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Document #: SD-W151-DA-004

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W-151 MIXER PUMP ENERGY ABSORPTION CYLINDER ANALYSIS

Pages: 29

Sta 4 (2)

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ENGINEERING DATA TRANSMITTAL

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Impact Level (F)	Reason for Transmittal (G)	Disposition (H) & (I)
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1	1	Cog. Eng. D. W. Crass [signature] 20 Sep 94 H5-68	R. B. Pan ESA Mgr. [signature] 9/14/94 H5-53	1	1
1	1	Cog. Mgr. R. K. Brown [signature] 2-6-96 H5-68			
1	1	QA R. E. Clayton [signature] S1-54			
1	1	Safety R. M. Nelson [signature] 2/6 R3-09			
		Env.			
1	1	D. L. Bjorklund [signature] H5-01			
1	1	E. M. Nordquist [signature] 9/26/94 R3-27			

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[signature] 9/13/94 Signature of EDT Originator Date A. H. Ziada	[signature] 2/6/96 Authorized Representative for Receiving Organization Date D. W. Crass	[signature] 2-6-96 Cognizant/Project Engineer's Manager Date R. K. Brown	Ltr. No. [] Approved [] Approved w/comments [] Disapproved w/comments

RELEASE AUTHORIZATION

Document Number:	WHC-SD-W151-DA-004, REV 0
Document Title:	W-151 Mixer Pump Energy Absorption Cylinder Analysis
Release Date:	2/6/96

This document was reviewed following the procedures described in WHC-CM-3-4 and is:

APPROVED FOR PUBLIC RELEASE

WHC Information Release Administration Specialist:

Kara Broz (signature) 2/6/96

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SUPPORTING DOCUMENT

1. Total Pages 25

2. Title

W-151 Mixer Pump Energy Absorption Cylinder Analysis

3. Number

WHC-SD-W151-DA-004

4. Rev No.

0

5. Key Words

energy absorption
accidental drop

6. Author

Name: A. H. Ziada

Signature

Organization/Charge Code Equipment Stress Analysis/8D430/D23D6

7. Abstract

This document provides the strength required for the energy absorption cylinder needed to prevent puncture through the AZ-101 tank resulting from a 59-ft drop of the W-151 mixer pump.

9. Impact Level SQ

10. RELEASE STAMP

W-151 MIXER PUMP ENERGY ABSORPTION CYLINDER ANALYSIS

PREPARED BY: ______________________ DATE: ________
A. H. Ziada, Engineer
Equipment Stress Analysis

REVIEWED BY: ______________________ DATE: 9/12/94
D. E. Barlow, Principal Engineer
Equipment Stress Analysis

APPROVED BY: ______________________ DATE: 9/14/94
R. B. Pan, Manager
Equipment Stress Analysis

Westinghouse Hanford Company
Hanford Operations and Engineering Contractor
for the
U.S. Department of Energy

CHECKLIST FOR INDEPENDENT REVIEW

Document Reviewed WHC-SD-W151-DA-004, REV. 0

Author A. H. Ziada

Yes	No	NA	
[✓]	[ ]	[ ]	Problem completely defined.
[✓]	[ ]	[ ]	Necessary assumptions explicitly stated and supported.
[ ]	[ ]	[✓]	Computer codes and data files documented.
[✓]	[ ]	[ ]	Data used in calculations explicitly stated in document.
[✓]	[ ]	[ ]	Data checked for consistency with original source information as applicable.
[✓]	[ ]	[ ]	Mathematical derivations checked including dimensional consistency of results.
[✓]	[ ]	[ ]	Models appropriate and used within range of validity or use outside range of established validity justified.
[✓]	[ ]	[ ]	Hand calculations checked for errors.
[ ]	[ ]	[✓]	Code run streams correct and consistent with analysis documentation.
[ ]	[ ]	[✓]	Code output consistent with input and with results reported in analysis documentation.
[✓]	[ ]	[ ]	Acceptability limits on analytical results applicable and supported. Limits checked against sources.
[✓]	[ ]	[ ]	Safety margins consistent with good engineering practices.
[✓]	[ ]	[ ]	Conclusions consistent with analytical results and applicable limits.
[✓]	[ ]	[ ]	Results and conclusions address all points required in the problem statement.

MANDATORY Software QA Log Number N/A

D. Barlow
Reviewer - D. E. Barlow

9/12/94
Date

09/22/93

DESIGN VERIFICATION METHOD

The need for design verification has been reviewed with the method selected as indicated below: (ESR/Work Plan # WP-8D430-310).

X	Independent Review
	Alternative Calculations
	Qualification Testing
	Formal Design Review

R. B. Pan
Cognizant/Project/Design Manger

SD # WHC-SD-W151-DA-004, Rev. 0

ECN #__________

DWG(S) #__________

09/22/93

CONTENTS

W-151 MIXER PUMP ENERGY ABSORPTION CYLINDER ANALYSIS

1.0 INTRODUCTION

This document provides the required strength analysis of the energy absorption cylinder (impact limiter) given the size and shape. In the case of an accidental drop of the 59-ft mixer pump that will be placed in the AZ101 tank, the impact limiter is to be used to prevent the pump from puncturing the bottom of the tank. The impact limiter has a 0.02-in. aluminum skin to protect it from external damage.

Conventional hand calculations were used to determine the strength. The analysis was based on the load that the tank riser can withstand. Because the load will not be applied directly on the riser, this calculation is very conservative. See Section 4.0 for details on the analysis.

2.0 RECOMMENDATIONS

An impact limiter to be used should have an average crush strength of 213 lbf/in^2 (221 lbf/in^2 maximum and 205 lbf/in^2 minimum) based on an outer diameter of 74 in., an inner diameter of 45 in., and a height of 48 in. The manufacturer should recommend the impact-limiter material that meets the average strength so that the maximum force applied to the riser of the tank is not more than 600,000 lb.

The compressive stresses in the impact limiter from the dead load (i.e., turntable that rests on top of the impact limiter) must not exceed the crushing strength (205 lb/in^2) of the impact limiter at any location.

During an impact, the impact limiter must be crushed uniformly across the entire top and bottom surfaces in order to absorb the required amount of energy.

The aluminum casing of the impact limiter should be crippled to preclude any initial buckling resistance spike from the casing.

It must be assured that the pump is capable of sustaining a deceleration of about 27.3 *g*. Additional calculations should be performed if the pump cannot withstand this force.

Analysis should be performed and verified that the impact limiter support structure on top of the tank can withstand the 600,000-lb impact from the pump drop.

3.0 CONFIGURATION AND LOADING

3.1 CONFIGURATION

The configuration of the impact limiter is documented in drawing H-2-818723, sheets 1 through 6.

3.2 LOADING

The loading applied is a drop load of 22,000 lb from 59 ft, which corresponds to a kinetic energy of 1,298,000 ft-lb. The impact limiter is used to prevent failure by reducing the impact load on the riser or tank.

4.0 ANALYSIS

Conventional hand calculations were used to determining the crush strength of the impact limiter. The allowable load of 600,000 lb was based on the puncture of the riser of tank 241SY101. Although the riser on the AZ101 tank is not identical to that on SY101, the configuration is similar. This value can be used with confidence because the drop load will not be applied directly to the riser. It will actually be applied to the soil above the tank surface. Therefore, the load will be distributed over a much larger surface area of the tank dome, which can carry a load greater than 600,000 lb. For conservatism, the allowable load of the riser was used. A vertical pump drop of exactly 59 ft is conservative. Realistically, the pump is not expected to drop vertically for 59 ft; instead, it would probably tilt and fall on its side above the tank. This scenario makes this analysis even more conservative, as the purpose is to prevent the puncture of the bottom of the tank. A conservative factor not taken into account is the buoyancy and drag forces of the sludge in the tank. They will slow the fall of the pump considerably.

5.0 REFERENCES

Strehlow, J. P., 1993, *Structural Analysis of Tank 241-SY-101 Mixing Pump*, WHC-SD-WM-DA-111, Rev. 1, Westinghouse Hanford Company, Richland, Washington.

Troitsky, M. S., 1982, *Tubular Steel Structures*, The James F. Lincoln Arc Welding Foundation, Cleveland, Ohio.

APPENDIX A

IMPACT LIMITER ANALYSIS

ANALYTICAL CALCULATIONS

Subject: Impact limiter Analysis 241-AZ101
Originator: AHMAD ZIADA Date: 7/14/94
Checker: D. BARLOW Date: 8/18/94

A1.0 Impact Limiter

INTRODUCTION:

The following calculations is to determine the crush strength of the crushable material (Impact limiter) in case of a 22,000 lb pump drop from 59 feet.

ASSUMPTIONS:

1- Allowable loads for the drop will be assumed to be equal to the punching shear capacity of the riser. The value of the punching shear capacity will be assumed to be equal to that of 241-SY101 (Ref. 1)

2- Drag due to sludge in tank will not be introduced in calculations for even more conservatism.

REFERENCES:

① Strehlow, J. P., 1993, Structural Analysis of Tank 241-SY-101 Mixing Pump, WHC-SD-WM-DA-111, Rev. 1, Westinghouse Hanford Company, Richland, Washington

② Troitsky, M. S., 1982, Tubular Steel Structures, The James F. Lincoln Arc Welding Foundation, Cleveland, Ohio.

ANALYTICAL CALCULATIONS

Subject Impact Limiter Analysis 241-AZ101

Originator AHMAD ZIADA Date 7/14/94

Checker D. BARLOW Date 8/18/94

Static Punching Shear Capacity of 42 inch Riser

The static shear capacity around the riser in the pump pit floor is 600,000 lbf.

This value has been obtained from WHC-SD-WM-DA-111 (Ref. Strehlow 1993)

Even though the value was for the 241-SY101 pump pit. The 241-AZ101 pump pit is very similar to the 241-SY101.

Moreover the two tanks are from the same design.

Also the pump weight was directly applied to the riser in 241-SY101, while in the 241-AZ101 the pump weight is applied on the soil above the tank surface, therefore, the value of 600,000 lb is overly conservative.

BD-6400-060.1 (07/93)

ANALYTICAL CALCULATIONS

Subject: Impact Limiter Analysis 241-AZ101
Originator: A.H. ZIADA Date: 7/14/94
Checker: D. BARLOW Date: 8/18/94

Impact Load Limiter Analysis

Pump weight $(W_p) = 22,000$ lb (maximum)

Drop height $(h_d) = 59$ ft. (maximum)

Dimensions:

I.D. = 45 in

O.D. = 74 in

Height = 48 in = $t_{mat.}$ = 4 ft

$$\text{Area } (A) = \frac{\pi (74^2 - 45^2)}{4} = 2710.4 \text{ in}^2$$

Drop Velocity:

$$V^2 = 2gh_d = 2\left(32.2 \frac{ft}{sec^2}\right)(59 ft) = 3799.6 \frac{ft^2}{sec^2}$$

$$\Rightarrow V = 61.64 \frac{ft}{sec}$$

Allowable force applied to the riser

$F_{allow} = 600,000$ lb_f (conservative)

(Ref. Strehlow 1993)

ANALYTICAL CALCULATIONS

Subject: Impact Limiter Analysis 241-AZ101

Originator: AHMAD ZIADA Date: 7/14/94

Checker: D. BARLOW Date: 8/18/94

Find Material Crush strength:

G-Method (Ref. HEXEL, Section A2.0)

$$G_i = \frac{V^2}{0.7\, t_{mat}\,(2)\, g} = \frac{3799.6 \frac{ft^2}{sec^2}}{0.7\,(4ft)(2)(32.2)}$$

$G_i = 21.07$ add Safety factor of 0.2

$\therefore G_f = 26.3375$

$$F = W_p G_f = (22,000\ lb)(26.3375)$$

$$= 579,425\ lb_f < 600,000\ lb_f = F_{allow}$$

$$\Rightarrow f_{cr} = \frac{W_p G_f}{A} = \frac{F}{A} = \frac{579,425\ lb_f}{2710.4\ in^2} = 213.8\ \frac{lb}{in^2}$$

Buckling of 0.02 in. Aluminum skin of Impact limiter

Overall Stability:

$$P_{cr} = \frac{\pi^2 E I}{L_e^2} = \frac{\pi^2 (10,000,000)(I)}{(48)^2}$$

$$I = \frac{\pi (d^4 - d_i^4)}{64} = 0.049087\,(74^4 - 73.96^4)$$

$$= 3180.04\ in^4$$

ANALYTICAL CALCULATIONS

Subject: Impact Limiter Analysis 241-AZ101
Originator: AHMAD ZIADA Date: 7/14/94
Checker: D. BARLOW Date: 8/18/94

$$\Rightarrow P_{cr} = \frac{\pi^2 (10\times10^6)(3180)}{(48)^2} = 136,221,102 \text{ lb.}$$

Obviously unrealistic ⇒ check localized instability.

Local Buckling (Instability):
critical buckling stress -

$$\sigma_{cr} = \frac{Et}{R\sqrt{3(1-\nu^2)}} = 0.6E\frac{t}{R} \quad \text{(Ref. Troitsky, 1982, P.2-2, eq. 2.1)}$$

$$= \frac{0.6(10E6)(0.02)}{37} = 3243 \text{ psi}$$

load per linear inch to buckle

$$p_{cr} = \sigma_{cr} t = 3243 \times 0.02 = 64.86 \text{ lb/in}$$

Total load to buckle entire tube

$$P_{cr} = p_{cr} C = p_{cr} \pi D = 64.86 \pi (74) = \underline{15,079 \text{ lb}}$$

$$\Rightarrow 15,079 \text{ lb} << 580,000 \text{ lb}$$

This could affect the calculations for the impact limiter slightly, therefore the aluminum casing should be crippled to preclude this initial buckling resistance

ANALYTICAL CALCULATIONS

Subject: Impact Limiter Analysis 241-AZ101
Originator: AHMAD ZIADA — Date: 7/25/94
Checker: D. BARLOW — Date: 8/18/94

CONCLUSIONS

1- All the of the flat area of the impact limiter must be subjected to the crushing load.

2- The maximum deceleration of the pump will be 27.3g at 221 psi crush. $\left(\frac{221 \times A}{22{,}000} = 27.3\right)$

3- The Aluminum casing of the impact limiter should be crippled to preclude any initial buckling resistance.

4- The crushing strength of the impact limiter is 213 lb/in² (221 psi maximum and 205 psi minimum)
$\left(\frac{600{,}000\ lb}{2710.4\ in^2} = 221\ psi\right)$ $\left(\frac{KE \cdot 1.2}{A \times 0.7 \times ?} = 205\ psi\right)$

5- It must be verified that the tank dome and impact limiter support structure can withstand the 600,000 lb impact from the pump drop.

6- The maximum impact load applied to the impact limiter and tank will be 600,000 lb.

SUMMARY OF DESIGN PROCEDURE

Energy absorption problems can be presented in several forms. However, most of these forms can be reduced to the following basic requirements:

1. GIVEN—The following information must be given or computed from the general formulas presented on Page 10 of this bulletin.

   W — Lbs. — Impacting Weight
   v — Ft/sec. — Impact Velocity
   G(1) — — G Limit
   A — In^2 — Impacting Area

2. MINIMUM THICKNESS—Enter the minimum honeycomb thickness graph on Page 4 and read a value for t_c minimum.

3. MAXIMUM CRUSH STRENGTH — Enter the maximum honeycomb crush strength graph on Page 5 and read a value for f_{cr} maximum.

> YOU NOW HAVE A PRELIMINARY SOLUTION INDICATING THE FEASIBILITY OF HONEYCOMB IN THIS APPLICATION. THE SOLUTION CAN BE COMPLETED BY SELECTING A HONEYCOMB SYSTEM FROM THE DATA PROVIDED ON PAGE 7 AND MAKING THE FINAL CHECK.

4. FINAL CHECK—In selecting a honeycomb material, it may be necessary to reduce the actual value of the f_{cr} being used below the maximum value obtained graphically (2). If this is the case, care must be taken to also **increase** the honeycomb core thickness to prevent bottoming out of the payload and thus increasing the peak G value. This balancing of the f_{cr} value and t_c value will be accomplished by equating t_c as follows:

$$t_c = \frac{Wv^2}{f_{cr}A} \times \frac{0.5}{0.7g} \times 12 = t_c \text{ in inches for units given on Page 2}$$

All final solutions should be checked through this equation.

(1) See Page 12 for the solution to problems in which G is not a design consideration.

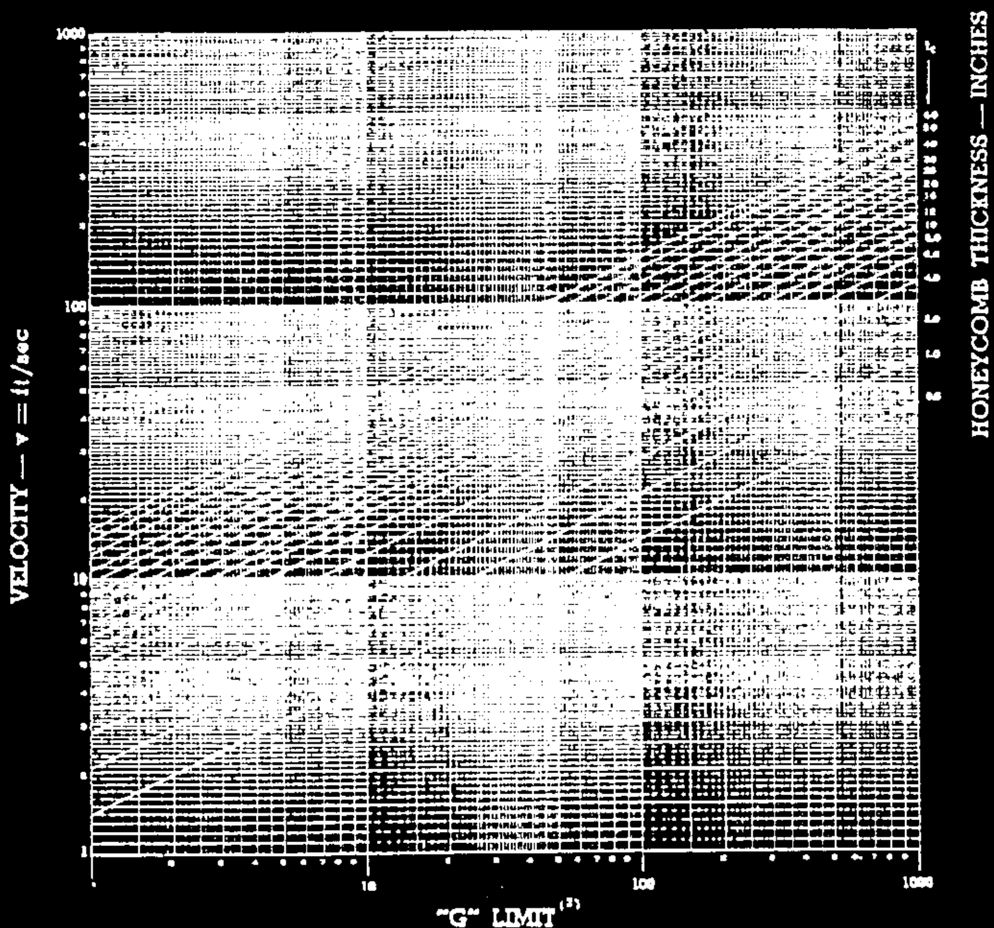
(2) Standard Core materials are supplied with fixed crush strengths. (See HEXCEL TSB #120).

H-66-30

PRELIMINARY SOLUTION

FOR

MINIMUM HONEYCOMB THICKNESS [1]



USE OF THIS CHART

GIVEN:

Impact velocity . . . v

G Limit . . . . . . G

1. With the known values of G and Impact velocity v, enter the chart and read a value for the minimum honeycomb thickness required in inches. Any greater honeycomb thickness can be used.

(1) This solution takes into consideration the fact that only 70% of the honeycomb material is available for crushing.

(2) See Page 12 for the solution to problems in which G is not a design consideration.

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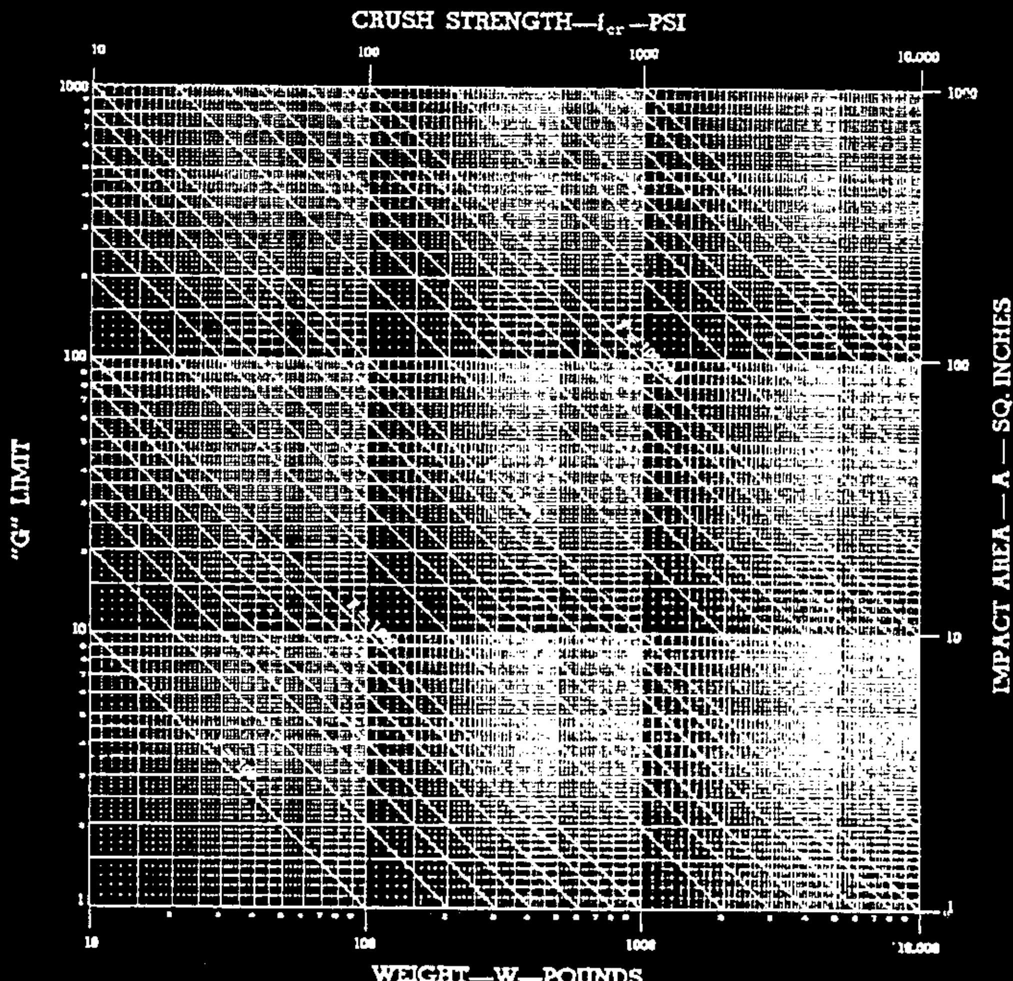
PRELIMINARY SOLUTION
FOR
MAXIMUM HONEYCOMB CRUSH STRENGTH



USE OF THIS CHART

GIVEN:

G Limit . . . . . G

Impacting Weight . . W

Impact Area . . . . A

1. Enter the above chart with the known values of W and G.
2. The intersection of the coordinates W and G define an F curve (slanted lines) representing the force of impact.
3. Move along this F curve to the intersection of the horizontal line representing the impact area (A) being considered.
4. At this point on the F curve, move vertically upward on the chart and read the maximum allowable crush strength (f_{cr}) for this application.
5. This value of f_{cr} may now be used to select a honeycomb energy absorption material.

SAFETY FACTORS

It should be understood that the method presented here is an idealized system, which will provide solutions indicating the feasibility and suggested design parameters of a honeycomb energy absorption system. Due to some observed increase in honeycomb crush strength with increasing velocities, pilot systems should be designed and tested before final design is adopted and used. This increase in f_{cr} at high impact velocities will, in most cases, be covered by multiplying the G value by 0.8 prior to entering design curves. Naturally, other safety factors normally applied to material properties, etc., should also be included as required.

CAUTION

Because of the maximum and minimum requirements of a designed energy absorption system, some safety factors may give opposite results. Inspect the net result of all safety factors.

SAMPLE PROBLEM

Provide an energy absorption system to protect a 150 pound payload against G loads in excess of 30 G's. The total kinetic energy at impact is 2200 foot pounds and the impacting area of the payload is 75 square inches. Provide a factor of safety of 20% against peak G's.

1. GIVEN —
   W = 150 Lbs.
   v = 30 ft/sec. from the kinetic energy graph on Page 11
   G = 30 x 0.8 = 24 with safety factor
   A = 75 In^2

2. MINIMUM THICKNESS—Entering the minimum honeycomb thickness chart on Page 4 with V = 30 ft/sec. and G = 24, read a value:
   t_c minimum = 10 inches

3. MAXIMUM CRUSH STRENGTH — Entering the maximum crush strength graph on Page 5 with G = 24 and W = 150 lbs., intersect F curve 3700. Moving along this curve to the intersection of A = 75 in^2 and then reading vertically to the top of the chart:
   f_{cr} maximum = 49 psi

4. SELECT A HONEYCOMB—Deciding to use a standard expanded aluminum honeycomb, we select a 3/16 3003—.0007 honeycomb material from Hexcel's TSB #120 "Mechanical Properties of Hexcel Honeycomb Materials". This material has a listed crush strength of 43 psi.

5. FINAL CHECK—Running a final check for t_c from the check equation given on Page 3.

$$t_c = \frac{Wv^2}{f_{cr}A} \times \frac{0.5}{0.7g} \times 12$$

$$t_c = \frac{150 \times 30^2}{43 \times 75} \times \frac{0.5}{0.7 \times 32.2} \times 12 = 11.2 \text{ inches}$$

6. USE —
   AL 3/16 3003—.0007 with f_{cr} = 43 psi
   at t_c = 11.2 inches

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TYPICAL HONEYCOMB CRUSH STRENGTH PROPERTIES

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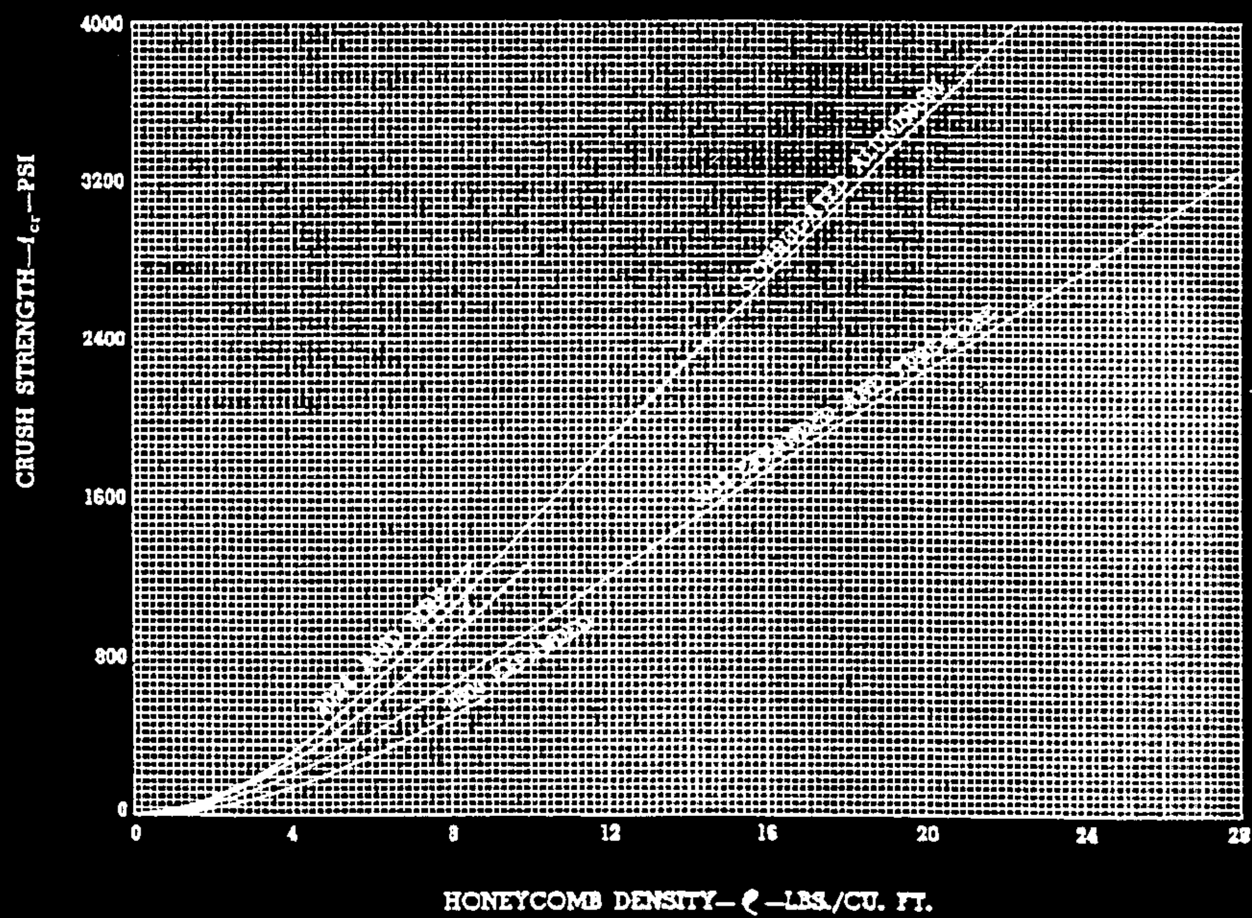
Due to the number of variables available in the manufacture of honeycomb energy absorption systems, it is suggested that the actual selection of a specific material, cell size, foil gage, etc. be left to the honeycomb manufacturer. Hexcel's Applications Engineers are available to interpret your specifications and select the most economical combinations suitable to your design requirements. Configurations such as TUBE-CORE and CROSS-CORE are always supplied as custom designed materials to meet the crush strength and thickness values required.

To provide a preliminary selection of the weight of honeycomb required to satisfy your design conditions, the graph below presents a plot of crush strength vs. density for various honeycomb configurations and materials. Actual f_{cr} values for expanded core materials in the one-to-eight pound density range may be found in Hexcel's Technical Service Bulletin No. 120, "Mechanical Properties of Hexcel Honeycomb Materials".

DYNAMIC CRUSH STRENGTH

It should be emphasized that the dynamic crush strength appears to be a function of the impact velocity and is usually higher than the static crush strength shown below. For preliminary design, an increase of 30% in the static value shown below may be used as the dynamic crush strength as a first approximation.

HONEYCOMB CRUSH STRENGTH VS. DENSITY



APPENDIX

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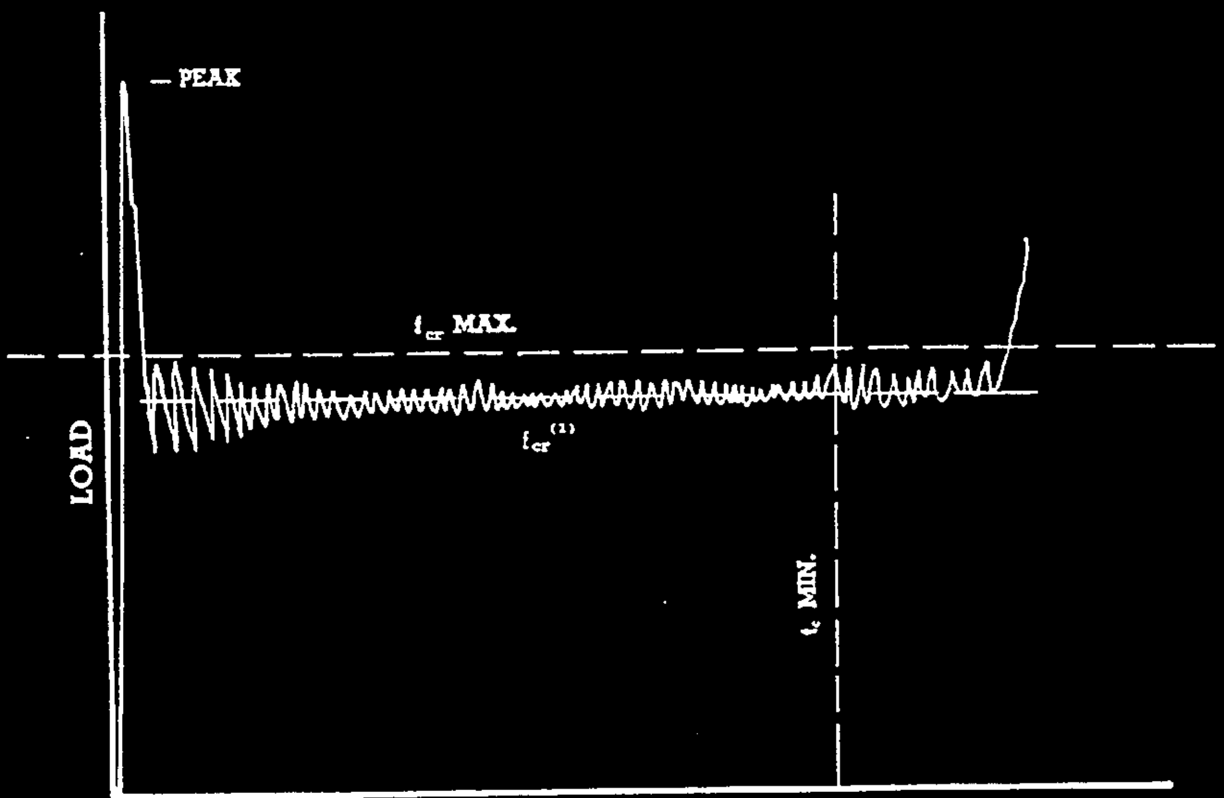
LOAD AND DEFLECTION

The load and deflection characteristics encountered in statically crushing honeycomb are graphically shown in the figure below. This curve indicates the value of the resistance to loading offered by the honeycomb as the compressive load is overcome and crushing starts and continues. Three items on this curve are of special interest:

A. COMPRESSIVE PEAK — Honeycomb systems which are not precrushed or in which the initial contact area has not been reduced exhibit this peak force level at impact. This undesirable peak can be easily eliminated by proper design.

B. MAXIMUM CRUSH LEVEL — A horizontal line has been drawn across this curve representing a maximum crush level. If this hypothetical line had been developed as a design maximum, then the actual honeycomb f_{cr} value must remain equal to or below this level for crushing to take place.

C. MINIMUM STOPPING DISTANCE — The vertical line drawn down this graph represents a hypothetical stopping distance minimum established in conjunction with the maximum crush level value. This value represents a minimum value for the maximum crush level line and any crush level selected below the maximum limit will require an increase in this minimum thickness.



(1) The actual crush strength of honeycomb is normally given as the average value of the load diagram inflections.

APPENDIX

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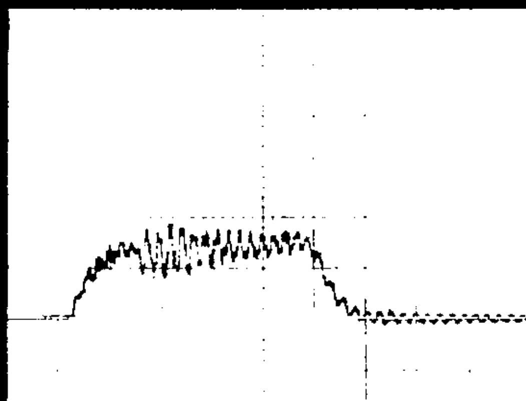
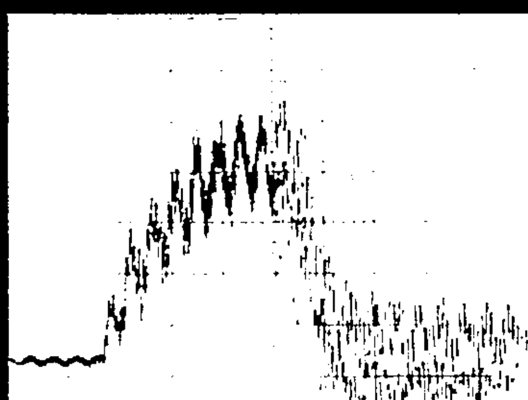
TYPICAL DYNAMIC RESPONSES

The accelerometer traces shown below are actual plots of deceleration vs. time (ordinate and abscissa respectfully) for three conditions of impact.



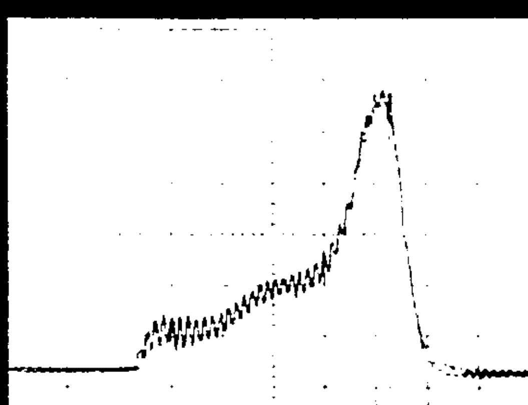
Condition #1

This square trace is the pattern normally obtained from the crushing of a constant area of honeycomb material.



Condition #2

The sloped trace is a pattern developed by crushing a honeycomb section in which the area of material is increasing with the deflection.



Condition #3

This trace shows the sharp "G" level increase produced when inadequate honeycomb thickness allows the payload to bottom out. Maintaining the designed t_c minimum should prevent this type of failure.

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APPENDIX

FORMULAS

→ imp.

The following formulas are those commonly encountered in simple energy absorption calculations.[1]

General: [2]

1. Kinetic Energy, $KE = \frac{1}{2} mv^2$
2. Mass, $m = W/g$
3. Dynamic Force, $F = ma$
4. $G = a/g$
5. Velocity, $v_f^2 = v_0^2 + 2aS$
6. Distance travelled, $S = v_0 t + \frac{1}{2} at^2$

Honeycomb Energy Absorption:

7. **Stopping Distance, S.** From 5. above for v_f equal to impact velocity and v_0 equal to zero,

$$v^2 = 2aS$$

and from 4. above, $a = Gg$. Therefore: $S = \frac{v^2}{2gG}$

8. **Minimum core thickness, t_c.** Assuming 70% of the total honeycomb thickness is available for crushing, then $S = 0.7t_c$ and therefore, from 7.

$$t_c = \frac{1}{0.7}\frac{v^2}{2gG}$$

This formula has been presented graphically on Page 3 of this bulletin.

9. **Crush strength, f_{cr}.** Since $f_{cr} = F/A$ and from 3. above:

$$F = ma = \frac{Wa}{g} = WG$$

$$\text{then } f_{cr} = \frac{WG}{A}$$

This formula has been presented graphically on Page 4 of this bulletin.

It can be shown that:

$$KE = f_{cr} AS$$

from 1. above

$$KE = \frac{1}{2} mv^2 = \frac{wv^2}{2g} = \frac{WGS}{2g} = WGS = FS = f_{cr} AS$$

Setting S equal to $0.7t_c$ and solving for t_c will produce the final check equation presented on Page 3.

1. Formulas based on acceleration being a constant
2. $g = 32.2$ ft/sec² for earth environment only

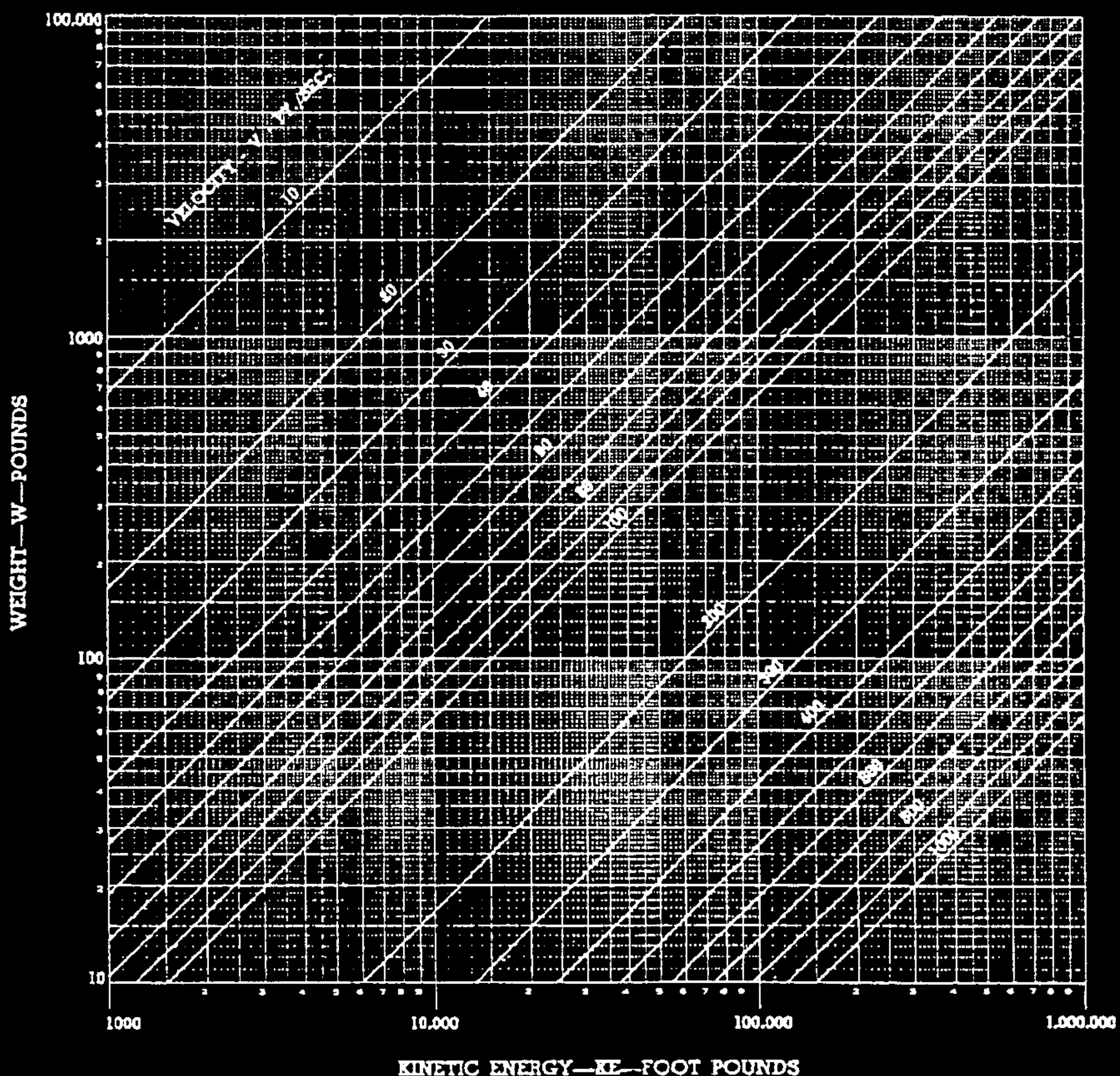
APPENDIX

H-66-30

KINETIC ENERGY EQUATION SOLUTION

This chart offers a rapid solution to the equation[1]:

$$KE = \frac{1}{2}mv^2 = \frac{1}{2}\ \frac{Wv^2}{g}$$



[1] Plotted for $g = 32.2$ ft/sec.^{2} (For earth environment only)

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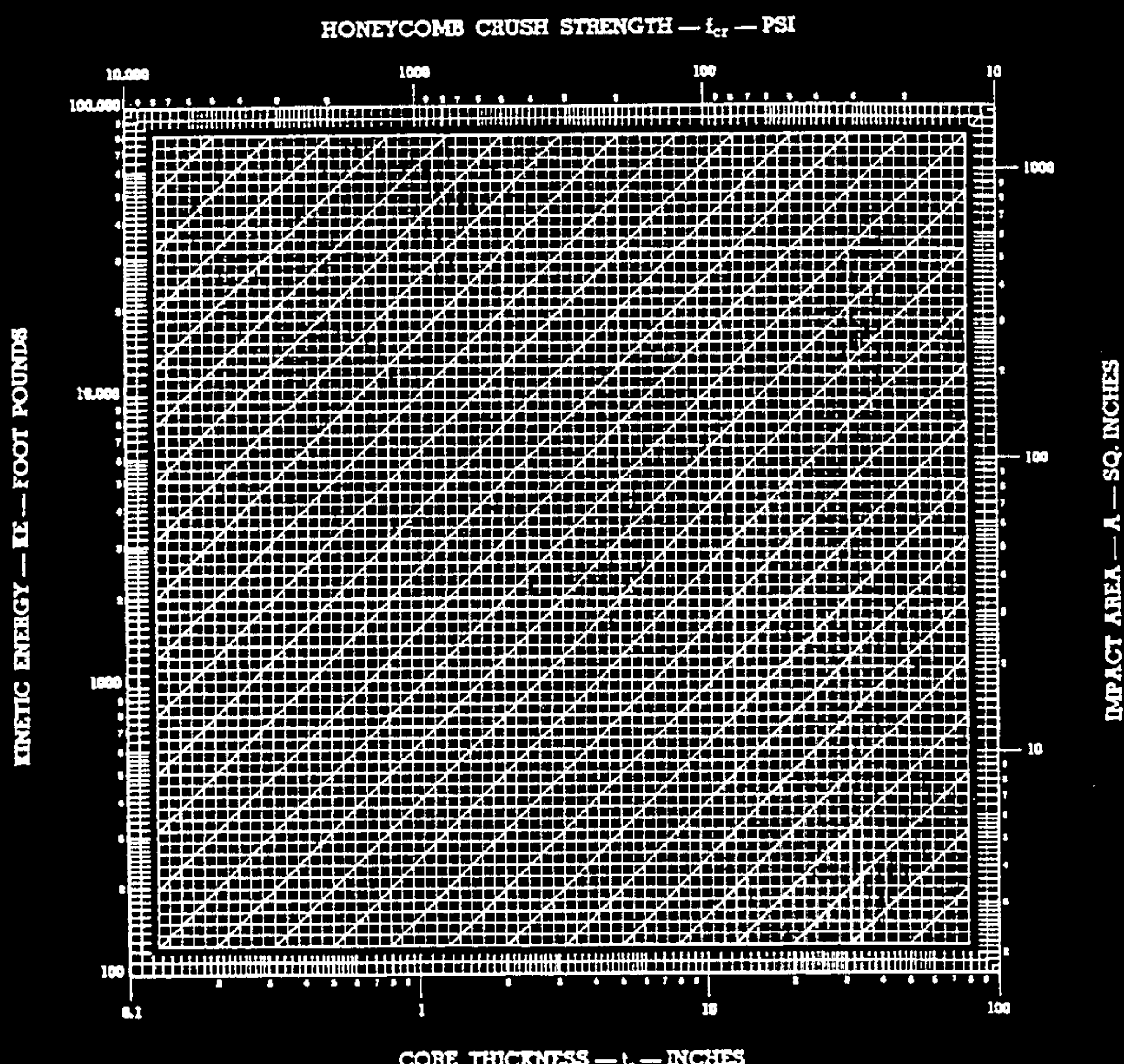
KINETIC ENERGY ABSORPTION

This chart offers a solution to energy absorption problems in which **no limiting G value is required** (i.e. stop a payload in a specific distance with no rebound - - - G not critical). The chart graphically solves the equation:

$$KE = f_{cr}\ AS = f_{cr}\ A\ 0.7t_c$$

USE OF THIS CHART

1. Enter the chart with the known value of KE in foot-pounds and total core thickness t_c in inches. The intersection of the coordinates KE and t_c defines a diagonal line.
2. Move along this diagonal to the intersection of the horizontal line representing the impact area A being considered.
3. At this point on the diagonal, move vertically upward on the chart and read the crush strength f_{cr} required.



DISTRIBUTION SHEET

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February 7, 1996

Project Title/Work Order:

Project W-151, Tank 101-AZ Waste Retrieval System
Mixer Pump Energy Absorption Cylinder Analysis, SD-W151-DA-004

EDT No.: 142177 **ECN No.:** N/A **Charge Code:** D2DA1

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