APPLICATION OF ROTATION RATE SENSORS IN STIFFNESS "RECONSTRUCTIONS" OF STRUCTURAL SYSTEMS

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1. Introduction

In some areas of Structural Health Monitoring (SHM) e.g. for civil engineering structures (reinforced concrete (r/c) beams, frames or masonry structures), it is not possible to localize damages in form of simple 'cuts' and localized stiffness losses as it is usually assumed in SHM. Instead more difficult tasks have to be undertaken, aiming at formal ”reconstructions" of spatially distributed stiffness variations (e.g. [1]). The problem of such “reconstructions” is particularly complicated for r/c structures due to the presence of multiple cracks even during their normal exploitation and under regular service loads. Recently, techniques of directly measuring angle variations have emerged [2] and matured to achieve angular resolution of 10^{-3} degrees. Thus, in addition to transversal accelerations, it is now possible to measure angle variations along the bar axis during vibrations of the structures. This way, the changes in curvature of the axes of the bars of the structures can be obtained almost directly. Numerical simulations demonstrated many potential advantages for these new angular measurements [3, 4]. The key advantage of rotational measurements for r/c structures is the ability to infer strain from rotation. Another particular advantage is the possibility to monitor plastic hinge development during seismic vibrations using two rotation rate sensors, as shown in Figure 1.

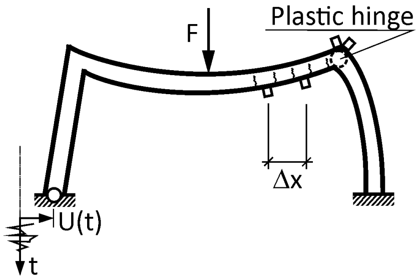

Figure 1: R/c frame with 2 rotation sensors measuring strain and other 2 to monitor plastic hinge

Before full scale, 'in situ' dynamic experiments one should carry on small scale laboratory tests. For this purpose, the Horizon HZ1 100-100 rotation rate sensors were chosen. Our presentation for the 41st SolMech will report results of experiments carried out using the Horizon sensors and plexiglass models of beams. In what follows a short description of the experiments is presented. Details of the methodology are given in paper [4], while the experiments are reported in the reference [5] and a very recent paper (see ref: [6]).

2. Description of the experimental set up

Consider vibrations of a cantilever beam under kinematic excitations, $u(t)$, (Figure 2). The vertical motion $u(t)$ of the plexi beam support was obtained by its kinematic movement using an actuator acting in the vertical direction on a 6 m, steel beam bearing, in the middle, the plexi model. The model beam dimensions were: h=1.45cm, b=11.45cm, L=80cm, Young modulus E=3.427·10^9N/m^2 and mass density 1203kg/m^3.

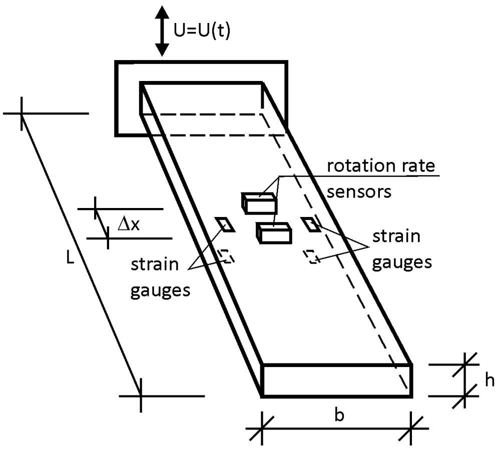

Figure 2: Sketch showing experimental set-up to measure direct strain and rotations of a beam

3. Indirect strain sensing

During this experiment, a seismic signal $u(t)$ drove vertical motion of the beam while the strains $\varepsilon(t)$ and rotations $\vartheta_1(t)$, $\vartheta_2(t)$ were simultaneously measured. Comparison of direct strains and strains derived from rotation difference $\Delta\vartheta$ using simple formula $\varepsilon(t)= h\Delta\vartheta/(2\Delta x)$ led to an accuracy of about 3% for Δx =10cm

4. Local stiffness modification

During this experiment, two measurements were carried out using the setup of Figure 2. The first experiment was done for an intact beam, the same as in previous experiment. Before the second experiment, a 20% stiffness drop was introduced to the beam by drilling holes in the plexiglass beam between the sensors, of Figure 2. The measured rotation rate differences of the intact and weakened cross section were integrated to obtain $\Delta\vartheta(t)$ and compared. A value of 9.6% maximum difference was obtained. Measuring such the stiffness drops could model early stages of plastic hinge development during e.g. seismic excitations (Figure 1).

5. Stiffness "reconstruction" using sets of translational and rotational sensors

During this experiment, the intact beam was excited by small, diagnostic, vertical, kinematic harmonic excitations $u(t)=u_0\sin(2\pi ft)$. Next, along the beam, starting from its support, three equally long sections of 15%, 30% and 45% cumulated stiffness drops were produced to mimic distributed structural "damage" similar to typical flexural stiffness losses of r/c beams. Respective mass losses were compensated by gluing additional ballasts to the beam. Calculations of the stiffness losses based on the changes in dynamic responses were done by measuring the amplitudes of the harmonic vibrations of the "damaged" beam and using special inverse problem algorithms [4]. Application of only translational sensors failed to "reconstruct" the bending stiffness loss distributions, while application of rotation rate sensors made the "reconstruction" successful with reconstructed stiffness drops 14%, 33% and 46% (see [5] for details).

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