ENAC / PROJET DE MASTER 2018
SECTION DE GÉNIE CIVIL

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Predicting the Change in Natural Period of Building due to Damage

Auteur(e)s : Antoine Mauron

Encadrement : Prof. Katrin Beyer[1]

[1] Earthquake Engineering and Structural Dynamics Laboratory (EESD), EPFL

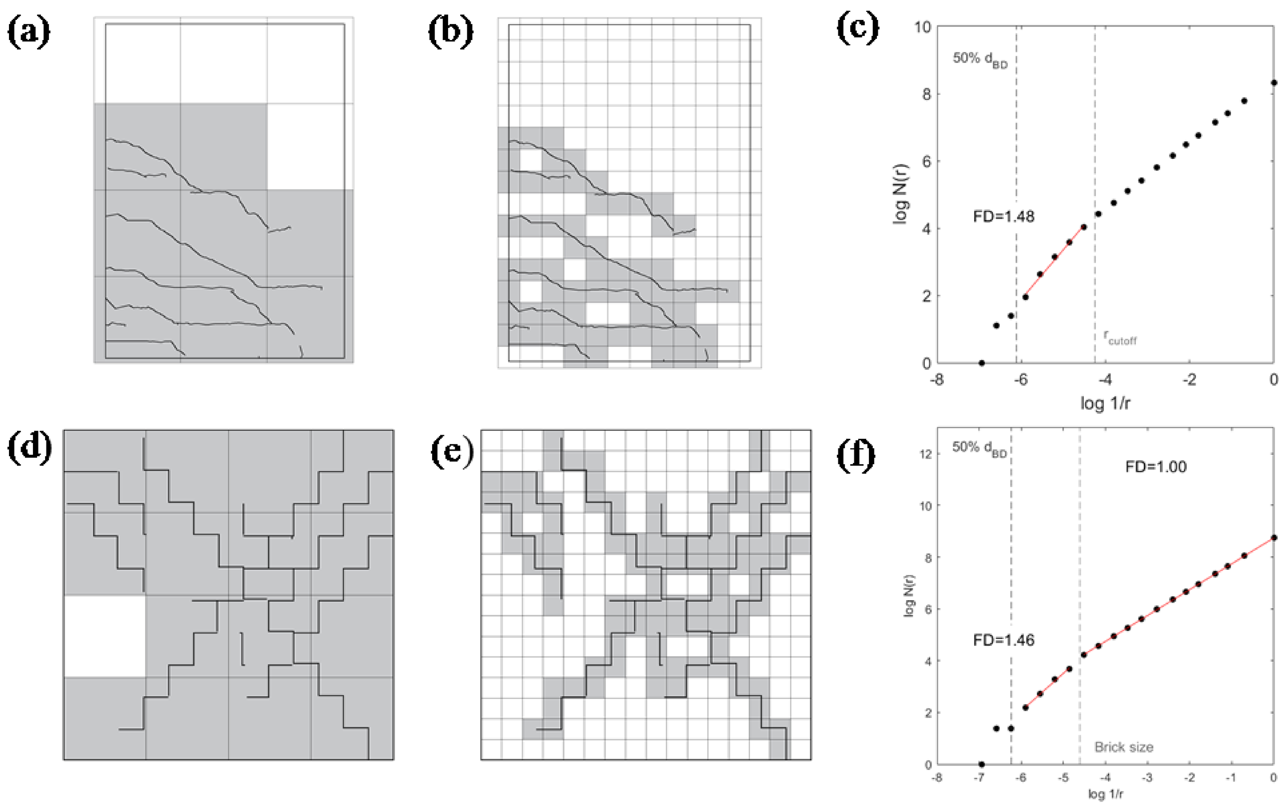
Introduction and objectives

After an earthquake, when buildings have been damaged, engineers assess the safety of these buildings by a qualitative visual inspection based on visible damage factors such as the type and extent of cracking, the crack width and the presence of spalling and crushing for concrete or masonry. Unfortunately these methods, in addition to be very time-consuming, are considered to be very subjective in nature. The quality of the inspection relies extensively on the experience and judgement of the inspector. The availability of high resolution digital photographs might allow in the future to automate this process completely. This requires on one hand image-based methods to detect structural elements and cracks on digital photographs of damaged structures. On the other hand, models are needed that link the damage pattern to the residual stiffness and strength of the damaged structural elements. It has been proposed that the concept of fractal dimension could be used to quantify the extent of cracking in a structural element and that the fractal dimension of the element can be linked to a certain loss in stiffness and strength. So far, this concept has only been applied to tests on isolated reinforced concrete (RC) and unreinforced masonry (URM) walls. The objective of this study is to investigate whether it can be extended to an entire building.
This study first aimed at developing a computer code capable of computing the fractal dimension of reinforced concrete and unreinforced masonry walls based on the box-counting method. The program was then tested on half-scale unreinforced masonry walls subjected to a quasi-static cyclic test. An approach based on the fractal dimension to estimate the residual stiffness of the specimens was analyzed and improved. Finally, the fundamental period of a four-storey building subjected to shake-table tests was predicted by means of a linear elastic model. The objective was to determine whether or not the approach based on the fractal dimension could accurately capture the period elongation of the building.

1. Fractal dimension and damage assessment

Fractals are shapes or patterns that are too fragmented and irregular to be described by the Euclidean geometry. Unlike components of the Euclidean geometry whose dimension can only be expressed as an integer, the dimension of a fractal may be a fraction. This measure is usually referred to as the fractal dimension (FD). Its value is usually greater than the topological dimension and characterizes the complexity and space filling property of a fractal shape. For example, a curve's fractal dimension will lie between 1 and 2, depending an how much space it occupies, while a surface will have a fractal dimension between 2 and 3.

The box-counting dimension is the most commonly used definition of the fractal dimension. The process of its evaluation consists of covering the object of interest with boxes of size r and counting the number of such elements N(r) that are necessary to completely cover it. The box-counting dimension is then reflected in the way N(r) behaves as the box sizes r is decreased towards 0. In practice, the fractal dimension is estimated by fitting a straight line to the log-log plot of N(r) versus 1/r. The slope of the line provides an estimation of the fractal dimension.



The box-counting method has been applied to RC and URM walls to characterize the extent of cracking. The FD should vary between 1 and 2 depending on how much of the surface of the wall is covered by cracks. A single value of FD characterizes the crack pattern of a RC wall, while two values are considered to describe URM walls, the structural and textural FD.

Previous studies suggested to estimate the stiffness degradation of RC and URM walls using damage indexes based on the fractal dimension:

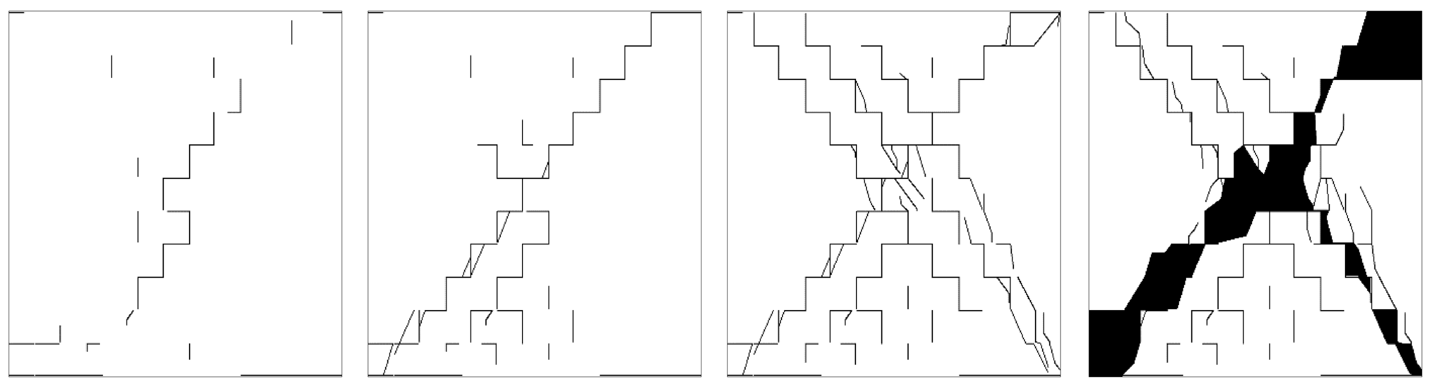
RC walls : $DI = \frac{FD_i - FD_0}{2 - FD_0}$

URM walls: $DI = FD_i^{stiffness} - 1$

avec $FD_i^{stiffness} = 0.5 \cdot (FD^{structure} + FD^{texture})$

2. Analysis of unreinforced masonry walls

The approach was tested on half-scale URM walls subjected to a quasi-static cyclic test. The crack patterns were manually drawn based on photos of the tests and characterized by means of the structural and textural FD. The stiffness degradation was evaluated and compared to the real relative stiffness loss (RSL) of the specimens.



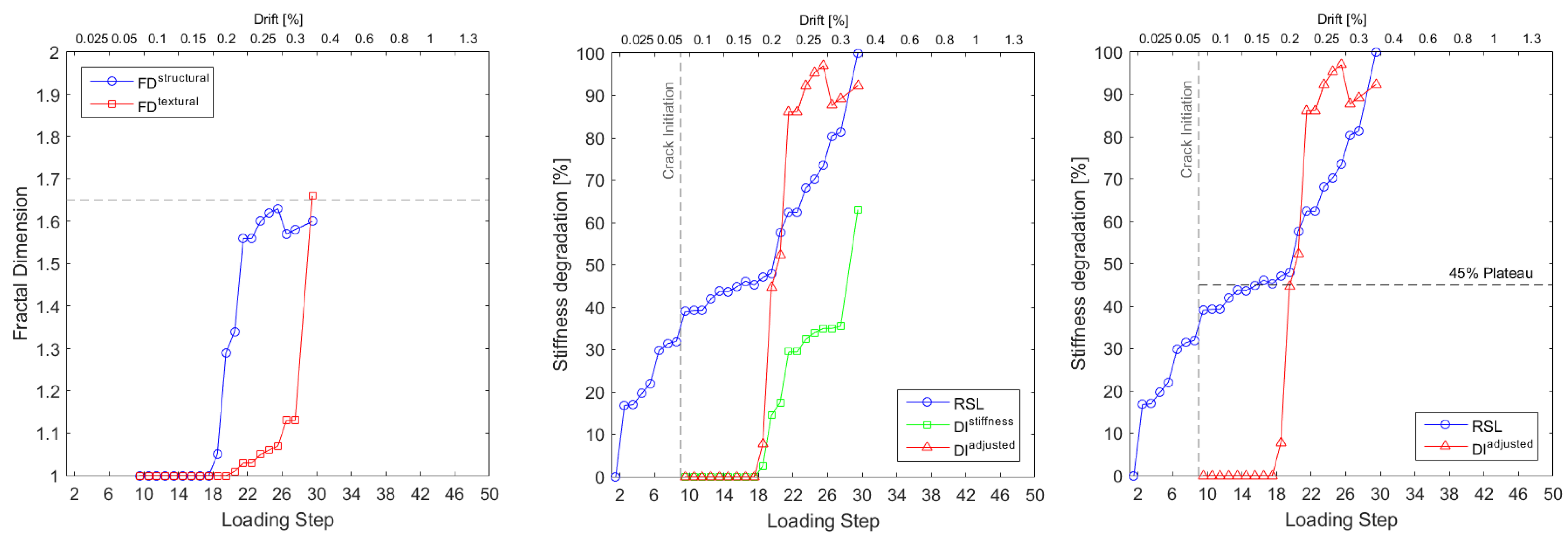
The first approach lead to poor estimations. An adjusted damage index was therefore proposed:

$$DI^{adjusted} = \frac{FD_i^{structure} - 1}{1.65 - 1}$$

a. Computation of the structural and textural FD

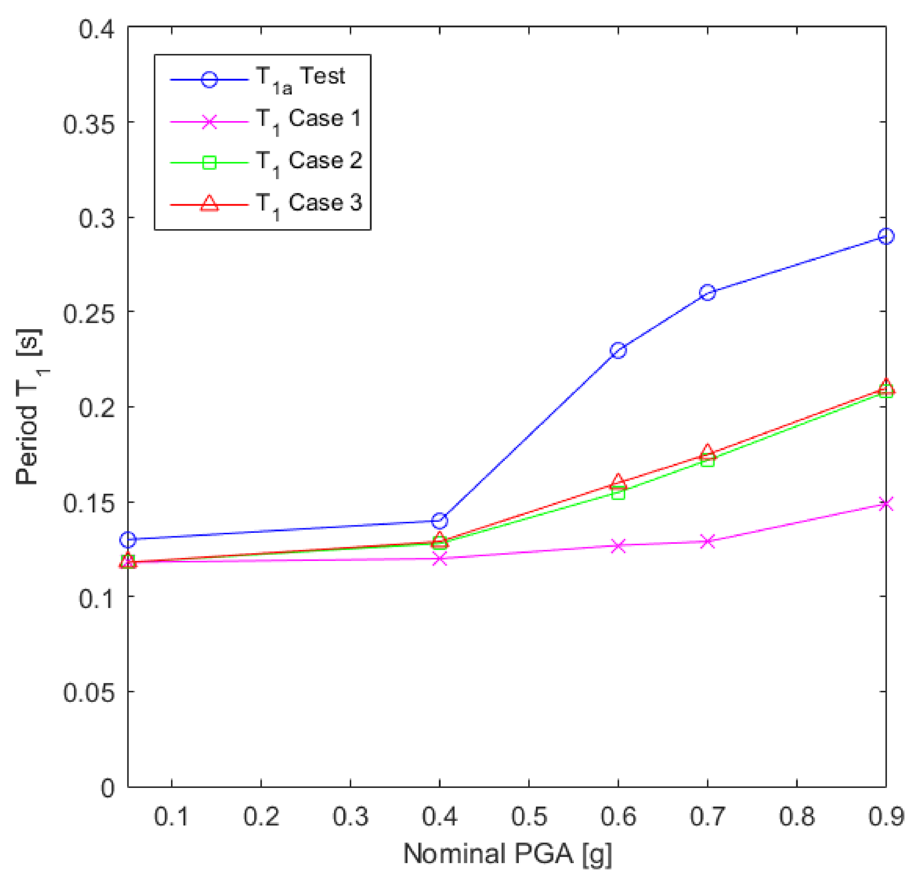
b. Initial and adjusted stiffness degradation comparison to RSL

c. Final proposed procedure to estimate the stiffness loss



3. Predicting the change in the period of a building

The approach was applied to a half-scale four-storey building composed of RC and URM walls coupled by RC slabs and subjected to uni-directional shake-table tests of increasing intensity. The crack patterns of the walls were manually drawn and characterized individually by means of the fractal dimension. The stiffness degradation of each element was then implemented into a linear elastic finite element model for which the fundamental period was computed. The latter was then compared to the real period elongation of the test unit observed during the shake-table tests.



Conclusion

In general, the predicted period displayed a satisfactory behavior with respect to the damage evolution of the structure. However, it seemed that the overall stiffness degradation of the building could not be accurately captured by the approach. A significant amount of damage, especially on the onset of inelastic deformations, was not reflected through the predicted fundamental period.

It was noted however that the proposed procedure to evaluate the stiffness loss of the URM walls provided a net amelioration compared to the original damage index.