UNDERSTANDING THE INERTIAL PROFILER

► **Prepared for:**

CalTrans and California Paving & Grinding Industries

Caltrans
CALIFORNIA DEPARTMENT OF TRANSPORTATION

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SSI

What is this about?

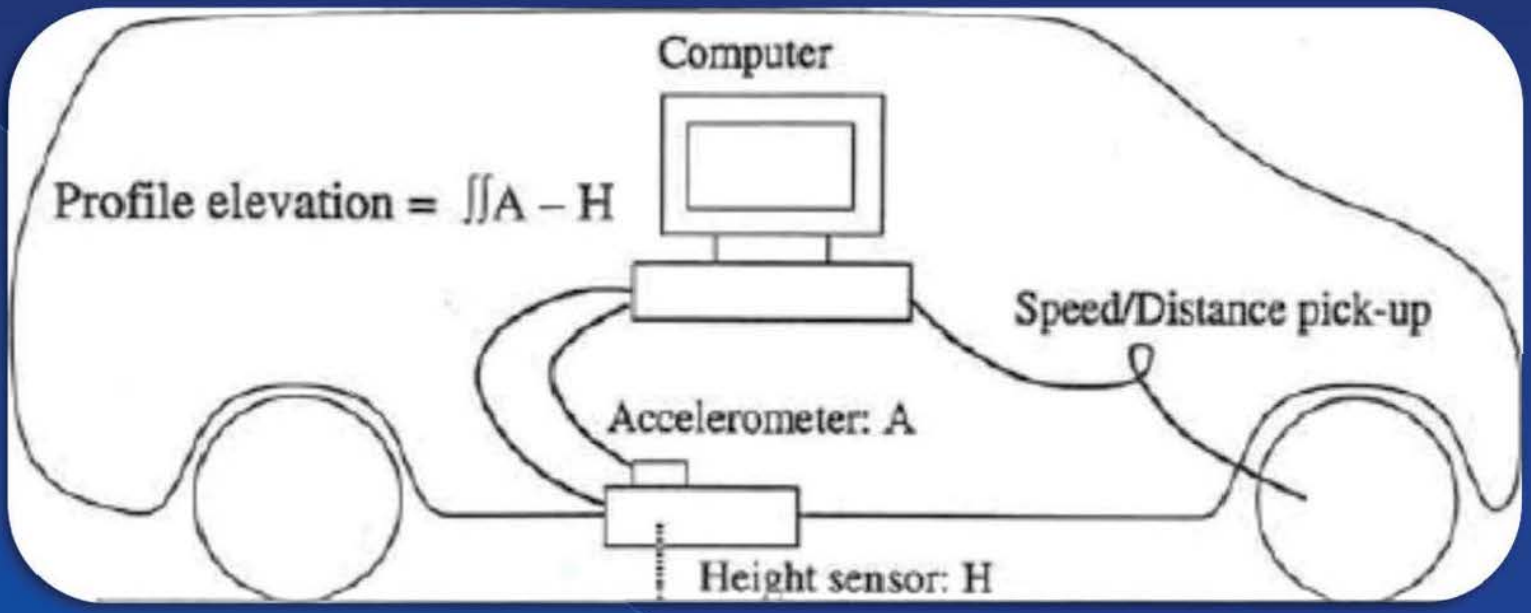
- Background on the Inertial Profiler
- Hardware & Software
- IP Setup & Calibration
- IRI and Localized Roughness
- IRI Grinding Issues

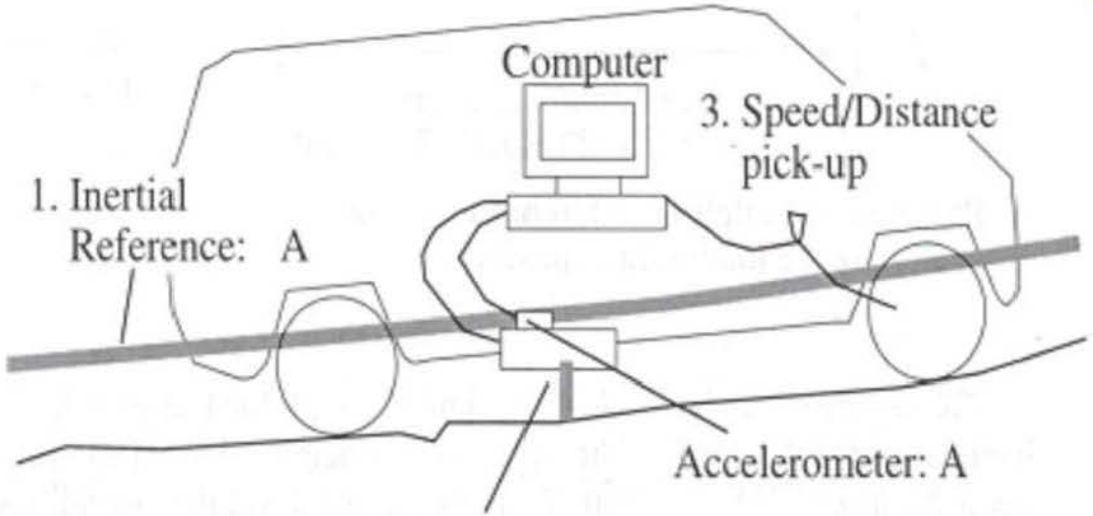
California Profilograph

- Increasingly Being Put Out to Pasture
  - Some State DOTs, Mexico, USACE/FAA still allow use
- Contractors' Frame of Reference
  - Especially must-grind bumps

Inertial Profiler

IP ANATOMY


Computer
Profile elevation = ∬A – H
Speed/Distance pick-up
Accelerometer: A
Height sensor: H


Computer
3. Speed/Distance pick-up
1. Inertial Reference: A
Accelerometer: A
2. Height relative to reference (laser, infrared, or ultrasonic sensor)

Inertial Profiler: Simple Facts

- Laser for height between vehicle and road
  - Mounted 12-16” (300-400mm) above surface
- DMI (“Distance Measurement Interface”) for measuring longitudinal position
- Accelerometer for vertical acceleration
  - Double integration process applied to accelerometer data to effectively eliminate vehicle suspension. Combine laser and DMI data to output a “road profile”
- “Host Vehicle”

INDUSTRY STANDARDS

- **ASTM E950 (**defines classifications of surface profiling devices)

  Longitudinal Sampling

  - **Class 1:** ≤ 25 mm (1 in.)
  - **Class 2:** ≥ 25 mm (1 in.) to 150 mm (6 in.)

  Vertical Measurement Resolution

  - **Class 1:** ≤ 0.1 mm (0.005 in.)
  - **Class 2:** ≥ 0.1 mm (0.005 in.) to 0.2 mm (0.010 in.)

  - **Application:** A Class I device must collect a valid pavement sample every one-inch (25 mm) longitudinally at all collection speeds.

- **AASHTO M-328** (Standard Specification for Inertial Profiler)
- **AASHTO R-054** (Accepting Pavement Ride Quality When Measured Using Inertial Profiling Systems)
- **AASHTO R-056** (Certification of Inertial Profiling Systems)
- **AASHTO R-057** (Operating Inertial Profiling Systems)

What Does an IP Measure?

- Elevation
  - Subtracts laser height from accelerometer displacement
  - "Relative" road profile is result
- One Inch Sampling Frequency
  - Governed by DMI and distance calibration
  - Cause the speed limitation for inertial profilers
  - 114 km/hr (74 mi/hr) *Speed limit
- GPS Location
  - Independent of elevation measurement (can profile w/o GPS)
  - No required resolution by CalTrans
  - Better GPS extremely useful for navigation, feature tagging (bridges, stations) and locating ALR

KEY COMPONENTS

▲Mount Hardware on Host Vehicle▲

▲Laser Rangefinder▲
▲+/- 5 g Accelerometer▲

▲DMI▲

▲Operator Computer▲ ▲Collection Computer▲

▲Custom Software▲

Host Vehicles

▲High Speed Profiler--Front Mounted▲

▲High Speed Profiler--Rear Mounted▲

▲Lightweight Profiler▲

▲Mid-Mount▲

Accelerometers

- ±5g accelerometers commonly used
- Double integrate acceleration to get displacement of vehicle
- Effected by changes in temperature and elevation
- Should be mounted directly over laser beam
- Calibrate by 0-180-90 Rotation, then Zero

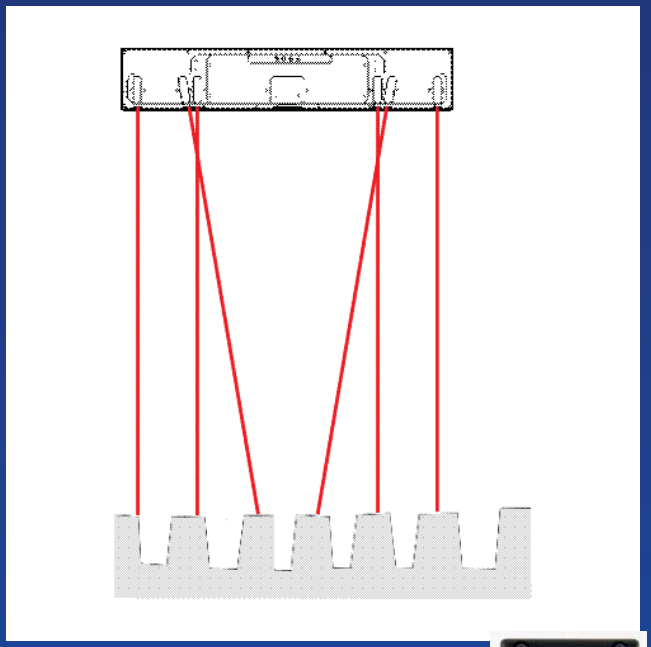
Lasers – Dots vs. Wide Spots

- .125”/.5” vs. 4” beam
- 5-32 KHz (1”/25 mm samples at highway speeds)
- Mature Technology

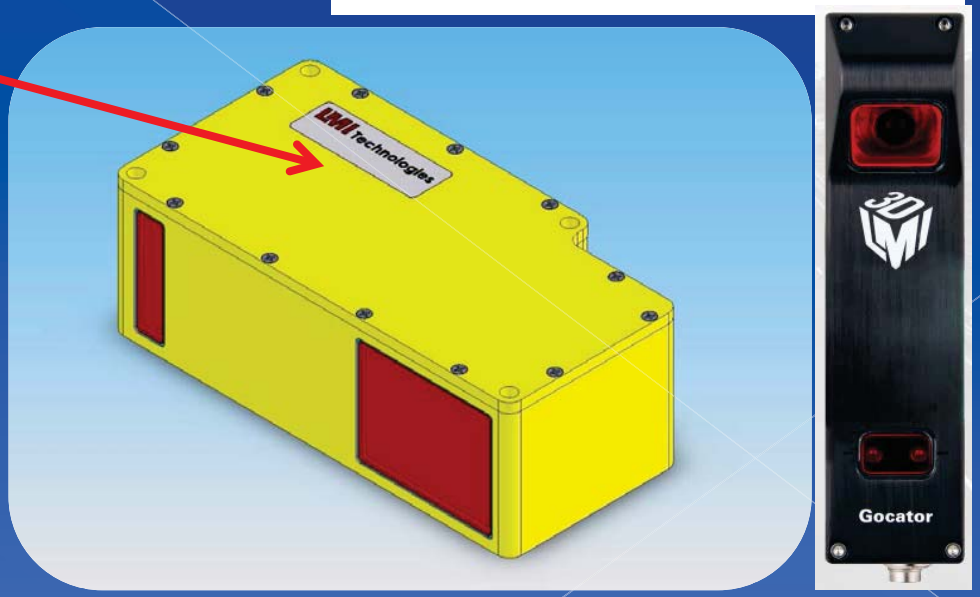
- “Single Point” vs. Wide Footprint Laser
- All lasers must be accurate within 0.01 inches

Wide Footprint Lasers

- **Goal:** Minimize variation of single point lasers on grooved, tyned or coarse textured pavements.



- "**Gocator/RoLine**" laser



- Required by Some Agency Smoothness Specifications (especially on concrete)

Impact of Wide Beam Laser

- Height Sampling Refined by Increased Surface Area Considered
- "Tire-Bridging" Algorithm Eliminates Recurring Low Points to Reduce Profile to Riding Surface Only
- Lower IRI Values vs. Spot Lasers. Approximate Impact:
  - ✓ 15-25% on diamond ground surfaces
  - ✓ 10-20% on longitudinally tined surfaces
  - ✓ 5-15% on asphalt mixes with void spacing in aggregate
  - ✓ 1-5% on dense asphalt

IP Setup & Calibration

Prepare Equipment

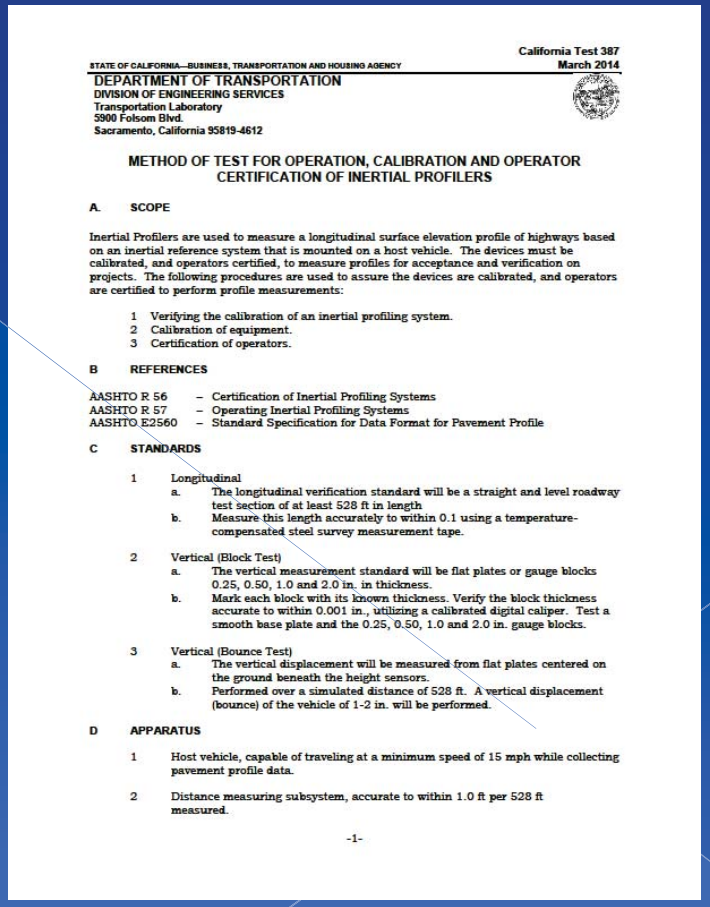
- Attach sensor modules (69” offset/12” stand-off)
- Attach DMI
- Connect power supply
- Initiate software

Calibrations/Verifications

- Laser verification (block test)
- Distance calibration
- Bounce test
- Accelerometer calibration
- Repeatability (initial IP use)

Applicable Procedures

- California Test 387
- Special Provisions



California Test 387
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STATE OF CALIFORNIA—BUSINESS, TRANSPORTATION AND HOUSING AGENCY

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METHOD OF TEST FOR OPERATION, CALIBRATION AND OPERATOR CERTIFICATION OF INERTIAL PROFILERS

A. SCOPE

Inertial Profilers are used to measure a longitudinal surface elevation profile of highways based on an inertial reference system that is mounted on a host vehicle. The devices must be calibrated, and operators certified, to measure profiles for acceptance and verification on projects. The following procedures are used to assure the devices are calibrated, and operators are certified to perform profile measurements:

1 Verifying the calibration of an inertial profiling system.
2 Calibration of equipment.
3 Certification of operators.

B REFERENCES

AASHTO R 56 – Certification of Inertial Profiling Systems
AASHTO R 57 – Operating Inertial Profiling Systems
AASHTO E2560 – Standard Specification for Data Format for Pavement Profile

C STANDARDS

1 Longitudinal
a. The longitudinal verification standard will be a straight and level roadway test section of at least 528 ft in length
b. Measure this length accurately to within 0.1 using a temperature-compensated steel survey measurement tape.

2 Vertical (Block Test)
a. The vertical measurement standard will be flat plates or gauge blocks 0.25, 0.50, 1.0 and 2.0 in. in thickness.
b. Mark each block with its known thickness. Verify the block thickness accurate to within 0.001 in., utilizing a calibrated digital caliper. Test a smooth base plate and the 0.25, 0.50, 1.0 and 2.0 in. gauge blocks.

3 Vertical (Bounce Test)
a. The vertical displacement will be measured from flat plates centered on the ground beneath the height sensors.
b. Performed over a simulated distance of 528 ft. A vertical displacement (bounce) of the vehicle of 1-2 in. will be performed.

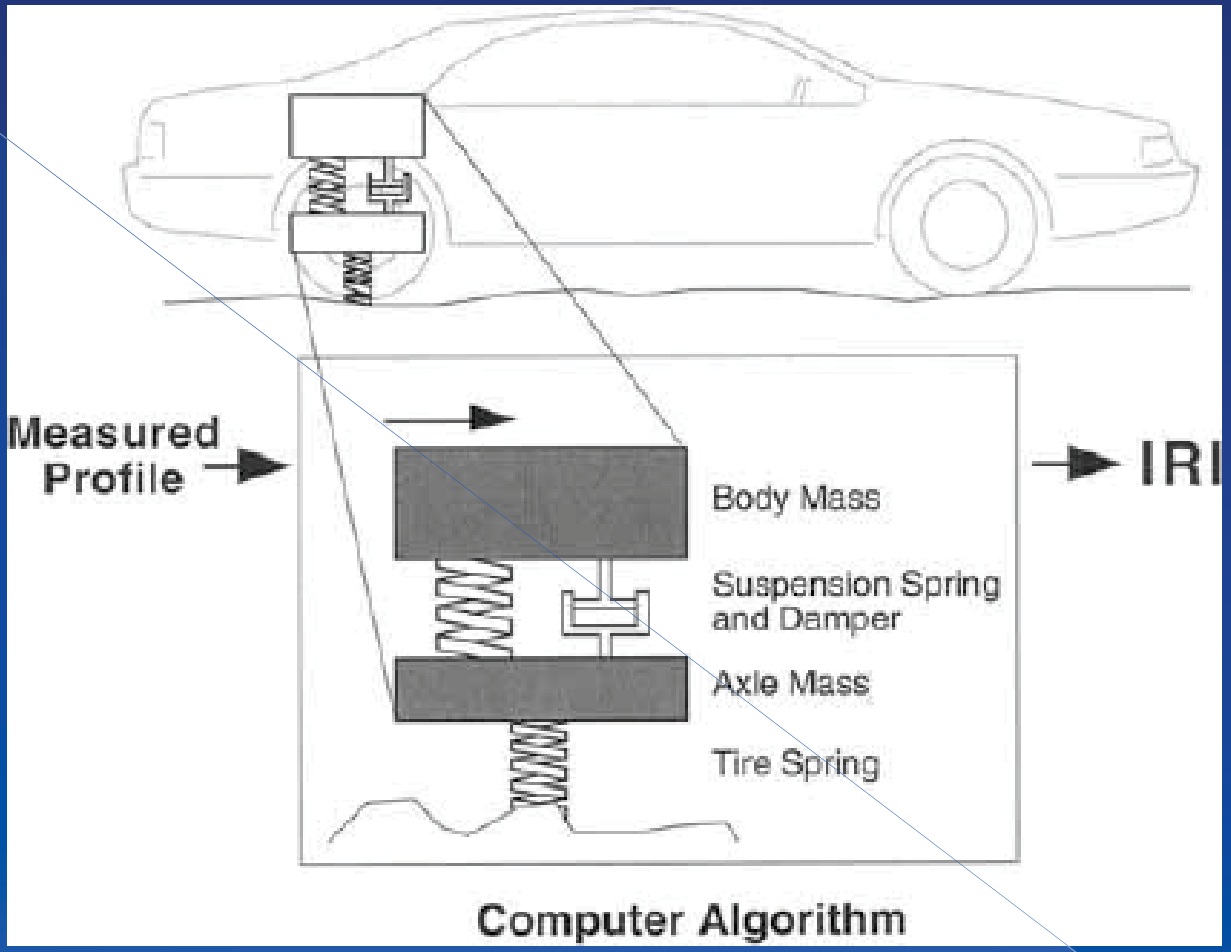
D APPARATUS

1 Host vehicle, capable of traveling at a minimum speed of 15 mph while collecting pavement profile data.

2 Distance measuring subsystem, accurate to within 1.0 ft per 528 ft measured.

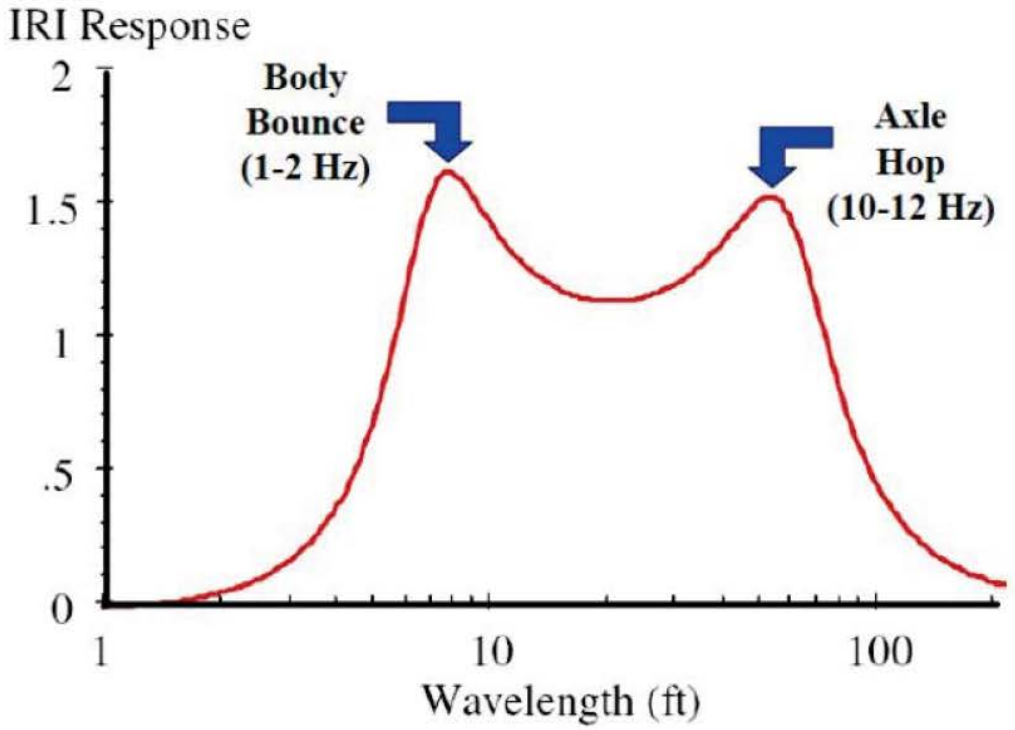
-1-

IRI (International Roughness Index)



- IRI = “Quarter-Car” mathematical model calculates suspension deflection of a simulated mechanical system with response similar to a passenger car.
- Simulated suspension motion is accumulated and divided by the distance traveled to give an index with units of slope (inches/mile, mm/km, etc.).

IRI Sensitivity



http://www.dot.ca.gov/hq/maint/Pavement/Offices/Pavement_Engineering/PDF/IP_Cert_Site.pdf

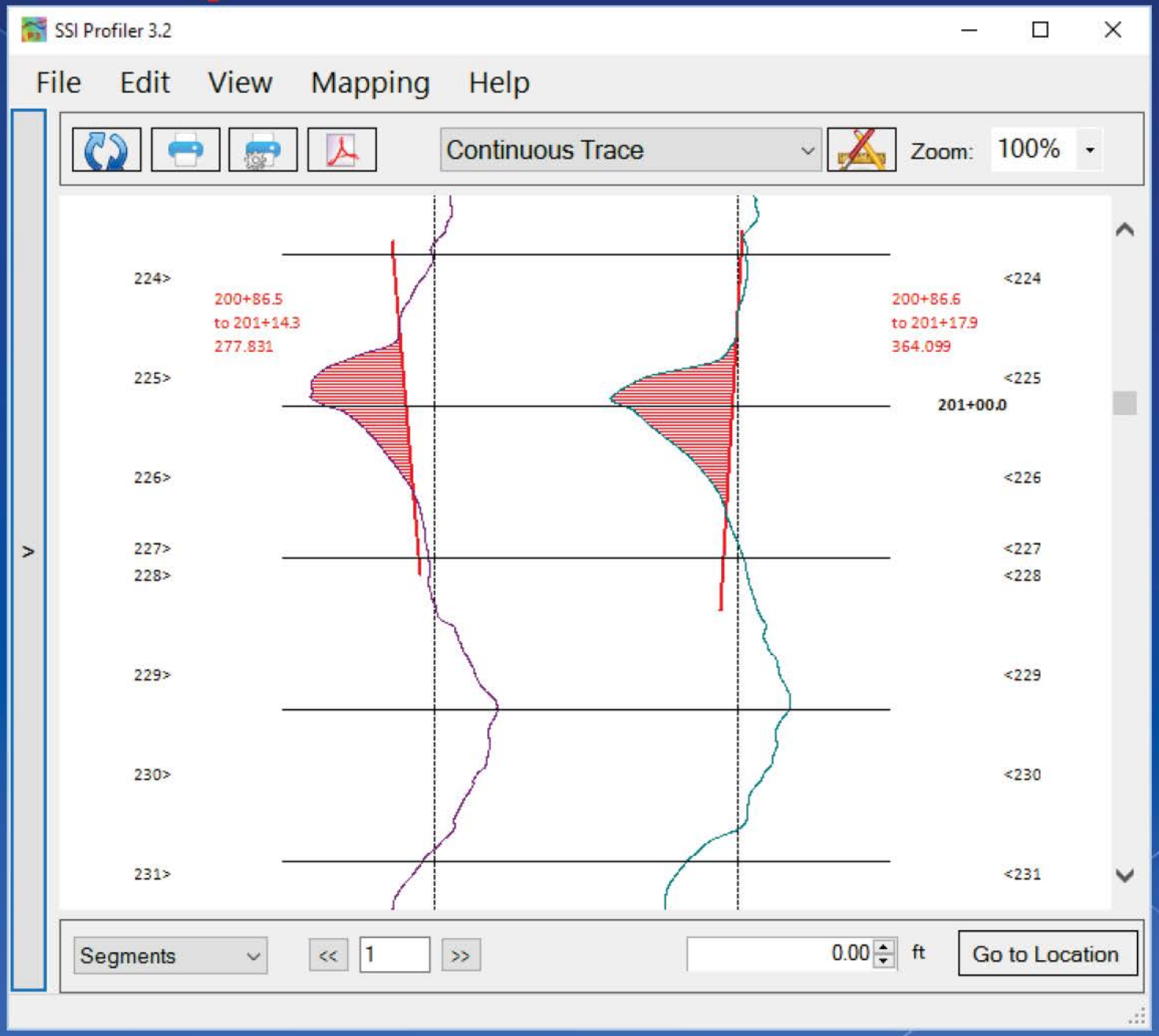
7 and 50 feet are the focus lengths

Sample Report—IRI/MRI

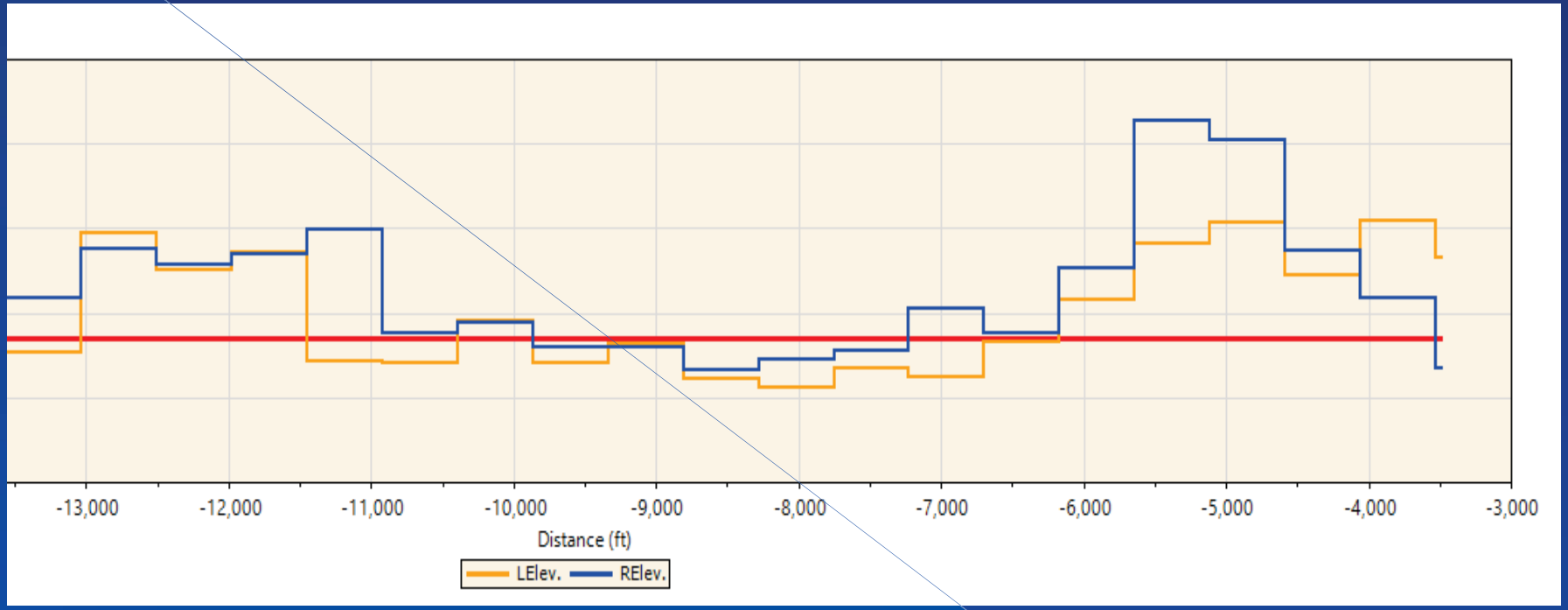
Run 1

Track 1			Track 2			Average
Seg	Station (ft)	IRI (in/mi)	Seg	Station (ft)	IRI (in/mi)	IRI (in/mi)
1	0+00.0 5+28.0	32.776	1	0+00.0 5+28.0	41.005	36.891
2	5+28.0 10+56.0	38.714	2	5+28.0 10+56.0	41.963	40.338
3	10+56.0 15+84.0	49.217	3	10+56.0 15+84.0	57.621	53.419
4	15+84.0 21+12.0	48.412	4	15+84.0 21+12.0	47.689	48.051
5	21+12.0 24+26.8	57.935	5	21+12.0 24+26.8	58.266	58.100
	0+00.0 24+26.8	**44.310**		**0+00.0 24+26.8**	**48.520**	**46.416**

Sample Inertial Profiler Trace

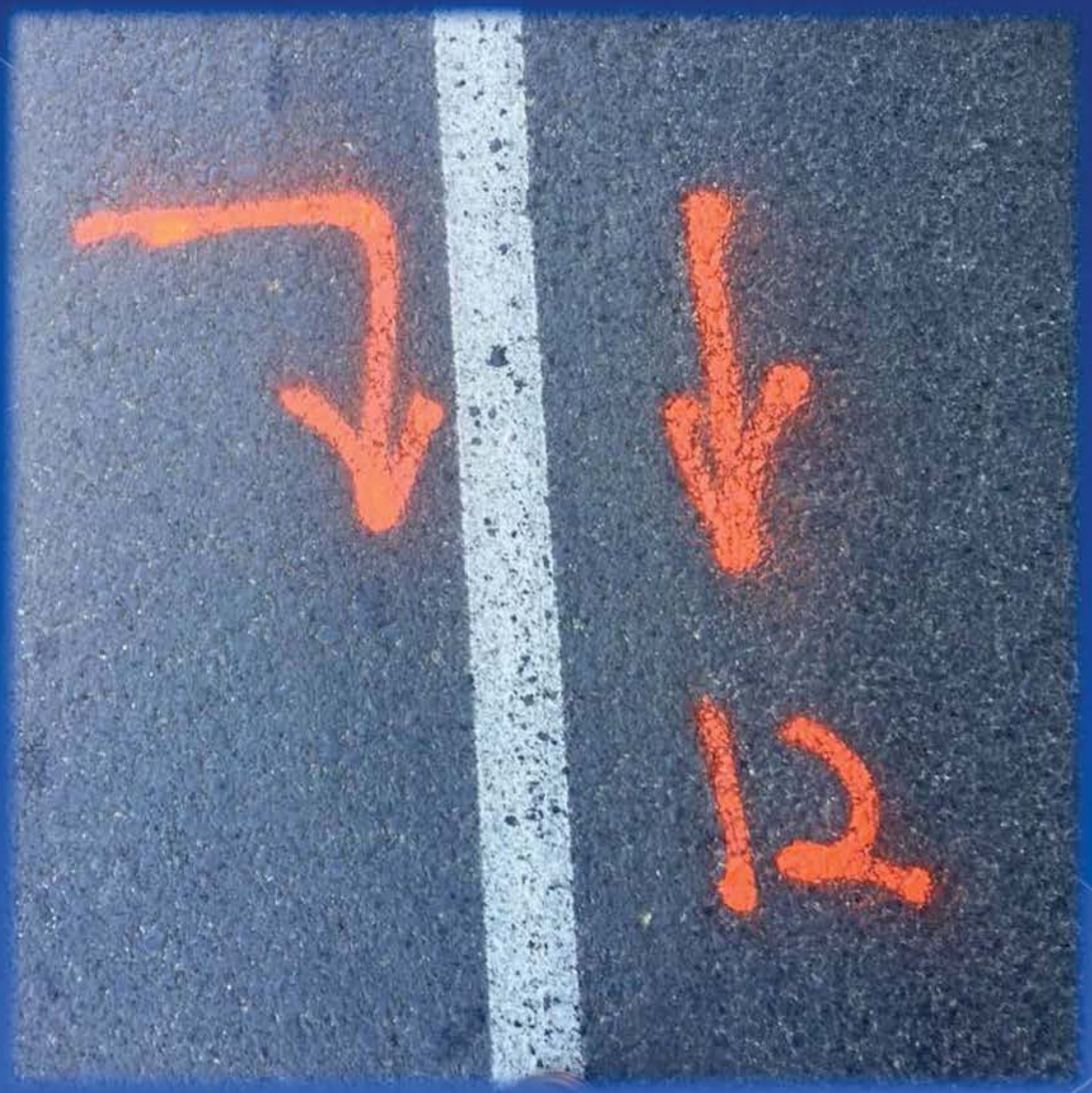


CalTrans IRI Specification

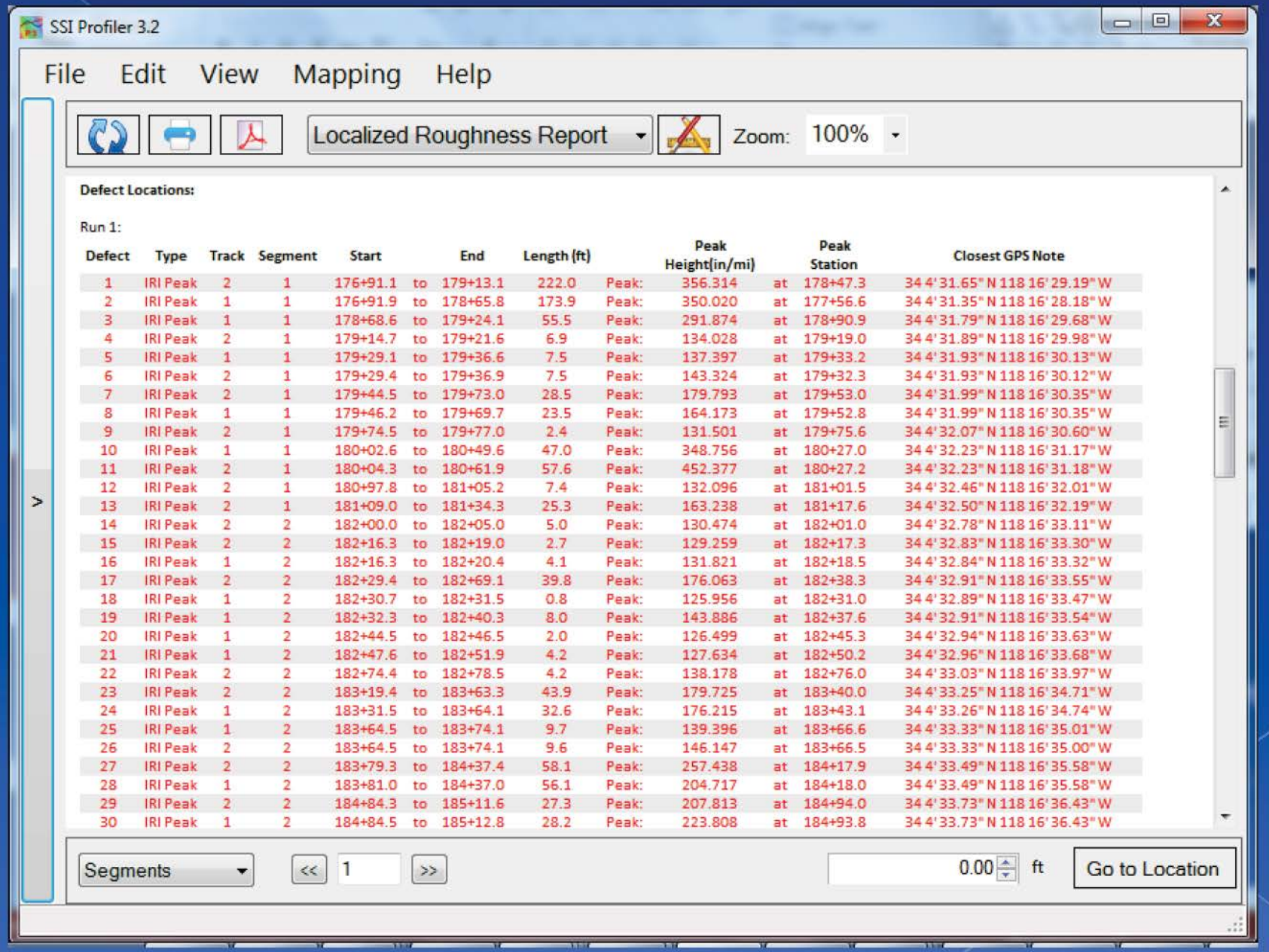


- MRI (average of wheel path IRIs)
  - < 60-75 in/mi (depends on type of work) 100% Pay (No Incentive)
  - >60-75 in/mi requires corrective action
- Fix Areas of Localized Roughness
  - HMA >160 in/mi (25ft base length)
  - PCC & Grinding >120 in/mi (25ft base length)

Localized Roughness



IRI vs. Profilograph (Straightedge)



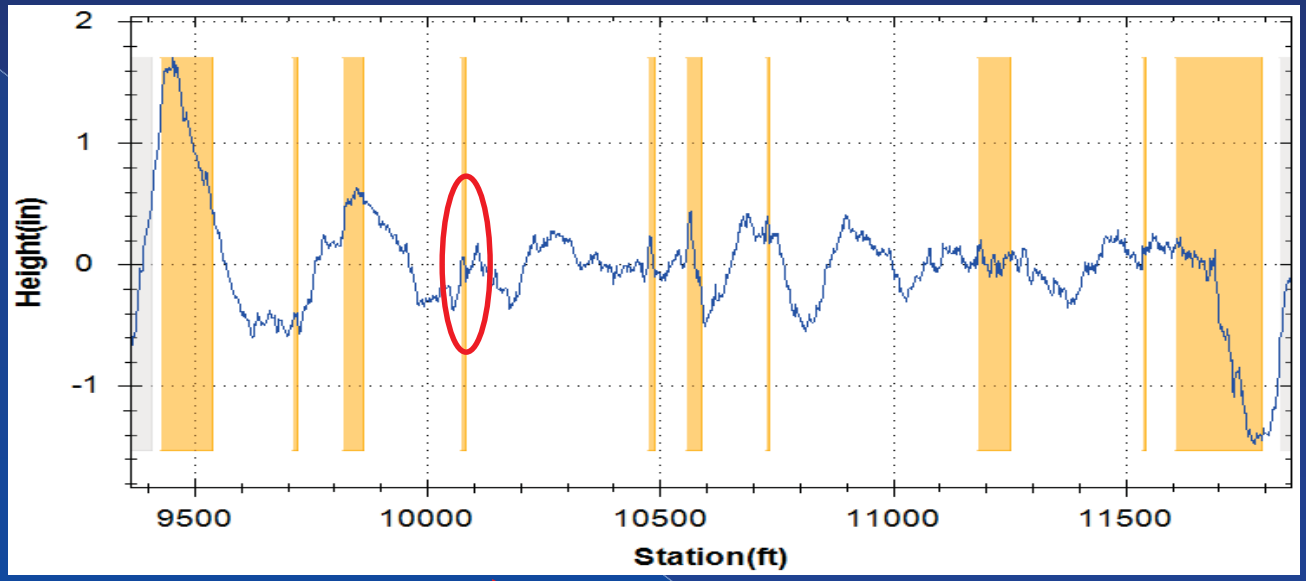
Defect	Type	Track	Segment	Start		End	Length (ft)		Peak Height(in/mi)		Peak Station	Closest GPS Note
1	IRI Peak	2	1	176+91.1	to	179+13.1	222.0	Peak:	356.314	at	178+47.3	34 4' 31.65" N 118 16' 29.19" W
2	IRI Peak	1	1	176+91.9	to	178+65.8	173.9	Peak:	350.020	at	177+56.6	34 4' 31.35" N 118 16' 28.18" W
3	IRI Peak	1	1	178+68.6	to	179+24.1	55.5	Peak:	291.874	at	178+90.9	34 4' 31.79" N 118 16' 29.68" W
4	IRI Peak	2	1	179+14.7	to	179+21.6	6.9	Peak:	134.028	at	179+19.0	34 4' 31.89" N 118 16' 29.98" W
5	IRI Peak	1	1	179+29.1	to	179+36.6	7.5	Peak:	137.397	at	179+33.2	34 4' 31.93" N 118 16' 30.13" W
6	IRI Peak	2	1	179+29.4	to	179+36.9	7.5	Peak:	143.324	at	179+32.3	34 4' 31.93" N 118 16' 30.12" W
7	IRI Peak	2	1	179+44.5	to	179+73.0	28.5	Peak:	179.793	at	179+53.0	34 4' 31.99" N 118 16' 30.35" W
8	IRI Peak	1	1	179+46.2	to	179+69.7	23.5	Peak:	164.173	at	179+52.8	34 4' 31.99" N 118 16' 30.35" W
9	IRI Peak	2	1	179+74.5	to	179+77.0	2.4	Peak:	131.501	at	179+75.6	34 4' 32.07" N 118 16' 30.60" W
10	IRI Peak	1	1	180+02.6	to	180+49.6	47.0	Peak:	348.756	at	180+27.0	34 4' 32.23" N 118 16' 31.17" W
11	IRI Peak	2	1	180+04.3	to	180+61.9	57.6	Peak:	452.377	at	180+27.2	34 4' 32.23" N 118 16' 31.18" W
12	IRI Peak	2	1	180+97.8	to	181+05.2	7.4	Peak:	132.096	at	181+01.5	34 4' 32.46" N 118 16' 32.01" W
13	IRI Peak	2	1	181+09.0	to	181+34.3	25.3	Peak:	163.238	at	181+17.6	34 4' 32.50" N 118 16' 32.19" W
14	IRI Peak	2	2	182+00.0	to	182+05.0	5.0	Peak:	130.474	at	182+01.0	34 4' 32.78" N 118 16' 33.11" W
15	IRI Peak	2	2	182+16.3	to	182+19.0	2.7	Peak:	129.259	at	182+17.3	34 4' 32.83" N 118 16' 33.30" W
16	IRI Peak	1	2	182+16.3	to	182+20.4	4.1	Peak:	131.821	at	182+18.5	34 4' 32.84" N 118 16' 33.32" W
17	IRI Peak	2	2	182+29.4	to	182+69.1	39.8	Peak:	176.063	at	182+38.3	34 4' 32.91" N 118 16' 33.55" W
18	IRI Peak	1	2	182+30.7	to	182+31.5	0.8	Peak:	125.956	at	182+31.0	34 4' 32.89" N 118 16' 33.47" W
19	IRI Peak	1	2	182+32.3	to	182+40.3	8.0	Peak:	143.886	at	182+37.6	34 4' 32.91" N 118 16' 33.54" W
20	IRI Peak	1	2	182+44.5	to	182+46.5	2.0	Peak:	126.499	at	182+45.3	34 4' 32.94" N 118 16' 33.63" W
21	IRI Peak	1	2	182+47.6	to	182+51.9	4.2	Peak:	127.634	at	182+50.2	34 4' 32.96" N 118 16' 33.68" W
22	IRI Peak	2	2	182+74.4	to	182+78.5	4.2	Peak:	138.178	at	182+76.0	34 4' 33.03" N 118 16' 33.97" W
23	IRI Peak	2	2	183+19.4	to	183+63.3	43.9	Peak:	179.725	at	183+40.0	34 4' 33.25" N 118 16' 34.71" W
24	IRI Peak	1	2	183+31.5	to	183+64.1	32.6	Peak:	176.215	at	183+43.1	34 4' 33.26" N 118 16' 34.74" W
25	IRI Peak	1	2	183+64.5	to	183+74.1	9.7	Peak:	139.396	at	183+66.6	34 4' 33.33" N 118 16' 35.01" W
26	IRI Peak	2	2	183+64.5	to	183+74.1	9.6	Peak:	146.147	at	183+66.5	34 4' 33.33" N 118 16' 35.00" W
27	IRI Peak	2	2	183+79.3	to	184+37.4	58.1	Peak:	257.438	at	184+17.9	34 4' 33.49" N 118 16' 35.58" W
28	IRI Peak	1	2	183+81.0	to	184+37.0	56.1	Peak:	204.717	at	184+18.0	34 4' 33.49" N 118 16' 35.58" W
29	IRI Peak	2	2	184+84.3	to	185+11.6	27.3	Peak:	207.813	at	184+94.0	34 4' 33.73" N 118 16' 36.43" W
30	IRI Peak	1	2	184+84.5	to	185+12.8	28.2	Peak:	223.808	at	184+93.8	34 4' 33.73" N 118 16' 36.43" W

Diamond Grinder

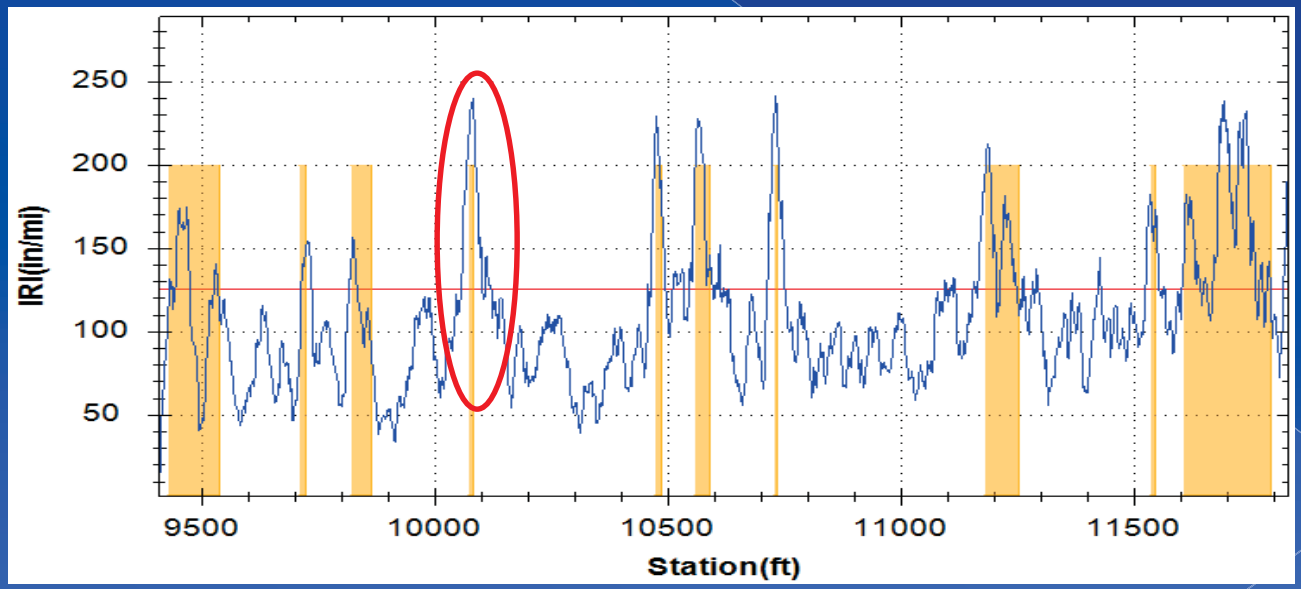
- Effective at addressing *some* ALR
- Understanding limitations

  Can outcomes projected by grind simulations be achieved?
- Pre-Pave Profiles: diamond grinder or micro-mill?

IRI Grinding (Long IRI Defect)

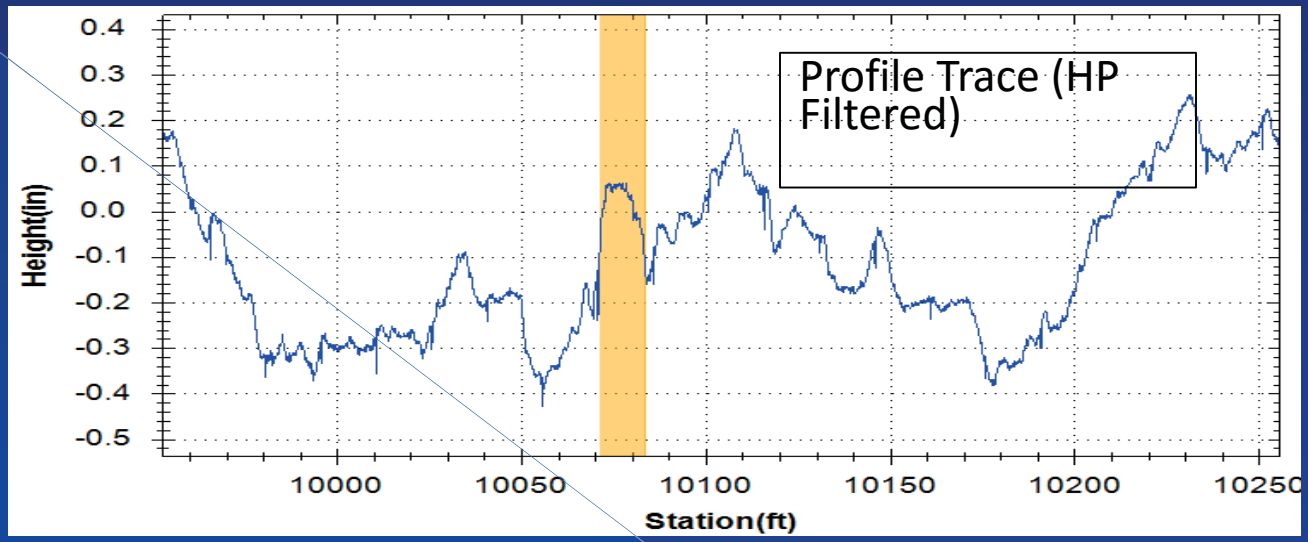


- Profile trace

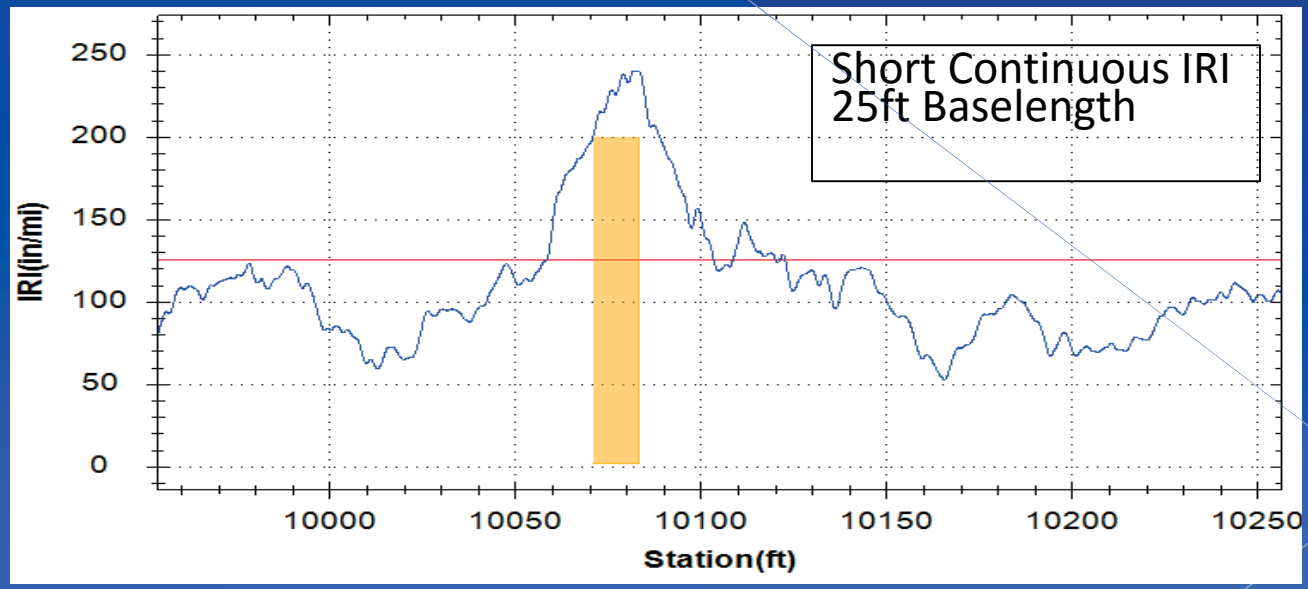


- Short Continuous (25ft base length)

IRI Grinding (Long IRI Defect cont.)

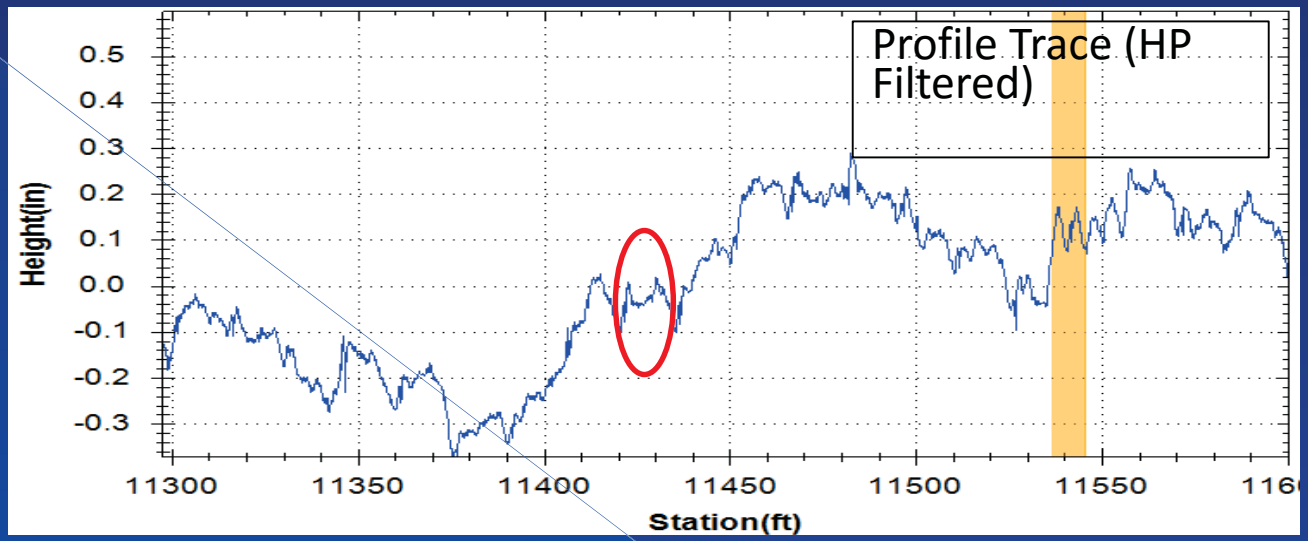


- Profile trace (12 ft defect for grinding physically)

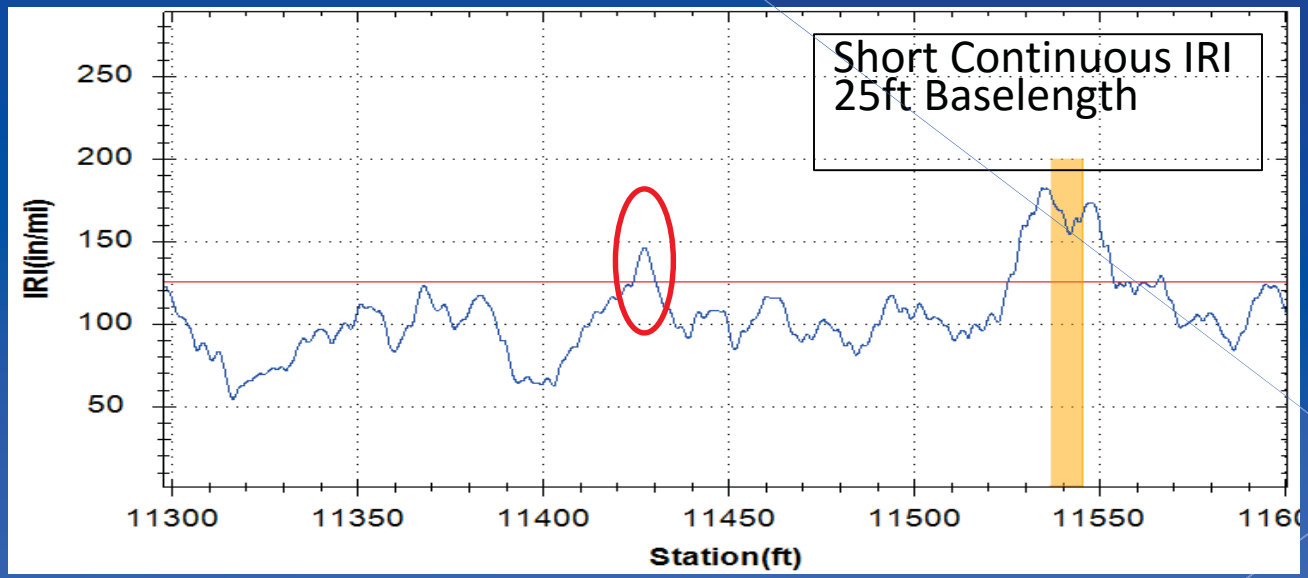


- Short Continuous IRI (50ft IRI defect)

IRI Grinding (small IRI defect)



- Profile trace (No physical feature to grind realistically)



- Short Continuous IRI (5ft IRI defect; 145 peak IRI)

Know The System and Process

- No limit on size of ALR
  - Can be 0.1 foot to entire collection length
- ALR and grind locations not the same!
  - ALR can be bumps OR dips
- DMI Error
  - Curves
  - Speed
  - Temperature
  - Path
- No GPS signal if no sky view
- Correction processes (A few options and opinions, explained later today)
- ProVal limitations
- Grinder limitations
- Operator limitations
  - Depending on process and needed accuracy, processing data takes much longer than profile data collection

Conclusions

- Inertial Profilers are a Welcome Change
  - Faster, safer, more data, better data
- CT IP specs have good checks and balances
  - Validated by certifications & field checks
- IRI roughness grinding is evolving
  - More training and pilot projects would help
- Need for evolved IRI specifications
  - An identical IRI spec does not fit all work

Thank You!

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