5th IWGoRS workshop, Sun Moon Lake, Taiwan, September 22-26, 2019

Testing rotation rate sensors in structural health monitoring

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(abstract)

1. Introduction and problem statement

Rotation rate sensors find application not only to extend the inventory of seismology but also in structural vibrations monitoring, see e.g. Schreiber et al., 2009, [1]. The evolution of natural frequencies with structural damage often do not properly reflect local stiffness losses. Since the advent of new, rotation measuring techniques a possibility of directly measuring angle variations of beam axes have emerged [2] and matured to achieve angular resolution of 10^{-3} degrees. Thus, it is now possible to measure angle variations along the bar axis during structural vibrations. This way, the changes in curvature of the bar axes can be obtained. Numerical simulations demonstrated many potential advantages for these new angular measurements, [3, 4]. The key advantage of rotational measurements for reinforced concrete (r/c) structures is the ability to infer strain from rotation even in the presence of multiple cracks which is inherent for the r/c structures. But particular advantage is seismic engineering applications it is the possibility to monitor plastic hinge development using two rotation rate sensors, as shown in the right corner of the frame shown in Fig. 1.

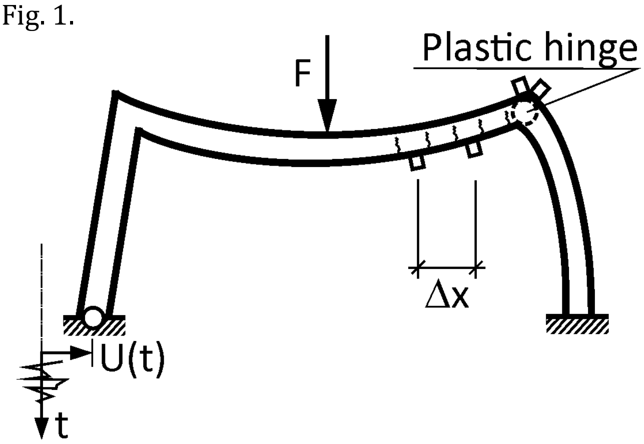

Fig. 1 Plane r/c frame under seismic excitations with two rotation rate sensors measuring strain and other two attached to indicate plastic hinge development

Consider vibrations of a frame from Fig. 1 or a cantilever beam under kinematic excitations, $u(t)$, as shown in Figure 2. For the Euler-Bernoulli beam one can also write well-known relations between the angle of beam axis, ϑ, radius of curvature, ρ, and strains at the beam surface, $\varepsilon_{\max}$:

$$\frac{1}{\rho} = \frac{\partial \vartheta}{\partial x} = \frac{\partial^2 w}{\partial x^2} \approx \pm 2 \frac{\varepsilon_{max}}{h} \quad (1)$$

Using rotation rate sensors respective rotational velocities (rotation rates), $\dot{\vartheta}$, are measured. Thus one needs to re-write the equation for the approximate velocity of strains, $\dot{\varepsilon}_{max}(t)$, in terms of beam height, h, distance between two adjacent rotation rate sensors, Δx (Figs. 1 and 3), and the difference in the measurements of these two sensors, $\Delta\dot{\vartheta}(t)$:

$$\dot{\varepsilon}_{max}(t) \approx \pm \frac{h\Delta\dot{\vartheta}(t)}{2\Delta x} \quad (3)$$

This way one can indirectly estimate strain by measuring rotation rate differences which is crucial to monitor stiffness variations of cracked r/c structures.

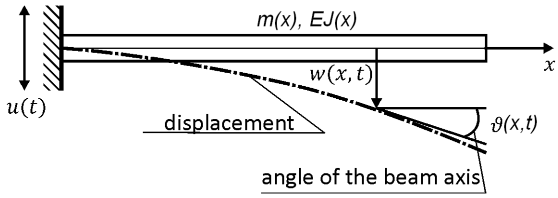

Fig. 2 Euler-Bernoulli, cantilever beam under vertical, kinematic excitations $u(t)$

2. Methods of research and results

Our presentation for the 5-th IWGoRS will report results of laboratory experiments carried out using three models of rotation rate sensors: Horizon HZ1 100-100, Gladiator G150Z-100-100 and low cost MPU-6050 sensors used in modern motion-based controllers e.g. in smartwatches or drone applications. The reported experiments deal with small, approximately 70cm long plexiglass beam models excited kinematically in vertical direction. The range of experiments cover:

a) comparison of measured strain determined from rotational measurements,
b) assessment of localized stiffness drop using two rotation rate sensors,
c) quantification of localized stiffness drops to emulate plastic hinge formation monitoring
d) vibration-based stiffness "reconstructions" of a beam using sets of rotation rate and translation acceleration sensors.

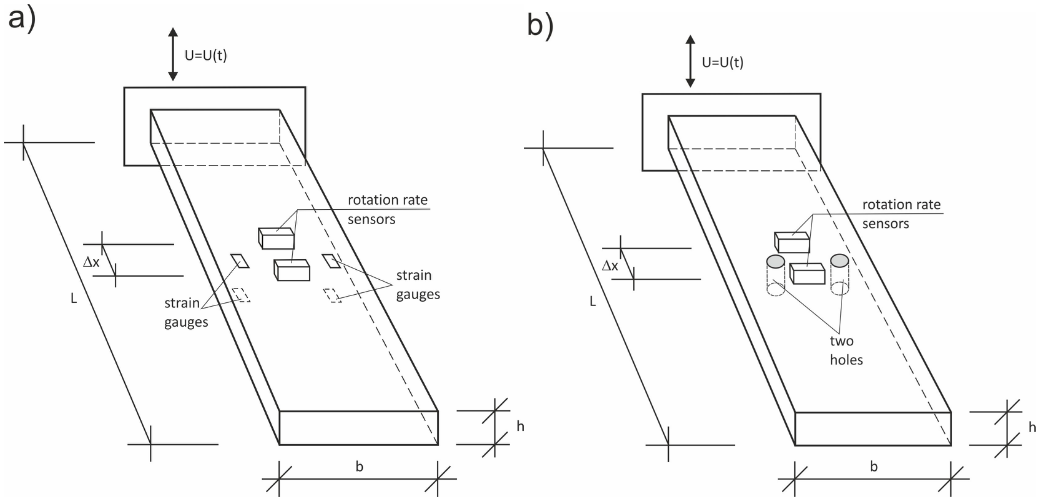

Fig. 3 (a): Sketch showing plexi-beam model with two rotation rate sensors with distance Δx and strain gauges, to verify rotation rate strain estimations.
(b): the same system without strain gauges but with 2 holes drilled to emulate localized stiffness loss

The experiments proved that rotation rate sensors have potential to dramatically improve SHM of civil engineering structures and with improved accuracy, these sensors can find wide application in on-line and post-earthquake structural assessment. Details of the measurement program and some of the results can be found in refs. [5, 6]. During the 5-th IWGoRS the presentation will be extended to include recent experiments on plexiglass beams as well as on real size r/c beams. This will complement other interesting applications of rotation rate sensors like the assessments of interstory drift, [1].

References

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