Structural assessment of a beam-columns structure – identification of close vicinity

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RESUME In the context of sustainability, the durability of the refurbished buildings involves structural retrofitting also. But the assessment methods for evaluating the actual state of such structures are still in progress. For instance, vibrational methods use to define the structural state of a beams-columns structure, conflict with the interaction with vicinity effects. The present paper proposes to define the close vicinity of a structural element, in which most of the effect is gathered. Here, the study was undertaken on a small scale structure made of a single beam – several columns structure. An experimental sample, as well as the numerical model of such a structure, was undertaken. The numerical results indicated that the close vicinity reduces to the two adjacent spans on each side of the considered one. Beginning from one corner of the beam, the actual state of the structure can be totally identified from one span to the next. The experiment results are in good agreement with the numerical results, thuswise this method should be applicable to a damaged structure also.

Mots-clefs structural health monitoring, close vicinity, beams-columns structure, step by step determination.

I. INTRODUCTION

Two major structural failures occurred in the last years in France, with the collapse of a building in Marseilles and more recently with the seismic damages caused on old masonry houses in the town named Le Teil. These two events remind us that the possibility of a significant structural defect of buildings should not be neglected. This should be even more considered when the refurbishment of the building is planned. The current standards allow the improvement of a building comfort (energetics, acoustics, health) without structural requirement, as soon as the mass of the building does not change (EN 1998-1: 2004). As pointed out in (Bournas, 2018), this approach could lead to economical loss during a major earthquake. Without strengthening consideration, this could lead to the structural destruction or the detachment of thermal insulation of refurbished buildings. In that manner, it could even make more sense to take into account both thermal conditions and seismic zoning to decide whether thermal, structural or both retrofitting are required (Mistretta et al., 2019). On the other hand, the structural diagnosis of the current state of a building is still an ongoing work. The actual frequencies and mode shapes of a multi-storey building can be assessed with ambient vibrations (Hans et al., 2005). From this reference, a global behaviour is targeted and the location of possible damages is not deducible from this technic. More recently, the effect of local damage on the behaviour of a structural element was carried out with accelerometers measuring ambient vibrations (Sentosa et al., 2019). Here, the damages are supposed to be concentrated in a finite number of points, which behaviour can be regarded as a plastic hinge, while the rest of the structure is assumed to be elastic. One issue of this method concerns the effect of the boundary conditions on the measured natural frequencies (Figure 1b). Interaction was observed between the natural frequencies of the studied element and the metallic frame if their values are close (Figure 1a). It seems that the deduced natural frequency does not correspond to the intrinsic frequency of the structure because of this vicinity effects. As a consequence, the intrinsic behaviour of the studied element is difficult to access. At the building scale, a huge number of accelerometers would be required to deduce the natural frequencies of the whole structural elements constituting the building. Hence, the study should be carried out in a partial area in turn. As a result, the same vicinity effects would bias the computed frequencies. An alternative method is required in order to establish these characteristics correctly.

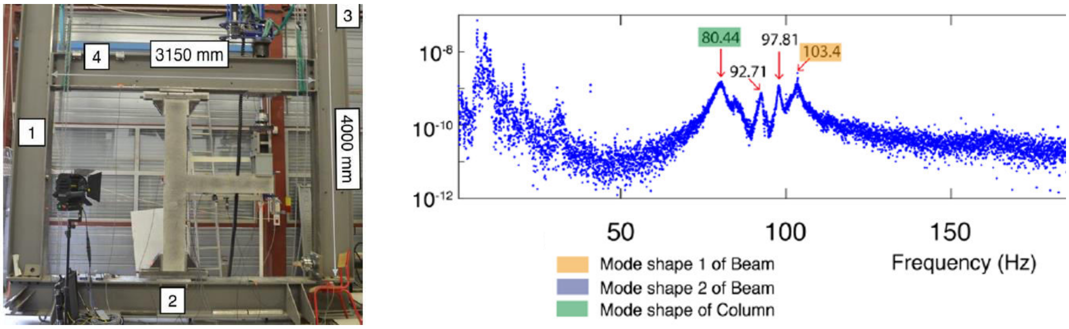

FIGURE 1. **Experimental configuration and interaction of the metallic frame with the structural element.**

II. DEFINITION OF A CLOSE VICINITY

A quasistatic method was elaborated here, as an alternative to the vibration method of identification. For the sake of simplicity, a concrete structure made of a single beam with 6 columns is considered next (Figure 2). The problem is bidimensional and the sizes chosen in the following are near to a 1:5 small scale of a real construction. The beam and columns sections are a square of side 60mm and their connections are assumed to be rigid first. The free parts of the beam and the columns are 550mm long. The columns are inserted on another bottom beam, whose section of 150 * 250 mm^2 ensure to behave as a fixed boundary condition. Let us consider a vertical load acting in the middle of the left span. This problem is close to the configuration of a continuous beam so that the effect of the loading becomes negligible far from the span on which the loading is applied. In other words, the loaded span is influenced by itself and by the part named “close vicinity”, while the rest of the structure can be neglected and considered as the “far vicinity” (Figure 2). This assumption is confirmed by modelling the corresponding structure with a finite element model. Five configurations were tested, from a single span to five spans, to capture the effect of the vicinity. In each case, the loading involves a vertical load of 500 N, applied on the middle of the left-most span. For example, the case with three spans seems that two spans are neglected.

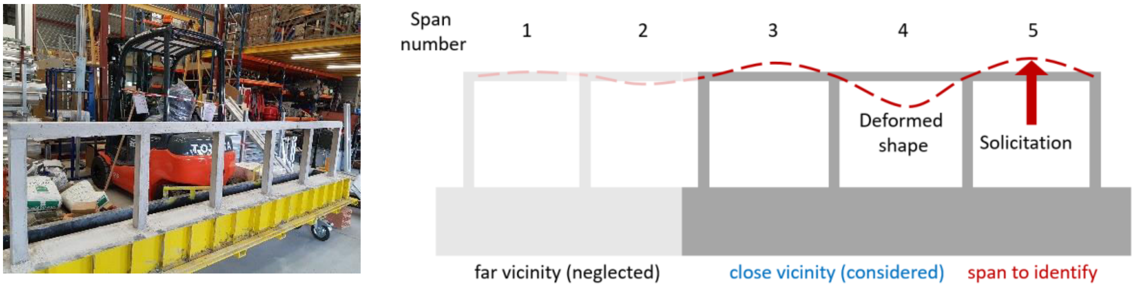

FIGURE 2. Beam-columns structure considered and definition of far and close vicinity.

Table 1 regroups the vertical displacement of the loaded point for each configuration. It shows that the relative variation of displacement is significant when considering a single or two nearby spans, while the effect of a supplementary span becomes tiny. Thus, the close vicinity involves the two adjacent spans located on each side of the considered span.

TABLE 1. Effect of the number of spans on the vertical displacement

Number of spans	Vertical displacement (mm)	Relative variation (%)
1	0,02932	-
2	0,02734	6,75
3	0,02688	1,68
4	0,02683	0,19

As a consequence, this method could be used to determine the current state of the right corner span, as in figure 2. Its characteristics are completely identified from the behaviours of span number 5 and spans number 4 and 3 also. Experimentally, this can be achieved if these three spans need to be instrumented simultaneously. Then, characteristics of the span number 4 are identified by considering the behaviour of span number 2, 3 and 4, as well as the intrinsic characteristics of the newly identified span number 5. Finally, a method from one span to the next is used to establish the complete state of the span and the structure.

The experimental study corresponding to figure 2 is planned shortly. This structure was carried out with a traditional concrete. A steel reinforcing cage was positioned in the bottom beam, while only one bar was inserted in the beam-columns structure. These bars of 6 mm diameter aim to avoid any shrinkage cracks. Moreover, they are positioned in the middle part of the section, to minimize their influence on the flexural behaviour. The bottom beam was clamped in four steel vices, which were laid on a flat floor in order to prevent the parasitic displacements. The applying load corresponds to a vertical load of 500 N, applied onto the middle of the right span, first. This small loading was chosen so that the displacements could be retrieved whilst avoiding any tensile crack occurrence. Digital image correlation (DIC) technic is used to determine the displacement shape (Vacher et al., 1999). At the current time, the first measurements were carried out. The efficiency of the DIC technics allows an accuracy of displacements measurement less than 2 µm.

The displacements computed along the beam confirm the presence of close vicinity that can be defined by the two first spans. However, the experiment still requires some improvement, as the displacements exhibit significant fluctuations, compared to the corresponding numerical model. Further investigations are required to establish the reasons of these variations.

III. PERSPECTIVES: APPLICATION TO A DAMAGED STRUCTURE

In the case of a damaged structure, with damage concentrated in a finite number of locations, the same method can be applied. Indeed, the damaged of the section at one place involves the relief of the flexural moment, so that the effect of the left part of the structure on the right one is reduced.

The characteristics of each span of the beam are assumed to be clearly identified, as no damage takes place on it. On the other hand, undetermined imperfections are represented by semi-rigid connections, which are assumed to be located in each connection. This one can be quantified with the fixity factor p (Sucuoglu, 1995) that could be identified by using a least square method Then, a nonlinear behaviour could be obtained with the creation of local notches in the beam. Damage detection method could be applied to retrieve the location of the corresponding defects, before quantifying them with the previous method. Then, vibrational methods are also planned to establish if close vicinity can be defined for dynamic loadings. If efficient, these technics could be used at building scale, to assess their current structural state. Finally, the effect of the damages on the close vicinity will be established.

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