GRIP Meeting 2024
Project BED26 TWO 977-07:
Vibrations and Ground Deformations due to Road Compaction

Start Date: March 2023
End Date: February 2025
Project Manager: Larry Jones (PM)
Rodrigo Herrera (Co-PM)

PRESENTED BY
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UNIVERSITY OF
CENTRAL FLORIDA

PRESENTATION OUTLINE

- Benefits and implementation
- Objectives
- Technical considerations and background
- Survey to practitioners
- Progress in field testing program
- Progress in numerical modeling
- Future tasks and deliverables

BENEFITS (EXPECTED) and IMPLEMENTATION

QUALITATIVE

- Reduce conservative limits for vibration monitoring protection of structures.
- Assist designers during preparation of project documents and plans. Time savings during construction due to more accurate estimate of extent of monitoring.
- Show relationships between construction equipment and vibration effects on soils.

QUANTITATIVE

- Project will provide computational framework currently unavailable to designers.
- Project will develop a model to estimate the zone of influence of activities associated with roadway construction.
- Project will produce a settlement chart or correlation due to road compaction equipment relating PPV, Dr, distance from source, and input energy.

IMPLEMENTATION

- Results will likely lead to updates to Specifications for Roadway and Bridge Construction, Soils and Foundations Handbook, and FDOT Specifications: “monitoring existing structures.”

OBJECTIVES

- To develop a prediction method of dynamic ground deformations and vibrations caused by road compaction.

- To understand the mechanisms of near-field and far-field ground deformations during road compaction.

- To investigate relationships among four components: ground deformations, vibrations, input energy, and distance from source of road compaction. Affecting parameters: soil strength and stiffness, type of road compaction equipment, relative density, and characteristics of the energy source.

- To develop a ground deformation chart (or correlation or equation) caused by road compaction as a function of PPV, relative density of soil, distance from the source, soil shear strain, and/or input energy.

SCOPE OF WORK

Task 1: Technical review of case studies (completed)

Task 2: Survey to practitioners (completed)

Task 3: Field testing in road compaction sites (In progress)

Task 4: Numerical modeling of road compaction settlement (In progress)

Task 5: Empirical prediction formula or chart(s) (In progress)

Task 6: Guidelines and recommendations (In progress)

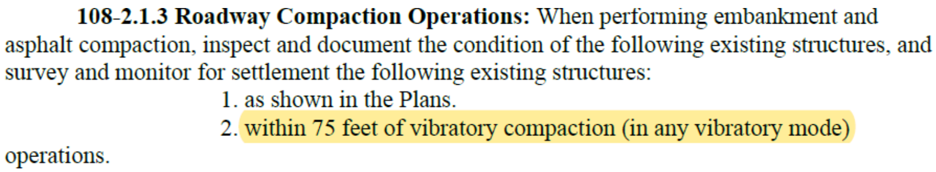
TECHNICAL BACKGROUND

VIBRATIONS AND GROUND DEFORMATIONS DUE TO ROAD COMPACTION

TECHNICAL BACKGROUND (Standards and Specifications)

FDOT Standard Specifications for Road and Bridge Construction (2021):

- Structures must be monitored within 75 ft of road compaction operations.
- Equipment must be capable of detecting vibrations of 0.01 in/s or less.
- Vibration limit (PPV) defined by FDOT is 0.5 in/s.



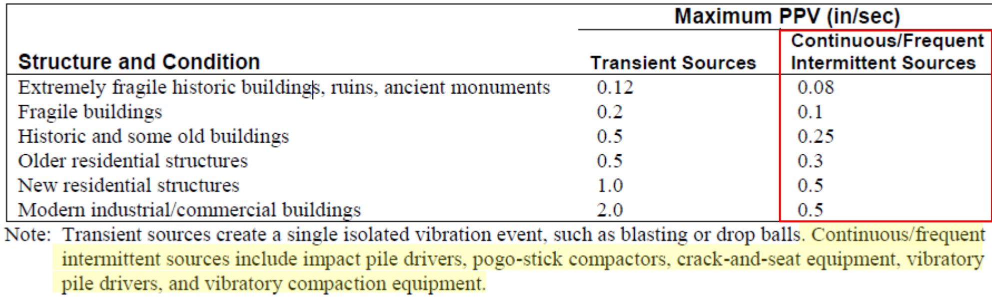
108-2.1.3 Roadway Compaction Operations: When performing embankment and asphalt compaction, inspect and document the condition of the following existing structures, and survey and monitor for settlement the following existing structures:

1. as shown in the Plans.
2. within 75 feet of vibratory compaction (in any vibratory mode) operations.

Section 108 Excerpt

Caltrans Transp. and Constr. Vibration Guidance Manual (2013):

- PPV limit criteria based on studies by Whiffin and Leonard (1971).
- Road compaction is categorized as a continuous sources of vibration.
- Several PPV limits defined depending on structure use and condition.



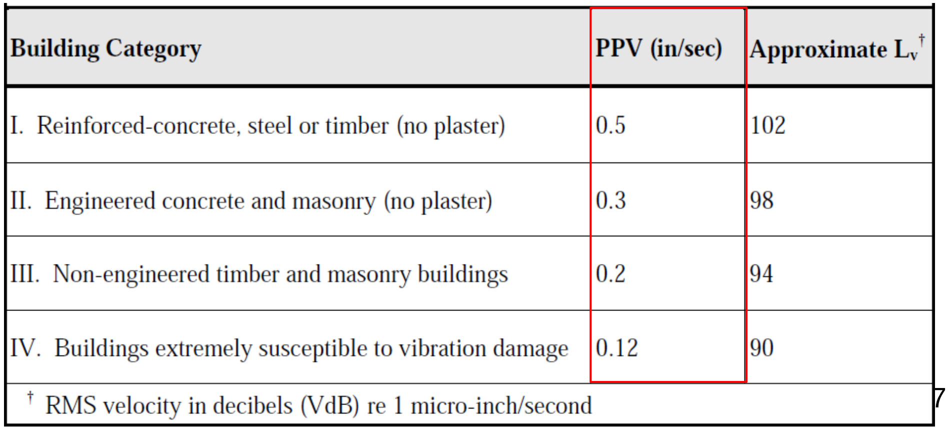
Structure and Condition	Maximum PPV (in/sec)	
	Transient Sources	Continuous/Frequent Intermittent Sources
Extremely fragile historic buildings, ruins, ancient monuments	0.12	0.08
Fragile buildings	0.2	0.1
Historic and some old buildings	0.5	0.25
Older residential structures	0.5	0.3
New residential structures	1.0	0.5
Modern industrial/commercial buildings	2.0	0.5

Note: Transient sources create a single isolated vibration event, such as blasting or drop balls. Continuous/frequent intermittent sources include impact pile drivers, pogo-stick compactors, crack-and-seat equipment, vibratory pile drivers, and vibratory compaction equipment.

Guideline for Vibration Damage Potential

FTA Transit Noise and Vibrations Impact Assessment (2006):

- Damage criteria dependent on the structure type
- FDOT's limit can be compared to building category I: Reinforced concrete.



Building Category	PPV (in/sec)	Approximate L_v†
I. Reinforced-concrete, steel or timber (no plaster)	0.5	102
II. Engineered concrete and masonry (no plaster)	0.3	98
III. Non-engineered timber and masonry buildings	0.2	94
IV. Buildings extremely susceptible to vibration damage	0.12	90

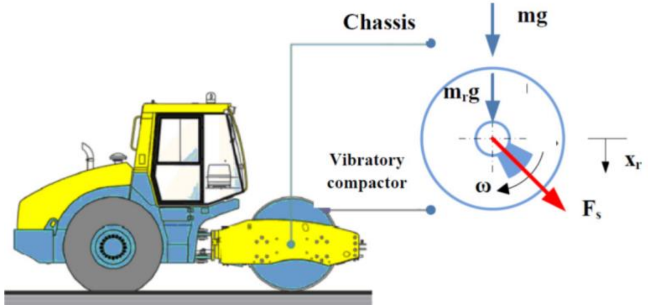
† RMS velocity in decibels (VdB) re 1 micro-inch/second

Construction Vibration Damage Criteria

TECHNICAL BACKGROUND (Triggering Mechanisms)

Xu et al. (2022)

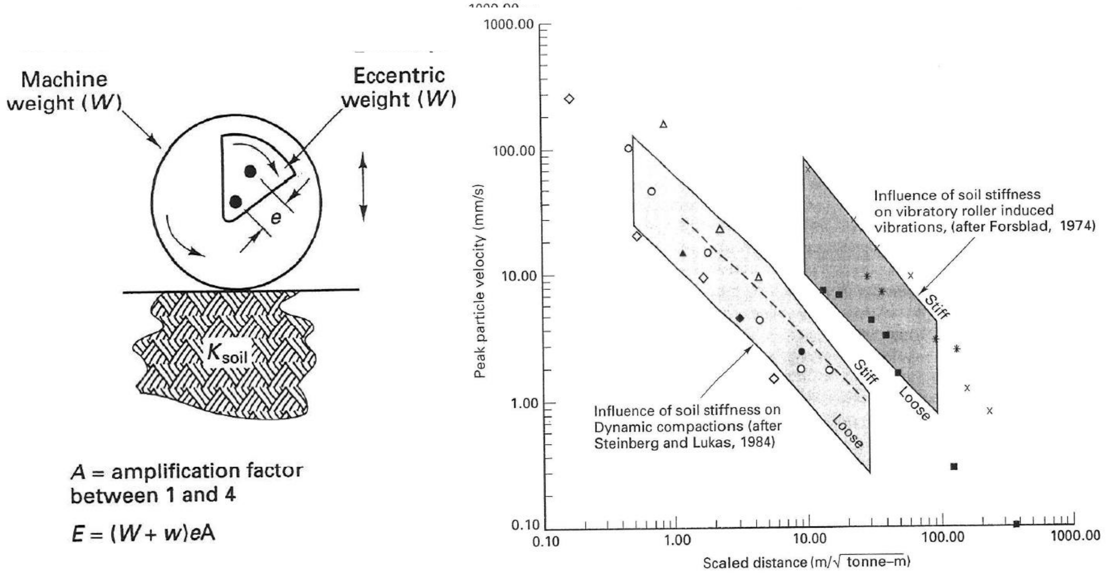
- Soil compaction is induced by combination of static forces (weights of frame and drum) and dynamic forces (rotation of the eccentric mass inside the drum).



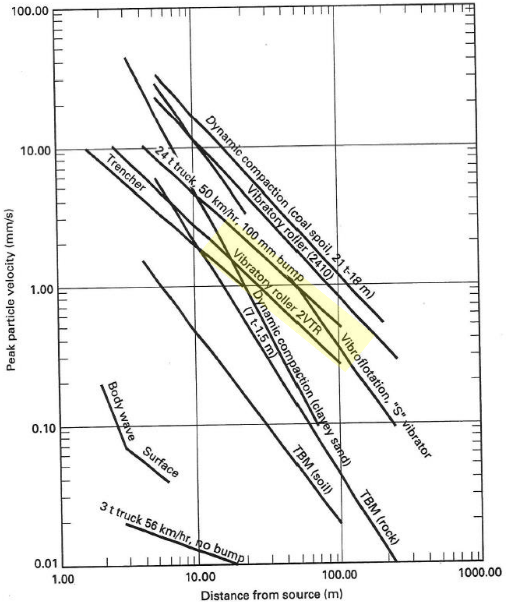
From Sergiu and Heriberto (2016)

Dowding (1996)

- Most studies focus on levels of PPV, ignoring energy transfer mechanisms.
- Stiff soils lead to a lower attenuation rate than soft soils due to inherent material damping.
- The energy transfer needs to consider relative masses of two components of the mechanism and the relative stiffness of the reaction medium and machinery.



From Dowding (1996)



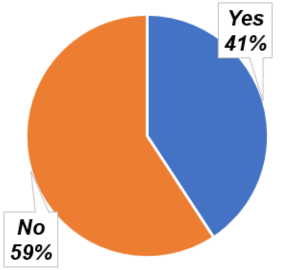
Attenuation of PPV with absolute distance for different construction equipment

SURVEY TO PRACTITIONERS

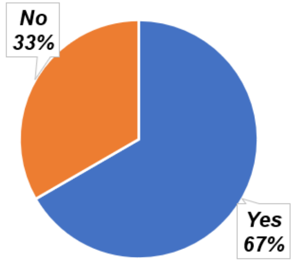
STATE OF THE PRACTICE IN FLORIDA REGARDING VIBRATIONS AND GROUND DEFORMATIONS DUE TO ROAD COMPACTION

SUMMARY OF MOST IMPORTANT OUTCOMES FROM THE SURVEY

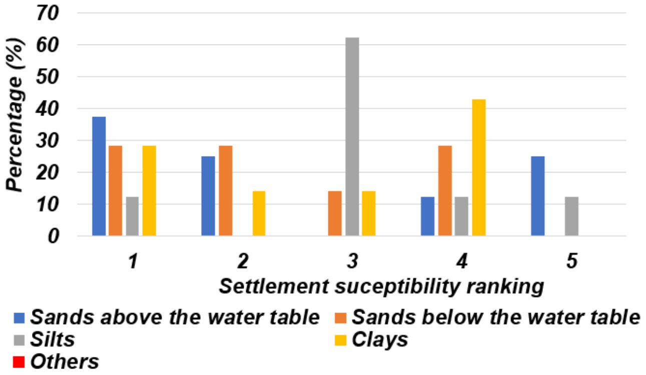
Question 1. Have you experienced in any past designs or construction projects any problem associated with ground surface settlement induced by vibratory roller compaction or road compaction in general?



Question 2. If your answer to **Question 1** was "Yes", did you observe or experience any type of damage to adjacent infrastructure during the road compaction because of high vibration levels (quantified in terms of high peak particle velocities) or large ground settlements or structural distortions?



Question 13. From your experience, ranking from 1-5 please provide what type of material is the most susceptible to develop the largest amount of settlement associated to vibratory roller compaction: (1 means the soil with the largest settlement).



General information:

- Web-based survey to investigate the perception of Florida practitioners on the effects of road compaction-induced vibrations on adjacent structures.
- Understand the common practices and experiences of practitioners in Florida.
- Contact information and email database shared by FDOT.
- Consultants participated: 27.
- Survey response rate 18%.

Main outcomes (1st part):

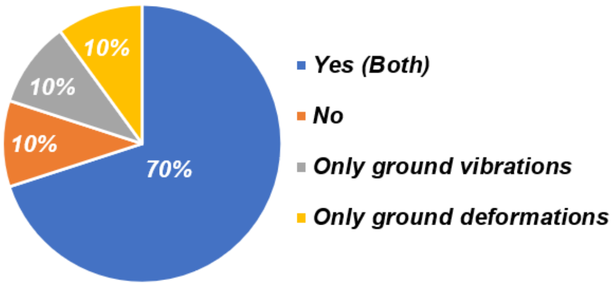
- Understanding their experience with *damages/problems* linked to road compaction-induced vibrations and deformations.
- 41% experienced issues regarding this phenomenon.
- 67% of those issues related to damages in adjacent infrastructure.
- 50% who described issues did not report PPV and settlements values higher than the FDOT limits.
- Problematic soil conditions: mostly surficial sandy soils (granular soils are susceptible to vibration-induced densification!)

SUMMARY OF MOST IMPORTANT OUTCOMES FROM THE SURVEY

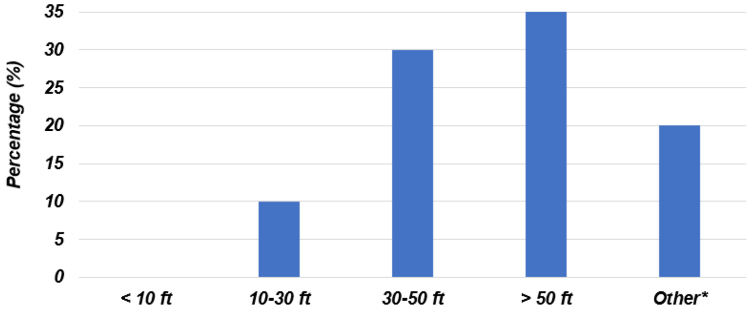
Main outcomes (2nd part):

- 70% considered important to monitor both vibrations and settlements
- Approx. 65% estimated the influence zone to be larger than 30 ft.
- Three main sources of road compaction-induced settlements:
  - (i) the relative density of the soils,
  - (ii) soil grain re-arrangement,
  - (iii) roller characteristics (the roller mass and its centrifugal force)
- Subgrade and base compaction are the stages that triggered the largest settlements.
- 40% is not familiar with any method to predict vibrations and deformations due to compaction!, which highlights the importance of the scope of this research project.

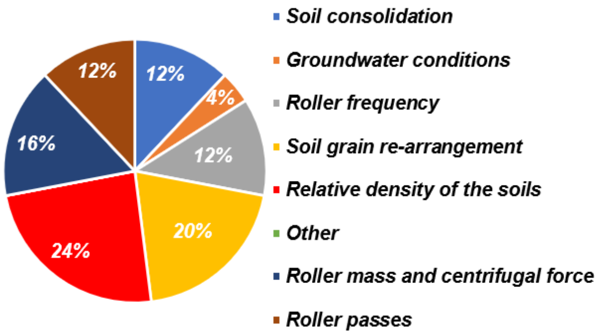
Question 8. Do you consider monitoring ground vibrations and ground deformations due to road compaction an important issue during the design phase of any road construction project?



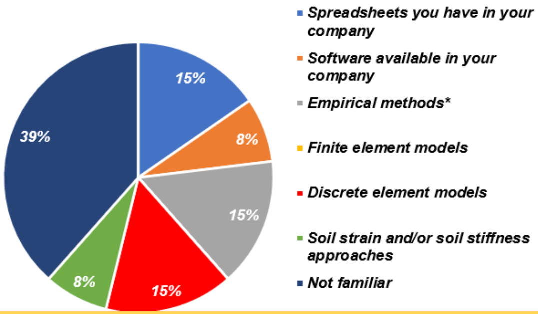
Question 16. From your experience, what is the maximum distance from the road compaction area at which infrastructure (e.g., buildings, public utilities, bridges, etc.) is not affected by the induced vibrations?



Question 14. From your experience, what are the main sources of vibratory roller-induced settlements in the surrounding soils? (You can select more than one choice)



Question 17. Which of the following methods and/or models do you use to estimate dynamic soil displacement due to vibratory roller compaction and/or to determine the impact of construction vibrations? (You can select more than one choice.)



FIELD TESTING PROGRAM

VIBRATIONS AND GROUND DEFORMATIONS DUE TO ROAD COMPACTION

FIELD TESTING: INSTRUMENTATION PLAN

Procedure:

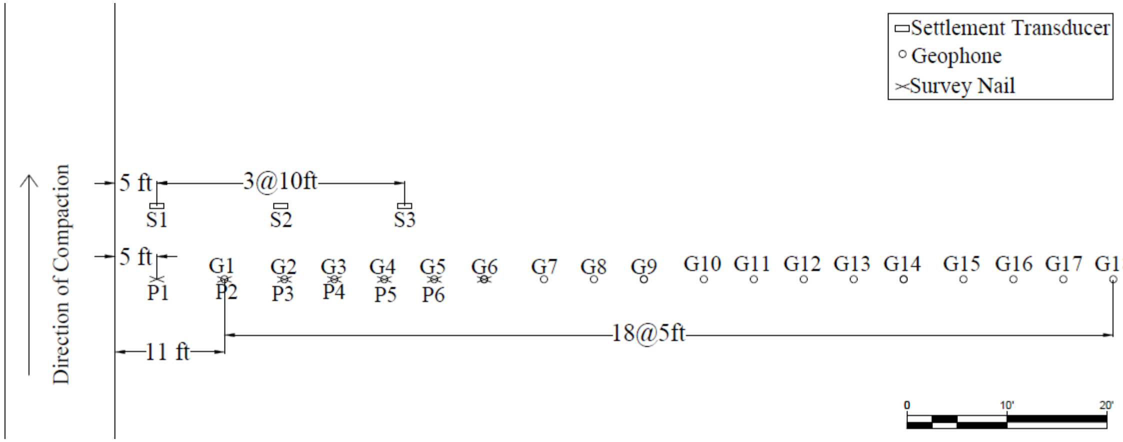
Site selection → Instrumentation → Data collection → Analysis

Field testing EDPs:

Measure PPV

Measure Ground Deformations

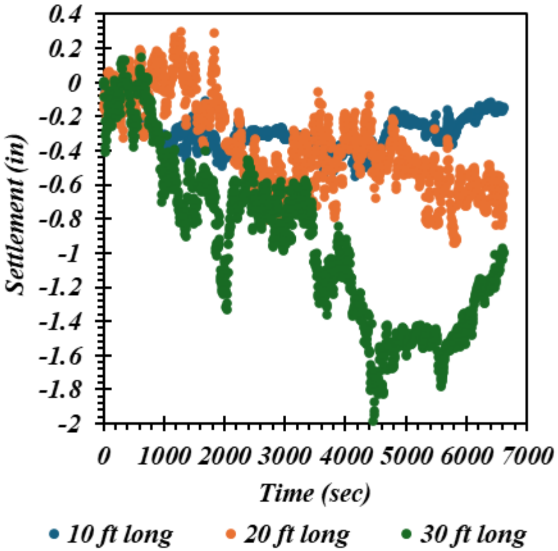
- Eighteen 5 Hz geophones (Sercel)
- Acquisition units (Sercel Unite)
- Three vibrating wire settlement transducers (Geokon)



Tentative instrumentation layout with respect to the direction of the roller

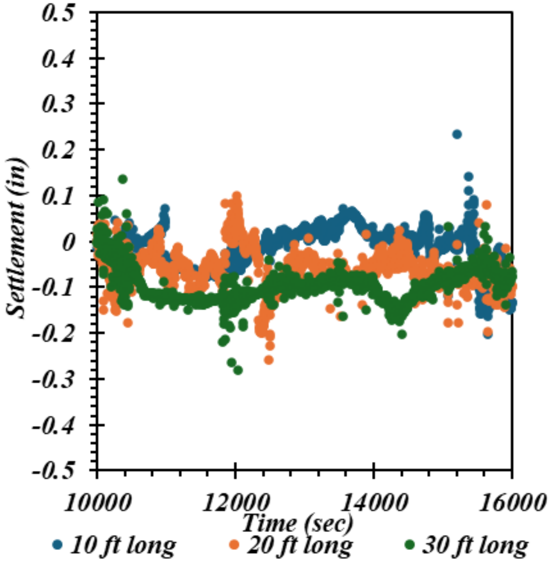
Sensors installed in the field during first field test

FIELD TESTING: CHALLENGES WITH SETTLEMENT SYSTEM



Sensors readings with no protection against sunlight and drastic temperature changes

- Settlement system should be used under temperature control conditions, avoid direct sunlight and drastic temperature changes.
- Large scatter in the measurements when subjected to sunlight (i.e., ~2.0 in).
- Several alternatives pursued to protect the tubes and the sensors.
- Best alternative (economically and technically) was Styrofoam casing tubes and provide protection to the sensors.
- Reading variations were in the order of 0.2 in trial tests with direct sunlight exposure.



Sensors readings with proposed protection alternative

Settlement system deployed in the field

Zoomed-in view of the proposed alternative to protect the sensors from sunlight

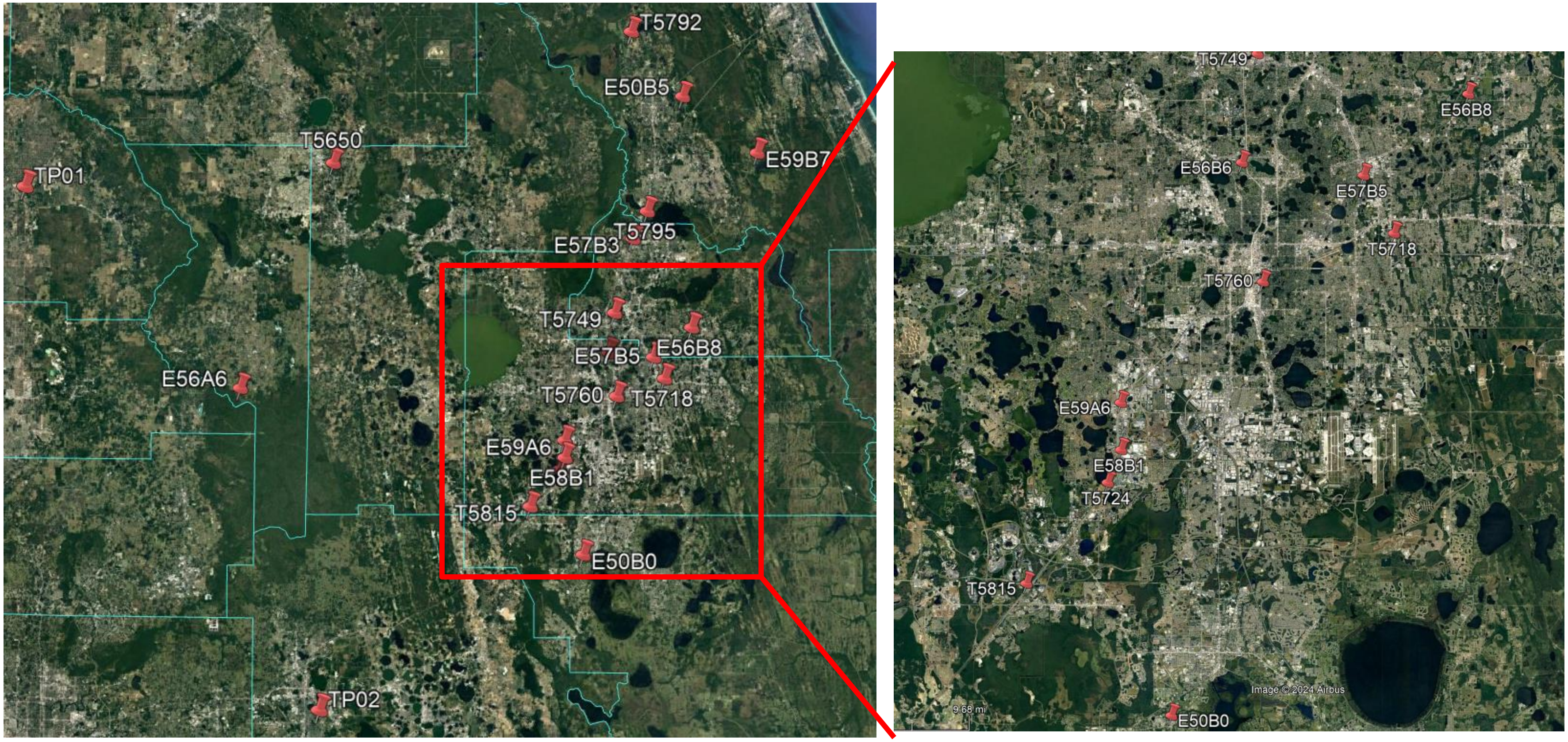
FIELD TESTING: TENTATIVE SITE LOCATIONS

Relevant information

- Preliminary sites selected in agreement with PM.
- Sites were given priority based on distance to UCF and magnitude of the road compaction.
- Road compaction efforts include lane widening, resurfacing, or repaving.
- The research team completed a visit to site E57B3 in Sanford on June 27th.
- Future visits scheduled for upcoming weeks.

Project site locations:

- A total of 20 tentative projects.
- 10 sites located nearby the I-4 corridor.
- Most projects in Osceola, Seminole, Orange, and Volusia Counties.



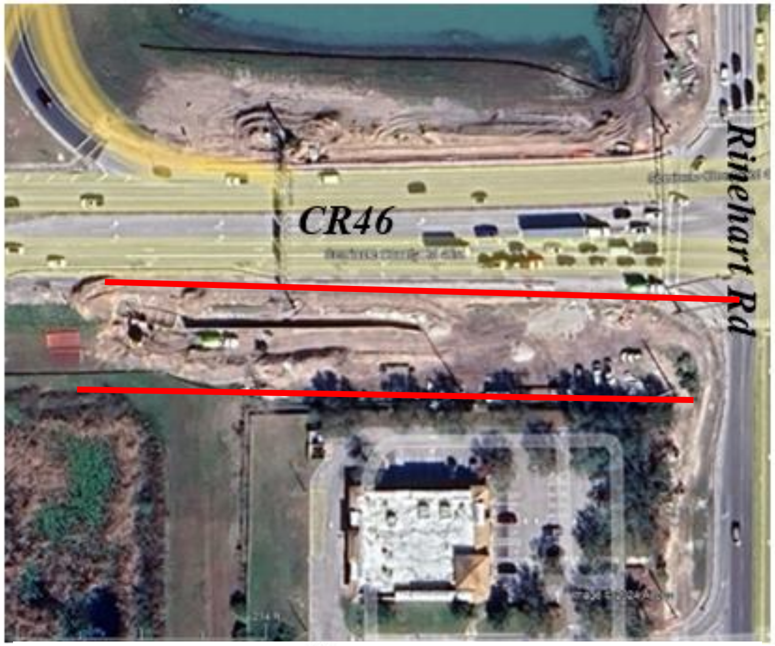
FIELD TESTING: TENTATIVE SITE LOCATIONS

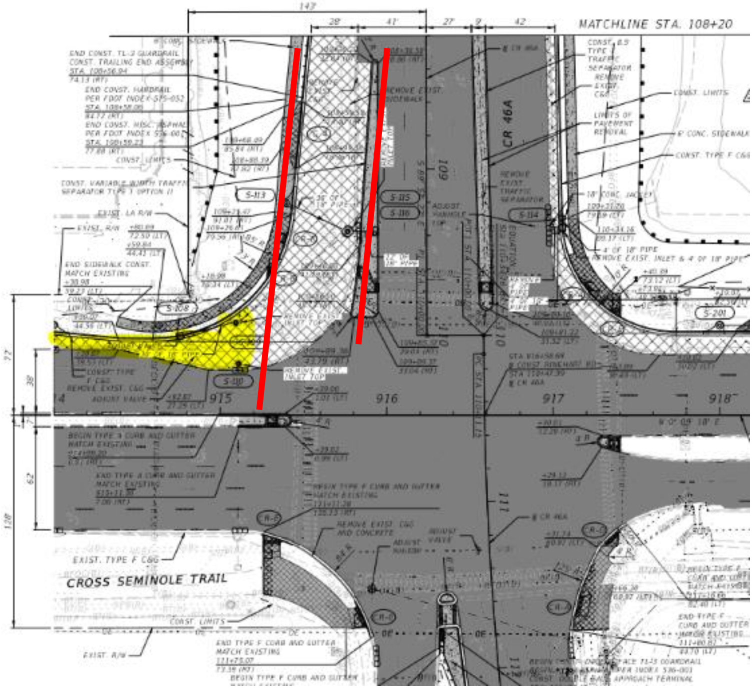
Project ID	Project Location	Type of Work	Progress
E56B8	SR 426 from Mystic Lake Dr. to Eyrie Dr.	Resurface	Canceled
E57B5	SR 436 from N. Old Cheney Hwy. to N. of University Park Dr.	Repave	Canceled
T5718	SR 551 from SR 408 to SR-50	New Lane	Canceled
E56B6	SR 426 from Edgewater Dr. to W. I-4	Repave	Canceled
T5749	SR 436 from Northlake Blvd. to Boston Ave.	Resurface	In progress
T5760	SR 527 (Orange Ave.) from Grant St. to Gore St.	Resurface	Not contacted yet
E57B3	I-4 from Rinehart Rd. to S. of CR 46A	New Lane	Visited
T5795	US 17/92 from Central FL Zoo to I-4 WB Ramps	New Lane	Canceled
E59A6	I-4 Sand Lake Rd. Interchange	New Lane	Not contacted yet
E59B7	SR 415 from E. of Acorn Lake Rd. to SR-44	New Lane	Not contacted yet
T5724	I-4 @ Daryl Carter Parkway Interchange	Exit Ramp	In progress
T5815	I-4 from World Dr. to Orange Co. Line	Resurface	Not contacted yet
E58B1	I-4 WB to SR 528 EB Ramp Widening	New Lane	In progress
E50B5	SR 44 Mill & Resurfacing from N. Hill Ave. to I-4 EB Ramp	New Lane	Not contacted yet
E50B0	SR 600 / US 17/92 from E. of Ham Brown Rd. to S. of Portage St.	Resurface	Not contacted yet
T5792	SR 15 (US 17) from South of Spring St to Lake Winona Rd	New Lane	Scheduled
E56A6	SR 50 from Hernando/Sumter Co. Line to east of CR 478A	New Lane	In progress
T5650	SR 500 (US 441) from Lake Ella Rd. to Avenida Central	New Lane	Not contacted yet
TP02	Central Polk Parkway	New Lane	Not contacted yet
TP01	Suncoast Pkwy with SR 44	New road	Not contacted yet

In coordination with FDOT, District 5 and Consulting Engineers:

- Michael Byerly (District 5)
- Leonel Cortes (District 5)
- William F. Sloup (Metric)
- Faisal Waseem (HNTB)
- Theresa Driskell (Volkert)
- R. Scott Moffatt (England-Thims & Miller, Inc)
- Matthew Simonds (Adaptive Consulting Engineers)

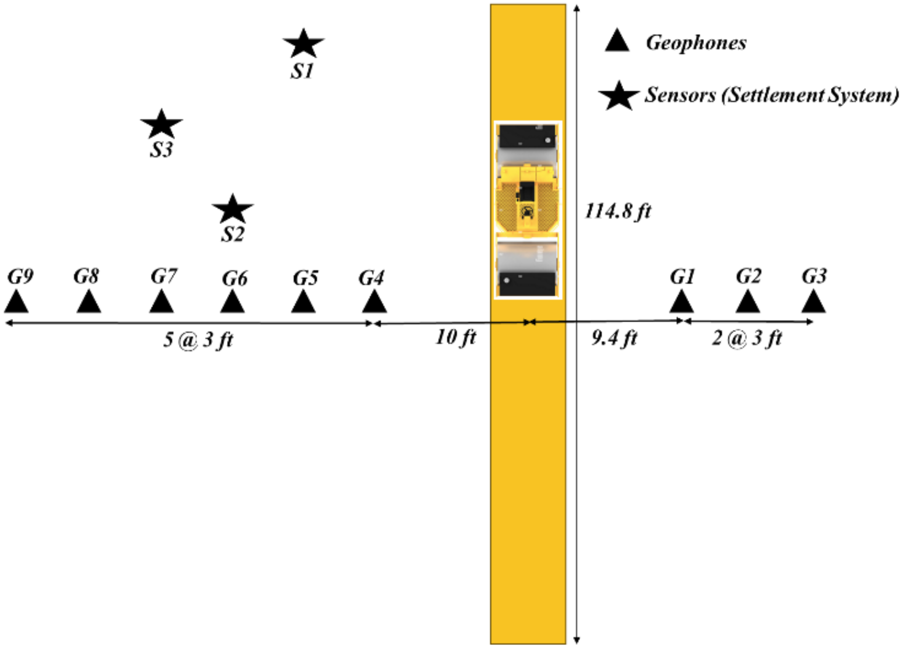
SITE DESCRIPTION: SITE E57B3

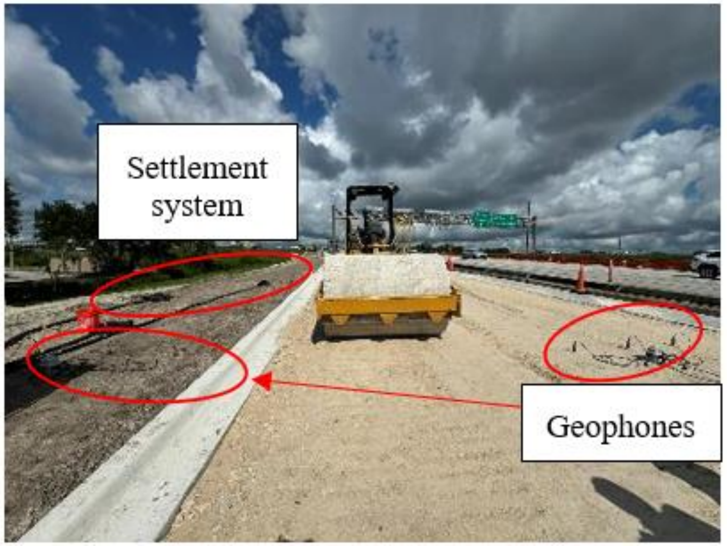




- Site located at the intersection between CR46A and Rinehart Road in Seminole County.
- Project consists of the construction of a new 28 ft-wide lane and a sidewalk.
- Most of the compaction efforts were already performed prior to the visit, soil was very dense.
- A Caterpillar CS-533E vibratory roller was used.
- The site was located on an embankment. Natural soil had negligible effect.

FIELD TESTING PROCEDURE AND INSTRUMENTATION LAYOUT: SITE E57B3





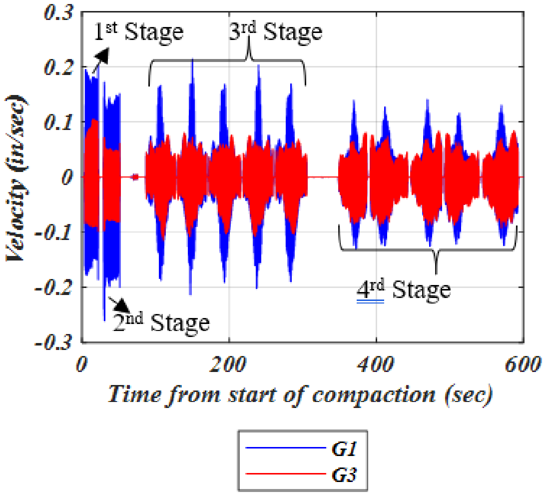
Stage	Roller location	Duration/# Passes	Roller vibration setting
1	Static	20 seconds	High setting
2	Static	20 seconds	Low setting
3	Passing by	5 passes	Low setting
4	Passing by	5 passes	High setting

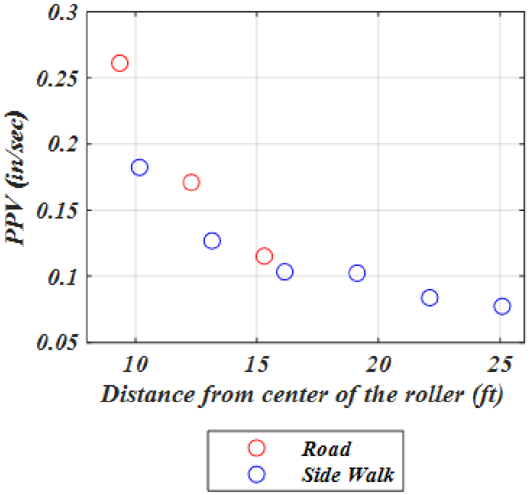
Roller stopped but vibrating

Roller moving and vibrating

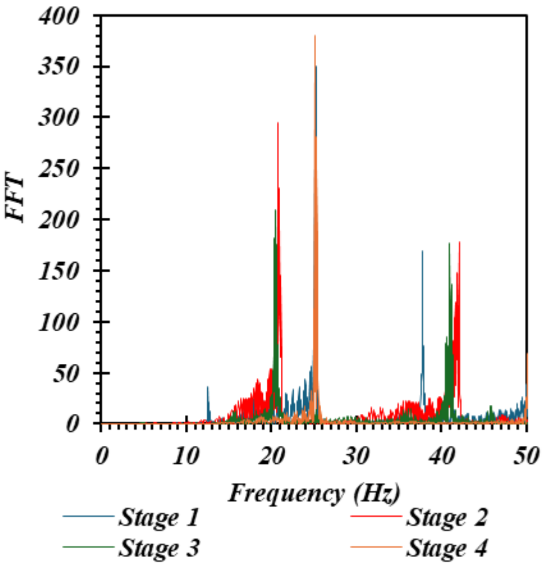
- Geophones located on both sides of the roller: sidewalk and roadway.
- Settlement sensors installed on the projected sidewalk.
- Test was divided in 4 stages varying roller settings and movement of the roller.
- Stages 1 and 2 lasted 20 seconds to match results from numerical models.
- 5 roller passes were sufficient to compact a pavement section based on survey.

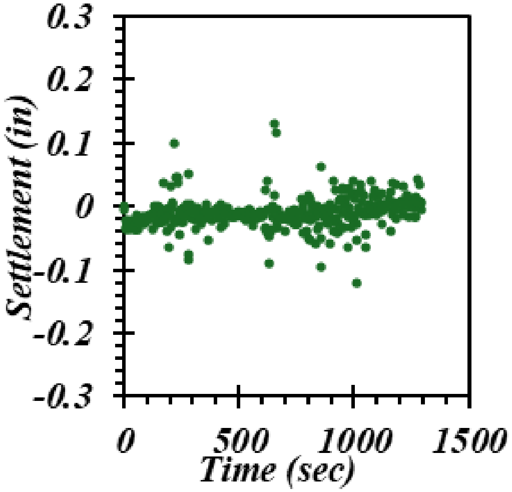
FIELD TESTING RESULTS





- Each stage of the test detected by sensors in vibration time history.
- Similar peaks regardless if the roller is stopped or moving.
- FDOT limit (0.5 in/s) was not reached.
- Contractor mentioned higher vibrations noticed during earlier compaction stages.
- Higher PPVs on road than sidewalk sidewalk.





- FFT analysis indicated different frequencies than given by the manufacturer (20 Hz Vs. 31Hz)
- This might be due to normal wear of equipment and soil propagation conditions.
- Negligible settlements were measured.
- Ground was compacted previously above 96% RC.

COMPUTATIONAL FRAMEWORK

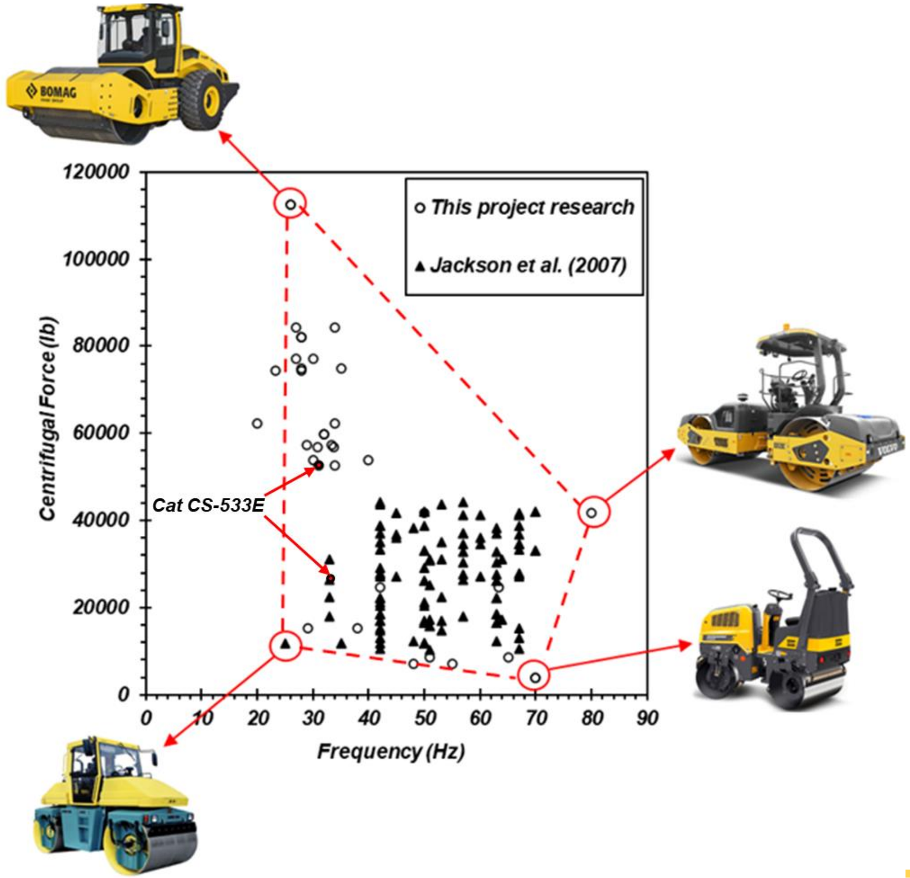
VIBRATIONS AND GROUND DEFORMATIONS DUE TO ROAD COMPACTION

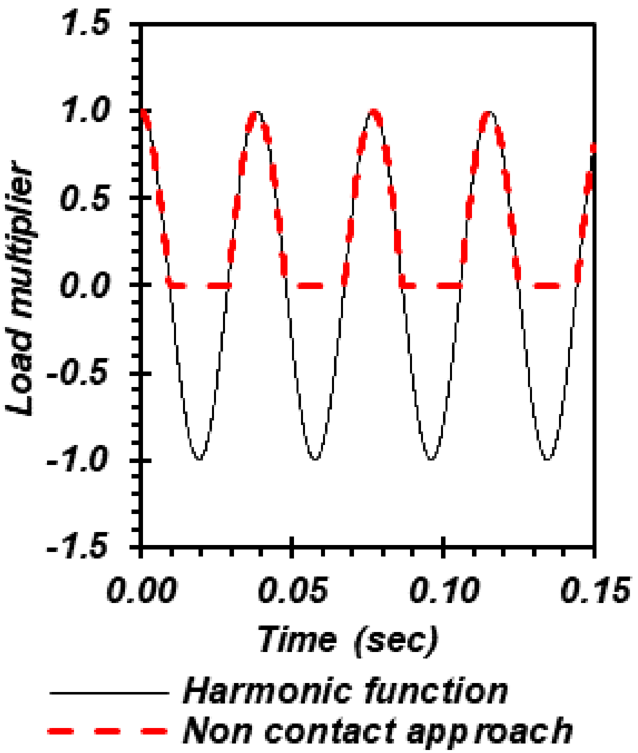
INPUT FORCES DUE TO VIBRATORY ROLLERS

$$F_c = \underbrace{(m_f + m_d)g}_{\text{Static axle load}} + \underbrace{m_o e_o w^2 cos(wt)}_{\text{Dynamic centrifugal force}}$$

Vibratory roller	Operating Weight [lb]	Centrifugal Force [lb]	Frequency [Hz]	Amplitude [in]
BOMAG BW 226 BVC-5	57016	112404	26	0.10
Volvo DD128C	28404	41770	80	0.03
Ammann AV95N	20900	11690	25	0.01
DYNAPAC CC900G	6389	3800	70	0.02

- 50 rollers were obtained from the technical literature.
- Vibratory roller main input parameters: static axle load, frequency, and centrifugal force.
- Currently, the corners of the enveloping polygon of the database are studied.
- Loss of contact considered by adjusting negative values of centrifugal force based on Pistrol et al. (2023).



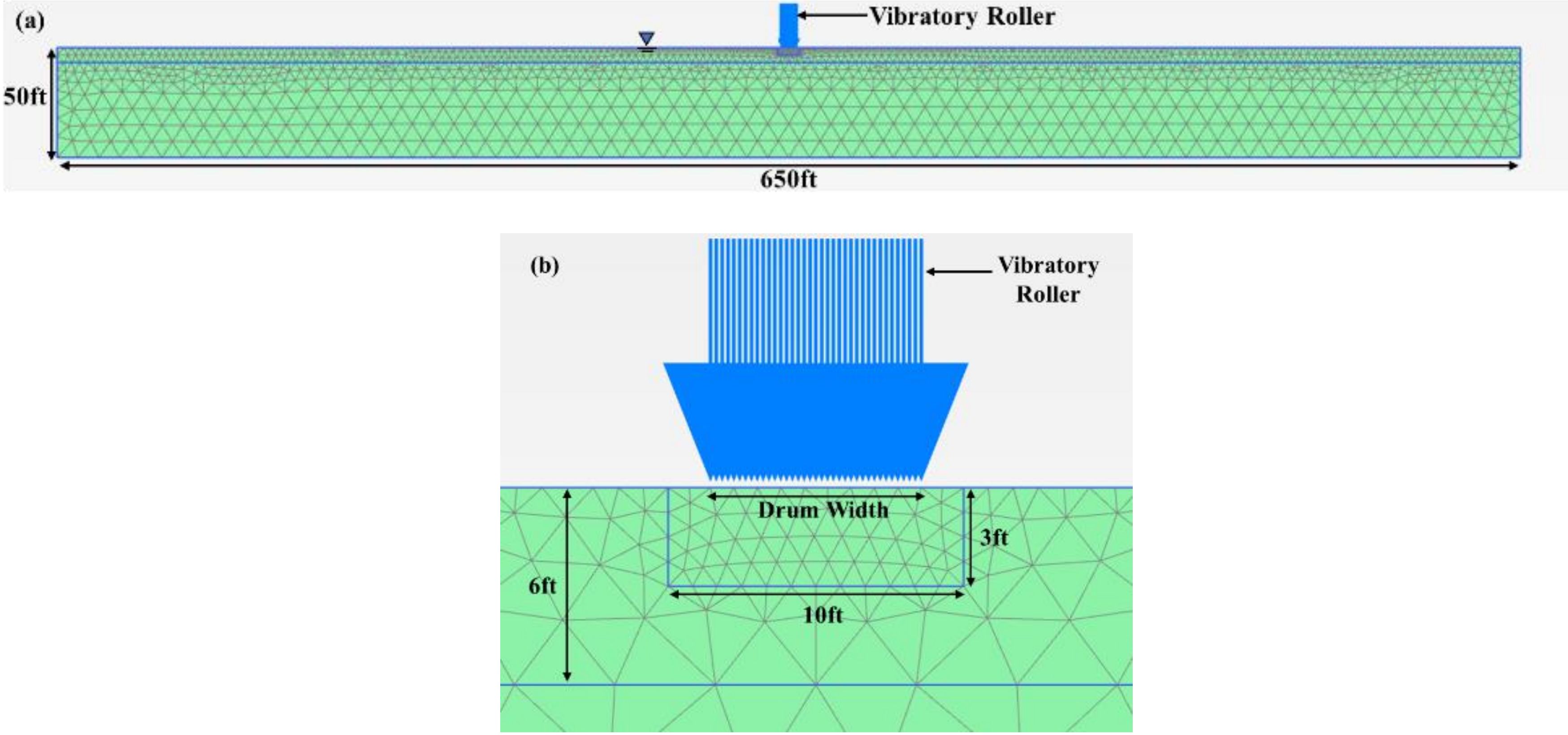


GENERAL DESCRIPTION OF THE FINITE ELEMENT MODEL

Model description

- 2D FE model in PLAXIS 2D.
- Plane strain conditions.
- Single layer of a sandy soil considering different Dr.
- Roller modeled as a dynamically distributed load with static and dynamic components.
- Dynamic analysis for 20 seconds to prevent excessive computational time.
- Soil modeled using the hypoplasticity model for sands enhanced with intergranular strain concept.

2D FE model zoomed-in view



CONSTITUTIVE SOIL MODEL PARAMETER SELECTION

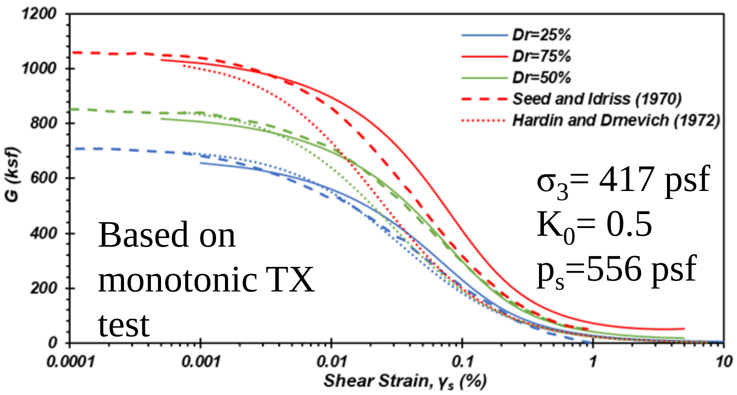
Select soil parameters
Define modeling strategy
Validate model
Perform parametric study
Create charts

Sand layer parameters

- Hypoplasticity model for sands enhanced with intergranular strain concept.
- Model selected to capture changes in void ratio (i.e., densification!).
- D_r: 25%, 50%, and 75% to model loose, medium-dense, and dense sands.
- Parameters calibrated based on expected shear modulus reduction curves.

e_{d0}=1.10 Maximum void ratio
e_{c0}=0.58 Minimum void ratio

From Zapata-Medina et al. (2019) and Lade et al. (1998)
Poorly Graded Sands tested in Dorchester, South Carolina and Nevada



Based on monotonic TX test

σ_3= 417 psf
K_0= 0.5
p_s=556 psf

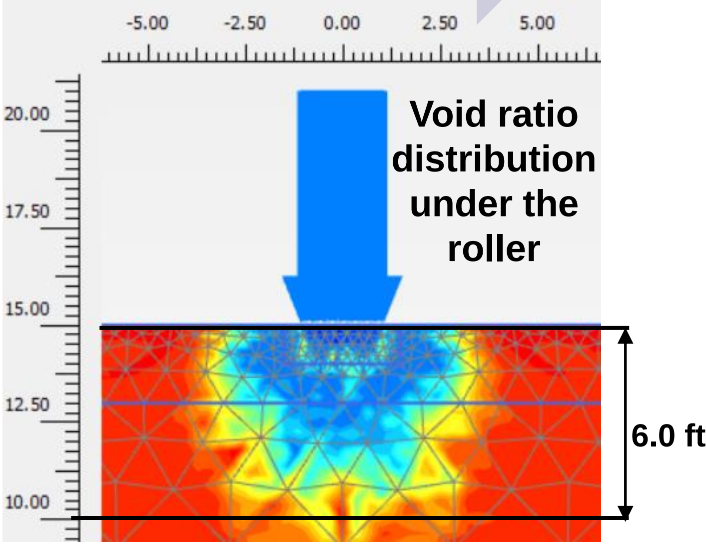
Parameter calibration based on shear modulus reduction curves

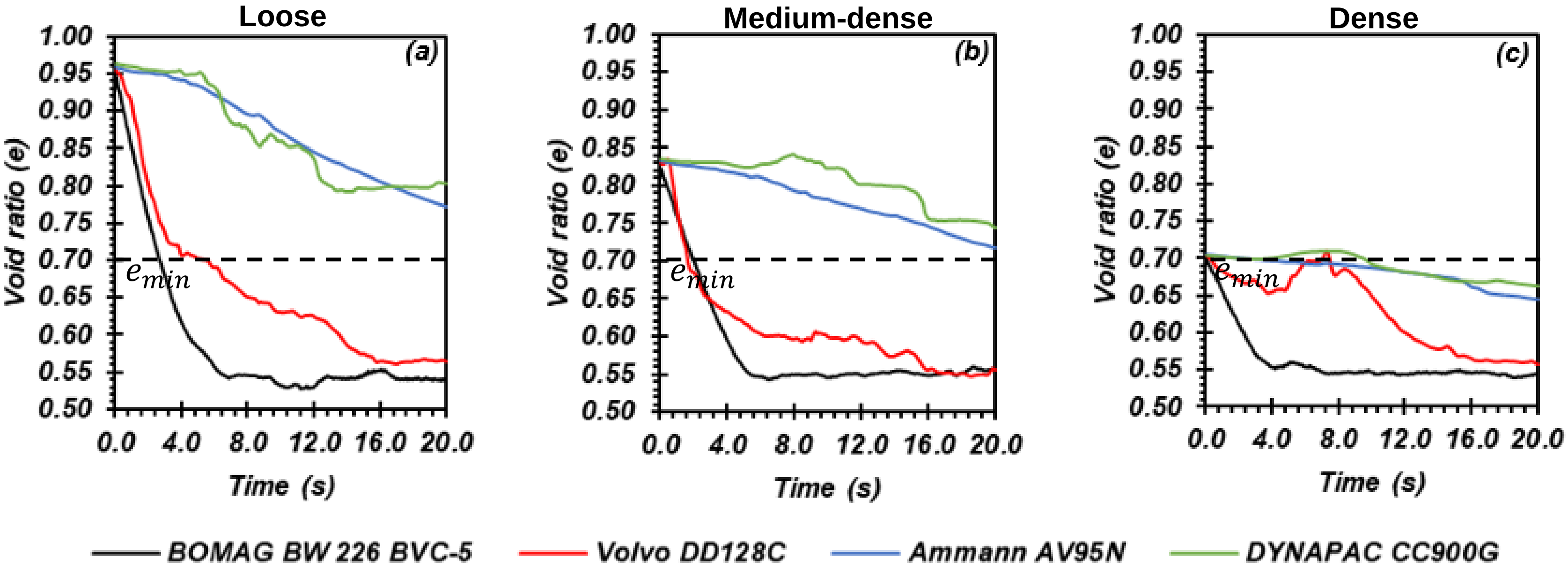
No.	Parameter	Description	Value	Unit
1	ϕ_c	Critical state friction angle	31	°
2	pt	Shift of the mean stress due to cohesion	0	psf
3	h_s	Granular hardness	25062	ksf
4	n	Exponent for pressure sensitive of a grain skeleton	0.37	-
5	e_{d0}	Minimum void ratio at zero pressure (ps = 0)	0.58	-
6	e_{c0}	Critical void ratio at zero pressure (ps = 0)	1.096	-
7	e_{i0}	Maximum void ratio at zero pressure (ps = 0)	1.315	-
8	α	Exponent for transition between peak and critical stresses	0.05	-
9	β	Exponent for stiffness dependency on pressure and density	1.4	-
10	m_R	Stiffness increase for 180° strain reversal	5	-
11	m_T	Stiffness increase for 90° strain reversal	2	-
12	R_{max}	Size of elastic range	5.00×10^{-5}	-
13	β_r	Material constant representing stiffness degradation	0.1	-
14	χ	Material constant for evolution of intergranular strains	1.0	-

MODELING STRATEGY

- Select soil parameters
- **Define modeling strategy**
- Validate model
- Perform parametric study
- Create charts

- Reaching the minimum void ratio of the soil was considered an appropriate criterion to determine when the compaction process ends, and it can be obtained from void ratio output from the model.
- The heavier the roller, the faster the void ratio converges to e_{min}.
- Light rollers did not reach e_{min}, thus they were analyzed after 20 seconds excitation.





Sample output of void ratio time histories for three relative densities and the four rollers

MODEL VALIDATION IN TERMS OF PPV

Select soil parameters

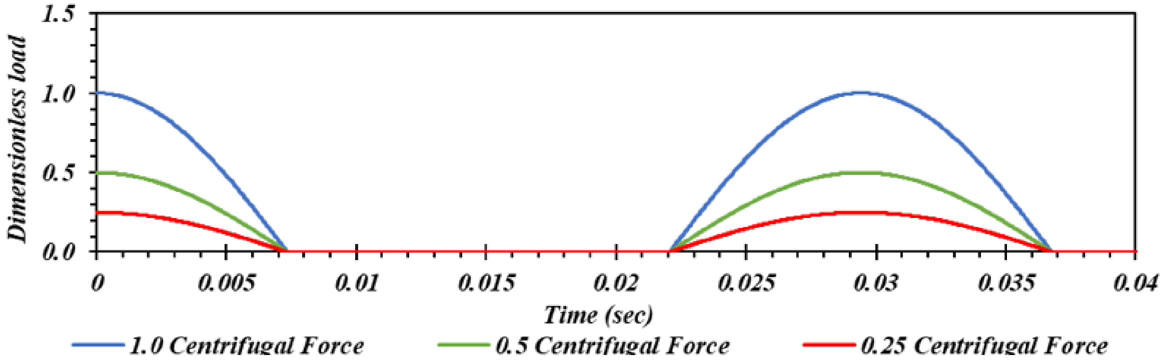
Define modeling strategy

Validate model

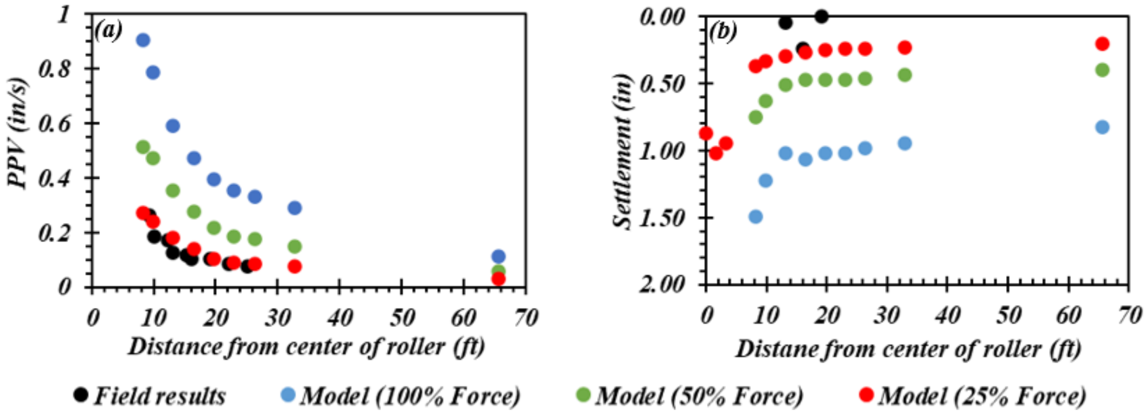
Perform parametric study

Create charts

- FE model validated with measurements from site E57B3.
- A relative density of 95% ($e = 0.6$) was used to simulate the state of compacted site.
- Efficiencies of 100%, 50%, and 25% considered to model differences with manufacturer specs.
- An efficiency of 25% matched the field results and 50% was considered acceptable.
- Using full centrifugal force for chart(s) and correlation production is conservative.



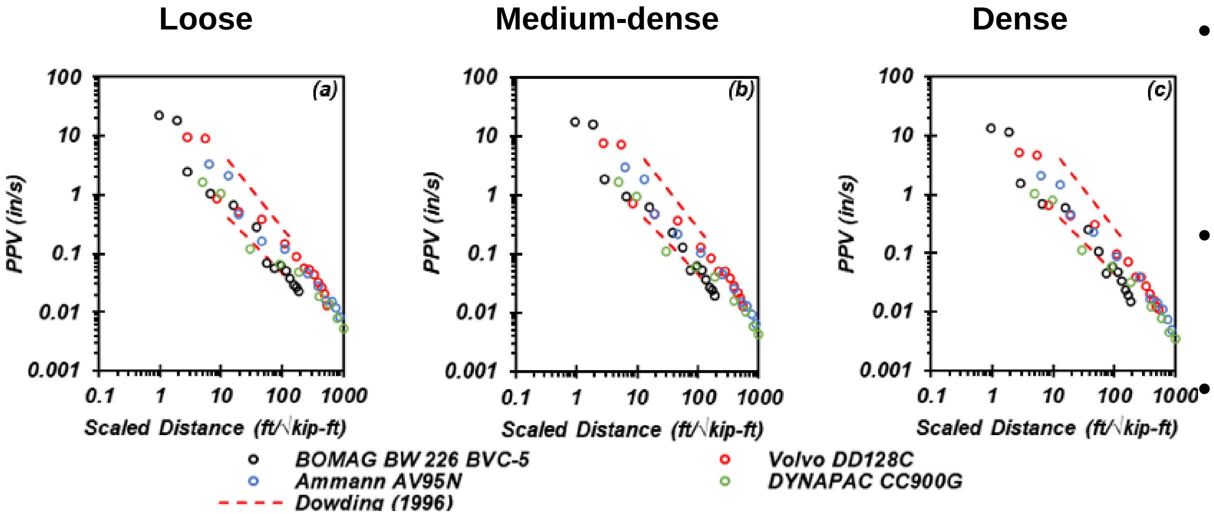
Centrifugal force time function used in the FE numerical model validation with the test results from site E57B3.



Comparison of measured and computed values during the validation of the FE model under 20 seconds of roller excitation in terms of (a) PPV and (b) ground deformations away from the roller.

NUMERICAL MODEL: PRELIMINARY PARAMETRIC RESULTS

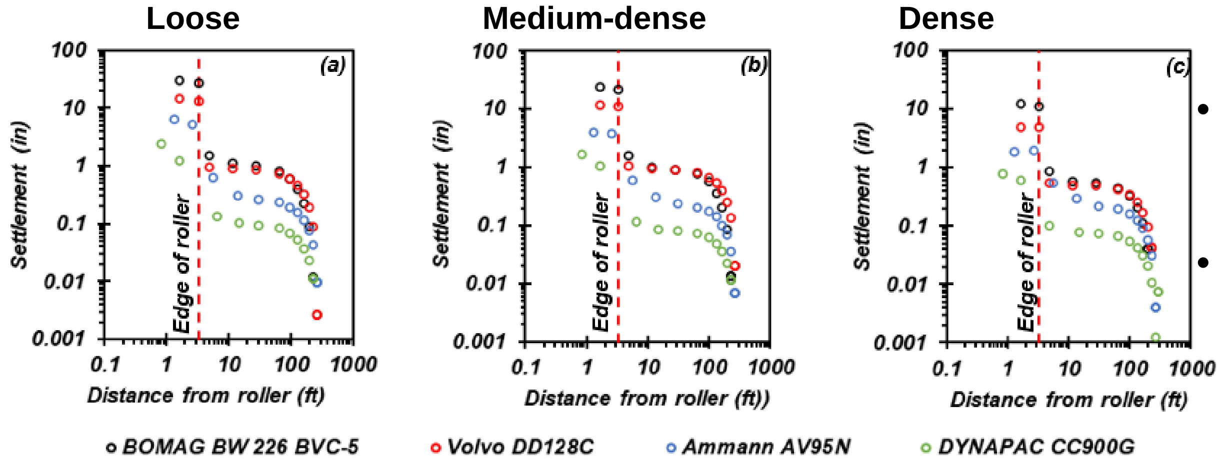
- Select soil parameters
- Define modeling strategy
- Validate model
- Perform parametric study
- Create charts



Computed peak particle velocities for three relative densities and four rollers

- The research team is currently analyzing the effect of each variable on both vibrations and deformations.
- Main variables include D_r, PPV, distance away from roller, frequency, and centrifugal force.
- Most of the results fall within limits presented by Dowding (1996).

$$E = \overbrace{(F}^{\text{Centrifugal Force}} + \underbrace{W_d)}_{\text{Drum Weight}} * \overbrace{2a}^{\text{Amplitude}}$$



Computed ground deformations for three relative densities and four rollers

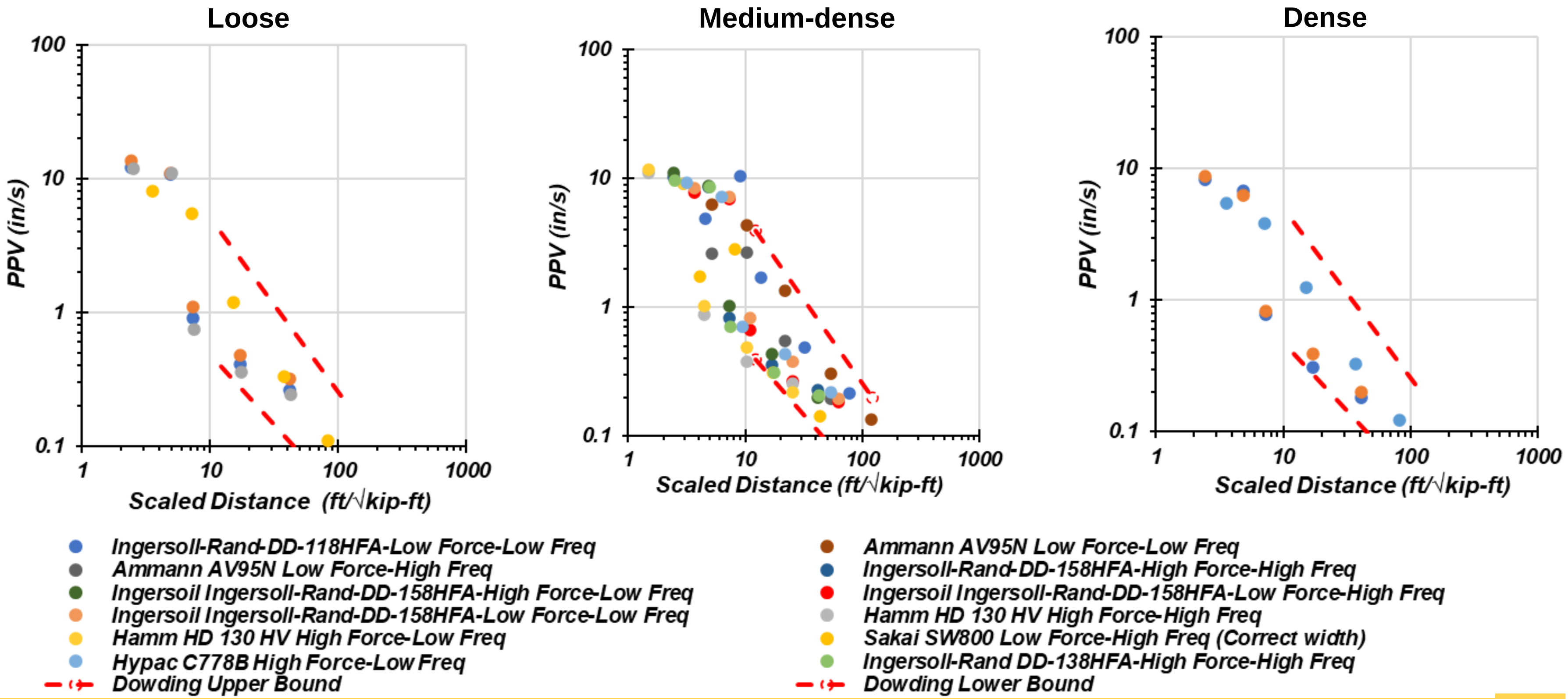
- Results have indicated that low frequency-high centrifugal force triggers the largest settlement.
- However, deformations tend to be rather small away from the roller (e.g., approx. 0.5 in at 6 ft away from roller).

MODEL VALIDATION IN TERMS OF PPV

Select soil parameters → Define modeling strategy → Validate model → Perform parametric study → **Create charts**

- Research team is currently analyzing additional rollers in the database.
- The heaviest rollers are being prioritized in this task.
- Results show PPVs fall within ranges of PPV by Dowding.
- Values for PPV attenuation (i.e., k and n) will be presented soon.

$$PPV = k\left(\frac{D}{\sqrt{E}}\right)^{-n}$$



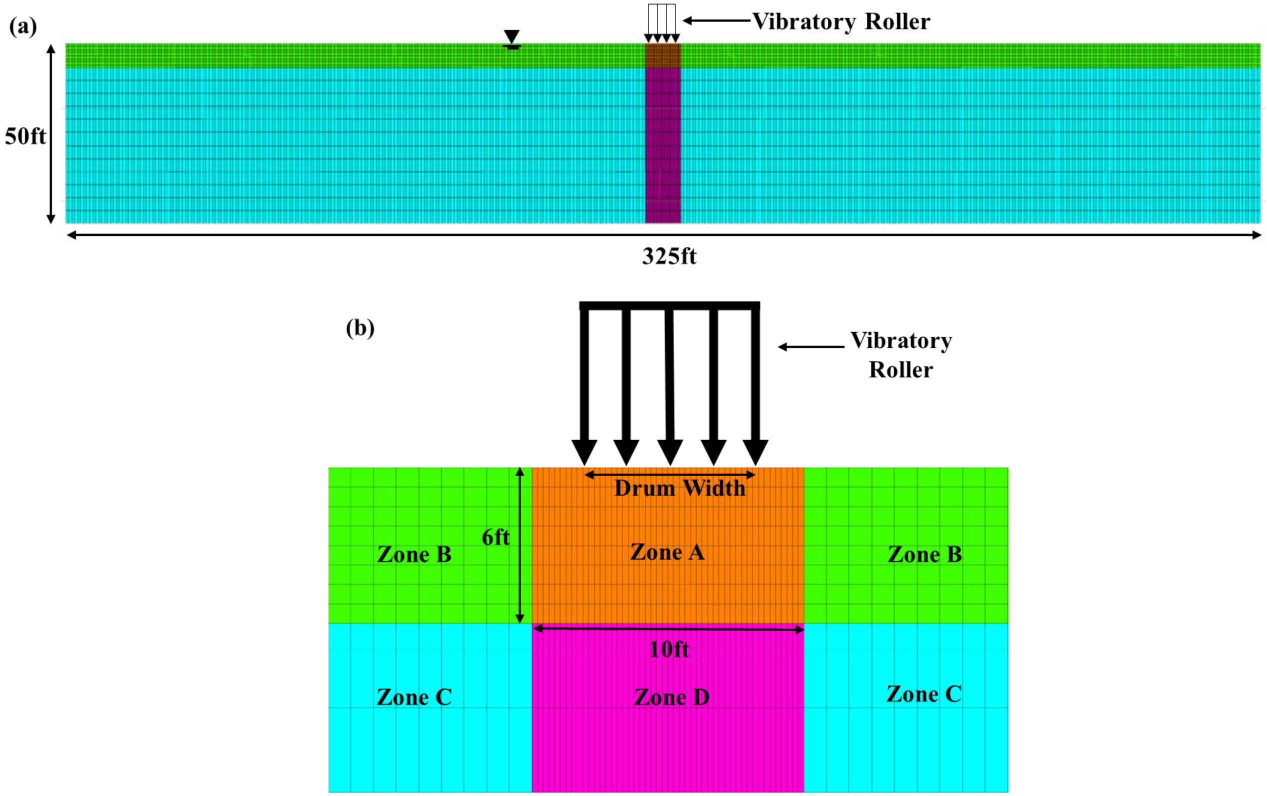
2D-FINITE DIFFERENCE NUMERICAL SIMULATION (FLAC2D)

Model description

- Finite Difference Method instead of FEM
- Similar modeling strategy than the FEM
- Constitutive model: PM4Sand
- Plane strain conditions
- Water table at ground surface
- Drained conditions

Motivation

- **FLAC2D** implements a more efficient formulation based on FDM.
- **PM4Sand** has been widely used to simulate sandy soils subjected to dynamic loads.
- The objective is to provide a second source of comparisons for the analysis.

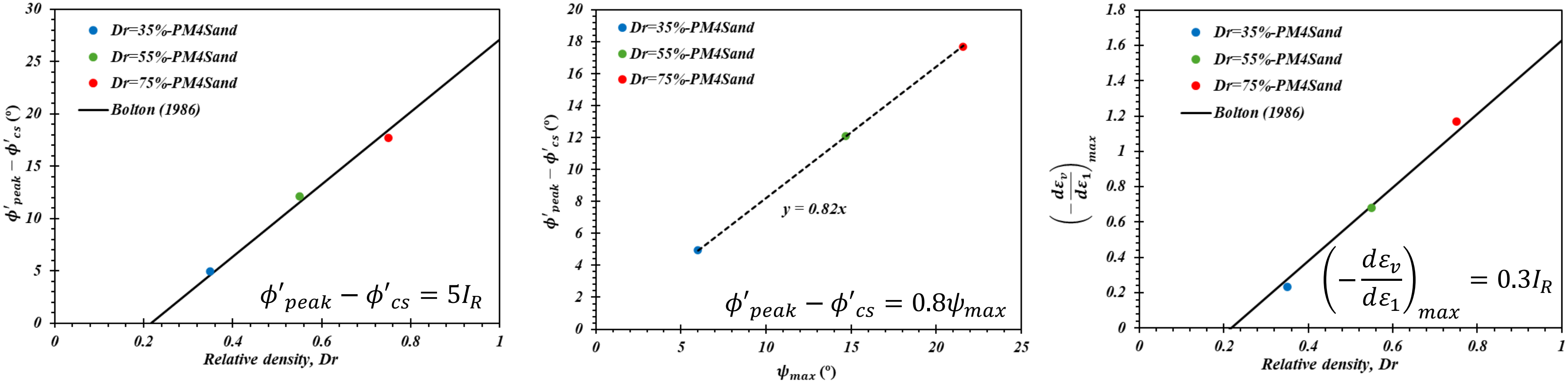


2D FD model zoomed-in view

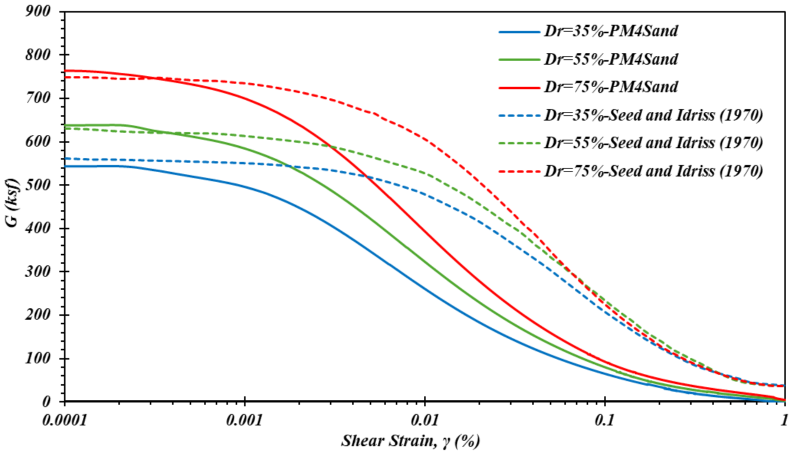
CALIBRATION PM4SAND

Constitutive soil parameter selection

- Calibration of soil parameters conducted based on monotonic DSS by using the dilatancy empirical correlations proposed by Bolton (1986) and stiffness degradation curves presented by Seed and Idriss (1970).
- Calibration was performed for loose, medium-dense and dense sands.



Comparison with the dilatancy empirical correlations proposed by Bolton (1986)



Comparison with the stiffness degradation curves presented by Seed and Idriss (1970)

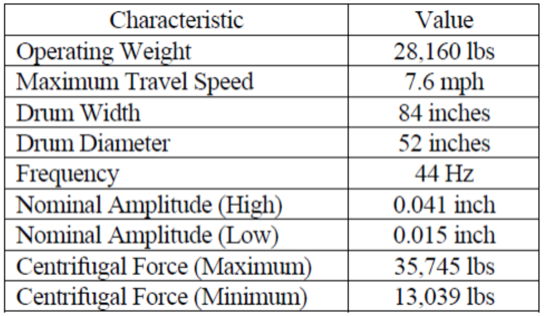
No.	Parameter	Description	Material		
			Loose	Medium-dense	Dense
1	D_r	Apparent relative density	0.35	0.55	0.75
2	G_o	Shear modulus coefficient	700	800	950
3	h_{po}	Contraction rate parameter	0.52	0.4	0.62
4	ϕ_{cv}	Critical state effective friction angle	31	33	35
5	n_b	Material constant that controls dilatancy	1.1	0.9	0.7
6	n_d	Material const. controls phase transformation		0.1	
7	e_{max}	Maximum void ratio		1.1	
8	e_{min}	Minimum void ratio		0.58	
9	ν	Poisson's ratio		0.3	
10	p_a	Atmospheric pressure (psi)		14.7	
11	Q	Bolton's material constants		10	
12	R			1.5	

Selected set of parameters

NUMERICAL MODEL VALIDATION

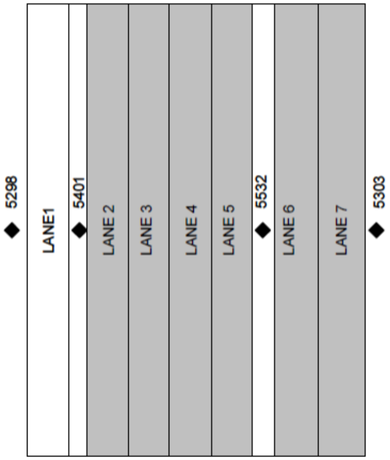
Field test conducted by Jackson et al. (2007)

- Test conducted in Gainesville, Florida.
- Caterpillar CB-634C vibratory roller was operated at low amplitude and low force.
- PPV measurements were performed perpendicular to the direction of the roller.
- Sensors were installed on the pavement by using bolts drilled into the asphalt instead of being installed at the ground surface.
- The computed PPVs are consistently lower than the measured values but match relatively well the measured responses.
- PPVs obtained from FLAC2D tend to be higher than those from PLAXIS 2D at every distance but their magnitudes are reasonably similar.

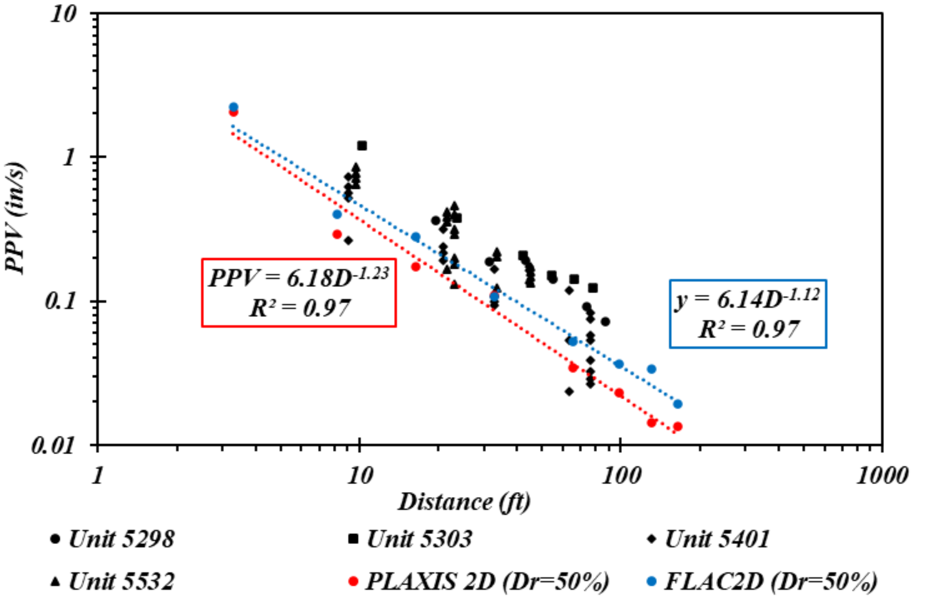


Characteristic	Value
Operating Weight	28,160 lbs
Maximum Travel Speed	7.6 mph
Drum Width	84 inches
Drum Diameter	52 inches
Frequency	44 Hz
Nominal Amplitude (High)	0.041 inch
Nominal Amplitude (Low)	0.015 inch
Centrifugal Force (Maximum)	35,745 lbs
Centrifugal Force (Minimum)	13,039 lbs

Vibratory roller specifications



Sensor location

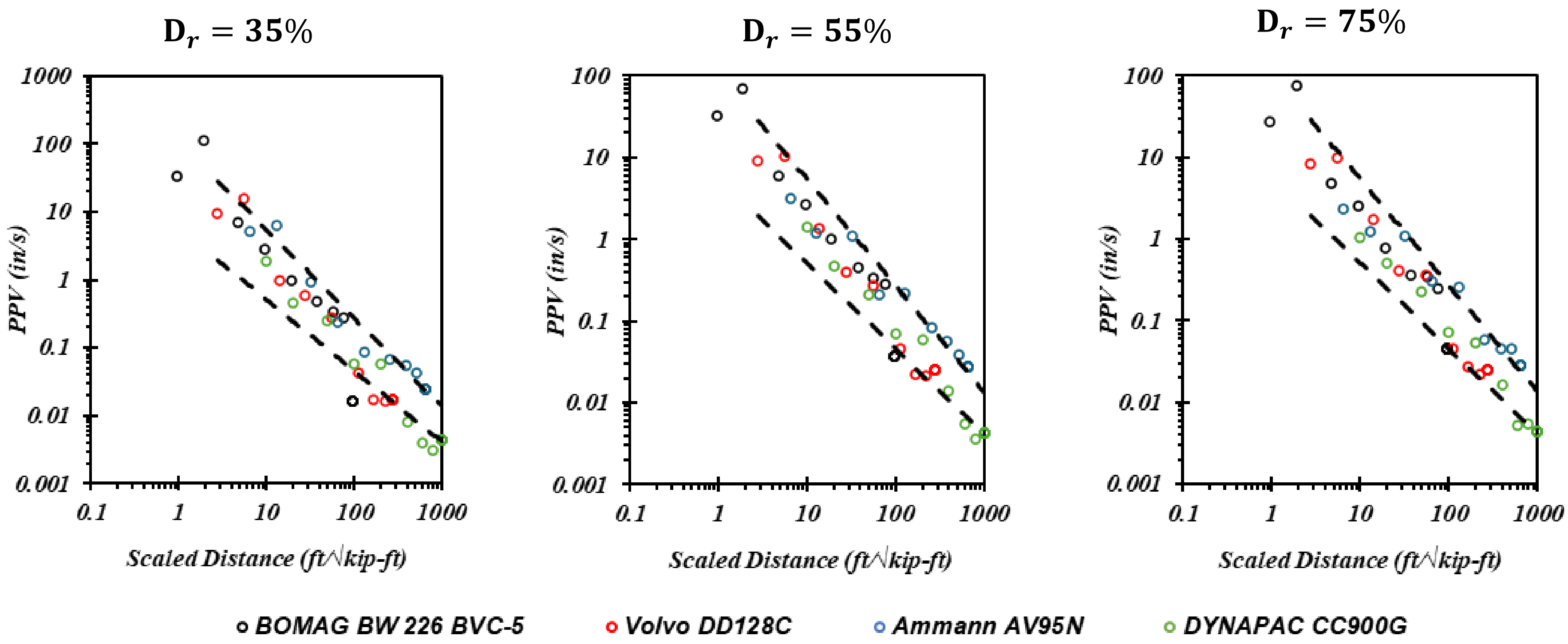


Comparison between computed and measured PPVs

2D-FINITE DIFFERENCE NUMERICAL RESULTS (FLAC2D)

Model description

- The four corners from the vibratory rollers database were successfully simulated.
- Relative densities of 35%, 55% and 75% were considered to represent loose, medium-dense and dense soil conditions, respectively.
- The ground vibrations were quantified in terms of PPV versus scaled distance away from the roller.
- Most of the computed values fall within the ranges presented by Dowding (1996), which is encouraging for the accuracy of the modeling strategy.



Numerical results in terms of PPVs

CONCLUSIONS AND PENDING ITEMS

Field testing program

1. A list of 20 tentative road compaction sites in Central Florida was created. One field test was completed, and more sites are planned in the upcoming weeks.
2. The field test was performed in 4 different stages that allowed the research team to test roller settings and compaction activities.
3. No significant effect in PPVs were observed if the roller was stationary or moving.
4. Computed frequencies showed different values than those specified by manufacturer.
5. The field test showed considerable levels of PPV away from the roller, but negligible settlements were measured.

Numerical modeling program

1. The road compaction process is currently modeled successfully by using a plane strain modeling approach with FE and FD approaches.
2. The FE model was validated based on the field test and published PPV attenuation charts. The research team will visit further sites in the coming weeks/months.
3. The analyses conducted so far have supported the conclusion that the centrifugal force is the main triggering variable of settlements and PPVs. Lower frequencies (close to the natural frequency of the soil) also tend to increase the soil response.

SUMMARY OF TASK/DELIVERABLE SCHEDULE

TASK AND ASSOCIATED DELIVERABLE	DATE
Kickoff teleconference	03/2023
Deliverable 1: A technical report presenting the results of the technical background on vibrations and ground deformations due to road compaction including asphalt compaction operations and other past case studies.	07/2023
Deliverable 2: A survey instrument and analysis of the data collected from consultants in Florida and from the survey directed to bituminous engineers in the districts to gather their experience on the requirement of static rollers to control vibrations in urban environments.	11/2023
Deliverable 3: A technical report summarizing the results of the field tests, including: (i) details and sequence of road compaction, (ii) soil properties at the selected sites and of the compacted material, (iii) specification of the compaction equipment used during the road compaction, and (iv) measured vibrations and ground deformations during the field visits.	04/2024
Deliverable 4: A technical report summarizing the results of the finite element numerical models and parametric studies developed in this research.	07/2024
Deliverable 5: A technical report summarizing the proposed correlations and recommendations regarding the vibrations and ground deformations due to road compaction.	10/2024
Deliverable 6a Draft final report.	11/2024
Deliverable 6b: Closeout teleconference meeting and PowerPoint presentation	02/2025
Deliverable 7: Final report	02/2025

PRESENTED BY

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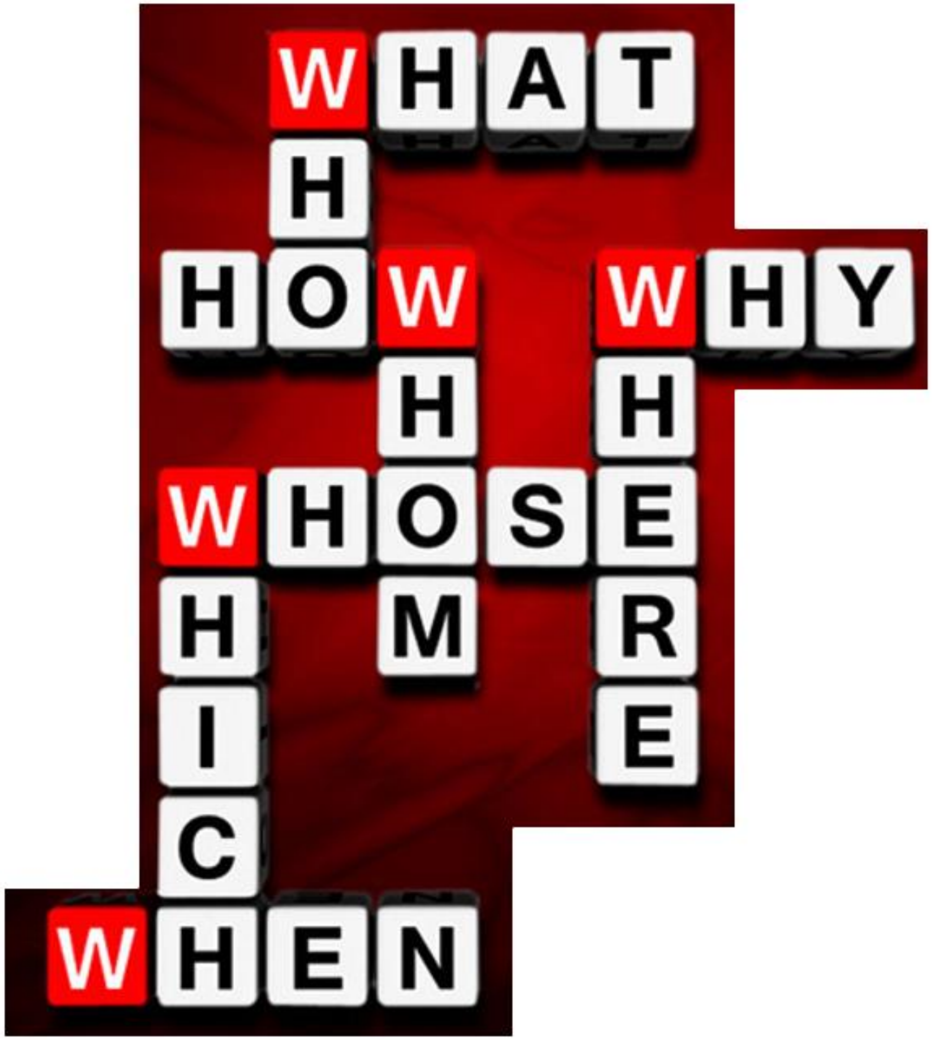
CENTRAL FLORIDA



Supplemental Slides

TECHNICAL CONSIDERATIONS

- Standard Specifications for Road and Bridge Construction (FDOT 2021), requires performing vibration monitoring on nearby structures for projects involving road compaction including asphalt compaction operations, and pile installations.

- Based on Chapter 108-2, during the construction of retaining walls and foundations for bridges, buildings, and structures, all nearby structures must be inspected, surveyed, and monitored for settlement: i) within 200 ft of sheet pile installation/extraction, ii) within 100 feet of soldier pile installation/extraction, iii) <u>within 75 feet when performing roadway compaction operations</u>, and iv) within certain limitation in terms of scale distance (i.e., square root of impact hammer energy) for pile driving operations.

- Chapter 108-2 also requires continuous vibration monitoring and recording ground vibration levels near structures during the operation of any equipment causing vibrations. Instrumentation must be capable of detecting velocities of 0.01 in/s or less. Upon detecting vibration levels reaching 0.5 in/s or damage to the structure, the source of vibration must immediately stop.

TECHNICAL CONSIDERATIONS

- Typical roadway construction involve the use of vibratory compaction equipment (e.g., rollers). These tools generate waves and generally result in a re-arrangement of the soil mass in the vicinity of construction activities.

- The re-arrangement of material and reduction in void ratio results from the repeated impact of the equipment. Those waves extend outward from the source and can have an effect on the soil volume.

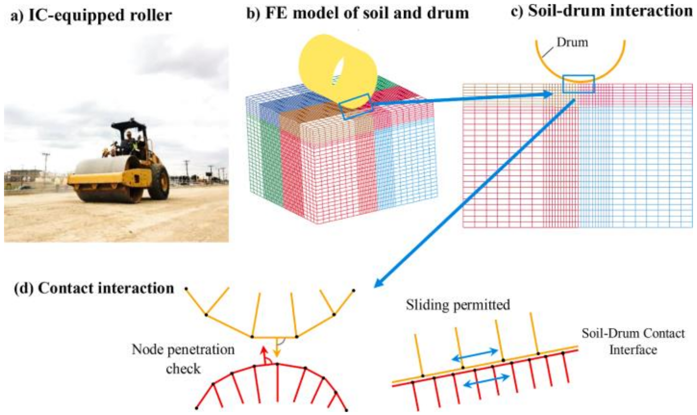
- The reduction in void ratio as a function of distance from the source is what will determine the settlement trough. In the past, the Department has dealt with claims involving either real or perceived damage to structures from typical roadway construction methods.

- This project aims to achieve a better computational model to assess the magnitude and geometry of settlement profile when vibratory rollers are used.

MORE TECHNICAL BACKGROUND (Numerical Analyses)

Fathi et al. (2021):

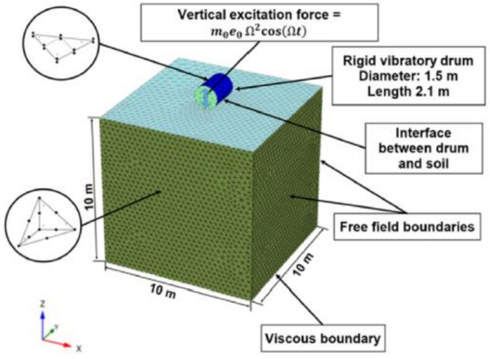
- Evaluation of depth of influence using 3D FE model in LS-DYNA.
- Drum considered as a rigid body.
- Single contact interface between pavement and drum.
- Results matched both displacement and vibrations at different depths



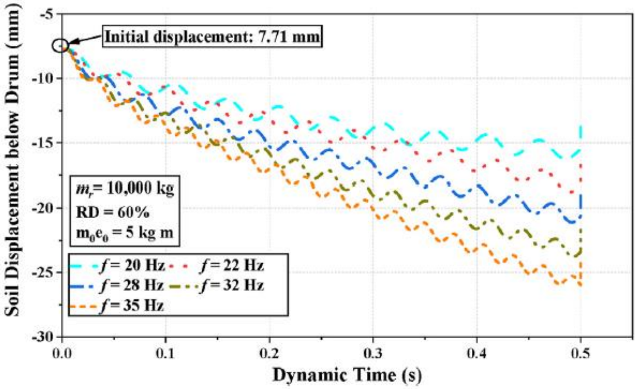
Schematic of drum/soil system

Xu et al. (2022):

- Estimated soil stiffness from drum response during compaction.
- More than 3000 simulations in PLAXIS 3D.
- Use of HS-Small constitutive model.
- Excitation modeled as harmonic
- Results showed increasing displacement as frequency increased



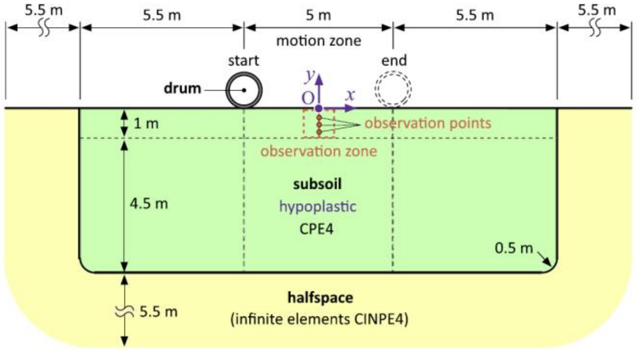
Adopted model



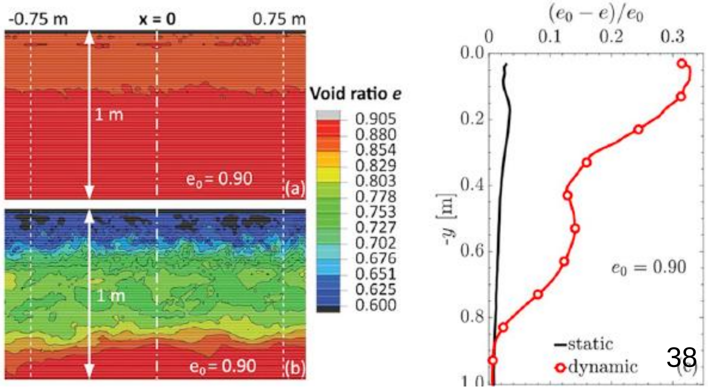
Soil settlement time history for different frequencies

Paulmichl et al. (2020):

- 2D FE model in ABAQUS.
- Plane strain.
- Hypoplasticity model for the soil to track void ratio changes!
- Contact between soil and drum using Coulomb's law.
- HAMM HD$^+$ 90 VO roller
- Frequency of 39 Hz



Sketch of the 2D FE model



(a) static and (b) oscillatory roller pass

FEM NUMERICAL MODELING

Similar to model 1:

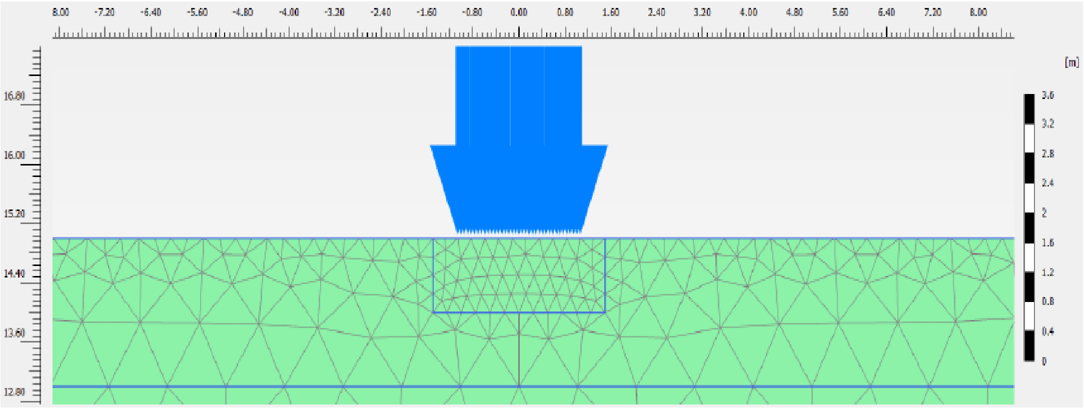
- 2D FE model.
- Plane strain conditions.
- Hypoplasticty used to model the soil.

Differences:

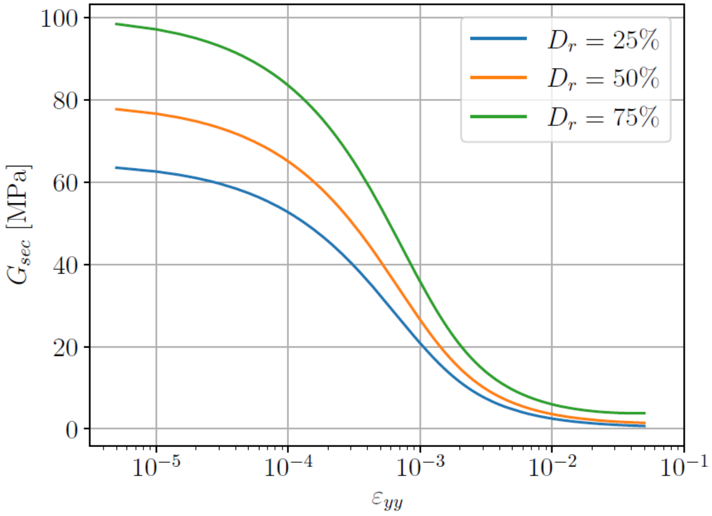
- Roller was modeled as a dynamic distributed load instead of point load.
- Dynamic analysis for 10 seconds.
- A more refined mesh.

Model	Ingersoll-Rand SD1500
Drum width [ft]	7
Weight [lbs/ft]	2935
Frequency [Hz]	26.5
Centrifugal force [lbf]	27652

Vibratory roller specifications

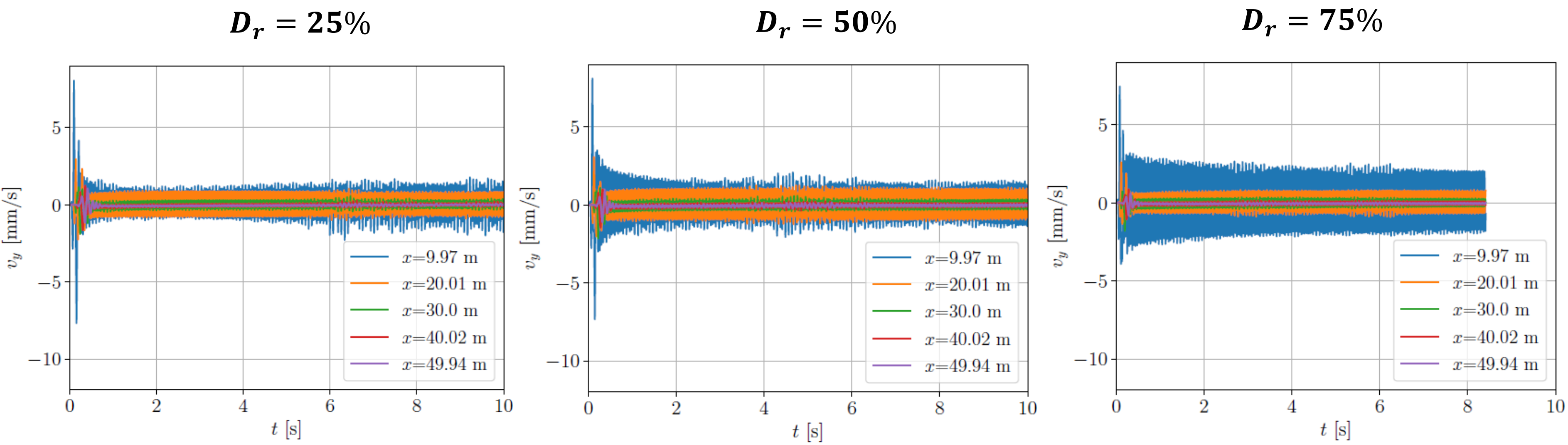


Improved FE model



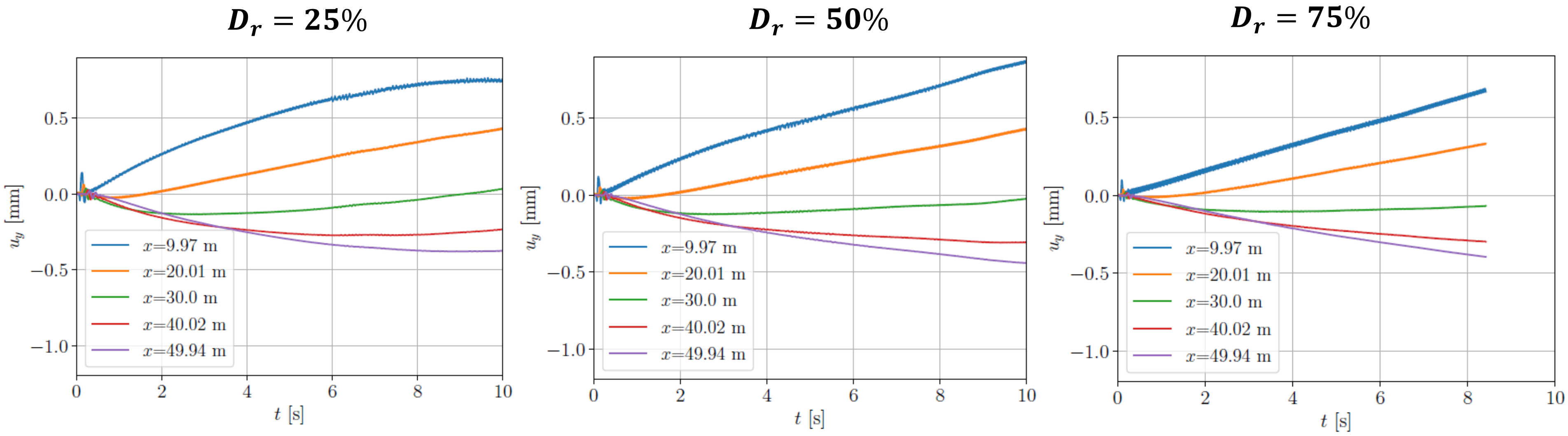
Stiffness degradation curves

FEM NUMERICAL MODELING



$D_r = 25\%$ $D_r = 50\%$ $D_r = 75\%$

Velocity time histories for three relative densities (Points up to 164 ft away from the roller location)

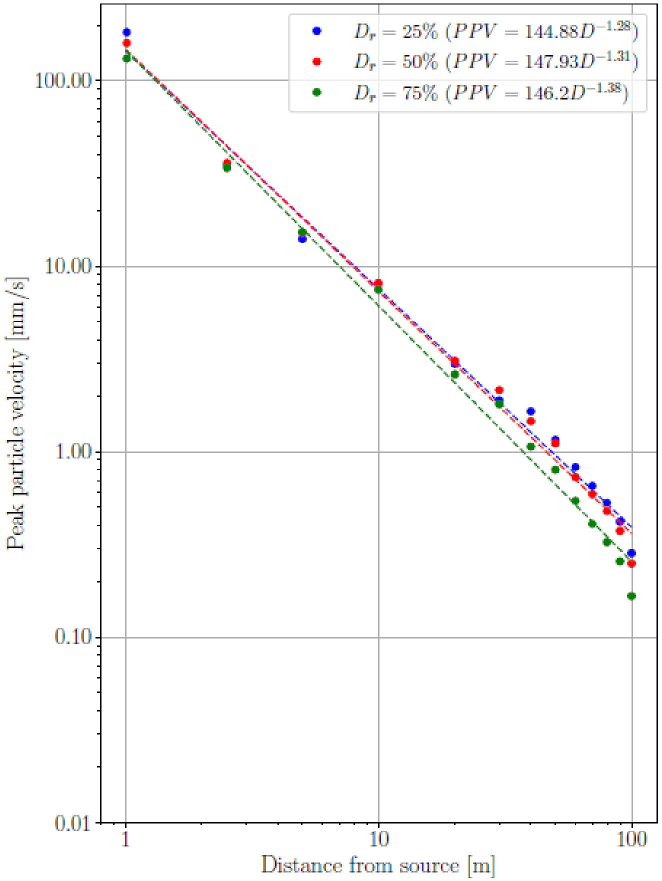


$D_r = 25\%$ $D_r = 50\%$ $D_r = 75\%$

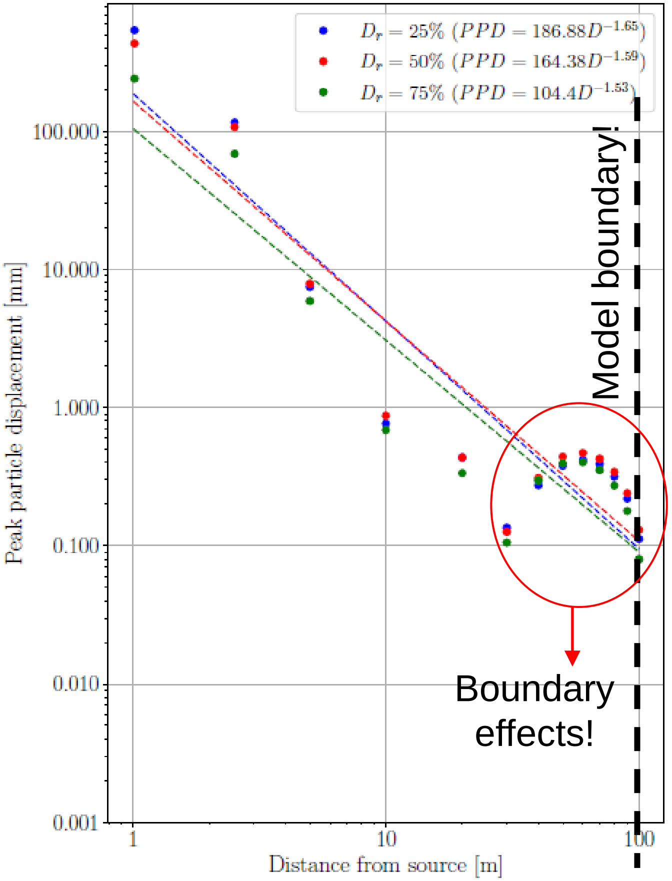
Deformation time histories for three relative densities (Points up to 164 ft away from the roller location)

NUMERICAL MODELING MISCELLANEOUS

Peak Particle Velocity (PPV)



Peak Particle Displacement (PPD)



Model boundary!

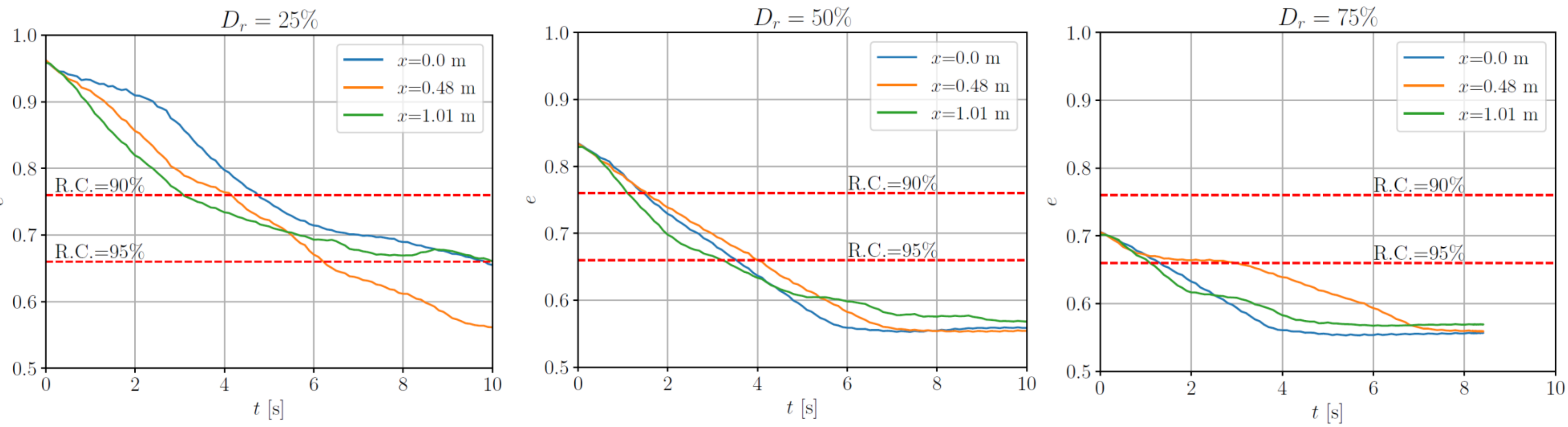
Boundary effects!

- PPV and Peak Particle Displacement (PPD) obtained for 3 relative densities were similar.
- PPV had a better fit to a linear regression than PPD.
- Dense sands tend to have less PPDs than loose materials.
- PPVs are obtained just after the roller begins to vibrate.
- Most PPDs correspond to the last step of the analysis. This value needs to be analyzed in depth also in relation to the target relative compaction (RC).

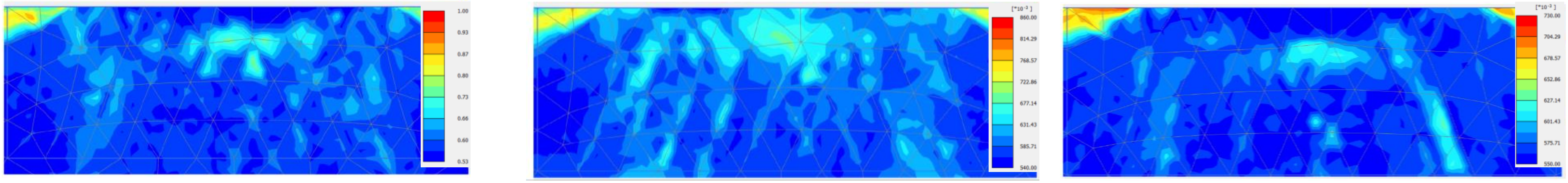
NUMERICAL MODELING MISCELLANEOUS

Relationship RC and Void Ratio:

$$R.C. = \frac{1 + e_{min}}{1 + e}$$



Void ratio time histories for three relative densities
(Points under the roller)



Void ratio distribution under the roller at the end of the simulation for three relative densities

- Relative compaction could be used to numerically determine when the compaction process ends. It can be computed from the void ratio.
- Void ratio under the roller varies with depth and distance.
- Research team plans to apply this approach to the results of upcoming models.

TRIAL FIELD TESTING FOR SETTLEMENT SYSTEM