Advanced Materials Research Vols. 133-134 (2010) pp 855-859

doi:10.4028/www.scientific.net/AMR.133-134.855

Strengthening Layout Using FRP in Industrial Masonry Chimneys under Earthquake Load

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Abstract Industrial masonry chimneys usually are considered as historical heritage since they remind the industrial revolution that took placed by the XIX century, shaping a particular landscape in many cities, what led many Town Halls to protect them as cultural heritage. In this work an assessment of the seismic vulnerability is performed to check the structural integrity according to a return period of 500 years. Detailed geometrical investigations took place and dynamic tests performed with the goal to obtain natural frequencies and structural damping using four seismic accelerometers at different heights and orientations. From the experimental results a numerical model has been calibrated adjusting numerical frequencies to match those experimentally obtained. Artificial accelerograms were generated specialized for the city of Valencia and the crack pattern was obtained corresponding to a return period of 500 years. After these analyses the model of the chimney was strengthened using strips of FRP and the calculations repeated to obtain the reinforced achieved regarding seismic vulnerability. Conclusions related to these calculations are outlined.

Keywords: Masonry, accelerogram, seismic vulnerability, strengthening, FRP, cracking

Introduction

Many industrial masonry chimneys in the city of Valencia (Spain) are located in the city centre after the urban development (Fig. 1). The singularity of this type of structures and the historical heritage that they provide as witnesses from the industrial revolution that took placed by the XIX century have led to the Town Hall to protect this structures as cultural heritage.

Figure 1: Masonry chimneys in the city center

These chimneys were used during the Industrial Revolution in the manufacturing process. Fuel was burned in the boiler to produce steam to drive the machinery, for example in the textile, paper and oil industries, although in some factories the boiler itself was the only production unit, for example in the ceramics industry. The smokes were evacuated through the chimney, helping the combustion. Some of them have been restored and are still in use for different industries away from the downtown. Accidental loads as earthquakes were not usually considered when designing these structures so, in this work, an assessment of the seismic vulnerability of an industrial masonry chimney is performed to check the structural integrity according to a return period of 500 years. Detailed geometrical investigations took place on one masonry chimney and dynamic tests performed with the goal to obtain natural frequencies and structural damping using four seismic accelerometers at different heights and orientations. Following the experimental tests, a numerical model has been calibrated adjusting numerical frequencies to match those experimentally obtained. The updated numerical model was used in a seismic analysis to know the seismic response of the chimney when different earthquakes act according to the Seismic Spanish Standard.

The usefulness of using vertical straps of FRP in the strengthening to meet the requirements of safety, serviceability and durability for the different earthquake load is studied, so strips of FRP are introduced in the calculations to obtain the reinforced level achieved regarding seismic vulnerability.

Geometric Study and Material Characteristics

The industrial masonry chimney studied in this work is located in the city of Valencia (Spain). In Fig. 2 it can be observed the chimney and the main dimensions obtained through a topographic survey.

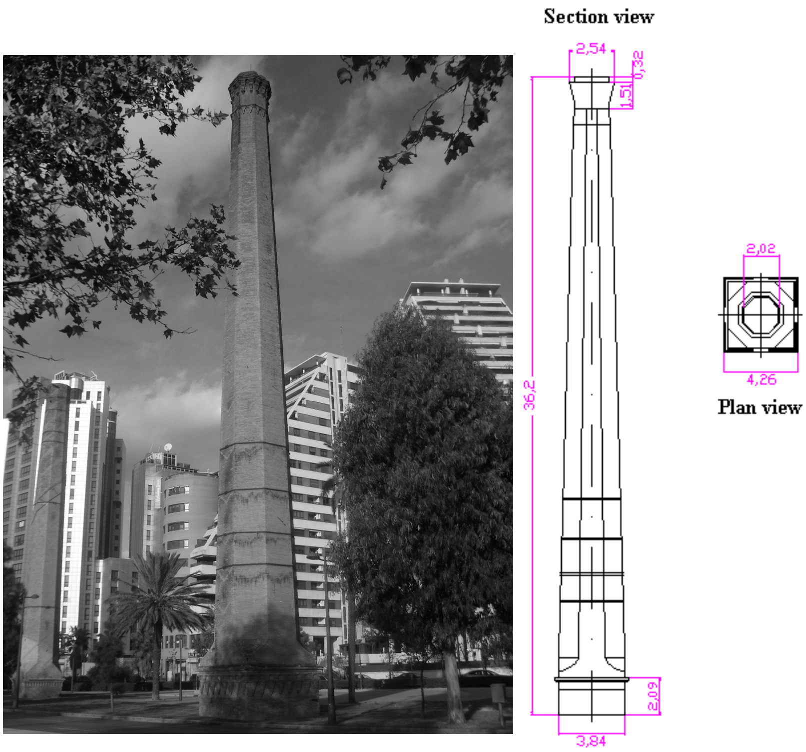

Figure 2: Masonry chimney studied and geometric dimensions

It is a vertical chimney 36 m high made in masonry without visible external cracks. It is made in masonry, using bricks and lime mortar. Since no experimental tests were done in the material, usual values (Esselborn 1952) for the main mechanic parameters were used to obtain a numerical model:

- uniaxial compressive strength: f_c= 637.500 N/m^2
- uniaxial tensile strength: f_t= 196.200 N/m^2
- elastic modulus: E= 5.886e9 N/m^2

- Poisson coefficient ν=0.2
- density: γ=1600 kg/m^3

Experimental Test

The tests were conducted placing four seismic accelerometers at different heights in perpendicular directions, as shown in Fig. 3.

Figure 3: Location of accelerometers

Accelerations were registered due to ambient vibrations, as shown in Fig. 4. It can be observed the impact excitation introduced during the test by an impact hammer.

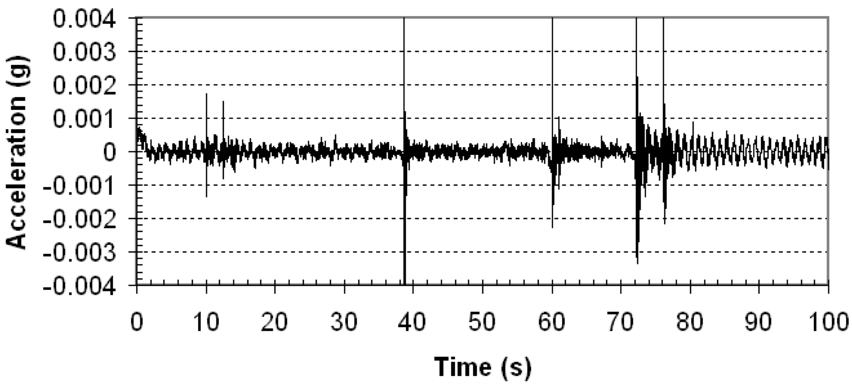

Figure 4: Registered accelerations

A Fast Fourier Analysis was applied to the registered accelerations to obtain the natural frequencies. Table 1 shows the two first values:

Table 1: Natural frequencies

Mode	*Hz*
1	1.07
2	3.32

Numerical Test

Artificial accelerograms compatible with the Spanish Seismic Standard (NCSE 2002) were generated an introduced to the numerical model using the Gasparini and Vanmarcke technique (Gasparini and Vanmarcke 1976). Fig. 5 shows the 3D numerical model used in the calculations to reproduce the actual geometry of the chimney, and cracks obtained for one of the accelerograms scaled up to a peak ground acceleration of 0.06g.

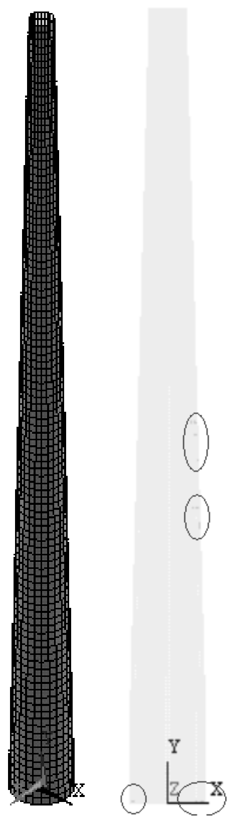

Figure 5: Numerical model and cracks obtained for a_b=0.06g

A macro-model with a homogeneous material was used with the mechanical characteristics shown previously, and the failure surface adopted was that proposed by Willam&Warnke (Willam and Warnke 1975), based on a smeared crack approach.

Strengthening Using FRP

Fiber Reinforced Polymers (FRP's) are being used in strengthening masonry structures against seismic loads. Main advantages of FRP are that provide high stiffness and are easy to install, adding little mass to the structure. Link elements have been used to model FRP in the shape of straps. The results presented here are obtained for CFRP with the following characteristics: 200 GPa elasticity modulus and a yield strength of 2500 MPa. Fig. 6 shows the layout of the straps up to a height of 20 m and 45º rotational symmetry angle; moreover cracks are displayed for the same seismic load previously shown in Fig. 5.

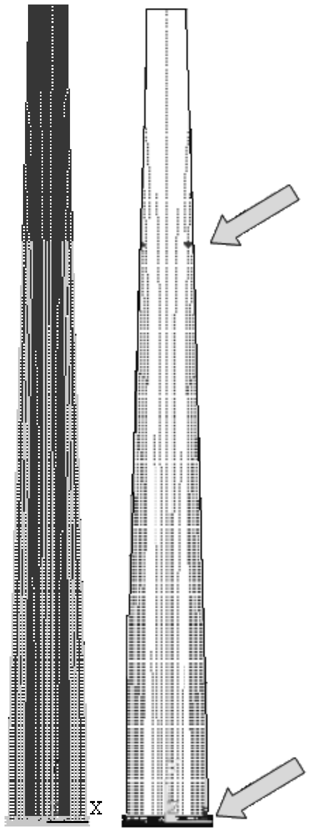

Figure 6: Longitudinal section of the reinforced chimney, top view and rotational symmetry angle of the reinforcement equal to45°

As can be observed, cracks are translated to the point where the strengthening ends.

Conclusions

Modeling masonry structures is a difficult task that requires a deep understanding on the behavior involved. It is been shown a technique to calibrate a numerical model using experimental results, for a dynamic analysis. Results from a seismic analysis applied to an industrial masonry chimney have been presented before and after the strengthening technique using CFRP.

Different configurations and FRP materials are possible to improve the seismic capacity of this type of structures. Here it is been shown how using CFRP and vertical straps, the seismic capacity of a masonry chimney is enhanced. Currently, investigations are being conducted to seismically characterize this type of industrial masonry chimneys and studying different configurations for strengthening.

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