Stringless Paving and Mobile Mapping Technology

South Dakota
2015 Airports Conference

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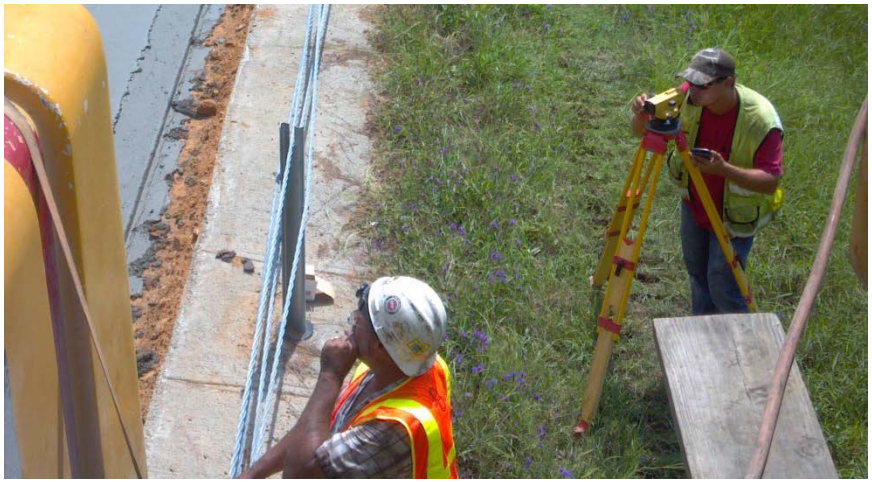
Outline

- Evolution of Surveying
  - Automated Surveying in the 21st Century
- Modern Mapping Technologies
  - Mobile LiDAR and Survey Data Fusion
- 3D Stringless System
  - Overview of available technology
- 1D/2D and 3D Hybrid Systems
  - Optimizing Available Resources and Project Specifications
- Accurate Machine Control
  - Meeting Project Specification
- Conclusion

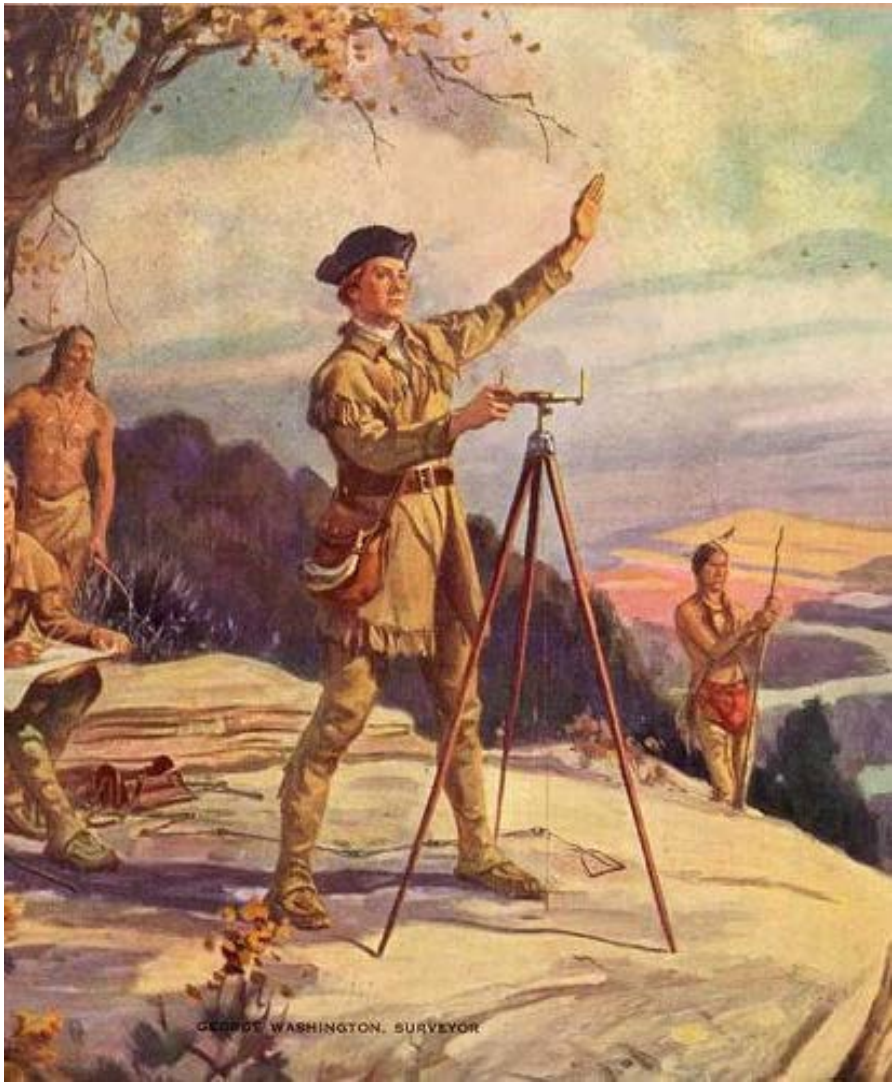
EVOLUTION OF SURVEYING

Surveying

- Measuring natural and manmade features near the earth's surface
- Direct measurements
  - Distances, Angles, Slope
- Indirect measurements
  - Areas, Volumes, Position, Slope, Stationing



History



- Distances have been measured by ropes, chains, and tapes
- Slopes are determined with plumb lines, & level lines being 90° to plumb
- Aqueducts, Cathedrals, Coliseums, & Pyramids, were all constructed with these time tested tools

Error Management

New measuring systems

- Increase productivity
- Reduce errors

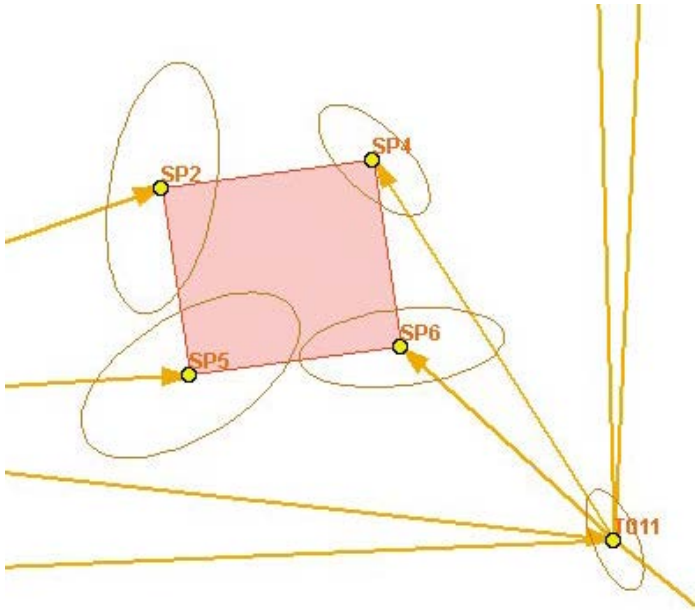
Systems include:

- Instruments & their
- Operators along with
- Processing Algorithms

The combined error of the system's components set the minimum error of the product

1. Determine the maximum error allowable (tolerance)

2. Choose the safest and most productive system



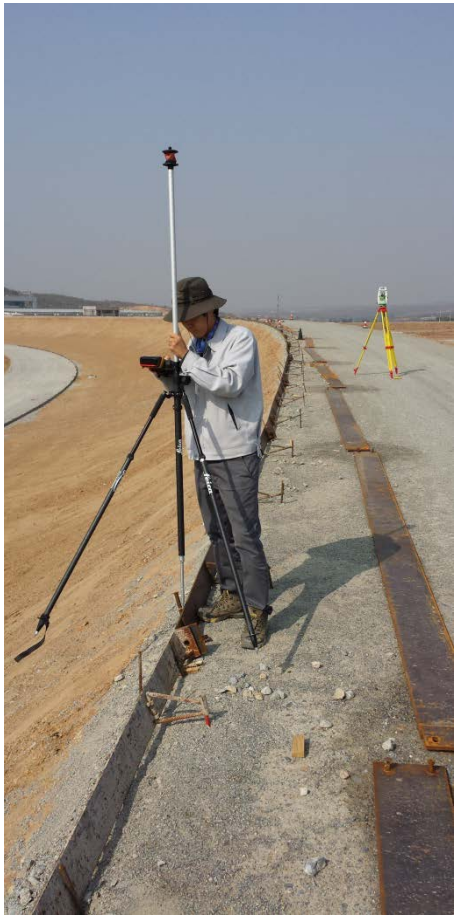
Surveying for Concrete

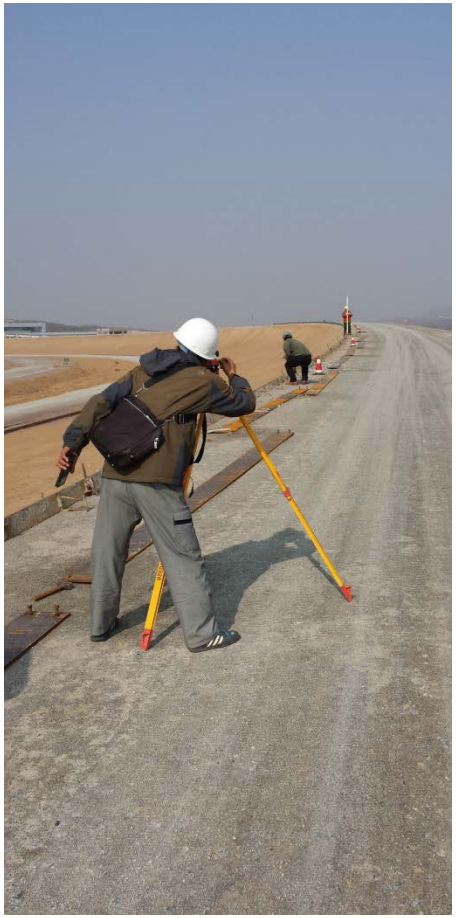
Surveying Operations

- **Mapping,**
- **Staking, &**
- **As-built**

Traditional concrete construction required layout (staking) for:

- Setting Forms &/or
- Stringline Slipforming





Evolution of Guidance Systems

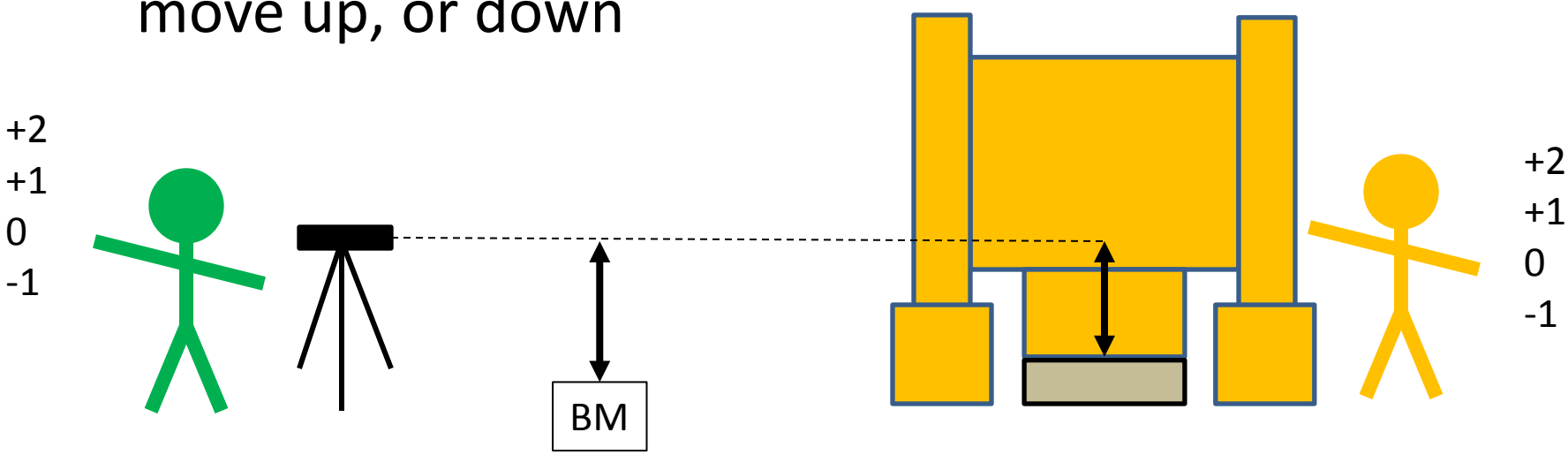
Real-time determination of positions with:

- RTK GPS
- Robotic Total Stations
- Inertial Sensors (i.e. distance encoder)

1. The observed positions enter the computer
2. The software determines the design
   - Elevation,
   - Orientation, &
   - Alignment: for that location
3. The measured deviations from design are minimized during layout, i.e. hubs set where the deviation is zero.

Information Propagation

1. Measure Benchmark
2. Measure Elevation of Top of Concrete
3. The surveyor signals the Operator to hold, move up, or down
4. Operator Receives hand signal
5. Operator Adjust machine by amount

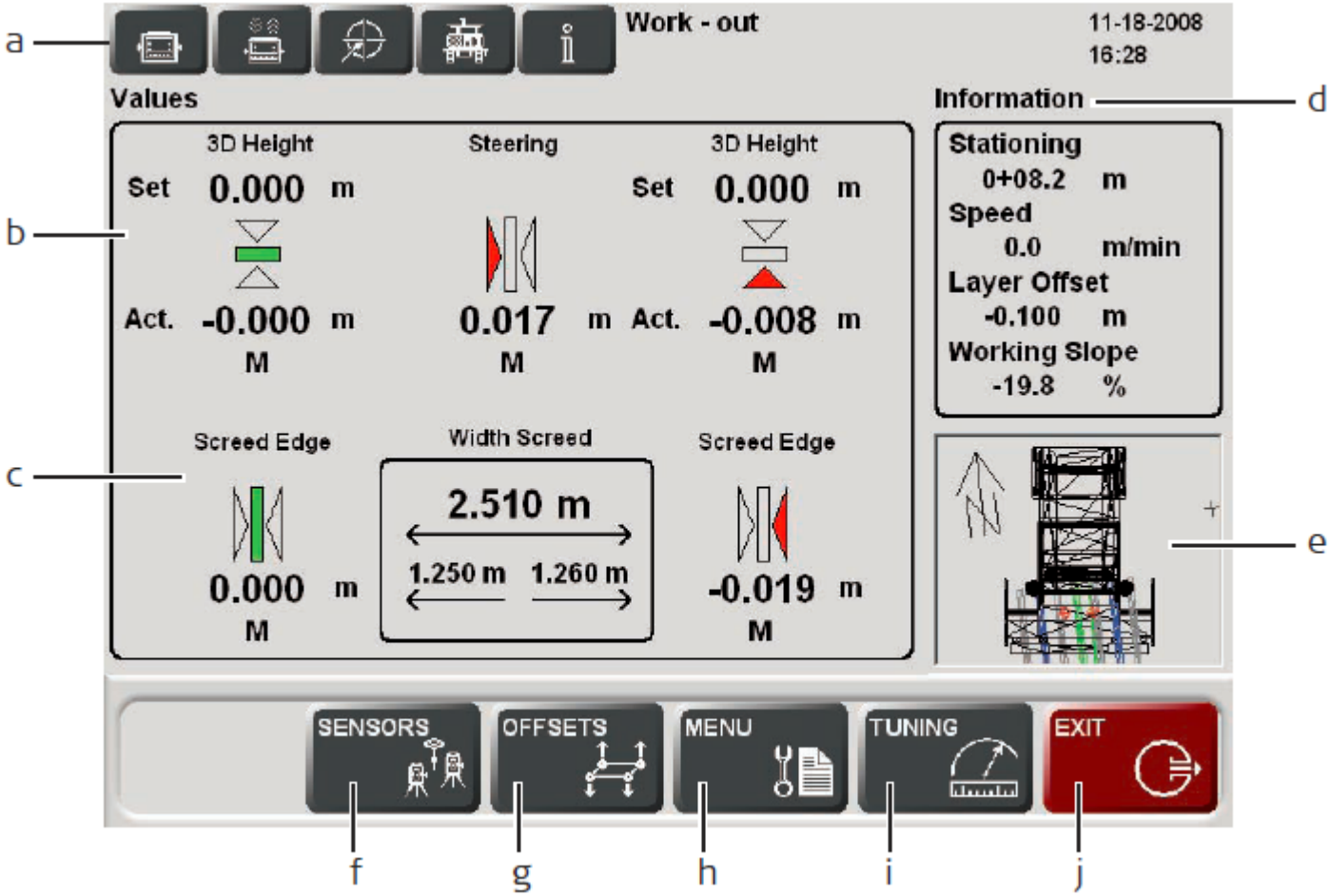


Navigation Guidance & Control

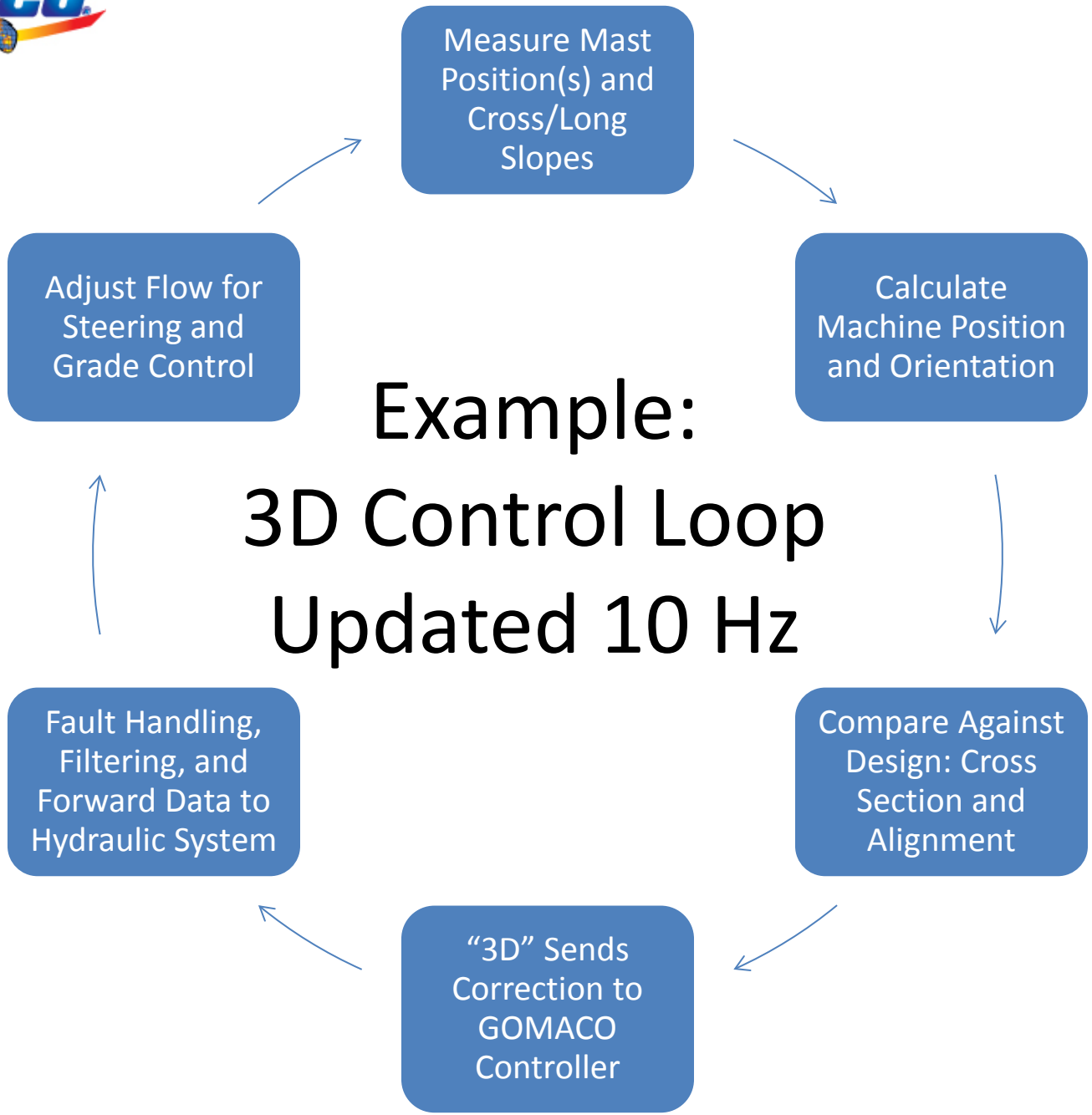
1. The machine determines its position
2. The guidance system computer determines the design elements and deviations from measured
   - Elevation,
   - Orientation, &
   - Alignment: for that location

3. The machine's control system responds with the objective to minimize these deviations
   - The automatic control system drives to zero

Real-time Survey System = Automated Machine Guidance



Example: 3D Control Loop Updated 10 Hz



MODERN MAPPING TECHNOLOGIES

Conventional Surveying

- Total Stations, RTK GPS, & Levels
  - Direct Sensing: The measuring instrument (rod) is placed directly on the feature to be mapped.
    - EX: The edge of concrete, top rear of curb, etc.
  - Total Stations measuring prisms are direct sensing
- Some Total Stations
  - Reflectorless (no prism)
  - They can measure the coordinates of a point remotely, e.g. <u>remote sensing</u>

Remote Sensing

Photogrammetric Mapping

- Handheld, Vehicle, Airplane, & Satellite Cameras
- Benefit by covering large areas very quickly
- 3D positions measured from overlapping images

Reflectorless Total Stations & Terrestiral LiDAR

- Smaller area mapping (sites, stockpiles, indoors)
- 3D Positions measured from a reflected signal

Passive

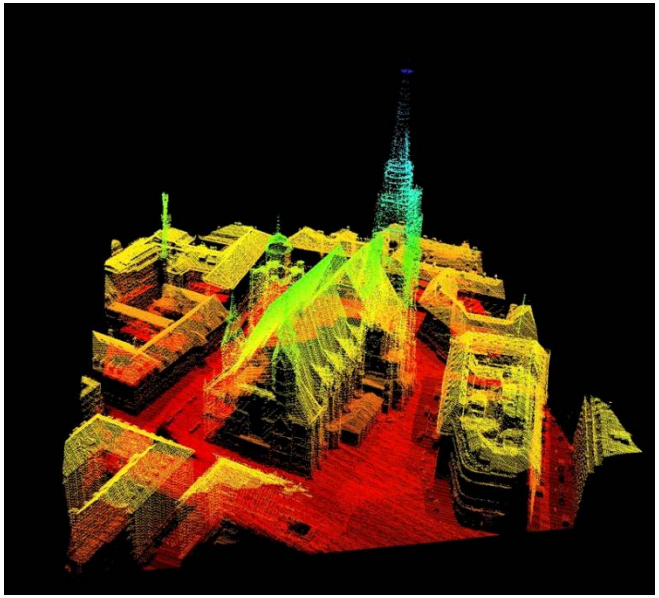
- Sensors only receive light reflected off surfaces and the measurement is the position of the feature in the image

Active

- Sensors send a light signal and measures the reflected signal to determine a distance and direction to the surface

Photogrammetric Camera
AIRBORNE SENSORS
Aerial LiDAR

ULTRACAM
somag
AG JENA



Mobile LiDAR

- Mobile LiDAR systems allows the collection of detailed topography and feature location of any project area at near highway speeds.

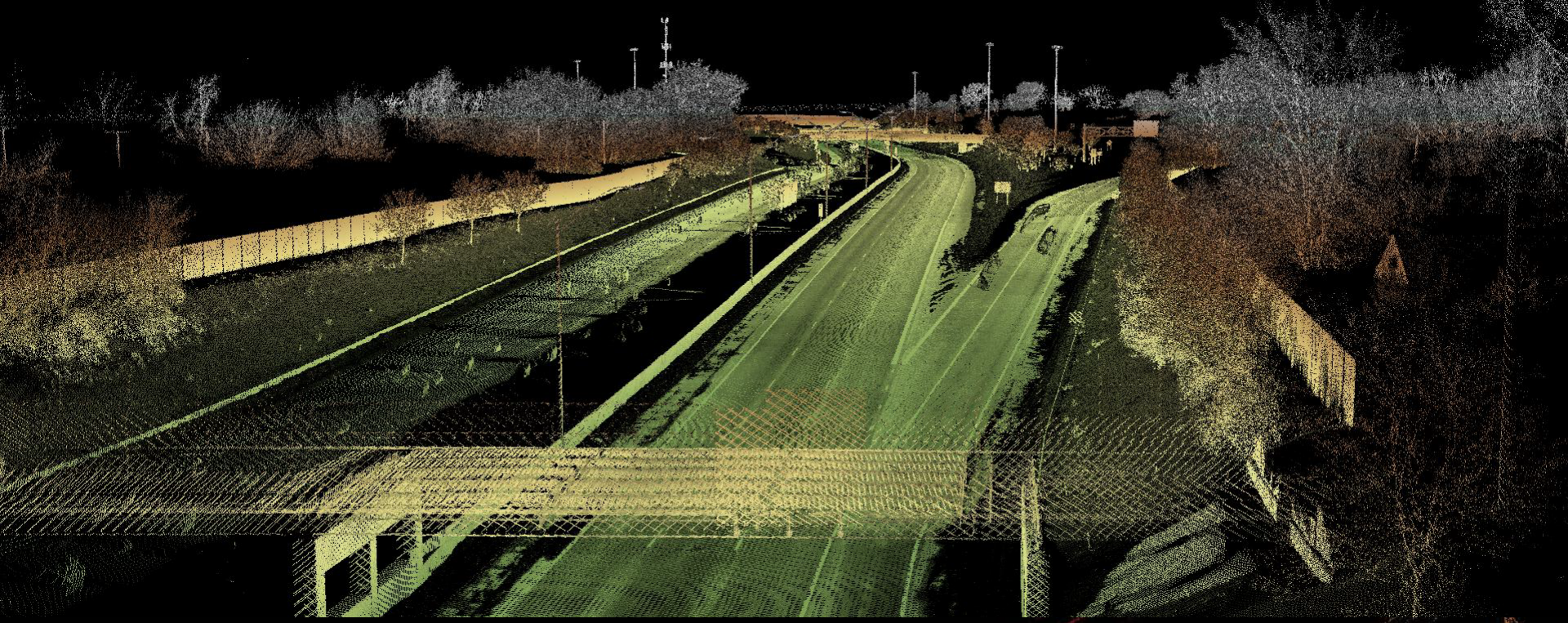
- The use of Mobile Laser Scanning technology allows LiDAR projects to be completed safely without disruption and lane closures for the motoring public.

http://www.ssi-mi.com

Mobile LiDAR Details

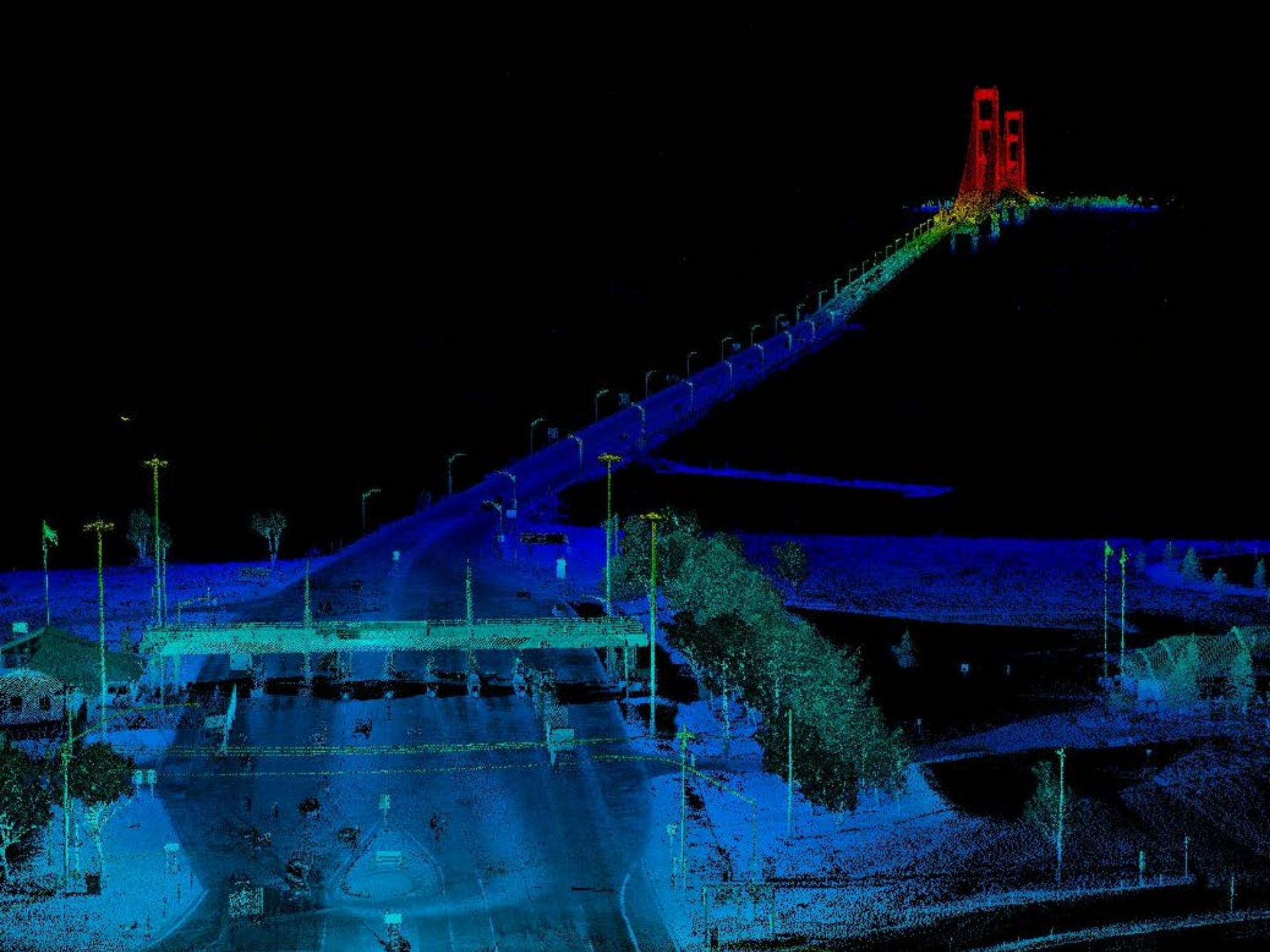
- Most corridor (ROW) LiDAR acquisitions can be completed in one day and are priced using:
  - Vehicle with sensor cost per day
  - Requires Survey crew to tie data to control points
  - Data Registration and Processing into deliverables
  - Consider mowing ROW before LiDAR collection

- No need to revisit site to get more survey data, simple use raw point cloud



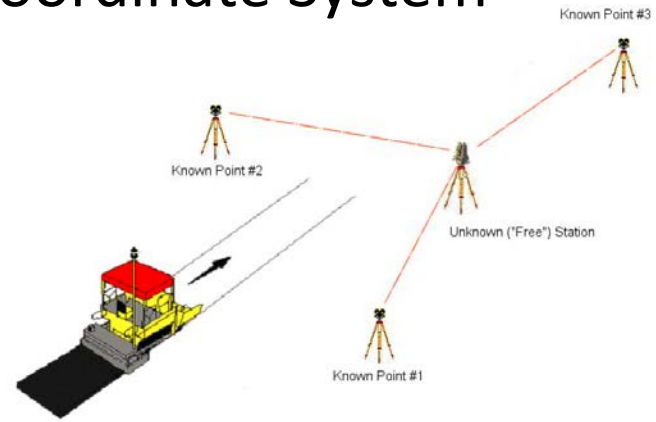
Registering Mobile LiDAR Scans

- MoLi is directly geo-referenced using static GPS processed to a local base station or the nearest CORS station.
- Using this will give us accuracies in the 1-2 cm range horizontally and 3-5cm range vertically.
- If we need a tighter vertical accuracy we further adjust the scan to ground control using algorithms within the least squares scan adjustment software.



Sensor Registration

- Registering spatial data is required regardless of the sensor(s) or mapping system
  - State/Province, Project, or Local Coordinate System
- Examples:
  - RTK GPS — Localization
  - Total Station — Resection
  - Photogrammetry — Triangulation
  - LiDAR — Direct Geo-refernceing
  - Encoder — Setting Trip Odometer



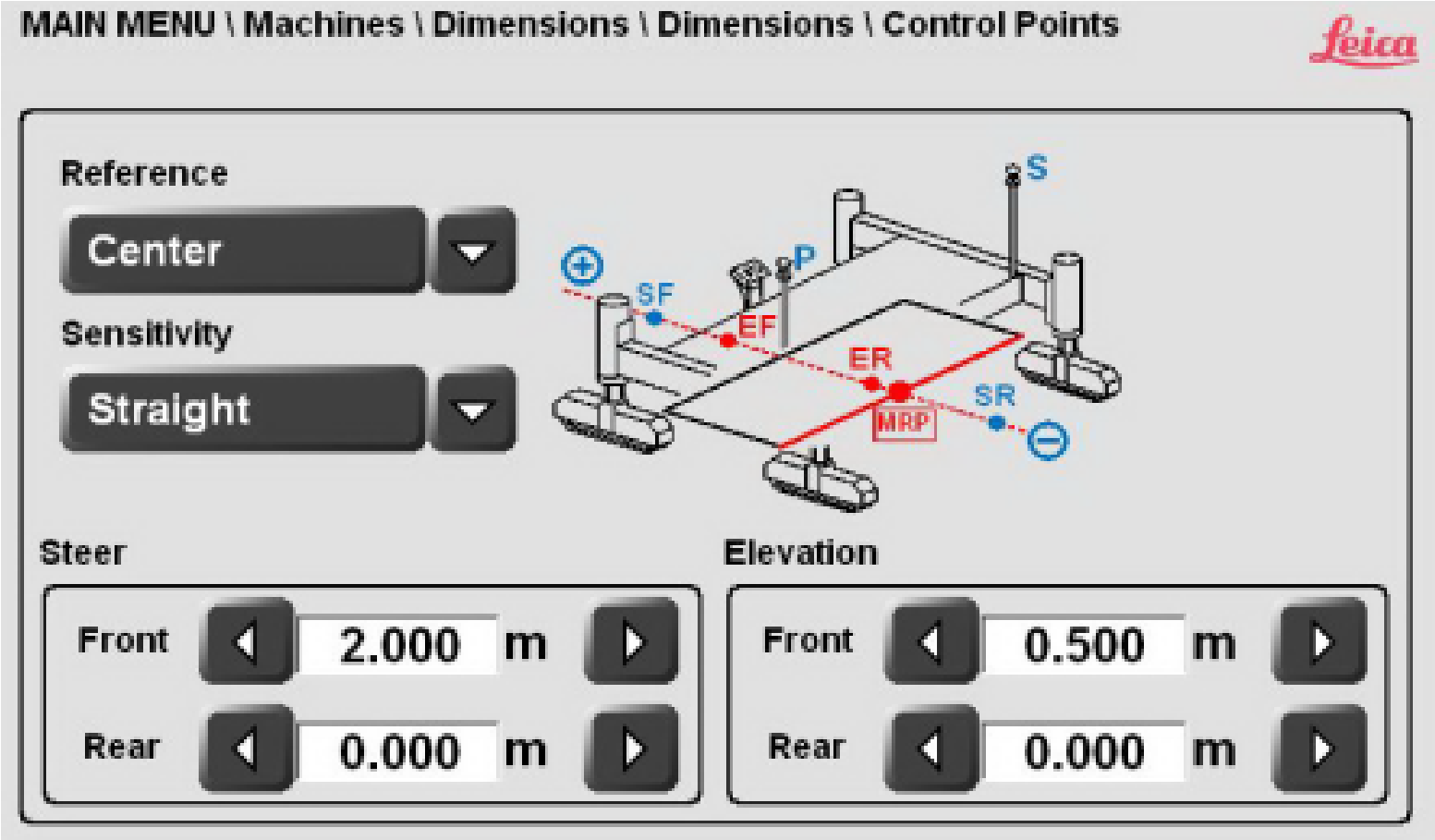
- Maps, Designs, and Machine Control Files
  - All tied together with common control points

3D – SYSTEMS

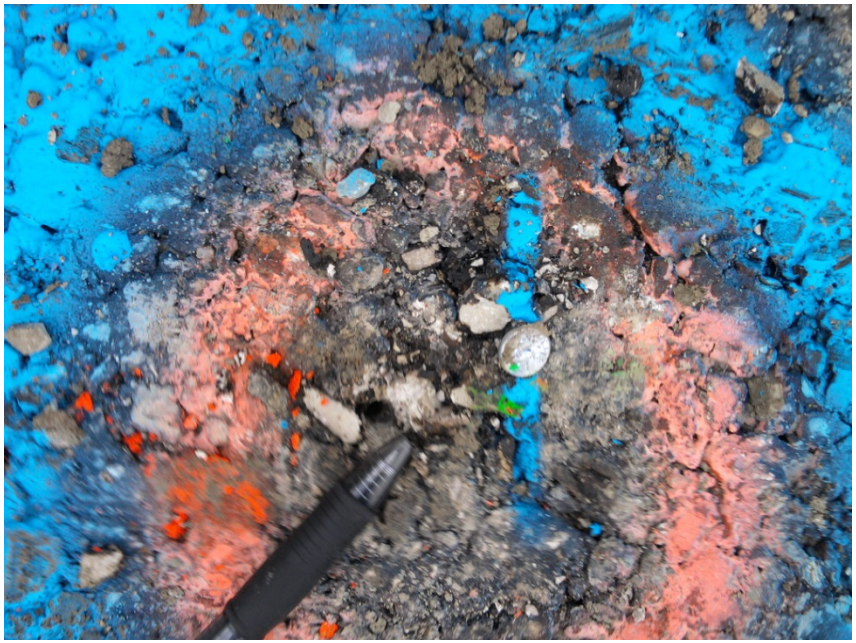
3D Systems

- Two 3D sensors to measure position and heading
  - Can be configured and installed to measure slope
- One or Two slope sensors to measure orientation
- All relative to project coordinate system
  - X,Y,Z of machine reference point (MRP)
  - Roll (Cross Slope), Pitch (Long Slope), Yaw (Heading)
- Design Data (model) is stored on Machine PC
  - Windows CE or XP Embedded
  - Transferred to PC by removable USB Drive
  - **Data is Converted to Propriety Format**

Example of “3D” Paver Setup

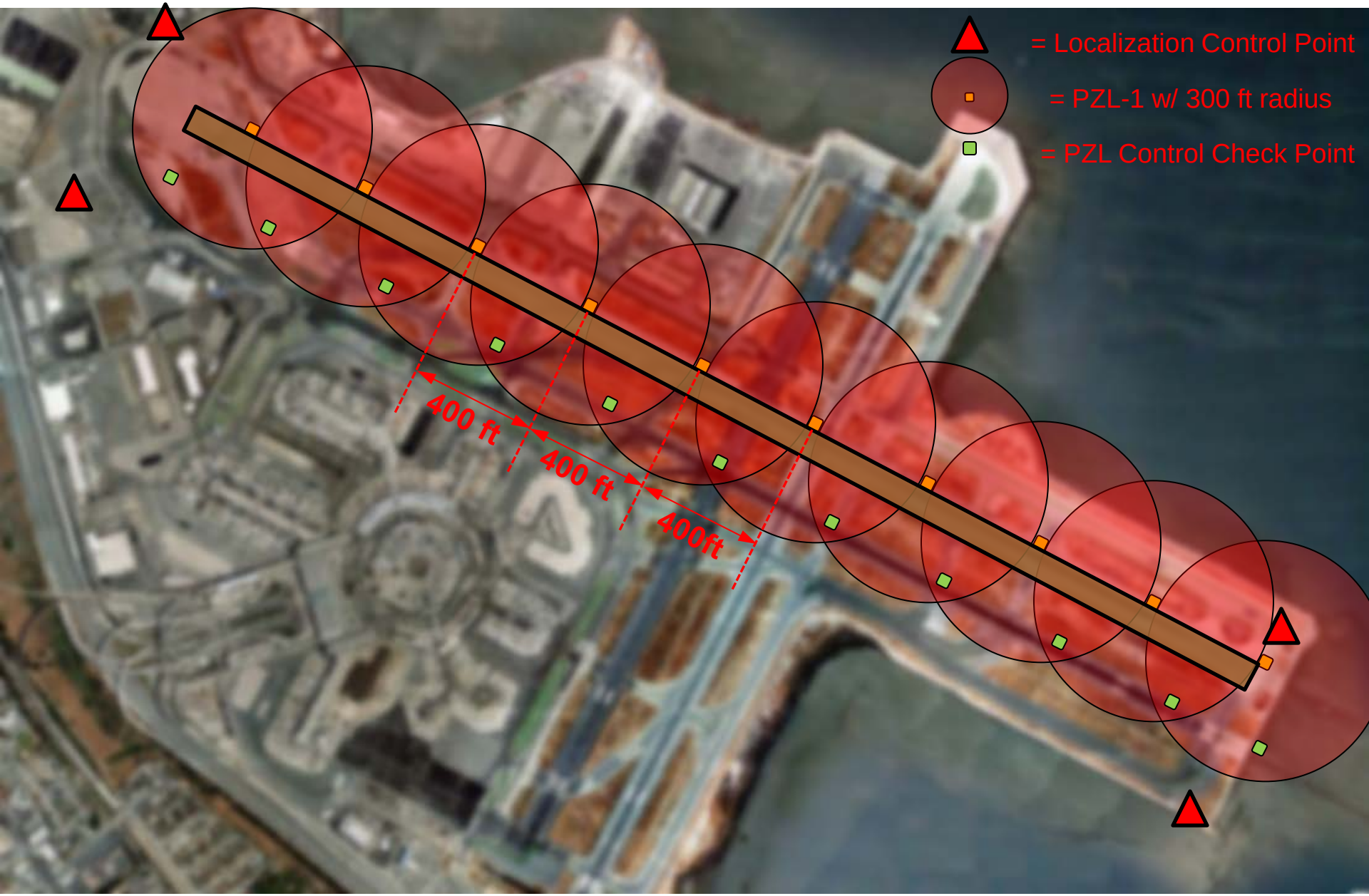


Deliverables – Hard: Control Points



- Set permanent monuments and/or mark control points
  - Consider Frost Heaving, Primary or Support Control, etc.
- Mark witnesses for primary control
- Stake hubs/nails for checking production

Airport Runway Paving Example

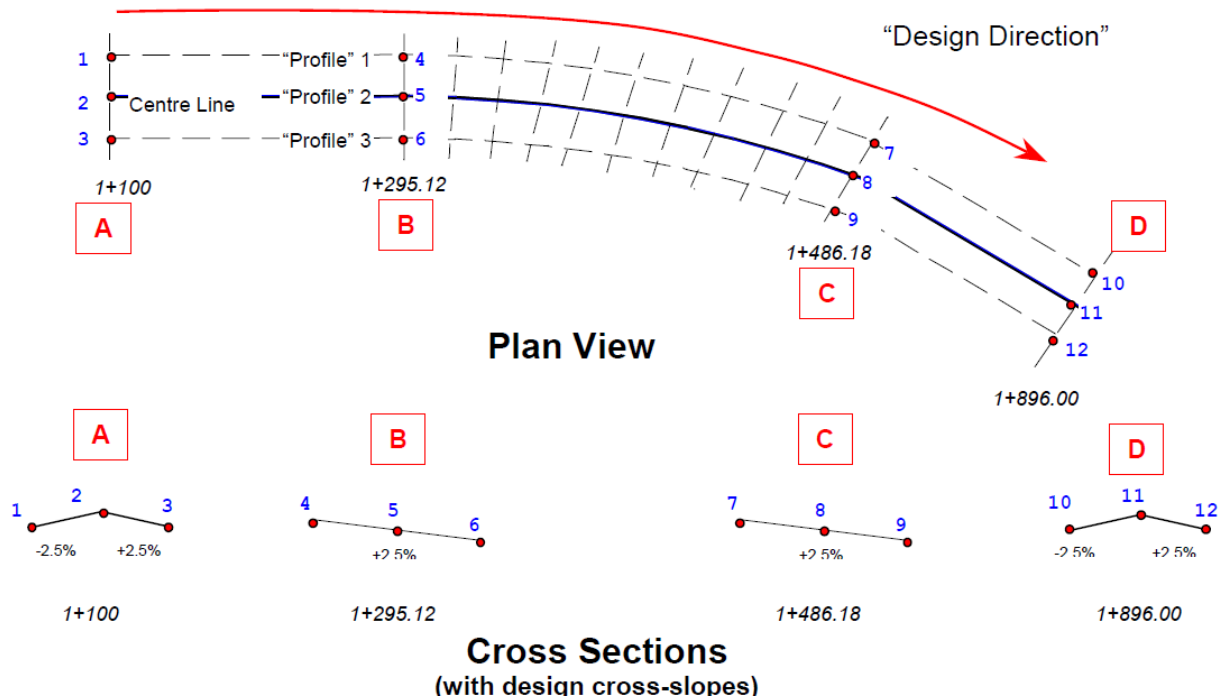


Topcon – Fan Laser Transmitter

Deliverables – Soft/Digital

D45 File Format : Example

Consider the following simple road alignment :



- Control Point Coordinates,
- Point Clouds,
- CAD,
- GIS,
- Hub Points,

  &/or
- Machine Control Files
  - Make 1-200 feet longer on each end

3D Systems and Sensors

- Leica **Viva (Pavesmart3D)**
  - Robotic Total Stations, GPS, or mixed (one of each)
  - 360 Prisms are Passive

  DATA: D45 ("hub" points , LMGS), Dual 3D Polylines (PS3D)

- Trimble **Business Center**
  - Robotic Total Stations
  - Machine Prisms are Active

  DATA: Steering Alignment and Surface (TIN)

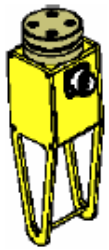
- Topcon **3D Office**
  - Dual mmGPS, mmGPS/GPS, Dual GPS
  - Line-of-Sight to Fan Laser Transmitter (if mmGPS)

  DATA: Steering Alignment and Surface, or
  Parametric Design (Horizontal Alignment, Vertical Profile and Cross Section Transition Templates)

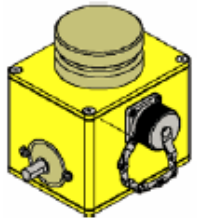
1D/2D SYSTEMS & 3D HYBRIDS

G+ CAN Sensor Support

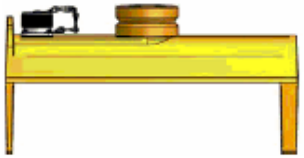
Dual Sonic
DUAS-1000



Digi-Rotary
ROTS-0300



Sonic-Ski-Plus
DUAS-1000



Laser Receiver
LS-3000

All G+ GOMACO Machines come standard with one or two Digital Dual Axis Slope Sensors

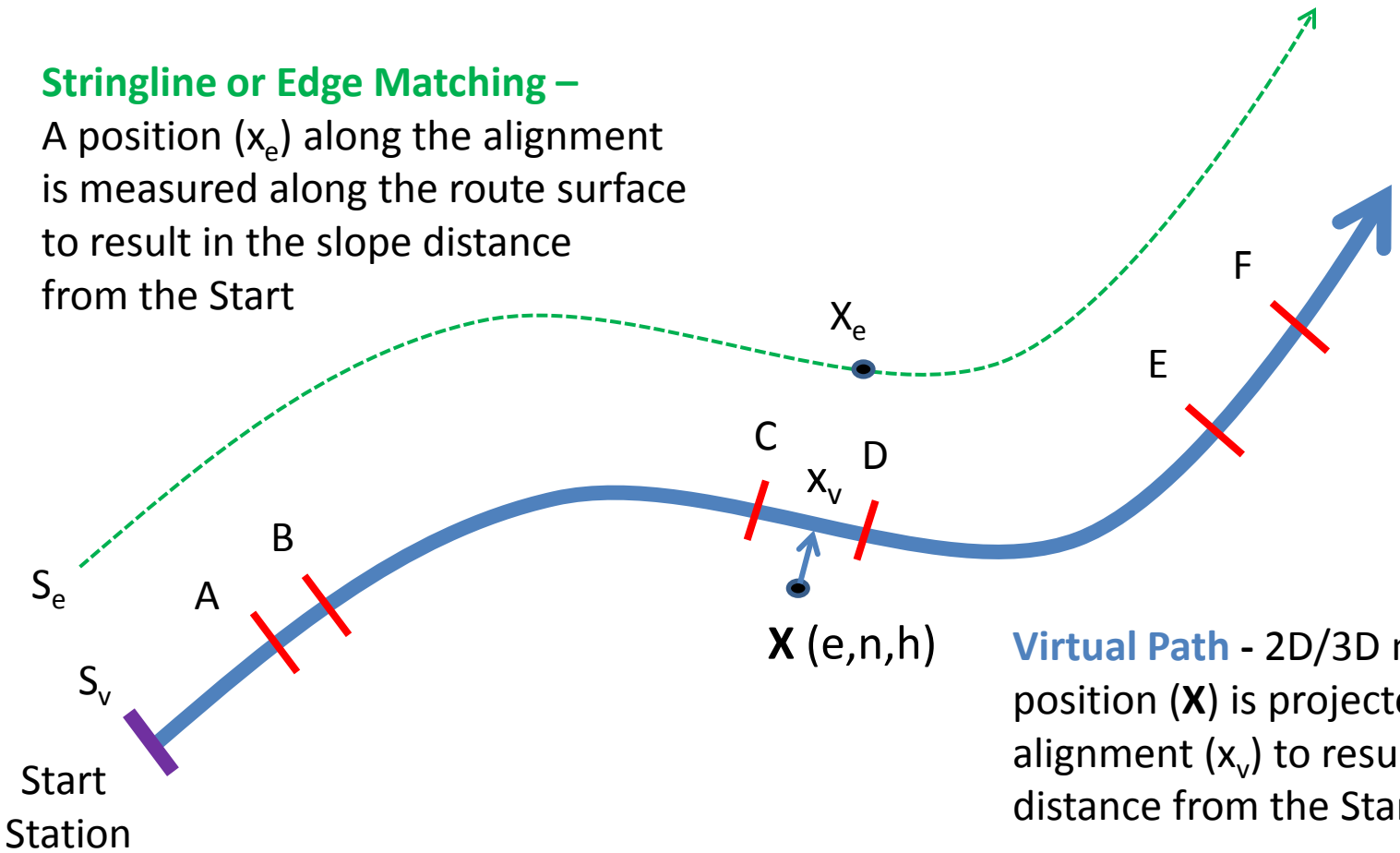
Hybrid Systems (2D/3D)

- Hybrid Systems typically consist of GNSS sensors to provide steering control and design data elements (i.e. design cross slope)
- The G+ Standard Machine Controls then controls the grade side grade using sensors with slope sensors control on the opposite side of the machine
- Significant Labor Cost Savings compared to full 3D system or Stringline
- Automates Transitions, i.e. **<u>slope for super-elevation</u>**

I-16 Highway Rebuild near Dublin GA

Encoder Stationing or Alignment/Position Stationing

Stringline or Edge Matching –
A position (x_e) along the alignment is measured along the route surface to result in the slope distance from the Start



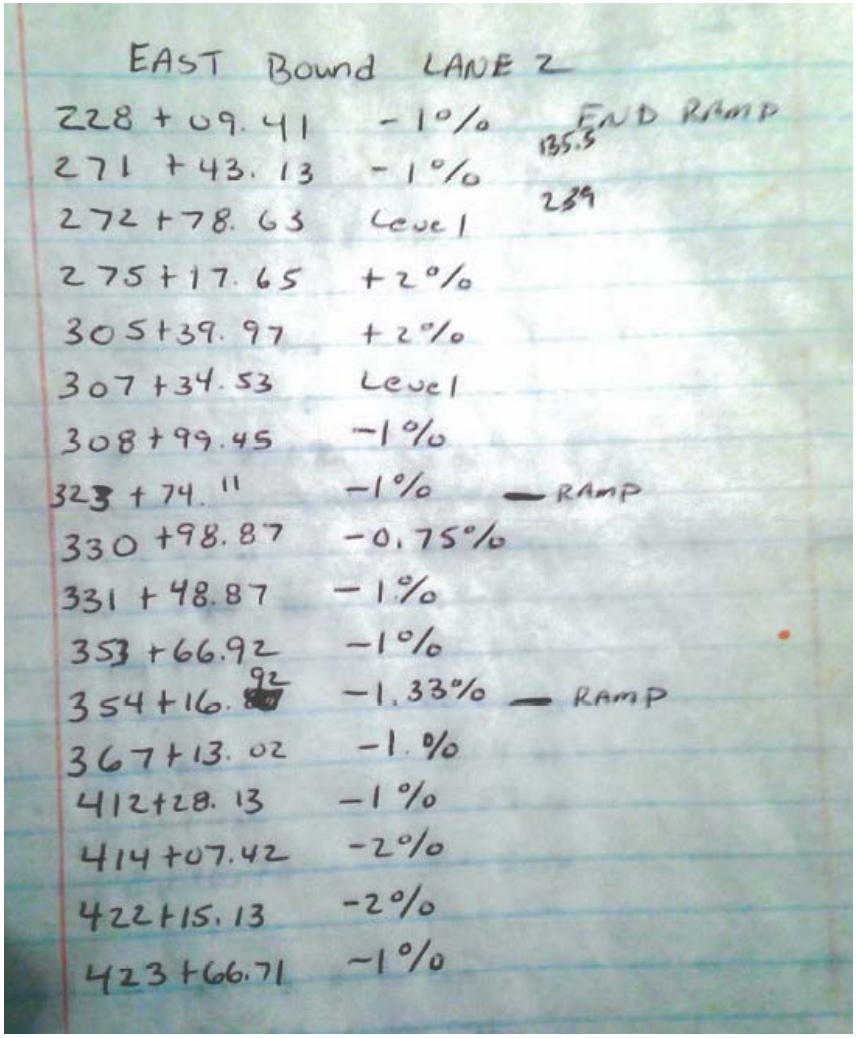
Virtual Path - 2D/3D measured position (**X**) is projected to the alignment (x_v) to result in the distance from the Start

Note: Stationing/Distance Traveled must be continuous, e.g. no jumps from back stationing

G+ Automated Slope Transition Data

- Encoder Transitions (1D/2D Hybrid)
  - G+ Integrated Track Encoder is used as an odometer to provide travel distance to transition module to smoothly change cross slope

- Alignment Transitions (2D/3D Hybrid)
  - 3D system's also provide the design cross and long slope to G+ standard machine controller



EAST Bound LANE 2

228 + 09.41	-1%	END RAMP 135.3
271 + 43.13	-1%	289
272 + 78.63	Level	
275 + 17.65	+2%	
305 + 39.97	+2%	
307 + 34.53	Level	
308 + 99.45	-1%	
323 + 74.11	-1%	— RAMP
330 + 98.87	-0.75%	
331 + 48.87	-1%	
353 + 66.92	-1%	
354 + 16.92	-1.33%	— RAMP
367 + 13.02	-1.%	
412 + 28.13	-1%	
414 + 07.42	-2%	
422 + 15.13	-2%	
423 + 66.71	-1%	

ACCURATE MACHINE CONTROL

Grading preparation

- Rough Grading – **TIN and other DTMs**
  - Dozers, Scrappers, Motor graders, etc.
  - Higher speeds with operator **manual steering**
  - RTK GPS Grade and slope control only
- Finish/Fine Grade – **3D Alignments, …**
  - Milling machines, trimmers, base placers
  - Slower Speeds with optional **automatic steering**
  - Accurate grade and slope control with sensors
    - Robotic Total Stations, Rotating Lasers, Sonics, String

Accurate Quantity Control

- When several lifts/layers all are produced using the same machine control system and design
  - The yield is more precisely controlled
- Examples:
  - The surface is trimmed or based placed in 3D and then the concrete is paved with the same model, sensors, and control
  - Reduces the survey and system errors introduced when supporting diverse guidance systems

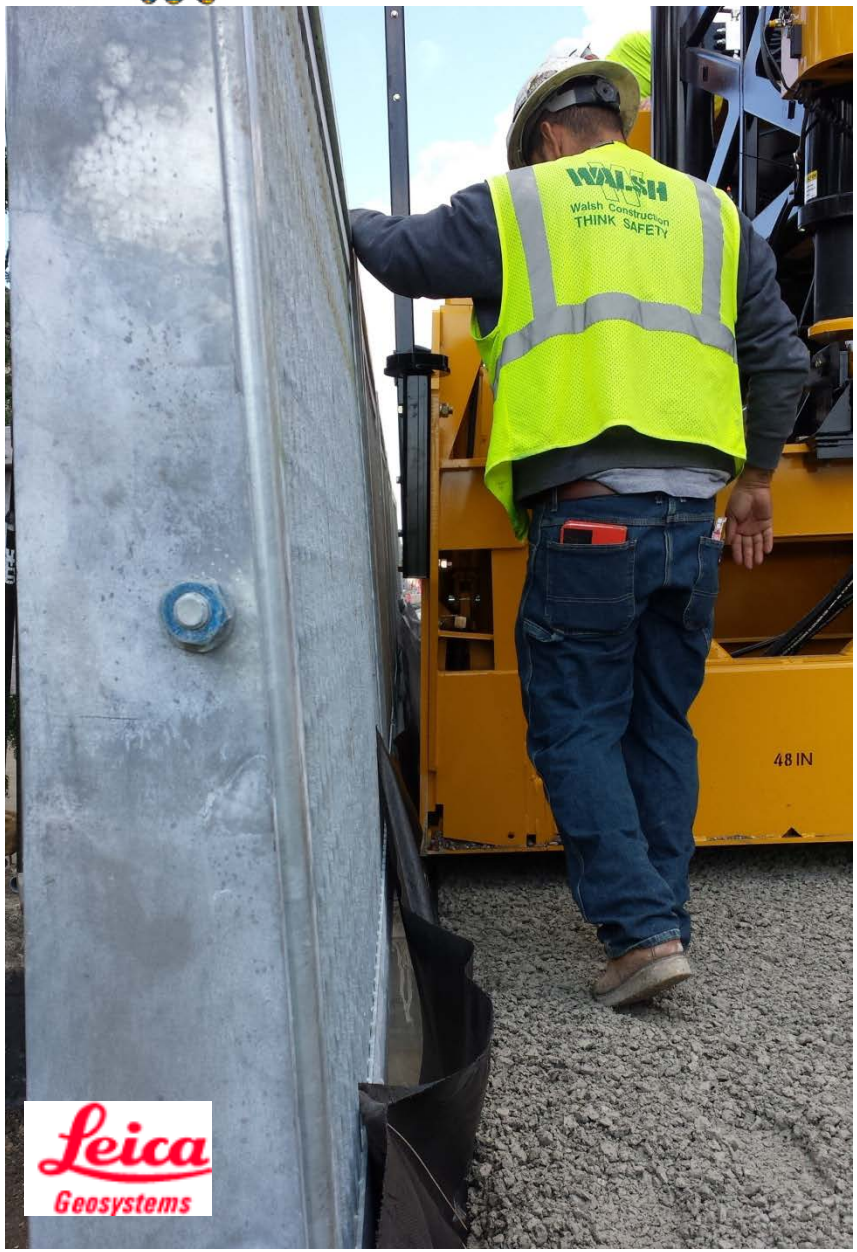
3D Rock Hopper

Auto Steer and Grade

Rest Area off I-69 North of Fort Wayne Indiana

3D Zero Clearance Stone Placing

“606” Bloomingdale Recreation Trail, Chicago Illinois


WALSH
Walsh Construction
THINK SAFETY
48 IN

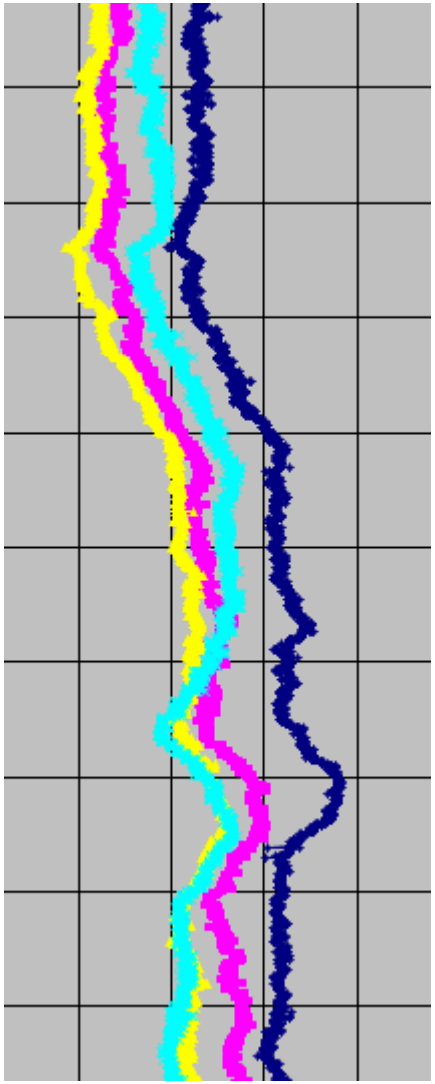
3D Trimming

Automatic Steer & Grade Control

I-75 North of Saginaw Michigan

Concrete Extrusion

- Paving, C&G, Barrier, and all concrete extrusion machines require:
  - Automatic Steering for
    - Precise alignment and
    - width control (when matching existing)
  - Automatic Grade/Slope for
    - Yield, Smoothness, and Depth optimization
- Pre-Production Data Check
  - Check Smoothness
  - Verify Alignment and Grade
    - if subgrade was not prepared and as-built with the same system and data



3D – Automatic Steering and Grade

US-10 Northwest of Midland Michigan

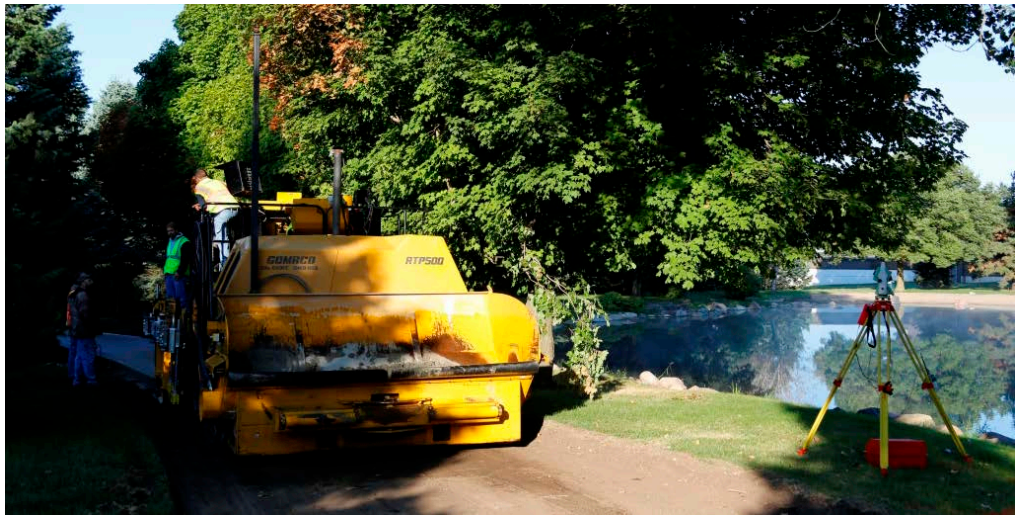
Barrier, Parapet, & Foundations

Truck to Train Overhead Crane Foundation, Gardner Kansas

Tight Radius Curb and Gutter

Wal-Mart Parking Lot C&G, Murfreesboro Tennessee

Zero Clearance Paving (Hybrid)



Ida Grove Iowa

Precise Slope Control

- Shoulders, Matching Lanes, and several concrete extrusion applications require the slope of the product be accurate
- GOMACO machines have built-in slope sensors allowing the machine controller to hold the machine at the design slope value

- Digital (Smart) Levels indicate the slope and can be used to check it

Precise Bar Placement

- Precise Bar placement in the concrete strengthens the product and lengthens its life
- Typical Tolerances
  - Position (Longitudinal, Transverse, Depth)
  - Alignment (Tilt and Skew)
- Scored individually and collectively by joints
  - Goal is to allow for load transfer strength and desirable motions (for expansion and contraction) of the entire stucture

Alignment: Dowel bars need to be …

- At Design Depth
  - GOMACO IDBI releases at the design depth

- Parallel to the surface
  - GOMACO Automatic Leveling Mode will level the bottom of the extrusion pans (top of concrete), then
  - Insertion Forks are adjusted to minimize tilt and skew in final position.
- Perpendicular to the Joint
  - GOMACO's proprietary Insertion Fork bar keepers minimizes skewed bars

3DBI - O’Hare Airport

Longitudinal Bar Positioning

- Conventional Insertion Systems
  - Encoder counting the distance the track(s) travel and spaces out side, tie, and dowel bars.
  - Proximity Switch with marker on the existing grade at the designed/matching joint location.
- Guidance Insertion System
  - 1D/2D/3D Position is used to get the Station of the machine reference point
  - Dowel bars are inserted at pre-planned stations, e.g. the center of the joint's station.
  - **This allows for intersection slabs (taxi-ways or streets) to align longitudinal joints with lane edges**

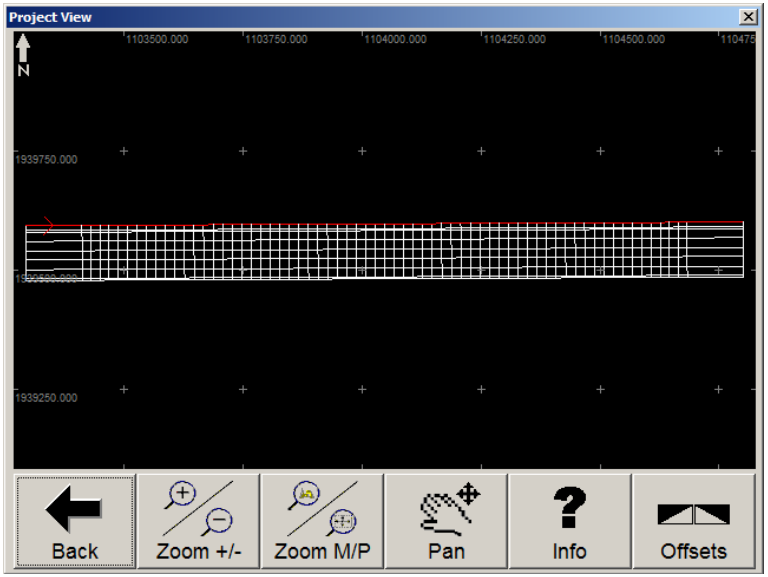
Accurate “3D” Bar Insertion (**3DBI**)

WITH DESIGN

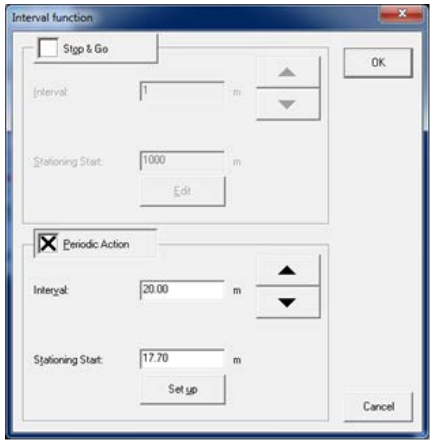
18.75	FIRST DBI INSERT (LMGS STATION)	118.75
	INTERVAL	18.75
	START STATION	91.37
	NUMBER OF INSERTS AT INTERVAL	5
	LAST DBI INSERT (LMGS STATION)	193.75
20	FIRST DBI INSERT (LMGS STATION)	213.75
	INTERVAL	20
	START STATION	185.12
	NUMBER OF INSERTS AT INTERVAL	26
	LAST DBI INSERT (LMGS STATION)	713.75
19.97	FIRST DBI INSERT (LMGS STATION)	733.72
	INTERVAL	19.97
	START STATION	705.12
	NUMBER OF INSERTS AT INTERVAL	3
	LAST DBI INSERT (LMGS STATION)	773.66
20	FIRST DBI INSERT (LMGS STATION)	793.67
	INTERVAL	20
	START STATION	765.04
	NUMBER OF INSERTS AT INTERVAL	27
	LAST DBI INSERT (LMGS STATION)	1313.67
18.75	FIRST DBI INSERT (LMGS STATION)	1332.42
	INTERVAL	18.75
	START STATION	1305.04
	NUMBER OF INSERTS AT INTERVAL	4
	LAST DBI INSERT (LMGS STATION)	1388.67

AGAINST DESIGN

18.75	LAST DBI INSERT (LMGS STATION)	118.75
	INTERVAL	18.75
	START STATION	221.13
	NUMBER OF INSERTS AT INTERVAL	5
	FIRST DBI INSERT (LMGS STATION)	193.75
20	LAST DBI INSERT (LMGS STATION)	213.75
	INTERVAL	20
	START STATION	742.38
	NUMBER OF INSERTS AT INTERVAL	26
	FIRST DBI INSERT (LMGS STATION)	713.75
19.97	LAST DBI INSERT (LMGS STATION)	733.72
	INTERVAL	19.97
	START STATION	802.26
	NUMBER OF INSERTS AT INTERVAL	3
	FIRST DBI INSERT (LMGS STATION)	773.66
20	LAST DBI INSERT (LMGS STATION)	793.67
	INTERVAL	20
	START STATION	1342.3
	NUMBER OF INSERTS AT INTERVAL	27
	FIRST DBI INSERT (LMGS STATION)	1313.67
18.75	LAST DBI INSERT (LMGS STATION)	1332.42
	INTERVAL	18.75
	START STATION	1416.05
	NUMBER OF INSERTS AT INTERVAL	4
	FIRST DBI INSERT (LMGS STATION)	1388.67

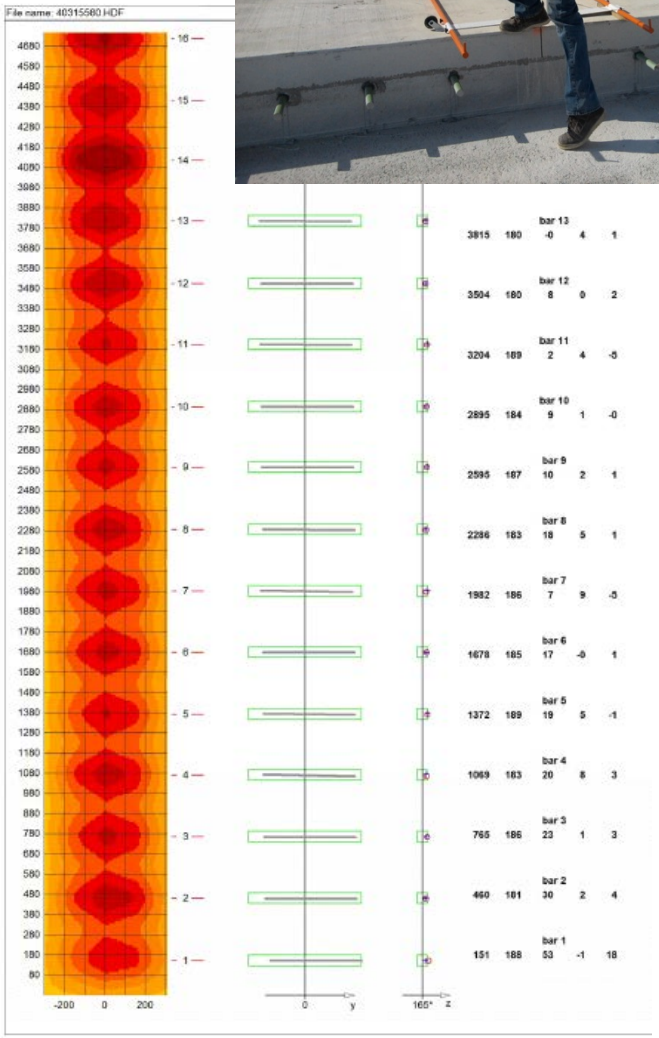


- **Leica Machine Guidance Software (LMGS 7.04) was used to with simple dialog box to set starting station and interval for the bar insertion.**
- **Leica Pavesmart allows an ASCI text file with station and bar type to preplan irregular bar spacing in addition to regular intervals.**



Bar Tolerance Checking

- Dig out sample areas and measure to front and rear top of the bar from the surface and edge just behind paver
- MIT Scan bars on cured concrete surface
- Destructive testing of cured joints



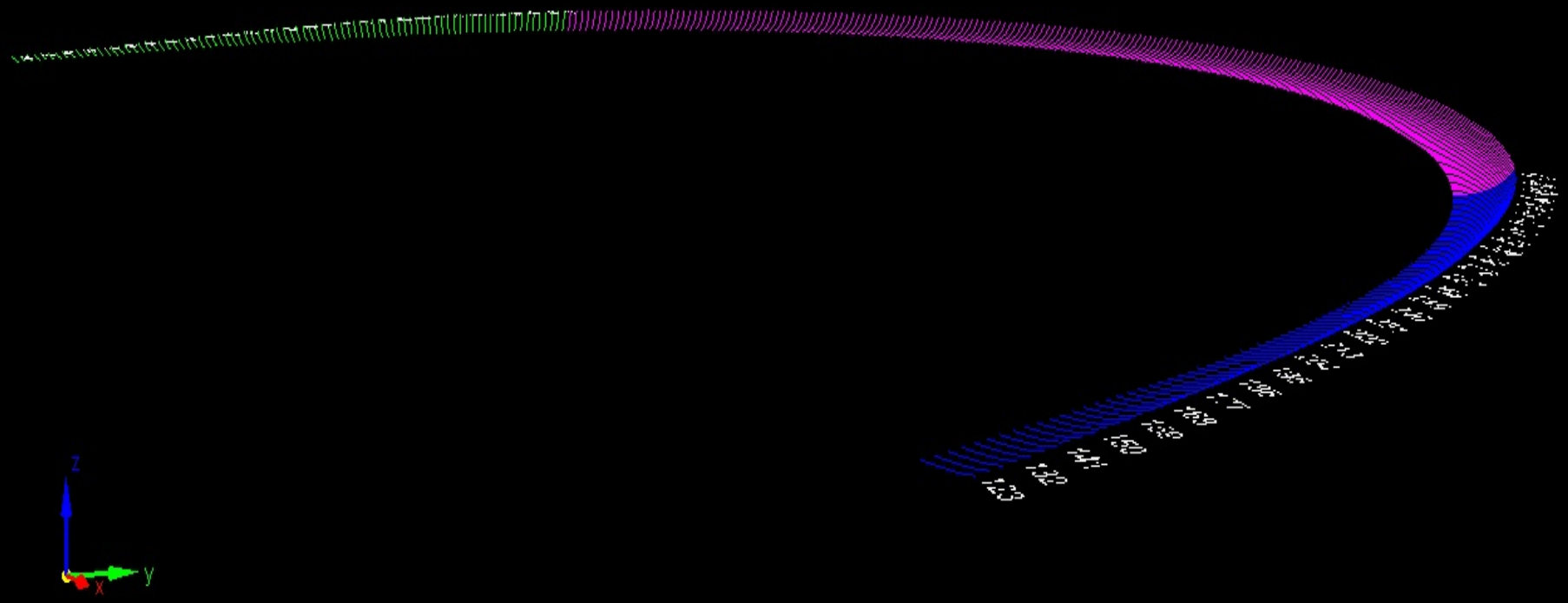
Real-time Smoothness Indicator

3D Cylinder Finishing

- Cylinder finishers are typically used for bridge decks with simple shapes (flat & crowned)
- Slope finishers are typically used for canal projects with constant slope, e.g. shape.
- Presented here is a smooth and continuous transition from linear (1%) to a custom cross section shape
  - Full super cross section is: parabolic, cubic, and linear
- Technology/machine can be used for bridge, complex surfaces, aprons, parking lots or other custom projects

3D Design Data

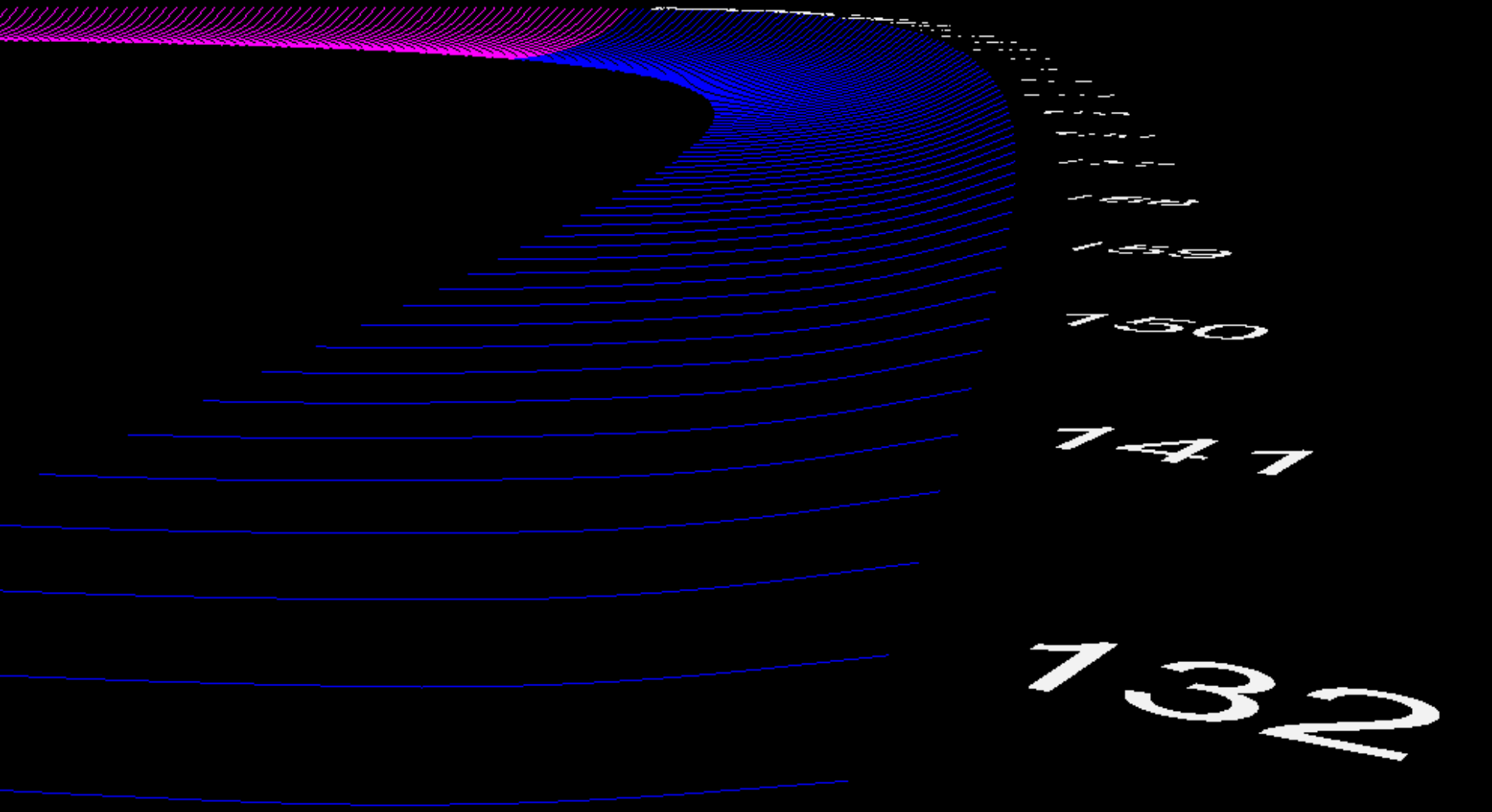
3D Polylines for each 3m Cross Section



SL750 for Custom Cross Section Shaping (McConnell Transition)

```
cout <<  "McConnell, W.A., Ford Motor Company\n" ;
cout <<  "Motion Sensitivity as a Guide to Road Design\n" ;
cout <<  "SAE Summer Meeting, Atlantic City, 1957\n\n\n";
```

Lean Base Finishing
Auto Test Track


747
732

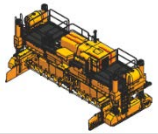
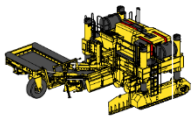
Concrete layer transition from flat to full super elevation

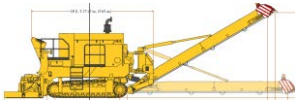
Concrete layer transition from flat to full super elevation

CONCLUSION

Machine

Machines & Implements



Six Grade and Two Steering Corrections to Hydraulic Controller
Implement Control Signals, i.e. Bar Inserter, Crown Adjustment

Mixed Modes

Operator is free to choose best sensor-system combinations to complete task.

G+ Connect™

Real & Virtual Sensor (deviations/corrections) and Design Data

Accessory

3D – Systems

Leica Geosystems

TOPCON

Trimble

2D – Systems

- Dual Axis Slope
- GPS Horizontal Position Only (E,N)
- Rotating Laser Plane Transmitter
- Dual Grade and Steer Sonic Sensors
- …

1D – Systems

- Stringline Sensor
- Draw Wire Sensor
- Smart Cylinders
- Single Axis Slope
- Crown Sensor
- Sonic Sensor
- Distance Encoder
- …

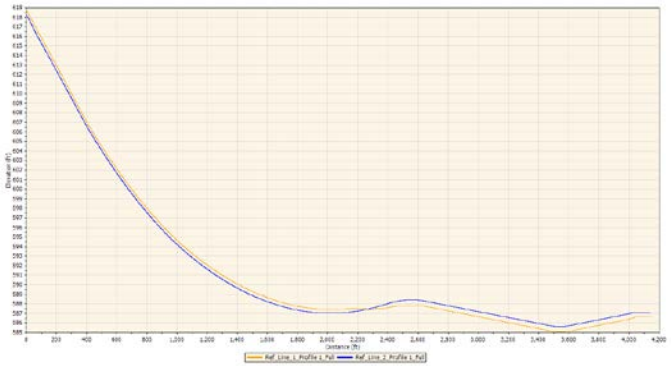
Contractor's Perspective

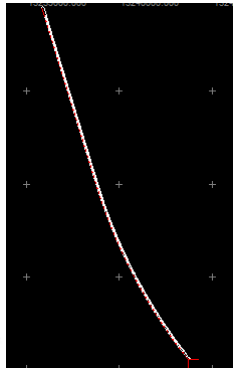
Improved access for trucks, greater options for production (do not wait for line to be set), and reduced labor in setting and removing stringline

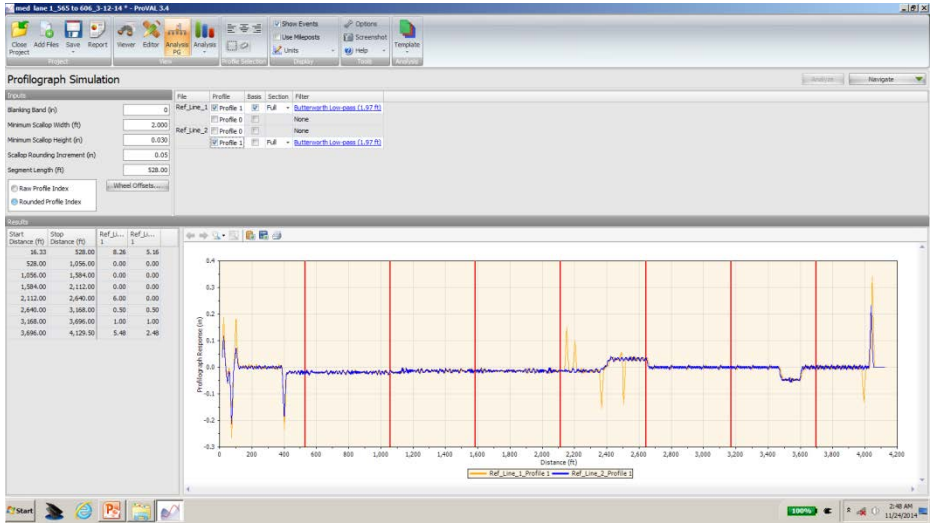
Half width paving - Cozad Nebraska

Design Data Review - Check Smoothness

- Ride quality can be checked in advance of production with data
- We still recommend grading (trim, mill, place base) with concrete model if possible







Inspectors Considerations

- Checking grade directly from control points eliminates staking and string setup error
  - Grade checking instruments are setup using control points
  - Paver work-bridges allows access to center of slab.
- Slope and Depth are still simple inexpensive checks
- Real-time profilegraph assist in mitigating issues
- Next day, lightweight (i.e. gator) mounted profilegraphs account for curing characteristics

“1D/2D” & Hybrid Systems

- Typically less labor intensive
  - No need to move 3D sensor (total station, laser) every 100m, or less, to maintain accurate elevation control
- Does require reference surface grade or simple single beam rotating transmitter
  - Grade side can be **smoothed** with rolling stringline or several averaging sonic sensors
  - Rotating plane can be flat or tilted in one or two directions
- Simpler operation with 2D only systems (less survey knowledge is required)

“3D” Considerations

- Control Points are the key to success
- Mapping with high density improves overlay designs and reduces yield overruns (cost)
- Contractors typically choose a flavor of machine guidance (Leica, Topcon, Trimble) for their entire fleet
- Choose the right paving machines for the job significantly change the production rates and determines lane closures
- Design **smoothness** into :
  - Original Designer Data (upstream: IRI, PI &/or McConnell)
  - Contractor’s 3D Model (downstream)

Comprehensive Design Data

- Accurate Elevation (thickness) is critical for strength, smoothness, and yield control
- Automatic Steering requires alignment data
- Safe surfaces need to shed water (slope)
- Precise positioning of steel extends the life
- New machines, measuring technology, and control software result in new methods
  - Faster construction and lower overall cost