequencies and detached conditions. Darker colour shows a higher frequency and a better attachment level.

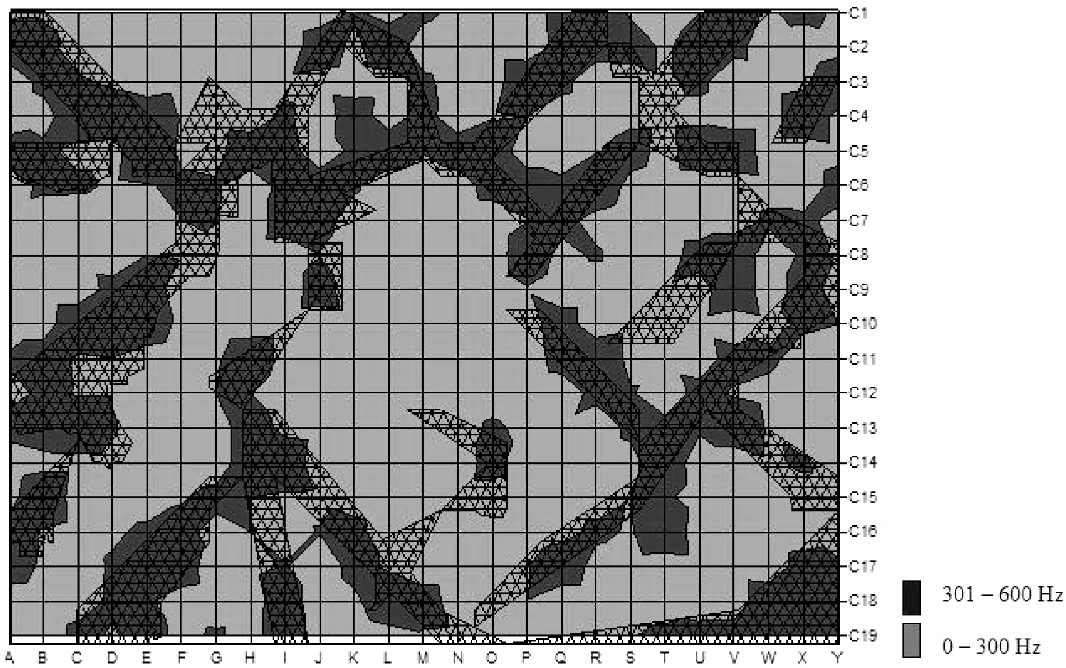

Figure 11 : Iso-frequencies contour (solid colours) and actual connection scheme (triangular hatch).

4 CONCLUSIONS

Dynamic tested was founded a useful tool to identify detachments in mural paintings. The first natural frequency of a segment of a mural can be representative of its attachment level.
It was not possible to find a quantitative correlation between the numerical value of the frequency and the attachment condition. A qualitative identification of the detachments was possible by comparing the values of the frequencies between each other. The data showed a clear trend, segregating into two groups: high frequencies averaging 400 Hz and low frequencies averaging 150 hz. The results were grouped in high and low frequencies using a threshold of 300 Hz. Changing the threshold to 250 or 350 hz did not produce any significant change on the iso-frecuency diagram. The hig-frecuency group was assumed to be attached and the other group (low frequency) detached. The same process was followed on a laboratory specimen and the results were completely satisfactory.
Some of the tests were carried out using glue on the accelerometer, some other were manually attached. No human interference was observed on the response and the manual attachment was obviously easier to carry on.
Deeper research is been carried out comparing the presented results and information obtained from Ground Penetration Radar. The damping ratio from the time domain signal is also been studied as a variable to identify internal voids or detachments.

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