LATOF Lightguide Glue Strength Tests

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Purpose: To test the breaking strengths of different acrylic plastic joints for possible use in affixing lightguides to the CEBAF Large Angle Time of Flight detectors (LATOF). Different surface preparations prior to gluing were tested with three glue types. Fig. 1 shows the setup for a simple face-to-face glue test with acrylic strips. In later tests the clamped piece was BC-408 scintillator to simulate actual detector joints.

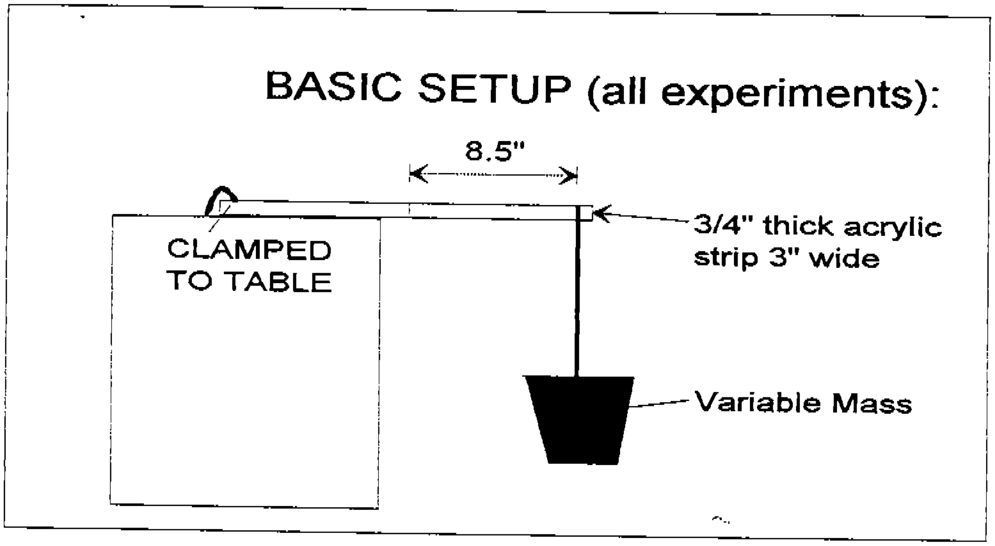

fig. 1

<u>TEST # 1:</u> Simple End Face Gluing with Sanded and Polished Surfaces
Clamped Surface Preparation: 240 grit sandpaper (non-UVT acrylic)
Free Surface Preparations: 600 grit and Polished (non-UVT acrylic, 2 strips)
Glue Used: Bicron BC-600 (cure time: 17 hours)

Results: The sanded free surface took **43 lbs. 3 oz.**, and the polished surface took **28 lbs. 1 oz.**. This indicates that the sanded surface bonds better.

TEST # 2: Acrylic Support Plate on Top of Glue Joint
To improve strength, a thin plastic plate was added over the joint (fig. 2).

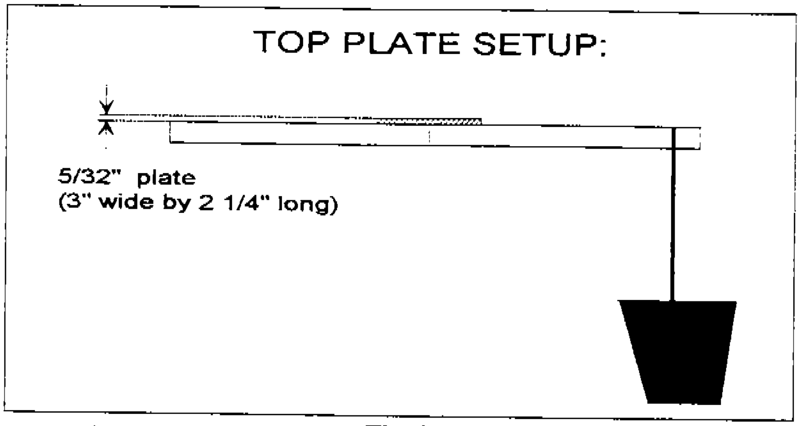

Fig. 2

Clamped Surface Preparation: 240 grit sanded (non-UVT acrylic)
Free Surface Preparation: 600 grit sanded (non-UVT acrylic)
Top Plate Surface Preparation: None (existing cast, non-UVT acrylic surface)
Glue: Bicron BC-600 (~18 hours cure time)

RESULT: It took **77 lbs., 15 oz.** to break joint. Free strip separated from clamped strip and the unbroken thin plate. This is almost a factor of 2 better than just gluing the 600 grit surface.

TEST # 3: 400 to 400 surface with "glue holes" drilled into it (see fig. 3)
Clamped and Free Surface preparation: 400 grit sanded (non-UVT acrylic)
Glue: Bicron BC-600 (~24 hr. cure time)
Top Plate: 5/32" thick, 3" x 2.25" in area, six 1/4" wide by 1/4" deep holes drilled through top plate and into strips then filled with glue to keep the plates from separating from the strips. See figure 3.

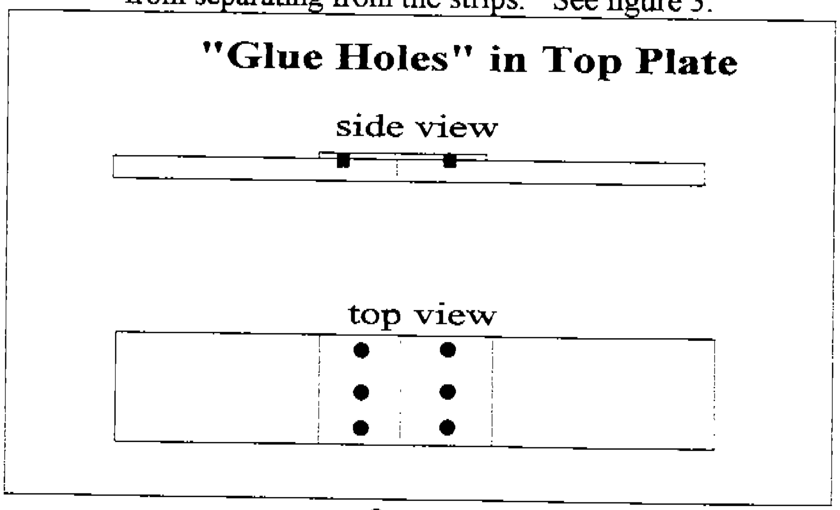

fig. 3

Result: Joint took **99 lbs. even** before it started to separate and break *at the glue holes.*

TEST #4: 400 to 400 Surface with Top Plates
Clamped and Free Surface preparation: 400 grit sanded (non-UVT acrylic)
Glue: Bicron BC-600 (~24 hr. cure time)
Top Plates: 5/32" thick, 3" wide for all three. Lengths were **1.00"**,**1.50"** and **2.25"**.
Result: Joints took **111 lbs. 6 oz., 93 lbs. 6 oz., and 113 lbs. 5 oz.** respectively --- before the *top plates broke instead of separating* , indicating that the plates and not the glue determined the strength of the joint.

TEST # 5: Repeating Test 1 for 5-Minute Epoxy
Clamped Surface Preparation: 240 grit sanded (non-UVT acrylic)
Free Surfaces Preparation: 240 grit and 600 grit sanded (non-UVT acrylic, 2 strips)
Glue: Tru-Value brand 5-Minute Epoxy (cured 17 hrs.)
Tests with no top plate:
Results: Both strips broke off with less than **13 lbs.** of force.

TEST # 6: Repeating Test 2 for 5-Minute Epoxy
Clamped Surface Preparation: 240 grit sanded (non-UVT acrylic)
Free Surface Preparation: 600 grit sanded (non-UVT acrylic)
Glue: Tru-Value brand 5-Minute Epoxy (cured 17 hrs.)
Test with top plate (5/32" thick, 3" x 2.25") over joint:
Result: Joint broke with **42 lbs., 12 oz.** of force (half that of BC-600)

TEST # 7: Evaluation of 400 grit to 400 grit Interface
Clamped Surface Preparation: 400 grit sanded (non-UVT acrylic)
Free Surfaces Preparation: 400 grit sanded (non-UVT acrylic, 2 strips)
Glue: Bicron BC-600 (cured ~24 hours)
No top plate.
Results: Joints took **49 lbs., 7 oz.**

TEST # 8: Evaluation of 400 to 400 Surface with Longer Cure Time
Clamped and Free Surface preparation: 400 grit sanded (non-UVT acrylic)
Glue: Bicron BC-600 (cured ~44 hours)
No top plate.
Result: Joint took **68 lbs., 2 oz.** to break. Indicates longer cure time for maximum strength than the assumed 24 hours. Bicron consulted and reports that the glue reaches maximum strength after 3 days.

TEST #9: Norland™ UV Cured Adhesive Test
Clamped and Free Surface preparation: 400 grit sanded (non-UVT acrylic)
Glue: Norland UV Optical Adhesive # 81 (~24 hr. cure time under 15 W UV lamp)

Result: Joint took approximately **17 lbs.** before breaking. This is not much better than 5-minute epoxy.

TEST #10: Loctite™ UV Adhesive
Clamped Surfaces: 400 grit sanded (non-UVT acrylic)
Free Surfaces: 400 grit sanded (one UVT and one non-UVT acrylic)
Glue: Loctite™ UV Adhesive (Impruv 349 Optically Clear, cured 1 hour)

Results: Joints took **26 lbs., 8 oz. each**. This confirms that acrylic type has no effect on glue joint strength.

TEST #11: UV Adhesive Curing Times vs. Strength
Clamped and Free Surfaces: 400 grit sanded (non-UVT acrylic)
Glue: Loctite™ UV Adhesive (Impruv 349 Optically Clear)
Curing Times Tested: 10 min., 1 hr. and 17 hrs.

Results: Joints took **33 lbs. 8 oz., 27 lbs., and 21 lbs. 8oz.** respectively.

TEST #12: Vertical and Horizontal Gluing with BC-600 (scintillator/acrylic interfaces)

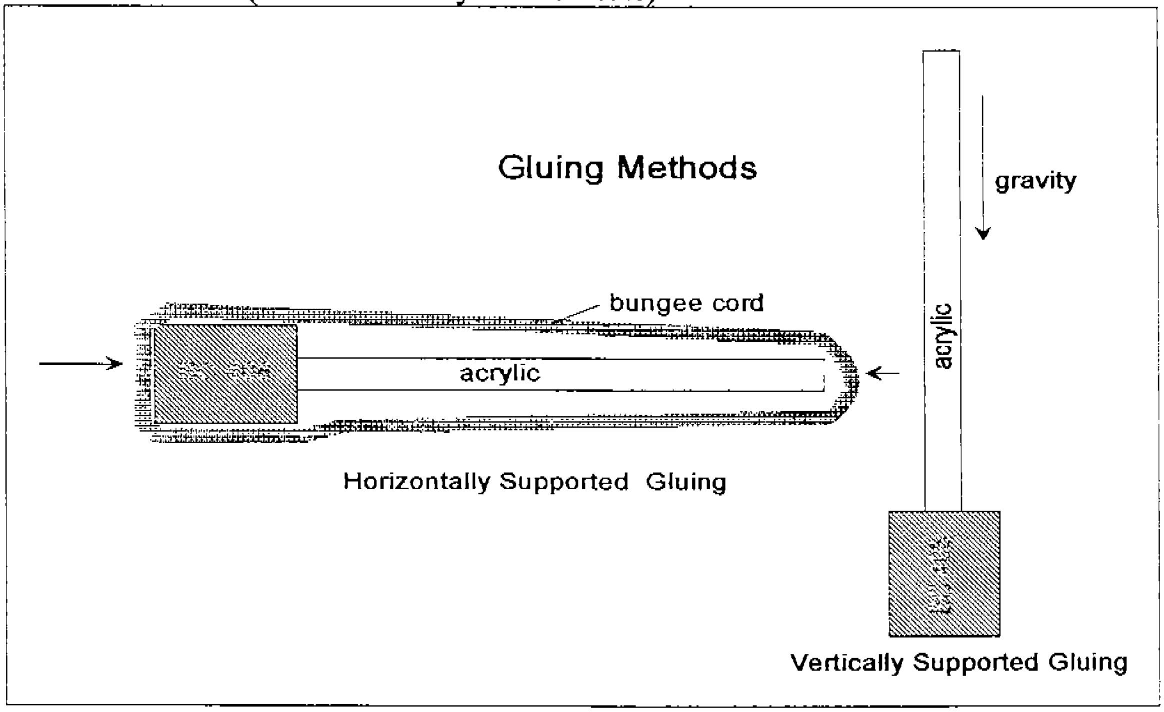

fig. 3a

Clamped Surfaces: 400 grit sanded BC-408 plastic
Free Surfaces: 400 grit sanded non-UVT acrylic (one glued horizontally under stress, one glued vertically)
Glue: Bicron BC-600 Optical Adhesive (cured 17 hours)

Results: The vertically glued joint took **45 lbs. 8 oz.**, while the horizontally glued one took **30 lbs. 8 oz.**

Correction due to weight of free hanging strip:

In the figures for breaking force, the numbers must be corrected to account for the mass of the plastic strip itself. Since the force acts all at the end (8.5" away) and the center of mass of the strip is half as far, the effective additional mass at the force point is half the actual mass of the strip. This actual mass can be calculated knowing that bulk acrylic has a density of about 1.1 gm/cm^3 (0.63 oz./cubic inch).

Mass of strip = 3/4" x 8.5" x 3.0" x 0.63 oz./cubic inch = 12.0 oz.

This means that the breaking force figures have to be adjusted by **6 oz.** to be accurate. This is done in the following table (next page):

SUMMARY DATA TABLE

Test #	Glue Type	Cure Time	Clamped Surface	Free Surface	Top Plate	Breaking Wt. (adj.) lbs.	oz.	Comments
1	BC-600	17 hrs.	240 grit	600 grit	None	43	9	
1	BC-600	17 hrs.	240 grit	polished	None	28	7	
2	BC-600	18 hrs.	240 grit	600 grit	2.25" long 3.00" wide 5/32" thick	78	5	
3	BC-600	24 hrs.	400 grit	400 grit	2.25" long 3" wide 5/32" thick	99	6	Plate w/ 6 Glue Holes
4	BC-600	24 hrs.	400 grit	400 grit	2.25" long 1.0" wide 5/32" thick	111	12	
4	BC-600	24 hrs.	400 grit	400 grit	2.25" long 1.5" wide 5/32" thick	93	12	
4	BC-600	24 hrs.	400 grit	400 grit	2.25" long 3.00" wide 5/32" thick	**113**	**11**	**Best Strength**
5	5-min epoxy	17 hrs.	240 grit	240 grit	None	<13		one brick
5	5-min epoxy	17 hrs	240 grit	600 grit	None	<13		one brick
6	5-min epoxy	17 hrs	240 grit	600 grit	2.25" long 3.00" wide 5/32" thick	43	2	
7	BC-600	24 hrs.	400 grit	400 grit	None	49	13	
8	BC-600	44 hrs.	400 grit	400 grit	None	68	8	Long Cure **Best Strength if No Plate**
9	Norland Optical Adhesive 81	24	400 grit	400 grit	None	≈ 17		weak
10	Loctite™ UV Glue	1 hr.	400 grit	400 grit	None	26	14	standard non-UVT
10	Loctite™ UV Glue	1 hr.	400 grit	400 grit UVT acrylic	None	26	14	UVT acrylic bond to non-UVT
11	Loctite™ UV Glue	10 min.	400 grit	400 grit	None	33	14	standard non-UVT
11	Loctite™ UV Glue	1 hr.	400 grit	400 grit	None	27	6	standard non-UVT
11	Loctite™ UV Glue	17 hrs.	400 grit	400 grit	None	21	14	standard non-UVT
12	BC-600	17 hrs.	400 grit	400 grit	None	45	14	Vertically Glued Joint
12	BC-600	17 hrs.	400 grit	400 grit	None	30	14	Horizontally Glued Joint

Calculations of actual glue strength in Newtons/square centimeter:

Description of glue joint and fracture dynamics:

Our glue joint represents what will be the interface between the LATOF lightguide and the scintillator plastic itself, namely a rectangular cross section with the faces perpendicular with the ground. The weight of the lightguide and PMT will cause a torque force that acts to separate the lightguide from the scintillator. This force will have a maximum when encountering bumps in the road during transportation of the detectors (see fig. 4). The formula in fig. 4 neglects the effect of shock absorbers. With stiff shocks, the same formula can be applied to the tires (making Xmax then the maximum compression of the tires).

Phototube Shock Limitations

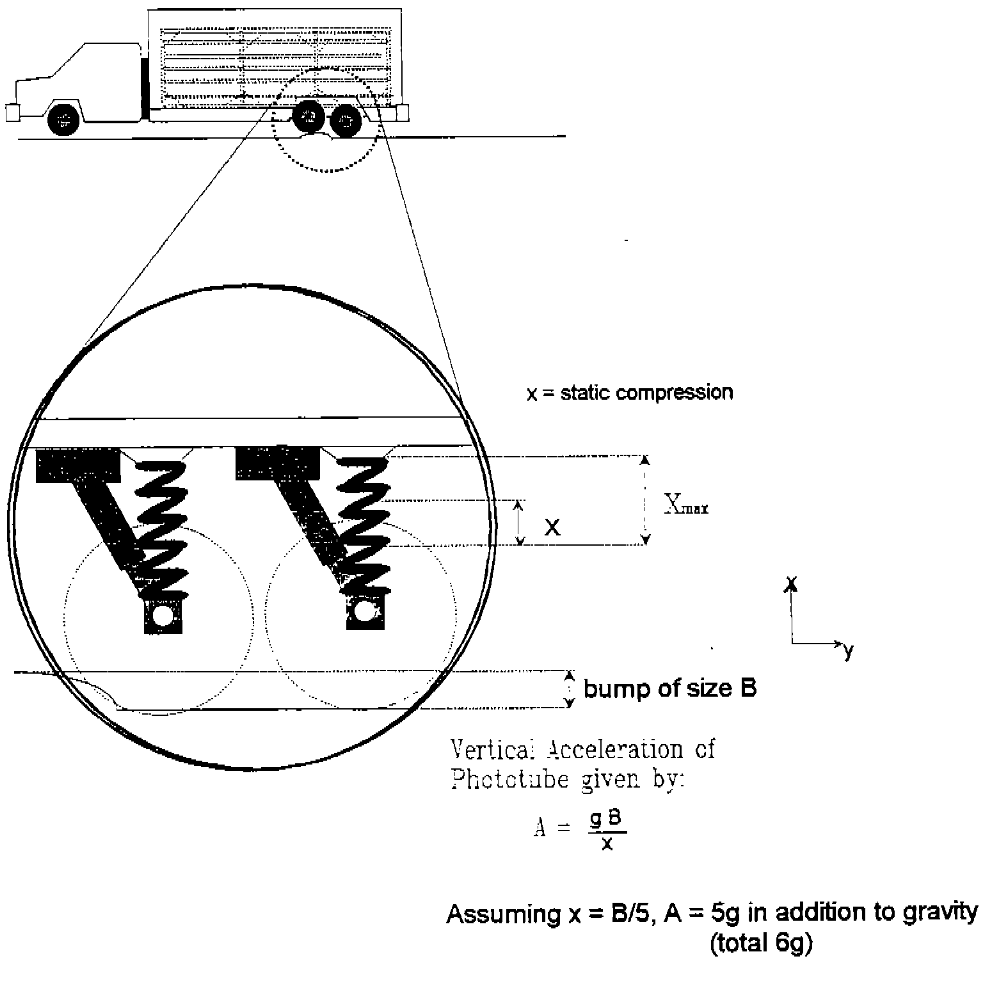

Fig. 4

When a glue joint is at its maximum stress point, it begins to fracture from the top down (farthest point from the center of torsional rotation). The majority of stress in the joint is therefore located in that part of the interface rather than uniformly distributed across the entire cross section (see fig. 5).

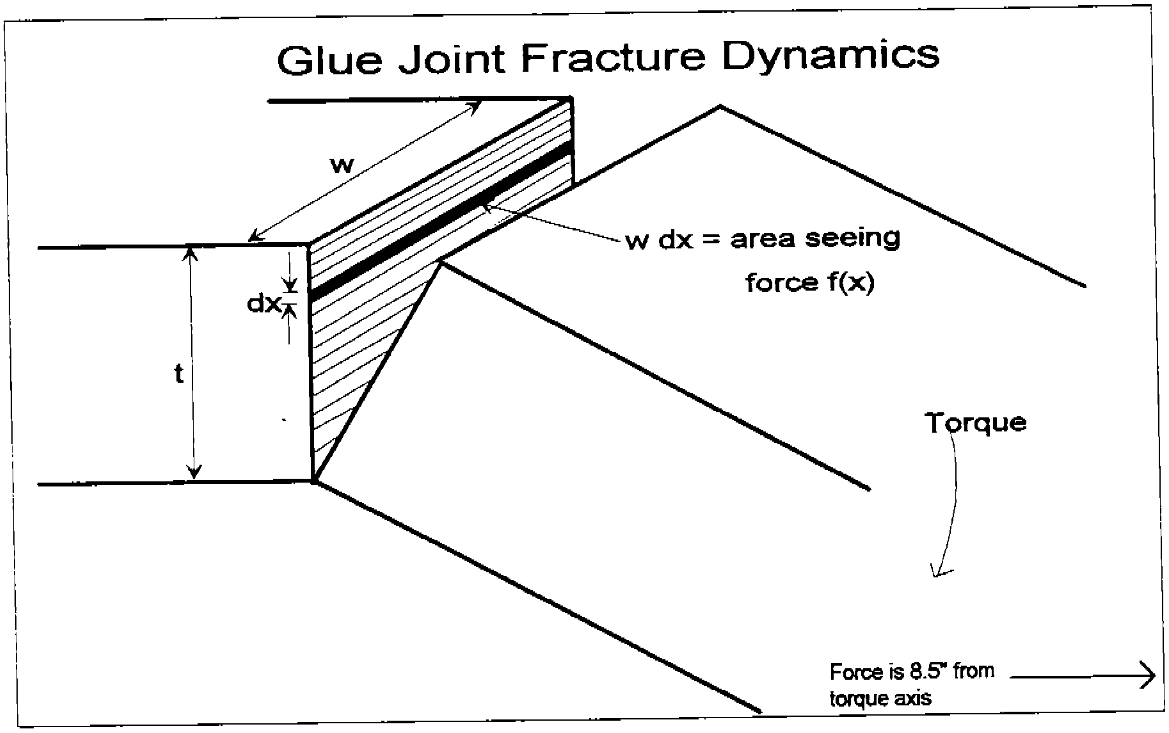

fig. 5

To calculate the strength of the glue per unit area, one must integrate the torque forces (due to f(x)) over the entire cross section using the following formulas:

Let x be the distance from the center of the strip designated by dx.
Let L be the moment arm that the total force is applied to.
Let k be the breaking force due to the mass at the end of the moment arm (f(x)).

Figure 6 shows the longitudinal tension dependent on x as can be found in texts on static mechanics:

Longitudinal Tension in an Interface of Thickness t

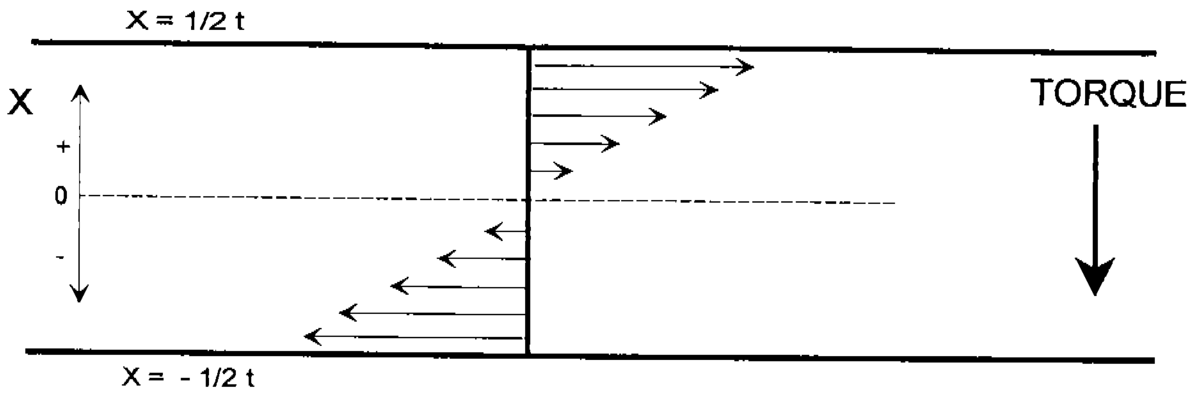

Fig. 6

$$\text{Torque} = L \times k = Lk = \int_{-1/2\,t}^{1/2\,t} w x f(x)\, dx = \int_{-1/2\,t}^{1/2\,t} c\, w\, x^2\, dx$$

(NOTE: since the force on any strip w dx is linearly proportional to its distance to the center [fig. 6], it can be represented as **cx** --- a constant times x)

The resulting integral

$$c\,w \int_{-1/2\,t}^{1/2\,t} x^2\, dx = Lk$$

solves to: ⇒ $(1/12)\, c\, w\, t^3$

this defines constant "c" as: $c = (12Lk)/(wt^3)$

using the experimental values:

t = .75" (1.9 cm)
L = 8.5" (21.6 cm)
k = 68 lbs, 8 oz. (303.8 N)
(best strength for no top plate, see data table)
w = 3" (7.6 cm)

gives the glue strength **ct /2** = $(6Lk)/(wt^2)$ which is calculated to be **1435 N/cm²**. It is interesting to note that Bicron Corp. specifies a value of 1190 N/cm². This value **ct/2** must remain constant in all calculations.

Determining maximum G-shock:

Applying the integral result to get the breaking torque for the LATOF lightguides:

letting $w = 22$ cm (8.67")

$t = 3.175$ cm (1.25")

this gives breaking torque = $(1/12)(ct)(w)(t^2) = 53{,}041$ Ncm

Knowing that the center of mass of the lightguide and PMT (L) is approximately 30 cm. from the joint and its mass is approximately 5 kg (49 N) , we can use the relationship A = Torque / (arm x mass) to find the maximum vertical acceleration that the lightguide can experience before breaking (noting that N=kg m/s^2):

$$A = 53{,}041 \text{ Ncm} / (30 \text{ cm} \times 5 \text{ kg}) = \mathbf{354\ m/s^2}.$$

This value is approximately 35 g's. Using the UV curing optical cement will reduce the maximum breaking shock to about half the calculated value (17 g's).

From the calculations of impact accelerations experienced by a truck on a bump (see fig. 4), the estimated maximum was 6 G's. This is safely below the theoretical breaking acceleration for either the BC-600 or UV cure optical cement joints used in these tests.

Conclusions:

By experimentation with glue strengths and calculation of maximum expected forces on our detectors, it is determined that lightguide joints glued with BC-600 cement >44 hr. cure for max strength) or Loctite UV optically clear adhesive (less than 1 hr. cure) will be safely stronger than necessary to survive transport. While the BC-600 edges out the UV cured optical adhesive in strength, the difference in curing times is a strong argument for using the UV glue.