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Development of a model to quantify dust emissions from truck traffic on earthmoving sites: approach and preliminary results

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Abstract:

Dust emission is a major issue in general but even more for civil engineering professionals. This is particularly important on earthmoving sites with truck traffic on compacted soils. Suspended dust causes many troubles, including visibility mitigation, which leads to safety risks. To prevent the lift of particles, soils are watered abundantly. When carried out in an arbitrary way, this solution can lead to a significant waste of this natural resource. Savings could be achieved by anticipating the necessary and sufficient quantities for dust suppression. For this purpose, a model is being developed to highlight and quantify the main factors involved in the lifting of soil particles by truck traffic. The approach adopted for the development of the model together with the preliminary results are presented. Soils degradation by traffic are studied in laboratory in order to assess the accumulation of particles on the surface. These particles are lift due to mechanical and aerodynamic forces, which are studied in test track and wind tunnel, respectively. This study allows to characterize the mechanism of dust emission on construction sites by

relying on physical parameters that are not considered in the empirical models currently available.

Keywords:

Dust emission, Truck traffic, Earthworks, Soil mechanics, Wake flows, Water savings.

1. Introduction

In an increasing stringent context of improving air quality, limiting dust emissions generated by human activities is an overriding objective for environmental and public health issues. Soil degradation is a major factor of particulate matter suspension in the atmosphere. It is caused in particular by vehicle traffic on unpaved roads. Due to the contact between the wheel and the ground, the aggregates of soil particles can be torn off and then crumbled. This leads to the formation of fine particles which are prone to fly away when vehicles pass by or because of the wind and related aerodynamic processes (ETYEMEZIAN *et al.*, 2003; GILLIES *et al.*, 2005; KUHNS *et al.*, 2010).

Airborne dust suspension leads to health issues (POPE & DOCKERY, 2006) as well as visibility mitigation (MOOSMÜLLER *et al.*, 2005; BADDOCK *et al.*, 2014). This involves significant safety risks, particularly in areas with vehicle traffic (ASHLEY *et al.*, 2015).

On earthmoving sites, the truck traffic on runways is a major source of dust (MULESKI *et al.*, 2005). The most common method to minimize particle lift is to spray the ground with a huge amount of water. This watering was estimated to be about 12 liters of water per cubic meter of earthworks in France in 2010 (SPTF, 2011). This can lead to a significant waste of water.

Resource savings could be made by anticipating the necessary and sufficient quantities to prevent dust emission. In order to achieve this goal, it is require to study the mechanisms of soil degradation and particle lift by traffic. To this end, research works have been undertaken in recent years at the University Gustave Eiffel (SEDIKI *et al.*, 2018; LE VERN *et al.*, 2020a; LE VERN *et al.*, 2020b). This paper aims at presenting the corresponding approach as well as some preliminary results.

2. Methodology

The dust emission mechanisms are assessed according to three main lines of study:

- The soil surface degradation under traffic stress is analyzed at the laboratory scale.
- The physical, mechanical and environmental parameters that govern dust emission when a vehicle is in motion are highlighted with a test track study.
- The transport of particles in the wake of trucks circulating on the earthworks runways is characterize with scale models in a wind tunnel.

Figure 1 illustrates the steps that lead to the dust plume formation. Above a certain threshold of particulate concentration that needs to be identified, suspended dust will

significantly reduce visibility. This nuisance requires the watering of the runways on the construction site. The aim of the study is to develop a model based on physical laws and experimental measurements for the quantification of dust concentration generated by trucks traffic on runways. A better knowledge of dust emission mechanisms would allow to limit them and to forecast the quantities of water needed during the construction project.

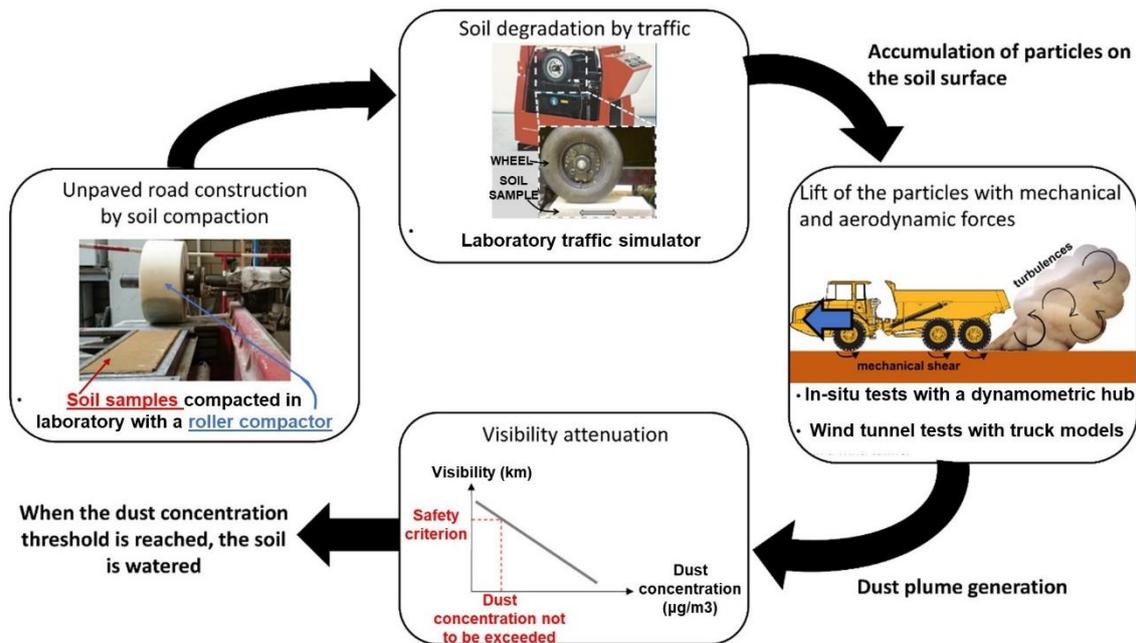


Figure 1. Processes related to dust emissions, from soil compaction to its watering.

3. Preliminary results

The dust emission model under development is based on three parameters:

- The number of particles likely to fly away as they are no longer bound to the granular matrix. They appear due to soil surface degradation by traffic;
- The Particle Size Distribution (PSD) of these particles;
- The mechanical and aerodynamic stresses on particles when vehicles are in motion.

These three points are discussed below.

3.1 Origin of dust: mechanical degradation of the soil surface

Earthworks runways are made by soil moistening and compaction. This process forms a granular matrix consisting of aggregates. Dust is generated by trucks traffic as these aggregates are torn off by the wheels. This phenomenon was studied with a traffic simulator reproducing the motion of a wheel on laboratory-prepared soils. They were made with two materials: Speswhite kaolin clay (denoted “K”) and Hostun HN38 sand (denoted “S”). Three samples were degraded in the traffic simulator: S0K100 (100%

clay), S50K50 (50% sand and 50% clay) and S75K25 (75% sand and 25% clay). Table 1 summarises their geotechnical properties.

Table 1 : Soil geotechnical properties

Soil	Liquid Limit (%)	Plastic Index (%)	Methylene blue value (g/100g)	Specific surface area (cm ² /g)	Unified Soil Classification System
S0K100	55.00	25.00	1.56	10.65	CH: High plasticity clay
S50K50	29.90	12.60	0.74	5.28	CL: Low plasticity clay
S75K25	23.10	7.60	0.43	2.47	SC: Clayed sand

Figure 2 shows the experimental results of their surface degradation as a function of the number of wheel passes. They represent the cumulative mass of aggregates torn off per unit of ground surface covered by the tire during its movement. The results show deviations of several orders of magnitude from one soil to another. For the same number of wheel passes, high-plasticity clay generates ten times more dust than clayed sand and hundred times more than low-plasticity clay. This latter has the least propensity to generate dust under traffic because it is a well graded soil with a high shear strength (LEVERN *et al.*, 2020a).

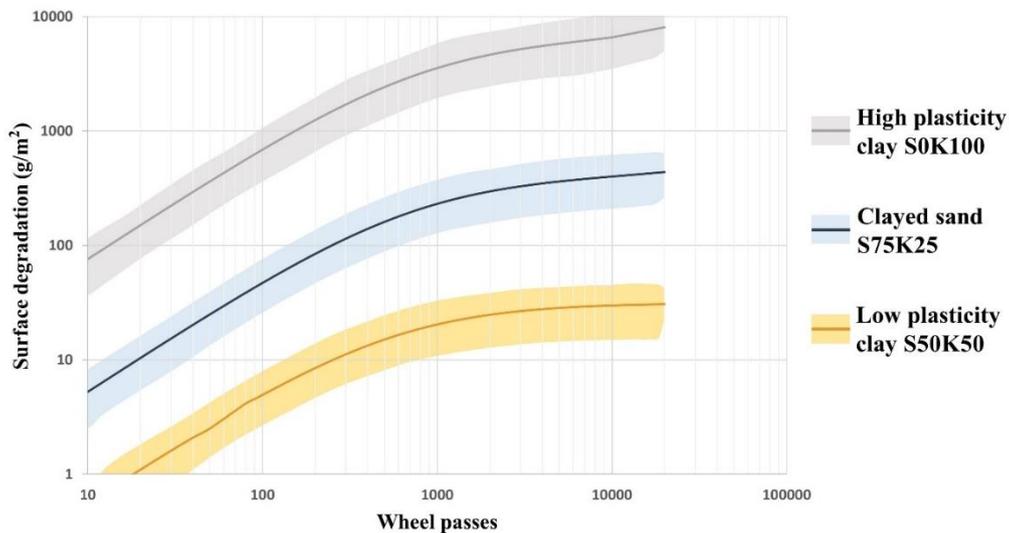


Figure 2. Soil surface degradation as a function of the number of wheel passes, with 50% uncertainty (shading).

3.2 Particle size distribution of dust during traffic degradation

By measuring the Particle Size Distribution (PSD) of the aggregates torn off during soil degradation by traffic, a typical trend can be observed. An example is given in Figure 3 for S75K25 sample.

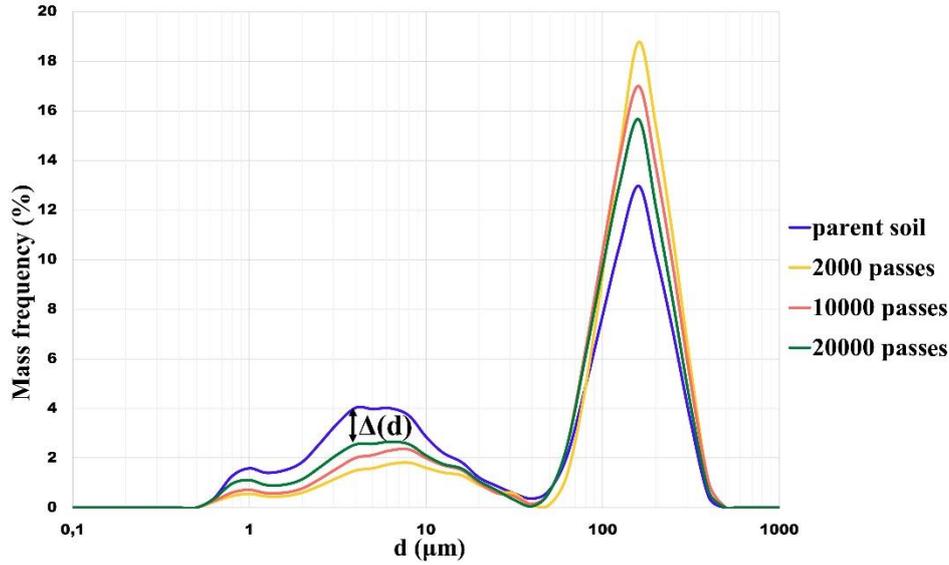


Figure 3. Particle size distributions of initial soil (S75K25) and dust particles after N passes of the wheel.

For the three soils, similar evolutions of aggregate PSD as a function of the number of wheel passes are observed. They are empirically modelled by the difference between the PSD curve of aggregates torn off after N wheel passes and the PSD curve of the parent soil, using the Δ function (equation (1)):

$$\Delta(d) = \frac{0.111 \times e^{[0.004(\%clay \times \%sand)]}}{0,49} \times (9.72 \times 10^{-10}N^2 - 4.92 \times 10^{-5}N + 1.09) \times \ln\left(\frac{d}{d_{min}}\right) \times \sin\left[\frac{2\pi}{\ln\left(\frac{d_{max}}{d_{min}}\right)} \times \ln\left(\frac{d}{d_{min}}\right) + \pi\right] \quad (1)$$

where d is the diameter of particle (μm), $\%clay$ is the mass percentage of particles smaller than $2 \mu\text{m}$, $\%sand$ is the mass percentage of particles between 20 and $2000 \mu\text{m}$, d_{min} and d_{max} represent the minimum and maximum soil particle diameter (μm) respectively (LE VERN *et al.*, 2020b). This empirical function highlights the capacity of a soil to form aggregates (characterized by the product $\%clay \times \%sand$) and their gradual crumbling when the number of wheel passes N increases. This makes it possible to know the PSD evolution of the dust to be put into suspension during the soil degradation by traffic.

3.3 Particle lift by vehicle motion

When a vehicle is in motion, the lift of particles depends jointly on physical (type and quantity of particles, vehicle geometry), mechanical (vehicle speed, tyre/surface contact dynamics) and environmental (wind, relative humidity and air temperature) parameters.

An experimental study on a test track was carried out to assess the impact of two different moving vehicles (Renault Clio III and Ford Ranger) on particle lift. Our attention was particularly focused on the effect of the above-mentioned parameters on airborne particulate matter concentration when vehicle traffic occurs over a bed made of four different types of particles:

- Montmorillonite clay
- Clayed silt from Marche des Dames (France)
- Silt from Val d'Europe (France)
- Loess from Strasbourg (France)

Each test consisted of running one of the two vehicles at a given speed (30, 45 or 60 km.h⁻¹) over one of the four types of particles previously placed on the ground at a given surface concentration (200, 400 or 600 g.m⁻²). This latter is directly related to the surface degradation (Figure 2). Figure 4-a shows the experimental setup. The concentration of resuspended particles was measured by suction of the dust plume behind the rear tire using a particle counter. Figure 4-b shows an example of measurements for one of the tests (PM_X being the concentration of particulate matter having a diameter less than X μm). Temperature, relative humidity and solar radiation were monitored with a weather station. The Renault Clio III was equipped with a dynamometric hub enabling real-time measurements of the longitudinal, vertical and transverse forces and torques applied to the right front wheel. Overall, 74 tests were conducted corresponding to a wide range of experimental conditions. The results are currently being analyzed.

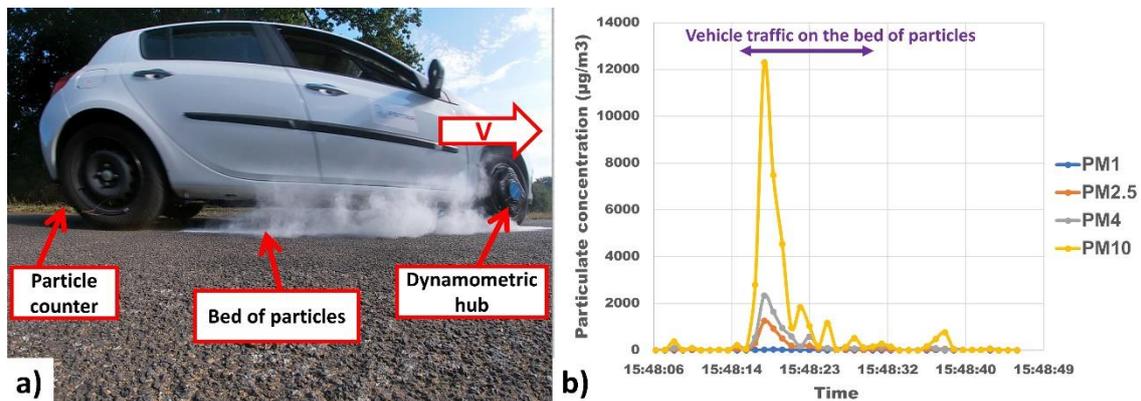


Figure 4. a) Configuration of test track experiments; b) Particulate concentration measurements during the vehicle traffic over the bed of particles.

4. Future works

Future works will be undertaken to characterize the transport of dust in the wake of trucks circulating on earthworks runways. The study will take place in a wind tunnel with two models corresponding to the types of trucks used to carry materials on construction sites: articulated dump trucks (Figure 5-a) and cab-over trucks (Figure 5-b). Wake flows (mean

and turbulent velocity fields) will be characterized by LASER Doppler Velocimetry and Particle Image Velocimetry. The final goal is to couple the results obtained in the wind tunnel with those observed on the test track in order to quantify the stresses on suspended particles.



Figure 5. Wind tunnel scale model of a) Caterpillar articulated dump truck and b) Mercedes 8x4 cab-over truck.

5. Conclusions

To date, works carried out have made it possible to characterize the appearance of dust during traffic on compacted soils. Models of surface degradation and PSD evolutions have been developed. They will need to be validated by testing a wider range of soils. This work represents a novelty in the field of dust emission studies and is a first step in the development of a robust model for the quantification of dust emissions. A particular attention will be drawn to the lift of particles due to mechanical and aerodynamic forces. Analysis of the test-track experiments results and wind-tunnel studies will be undertaken to this end.

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