API 653 Differential Settlement: Overhaul

New methods of addressing tank differential settlement

PEMyers, PEMY Consulting, LLC.

phil@pemyconsulting.com

Benefits of Modifying Annex B of API 653

Change	How
Incorrect use of R2	Use p-value
Reduce noise and bias	Use Andreani instead of Marr
Prevent non repeatable methodology	Eliminate Andreani alternate graphical method
Handle laser scan data	Trig regression
No gold standard mentioned	Explicitly allow FEA

Rigid Tilt, R^2, p-value

Rigid Tilt plane

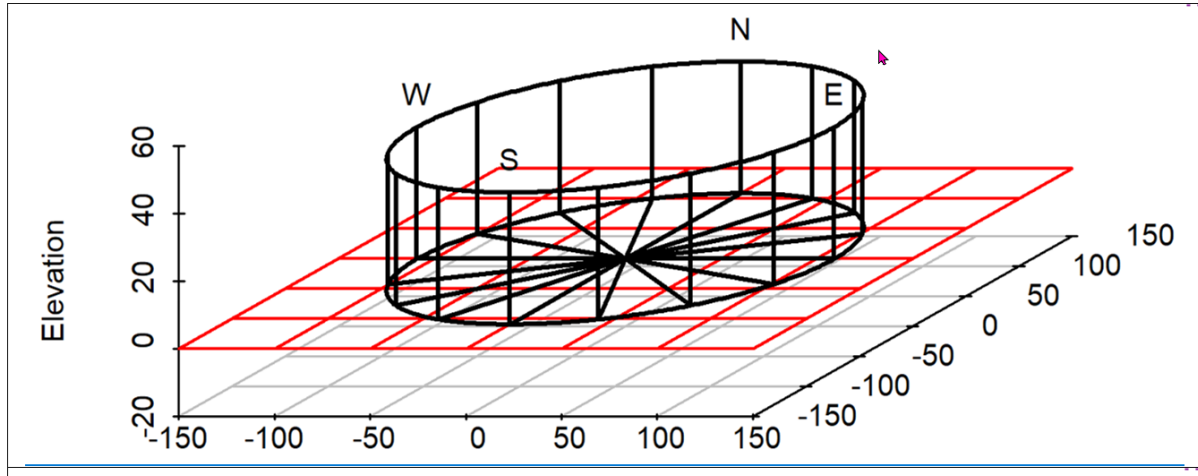
R^2 vs. p-value

R^2 is a measure of how much planar tilt contributes to variance in the data.

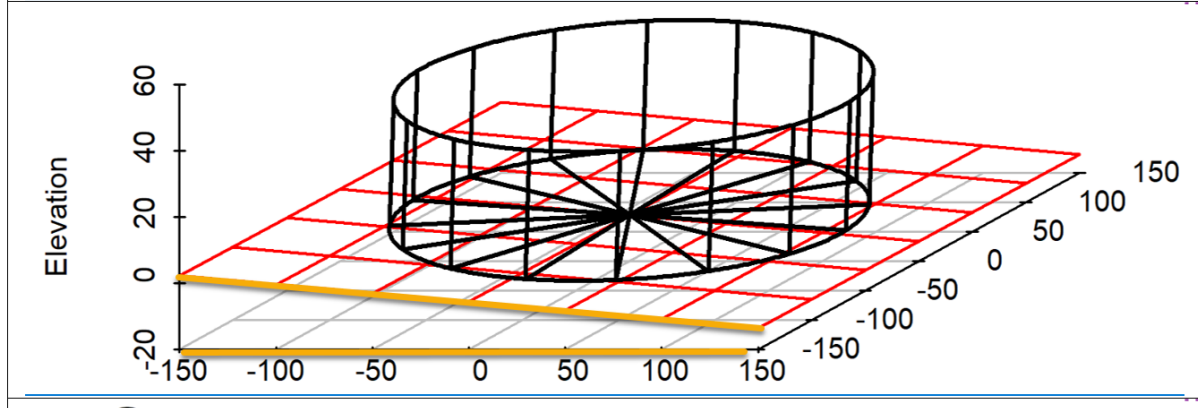
R^2 is low if data is noisy.

Candidate exploratory variables are selected for their ability to *increase* adj- R^2.

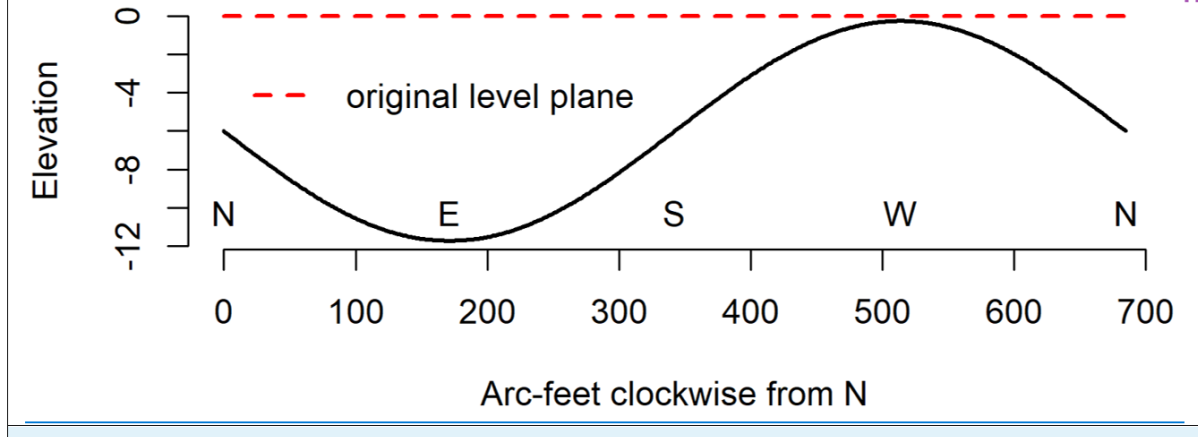
P-value determines existence and validity – NOT the R^2 vale



Tank as originally installed on a level plane. Plan view is a circle.



Tank after rigid settlement onto a tilted plane. Plan view is an ellipse.



Elevation view of bottom edge of tilted tank is a cosine wave

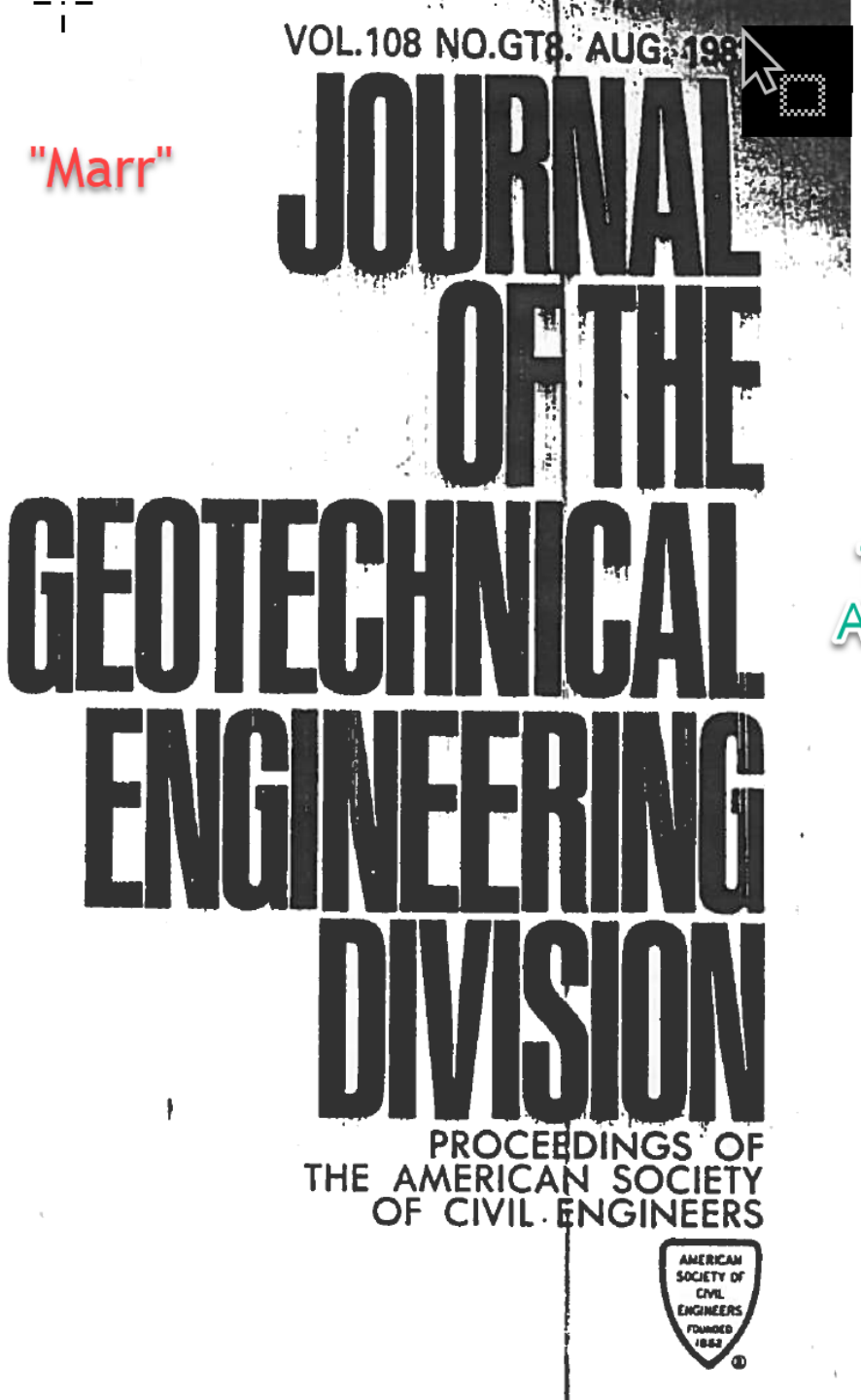
$$Z(\theta) = A \cdot \cos(\theta - \varphi) + \Delta s$$

Proposed API 653 Verbiage

- e) The calculated cosine curve is unnecessary if statistical tests indicate there is no planar tilt occurring. More specifically, there is no strong evidence of a tilt plane if the p-value of the least-squares fit exceeds the appropriate threshold (conventionally, 0.15).

Differential Settlement Analysis Methods

Marr, Andreani, Andreani's Alternative, and Trig-Reg



"Marr"

"Andreani"

Two key inputs to API 653 Differential Settlement

FINAL REPORT ON THE STUDY OF OUT–OF–PLANE TANK SETTLEMENT

API, Washington, D.C.

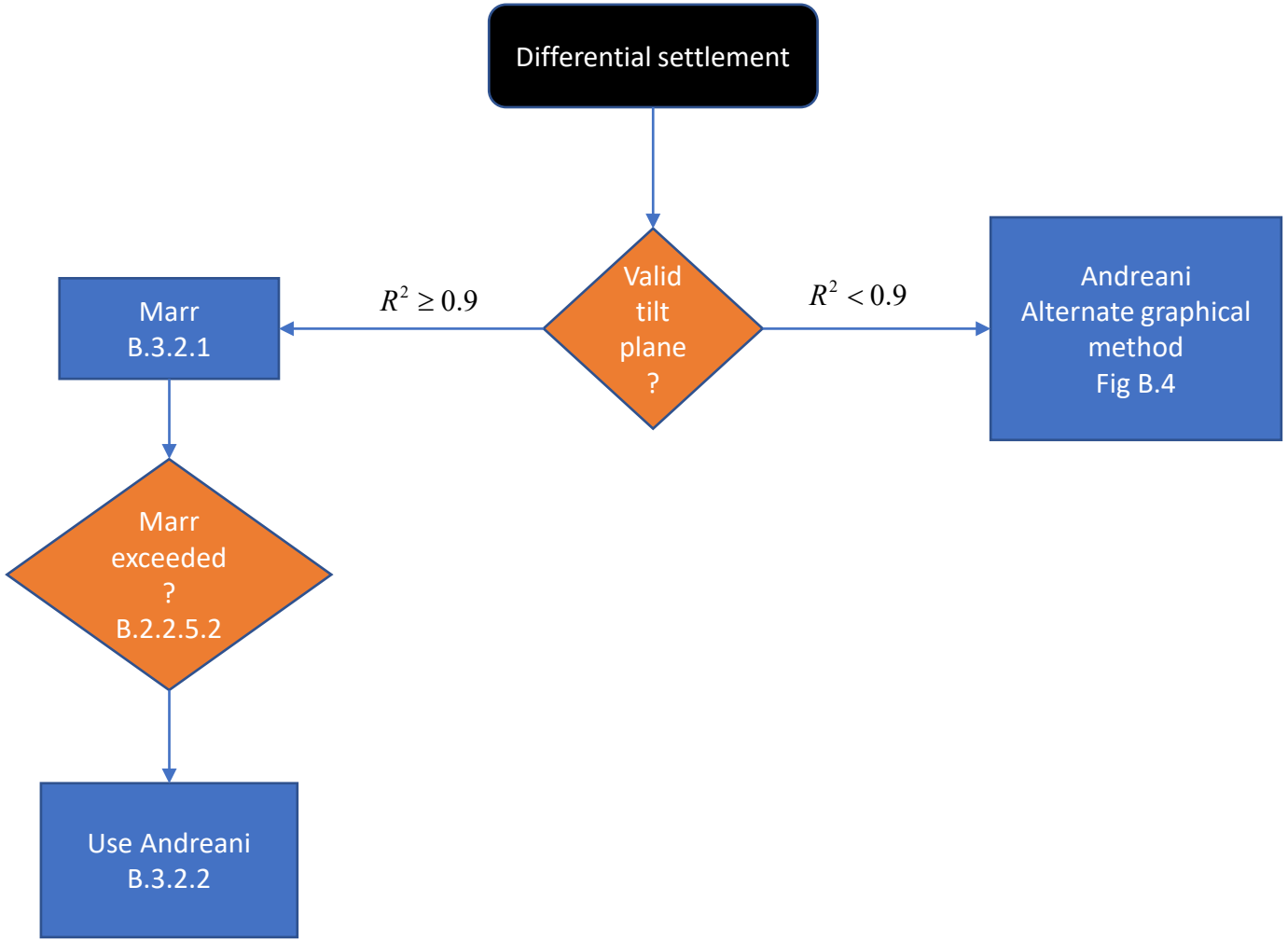
Submitted to:
API SCAST, SCI
May 2007

The Equity Engineering Group, Inc.
Project Number: APIN004–0–04

Project Manager:

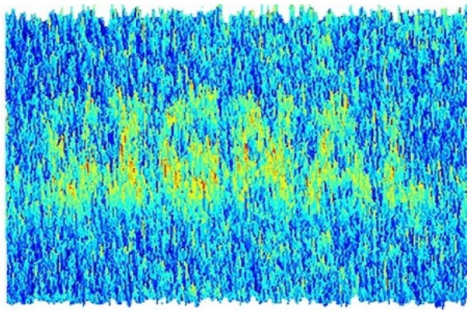
Joel L. Andreani
Principal Engineer

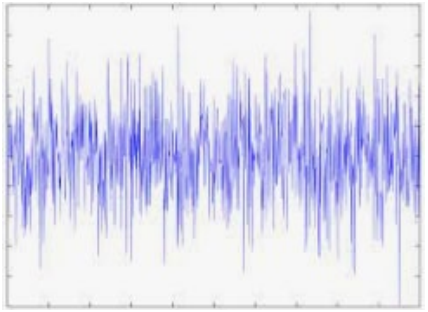
API 653 as is today



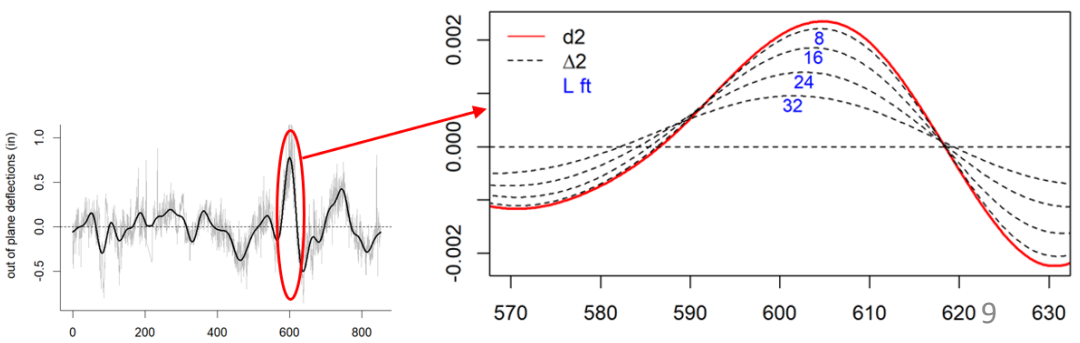
Marr's has 2 saboteurs: bias and noise

- Marr is highly sensitive to the spacing between measurements.
  - Bias is large for L > 20 bias due to using 2nd difference not 2nd derivative
  - Uncertainty is large for L < 20 (noise propagation)
- Noise – measurement error, welds, bumps, etc (things not relevant to settlement evaluation)
- Marr is based on beam theory which is a poor proxy for a cylindrical shell.
- Marr is not experimentally calibrated.





Bias in Marr's methodology



Andreani Pros and Cons

- Andreani, et al. validated their method using *FEA* to compute maximum stress produced by single folds ranging from 20 feet to the full diameter.
- Andreani does not depend on curvature. Andreani is based on finite element analysis of cylindrical shells.
- Andreani is calibrated by the highest 3% strain anywhere in the shell.

- Andreani only validated on 20ft or greater simple folds – it may not work well on twist or multi-modal folds
- Andreani graphical method has a fatal flaw and should not be used:
  - Assumed no reliable tilt plane when $R^2 = 0.617$ is less than 0.90 (wrong)
  - visually identify settlement arcs instead

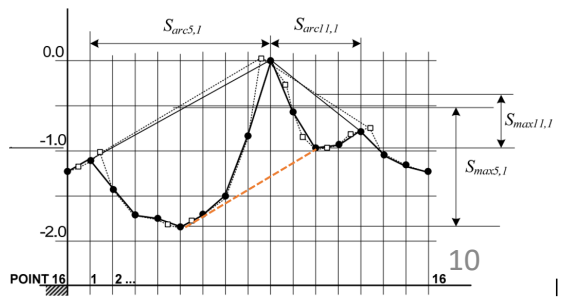


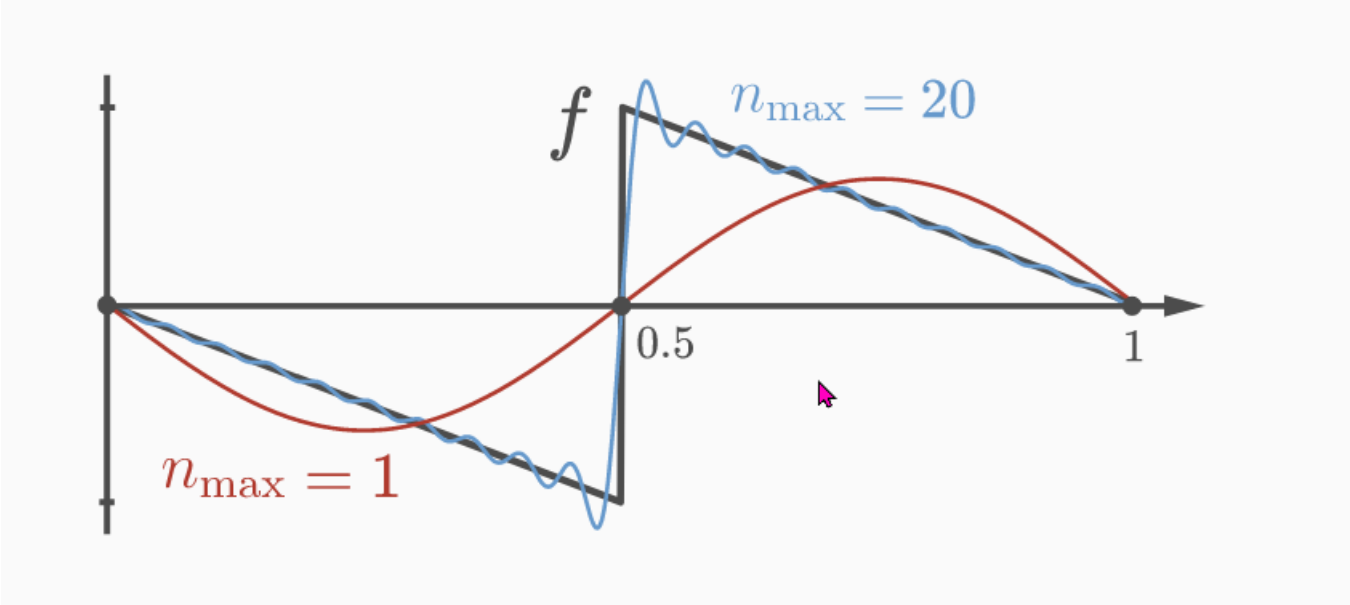
Figure 20. API 653 Figure B.4.

Sparse vs. Dense Data

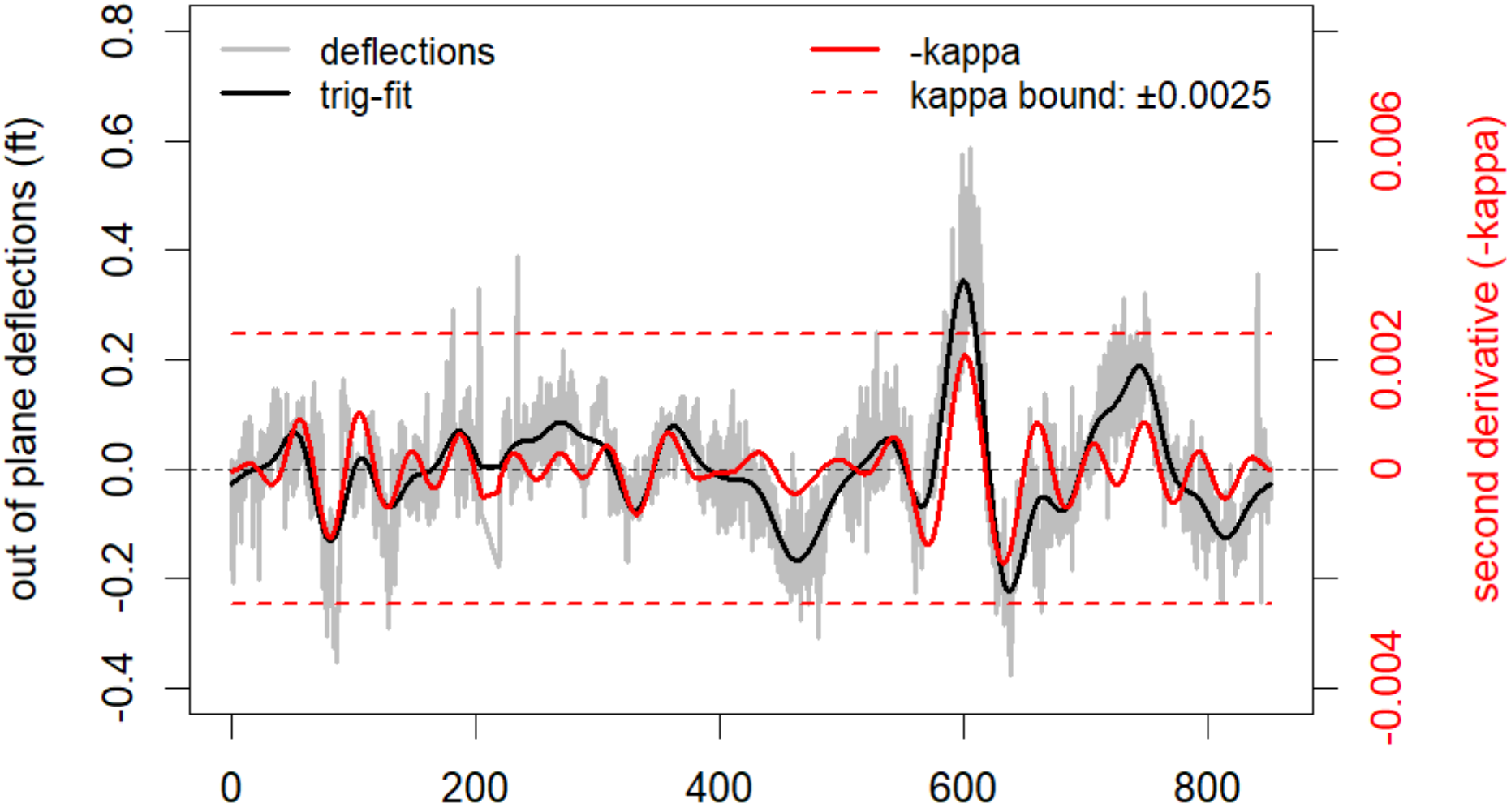
- Pros:
  - Instead of 16 or 32 points, thousands to millions
  - Accuracy far better than conventional
  - Data support for all kinds of fitness for service – buckling, dents, damage
- Cons
  - Large file sizes
  - In some cases proprietary data formats
  - Unequal spacing (more difficult settlement analysis)
  - Requires data manipulation
- Overall
  - Better more accurate settlement analyses *if data is used* (not in Marr method)
  - Can do analyses that were never possible before (e.g. 32 points v 32000 pts for differential settlement)

Beyond API 653, using Trig Regression

- Fourier's Theorem: A periodic function f(x) which is reasonably continuous may be expressed as the sum of a series of sine or cosine terms (called the Fourier series), …



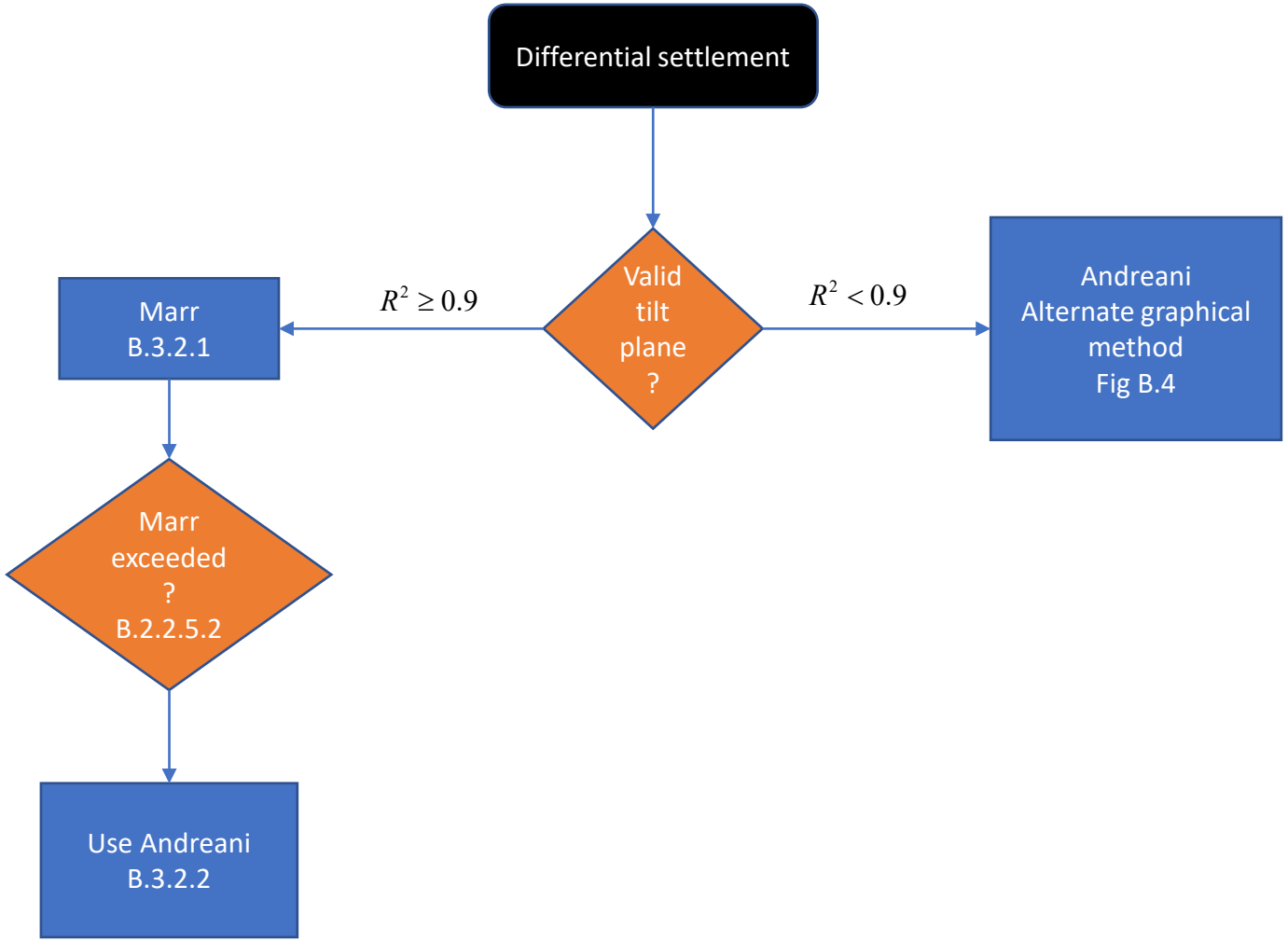
Trig-Reg Example



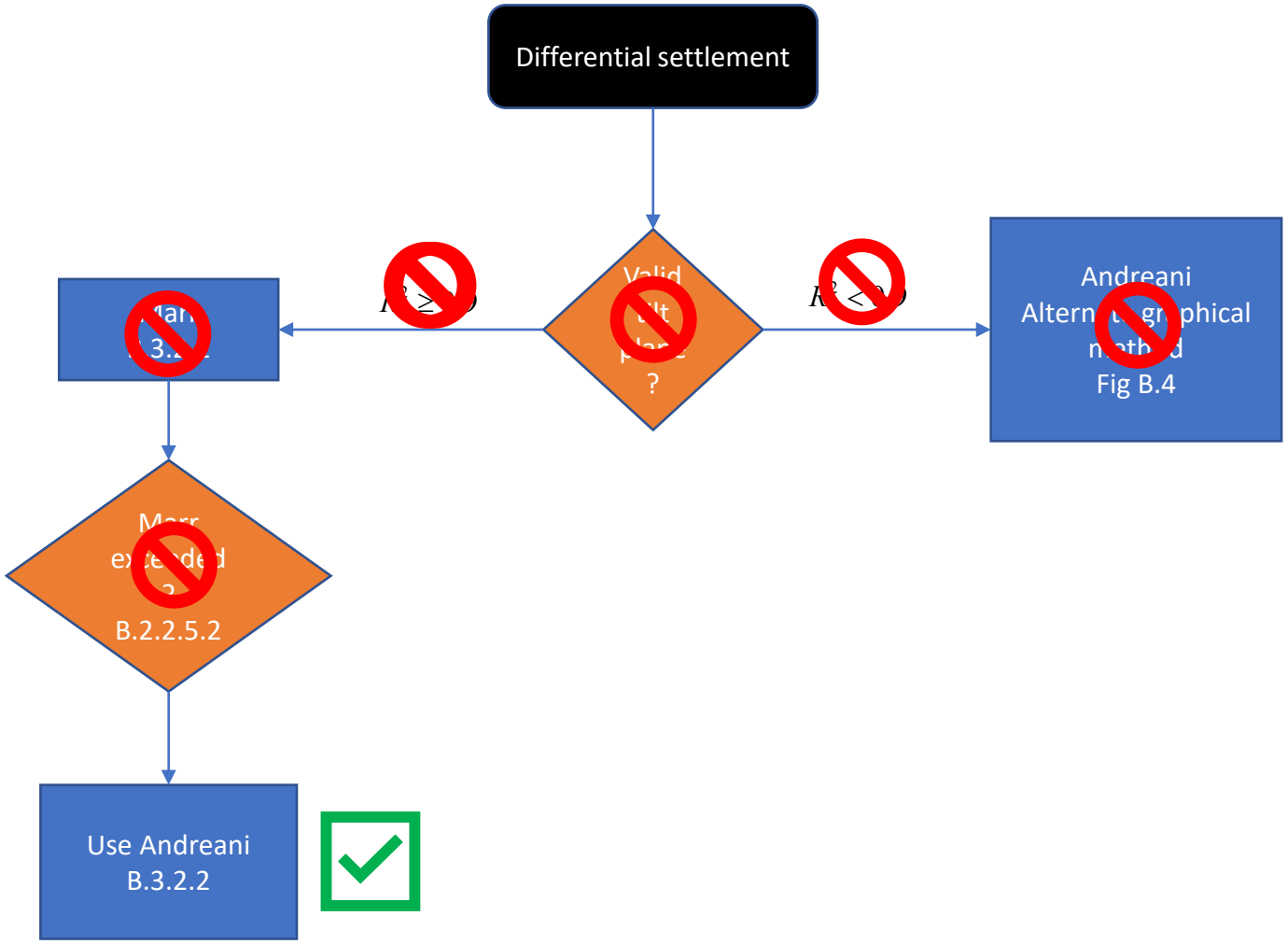
Take Aways

- Marr's method agrees Andreani's method when the distance between stations is 16-20 feet. Outside these limits it has large errors because it is biased and noisy
- Andreani's method does not require specifying distance between measurements, but it is only calibrated for arc lengths greater than 20 ft. It is better calibrated than Marr and adjusts the upper bound on curvature for type of roof and for diameter of tank. It should be the base methodology for sparse data analysis.
- Trig-fit is an estimate of curvature but it is not sensitive to noise and bias. It is more general than the other methods because it accounts for any number of modes that exist (i.e. twist, lawn chair, wavy bottom, etc). It requires dense data and should not be used for sparse data.
- Therefore, we propose …

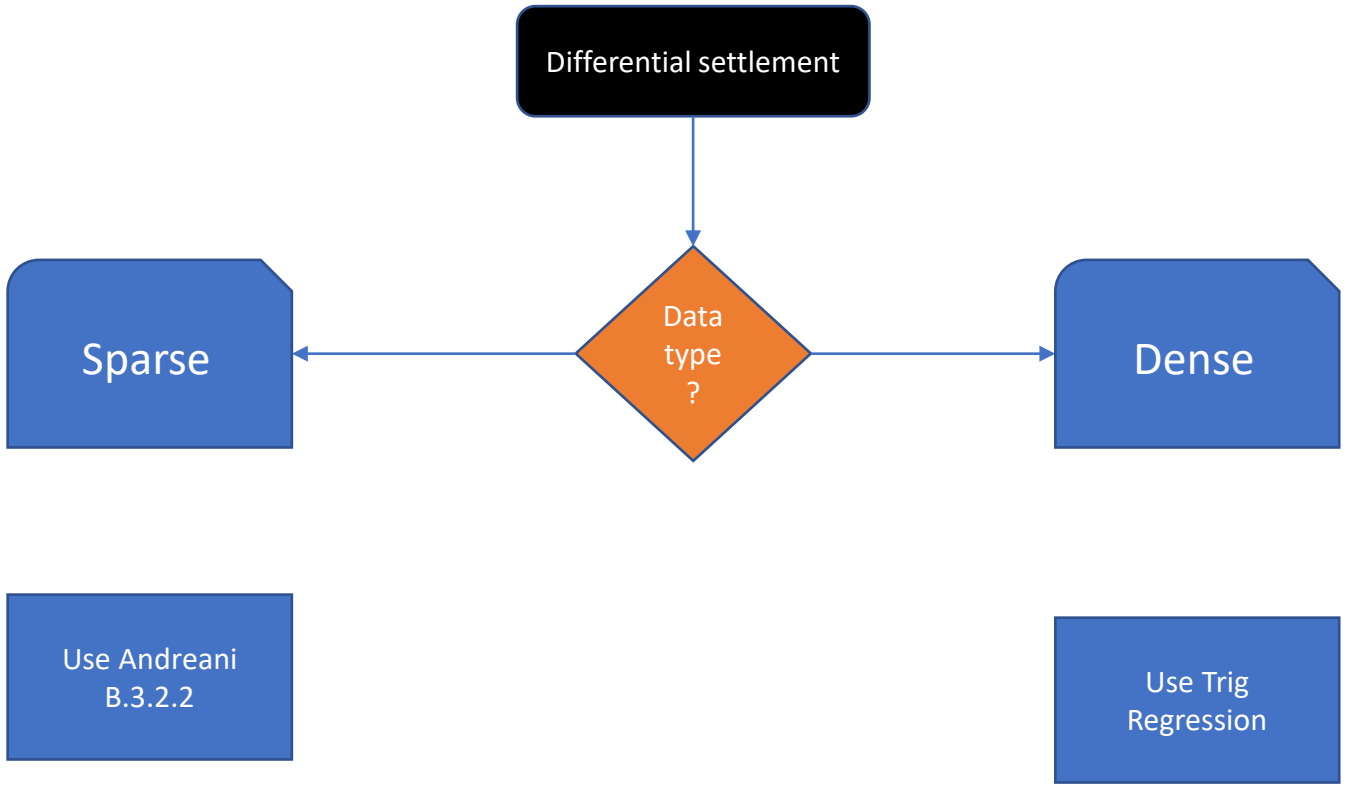
API 653 as is today



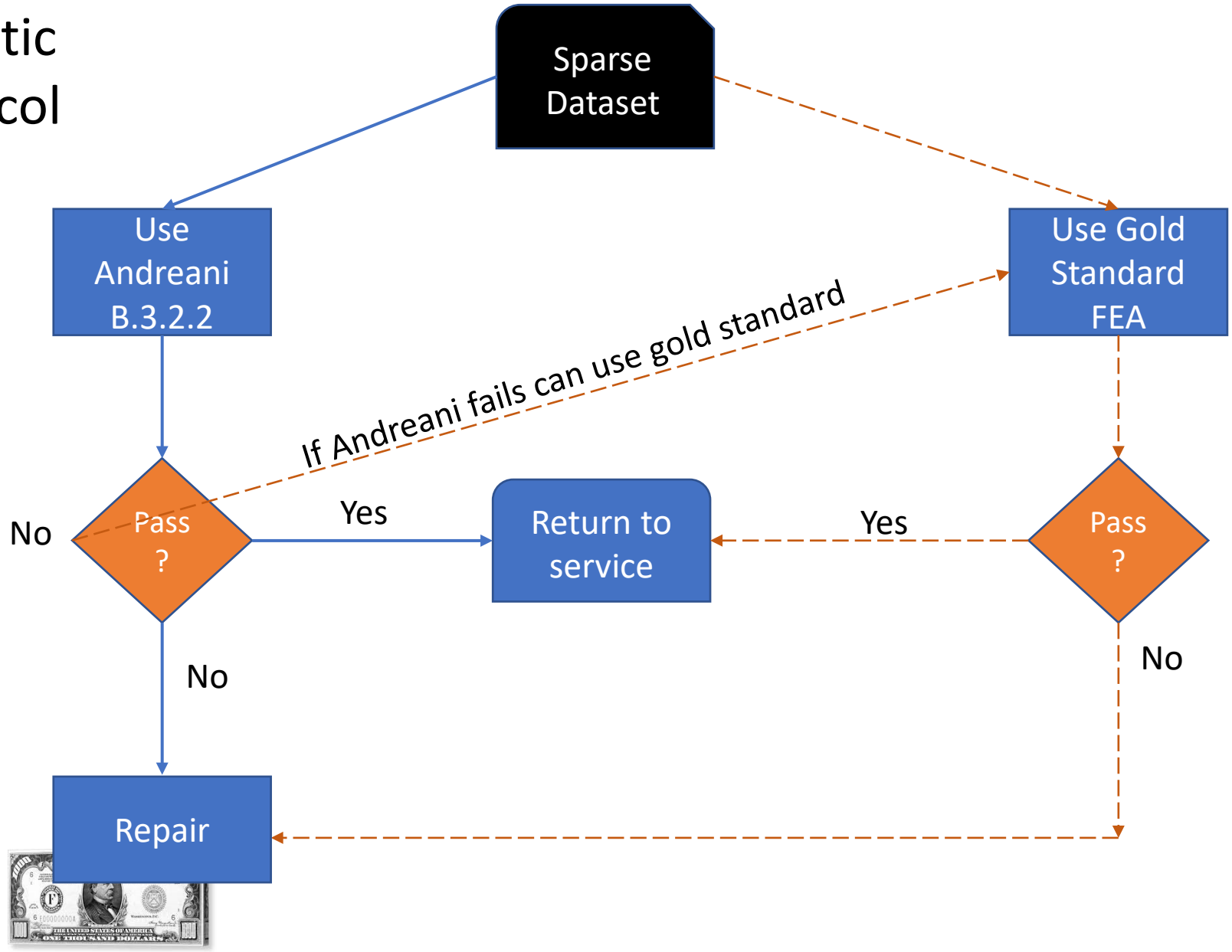
Problems with API 653 as is today

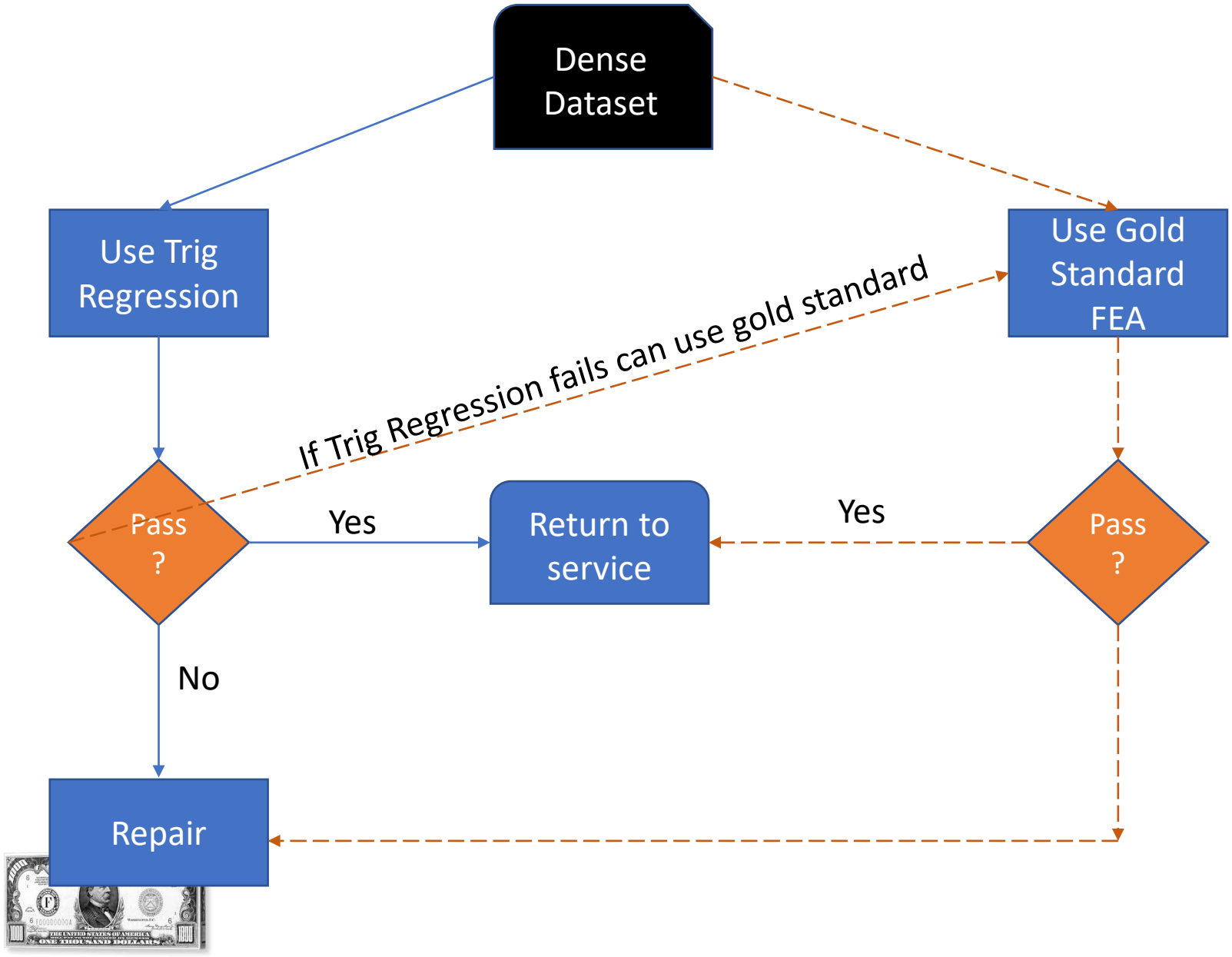


Additional problem - sparse and dense data sets



Realistic Protocol




Dense Dataset
Use Trig Regression
Use Gold Standard FEA
If Trig Regression fails can use gold standard
Pass ?
Yes
Return to service
Yes
Pass ?
No
Repair

Benefits of Modifying Annex B of API 653

Change	How
Incorrect use of R2	Use p-value
Reduce noise and bias	Use Andreani instead of Marr
Prevent non repeatable methodology	Eliminate Andreani alternate graphical method
Handle laser scan data	Trig regression
No gold standard mentioned	Explicitly allow FEA

Model comparison

	Model basis	Calibration	Issues to consider*	comment
Marr	Beam (curvature)	Tanks at one terminal did not fail	Bias at large spacing; noise at small spacing.	Optimal at 16-20 ft spacing and matches Andreani. API 653 limits spacing 8 – 32 ft
Andreani	Strain limit	FEA 3% strain simulated	Calibrated only for simple folds ≥ 20 ft	Calibrated from FEA simulated runs. May not correctly identify curvature from 3 or more modes.
Trig Regression	Beam (curvature)	White paper demonstrated that Marr and Andreani strain limit agree at 20 ft	Should not be used for sparse dataset such as manual surveys	Solves Marr bias and noise problems. White paper shows Marr and Andreani agree at 20 ft arclength. See white paper for computational methodology. Methodology is not proprietary.
FEA	Stress analysis	Widely accepted gold standard	Highest skill level and analysis time required	Methods from API 579 may be directly applied

Marr and Andreani methods were developed for sparse data (up to 64 points). More recent methods (i.e. laser scan data) best suited for methods Trig Regression and FEA. See PEMY white paper.