CIAMTIS

U.S. DOT Region 3 University Transportation Center

Transportation Asset and Infrastructure Management Conference

PENNSTATE 1855

Asphalt Pavement Compaction: What Can We Learn from the Particle Rotation?

1

Shihui Shen

Penn State Altoona

October 28, 2019

Background

Pavement compaction

- Compaction is one of the most critical steps in asphalt pavement construction that ultimately impacts pavement performance.

Air void content

Air void distribution

Air void size

Smoothness

Uniformity

Pavement performance and durability (resistance to cracking, rutting, and moisture damage)

Background

Pavement compaction

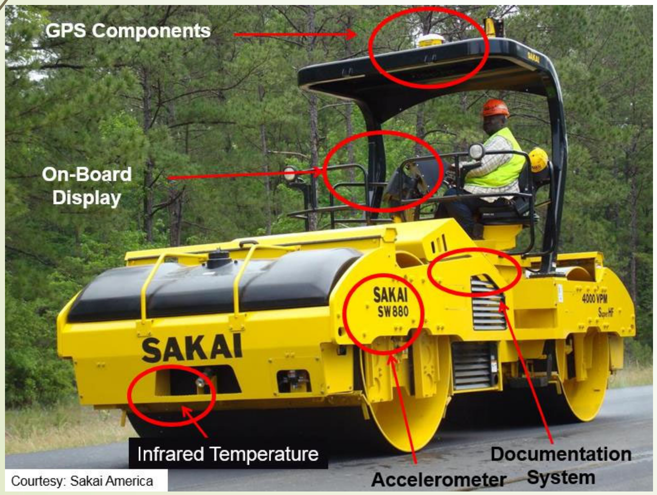
- Experience-based field compaction that leads to over/under compaction

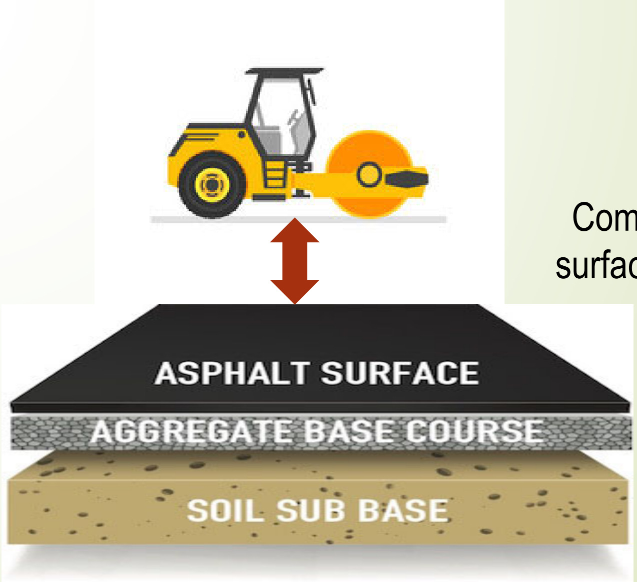
Background

Pavement compaction

- Intelligent Compaction
  —— Good improvement, accurate density control is still questionable

Hypothesis: particle movement, especially rotation, plays a significant role in the densification process of a particulate structure --- meso scale behavior





Complex vehicle-surface interactions

Objectives

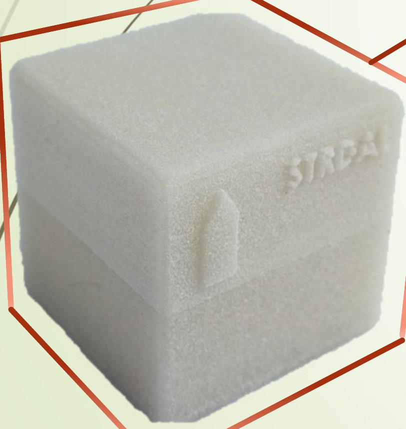
- Understand asphalt pavement compaction mechanism from the perspective of particle movement especially rotation
  - ❖ Correlate particle movement to different compaction methods;
  - ❖ Provide preliminary insight into the compaction mechanism; and
  - ❖ Explore the correlation between the SGC and field compaction at meso-scale.

Methodologies

- Using embedded sensors (SmartRock sensor) to capture the ***compaction (skeleton formation) characteristics*** of asphalt mixture in both field and lab

Methodologies

SmartRock Sensors

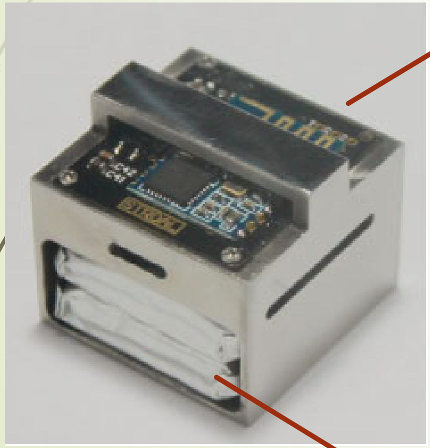


Outside

- 3D – printed
  Can be defined to be similar to real stones
- Material
  High-temperature resistant (140-170℃)
  High strength
  Good compatibility and cohesion with asphalt
- Reduced size
  Less than 1 inch each side

Methodologies

SmartRock Sensors



Inside

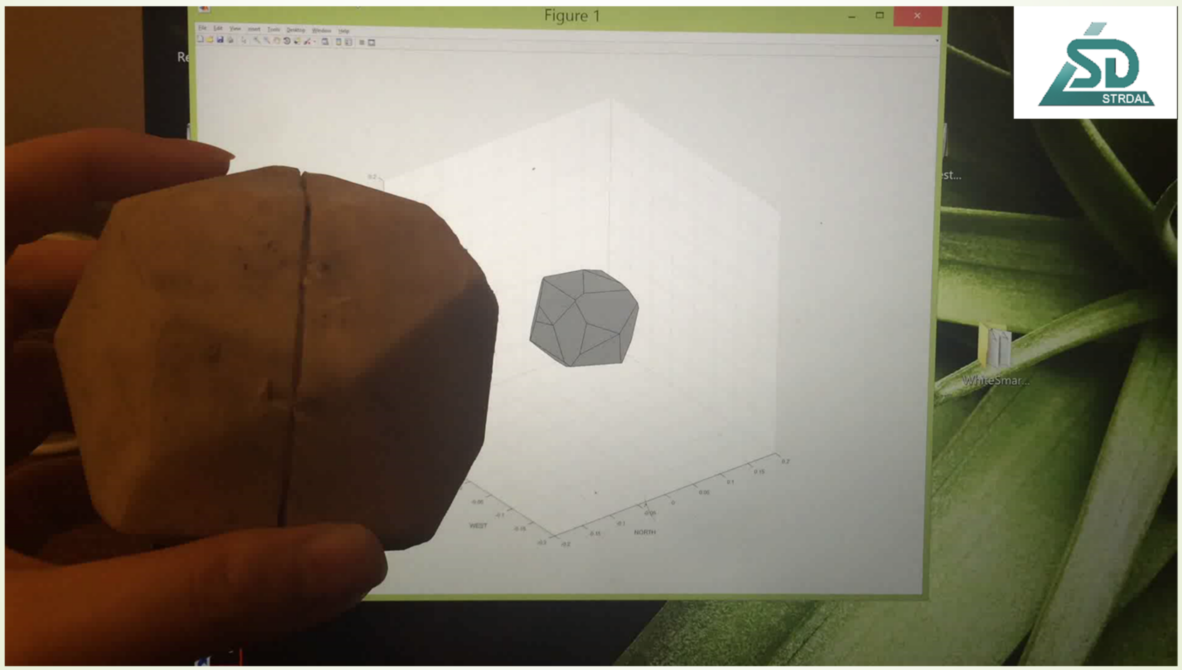
- Tri-axial gyroscope
- Tri-axial accelerometer
- Tri-axial magnetometer
- Temperature sensor
- Three directional stress cells

- 6 months ~ 1 year

Long-life battery

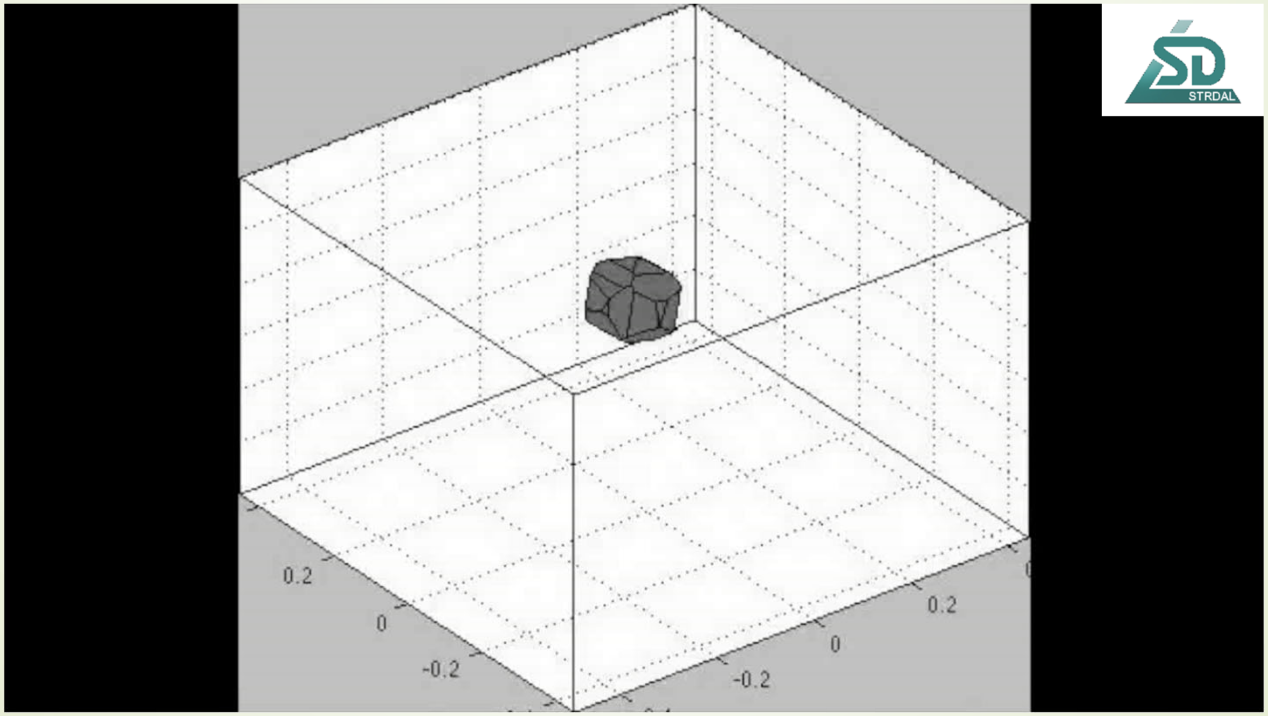
Methodologies

SmartRock Sensors



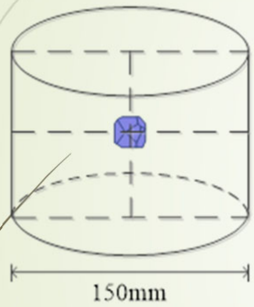
Methodologies

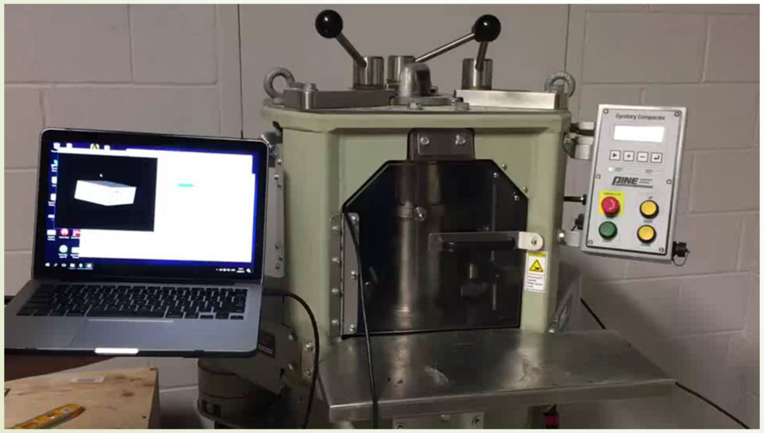
SmartRock Sensors

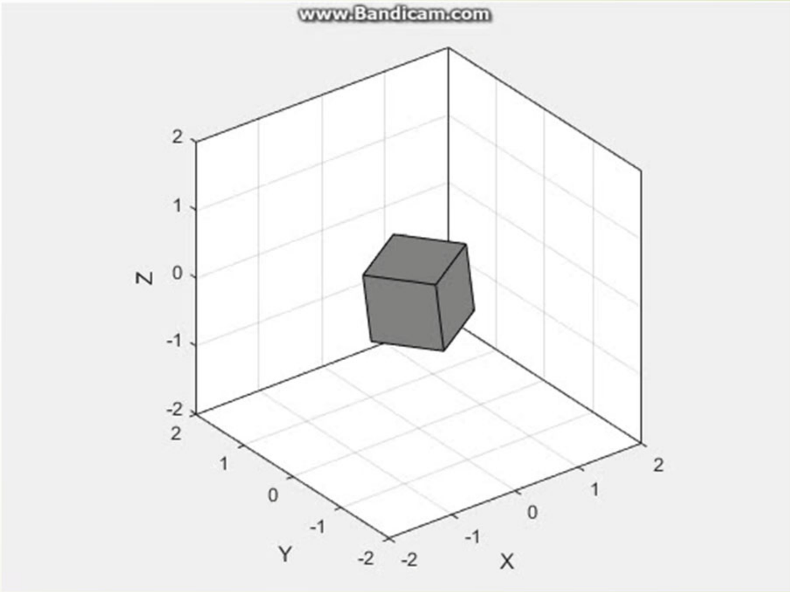


Compaction characteristics in the lab

- SmartRock in Superpave gyratory compactor



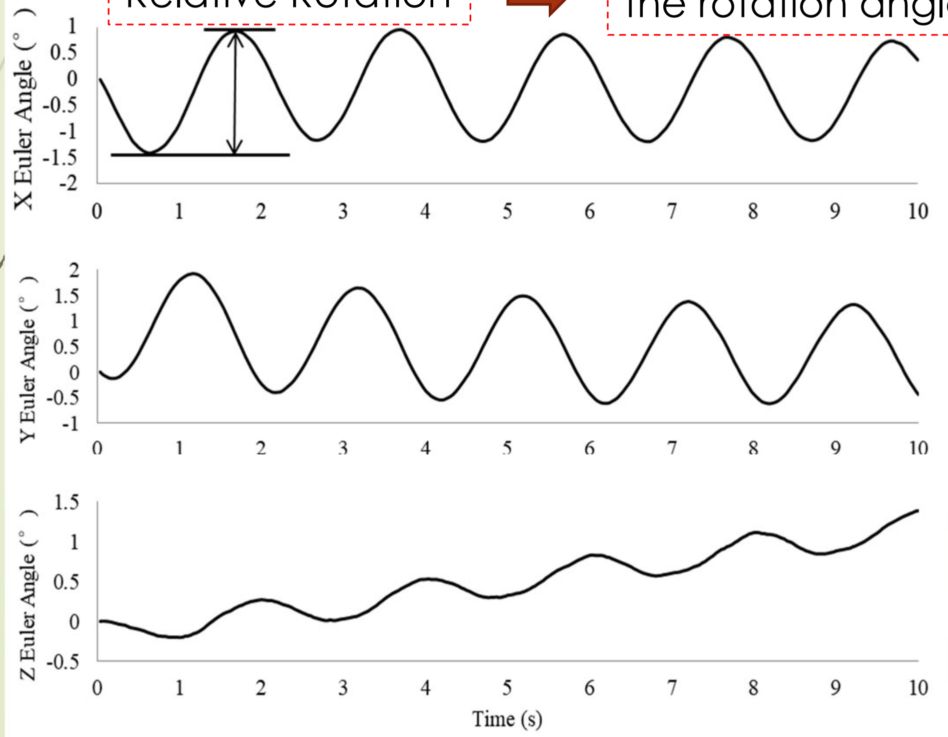




Compaction characteristics in the lab

- Rotation plays a significant role for particle movement in a confined particulate structure.

Relative Rotation → The difference between the peak and the valley values of the rotation angle for each cycle.

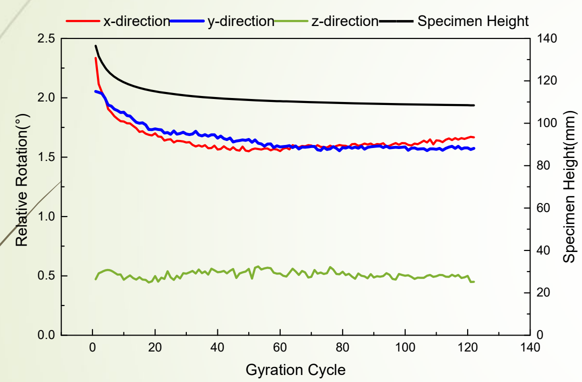


Particle follows a **cyclic rotation pattern** that repeats every 2 seconds that matches the SGC rotation speed of 30 rpm.

A segment of rotation data output

Compaction characteristics in the lab

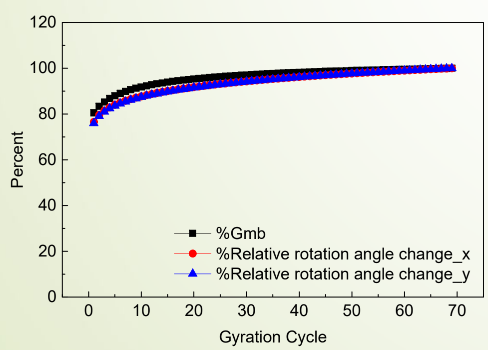
- Relationship between particle rotation and mixture density

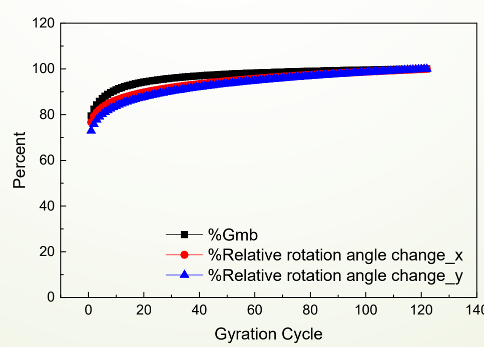


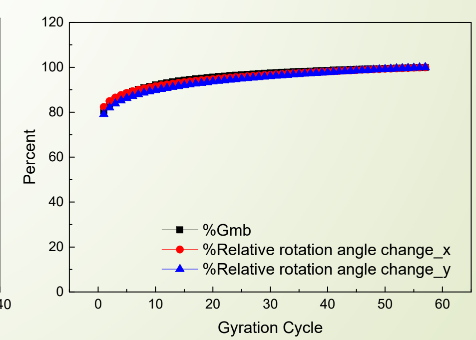
$$\%G_{mb,i} = \frac{Gi}{G_{mb}} = \frac{h_{min}}{hi} \times 100\%$$

$$\%\text{Relative rotation, i} = \frac{\textit{minimum relative rotation}}{\textit{relative rotation at cycle i}} *$$

In SGC compaction, the relative rotation pattern of particles along x- and y- axis was directly related to material density change.



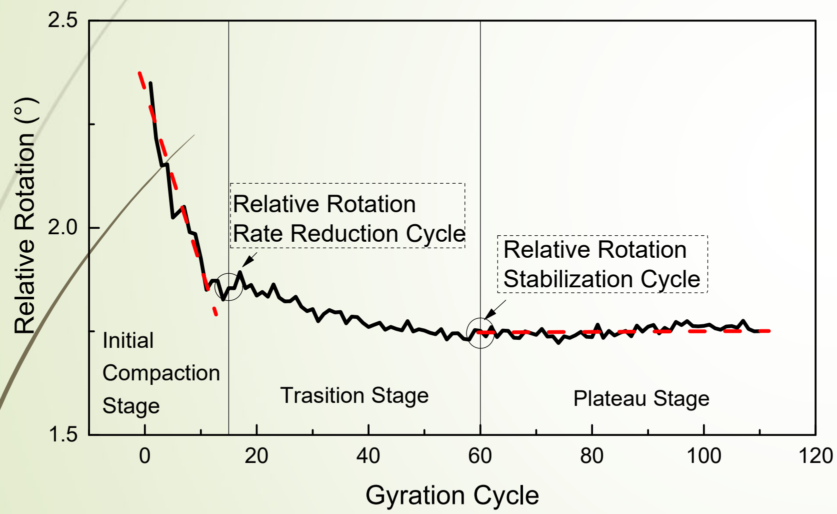




*Wang X, Shen S, Huang H, et al. Characterization of particle movement in Superpave gyratory compactor at meso-scale using SmartRock sensors. Construction and Building Materials, 2018, 175: 206-214.

Compaction characteristics in the lab

- Compaction as a three-stage process



Stage I : Initial compaction stage
(Particles had large relative rotation and also a sharp reduction, due to much compaction and height reduction.)

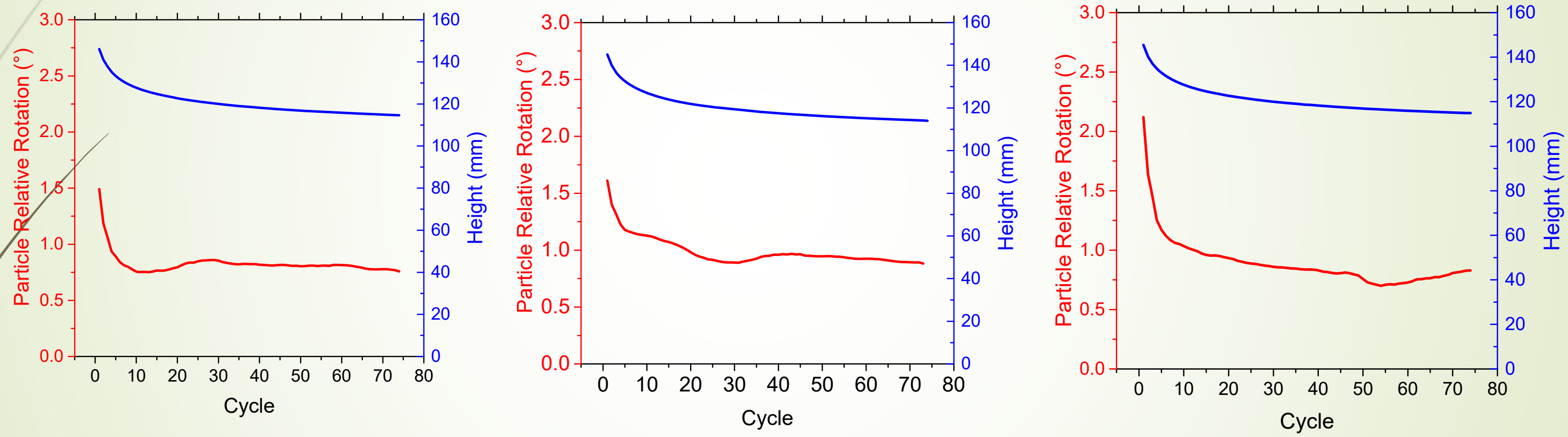
Stage II : Transition stage
(Particle movement was restricted as represented by the reduced relative rotation rate.)

Stage III : Plateau stage
(Particle rotation was much restricted by the compacted structure, except following the regular rotation of SGC.)

*Wang X, Shen S, Huang H, et al. Characterization of particle movement in Superpave gyratory compactor at meso-scale using SmartRock sensors[J]. Construction and Building Materials, 2018, 175: 206-214.

Compaction characteristics in the lab

AC relative rotation and specimen height change

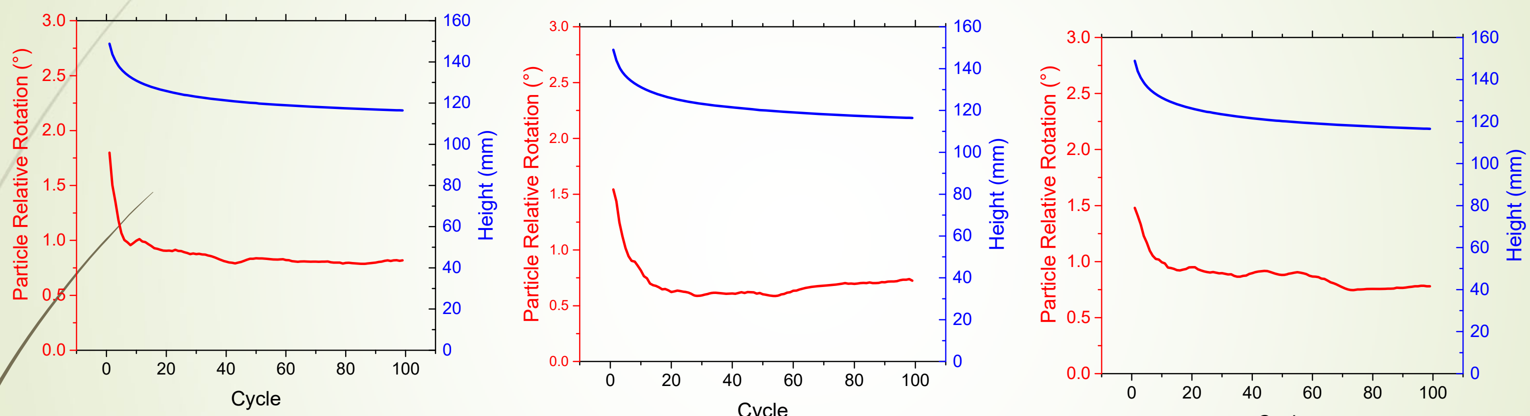


3 trials

- Generally, the relative rotation pattern of particles along x- and y- axis was directly related to material density change during the compaction process.

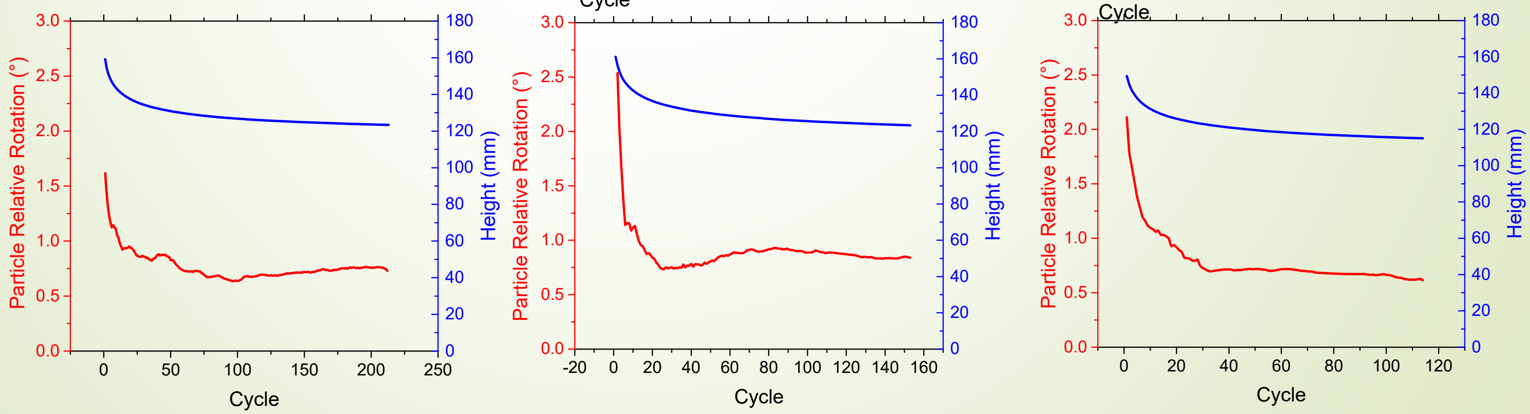
Compaction characteristics in the lab

Other mixture types: Relative rotation and height



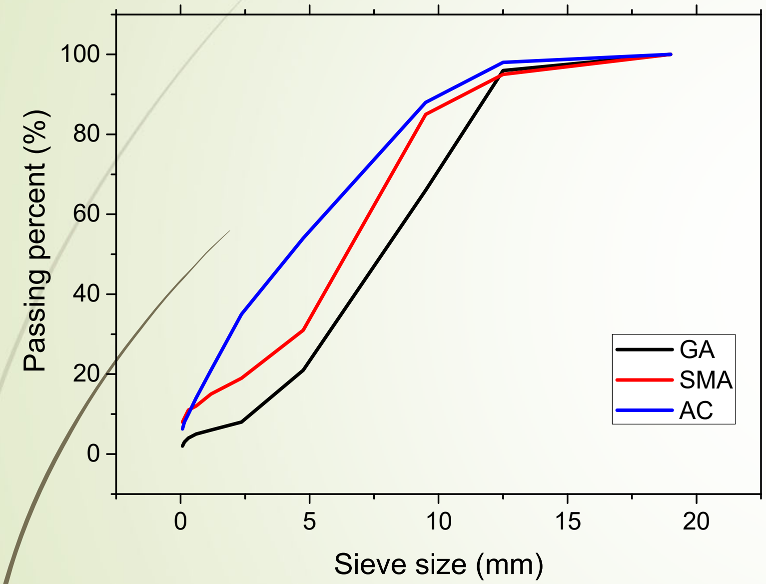
SMA

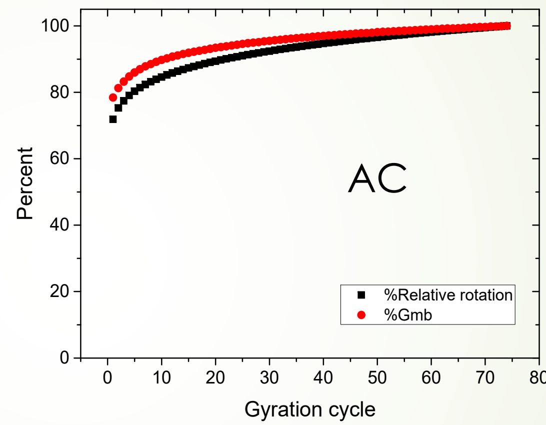
PFC

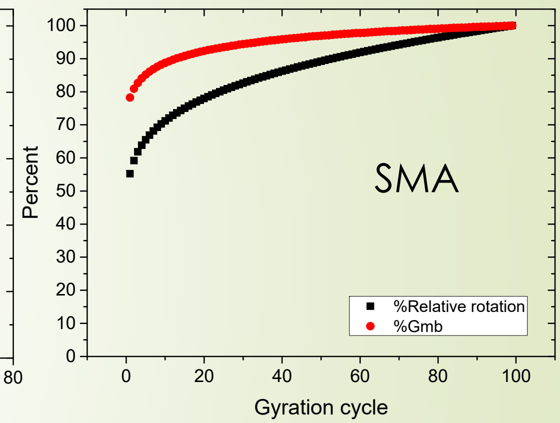


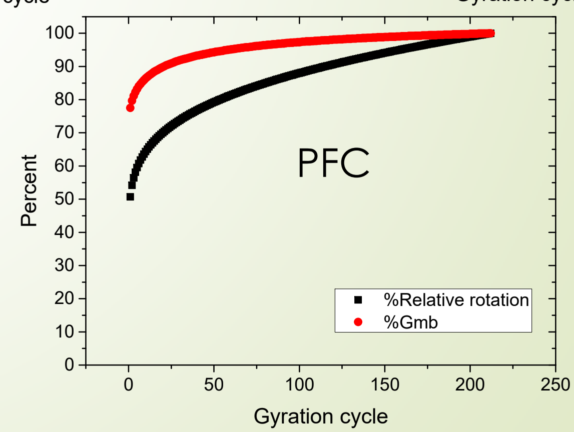
Compaction characteristics in Lab

Effect of gradation on particle rotation and compaction









Relative rotation change curve:
Structural-skeleton-related

- Dense structure: affected by both coarse and fine particles
- Gap/open structure: affected by coarse-coarse interaction

Compaction characteristics in field

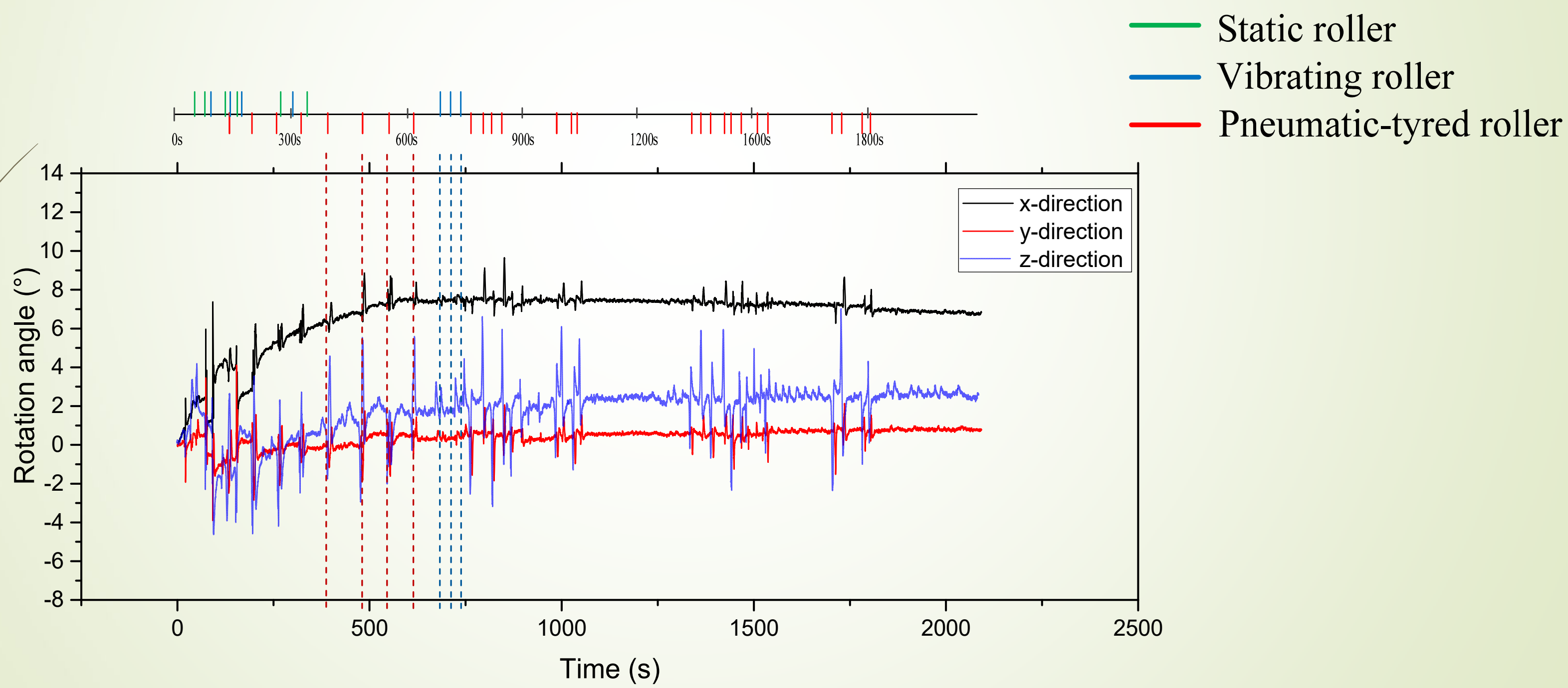
SmartRock in field asphalt pavement compaction

Pavement Maintenance Project

Lane-widening Project

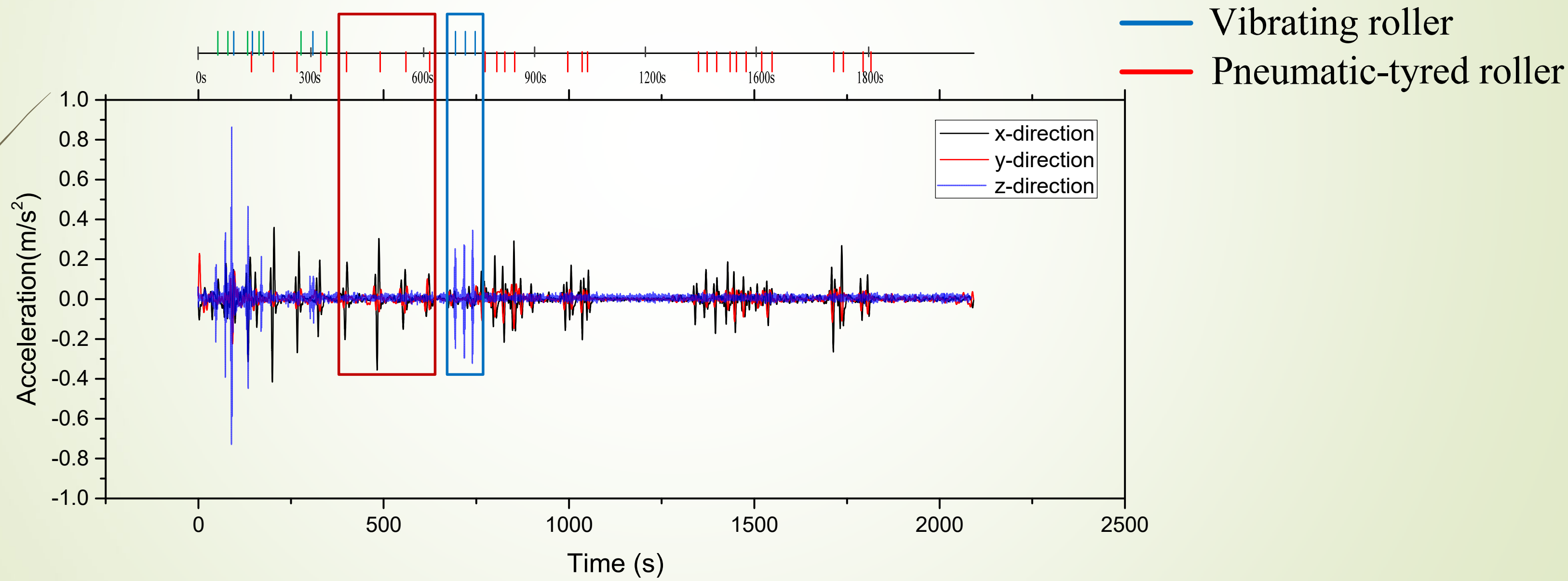
Compaction characteristics in field

Particle rotation recorded by SmartRock in field asphalt layer compaction



Compaction characteristics in field

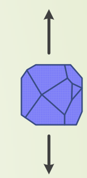
Particle acceleration recorded by SmartRock in field asphalt layer compaction



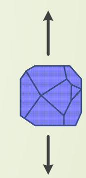
Compaction characteristics in field

Particle's reaction to different rollers in asphalt layer

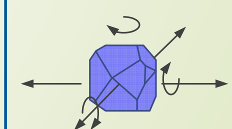
Static roller
Particle translated in z-direction (vertically), however, only in 1~2 passes in the initial compaction stage when asphalt mixture was quite loose.



Vibrating roller
Particle translated in z-direction (vertically) in the whole compaction process when vibrating roller was on.



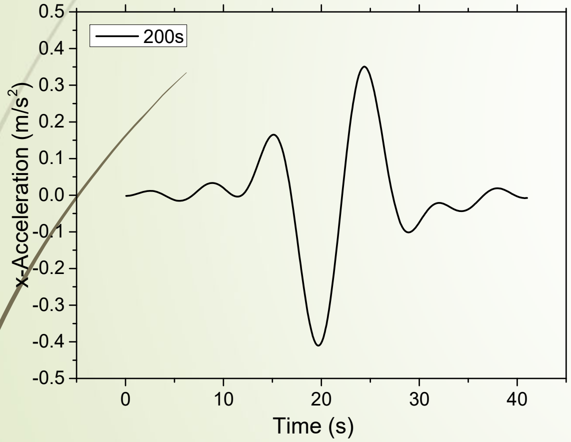
Pneumatic-tyred roller
Particle translated in x and y-directions, at the same time rotating in three directions.

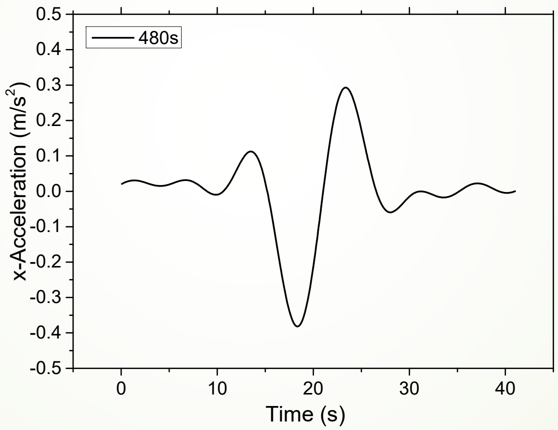


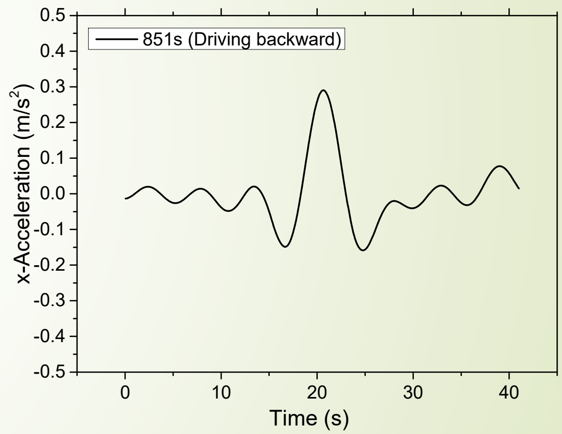
Compaction characteristics in field

Particle movement characteristics in asphalt layer compaction

Driving backward





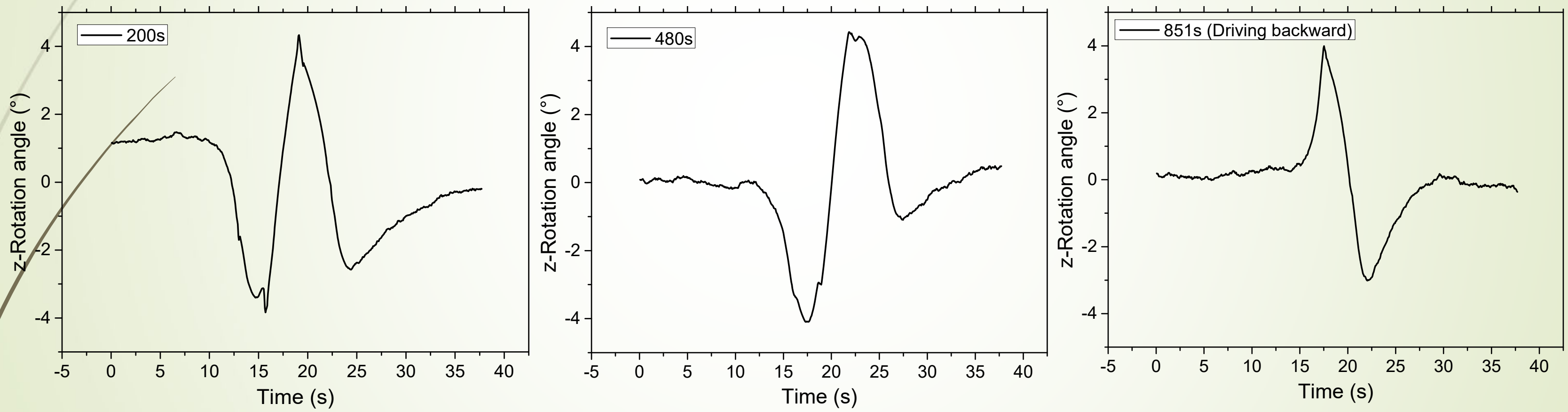


Particle x-direction acceleration to pneumatic-tyred roller

Compaction characteristics in field

Particle movement characteristics in asphalt layer compaction

Driving backward

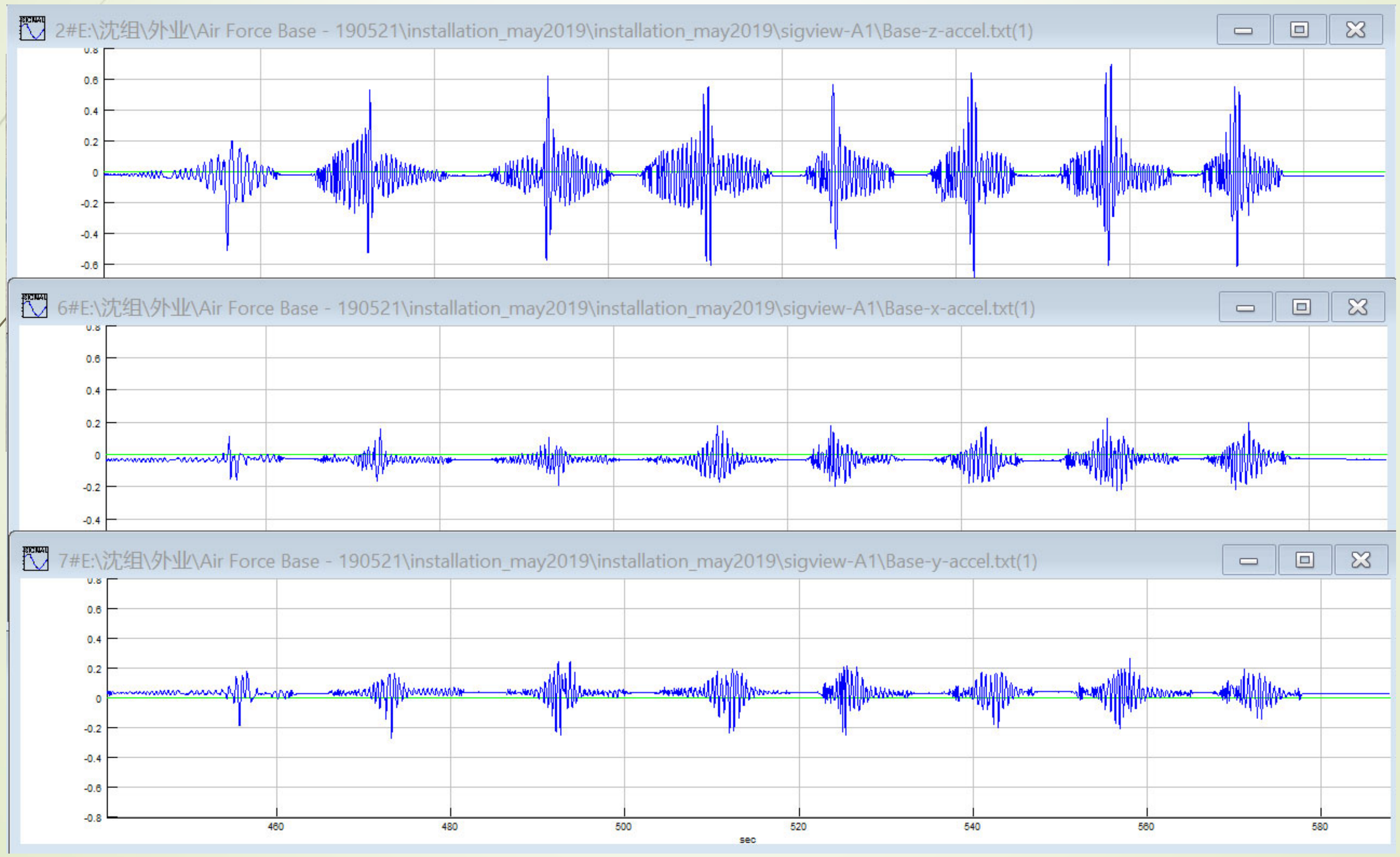


Particle z-direction rotation to pneumatic-tyred roller

Compaction characteristics in field

Particle three-axial acceleration in base layer compaction (initial stage)

Four times of roller working forward and backward



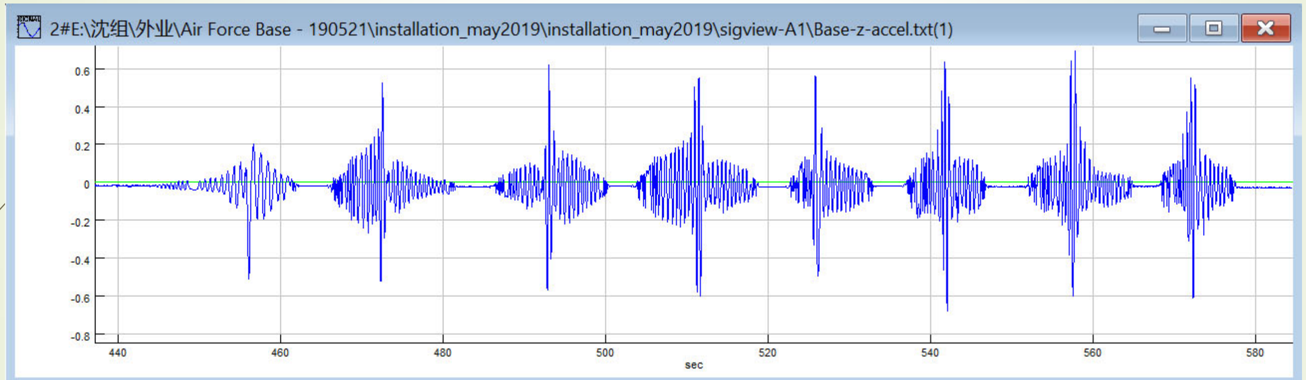
Z-direction

X-direction

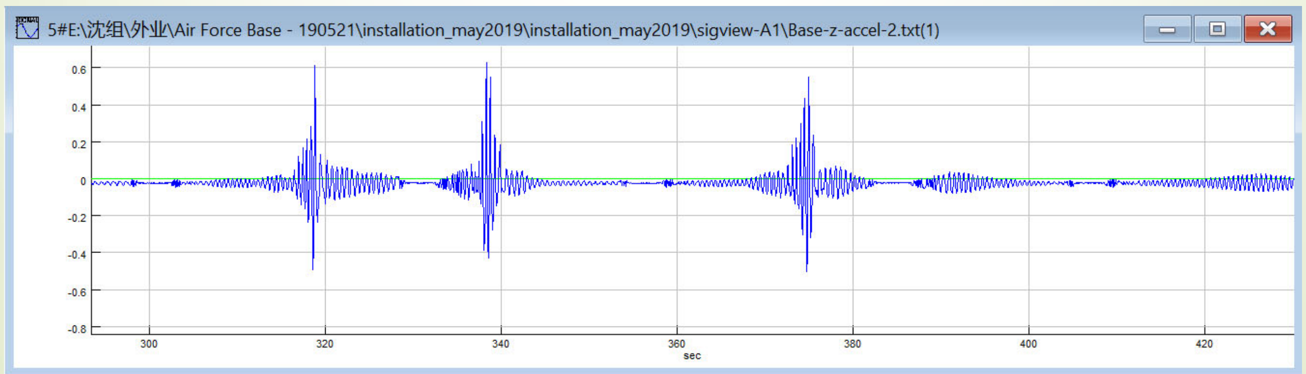
Y-direction

Compaction characteristics in field

Comparison of particle acceleration in base layer during the initial and late stage



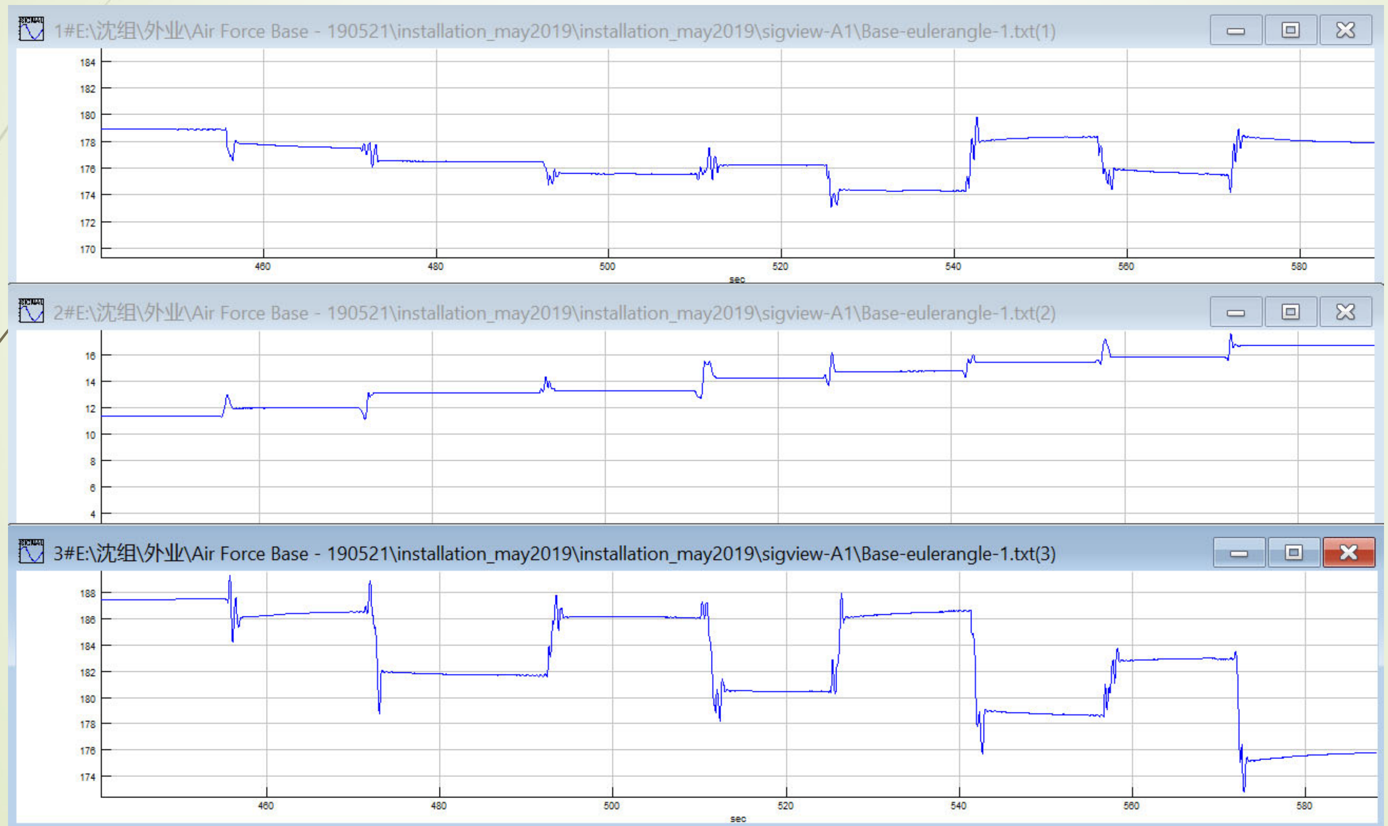
Initial stage



Late stage

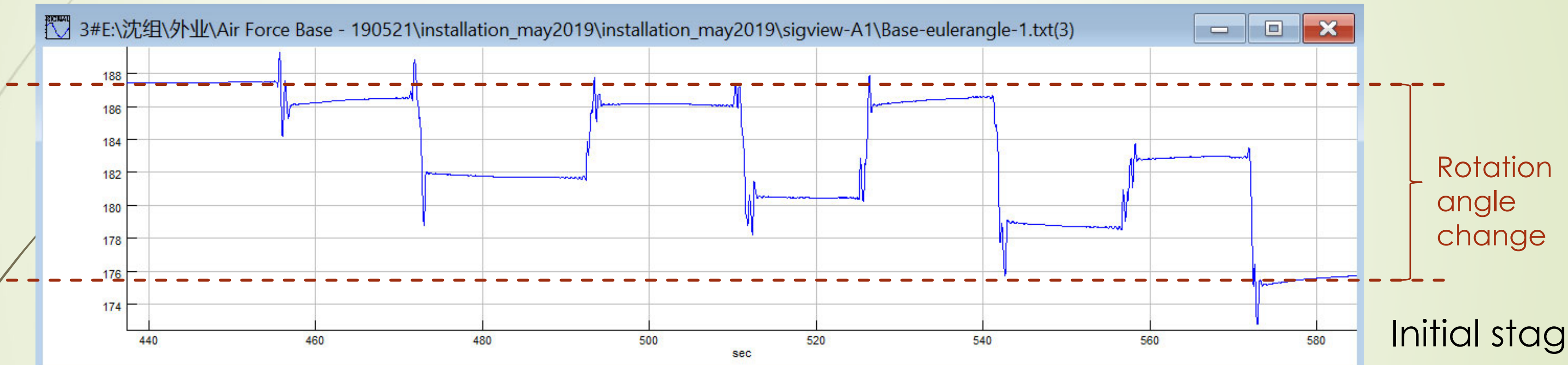
Compaction characteristics in field

Particle three-axial rotation in base layer compaction (initial stage)

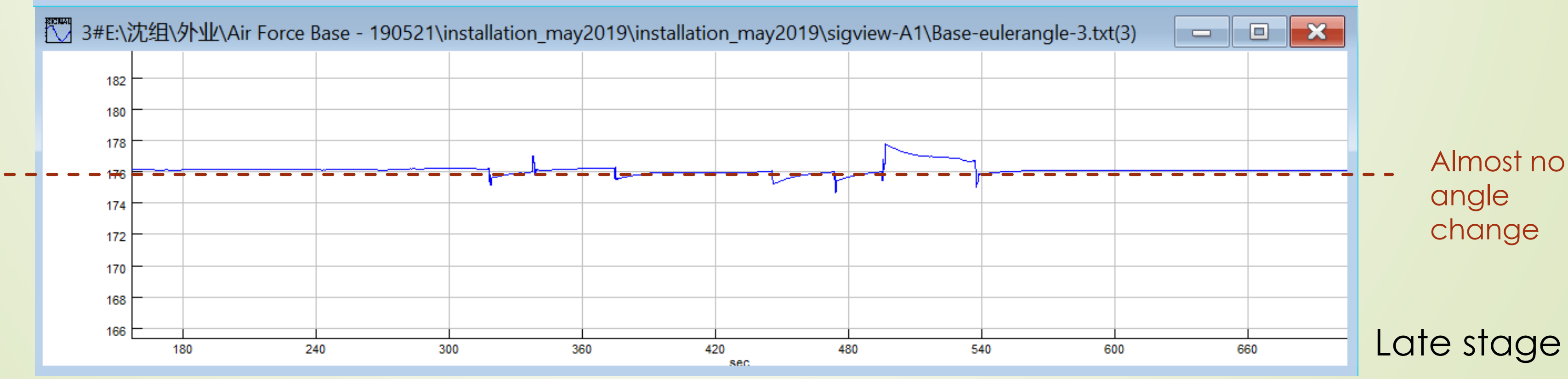


Compaction characteristics in field

- Comparison of particle rotation in base layer during the initial and late stage



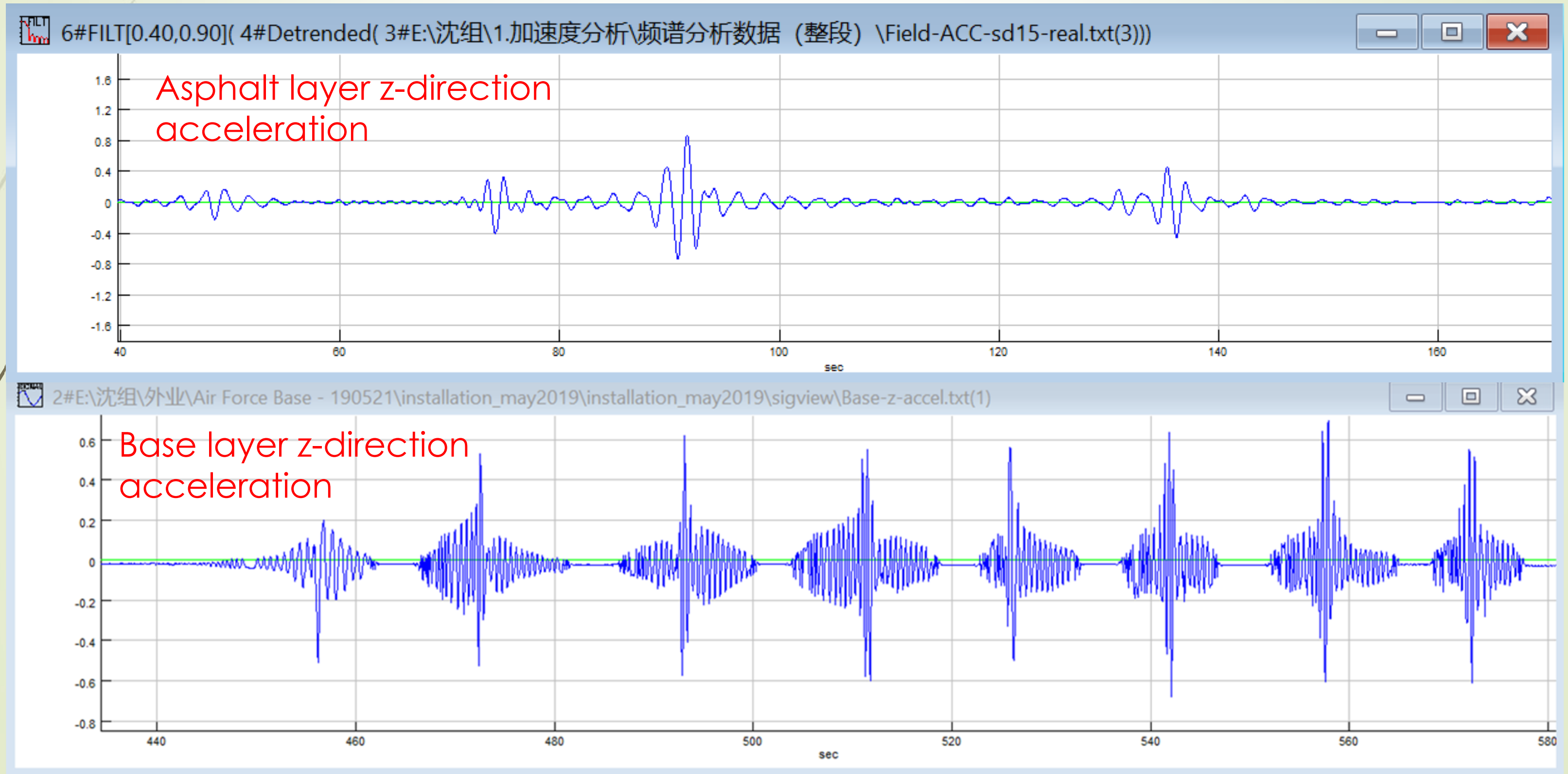
Initial stage



Late stage

Compaction characteristics in field

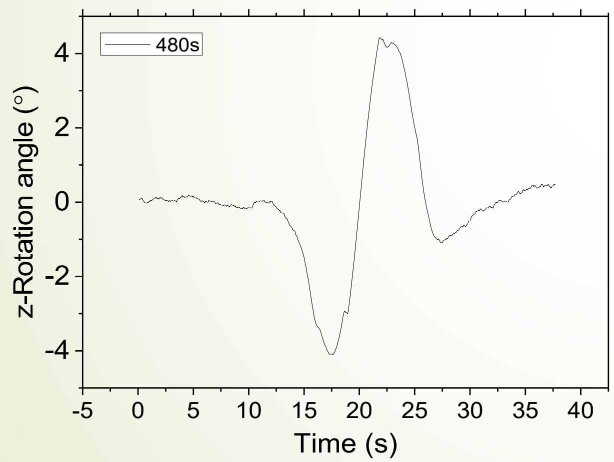
- Different particle acceleration mode in asphalt and base layer (initial stage)



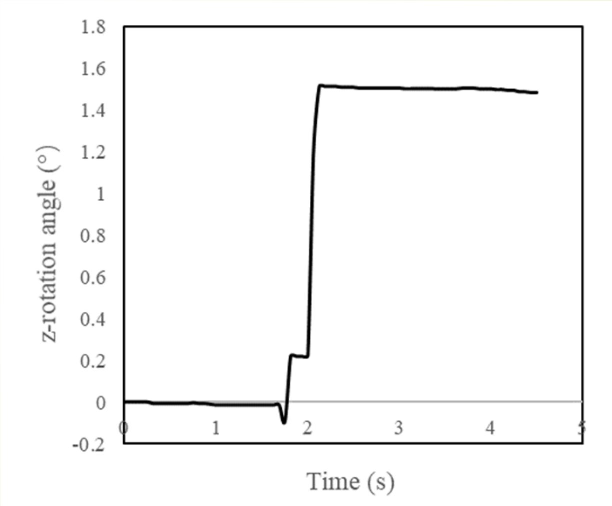
Compaction characteristics in field

- Different particle rotation mode in asphalt and base layer (initial period)

Asphalt layer

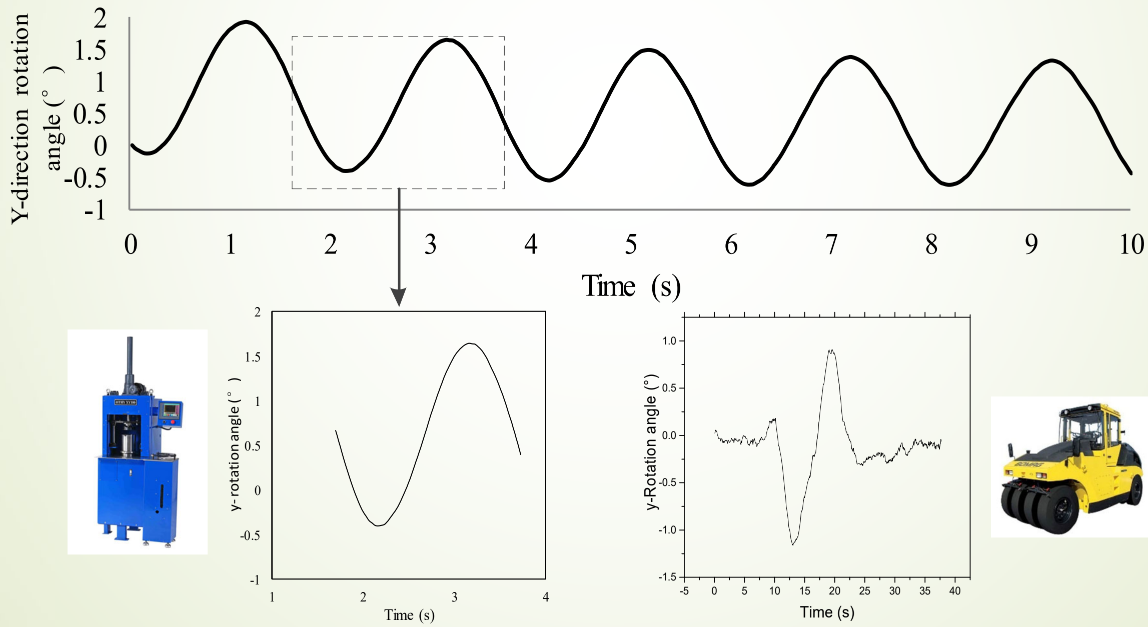


Base layer



Comparison between Lab and Field Compaction

Relationship between SGC and field compaction of asphalt mixture



Summary

- **The SmartRock is capable** of recording real-time particle translation and rotation in the field and lab asphalt mixture compaction.
- Compared with the traditional sensors, the **SmartRock has advantages** in pavement research : (1) it is wireless; (2) durable; and (3) it does not alter the motions of surrounding particles when embedded in asphalt mixture.
- Particle **reacted differently to different rollers**, and the reaction can be explained by roller's working mechanism.
- Particle **reacted different in different types of materials** during compaction.
- **Particle rotation characteristics** is closely related to material density change during compaction, and is affected by mixture gradation and skeleton.
- The **SGC** compaction method could **well simulate** the kneading process produced by **pneumatic-tyred roller**.

Acknowledgements

- Railroad Technology & Services (http://www.railtechs.com/) for technical support of SmartRock sensors and its application

RTS

- Graduate and undergraduate students at Penn State University and visiting scholar from Tongji University in China for running experiments and data analysis

Thank you!

Any questions?