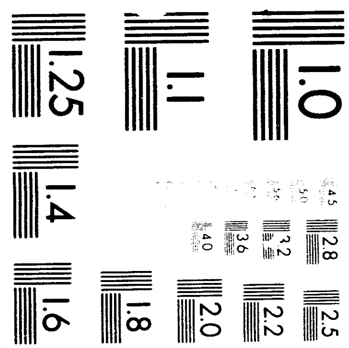
1.0
1.1
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# GRAVITY SAG OF SANDWICH PANEL ASSEMBLIES AS APPLIED TO PRECISION CATHODE STRIP CHAMBER STRUCTURAL DESIGN

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AUSPICES

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# Gravity Sag of Sandwich Panel Assemblies

# As Applied To

# Precision Cathode Strip Chamber Structural Design

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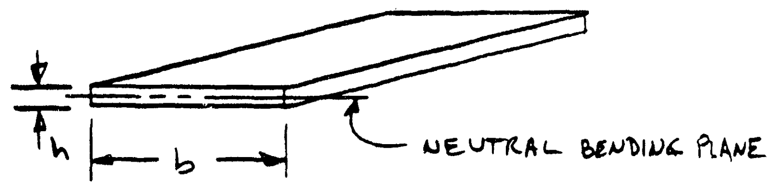
July 12, 1993

Abstract:
The relationship between gravity sag of a precision cathode strip chamber and its sandwich panel structural design is explored parametrically. An algorithm for estimating the dominant component of gravity sag is defined. Graphs of normalized gravity sag as a function of gap frame width and material, sandwich core edge filler width and material, panel skin thickness, gap height, and support location are calculated using the gravity sag algorithm. The structural importance of the sandwich-to-sandwich "gap frame" connection is explained.

# HOW TO CALCULATE THE STIFFNESS OF A STACK OF SLABS

STIFFNESS OF ONE SOLID SLAB
WITH RECTANGULAR CROSS-SECTION

$$I_{SLAB} = \frac{bh^3}{12}$$




NOTE:

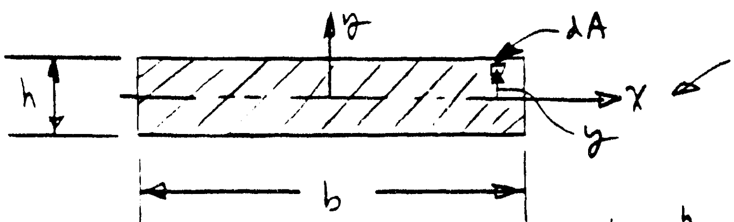
$I_{SLAB}$ IS THE "AREA MOMENT OF INERTIA" OF THE CROSS-SECTION CALCULATED WITH RESPECT TO THE CENTROID OF THE SECTION.

THE DEFINITION OF "I" IS,

$$I = \int_{AREA} y^2 \, dA$$

WHERE $y$ = DISTANCE FROM THE NEUTRAL PLANE TO ELEMENT $dA$

THE "INERTIA" OF A RECTANGULAR $b \times h$ CROSS-SECTION IS,




THE VERTICAL CO-ORDINATE OF THE CENTROID IS ALSO CALLED THE NEUTRAL PLANE

$$I = \int_{AREA} y^2 \, dA_{REA} = \int_0^b \int_{-\frac{h}{2}}^{\frac{h}{2}} y^2 \, dy \, dx$$

$$I = \left[ \int_{-\frac{h}{2}}^{\frac{h}{2}} y^2 dy \; x \right]_0^b = \left[ \left[ \frac{y^3}{3} \right]_{-\frac{h}{2}}^{\frac{h}{2}} x \right]_0^b$$

$$I = \frac{(2)\, h^3 \, b}{(8)(3)}$$

$$\boxed{I_{RECTANGLE} = \frac{bh^3}{12}}$$

= MOMENT OF INERTIA OF ONE RECTANGULAR SLAB

FOR COMPARISON,

SUPPOSE THE TWO SLABS ARE <u>NOT</u> <u>GLUED</u>.

$$I_{ASSEMBLY} = \sum I_o$$

$$I_{ASSEMBLY} = \frac{bh^3}{12} + \frac{bh^3}{12}$$

$$I_{ASSEMBLY} = \frac{2bh^3}{12}$$

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SUMMARY:

FOR TWO SLABS OF WIDTH "b" AND HEIGHT "h" STACKED TOGETHER,

IF ALLOWED TO SLIP (i.e. SHEAR IS ALLOWED)

$$I_{ASSEMBLY} = \frac{2bh^3}{12}$$

---

IF NOT ALLOWED TO SLIP (i.e. "IDEAL" ZERO-SHEAR GLUE)

$$I_{ASSEMBLY} = \frac{8bh^3}{12}$$

CSC OBSERVATIONS:

AS APPLIED TO CATHODE STRIP CHAMBERS, A "SLAB" IS ANALOGOUS TO A SANDWICH PANEL.

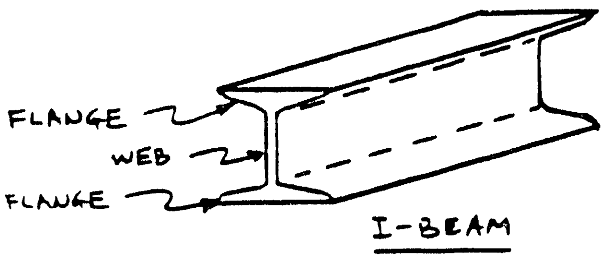
THE "GLUE" BOND THAT IS NECESSARY TO PREVENT SLIDING BETWEEN SLABS IS THE "GAP FRAME". IT BONDS TOGETHER THE SANDWICH PANELS.

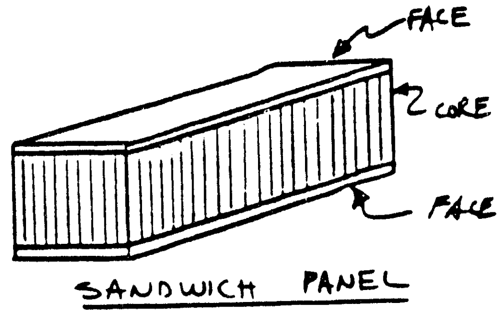
THE STRUCTURAL PURPOSE OF THE GAP FRAME IS TO PREVENT SLIDING BETWEEN SANDWICH PANELS.

THE GAP FRAME MATERIAL AND GEOMETRIC DESIGN MUST RESIST SHEAR DEFORMATION.

## STIFFNESS OF A SANDWICH PANEL

THE CORE OF A SANDWICH PANEL BEHAVES LIKE THE "WEB" OF AN I-BEAM, PREVENTING SLIDING BETWEEN TOP AND BOTTOM FLANGES.

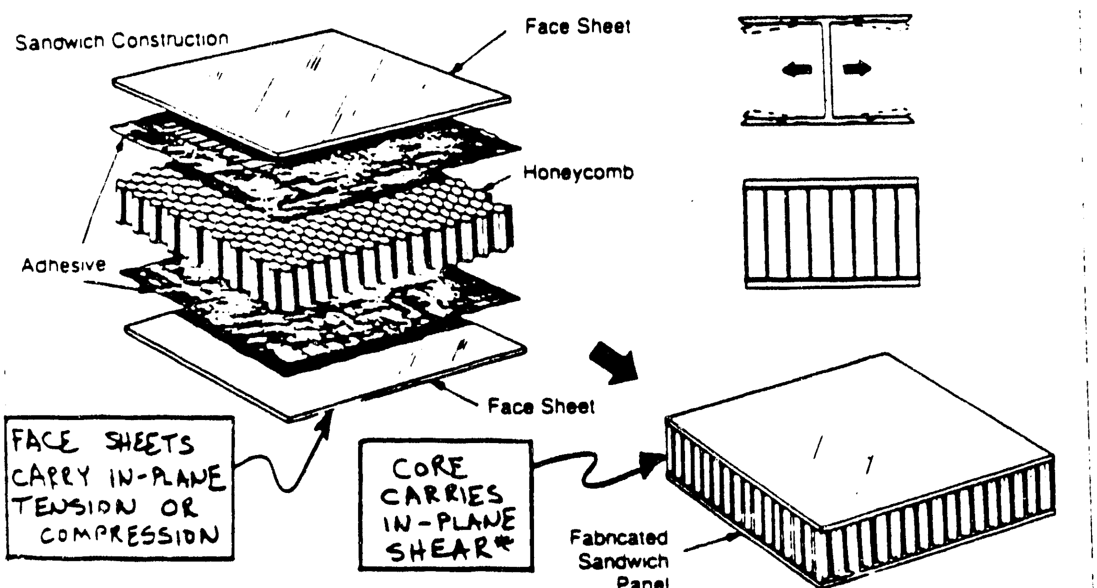




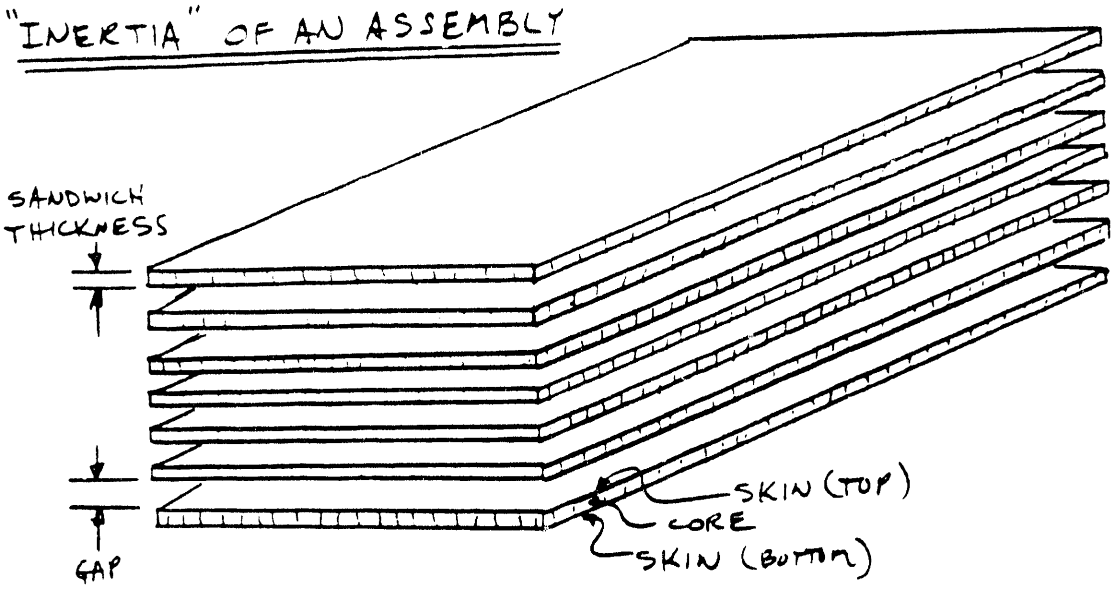

The facings of a sandwich panel used as a beam act similarly to the flanges of an I-beam by taking the bending loads — one facing in compression and the other in tension. Expanding this comparison further, the honeycomb core corresponds to the web of the I-beam. This core resists the shear loads, increases the stiffness of the structure by spreading the facings apart, but unlike the I-beam's web, gives continuous support to the flanges or facings. The core-to-skin adhesive rigidly joins the sandwich components and allows them to act as one unit with a high torsional and bending rigidity.

Figure 1




* AND SLIGHT NORMAL LOAD TO PREVENT SKIN BUCKLING

## "INERTIA" OF AN ASSEMBLY




ASSUME, 7 EQUALLY SPACED SANDWICH PANELS (DIMENSIONS AS SHOWN)

"IDEALLY" PREVENTED FROM SLIPPING BY PERFECT MASSLESS GLUE.

TREAT EACH SKIN (7 SANDWICHES × 2 SKINS/SANDWICH = 14 SKINS) AS A COMPONENT,

$$I_{ASSEMBLY} = \sum_{i=1}^{14} I_i + \sum_{i=1}^{14} A_i y_i^2$$

WHERE $I_i = \frac{b\, t_{SKIN}^3}{12}$

$A_i = b\, t_{SKIN}$

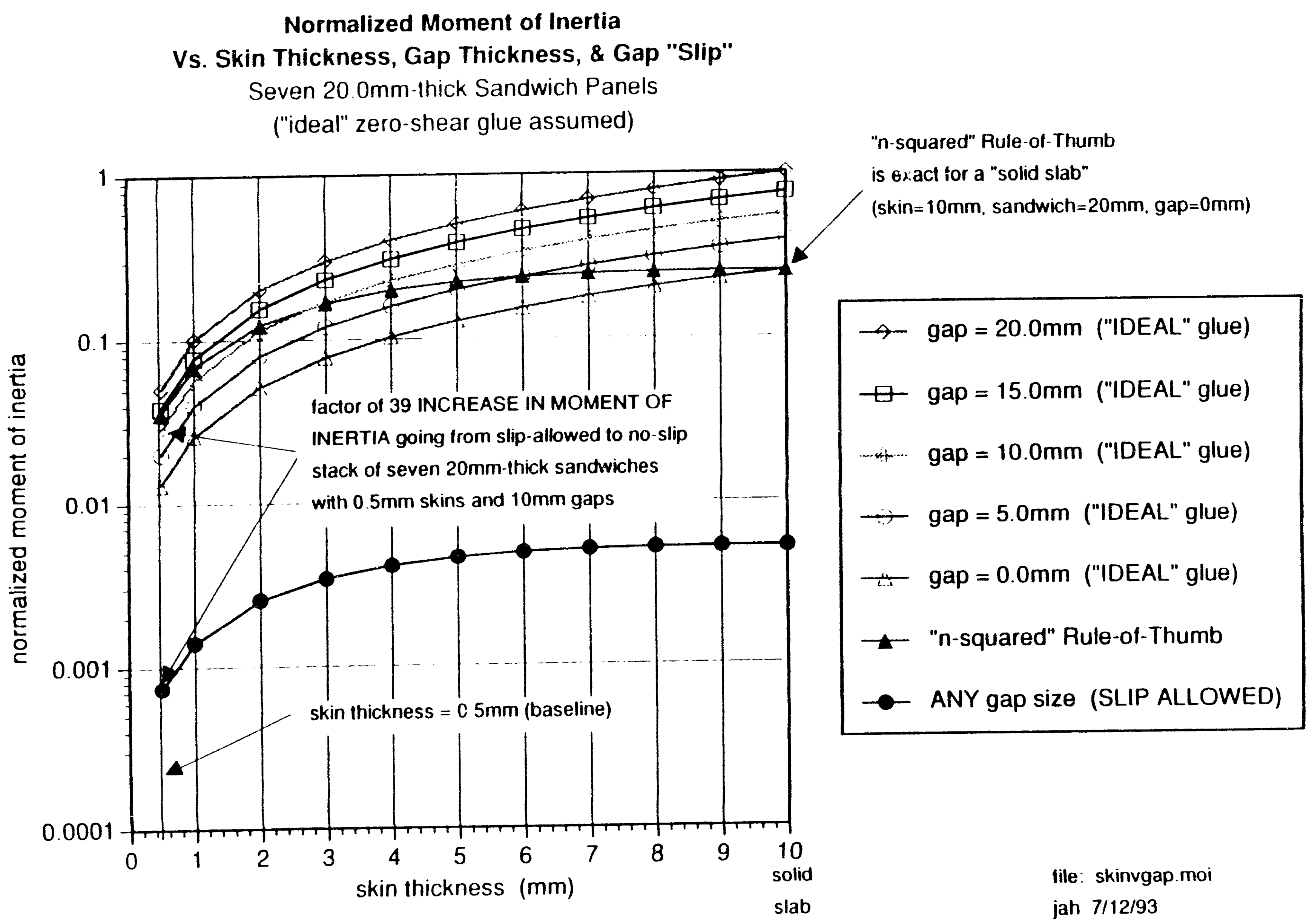
$y_i$ = DISTANCE FROM NEUTRAL SURFACE OF ASSEMBLY TO NEUTRAL SURFACE OF THE $i$-th SKIN

---

THIS ARITHMETIC HAS BEEN PROGRAMMED INTO A SPREADSHEET MODEL.

THE SPREADSHEET CALCULATES $I_{ASSEMBLY}$ USING THE PARALLEL AXIS THEOREM, THE SAME AS ABOVE.

| |
|---|
| THE SPREADSHEET MODEL PROVIDES RAPID CALCULATION OF ASSEMBLY STIFFNESS AS A FUNCTION OF VARIOUS PARAMETER VALUES. |

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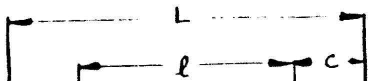
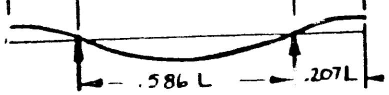
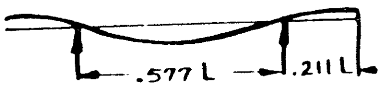
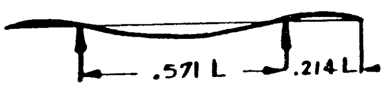
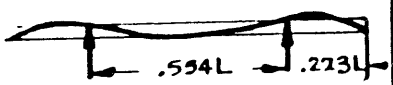
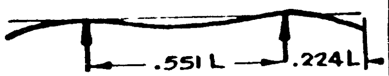
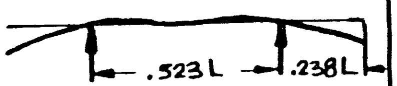
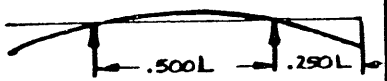
# BEAM CALCULATIONS - SPECIAL CASES OF SYMETRICAL OVERHANGING BEAMS WITH UNIFORM LOAD $w$ = UNIT LOAD (e.g. lbs/IN)

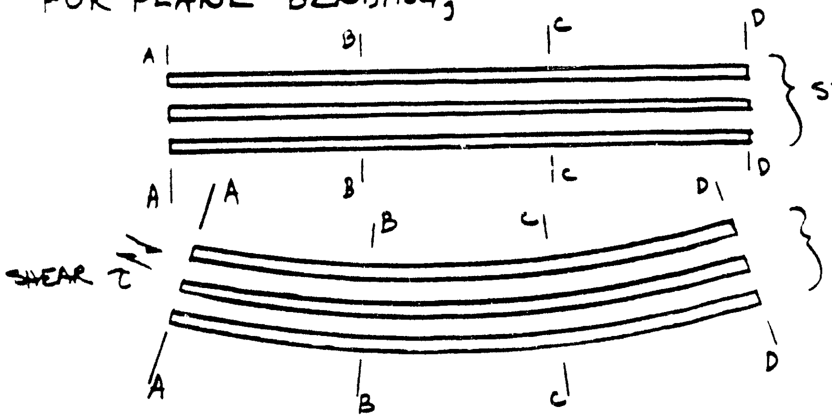
| SPECIAL CASE / CASE # |  | DISTANCE EACH WAY FROM CENTER TO INFLECTION POINT (POINT OF ZERO MOMENT) $=\sqrt{\frac{\ell^2}{4}-c^2}$ | MOMENT AT CENTER $=\frac{w(c^2-\frac{\ell^2}{4})}{2}$ | MOMENT AT SUPPORTS (MAX. MOMENT) $=\frac{wc^2}{2}$ = MAX. MOMENT | DEFLECTION AT ENDS $=\frac{wc}{24EI}(3c^2(c+2\ell)-\ell^3)$ PLUS = DOWN MINUS = UP | DEFLECTION AT CENTER $=\frac{w\ell^2}{384EI}(5\ell^2-24c^2)$ PLUS = DOWN MINUS = UP |
|---|---|---|---|---|---|---|
| ① EQUAL MOMENTS AT SUPPORTS & CENTER |  | .207 L | $.0214\ wL^2$ | $.0214\ wL^2$ | $-.00021\ \frac{wL^4}{EI}$ | $.000615\ \frac{wL^4}{EI}$ |
| ② ZERO SLOPE AT ENDS |  | .196 L | $.0192\ wL^2$ | $.0223\ wL^2$ | $-.000078\ \frac{wL^4}{EI}$ | $.000512\ \frac{wL^4}{EI}$ |
| ③ NO END DEFLECTION |  | .183 L | $.0177\ wL^2$ | $.0230\ wL^2$ | 0 | $.000446\ \frac{wL^4}{EI}$ |
| ④ END & CENTER DEFLECTIONS EQUAL. MINIMUM OVERALL DEFLECTION |  | .164 L | $.0135\ wL^2$ | $.0248\ wL^2$ | $.000268\ \frac{wL^4}{EI}$ | $.000268\ \frac{wL^4}{EI}$ |
| ⑤ ZERO SLOPE AT SUPPORTS |  | .159 L | $.0126\ wL^2$ | $.0252\ wL^2$ | $.000317\ \frac{wL^4}{EI}$ | $.000237\ \frac{wL^4}{EI}$ |
| ⑥ NO CENTER DEFLECTION |  | .106 L | $.0057\ wL^2$ | $.0284\ wL^2$ | $.000759\ \frac{wL^4}{EI}$ | 0 |
| ⑦ INFLECTION POINT AT CENTER MAX. DEFLECTION AT CENTER ZERO MOMENT AT CENTER |  | 0 | 0 | $.0312\ wL^2$ | $.00113\ \frac{wL^4}{EI}$ | $-.000162\ \frac{wL^4}{EI}$ |

# THE EFFECT OF GAP FRAMES ON DEFLECTION

IN THE PREVIOUS ANALYSIS THE STACK OF SANDWICH PANELS (WITH GAPS BETWEEN PANELS) WAS ASSUMED BONDED ACROSS THE GAPS WITH "IDEAL" MASSLESS GLUE.

IN MECHANICS, THIS BENDING ANALYSIS ASSUMPTION IS STATED AS "CROSS-SECTIONS REMAIN FLAT DURING BENDING."

FOR PLANE BENDING,

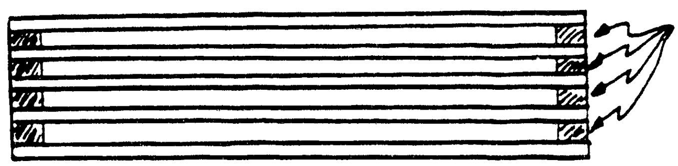



ALL CROSS-SECTION PLANES (A-A, B-B, ...) REMAIN FLAT DURING BENDING

TO ACHIEVE THIS LINKING BETWEEN SLABS THE GAPS MUST BE SPANNED AT SUFFICIENT LOCATIONS AND IN A MANNER THAT RESISTS THE SHEAR LOAD INDUCED BETWEEN SLABS.

SHEAR BETWEEN SLABS CAUSES THE ABOVE SECTION PLANES TO WARP. THIS RESULTS IN AN ADDITIONAL COMPONENT OF SAG CALLED "SHEAR DEFLECTION".

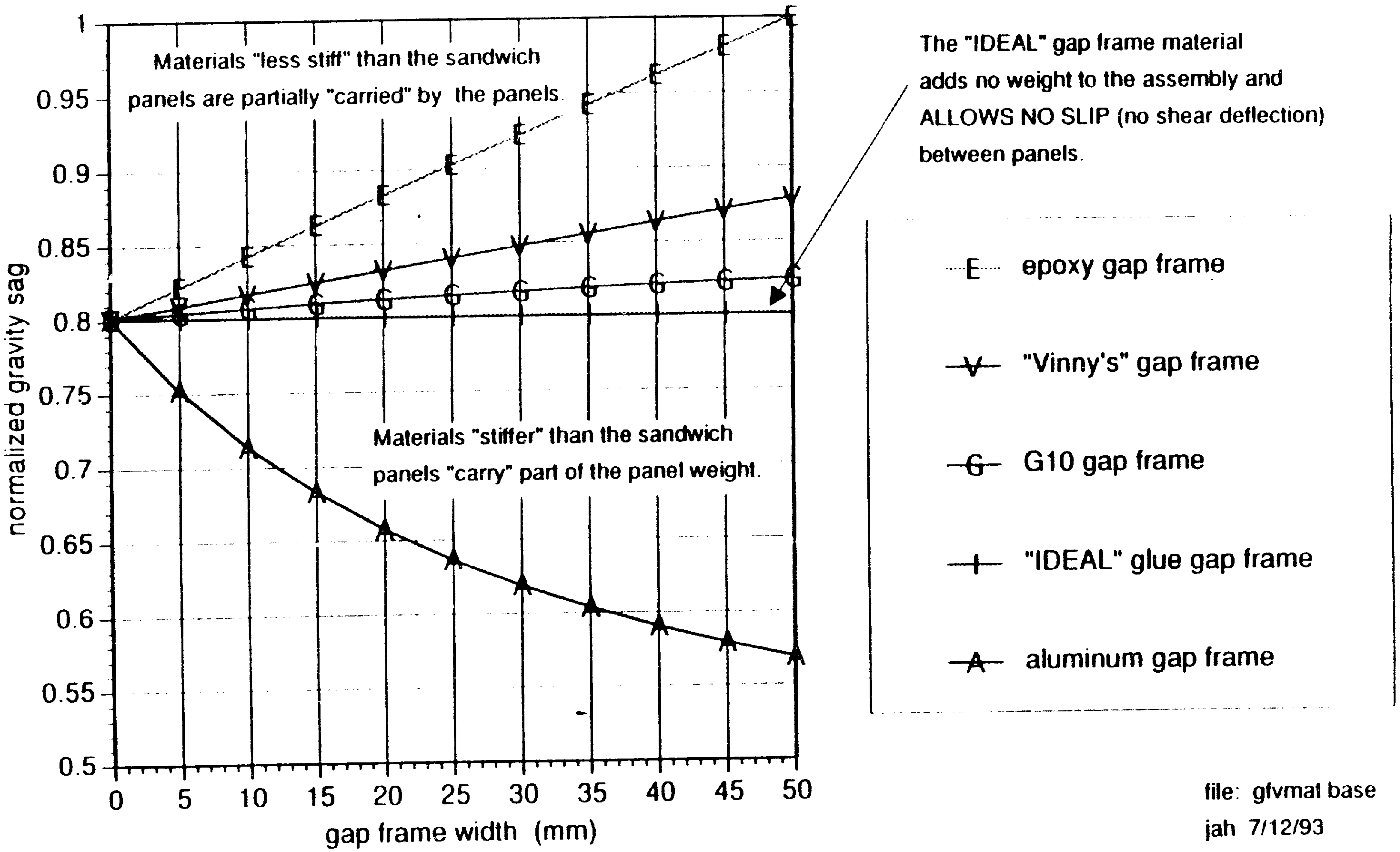
THE SANDWICH PANELS ARE LINKED TOGETHER INTO A "SANDWICH OF SANDWICHES" BY THE GAP FRAME. IDEALLY THE GAP FRAME SHOULD PREVENT SHEAR DEFORMATION (SLIPPING).




THE EFFECT OF GAP FRAME WIDTHS AND MATERIALS ON ASSEMBLY GRAVITY SAG IS CALCULATED USING ANOTHER SPREADSHEET[13] AS FOLLOWS:

## Normalized Gravity Sag
## Vs. Gap Frame Width & Gap Frame Material

Seven 20.0mm-thick Sandwich Panels, No Core Edge Filler,
Skin Thickness = 0.5mm, Gap Height = 10mm, NO SLIP ALLOWED

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# THE EFFECT OF SANDWICH CORE EDGE FILLER

CORE EDGE FILLER IS SIMPLY A SUBSTITUTE FOR THE SANDWICH CORE MATERIAL.

ITS EFFECT ON DEFLECTION IS PROPORTIONAL TO ITS RELATIVE "EFFECTIVE STIFFNESS" (AS DISCUSSED IN RELATION TO GAP FRAME EFFECTS).

THE ONLY MINOR DIFFERENCE IS THAT CORE EDGE FILLER <u>DISPLACES</u> HONEYCOMB MATERIAL. SINCE HONEYCOMB HAS ZERO MODULUS IN THE PLANE OF THE PANELS, LIGHT AND STIFF EDGE FILLERS SUCH AS G10 PROVIDE SOME BENEFIT, BUT ADD MASS.

Assumed Material properties

The following material properties were used in the normalized gravity sag calculations:

| material | elastic modulus (psi) | mass density (lb sec^2/in^4) | elastic modulus (MPa) | mass density (g/cm^3) |
|---|---|---|---|---|
| G10 laminate | 3,300,000 | 0.000180 | 22,759 | 1.926 |
| epoxy | 400,000 | 0.000111 | 2,759 | 1.190 |
| "Vinny's" | 98,395 | 0.000039 | 679 | 0.420 |
| aluminum | 10,000,000 | 0.000254 | 68,966 | 2.718 |
| Nomex core | - - - | 0.000003 | - - - | 0.029 |

Effect of Support locations

The normalized gravity sag graphs assume some constant support point locations. The chamber mass is assumed to be uniformly distributed along its length. The chart of beam deflection expressions shows that the maximum gravity sag is reduced by a factor of 48.6, i.e. (5/384)/0.000268, by going from support at the extreme ends to support at points 0.223L from the ends. Actual chamber sag will fall between these limits to the extent that weight is evenly distributed along the chamber length and shear deflection is prevented by proper panel-to-panel connection.

Conclusions

The magnitude of chamber sag is highly dependent on chamber support location and design of the gap frame. The gap between sandwich panels must be able to resist shear deformation. The major component of gravity sag is due to beam bending if shear deflection can be avoided. Gravity sag increases by a factor of 39 going from an "ideal" shear connection to slip-allowed between sandwich panels.

The mechanical connection between panels (gap frame and posts) will determine the magnitude of additional gravity sag introduced due to shear deflection. The design parameters that influence this value are the geometry of the gap frames around the perimeter of the panel, its mechanical properties, and the reliability of the panel-to-panel attachment technique (preloaded bolts, adhesives, pins, etc.)

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