Localization of walking load in concrete slabs

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Problem statement

› The work presented here use guided wave characteristic to localize impact source by a correlation technique that mimick time reversal.
› Time reversal in acoustic is a very efficient solution to focus sound back to its source in a wide range of material including reverberating media : a wave still has the memory of its source location.
› Previously applied in ultrasonic in the 2000's at Institut Langevin [Ing, 2005], we implement localization technique for building use.
› Guided waves in concrete slabs have specific characteristic : we show through experimentation that it is possible to adapt the localization technique.

State of the art

› In plate localization technologies :

— Surface acoustic wave absorption
— Triangulation process
— Amplitude disturbed ultrasonic wave diffraction pattern
— Pressure sensors in tile

Applications

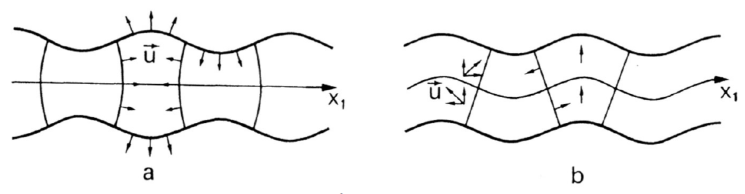
› Applications to localization of foot load in concrete slabs are multiple :

— Flow measurement
— Man-machine interface
— Home automation

Guided wave in plates

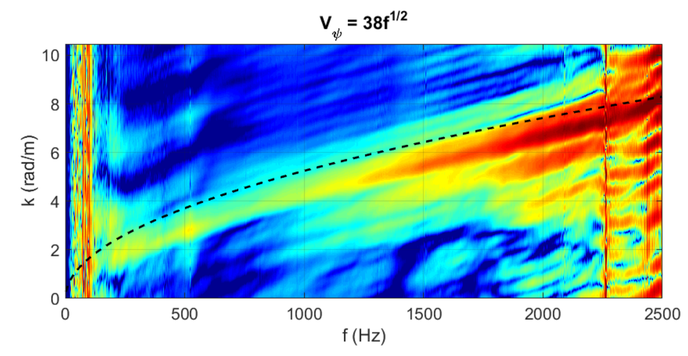
› The system function on the detection of the anti-symmetric Lamb waves, which is the main acoustic energy propagating in thin plates (where $\lambda \ll 2h$ with λ the wave length and $2h$ the plate thickness).

— Lamb waves are guided dispersive waves formed by interference of longitudinal and shear waves [Viktorov, 1967]



Lamb waves in plate : (a) S_0 and (b) A_0 mode

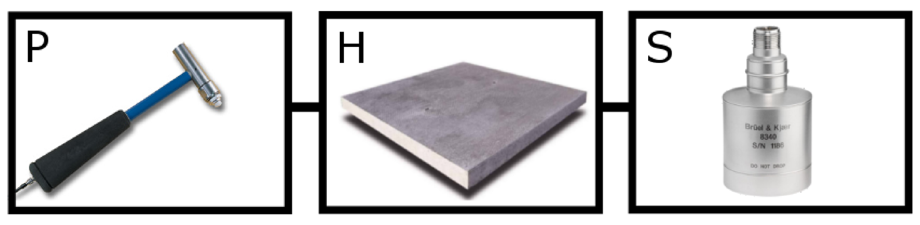
— At low frequencies, only the S_0 and A_0 mode exist. The latter dispersion curve approach the bending wave velocity and varies as $\sqrt{f}$



Feat of the dispersion curve of the concrete slab of the laboratory (only A_0 mode is visible)

Localization technique

› The localization technique is based on two fundamental principel : the time reversal focus sound back to its source [Ing, 1998] and reciprocity enable to reverse emitters and sensors position [Cassereau, 1992].
› It involves the comparison by cross-correlation between impulse responses recorded on a discretized surface and impact on the surface.
› This technique of acoustic imaging is comparable to a simulation of time reversal : the cross-correlation gives a focalisation pattern all the stronger as the signals are related.

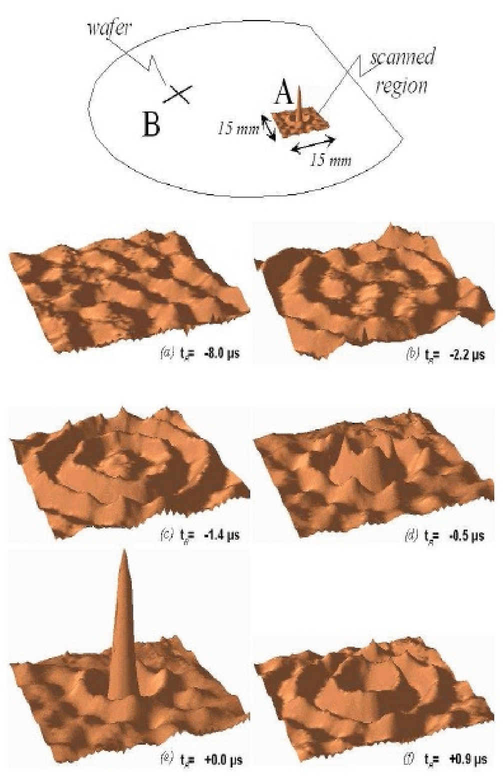


Impulse response block diagram : position of impact P, medium H and sensor S

Cross-correlation coefficient $C_{ij,1}$ between sensor S_1 and positions P_i and P_j is :

$$C_{ij,1} = P_i H_{i,1} S_1 (P_j H_{j,1} S_1)^*$$
$$\rightarrow C_{ii,1} = |P_i|^2 |H_{i,1}|^2 |S_1|^2$$

We use a 2^{nd} sensor to avoid P phase [Ing, 2007] :
$C_{i,12} = |P_i|^2 H_{i,1} H^*_{i,2} S_1 S^*_2$
$C_{ij,12} = C_{i,12} C^*_{j,12}$
$= |P_i|^2 |P_j|^2 H_{i,1} H^*_{j,1} H^*_{i,2} H_{j,2} |S_1|^2 |S_2|^2$



Time reversal cavity

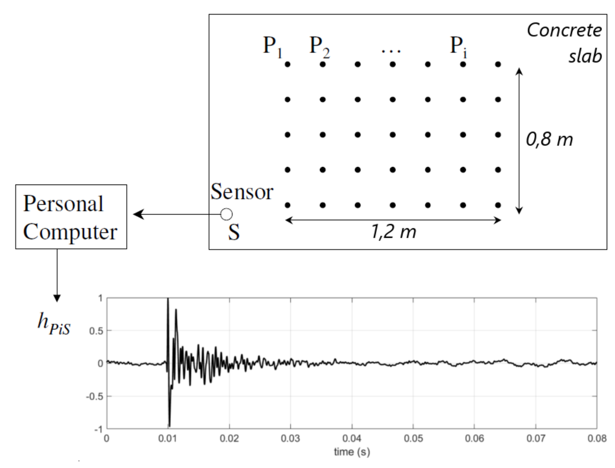
Experimental design

› The experimental design includes two steps : one first spatially dicretize the surface and record the impulse responses h_{PS} between impact position P_i and sensor S. To this end, the sensor must be designed to specific signal characteristics in concrete slabs :

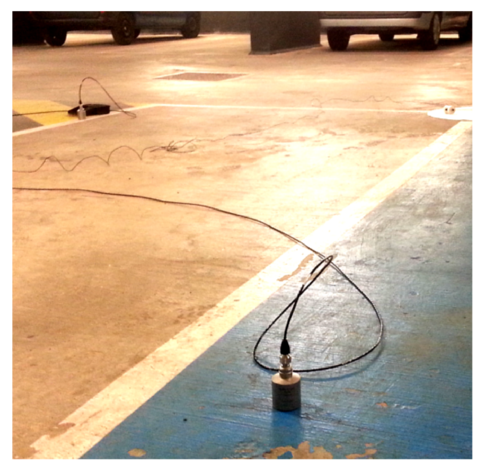
— Noise acceleration level : 65dB
— Footfall peak : 97dB ($7.5e^{-3}$g)

› Sensor characteristic :

— B&K sensitivity : 10V/g
— B&K noise : $5e^{-2}\mu g/\sqrt{Hz} = 25dB(1kHz)$



Concrete slab discretization

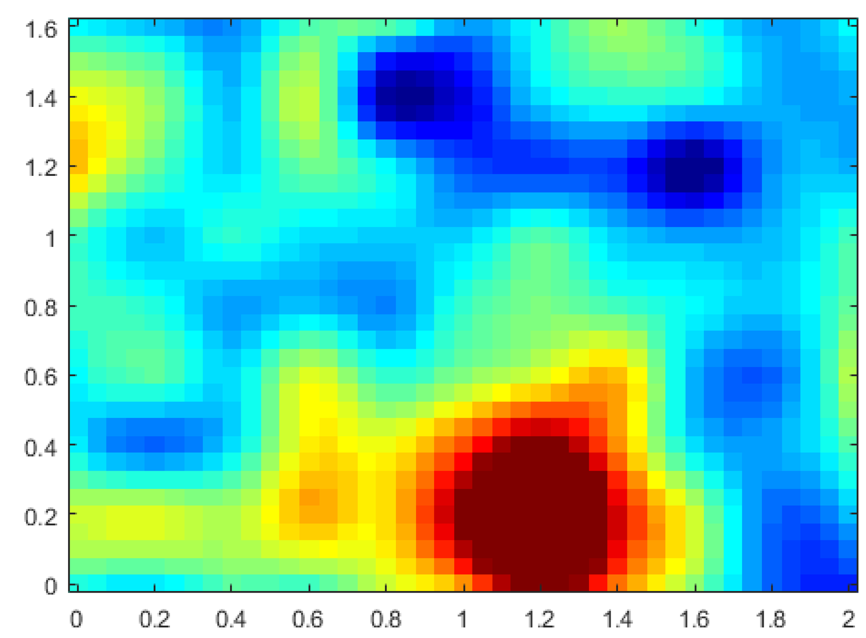


Sensor B&K in the parking of the laboratory

Results

› In a second step, the new impulse response is time reversed and virtually re-emitted by the sensor. We compare the impulse response from one point of the surface with the recorded ones.

— Band width 500-1500Hz
— Grid : 20cm
— Area$> 10 \times 10$m^2

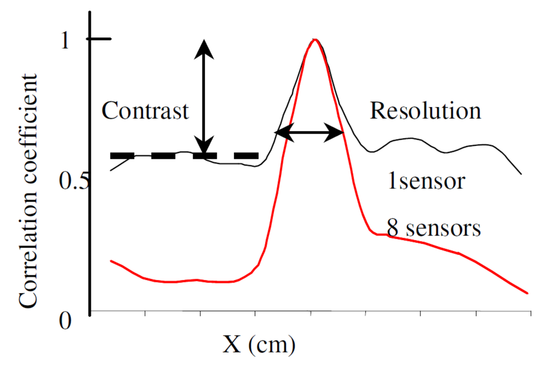


Correlation coefficient of a footfall on a concrete slab ($2 \times 1.6m^2$) maximum of correlation : 87%; contrast : 2,3

Contrast C_t

› The maximum to ground level ratio of the correlation coefficient is theoretically linked to the band width, which is in good agreement with our results.

— Maximum peak to ground level ratio $C_t \geq 2$
— N sensors : $C_t \rightarrow \sqrt{N} C_t$

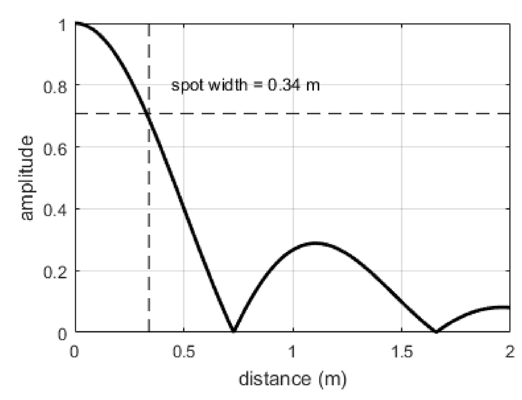


Typical normalized correlation patern

Resolution

› The focusing patterns show a -3 dB width in good agreement with the diffraction theory and corresponding to the dispersion law in a cavity.

— Experimental resolution at -3dB width : 36cm
— Theoretical resolution : $J_0(kr) = 34$cm (with k the wave number)
— Diffraction theory limit : $\frac{\lambda_{1,5kHz}}{2} = 50$cm



Theoretical spot width

Outcome

— Localization of impacts in concrete slabs
— Using cross-correlation product to mimick time reversal process
— Resolution and contrast are the main characteristics

Outlooks

— Enhance contrast and avoid false detection
— Use inexpensive sensors
— Simplify implementation (wave superposition method)

Fête de la science 2017 - inside the laboratory

References

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