Long Term Measurement Approaches for Foundation Settling and Positional Change

By: STEVEN PERRY
BENGAL RESOURCES & ASSOC., INC
www.bengalresources.com
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The information in this presentation comes from 30 major projects and over 60 smaller projects since 1991 on both steam and gas turbines. Some of the procedures are protected, but there are many ways to collect useful data as technology is constantly changing.

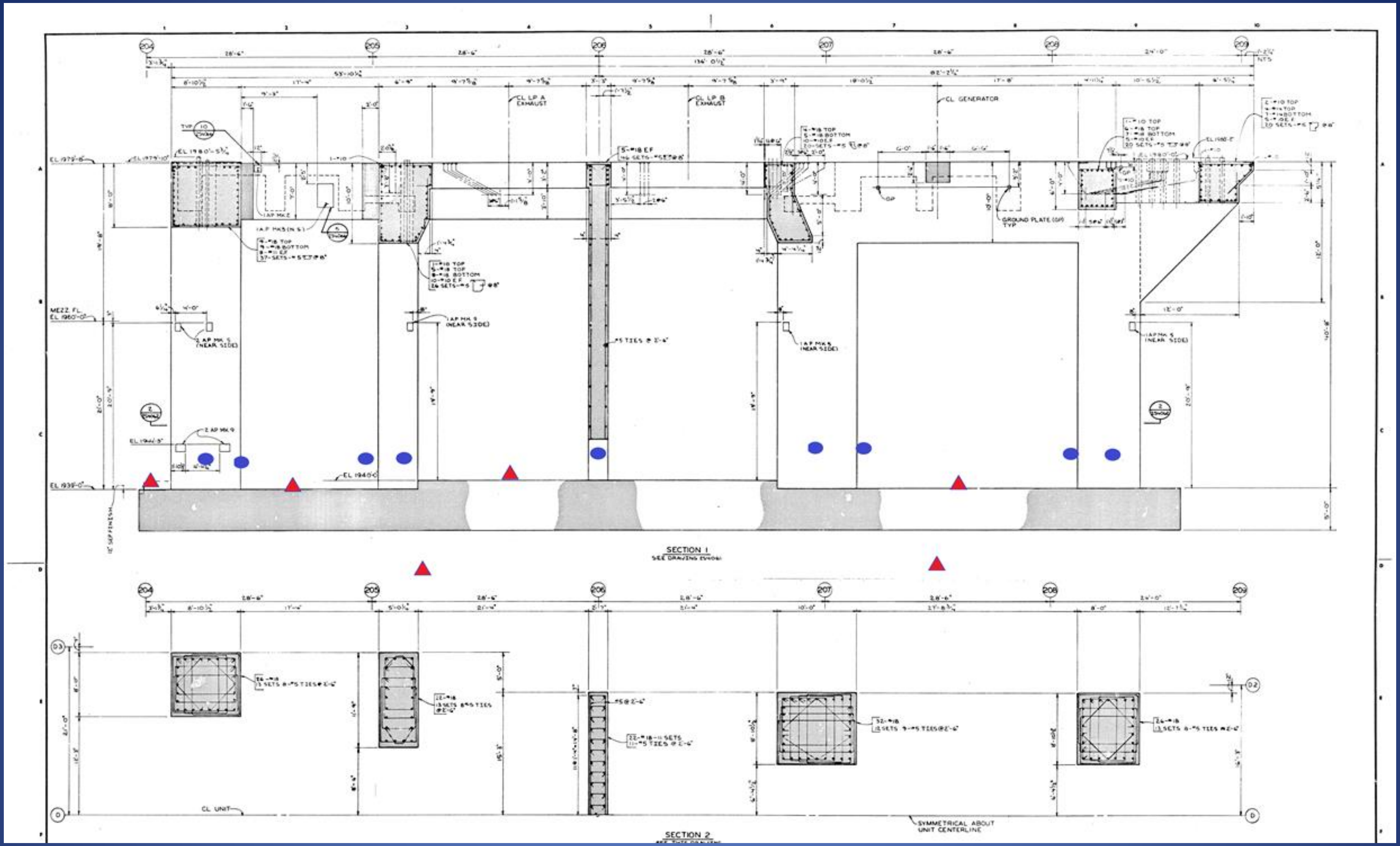
We hope that some of this information provides ideas for people seeking to learn more about the behavior of their units to improve understanding, reliability, and performance.

1. Introduction to Problem of Foundation Settling/Symptoms

Unexplainable changes in alignment readings over time. Potential questions are:

a. Have there been seismic events? Cracks could mean nothing/curing.

Example: A utility reported a 90 thou change in vertical offset at their "A" coupling. Adjustment was made. A long term plan for monitoring concrete pylons was introduced based on previous projects in Europe and the US. This event never repeated or trended again. Poor performance has continued intermittently. A recorded seismic event precipitated the test. No data has confirmed foundation settling. A large one time alignment shift would be characteristic of a seismic event.



Example of global monument and benchmark layout at basement level. Elevation view.

b. Are unexplainable alignment changes due to expansion or contraction of concrete? If so, this is not foundation settling.

- Concrete expands and contracts with a similar coefficient of expansion to mild steel.

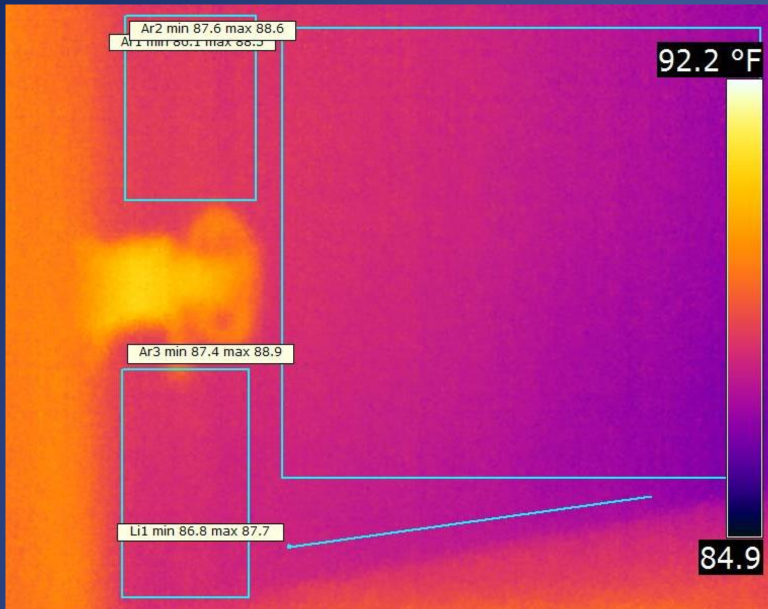
- Outdoor units experience large changes in ambient conditions.

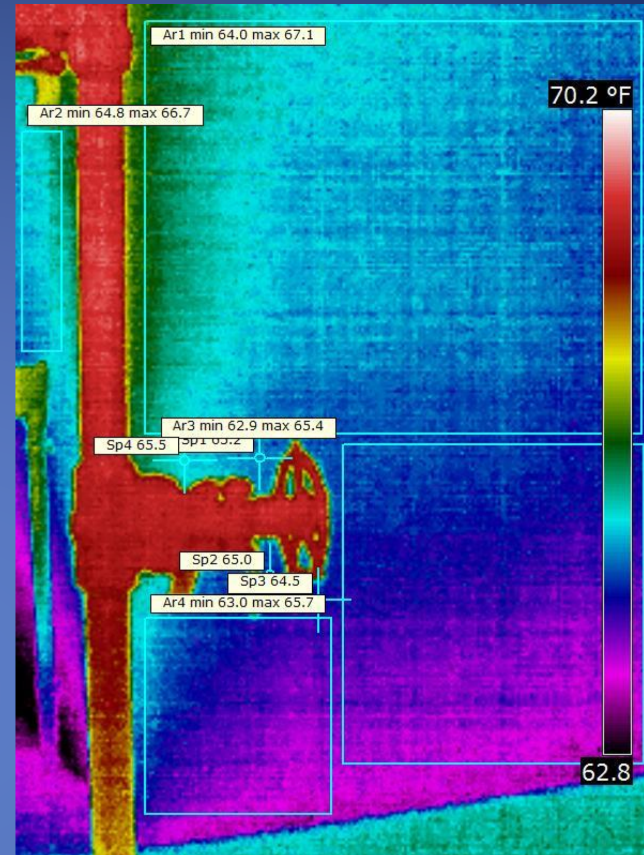
- Pylons for both indoor and outdoor units are subject to temperature fluctuations depending on whether the unit is energized or cold.

- Piping and condenser location can effect concrete pylon temperature.

- Inner pylons are frequently warmer than front standard and generator pylon supports.

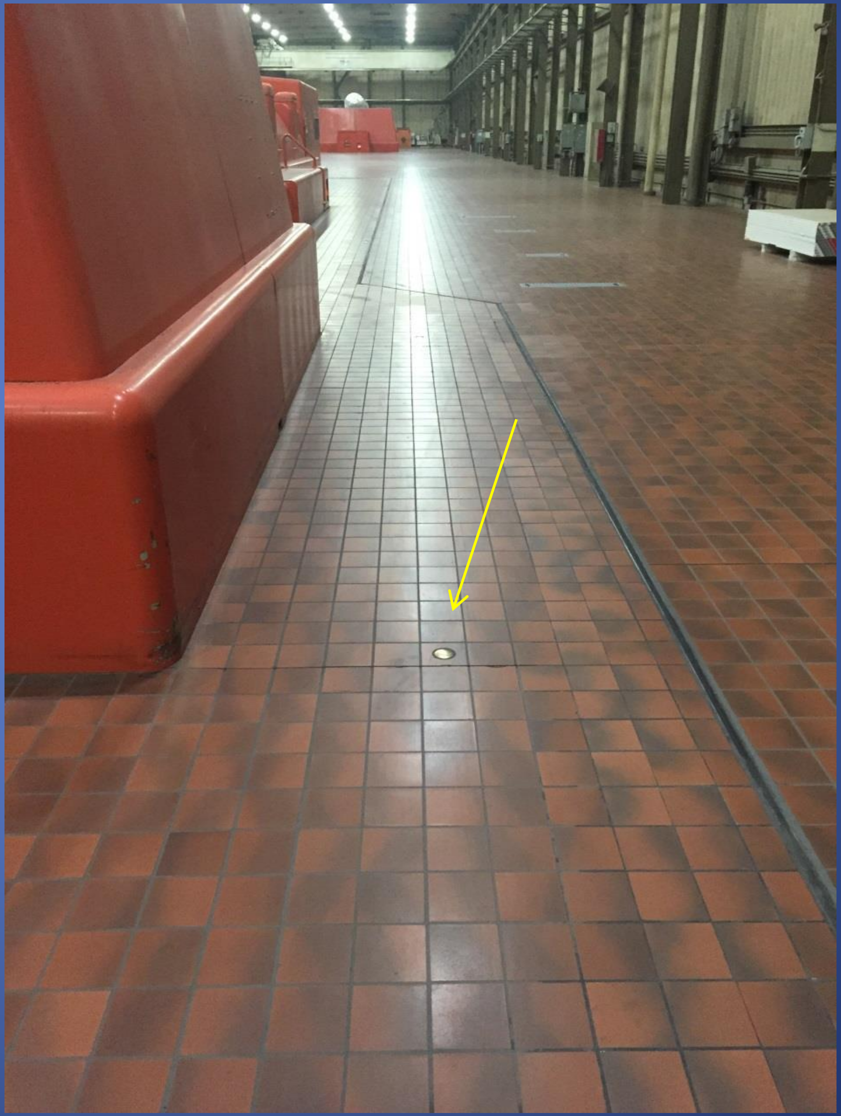
- Considering a 50 to 60 foot column height, one can have an appreciation as to the effect on alignment for machinery mounted on the turbine deck.



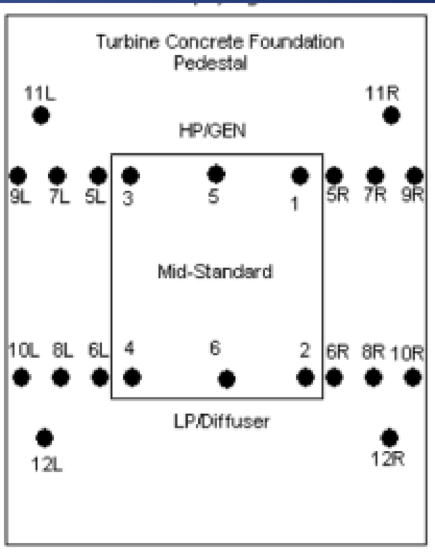


Manifested changes in alignment data due to expansion or contraction of concrete are much less than a seismic event (10 thou or less offset at the coupling in most cases), but can be vexing to holding an alignment and impact performance seasonally. The above pictures are cold vs hot of an indoor unit at ground level. Outdoor units experience greater temperature changes. Sample calculation for one pylon is provided in Section 3.

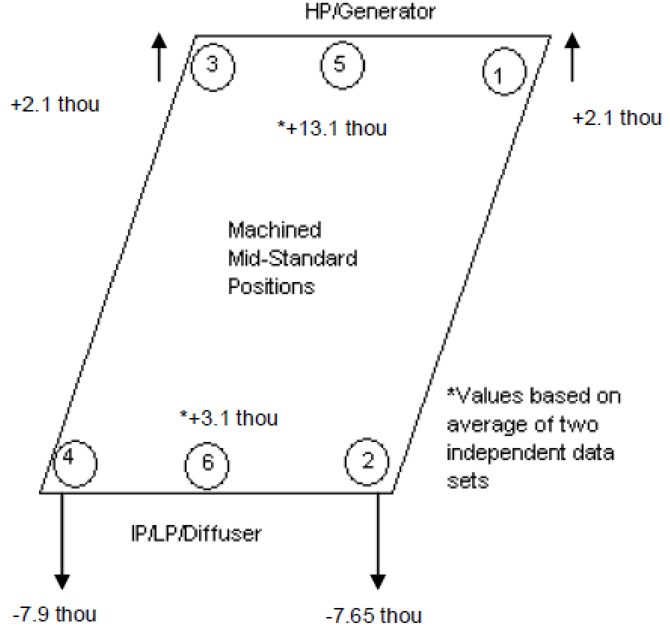
c. Grout cracks - are these a sign of foundation settling? Maybe…Maybe not. Cracks in grout and on concrete at turbine deck can be attributed to unit design or strong axial loading/flexure at stationary positions from which the unit is built - hundreds of KIPS in some cases.



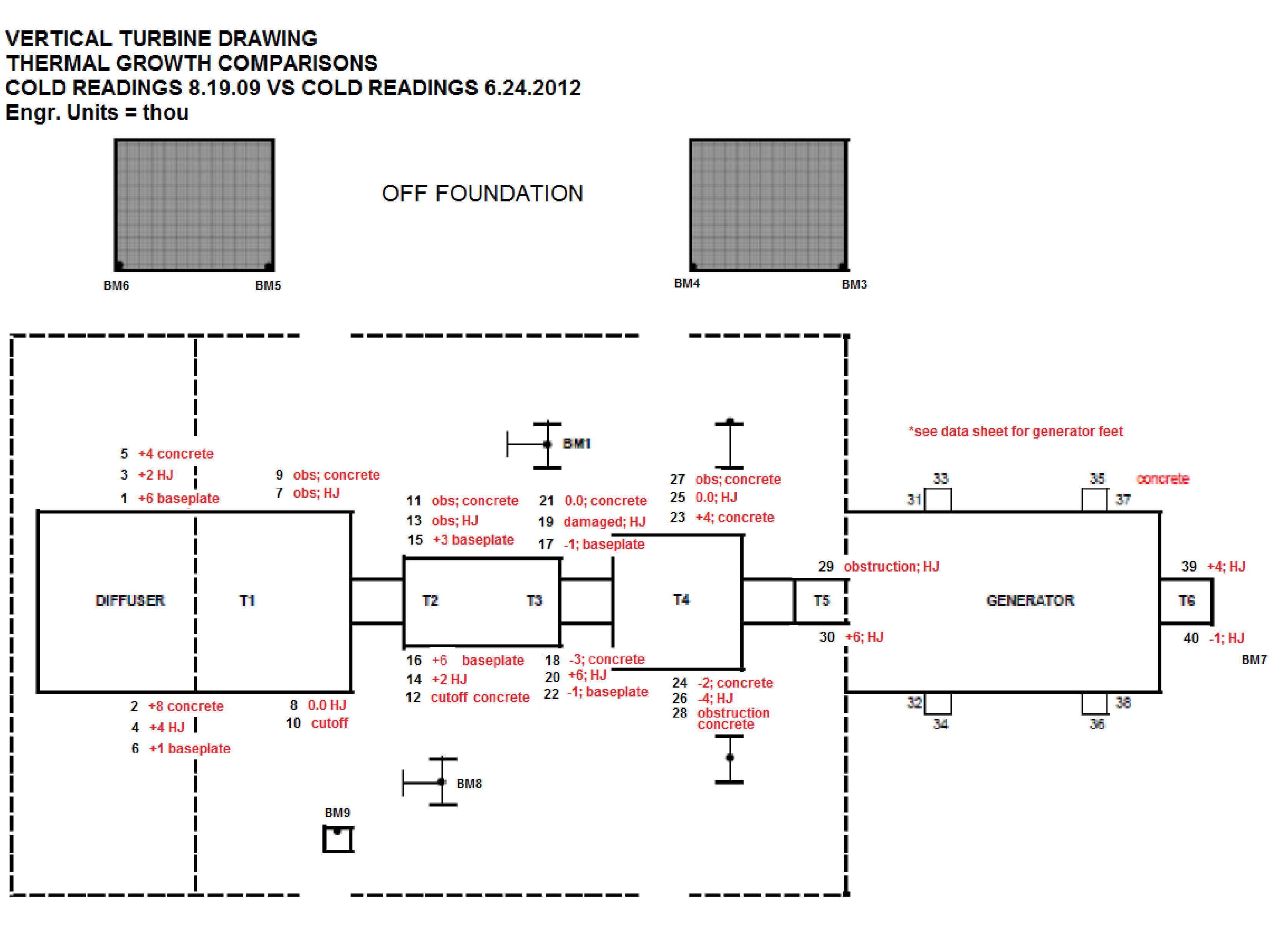
Example of setup and results for evaluating deflection of a standard.



1.20-21.06
Warm after repeated Steam Seal Operations; warm NO VACUUM & NO STEAM SEALS to near FULL VACUUM with STEAM SEALS (4"-5" Hg);
Average of two independent data sets



* Denotes optical data which must have Thermal Growth to the top of the mid-std subtracted from the delta measurement to ascertain change due to load.



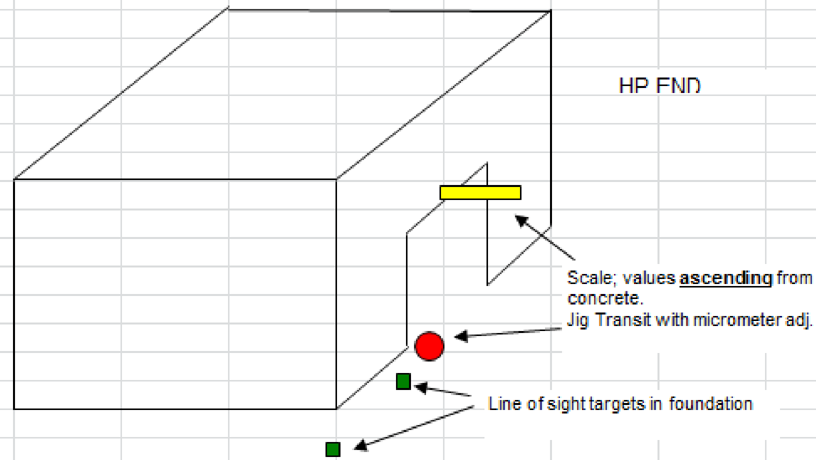
Example of monument and benchmark layout at turbine deck level - plan view

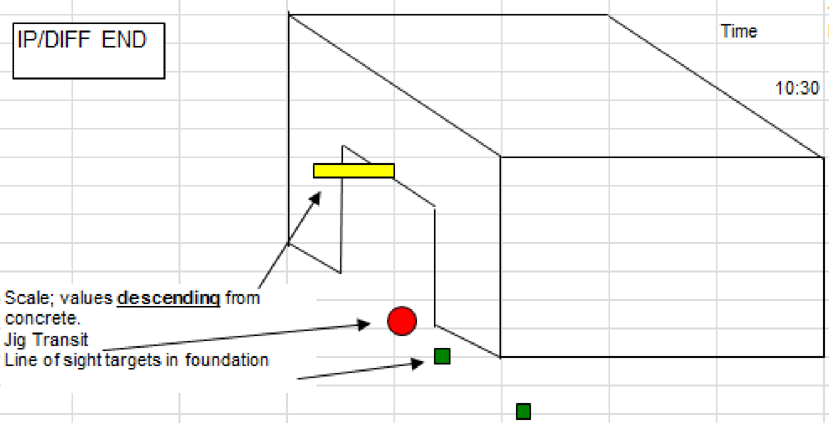
Axial movement of Mid. Std. Pad; bottom-HP end

2.9.7	**2.10.7**	**2.11.7**	**2.12.7**
Base Load	**No Load**	**No Load**	**Base Load**
	NO Vac	**S.Seal+Vac**	
5.04	5.035	5.0385	5.039

Δ = 5 mils

relaxed to MS: HP end





Time	**2.11.7 No Vac or Steam Seals**	**2.12.7 Base Load**
10:30	5.488	5.4925

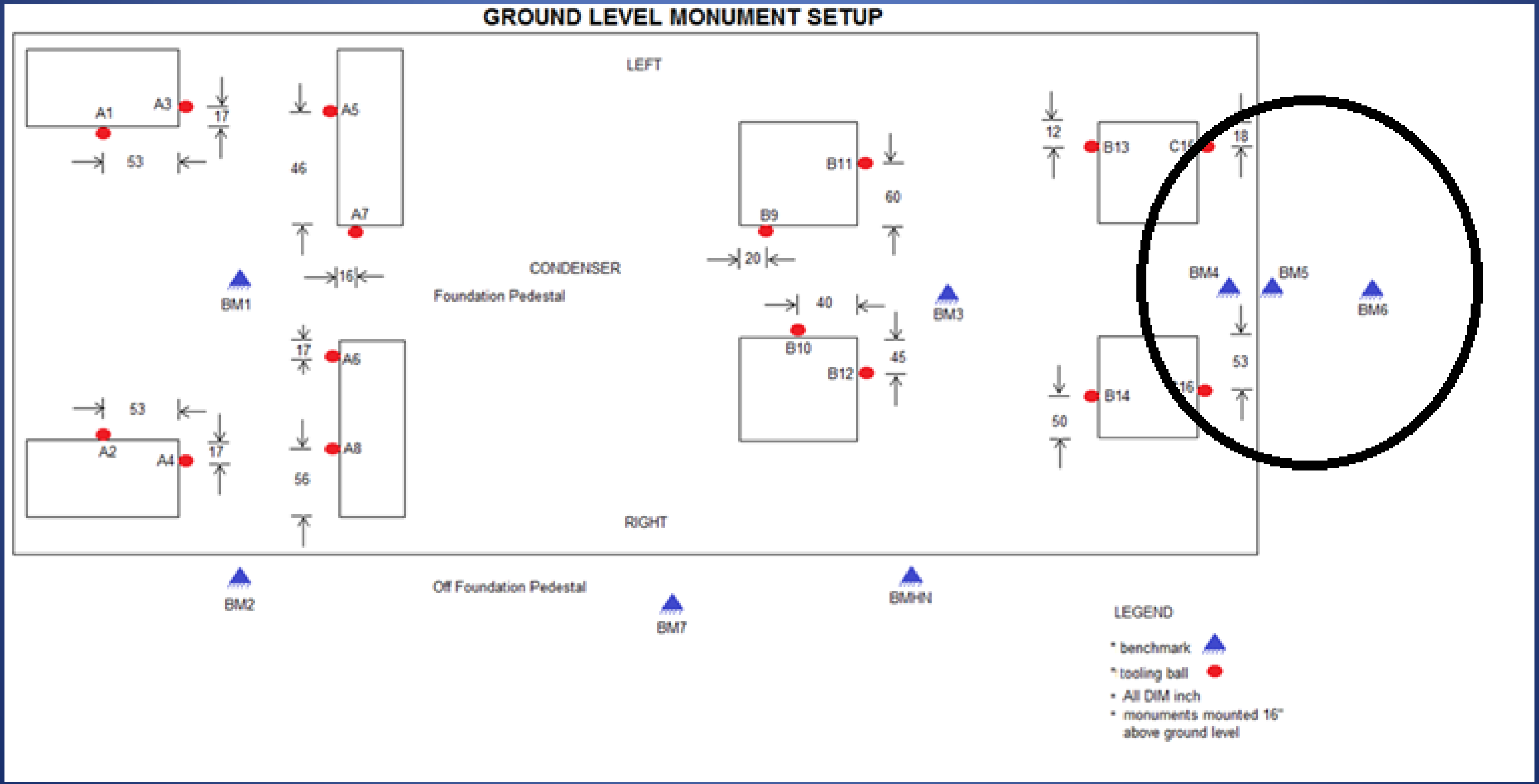
Δ = 4.5 mils

relaxed to MS; IP/Diff end

Example of optical setup of pylon for measuring axial movement

d. Discrepancies between poured primary foundation in basement and off foundation adjacent concrete is a good indicator. Amplitudes should creep over time….20 thou+ range over time.

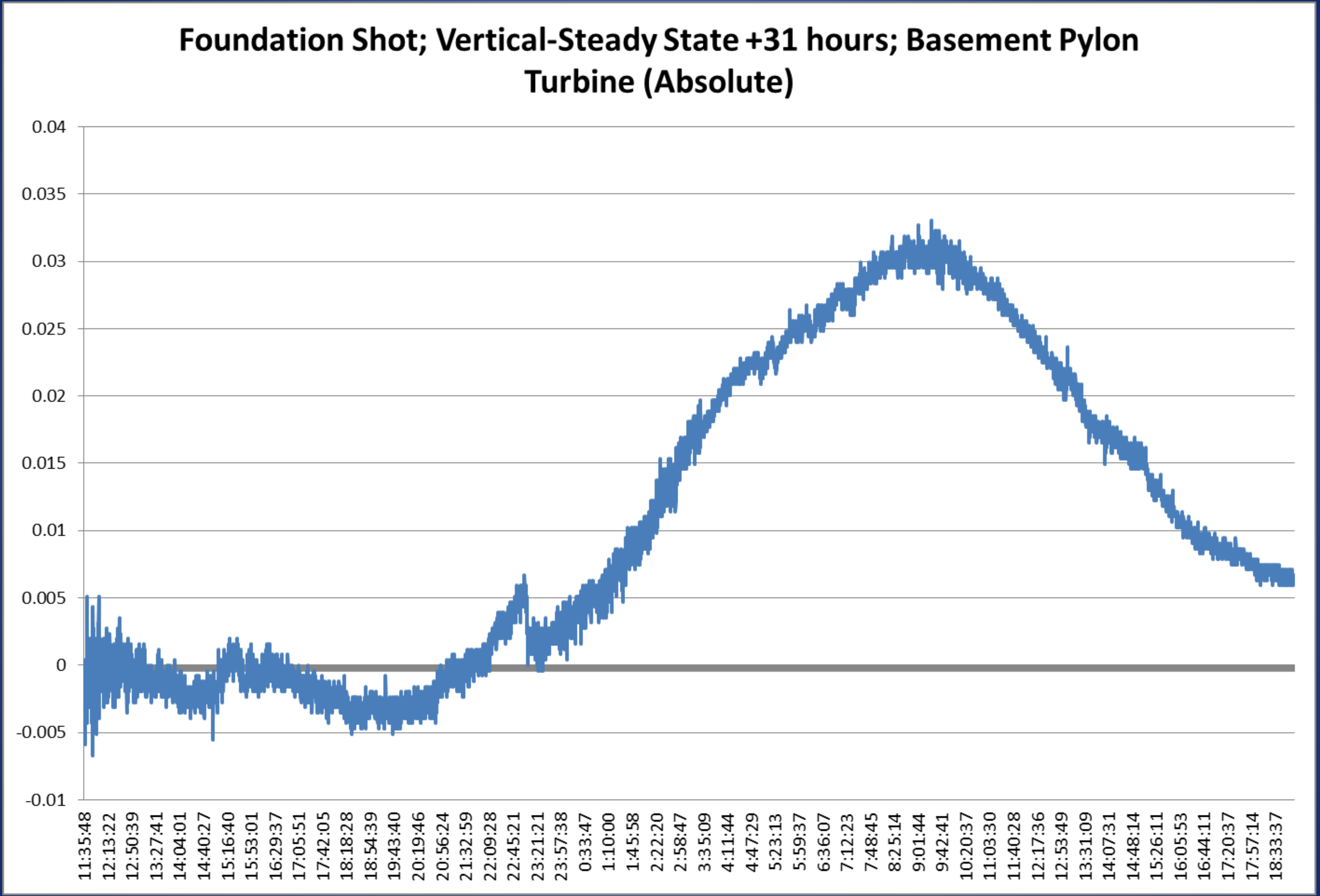
Monument setup should be weighted to the suspect area. Primary benchmarks should be overlapping and connected. However, global data reduction is usually not necessary to confirm a ***settling trend***.



Monument sketch Plan view setup; Data acquired with 3 setups

Example of vertical benchmarks both on and off foundation pedestal.

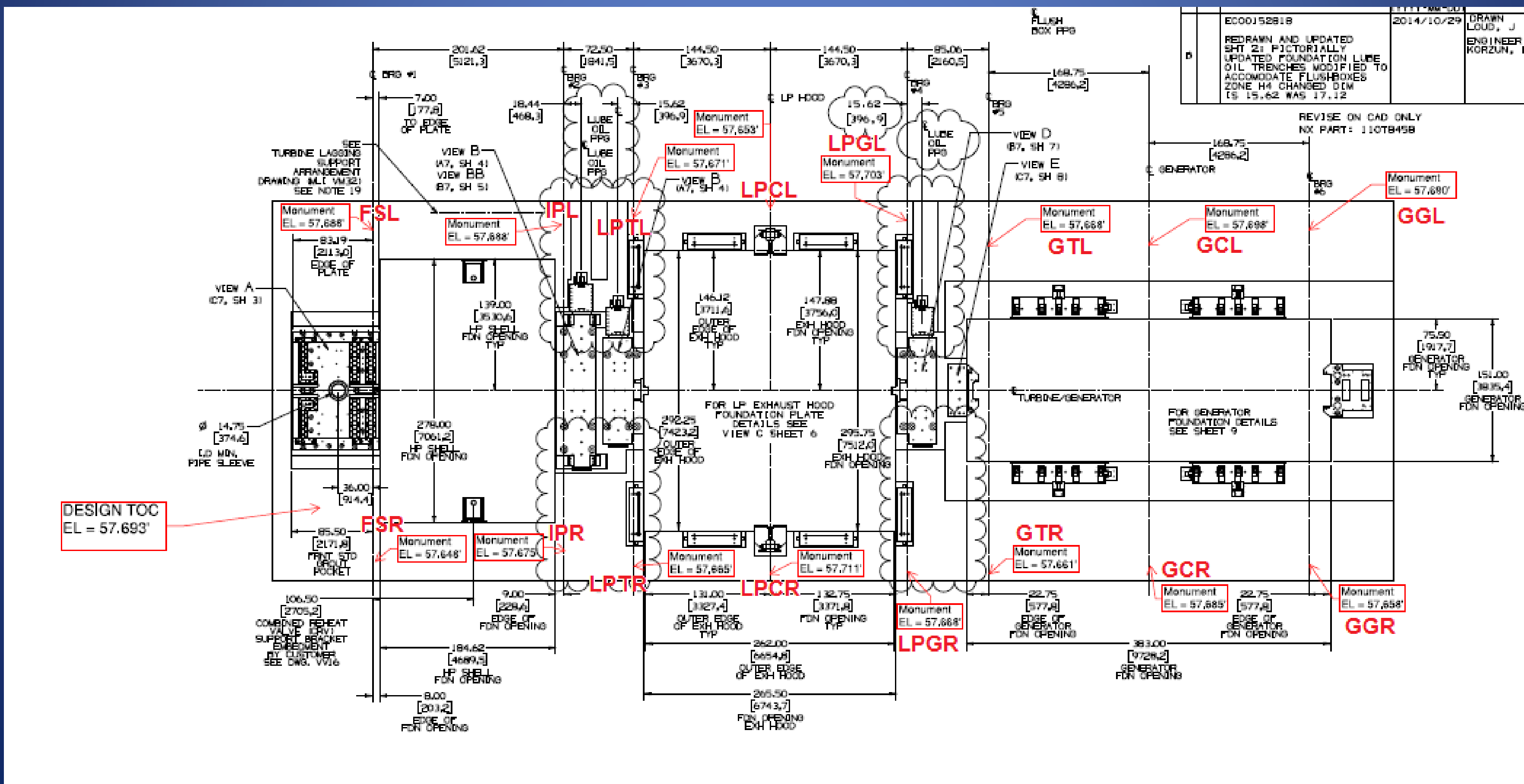
e. Water migration through cracks in basement. Factors influencing this phenomena are: tidal pressure, unit age, proximity to body of water, tidal surge. The unit pictured below was 56 years old at the time. There are products and services available to stabilize local geology that can prolong the life of a unit. Additionally, there are technologies available that can confirm grout and concrete degradation.


Foundation Shot; Vertical-Steady State +31 hours; Basement Pylon Turbine (Absolute)
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
-0.005
-0.01
11:35:48
12:13:22
12:50:39
13:27:41
14:04:01
14:40:27
15:16:40
15:53:01
16:29:37
17:05:51
17:42:05
18:18:28
18:54:39
19:43:40
20:19:46
20:56:24
21:32:59
22:09:28
22:45:21
23:21:21
23:57:38
0:33:47
1:10:00
1:45:58
2:22:20
2:58:47
3:35:09
4:11:44
4:47:29
5:23:13
5:59:37
6:36:07
7:12:23
7:48:45
8:25:14
9:01:44
9:42:41
10:20:37
11:03:30
11:40:28
12:17:36
12:53:49
13:31:09
14:07:31
14:48:14
15:26:11
16:05:53
16:44:11
17:20:37
17:57:14
18:33:37

2. Methods of Measurement

a. GPS surveying instruments civil engineering grade

These instruments are good enough for construction. They give results to the correct decimal places in some cases, but not repeatable to mechanical standards over time. Review the following drawing and notice the engineering units are in feet. If one were to use these benchmark values as a reference to machined surfaces on the turbine & generator, questions would eventually arise.



b. Optics

Brunson K&E, Jig transit & tilting level, angular resolution 1 arc second (2.25 thou over 40 feet)

Pros: affordable, simple, can “see” the data (like a dial gage), field calibration strongly verifiable and may be corrected in the field, travels well, repeatable data over 40 feet to w/i couple thou, flexible line of sight vertical and horizontal. No batteries or software can be an advantage at times. This class of measuring instruments are as reliable as mechanical dial gauges.

Cons: requires user experience, data variation between operators 2 to 4 thou, steam and vibration usually not a factor.

c. Scanning Lasers

Pros: Less operator dependent than optics; Many ways to apply tool.

Cons: line of sight issues, vibration issues to instrument and reflector, heat, steam, non-continuous data expressions for analysis to catch transient/semi-transient events (same as optics), repeatability issues on energized high vibration/heat/steam environments.

d. Biaxial laser detectors

Example of a linearized laser measuring system with a resolution of one micron throughout the entire detector range of 0.630". The system, which uses a bi-axial detector, permits measurement at distances of up to 30 feet (shots should be kept to 10 feet or less). This system is time (vibration) and temperature stabilized.

Pros: simple, fixed, low maintenance, RUGGED, plug and forget (except for periodic lens cleaning and resetting detector ranges), continuous data for Excel to catch process transient and semi-transient events, large detector area, instrument can take high temperatures/reflectors can take even higher temperatures -Very stable across beam path, direct measurement of displacement or angle.

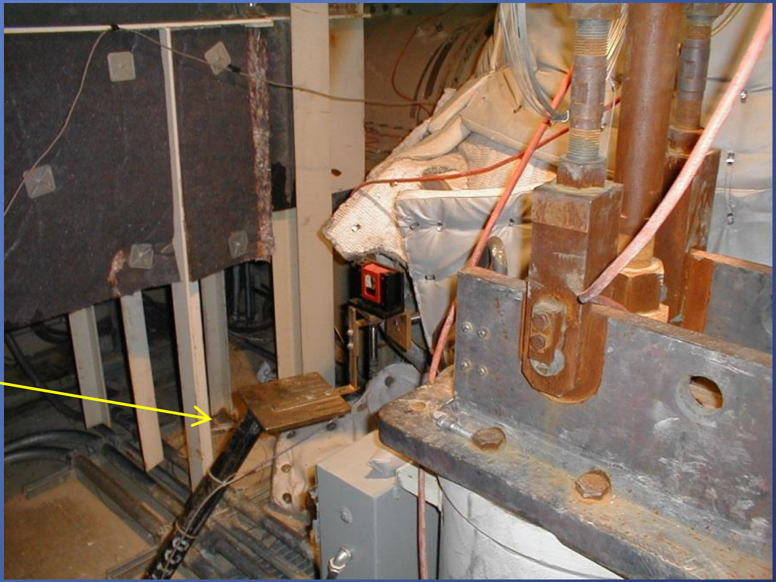
Cons: time consuming setup with meticulous detail, instruments must be very secure to eliminate monitor & reflector migration, mounting may require protection and insulation, small mounting errors can render data worthless, subject to bracket hysteresis, subject to laser pedestal error (temperature, stress relief), relative large in size.

e. Eddy current probes & inductive displacement transducers

Pros: These sensors are inexpensive, very good and proven in field applications. However, the apparatus upon which they are mounted frequently introduce substantial error to a "clean" data gathering – such as "Christmas Trees".

Cons: No way to determine how mounts behave. The mounts must be stress and heat relieved after welding. Still, they introduce unknown variables. They also introduce complex and variable fit issues to turbine (i.e. piping, available concrete to mount upon and access). Materials for mounting are also an issue.

Xmas Tree;
What are you really measuring?



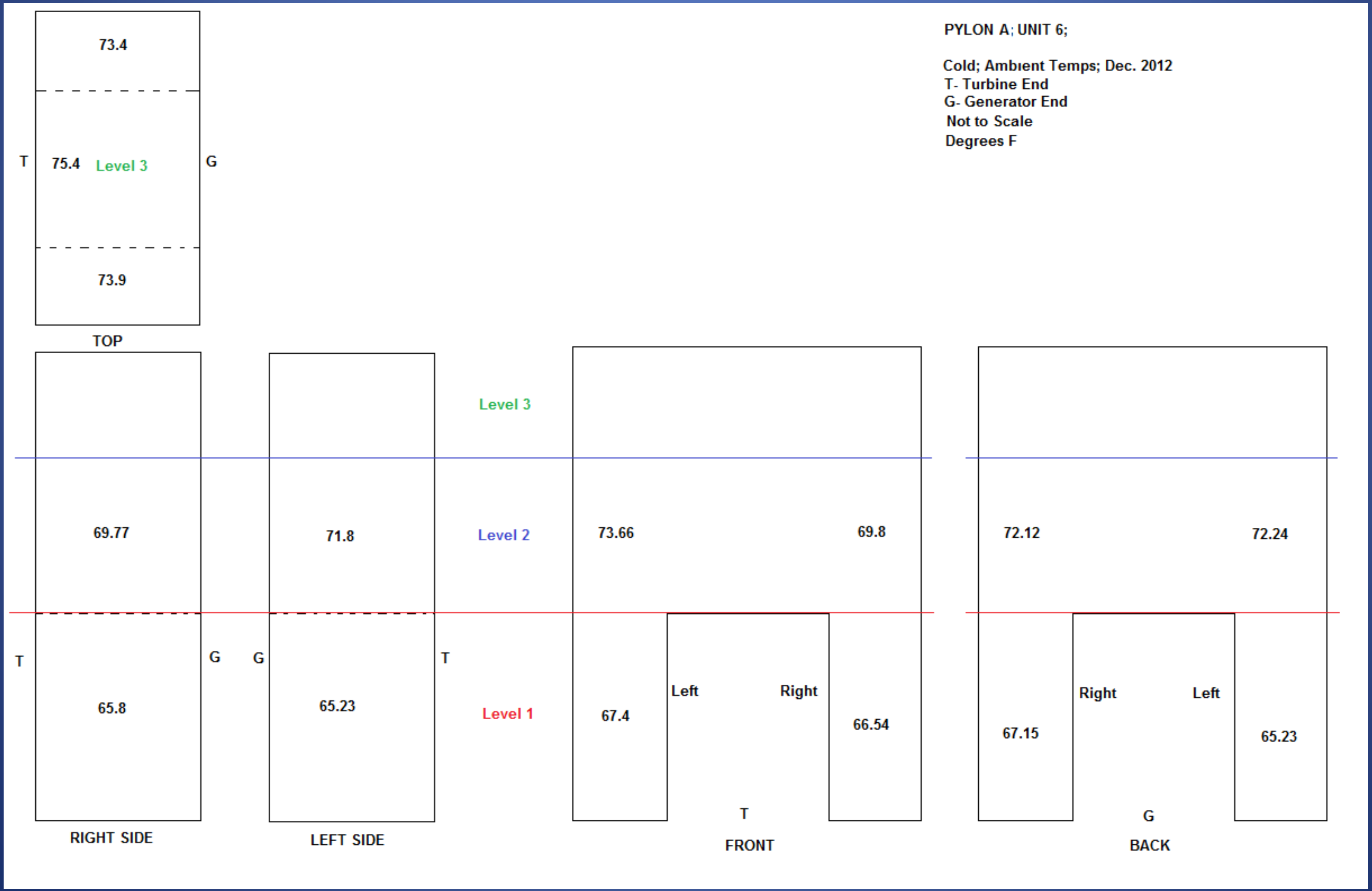
f. Rotating Lasers

These units are widely available from several different sources. The sensors (photocell) accuracy exceeds the laser plane accuracy in most cases. Many units have difficulty passing a 1 arc second peg test at 40 feet. Unit pictured passed on random test of two units. See Brunson for field peg test procedure.

g. Worth mentioning: Photogrammetry and newly introduced electronic inclinometers.

3. Positional Change of Turbine Pedestal and Standards Affecting Alignment other than Settling

a. Temperature; IR; example of indoor unit data; Outdoor units experience greater deltas, particularly at front standards and generator aft bearings. Condenser locations effect concrete temperatures.

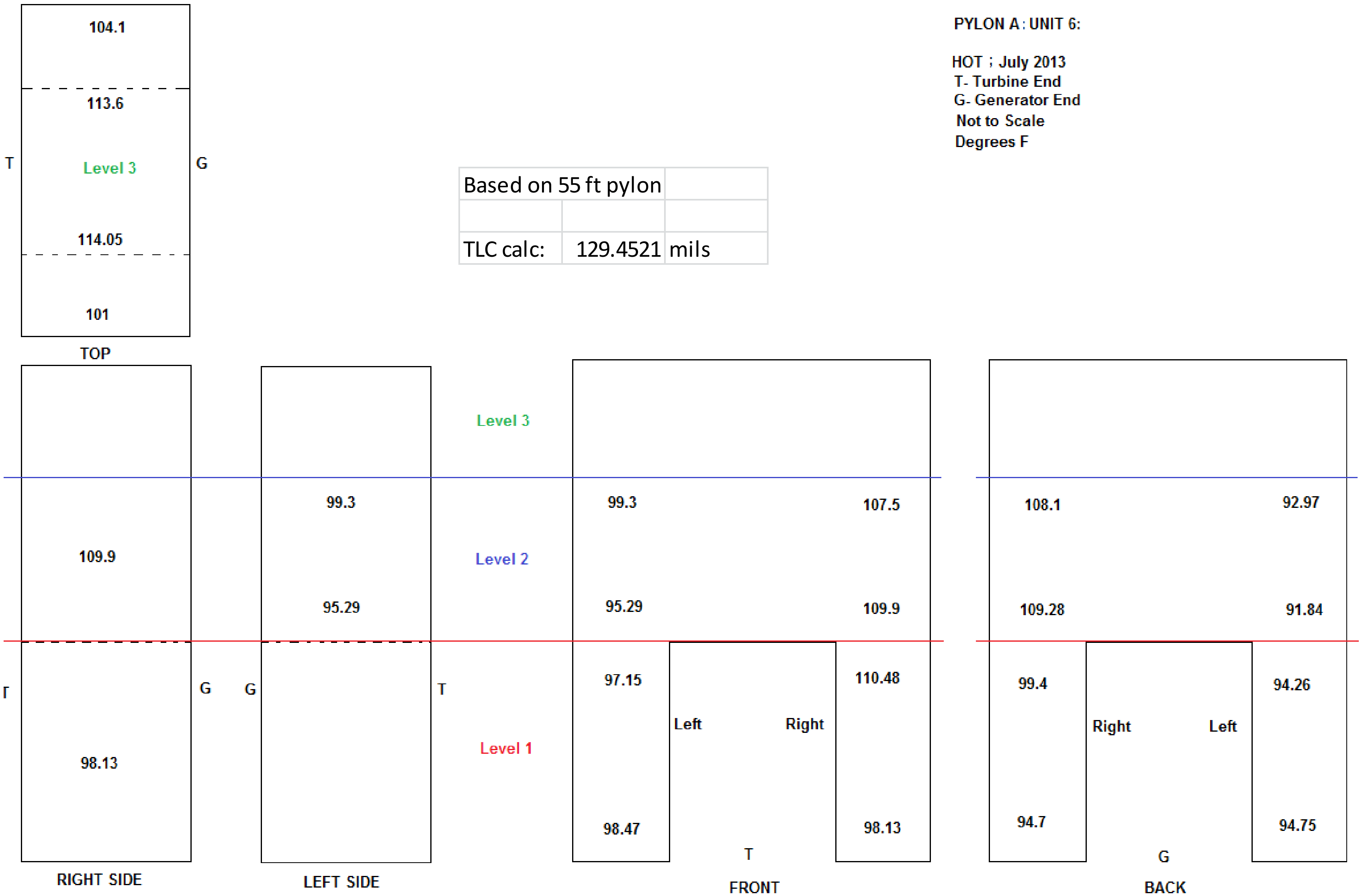


3a. Cont'd

PYLON A : UNIT 6:

HOT ; July 2013
T- Turbine End
G- Generator End
Not to Scale
Degrees F

Based on 55 ft pylon		
TLC calc:	129.4521	mils



3a cont’d: Condenser location effects concrete temperature. Non-adjacent pylons do not experience this. Insulation helps.

3a cont'd:

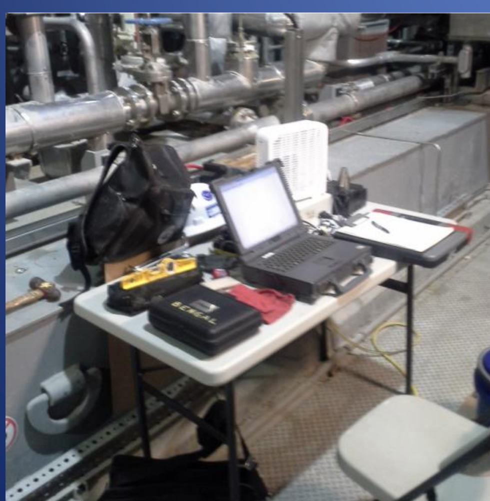
Some manufacturers have installed thermocouples during construction and automated data collection. Additionally, reduced footprints/reduced heights of newer combined cycle designs minimize concrete thermal effects to turbine alignment.

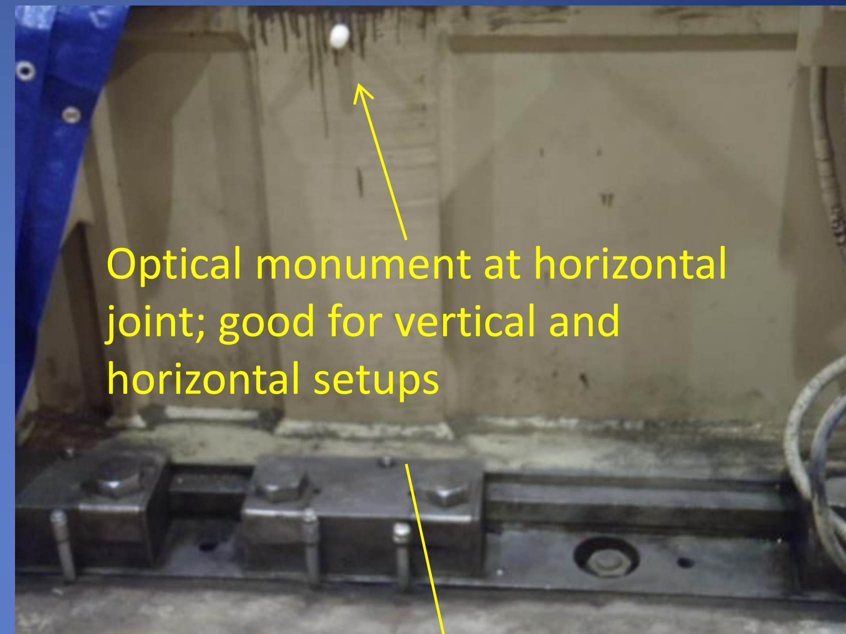
Note: Foundation Settling is sometimes blamed for alignment changes when the true cause may be differential concrete expansion of turbine pedestals/pylons.

3b. Foundation Deflection Due to Load. See Introduction.

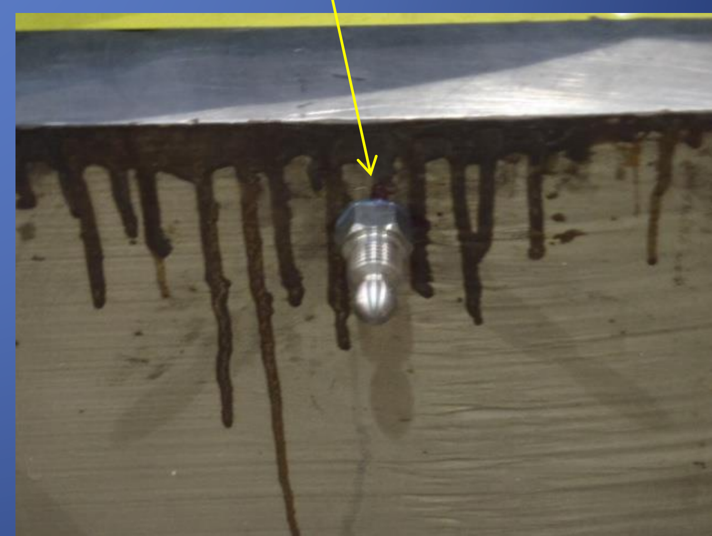
3c. Flexing of bearing standards at horizontal joints due to vacuum or other loading.

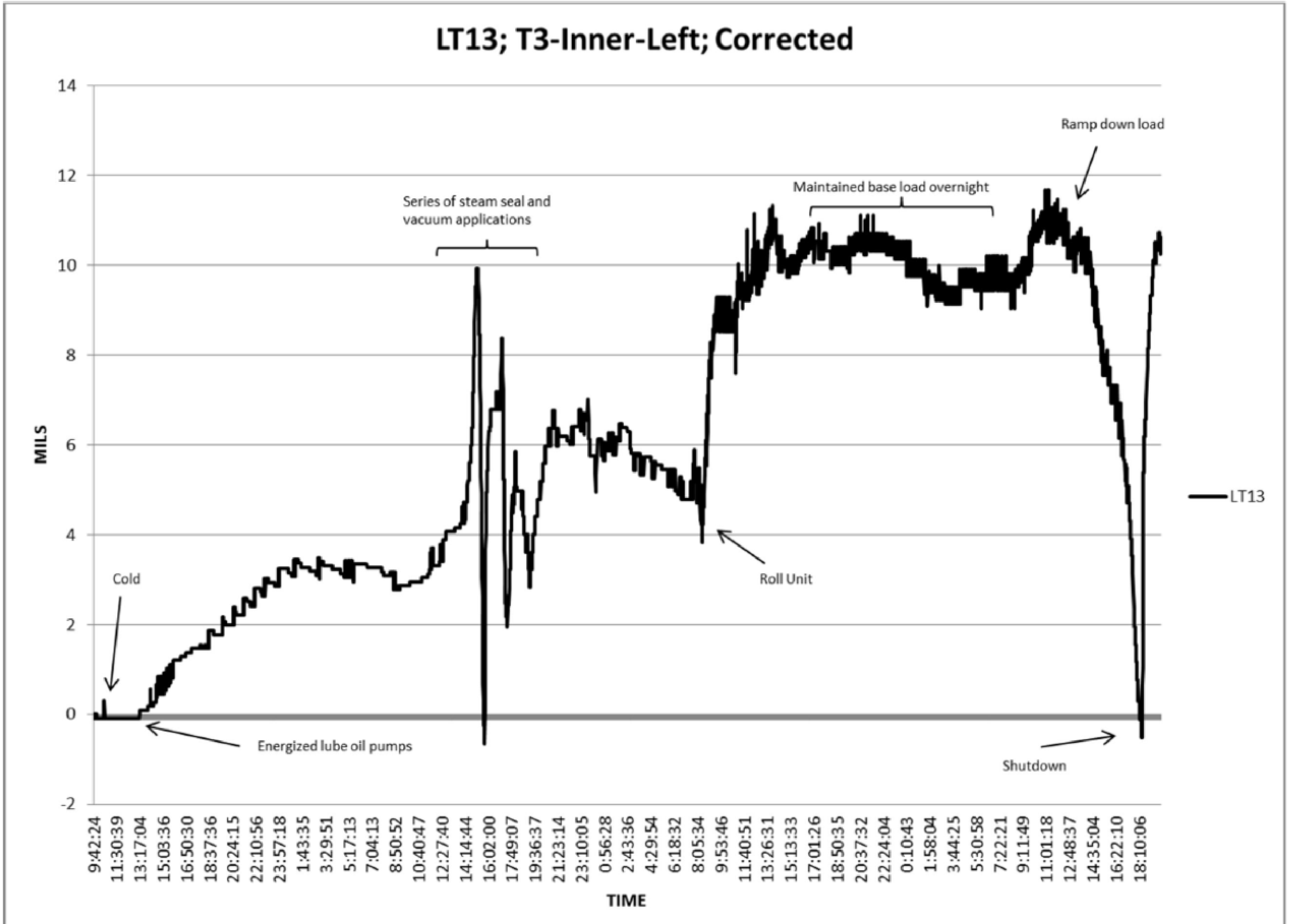
Laser reflector setup for bearing housing deflection measurement





Optical monument at horizontal joint; good for vertical and horizontal setups

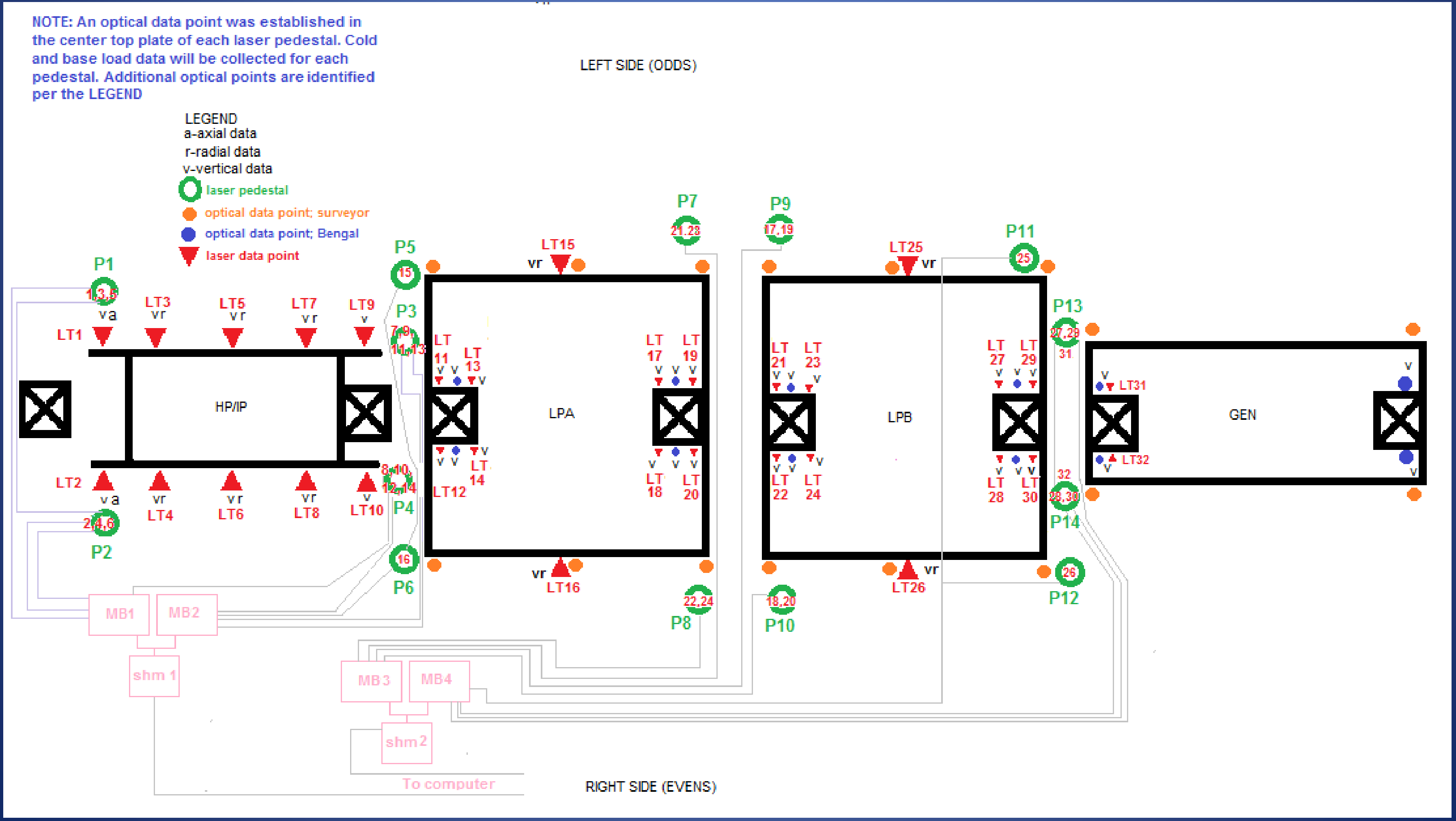




LT13; T3-Inner-Left; Corrected
MILS
TIME
Series of steam seal and
vacuum applications
Maintained base load overnight
Ramp down load
Cold
Energized lube oil pumps
Roll Unit
Shutdown
LT13
14
12
10
8
6
4
2
0
-2
9:42:24
11:30:39
13:17:04
15:03:36
16:50:30
18:37:36
20:24:15
22:10:56
23:57:18
1:43:35
3:29:51
5:17:13
7:04:13
8:50:52
10:40:47
12:27:40
14:14:44
16:02:00
17:49:07
19:36:37
21:23:14
23:10:05
0:56:28
2:43:36
4:29:54
6:18:32
8:05:34
9:53:46
11:40:51
13:26:31
15:13:33
17:01:26
18:50:35
20:37:32
22:24:04
0:10:43
1:58:04
3:44:25
5:30:58
7:22:21
9:11:49
11:01:18
12:48:37
14:35:04
16:22:10
18:10:06

3d. Setup Example - Measured Positional Changes at Turbine Deck Level

Measured positional changes at turbine deck level that vary from calculated theoretical alignment are influenced by operational loads, vacuum, thermal growth of turbine materials/concrete. Example of turbine deck setup.



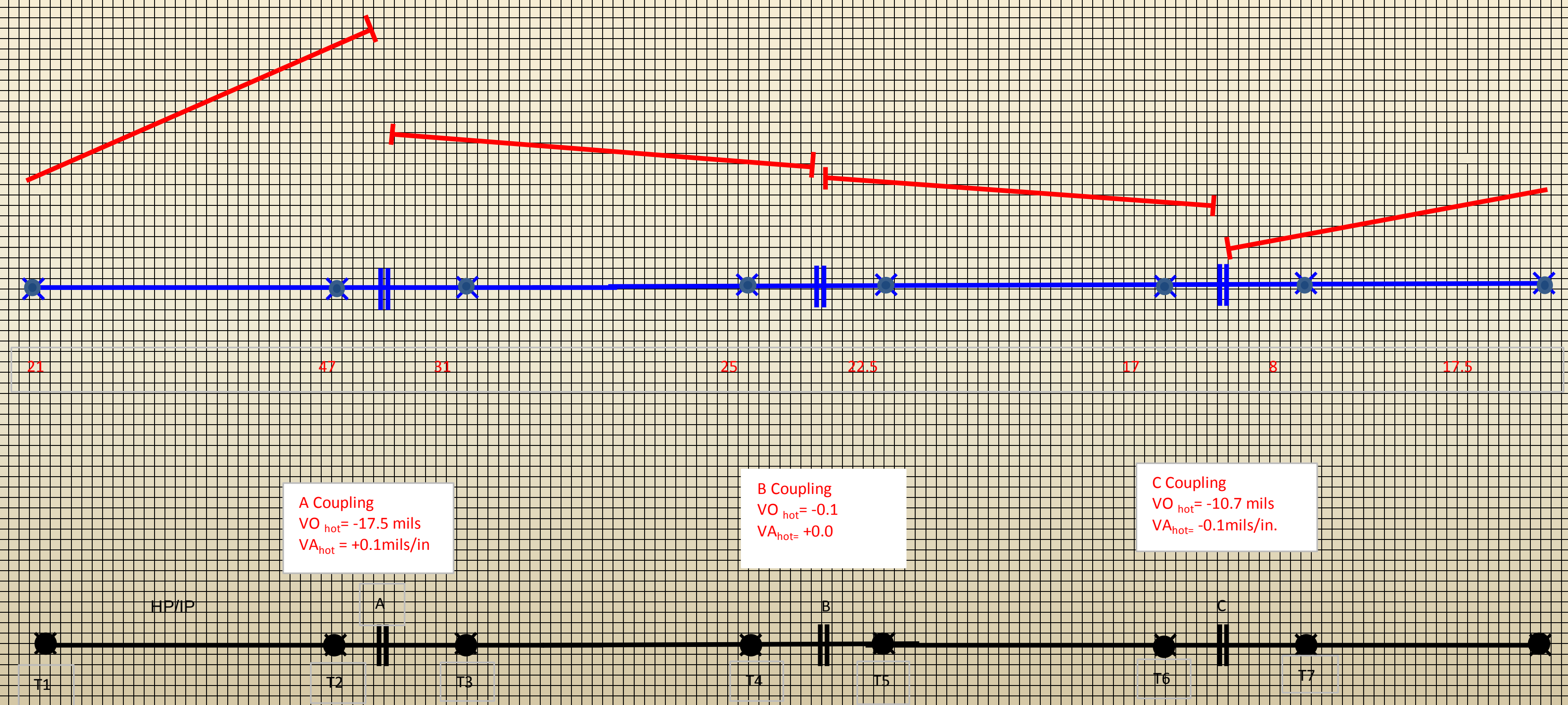
SCALE:
LINEAR - 8.0" PER SQUARE
VERTICAL - .002" PER SQUARE

Unit 3 VERTICAL POSITIONAL CHANGE MEASUREMENT
Horizontal Joint Measurements

03.16.2013

VERTICAL RELATIVE COLD POSITION
VERTICAL THERMAL AVG. LASER/Optical Data
BRG/SHIM PLANE LOCATION
TOOLING BALL LOCATION
*Coupling values verified with PT software

*OFFSETS ARE @
COUPLING CENTER
Engr. unit= MILS



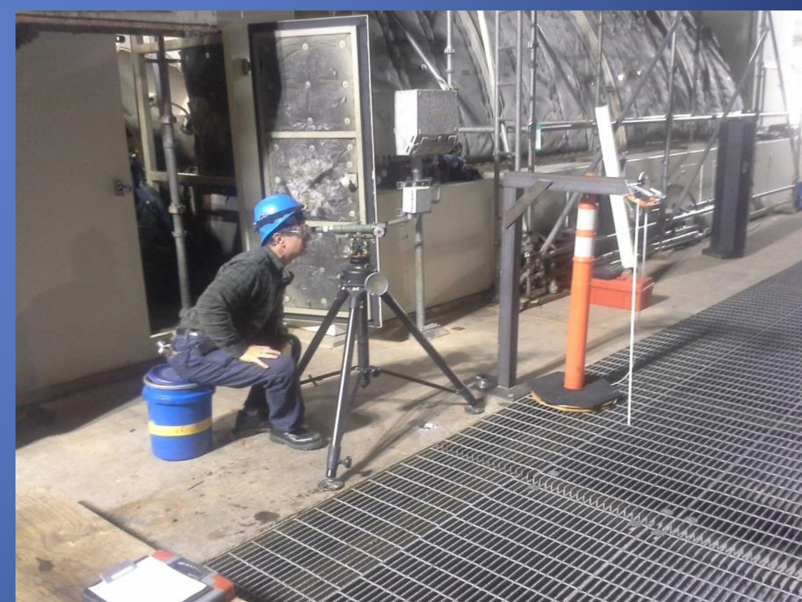
4. The Issue of Obstructions to Line of Sight for Basement Foundation Measurements

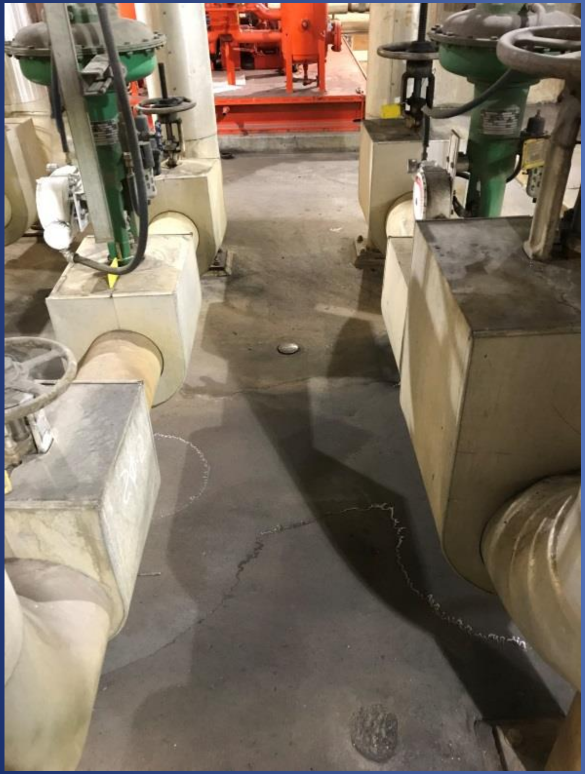
This issue represents one of the toughest problems when setting up monuments for long term monitoring of foundation pylons.

- Whether using lasers or optics, one must have a line of sight to each monument and benchmarks so that a single setup can capture all data points within a section (for best results). It is best if a single setup can capture both on foundation and off foundation benchmarks.

- Benchmarks should be “relatable” to benchmarks to subsequent sections if a global settling diagram is desired. However, this is usually not needed and each section may be successfully analyzed to its own benchmarks in order to ascertain potential settling.

The following photos illustrate the difficulties with regard to setup and line of sight issues.





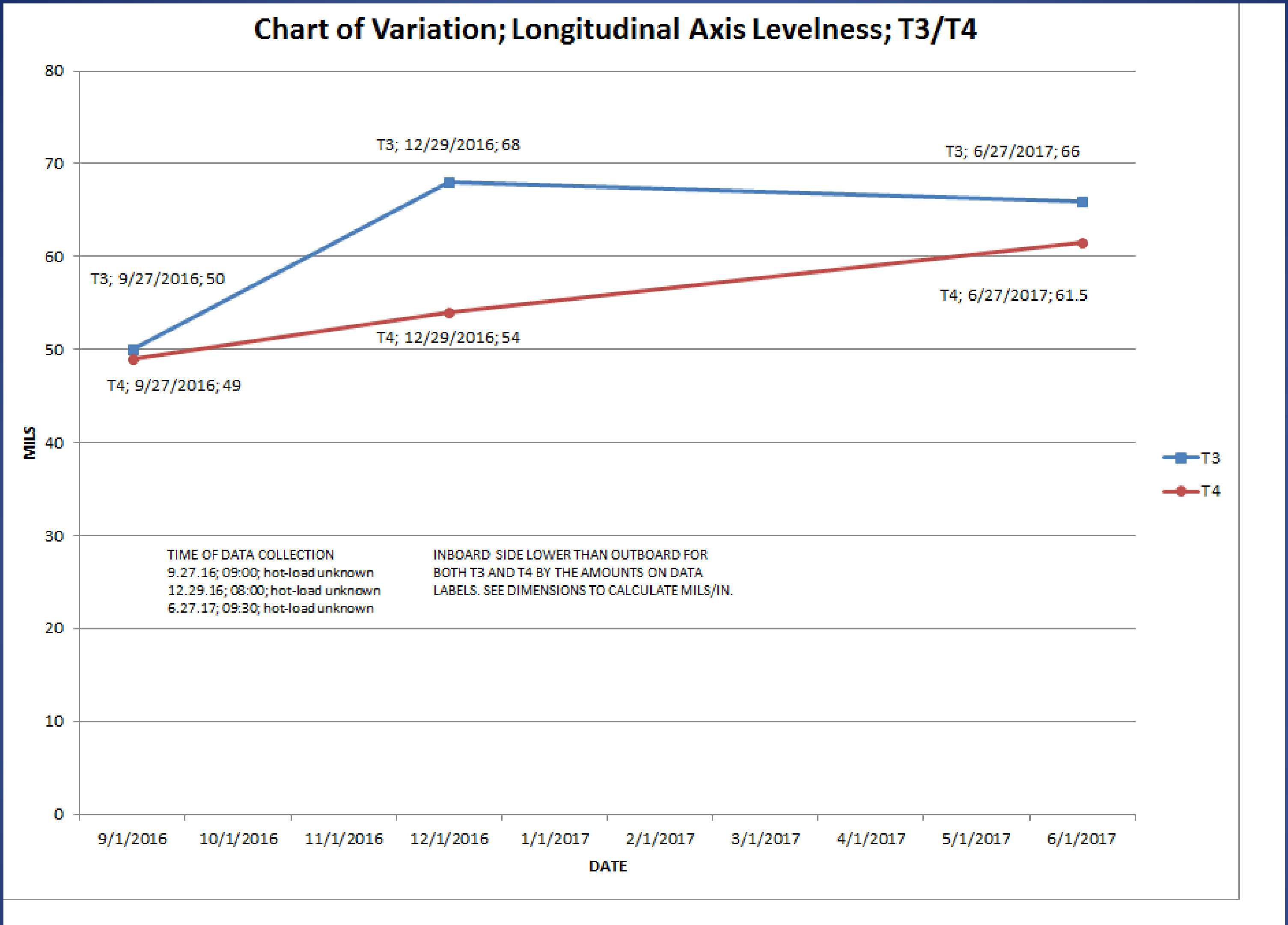
5. Data Expectations

- At basement level; any changes from ground level benchmarks to ground level pylon monuments below 20 thou do not require further investigation in most cases.

- Many factors can be attributed to this besides foundation settling. Concrete turbine pedestals generally move together and the unit above moves with it.

- Factors to consider are whether the unit is an indoor or outdoor unit and the construction geometry with regard to piping and condenser location.

- Trending at basement level over time is important.



Example of a trend chart at turbine deck level. T3 stable but T4 changing. Potential causes - operational variances, grout condition, and plastic or elastic deformation of standards due to load.

If foundation settling is suspected, optical setups offer a method for data transfer to from turbine deck to ground level.

- These setup points are best located at the bearing standards where suspicion of settling is occurring.

- Obstructions to line of sight introduce impediments to accurate transfer of data from turbine deck level to basement level.

- Tooling tape offers a method to quantify this dimension. We have not found a verifiable alternative to optics for transferring turbine deck benchmark data to ground level benchmarks, though there may be one.

Example of optical tooling tape at ground level with calibrated weight. Must be temperature corrected The purpose of this type measurement is to transfer a turbine deck level benchmark to a ground level benchmark. <u>Date, time, and ambient temperature are important</u>. Theoretical accuracy - 2 thou. Practical accuracy , 5 to 8 thou

Example of a protected benchmark installation.

Final Observations:

1. There is a need for standardization of global mounting techniques for benchmarks, horizontal joint monuments, pylon monuments and documentation guidelines.

2. Concrete benchmarks - measurement standard should be to the top of the convex surface, below grade, and protected in high traffic areas.

3. Regardless of technology employed, a field peg test (where applicable) should be required with documentation to check for levelness accuracy over 40 feet prior to measurement. Angular spec to earth: 3 thou or less/40 ft.

In conclusion, I would like to thank EPRI for inviting me to speak and all the people that have assisted me in my work.