Abstract

Seismic risk for cultural heritage buildings has been underestimated for a long t in Switzerland. A strong earthquake can occur at any time in our regions, as it has been shown during the last centuries. As reminder the 1356 seismic event that destroyed the city of Basle can be quoted; this event, whose intensity is assessed as having been I=IX on the European Macroseismic Scale (EMS-98), is recorded as the most violent earthquake that struck central and northern Europe. Besides this very strong seismic event, it must be said that the rest of the country has also been faced with several earthquakes that, although less stronger than the Basle event, resulted in serious damage to the heritage buildings.

Since 2003 or even 1989, the seismic safety of common buildings is well defined through modern building codes (Swisscodes (SIA)). On the contrary, this is not the case of cultural heritage buildings whose seimic vulnerability has been only partly addressed. According to the *Charte d'Athènes* and in order to protect its cultural heritage, Swiss authorities initiated a national research program, whose main purpose was to develop a methodology that allows us to assess the seismic vulnerability of historical edifices. The creation of such a methodology has been the main purpose of this PhD thesis.

Surveys carried out on cultural heritage buildings after seismic events showed that such kind of structures are particularly vulnerable under seismic actions. This vulnerability is essentially due to their particular structure that is characterized by slender components (pilars), wide open spaces, quite big masses that are located at high levels (vaults, lantern towers, etc.), few components that can resist the lateral actions perpendicular to the nave, a masonry fabric that can be very brittle and non-ductile, etc. Morover the non-existence of a stiff horizontal component (or a deformable one in case of wooden ceilings) and heavy masses concentrated in walls rather than at floors make impossible to apply models that have been developed for common buildings. Because of the aforementioned reasons, methodologies that allow us to assess the seismic vulnera-

bility of cultural heritage buildings are not numerous. Almost every available methodology nowadays is listed in the chapter state of the art of this PhD thesis.

The structure of this report reflects the chronological unfolding of the research work. First, one of the main task was to study the Swiss cultural heritage buildings from an engineering point of view, that is to say to study their shape, structure, type of masonry and their state of maintenance. The salient points resulting from this extensive study are gathered in one chapter; furthermore the obtained observations gave way to a standardization of structural units that can be found in every sacred edifice in Switzerland. Instead of dealing with the specificity of each edifice, this standardization made possible to treat only a few structural components and to export them to each studied sacred building.

Observations of damage resulting from earthquakes is of prime importance since it allows us to identify the weakest point of the structure. Consequently, a search as extensive as possible for related documents, such as books, survey reports in cantonal archives, parishes archives as well as at bishoprics archives has been carried out. Moreover, a survey was made in the framework of this PhD thesis on the damage due to the earthquake that occurred in September 2005 in the Alps. This search has led to identify series of prevalent (often observed) damage and weak points on sacred buildings as well as the related structural explanations.

Methodologies that have been developed to define the seismic vulnerability of cultural heritage buildings are based on structural models that were developed from the study of the recorded damage patterns. In order to assess their applicability to the Swiss cultural heritage buildings, a chapter is devoted to the application of the existing methods on a selection of historical edifices in Switzerland. The obtained results, which show their avantages and their drawbacks of them, allowed us to set the basis of the methodology that will be presented at the end of the report.

As aforementioned, masonry characteristics, such as brittleness and low ductility, influence a lot the level of damage of edifices that are subjected to seismic actions. For these reasons, one chapter is devoted to the topic masonry and presents its mechanical properties as well as models that have been developed up to the present time to calculate masonry strength under compression and/or shear for one-leaf walls or multiple-leaf walls. Nevertheless, it must be said that scientists have essentially dealt with brick masonry and not natural stone masonry. This field has not been thoroughly addressed and mechanical properties of old natural stone masonry (from historical edifices) are particularly missing. In order to fill this gap of knowledge, at least partially, an experimental investigation was carried out at the Institute of structural engineering of the *Ecole Polytechnique Fédérale de Lausanne*. A 0.53 x 2.1 x 1.7 m wallet was built with large sandstone blocks from the abutments of Lausanne Cathedral, closely according to the medieval way of doing. This specimen was then subjected to a cyclic lateral load that increased in stages (pseudo-static test) until it failed by shear collapse. The strength and ductility of this square blocks masonry were astonishingly high compared with the expected values.

The obtained values of strength and ductility were used in the chapter devoted to the study of the structural behaviour of sacred edifices under seismic actions. This part is clearly essential for what follows, i.e. the methodology. Explanations of the structural behaviour are indeed given and the models that are applied in order to calculate the highest peak ground acceleration that the edifice can resist to are also presented. The methodology, which is presented in the next chapter, 'takes into account some of the advantages given by the existing methods and proposed the application

of other models that give more possibilities for dealing with Swiss cultural heritage buildings in the author's opinion.

For the purpose of explaining the methodology (i.e. answer the question: «how to proceed with the assessment»), an application example is presented on a fictitious sacred edifice. The reasons that have led to this choice are justified by the need to show a sacred building whose shape is commonly found in Switzerland instead of choosing one edifice that is, by the nature of historical buildings, too unique to be generalized. The results are then discussed and led to some conclusions and recommendations.

Though the report related to the PhD thesis is to be finished at the end of 2007, the defence of the research work will take place at the beginning of 2008.