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TRIGS

TRIGGERING INSTABILITIES IN MATERIALS AND GEOSYSTEMS

Sixth Framework Programme (FP6) - STREP

New and Emerging Science and Technology Pathfinder (NEST)

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Introduction

The purpose of this WP was to establish the effects of triggering in heterogeneous materials at the laboratory scale. In particular, this Task 1.2 was to be devoted to triggering the shear experiment present at CNR in Rome. The apparatus consists of a circular *Couette* shear cell, filled with some granular medium (GM), and sheared by an overhead rotating plate *via* a torsion spring. The apparatus is principally intended as a greatly simplified earthquake fault, slowly loaded from overhead, and is considered a more complex version of the simple slider-block experiments of Task 1.1.

More specifically, this task focussed on the application of vibrations to the apparatus in question, in order to reveal how the properties of granular friction change when subjected to vibrations of various types. Here we have conducted experiments in which the frequency and intensity of the applied vibration was varied.

In order to apply vibration, the circular channel in which the top plate moves was mounted on a Type 4809 Bruel & Kjaer Vibration Excitor, through 4 diagonal struts bearing the weight. Initial trials clearly indicated that the vibration had a strong effect on the overall dynamics of the system as illustrated in deliverable D1.2.1 (fig. 5) – the top plate changed from clear quasi-periodic stick-slip to a noisy steady sliding.

It was desirable to establish the differing effects of vibration on granular friction for different heights of a granular sample. For this reason, we chose 3 & 9 layers as being respectively below and above the “critical depth” (above which the GM completely screens the channel floor) observed in other experiments (see appendix, fig. 7). We have applied various vibration excitations to the GM as illustrated in the table below.

Series	Layers	Drive (rad/s)	Vibration Γ_{RMS}	Vibration type	Frequency (Hz)
A - ref	0 - 13	0.01 - 10	0	None	
B1	9	0.01 - 0.3	0 - 1	Square 175Hz	175
B2	9	0.01 & 0.3	“High” & “Low” *	Sine freq. sweep	10 - 1000
C1	3	0.01 - 10	0 - 10	Sine ampl. sweep	190Hz
C2	3	0.01, 10	“High” & “Low” *	Sine freq. sweep	10 - 1000

** Vibration intensity not trivially imposed during frequency sweeps due to resonances*

We first consider the case of a deep granular medium, with 9 layers. The first surprising result, shown in figs. 1 & 2, demonstrates that the stick-slip state of the GM can be destroyed by applying a bare minimum of vibration, in this case 0.02g RMS – just four times the measured background level of vibration. The steady-sliding state is naturally less affected by vibration. More surprising is the effect of the vibration on the friction, shown in fig. 2, where we observe that steady-sliding experiments are almost unaffected by vibration. Stick-slip experiments, however, observe a 25% decrease in friction as vibration is applied. We may assume that the slight vibration destroys granular contacts in slow shear whereas in fast shear, friction is dominated by collisions.

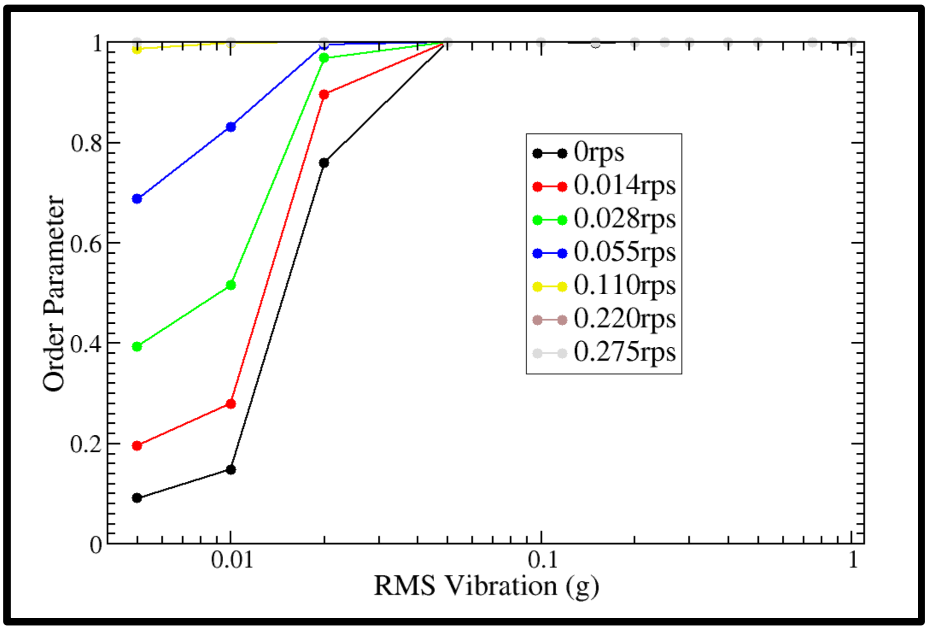

Fig. 1 – The effects of applying vibration to the sheared GM. Fast experiments are always 100% fluidised, but slow experiments, normally stick-slip, become steady-sliding with a bare minimum of vibration.

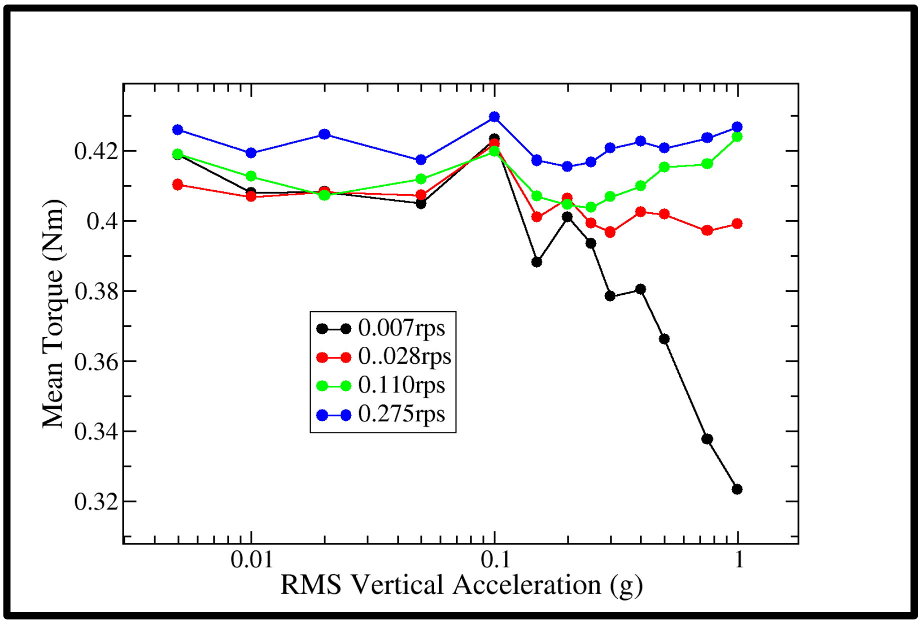

Fig. 2 – The vibration has little effect on the friction coefficient of fast shear experiments, whereas slow-shear demonstrates a 25% reduction in friction.

The second set of experiments consisted in altering the frequency of the applied vibration, while maintaining a roughly constant intensity. Once again, the fast shear experiments (blue and red in fig. 3) are largely unaffected by the vibration, maintaining a constant friction during the test. The slow shear experiments, on the other hand, were greatly affected, in particular with a larger vibration amplitude (green in fig. 3). Here we have a very anomalous response from the GM indicating that there is considerable complexity yet to be explained. For example, the biggest friction reduction at appx. 15Hz might possibly be linked to a resonant frequency of the channel mount (appx. 14Hz), however the remaining reductions (~30Hz, 100Hz, 300Hz) are of unknown origin.

Additionally, fig. 4 shows the Order Parameter for the same slow shear experiment. Clearly, some frequencies (150-180Hz, 400Hz) excite the system in such a way as to completely fluidise the GM, without any consistent effect on the frictional properties.

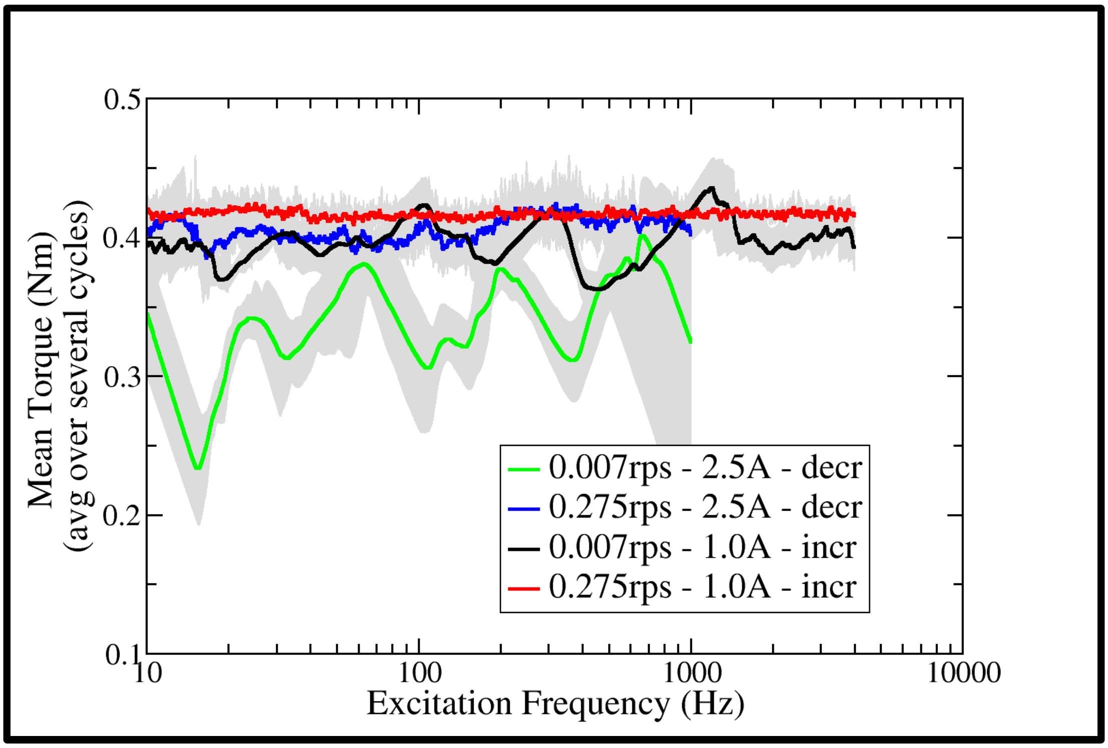

Fig. 3 – The frictional properties of a shaken GM as a function of the excitation frequencies. Fast shear is largely unaffected (blue & red) whereas slow shear shows strong dependence, particularly for high intensity shaking (green).

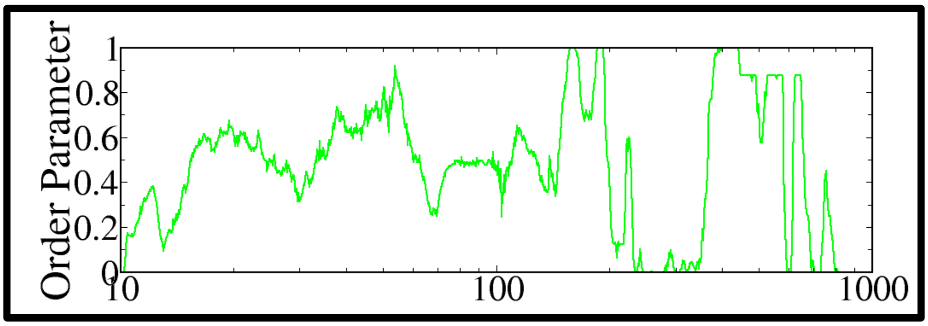

Fig. 4 – The Order Parameter of the slow-shear high-intensity experiment (green curve) of fig. 3. The GM shows strong dependence on the vibration frequency under these conditions.

We now consider the case of a thin granular layer, that is, with approx. 3 layers of GM, and perform the same frequency response analysis of the previous section. Here we observe a strikingly different behaviour – firstly fast shear (red & black curves) **does** observe a slight alteration in the mean friction for low frequency vibration ~15 Hz (again, possibly related to efficient vibration at the apparatus response resonant peak). The slow shear experiments (blue & green) instead show a strong dependence, with an almost 50% friction reduction at 15Hz. The anomalous response present with 9 layers of GM is no longer evident and, once above 15Hz, the granular friction remains constant. However, as before, the inset to fig. 5 shows that there is a highly variable fluidisation even when the friction response remains constant. There is a broad peak in the Order Parameter around the 15Hz frictional minimum, but in the constant response regime (>30Hz), the fluidisation fluctuates significantly and rapidly.

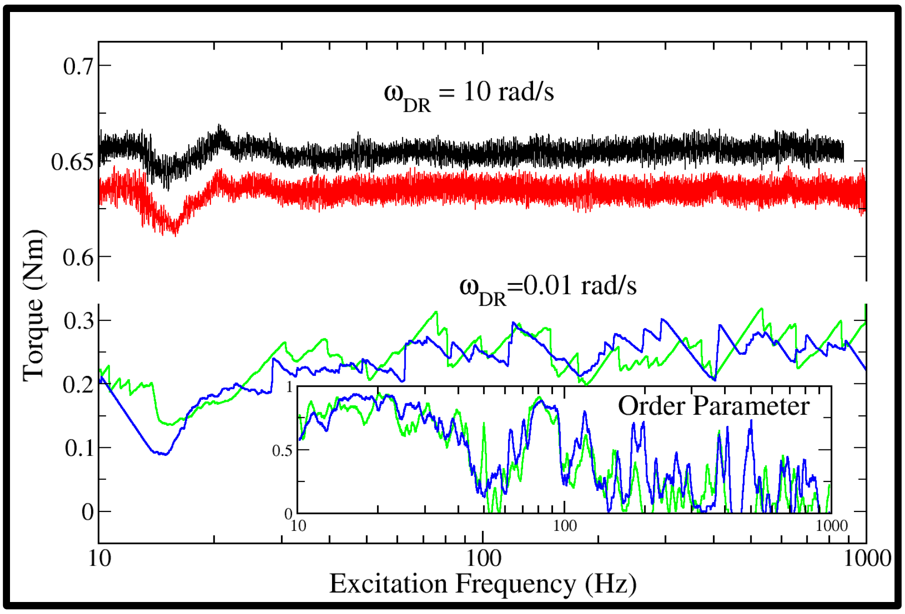

Fig. 5 – The friction response of a thin granular medium (3 layers). Fast shear and slow shear show no response above ~30Hz, and a minimum at ~15Hz. There is a 50% friction reduction for slow shear experiments at 15Hz.

Finally, we consider the amplitude response of the thin granular layer. Though the data do not have sufficient resolution to explore the regime of weak vibration we can nonetheless observe the effect an increasing vibration has on the system as shown in fig. 6. The black curves show the mean friction as a function of driving speed, and reproduce results previously obtained. The blue curves, however, referenced on the right axis, indicate whether vibration causes an increase or a decrease in friction. Consistent with our earlier graphs, we find that slow shear experiments undergo a decrease in friction, while fast shear undergoes a mild increase, though in all cases the effect is much weaker here than in the previous case with a deep granular layer.

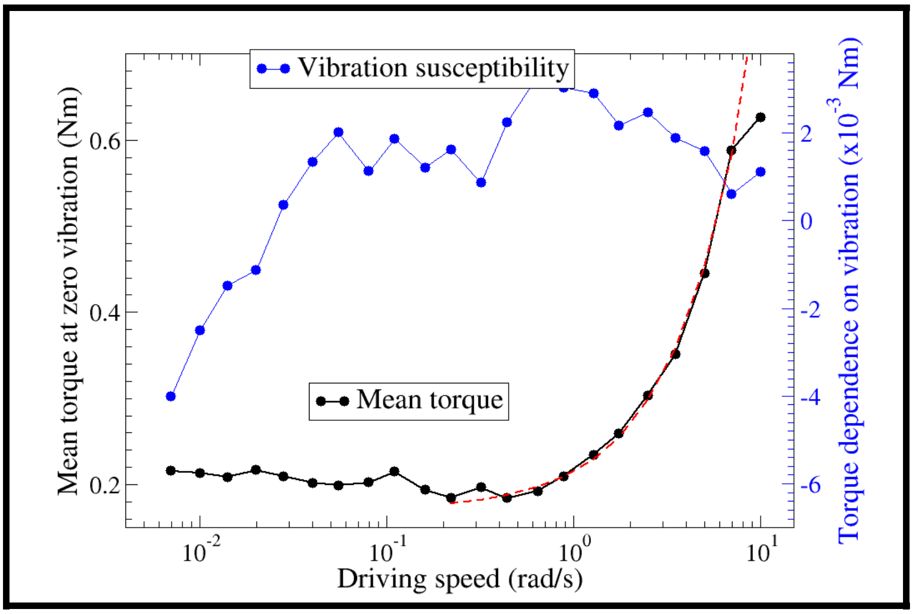

Fig. 6 – The friction response to vibration intensity for a thin granular layer. The blue curves indicate that, for slow shear, there is vibration weakening, while for fast shear, there is a slight vibration strengthening.

Appendix: Transition from thin to thick layer granular friction.

Is a series of reference experiments, we have observed that there is a transition from thin-layer behaviour to thick-layer behaviour as additional granular material is added to the channel. Fig. 7 shows how the mean frictional torque and the mean fluidisation change as the granular bed is deepened. Clearly, fast shear experiments show 100% fluidisation (O=1) almost all the time, whereas show shear experiments arrive at a constant value of O when there are 5 or more layers. The frictional torque also reaches a constant value at 5 layers (slow shear). Fig. 8, below, represents the distribution of slip-events in the slow-shear experiment. Below 5 layers, there is a single large characteristic size event superimposed on a broad distribution of small events. Above 5 layers, however, the single large size event vanishes and is replaced by a power-law distribution of events across all scales.

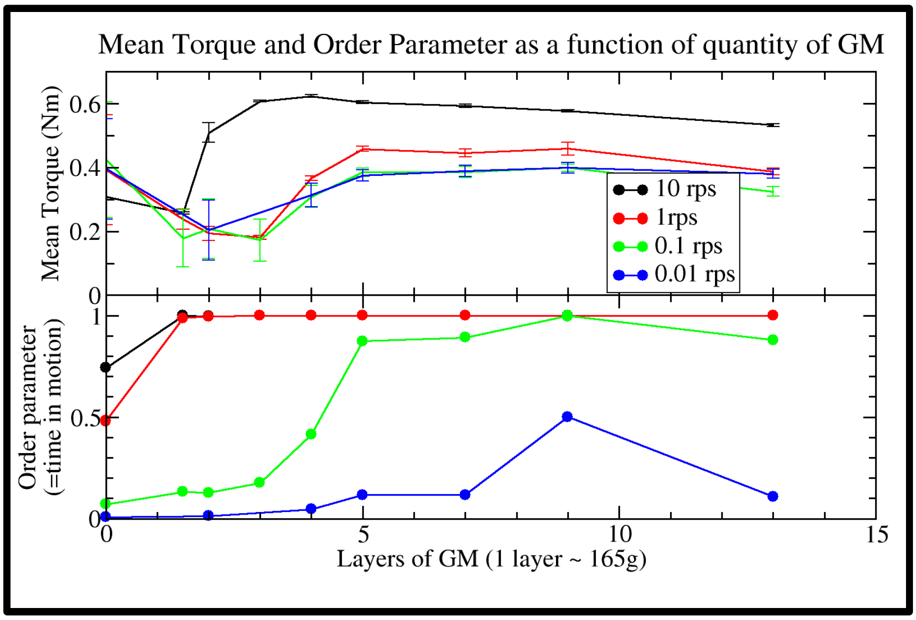

Fig. 7 – The frictional properties and the Order Parameter of the slow shear experiments demonstrates a transition from thin to thick layer behaviour at 5 layers.

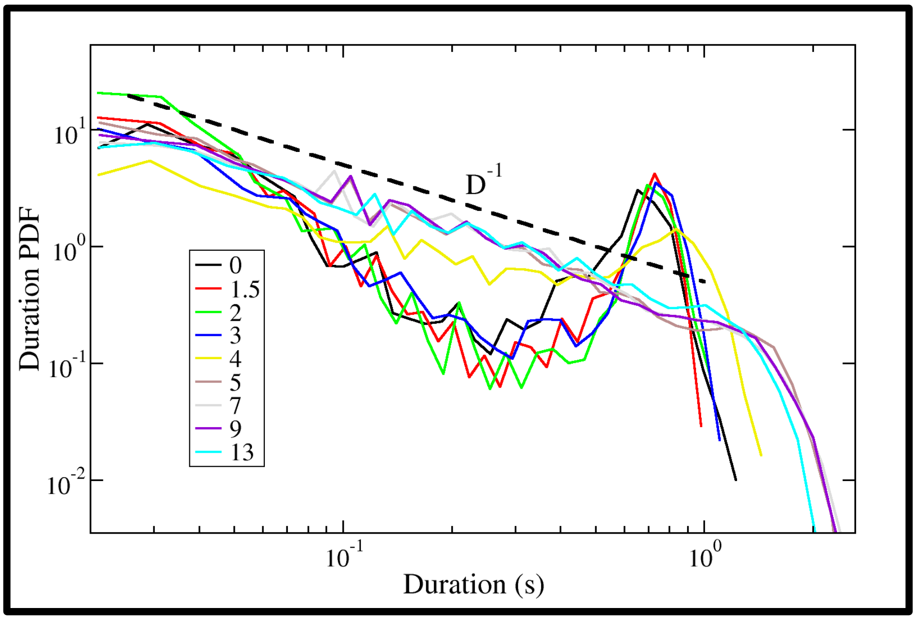

Fig. 8 – The slip event distribution shows the same transition for slow-shear (no such distribution exists for fast shear), again, at 5 layers.