Status of Structural Analysis and Testing
WBS 1.8.1/1.8.2

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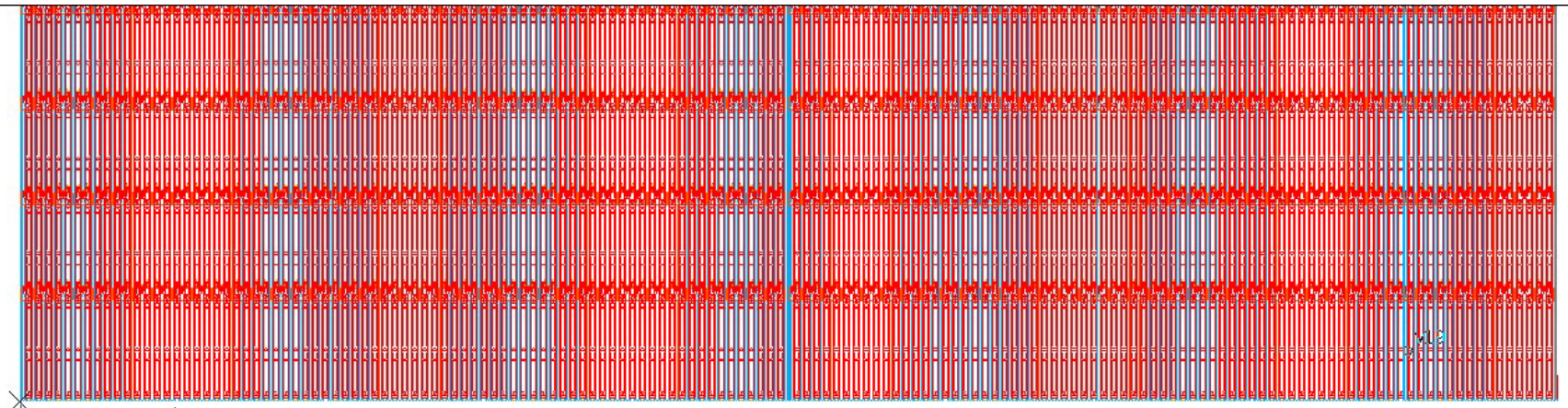
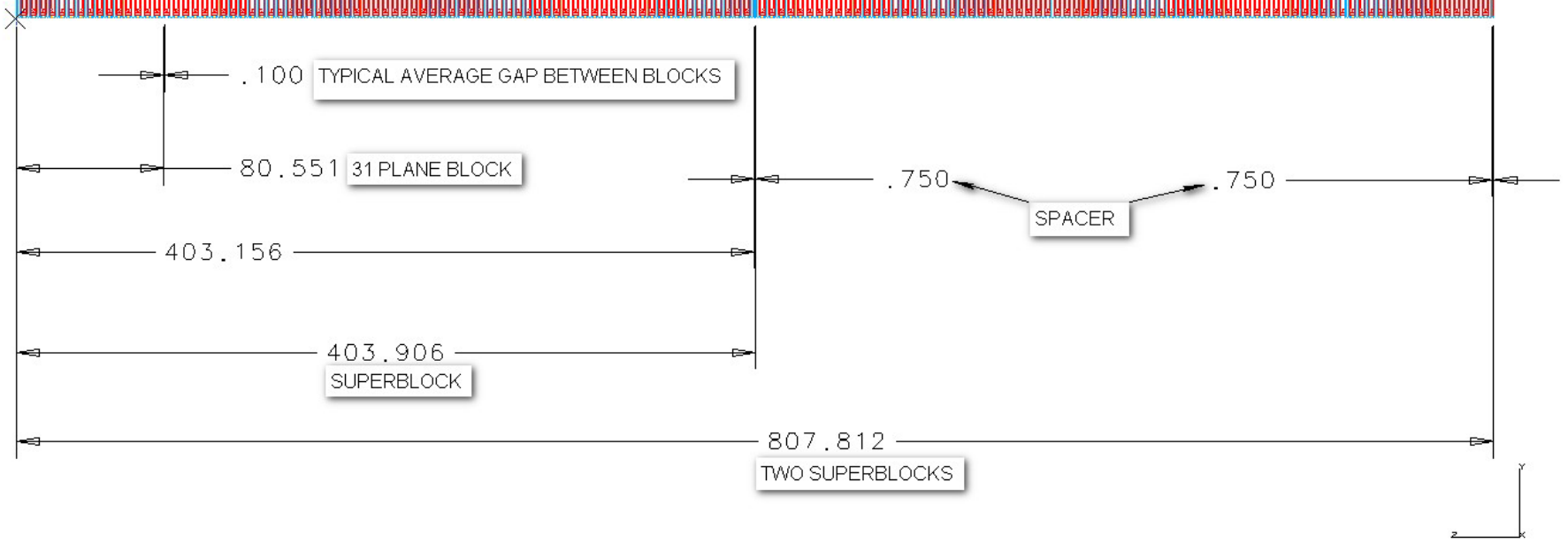
FNAL Director's Review

Detector Assembly

- The detector is constructed from 31 plane blocks – “A” and “B” blocks
- “A” blocks have vertical modules on the outside surfaces --- “B” blocks have horizontal modules on the outside surface.
- Five blocks are assembled into close contact to form a “Super-Block” – a gap of 0.75” between Super-Blocks.

Detector Assembly





Detector Assembly

- *Why "A" and "B" blocks and "Super-Blocks"????*
- For structural reasons blocks should be symmetric. A and B blocks together provide alternating Vertical and Horizontal planes.
- Blocks swell under pressure and swelling is transferred between blocks and gets progressively larger leading to increased PVC/adhesive stresses. Super-block separation prevents the continued buildup of swelling.

Overview of Structural Analysis and Testing

- The goal of the structural analysis and testing is to design a structure that:
  - Can be built in modularized blocks.
  - That each block can be handled by a pivoter.
  - That each block can be filled while installation is still in progress.
  - The completed detector will remain structurally stable for at least 20 years with an adequate safety factor.

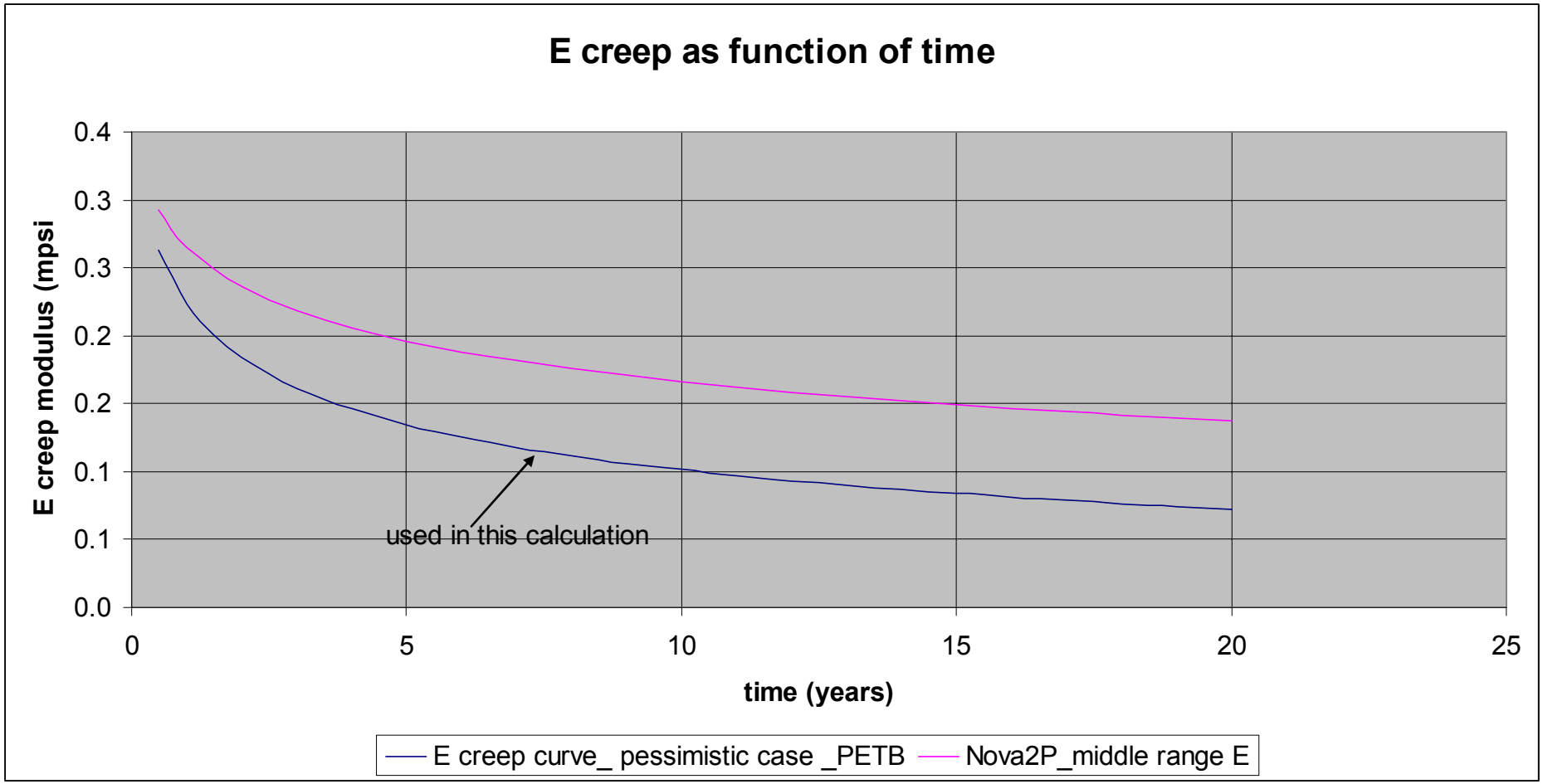
Overview of Structural Analysis

- Extensive analysis has been done on:
  - Individual extrusions
  - Assembled blocks
  - Stability of blocks
  - Completed Detector
  - Mechanical prototyping
- This talk will summarize all of the analysis and where we are at and describe testing to confirm analysis.

Assumptions of Analysis

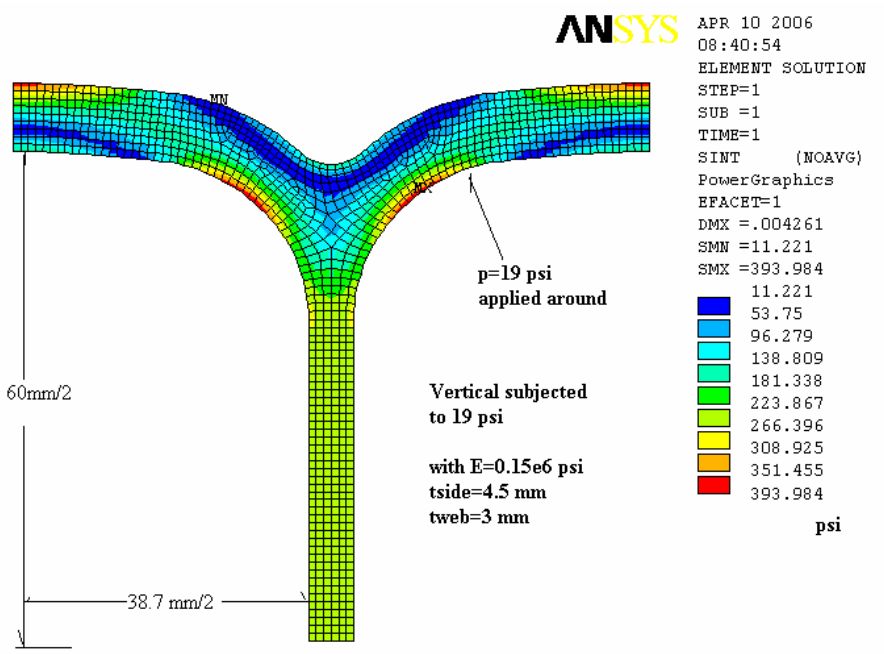
- 20 year life of the detector.
- Construction ends at 4 years.
- PVC stress has to be less than 600psi to remain in the viscoelastic region.
- Creep!! Final PVC mixture has been chosen and testing creep evaluation has begun. Analysis though has been using the pessimistic creep curve based on PET B.
- Current Analysis has been based on 31 plane blocks with verticals on the outside of the blocks

Creep Curves



Analysis Performed -- Extrusions

- Analysis started by looking at individual extrusions under 19psi.
- Stress analysis and input from extruder resulted in our current geometry.
- See DocDb #79, 379

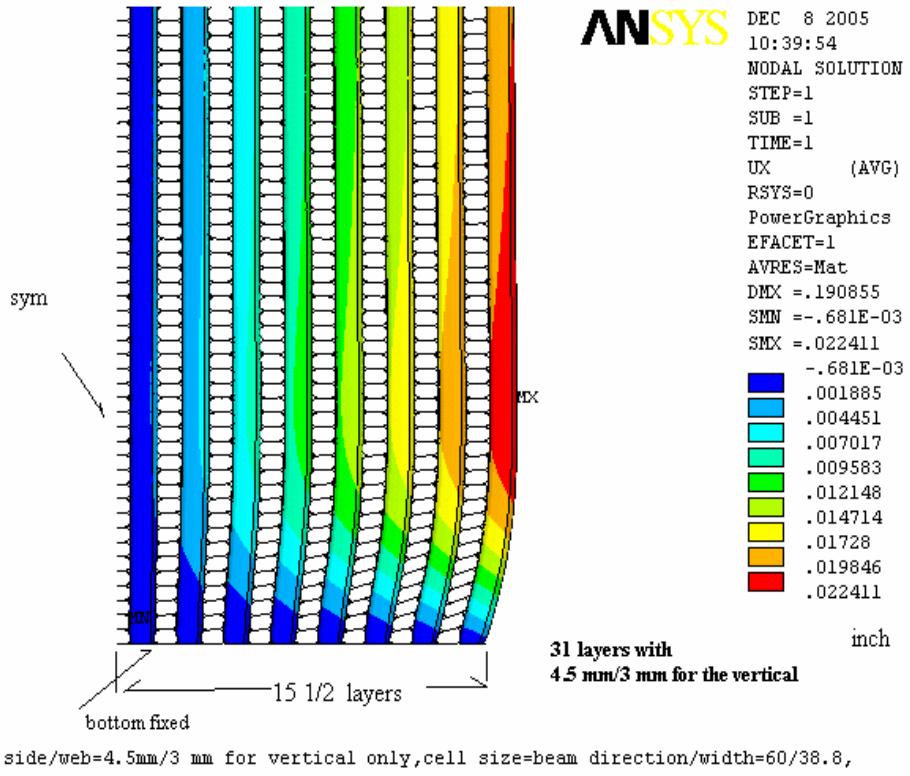


Analysis Performed -- 31 Plane Blocks

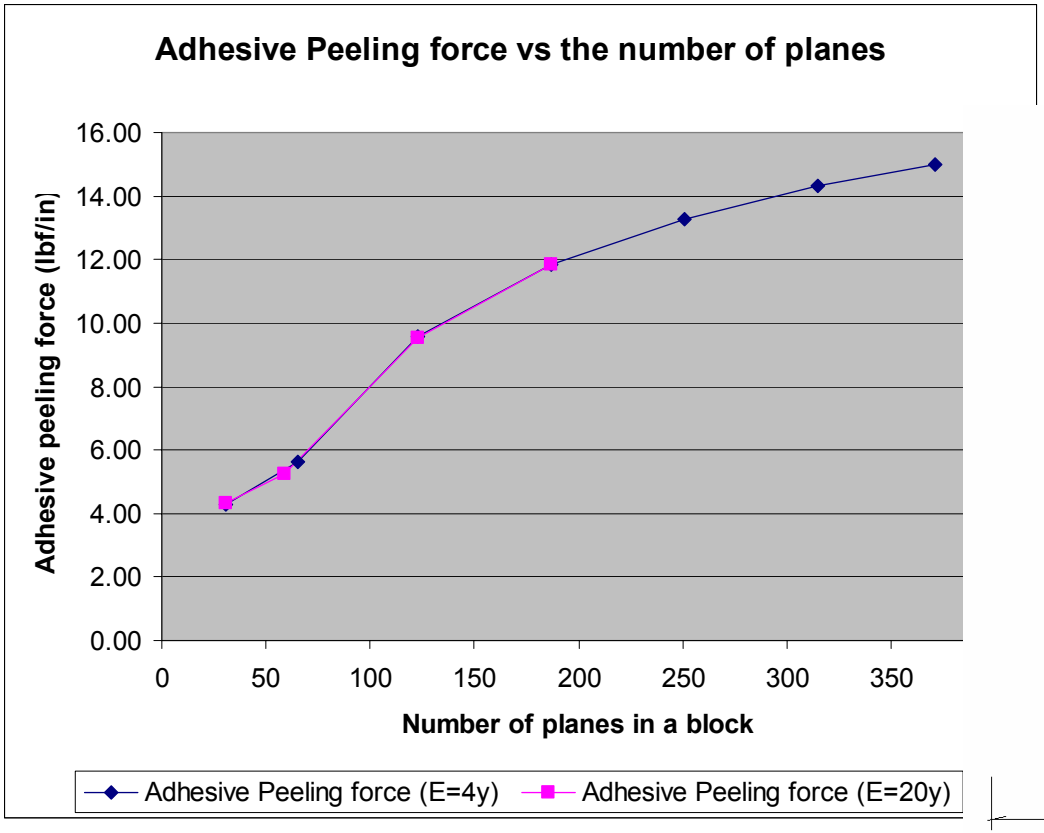
- Extensive analysis of blocks have been done. See DocDb# 278, 628, 269, 804, 826, 871, 880, 957,114,1151,1297,1298
- Analysis has focused on:
  - Swelling of blocks at 20 years and the resulting stresses in PVC and Adhesive.
  - The maximum number of planes that can be in a block.
  - Stability of filled and unfilled blocks at 4 years
  - Long term stability of blocks

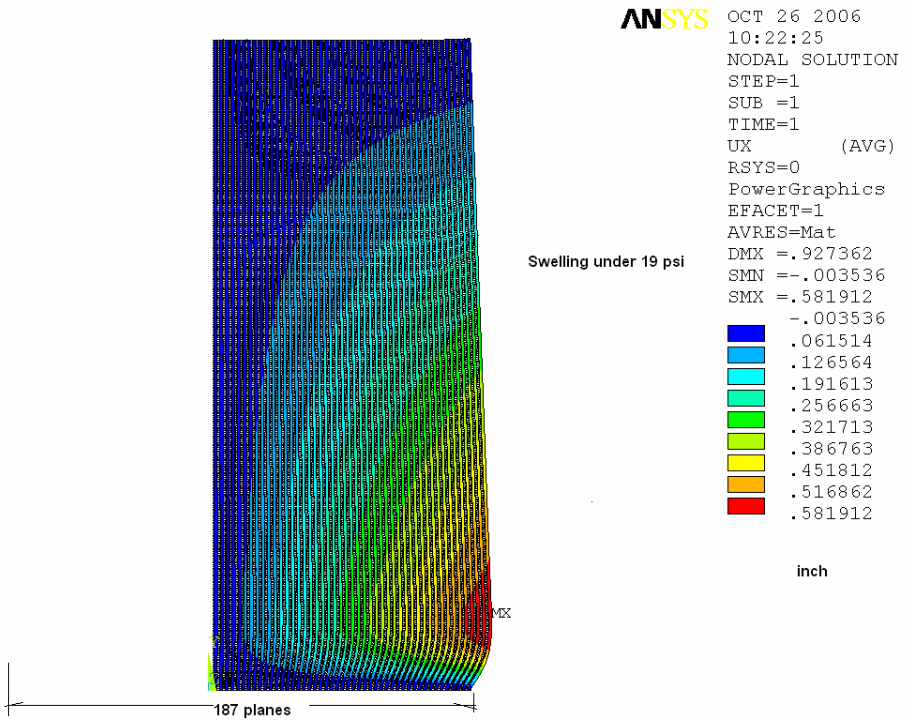
Analysis Performed
31 Plane Blocks - Swelling

- Internal pressure and assumption of no movement at floor results in swelling or "pregnant" shape.
- As the number of Planes increases the swelling increases which increases the PVC/Adhesive stresses.
- 31 Plane blocks were chosen to minimize adhesive stresses and was the maximum size that still gave an adequate SF in Buckling.



Analysis Performed
31 Plane Blocks – Maximum # of Planes



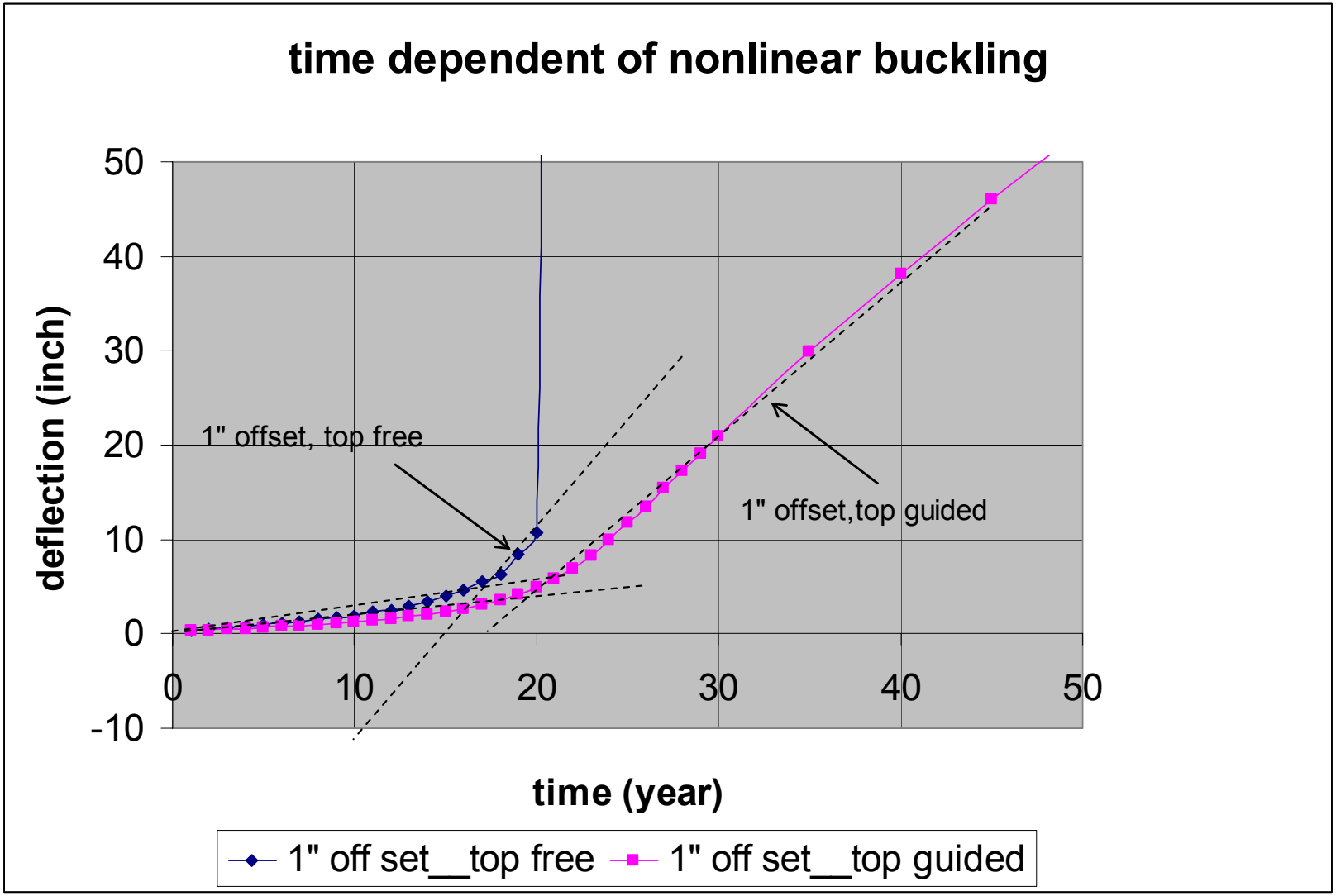


The maximum number of Planes is limited by the adhesive peel and shear stresses and PVC stresses – In order to maintain an adequate safety factor the maximum # of planes in contact should be kept below 160

Analysis Performed
31 Plane Blocks – Stability

- The stability of a filled block at 20 years was examined using 3 analyses:
  - Euler buckling (classical buckling theory)
  - Static non-linear analysis (Modulus at 20 years used and loading increased in increments)
  - Time dependent non-linear analysis (Modulus incremented over time)
- All three methodologies gave the same answer that the structure becomes unstable at 20 years using the pessimistic creep curve.

Analysis Performed
31 Plane Blocks – Stability

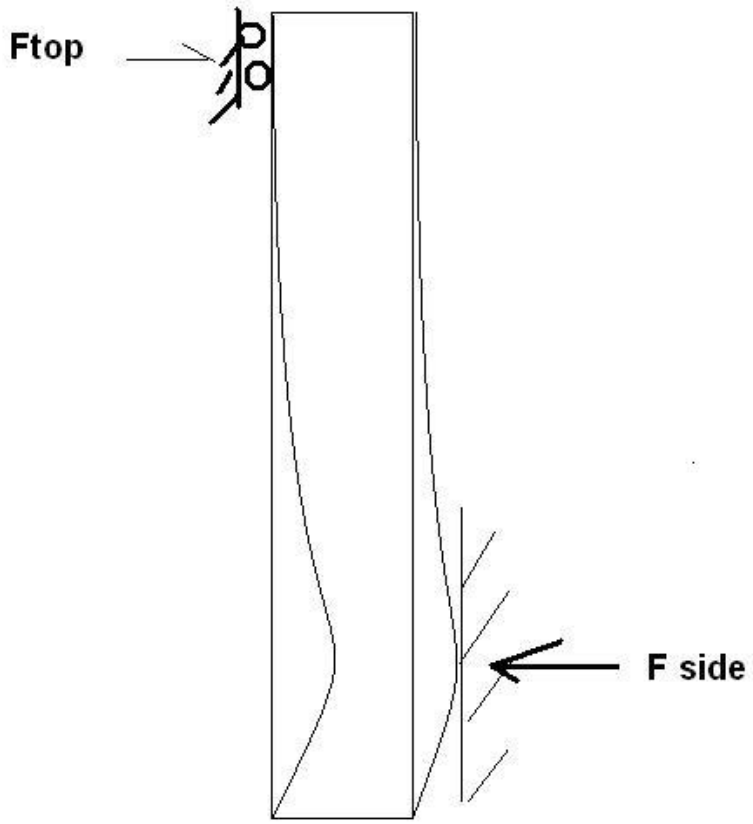


Stability of Assembled Detector

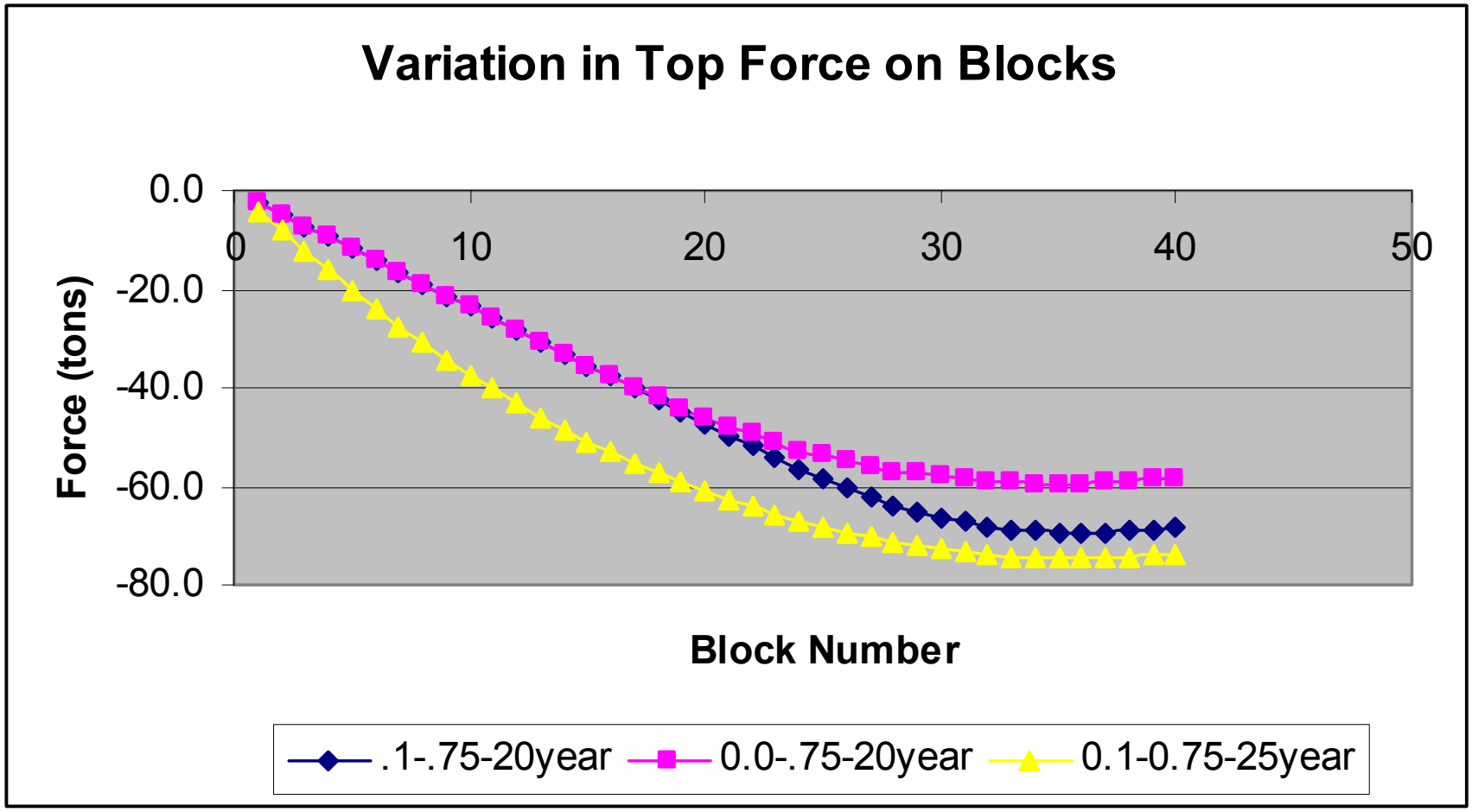
- Instability of individual blocks can be handled within the assembled detector which will be sandwiched between two bookends.
- It is important to minimize gaps between blocks in order to minimize the long term space that is available for the blocks to deform into.
- But…..Gaps are needed between blocks to prevent progressive swelling.
- The current plan is that the Detector will be assembled into super-blocks which are 5 blocks with zero gap between them. There will be a 0.75” gap between superblocks.
- In the worst case all of the blocks deform in the same direction. The last block and bookend must resist the cumulative leaning force of all the blocks.

Stability of Assembled Detector

- Two forces act on each block:
  - Restraint at top.
  - Force of Contact on the side.
- Blocks are always in contact at the top.
- As blocks deform they begin to make contact on the side.
- Examined the forces with various gaps between blocks and superblocks.

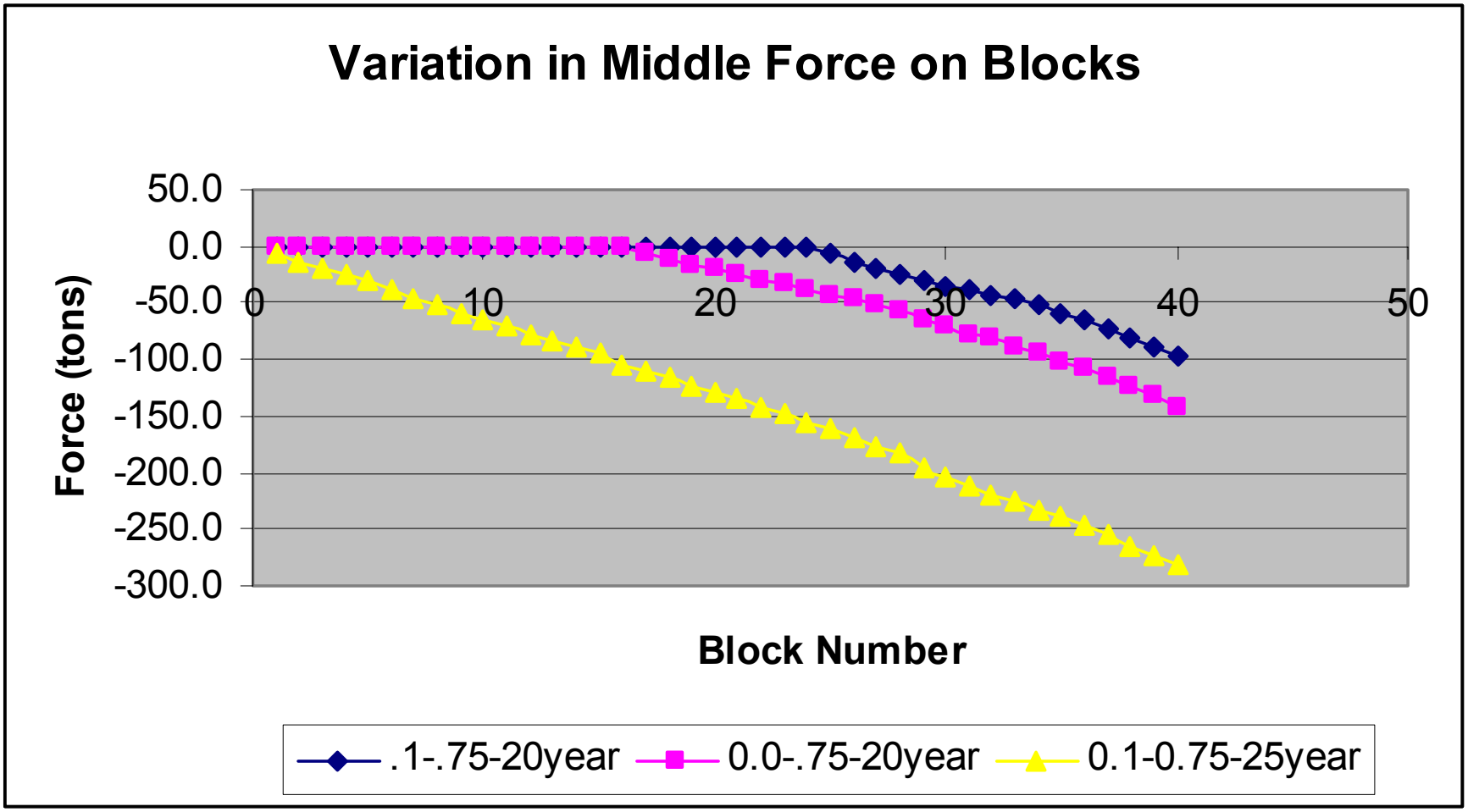


Stability of Assembled Detector



.1-.75-20year means 0.1" gap between blocks within super block. 0.75" gap between superblocks and using 20yr. Modulus.

Stability of Assembled Detector

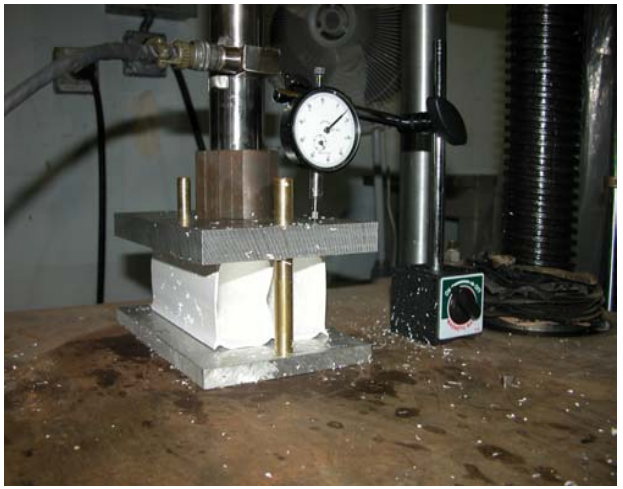


.1-.75-20year means 0.1" gap between blocks within super block. 0.75" gap between superblocks and using 20yr. Modulus.

Structural Analysis -- Conclusions

- Blocks stability when restrained at the top.
  - Safety factor of empty block is ~10 at 4 years
  - Safety factor of filled single block ~2.7 at 4 years
  - Safety factor of filled single block at 20 years ~1.1 (see next bullet point before panicking)
- Long term stability is achieved by restraining detector between bookends.
- PVC stresses are within acceptable levels. (less than 600psi)
- Adhesive shear and peel stresses provide a safety factor of 5.
- **All analysis has used WORST CASE CREEP CURVES**
- *Extensive Testing is planned to confirm analysis*

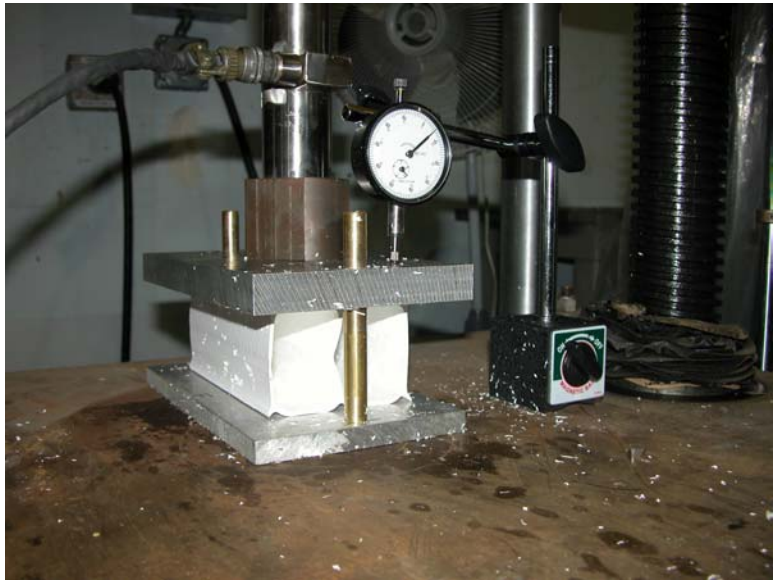
Testing

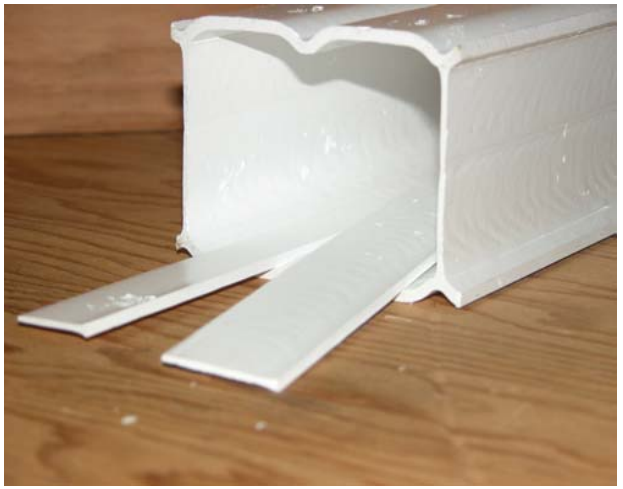


Testing

- Many tests have been performed and are planned on being performed to validate the structural calculations
- Performed Tests:
  - Single Extrusion under pressure (docdb1120)
    - Strain/stress and deflection measurements match analysis
  - 3 Plane Extrusions under pressure (docdb1194,1217)
    - Strain/stress and swelling conform to analysis
  - 11 Plane extrusion test
    - Swelling and deflections conform to analysis
  - Adhesive shear and peel tests (docdb 864,1347)
    - Adhesive strength provides a safety factor of 5
  - IPND mechanical prototype (docdb1369)
    - First attempt to assemble large extrusions and evaluate assembly methods
  - Extrusion buckling tests
    - Evaluation of strength of webs to withstand forces between blocks.
    - Evaluation of adhesive bonds
- Planned Tests:
  - IPND prototype under pressure and applied weight.
  - Extrusion/adhesive bond tests
  - Full size assembly prototype
  - Full height prototype
  - Adhesive aging

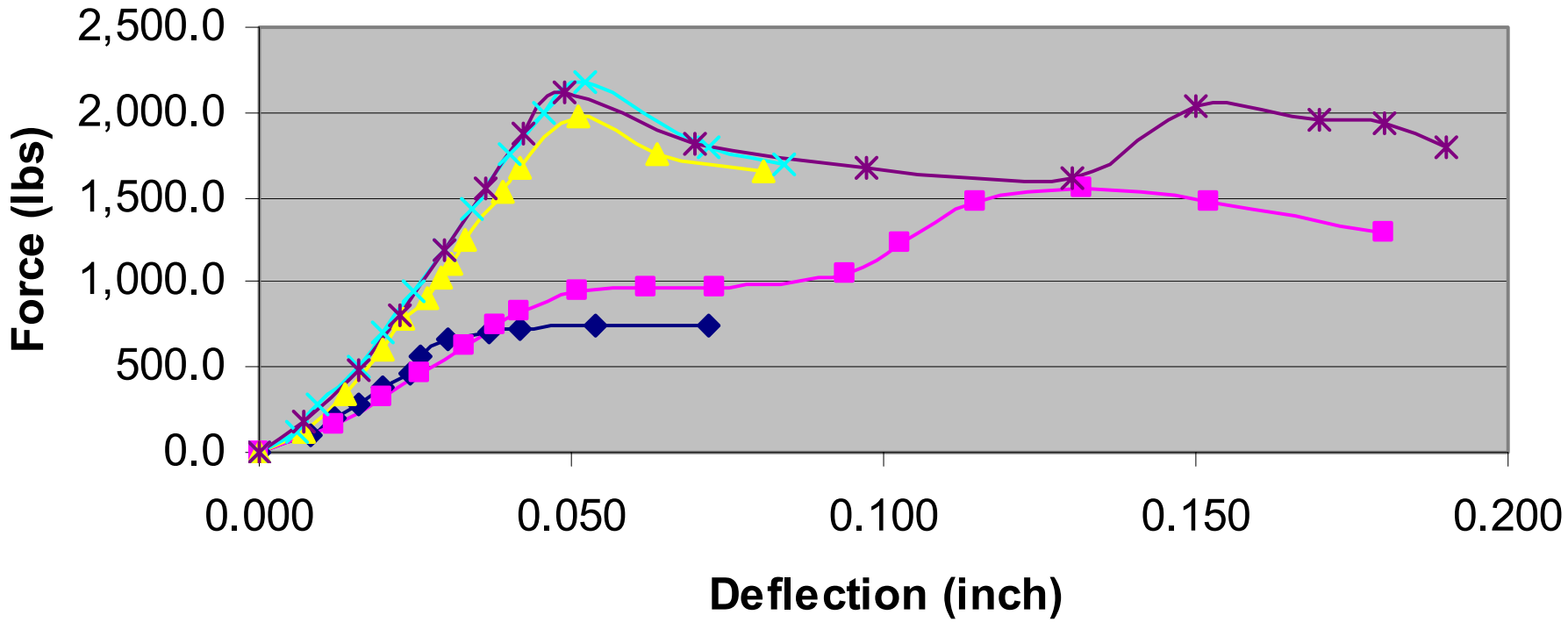
Testing
Web Buckling Test





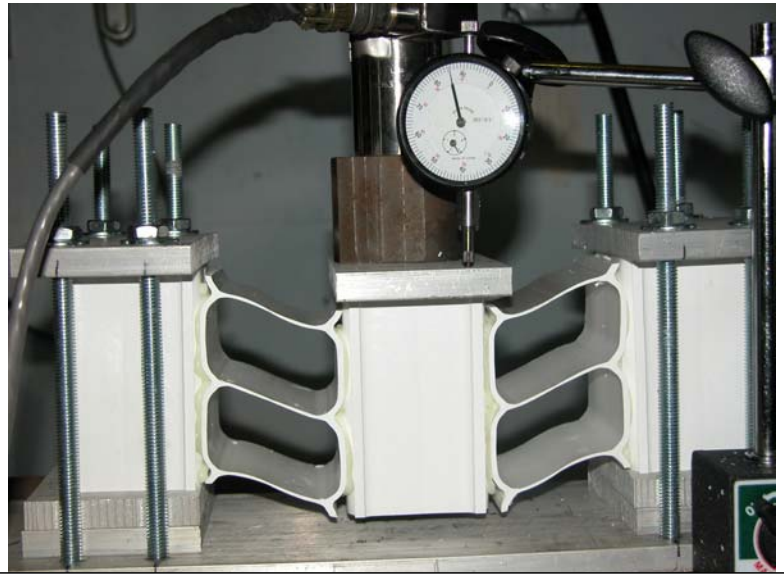
- At 20 years blocks will buckle and make contact with each other.
- Buckling strength is needed to resist contact between blocks for long term stability.
- Analysis shows that 5-6psi will be applied to extrusions at 20 years.
- Tests with 2.3mm thick webs show a buckling strength of 95psi. Scaling the modulus for creep (reduction by a factor of 5 over 20 years) shows a strength of 19psi.
- Need to perform a large number of tests because of the many variables involved.

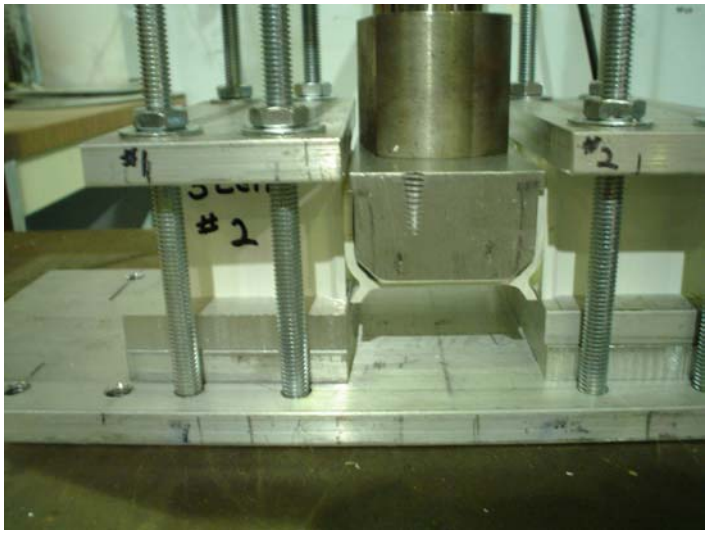
Testing
Web Buckling Test

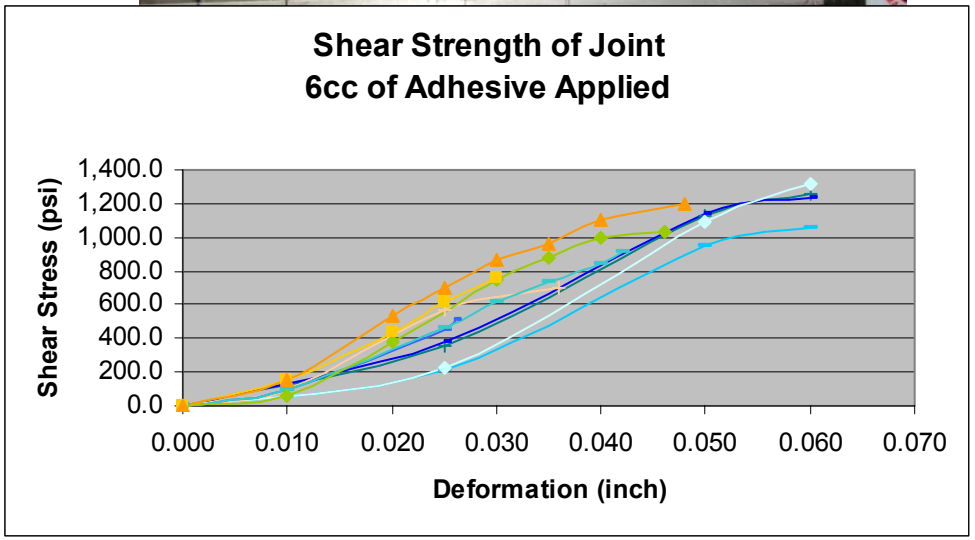


Testing
Shear/Peel of Extrusion Joints

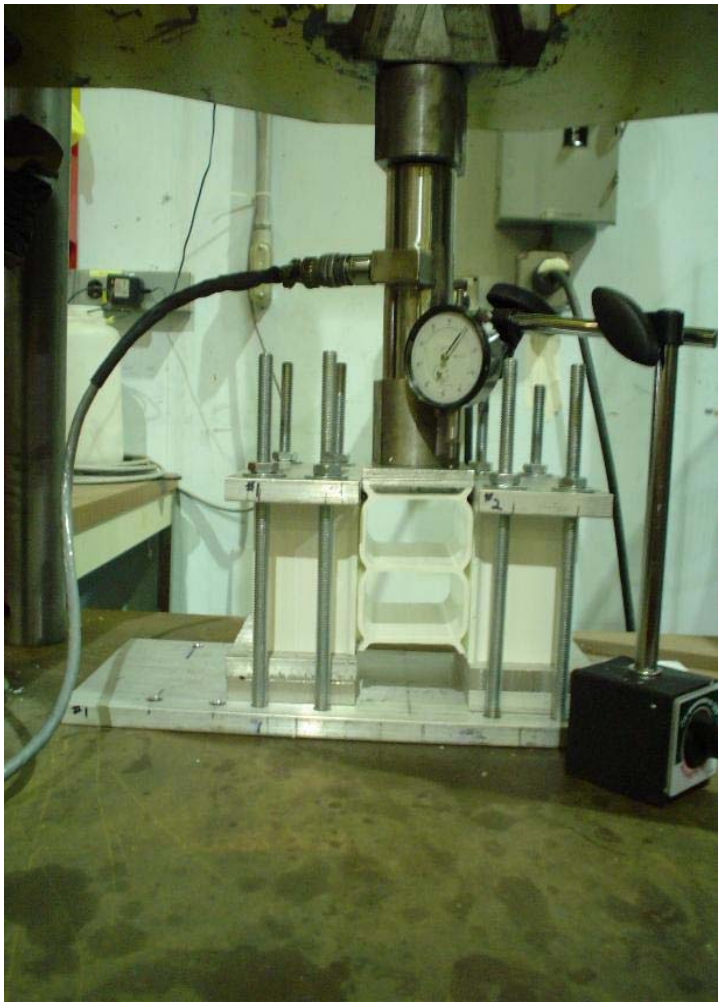
- Tests are being conducted of actual joints between extrusions.







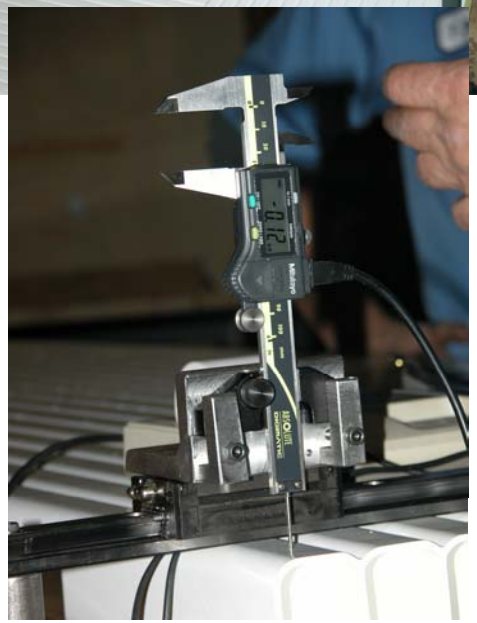
Testing
Shear/Peel of Extrusion Joints



Testing
IPND Mechanical Prototypes

- **Two Prototypes have been constructed – a 4 plane and 8 plane prototype**
- 6 extrusions for horizontal layer and 4 extrusions for vertical layer
- Purpose:
  - Gain a feel for assembling large extrusions
  - Understand forces needed to move glued modules.
  - Understand forces needed to take out banana.
  - Take ES&H measurements during gluing of large area.
  - Understand what is needed for compression of modules.
  - Record Extrusion Thicknesses

Testing
IPND Mechanical Prototype

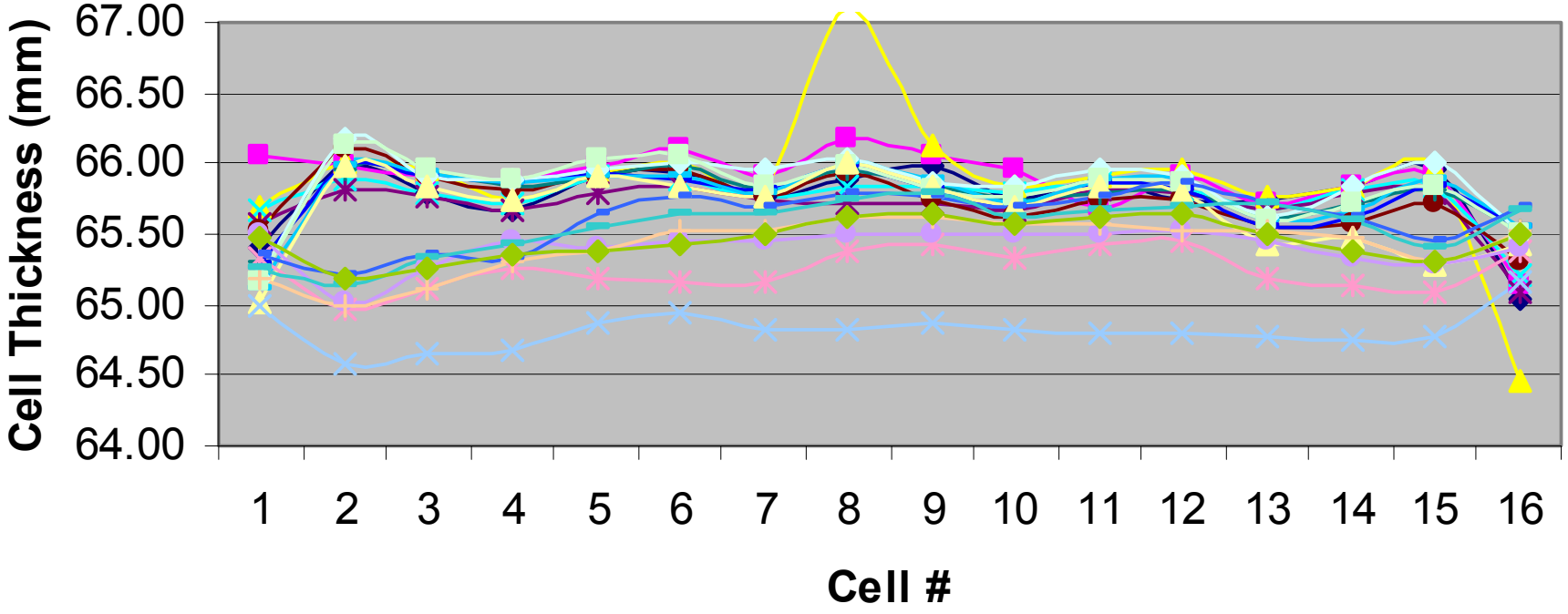


Testing
IPND Mechanical Prototype

Rotated assembly to 45 degrees – maximum deflection is ~1mm. Assembly is now simply supported and deflection over time will be measured.

Testing

IPND Mechanical Prototype – Extrusion Thickness



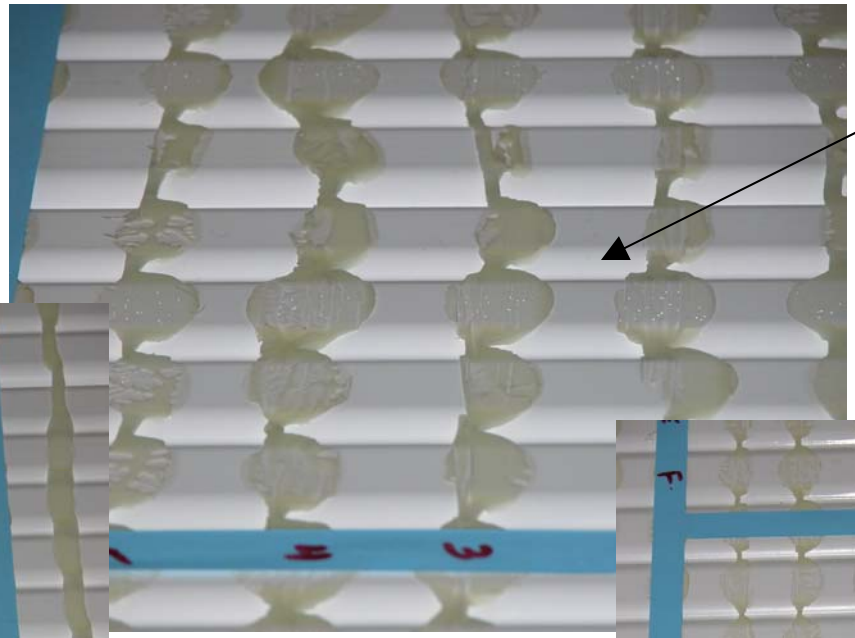
Testing

IPND Mechanical Prototype - Glue Pattern

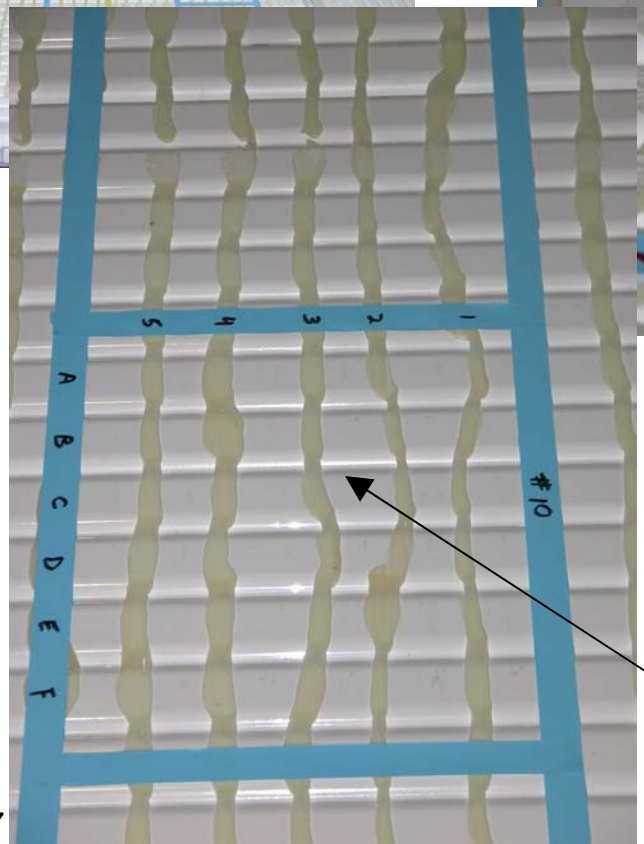
- Two of the top layer vertical extrusions were shrink wrapped so that they could be removed later to observe the glue line pattern. One extrusion was rolled with weight, the second had no compression.
- With no compression the glue thickness was an average of 0.6mm and did not spread out over any area.
- Better glue pattern with compression. Average thickness was 0.33mm which is consistent with glass bead diameter.
- Standard deviation of glue line thickness was 0.11mm which is consistent with variation in extrusion thickness.
- Cells 1 and 16 are the thinnest (on average) and showed the least compression

Testing

IPND Mechanical Prototype - Glue Pattern

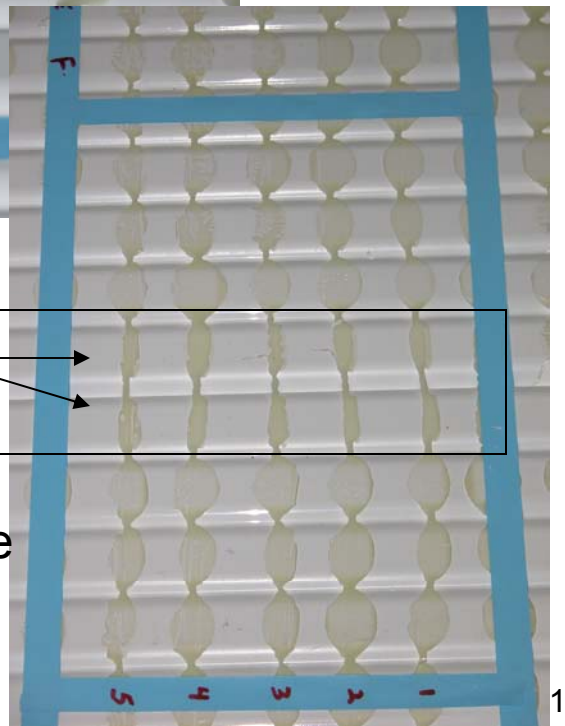


Compressed Glue Lines



Cells 1 and 16 of abutting extrusions

Non-Compressed glue lines



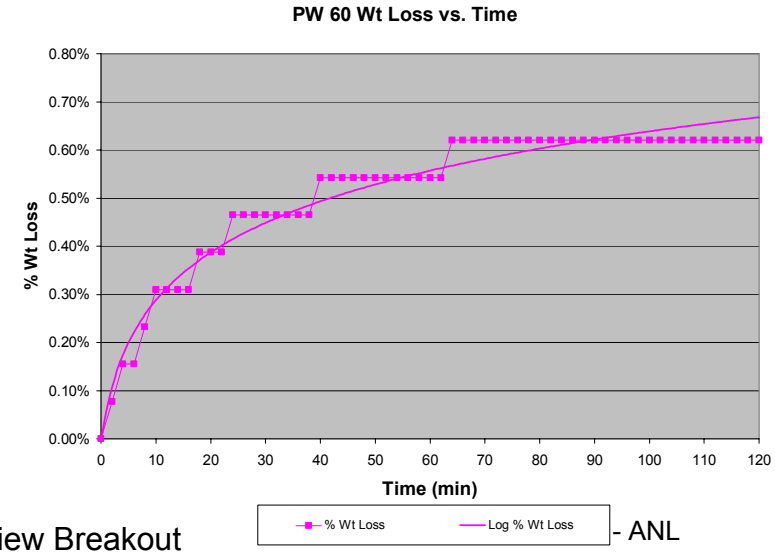
Testing

IPND Mechanical Prototype – Conclusions

- The use of rollers for compression looks promising.
- Need to do further tests to understand glue compression and coverage.
- It is possible to move modules once they have been placed.
- For assembly it would be best if any gaps due to banana were accepted and no effort was made to take them out.

Testing --Adhesive

- Recommending that baseline adhesive be changed to Devcon 60
- See DocDb 1347 for details.
- There is on-going ES&H evaluation.
- Initial ES&H measurements taken during IPND prototype.
  - Volatiles were below 50 ppm allowed but still significant for the people applying the adhesive.
  - Volatiles dropped rapidly away from adhesive application area.
  - There was no ventilation in the area during IPND prototype production.



Continuing Work

- Analysis of blocks when supported on forks/pallets connected to pivoter.
- Design and analysis of pallet/forks.
- Continue to evaluate ES&H
- MECHANICAL TESTING!

Conclusions

- Extensive analysis has been done on the detector.
- We think we have a viable design that takes into account the worst case creep properties.
- Extensive physical testing is needed to confirm the analysis over the next few years.