SBEDS

(Single degree of freedom Blast Effects Design Spreadsheets)

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Background

- **Implementation of DoD antiterrorism standards requiring more blast design of 'conventional' facilities**
- **Existing blast resistant structural design tools developed for design of more robust structures**
- **Existing tools cumbersome for design of more conventional structures**
- **USACE Protective Design Center, through Baker-Risk, developed SBEDS as a designer friendly tool for more typical construction**

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SBEDS - General

- **SBEDS is an EXCEL© workbook that combines all steps to design/analyze a wide variety of blast-loaded structural components**
- **User inputs basic geometry, boundary condition, material property, response mode, and blast load for component**
- **SBEDS calculates single degree of freedom (SDOF) response for 10 types of structural components**
  - **Also allows for user input of general SDOF system**
- **Follows Army TM 5-1300/UFC 3-340-01 guidance as applicable**

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SBEDS – General (continued)

- **Calculates equivalent SDOF parameters and determines dynamic response w/ time-stepping SDOF calculator**
- **Considers many different response modes**
- **Outputs maximum response parameters and response history plots**
- **Also performs shear check w/ stirrup design for concrete & CMU components**
- **Designated Metric or English Units**
- **Detailed Help/Users Guide hot-linked to workbook**

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Available Component Types

- **One-Way Corrugated Metal Panel**
- **One-Way or Two-Way Steel Plate**
- **One-Way Steel Beam or Beam-Column**
- **One-Way Open-Web Steel Joist**
- **One-Way or Two-Way Reinforced Concrete Slab**
- **One-Way Reinforced Concrete Beam or Beam-Column**
- **One-Way or Two-Way Reinforced Masonry**
- **One-Way or Two-Way Unreinforced Masonry**
- **One-Way or Two-Way Wood Panel**
- **One-Way Wood Beam or Beam-Column**
- **General SDOF system**

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SBEDS Structure

- **ReadMe Sheet**
  - **General administrative information**
  - **Support information**
- **Intro Sheet**
  - **Component selection**
  - **Units selection**
  - **Link to User's Guide for discussion of methodology and many of the inputs**
  - **Workbook instructions**
  - **Discussion of workbook design**

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SBEDS Structure (continued)

- **Input Sheet**
  - Separate component and units specific input sheets for each component
  - Input sheets show all required input parameters and calculated resistance-deflection relationship
  - Applicable input sheet pulled into main SBEDS workbook by macro from separate workbook (SBEDS_templates.xls)
  - Reports calculated equivalent SDOF system and maximum response parameters
- **Results Sheet**
  - Maximum response parameters
  - Response histories

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SBEDS Structure (continued)

- **SDOF Sheet (hidden)**
  - **Equivalent SDOF system**
  - **Time-stepping SDOF solution**
- **Database Sheet**
  - **Properties of library members**
  - **SDOF constants**
- **PositivePhasedLoad Sheet (hidden)**
  - **Positive phase blast parameters**
- **NegativePhaseLoad Sheet (hidden)**
  - **Negative phase blast parameters**
- **Wait**

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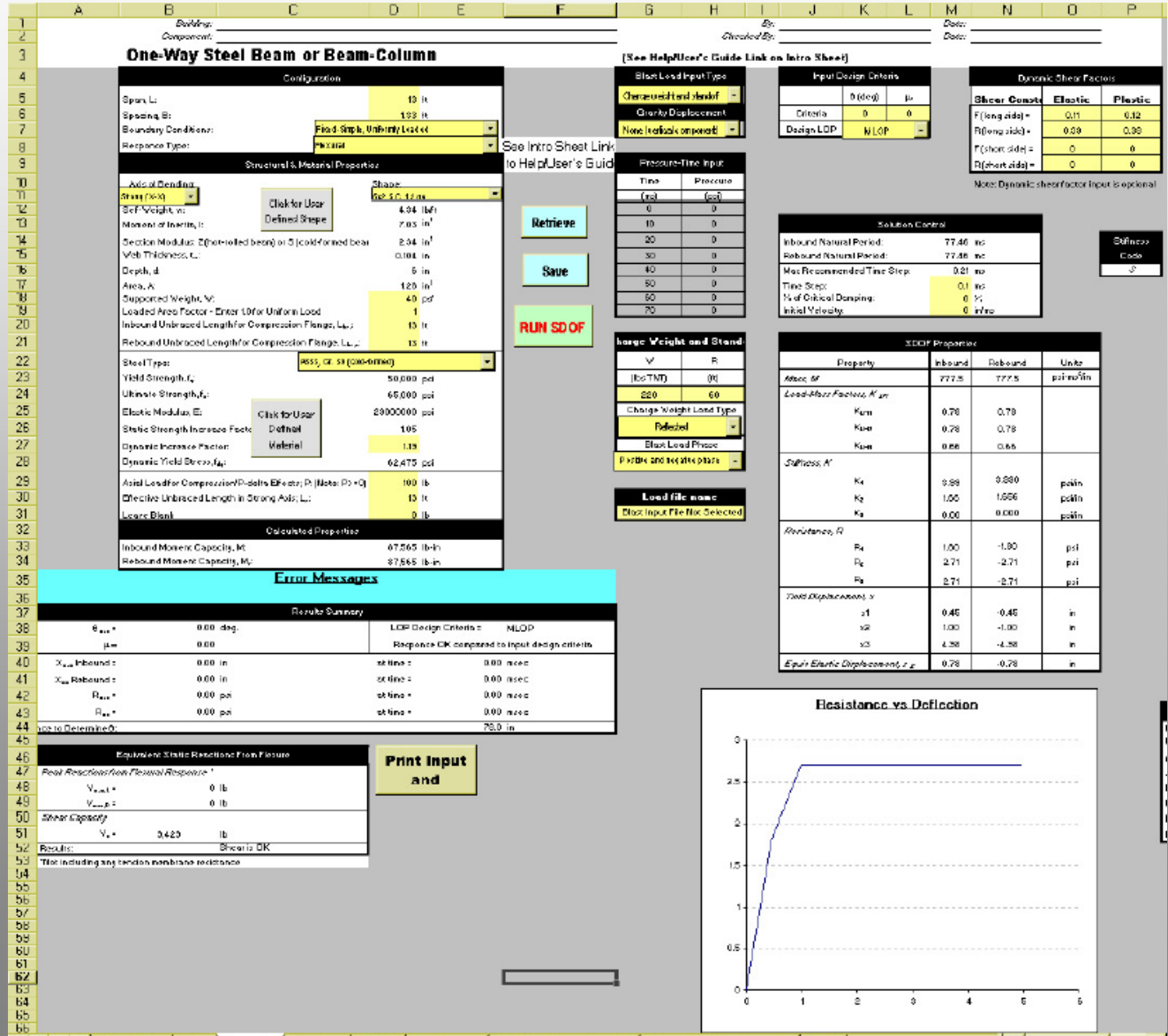
Input Sheet (for One-Way Steel Beam or Beam-Column)



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SBEDS Inputs

- **Select one of 10 different component types**
- **Select designated English or Metric units**
- **Select from various boundary conditions**
- **Select applicable response mode/type to calculate resistance-deflection curve**
- **Select load input type**
- **Solution options**

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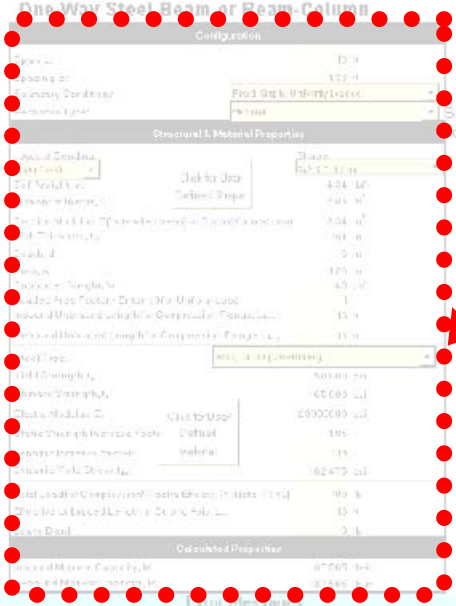
Component Input



Configuration		
Span, L:	13	ft
Spacing, B:	2	ft
Boundary Conditions:	Fixed-Simple, Uniformly Loaded	
Response Type:	Flexural	

Structural & Material Properties		
Axis of Bending:	Strong (X-X)	
Shape:	6x2.5.7 12 ga	
Click for User Defined Shape		
Self-Weight, w:	4.34	lb/ft
Moment of Inertia, I:	7.01	in^4
Section Modulus: Z (hot-rolled beam) or S (cold-formed beam):	2.29	in^3
Web Thickness, t_w:	0.104	in
Depth, d:	6	in
Area, A:	1.28	in^2
Supported Weight, W:	20	psf
Loaded Area Factor - Enter 1.0 for Uniform Load	1	
Inbound Unbraced Length for Compression Flange, $L_{br,i}$:		ft
Rebound Unbraced Length for Compression Flange, $L_{br,r}$:		ft
Steel Type:	A992, A913, A572, A529 (All Gr. 50) rolled shapes	
Yield Strength, f_y:	50,000	psi
Ultimate Strength, f_u:	70,000	psi
Click for User Defined Material		
Elastic Modulus, E:	29000000	psi
Static Strength Increase Factor:	1.05	
Dynamic Increase Factor:	1.19	
Dynamic Yield Stress, f_{dy}:	62,475	psi
Axial Load for Compression/P-delta Effects; P: (Note: P>=0)	200	lb
Effective Unbraced Length in Strong Axis; L_e:	13	ft
Leave Blank		lb

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SBEDS Drop-Down Menus (All in Metric/English)

- **Support conditions**
- **Response mode**
- **Beam sizes (AISC and cold-formed girts/purlins)**
- **Open web steel joist sizes (K and LH series)**
- **Masonry (Brick, European block, Heavy-Medium-Lightweight CMU)**
- **Corrugated metal panel sizes (MBCI and Vulcraft sizes, traditional and standing-seam deck)**
- **Typ. steel plate, beam, and rebar material properties**
- **All drop-downs automatically insert properties of selected size/type into spreadsheet**
- **User-defined option available for all drop-down menus**

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Available Boundary Conditions and Loadings

Supports Conditions	Component Types	Loading		
		Concentrated[1]	Uniform	P-Delta
Cantilever Fixed-Fixed Fixed-Simple Simple-Simple	One-way Corrugated Metal Panel		X	
	One-Way Steel Plate		X	
	One-Way Reinforced Concrete Slab		X	X
	One-Way Reinforced Masonry		X	X
	One-Way Unreinforced Masonry		X	X
	One-Way Wood Panel		X	
	One-Way Steel Beam or Beam-Column	X	X	X
	One-Way Reinforced Concrete Beam or Beam-Column	X	X	X
	One-Way Wood Beam or Beam-Column	X	X	X
Four/Three/Two Adjacent Sides Supported – Fixed Four/Three/Two Adjacent Sides Supported – Simple	Two-Way Steel Plate		X	
	Two-Way Reinforced Concrete Slab		X	X
	Two-Way Reinforced Masonry		X	X
	Two-Way Unreinforced Masonry		X	X
	Two-Way Wood Panel		X	
Simple-Simple	Open-Web Steel Joist		X	
N/A	General SDOF System		X	X

[1] – Load located at end of cantilever members, midspan for other support conditions.

Available Response Modes

Component Types	Flexure	Tension Membrane	Compression Membrane
Corrugated Metal Panel	X	X	
Steel Plate	X	X	
Steel Beam or Beam-Column	X	X	
Open-Web Steel Joist	X		
Reinforced Concrete Slab	X	X	X
Reinforced Concrete Beam or Beam-Column	X	X	X
Reinforced Masonry	X	X	X
Unreinforced Masonry	X[1]		X[2]
Wood Panel	X		
Wood Beam or Beam-Column	X		
General SDOF System	N/A, user directly inputs resistance function		

[1] - Brittle flexure w/ axial load softening or ductile flexure

[2] - Rigid arching only

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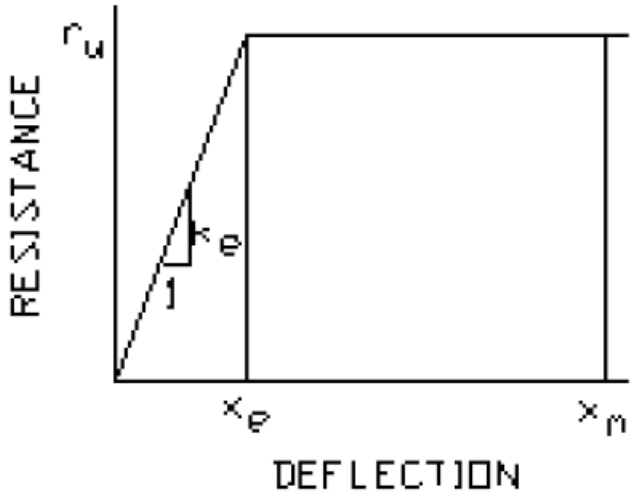
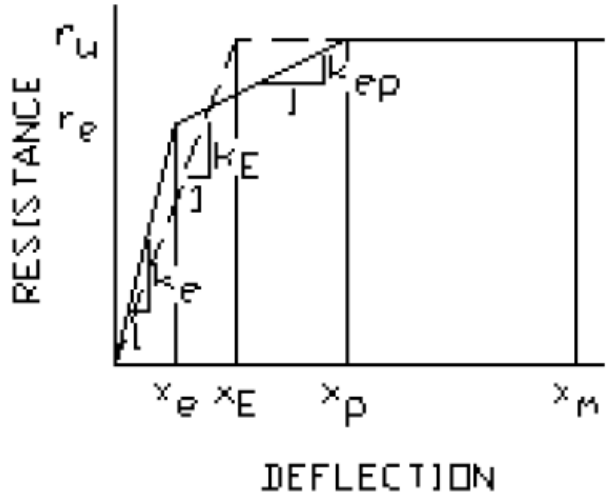
Resistance Functions – Flexure



Determinate Boundary Conditions



Indeterminate Boundary Conditions
(Solid Curve Used for Flexure Only)
(Dashed Curve for Flexure and Tension Membrane)

Figure 4. Resistance-Deflection Curve For Flexural Response

Tension Membrane (TM) for Steel Components

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- **Approximate method that adds tension membrane resistance to flexural resistance**
- **TM causes linear increase in resistance based on max. TM force**
- **Max. TM force based on lesser of input in-plane connection capacity or cross sectional yield**
- **TM increase in resistance occurs at yield deflection plus deflection to develop max. TM force in TM response**
  - **Inclusion of yield deflection approximately accounts for flexibility in system**

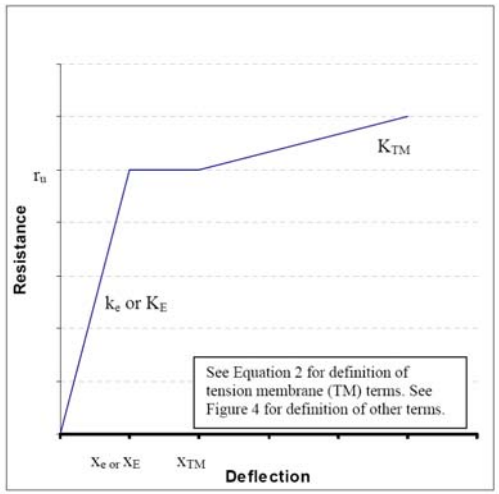

Figure 5. Resistance Deflection Curve for Steel Components with Tension Membrane

$$x_{TM} = x_E + \sqrt{\frac{4TL^2}{\pi^2 EA}} \quad \text{where} \quad T = \text{Minimum}\left[\left(f_{dy}A\right), V_c\right]$$

$$K_{TM\_1} = \frac{8T}{bL^2}$$

$$K_{TM\_2} = \frac{T\pi^3}{4L_y^2 \sum_{n=1,3,5,7}\left[\frac{1}{n^3}(-1)^{(n-1)/2} A\right]} \quad \text{where} \quad A = 1 - \frac{1}{\cosh\frac{n\pi L_x}{2L_y}} \quad \text{and} \quad L_x \geq L_y$$

Equation 2

where:

x_{TM}= assumed deflection at beginning of linear tension membrane response adding to flexural response for one and two-way response

K_{TM_i}= linear tension membrane slope for one-way (i=1) or two-way (i=2) response

x_E = equivalent elastic yield deflection

f_{dy} = dynamic yield strength

A = component cross sectional area within loaded width b

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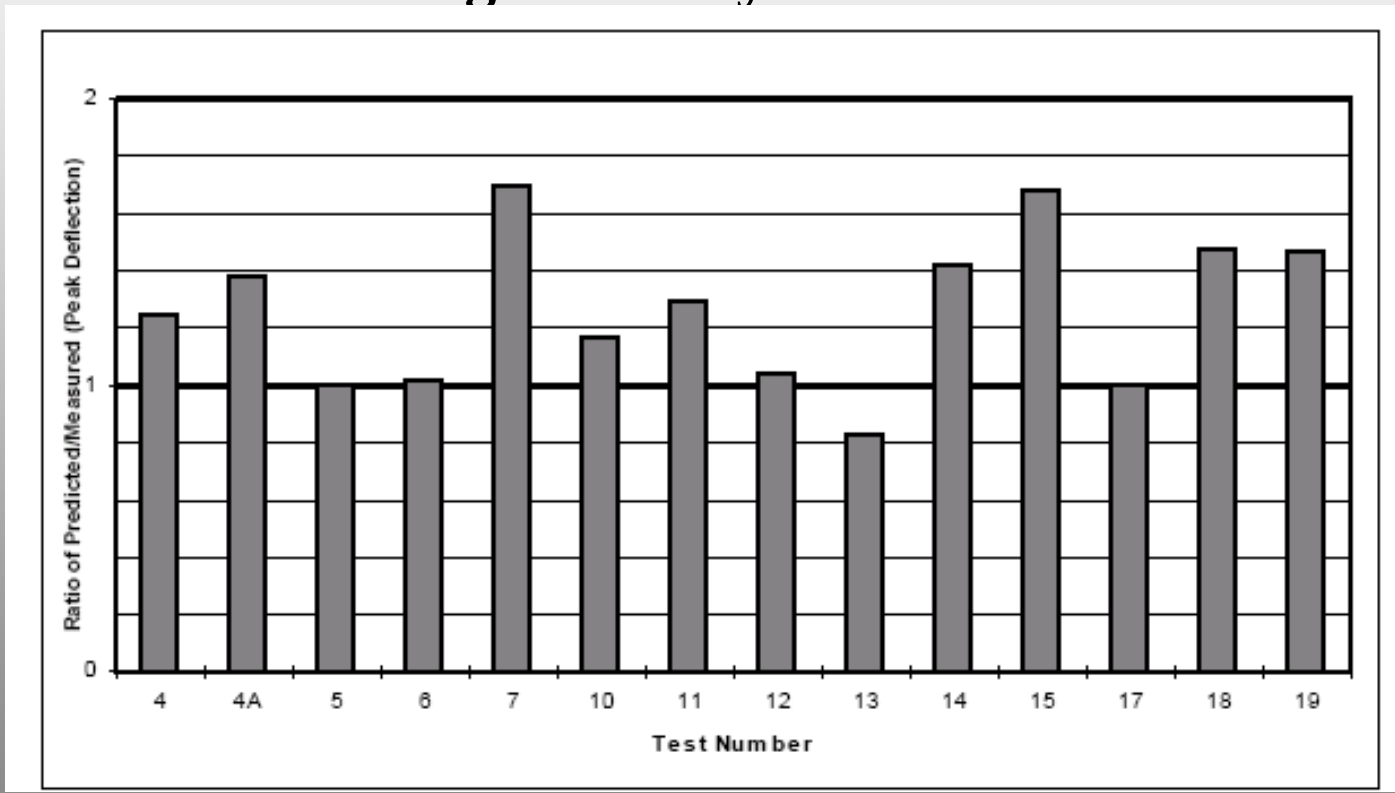
Validation of SBEDS Tension Membrane Approach

- **Method compares well to limited shock tube test data of cold-formed girt/wall systems**



Girt deflections from shock tube tests by BakerRisk.

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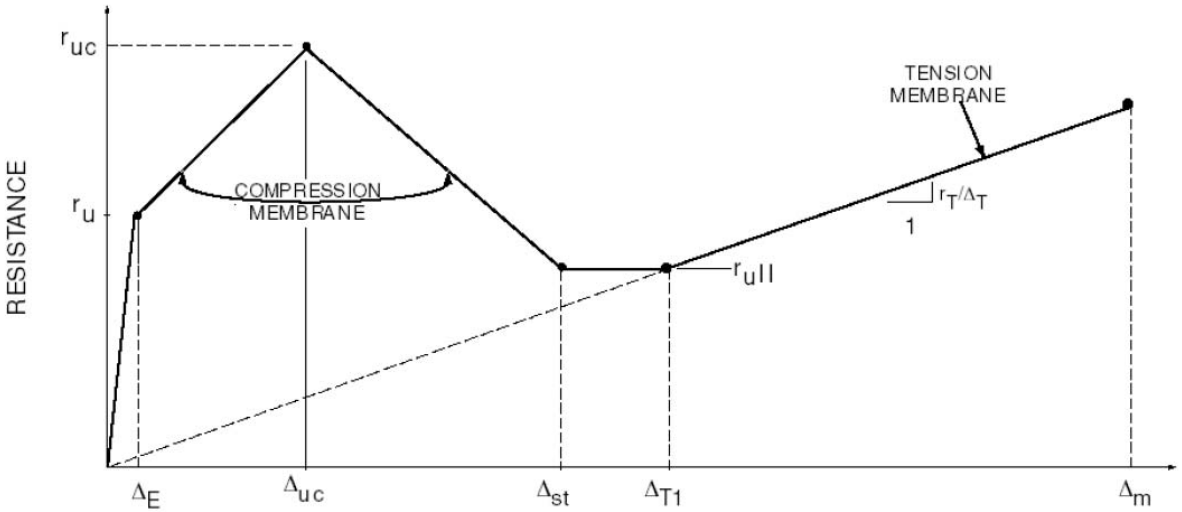
Resistance Function – Compression Membrane



r_{uc} = COMPRESSIVE MEMBRANE ULTIMATE RESISTANCE TO UNIFORM LOAD (PARAGRAPH 10.4.2)

Δ_{uc} = CENTRAL DEFLECTION OCCURING AT r_{uc} (PARAGRAPH 10.4.2)

r_{ull} = FLEXURAL RESISTANCE USING TYPE II ULTIMATE MOMENT CAPACITY (PARAGRAPHS 10.3.3.2 AND 10.9.1)

r_T/Δ_T = TENSILE MEMBRANE RESISTANCE/CENTRAL DEFLECTION (PARAGRAPH 10.4.3)

Δ_m = MAXIMUM CENTRAL DEFLECTION, CORRESPONDING TO DESIGN RESPONSE LIMIT (PARAGRAPH 10.10)

Δ_{st} = CENTRAL DEFLECTION AT SNAP-THROUGH (PARAGRAPH 10.4.2)

Δ_{T1} = CENTRAL DEFLECTION WHERE TENSILE MEMBRANE SLOPE THROUGH ORIGIN REACHES r_{ull} (BUT $\Delta_{T1} \geq \Delta_{st}$)

r_u = ULTIMATE FLEXURAL RESISTANCE TO UNIFORM LOAD (PARAGRAPH 10.9.1)

Δ_E = EQUIVALENT ELASTIC DEFLECTION IN FLEXURE (PARAGRAPH 10.9.1)

Figure 18. Resistance-Deflection Curve for Reinforced Concrete and Masonry Components with Compression and Tension Membrane (from UFC 3-340-01)

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Resistance Function – Brittle Flexure w/ Axial Load Softening (Unreinforced Masonry)

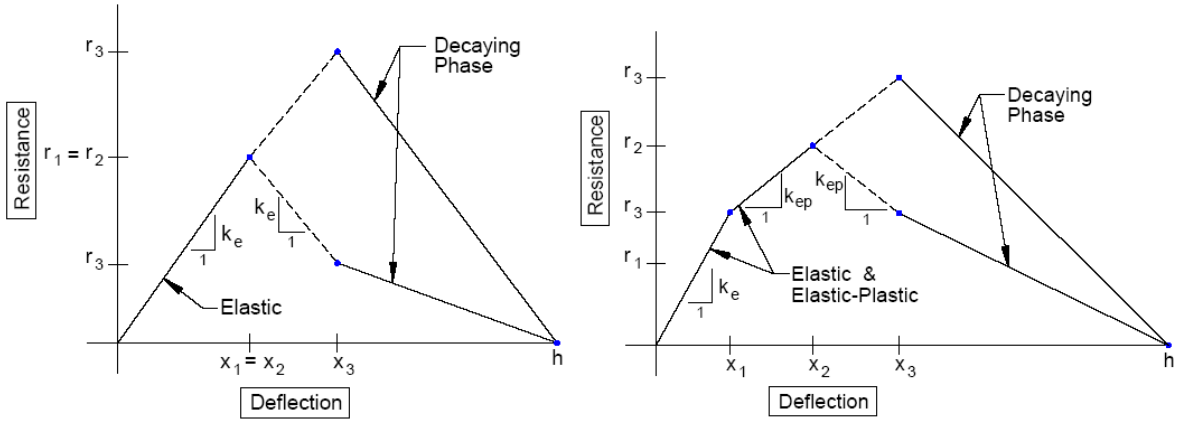

Figure 25. Resistance-Deflection Curves for Unreinforced Masonry with Brittle Flexural Response and Axial Load From WAC Program

$$r_3 = \frac{4}{L^2}(h-\Delta)\left(P+\frac{WL}{2}\right)$$

Equation 7

where:

r_3 = maximum resistance from axial load effects

x_3 = flexural deflection at $r_2 + (r_3 - r_2)/K_{ep}$

K_{ep} = elastic-plastic stiffness for indeterminate components, otherwise equal to elastic stiffness

h = overall wall thickness

P = input axial load per unit width along wall, P_{axial}

W = areal self-weight and supported weight of wall

L = span length equal to wall height

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Resistance Function – Compression Membrane (Unreinforced Masonry)

Equations for compression membrane from Reinforced Concrete Slabs by Park and Gamble modified to account for gap between wall and rigid support and non-solid cross section

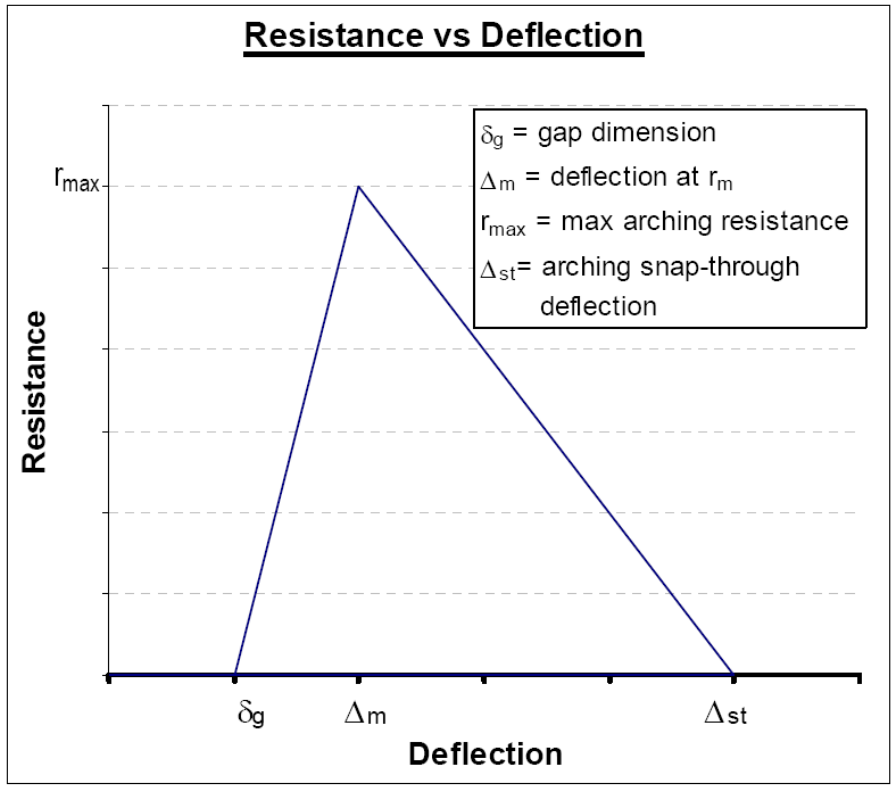

Figure 26. Arching Resistance-Deflection Curve

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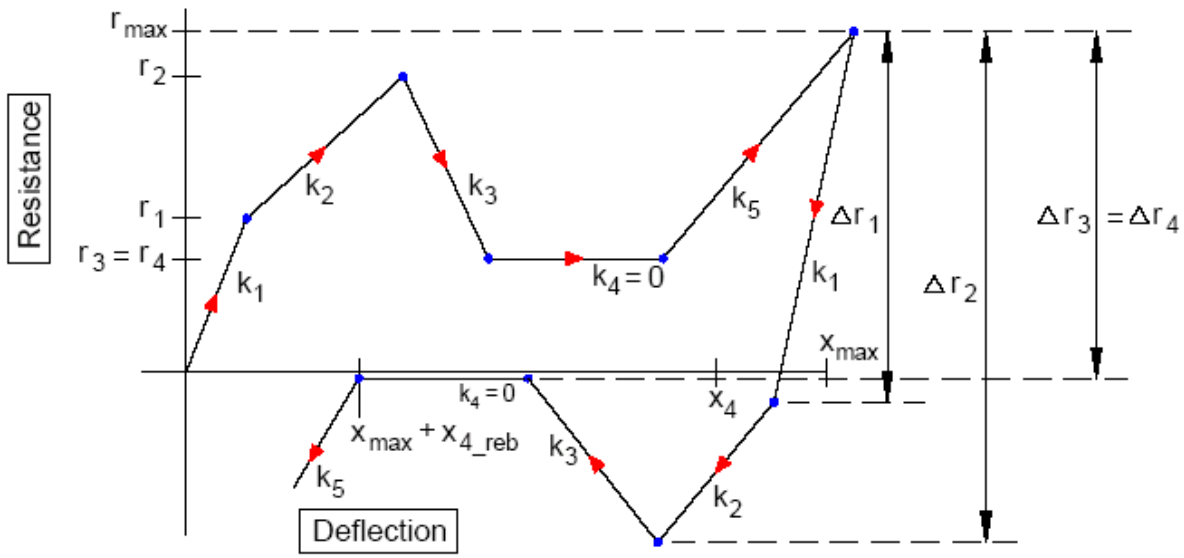
General System Resistance-Deflection Curve in SBEDS



Note: k_i are input stiffness for response ranges i = 1 to 5: $k_i \geq 0$
r_i are input inbound resistances for response ranges i = 1 to 5: $r_i \geq 0$
$\Delta r_i = (r_i - r_{i\_reb})$
r_{i_reb} are input rebound resistances for response ranges i = 1 to 5: $r_{i\_reb} \leq 0$
x_i are input inbound maximum deflections for response ranges i = 1 to 5: $x_i \geq 0$
x_{i_reb} are input rebound maximum deflections for response ranges i = 1 to 5: $x_i \leq 0$
Note 1: x_i and x_{i_reb} are only used if $k_i = 0$
Note 2: rebound in both directions is calculated as shown above for first rebound

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Calculated Resistance-Deflection Relationship on Input Sheet

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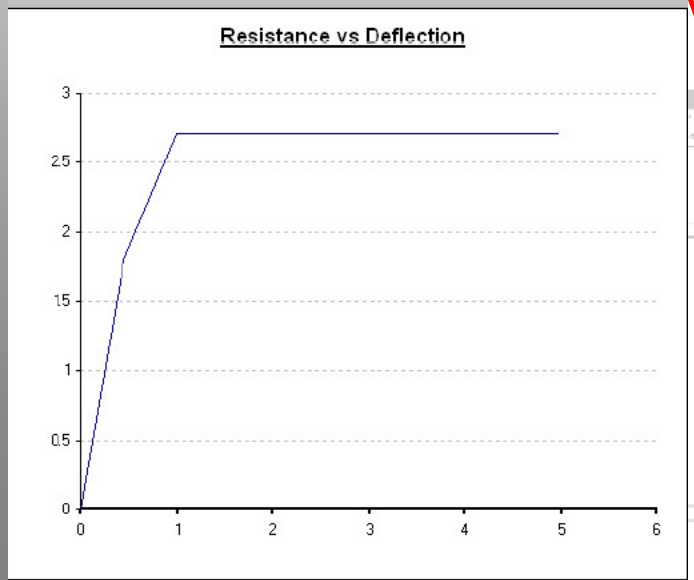
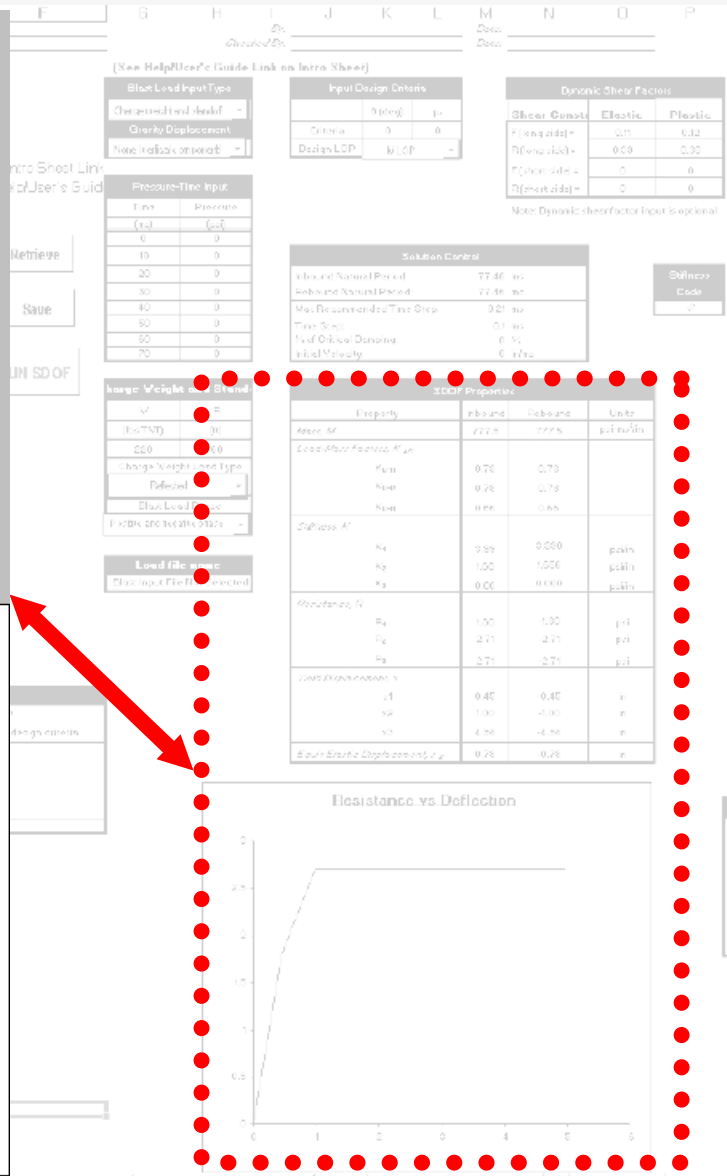
SDOF Properties			
Property	Inbound	Rebound	Units
Mass, M	777.5	777.5	psi-ms²/in
Load-Mass Factors, K LM			
K_{LM1}	0.78	0.78	
K_{LM2}	0.78	0.78	
K_{LM3}	0.66	0.66	
Stiffness, K			
K_1	3.99	3.990	psi/in
K_2	1.66	1.656	psi/in
K_3	0.00	0.000	psi/in
Resistance, R			
R_1	1.80	-1.80	psi
R_2	2.71	-2.71	psi
R_3	2.71	-2.71	psi
Yield Displacement, x			
x1	0.45	-0.45	in
x2	1.00	-1.00	in
x3	4.98	-4.98	in
Equiv Elastic Displacement, x_E	0.78	-0.78	in





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Equivalent P-delta Load

- **SBEDS calculates the lateral force on component causing same maximum moment as P-delta effect at each time step**
  - **P-delta load based on axial load, geometry, and boundary conditions/load type of component and deflection at each time step**
- **Equivalent P-delta load history is added to input load history and separately plotted in output**
- **Approach is consistent with other dynamic analyses methods considering P-delta effects including FEA based approaches**

SBEDS and Theoretical (Moment Magnifier) Static, Elastic Deflections w/ Axial Load

- **SBEDS method also applicable in plastic range**

Table 8. Calculated Deflections from SBEDS for W12x40 Beam-Column with Axial and Uniform Lateral Load Compared to Theoretical Values (Moment Magnifier)

Boundary Condition	Span (ft)	Effective Length (ft)	Calculated with SBEDS	Theoretical (Calculated with Moment Magnifier Method*)	SBEDS/Theoretical
Fixed-Fixed	50	25	1.25	1.11	1.13
	40	20	1.16	1.02	1.14
	30	15	1.09	0.94	1.16
Fixed-Simple	50	35	1.46	1.45	1.01
	40	28	1.33	1.28	1.04
	30	21	1.19	1.13	1.05
Simple-Simple	50	50	1.81	1.78	1.02
	30	30	1.45	1.43	1.01
	15	15	1.11	1.11	1.00

*C_m=0.85 for fixed support, C_m=1.0 for simple support, C_m estimated as 0.93 for fixed simple support

Note: Static lateral load in SBEDS was 50% of load causing first yield and axial load was 50% of axial load capacity in all cases above for W12x40 where weak axis had continuous lateral support.

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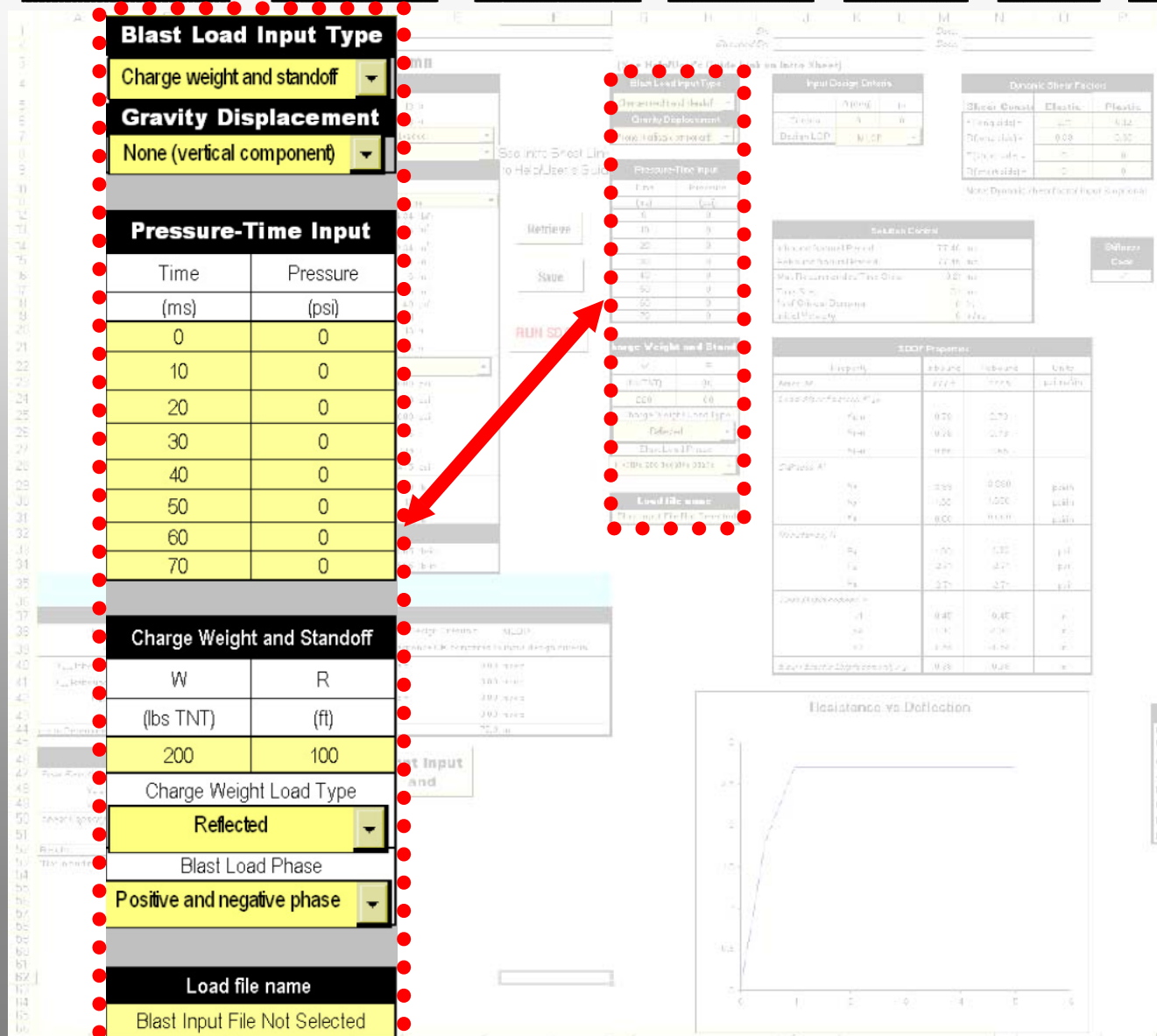
Loading Input



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Loading Options

- **User directly inputs up to 8 time-pressure pairs defining a piecewise linear pressure history**
- **User inputs charge weight and standoff distance**
  - **Pressure history for hemispherical surface burst is calculated based on Kingery-Bulmash parameters**
  - **Side-on or reflected load**
  - **With or without negative phase**
- **User designated file with up to 2,000 time-pressure pairs**
  - **One time-pressure pair separated by commas per line**
  - **Consistent with DPLOT file saved using the ASCII file option**
- **Member orientation**

SBEDS Generated Loading

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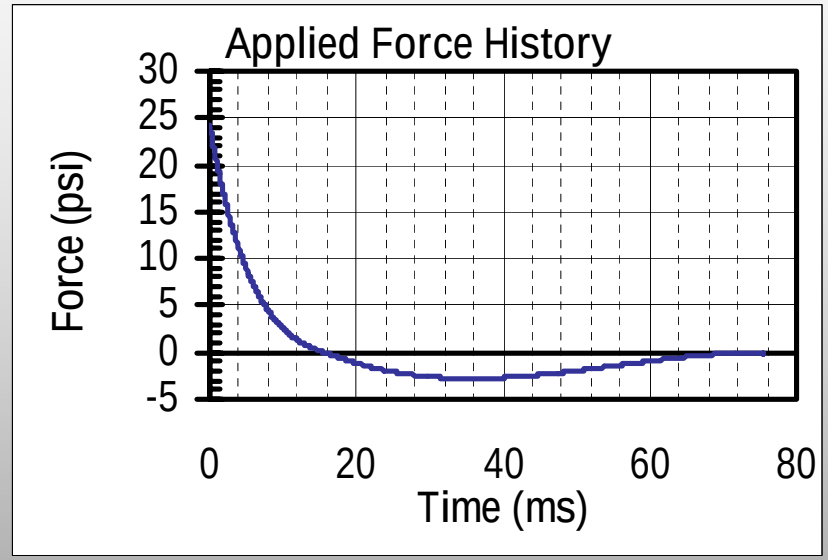
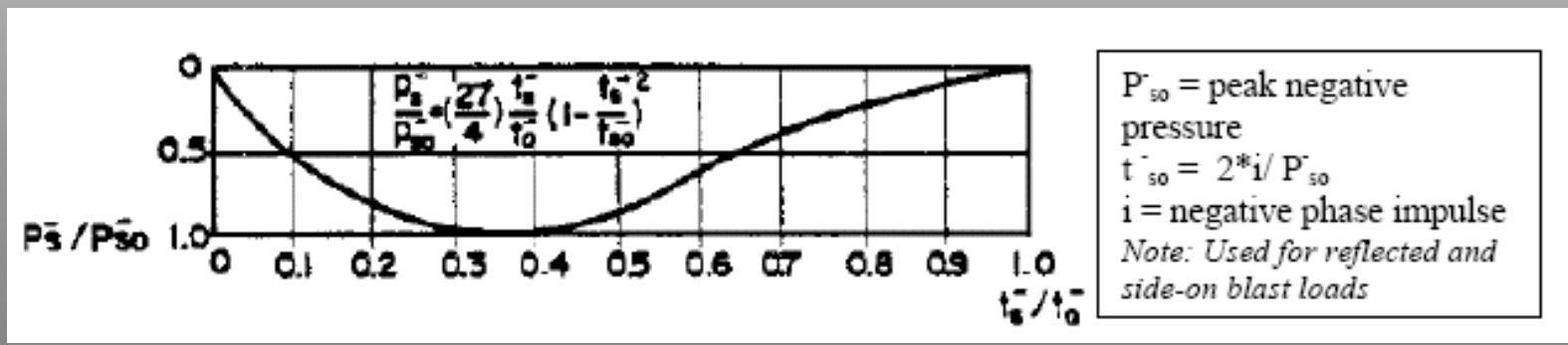
- **Exponential decay in positive phase pressure-history using curve-fit to decay constant from CONWEP**
- **Curve-fit to negative phase using method from Navy document "Blast Resistant Structures, Design Manual 2.08, December 1986" (see below)**





P^-_{so} = peak negative pressure
$t^-_{so} = 2*i/P^-_{so}$
i = negative phase impulse
Note: Used for reflected and side-on blast loads

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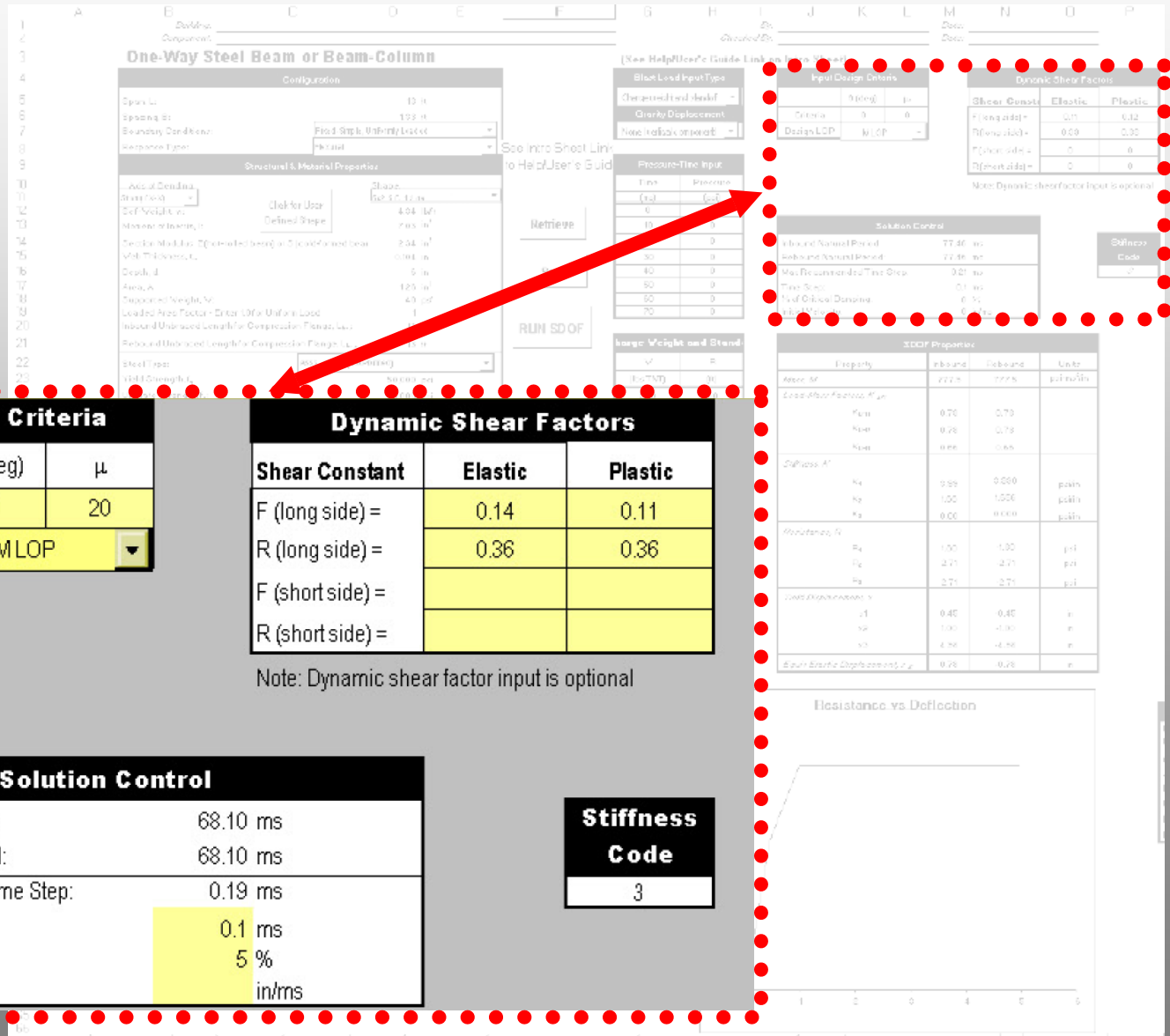
Solution Options



Input Design Criteria		
	θ (deg)	μ
Criteria	2	20
Design LOP	MLOP	

Dynamic Shear Factors		
Shear Constant	Elastic	Plastic
F (long side) =	0.14	0.11
R (long side) =	0.36	0.36
F (short side) =		
R (short side) =		

Note: Dynamic shear factor input is optional

Solution Control		
Inbound Natural Period:	68.10	ms
Rebound Natural Period:	68.10	ms
Max Recommended Time Step:	0.19	ms
Time Step:	0.1	ms
% of Critical Damping:	5	%
Initial Velocity:		in/ms

Stiffness Code
3

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Solution Options (continued)

- **Response limits/level of protection desired (optional)**
  - **Does not effect calculations, bookkeeping aid**
- **Dynamic shear constants (optional)**
- **Damping**
  - **0.05% of critical used by default, greater values can be input**
- **Initial velocity**
- **Time step (recommended value provided)**

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Recommended Time Step – Smallest Value Based On:

- **10% of the natural period**
- **10% of the smallest time increment in a manually input blast load**
- **3% of the equivalent triangular positive phase duration or 1.5% of the equivalent triangular negative phase duration of an input charge weight-standoff blast load**
- **3% of the smallest calculated time between local maxima and minima points of a input blast load file**
- **The total 2900 time steps in the time-stepping SDOF method in SBEDS divided by 8 natural periods (but not less than 0.01 ms)**

General Commands

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SDOF Solver in SBEDS

- **Constant velocity integration method used to numerically solve SDOF equation of motion at each time step**
  - **Very stable solutions if small enough time step used**
- **3000 time steps in program so very small time steps are usually recommended (less than 1 ms)**
- **SBEDS solver can handle resistance-deflection curve with 5 stiffness realms**
- **Checked against SOLVER and WAC codes within about 1%-2% for numerous cases with multiple yield and stiffness combinations**
- **Validated against higher order analysis and empirical data**

Validation

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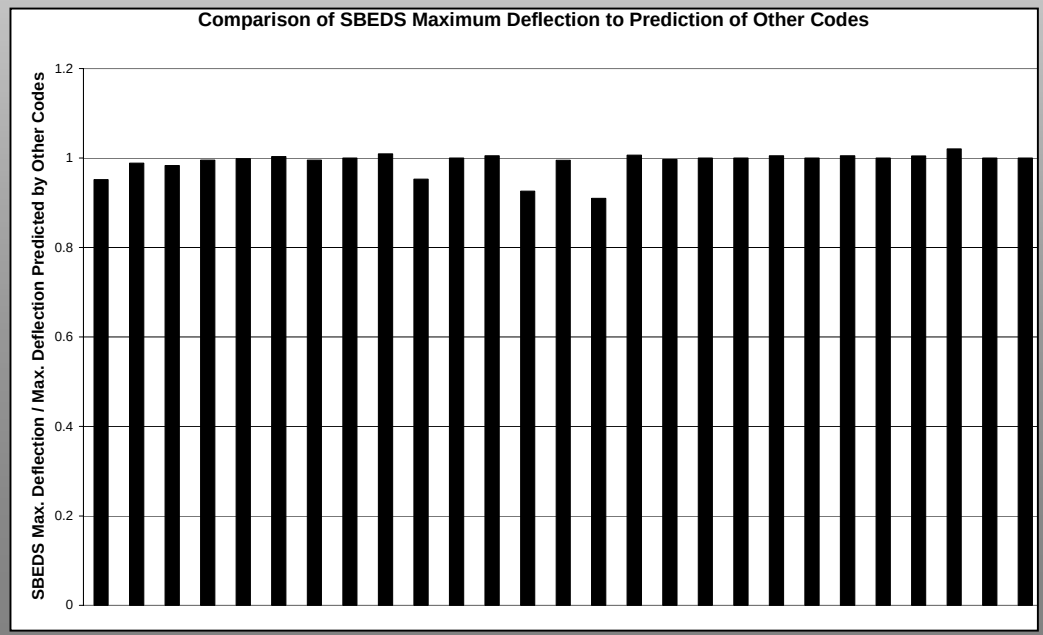
Analysis Description	Response Range	SDOF Model		ADINA Model		Percent Difference
		Maximum Displacement (in)	Time of Max. Displacement (msec)	Maximum Displacement (in)	Time of Max. Displacement (msec)	
Rectangular Beam	μ=3	5.507	35	5.232	33	**5.0**
	μ=10	17.17	51	15.19	47	**11.5**
	μ=20	33.73	65	28.58	58	**15.3**
	μ=20	26.11 **SDOF based on Z**	55	28.58	58	**-9.5**
I-Shaped Beam (W8x24)	Elastic	2.297	23	2.250	24	**2.0**
	μ=2	5.962	29	5.853	29	**1.8**
	μ=10	29.81	51	26.26	47	**11.9**
	μ=20	59.55	66	49.98	58	**16.1**



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SBEDS Output

- **Maximum deflection and resistance in inbound/outbound response**
  - **Maximum support rotation, ductility ratio, strain rate(s), and equivalent static and dynamic shears**
- **Response history plots for deflection, resistance, equivalent P-delta load, and dynamic shear and resistance-deflection plot**

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SBEDS Summary Output

Error Messages

Results Summary

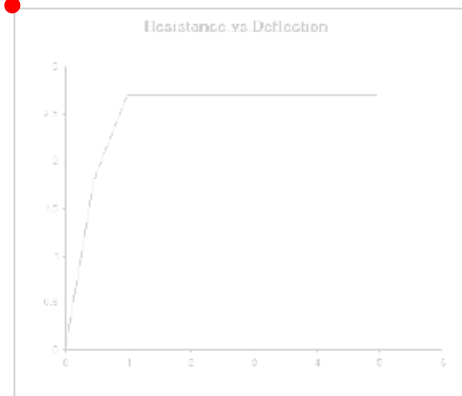
θ_{max} =	-1.87 deg.	LOP Design Criteria =	MLOP
μ =	1.99	Response OK compared to input design criteria	
X_{max} Inbound =	2.16 in	at time =	25.00 msec
X_{min} Rebound =	-2.55 in	at time =	70.20 msec
R_{max} =	2.93 psi	at time =	16.20 msec
R_{min} =	-2.93 psi	at time =	52.20 msec
Shortest Yield Line Distance to Determine θ:			78.0 in

Equivalent Static Reactions From Flexure

Peak Reactions from Flexural Response *		
$V_{max,L}$ =	6,852	lb
$V_{max,R}$ =	4,111	lb
Shear Capacity		
V_s =	9,429	lb
Results:	Shear is OK	

*Not including any tension membrane resistance

Print Input and



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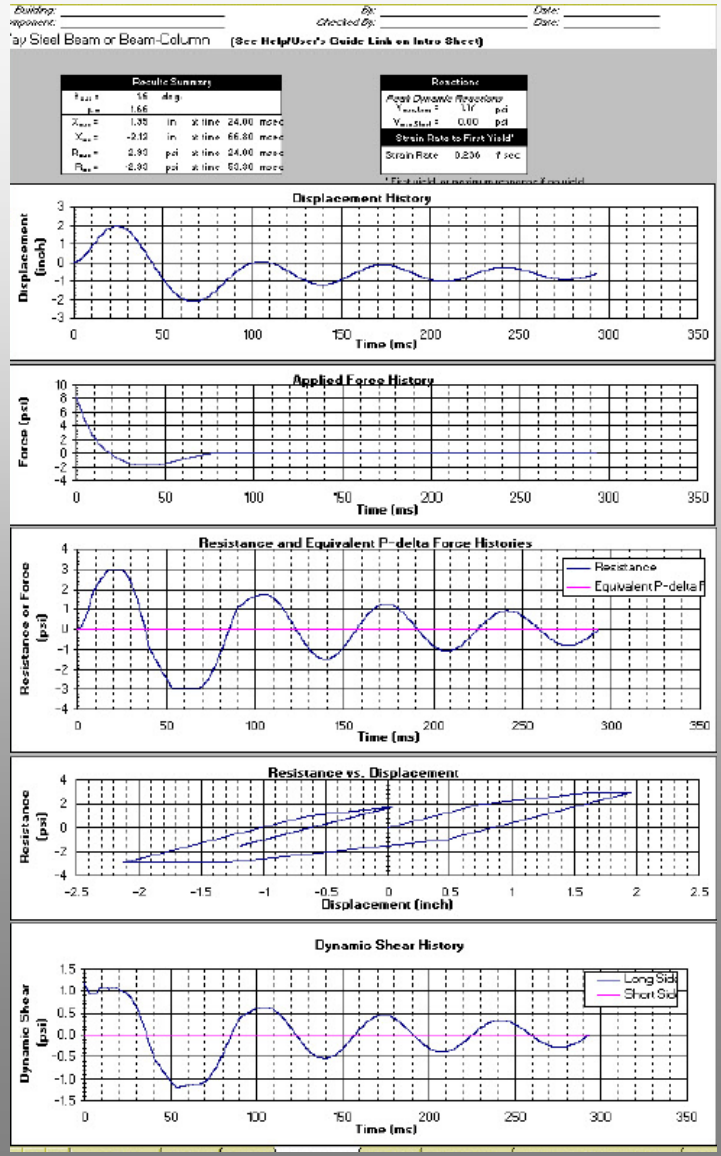
SBEDS Detailed Output



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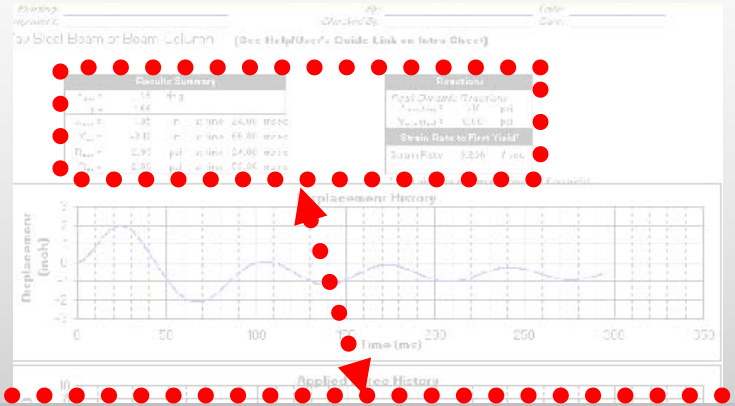
Peaks

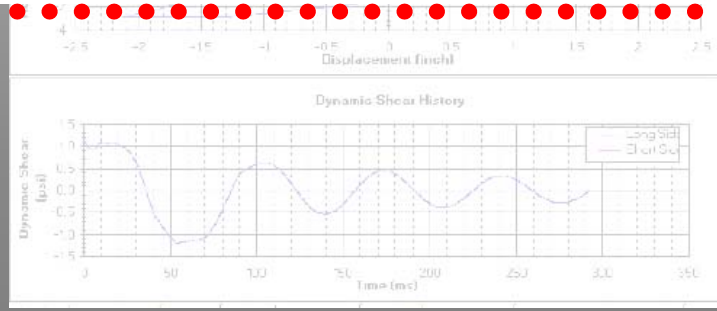


Results Summary				
θ_{max} =	-1.6	deg.		
μ =	1.66			
X_{max} =	1.95	in	at time =	24.00 msec
X_{min} =	-2.12	in	at time =	66.80 msec
R_{max} =	2.93	psi	at time =	24.00 msec
R_{min} =	-2.93	psi	at time =	53.30 msec

Reactions		
Peak Dynamic Reactions		
$V_{max,Long}$ =	1.17	psi
$V_{max,Short}$ =	0.00	psi

Strain Rate to First Yield*		
Strain Rate	0.236	1/ sec

* First yield, or maximum response if no yield



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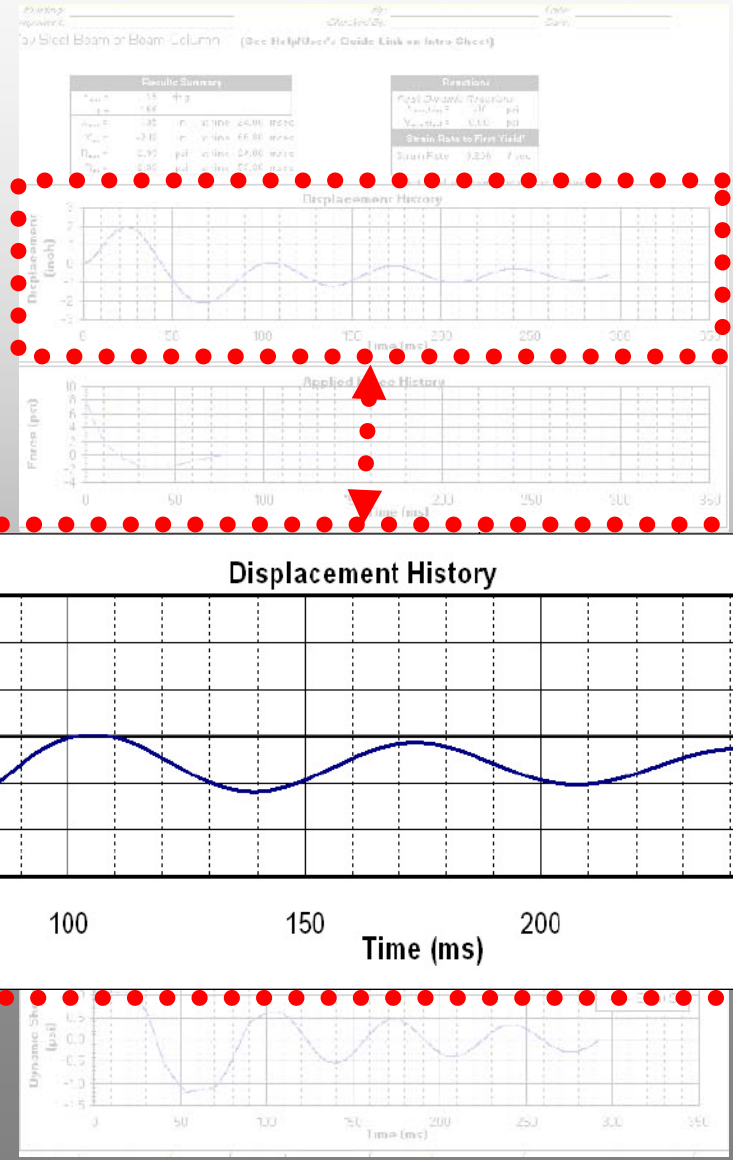
Displacement History



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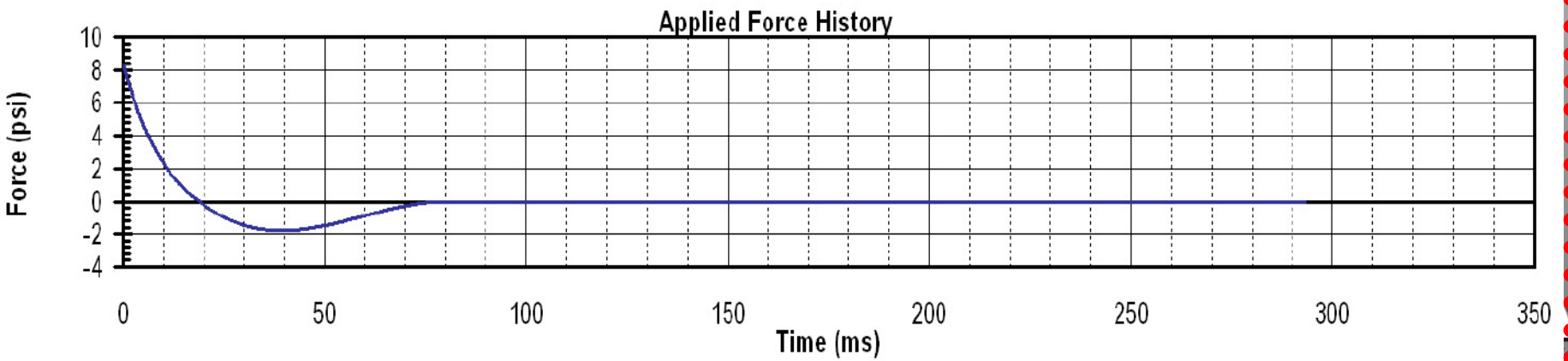
Applied Force History



Resistance and Equivalent P-delta Force History

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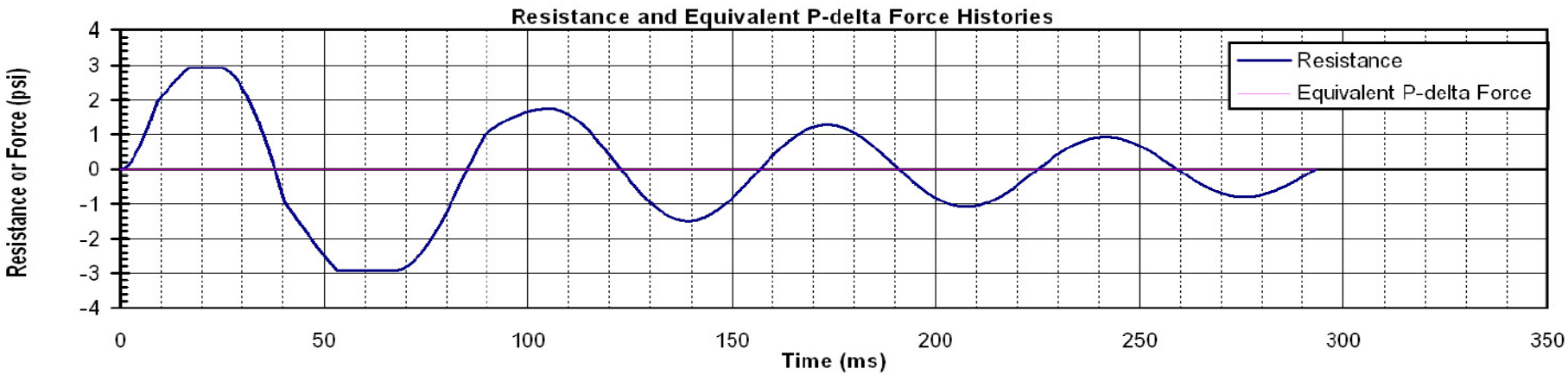

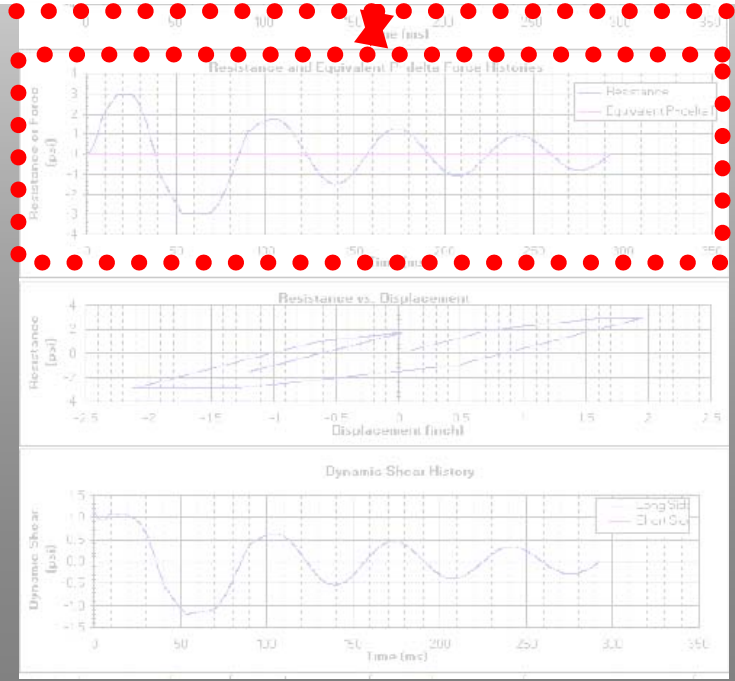

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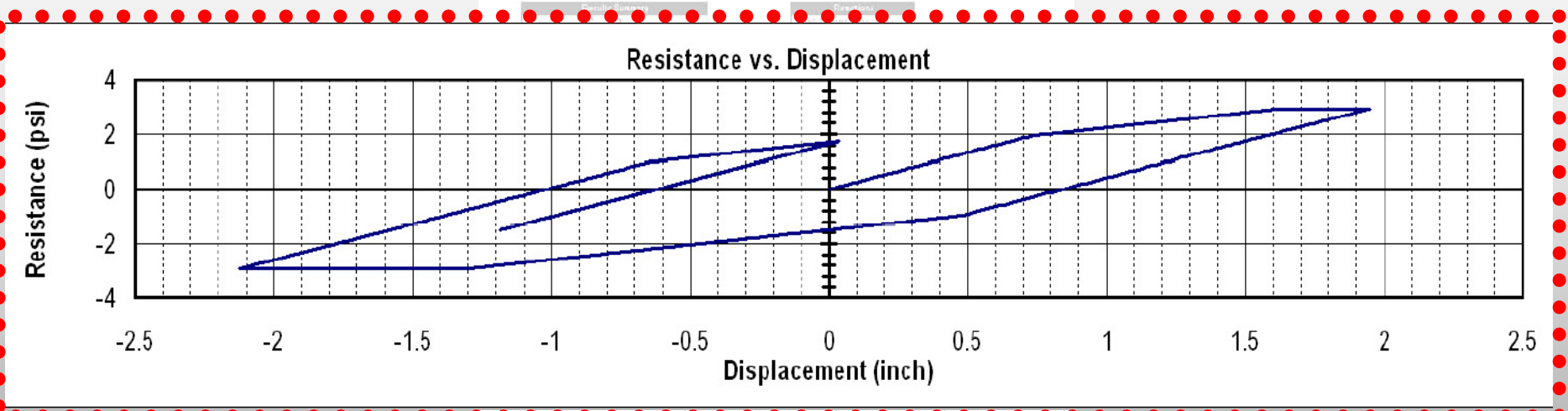
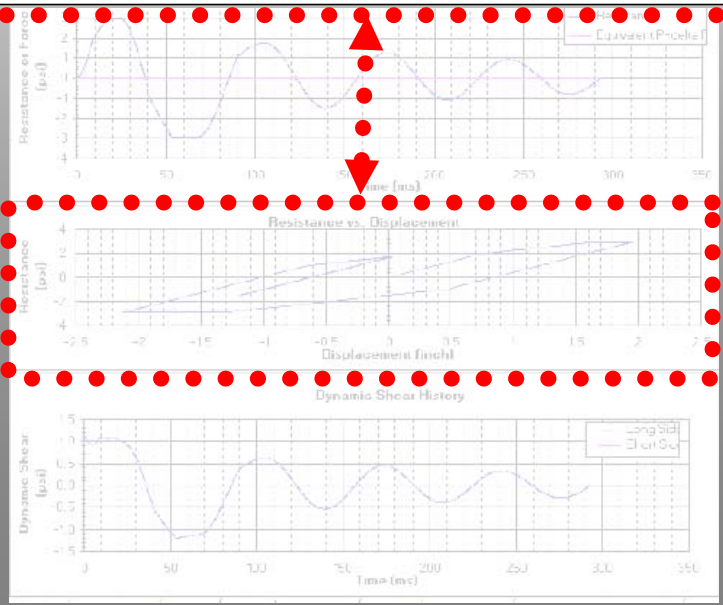
Resistance – Displacement Function





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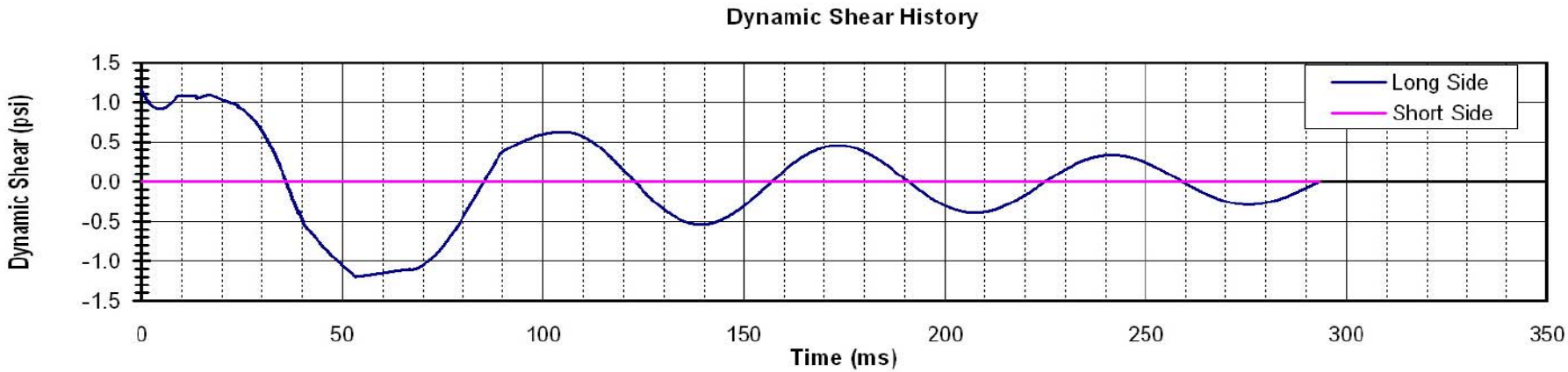
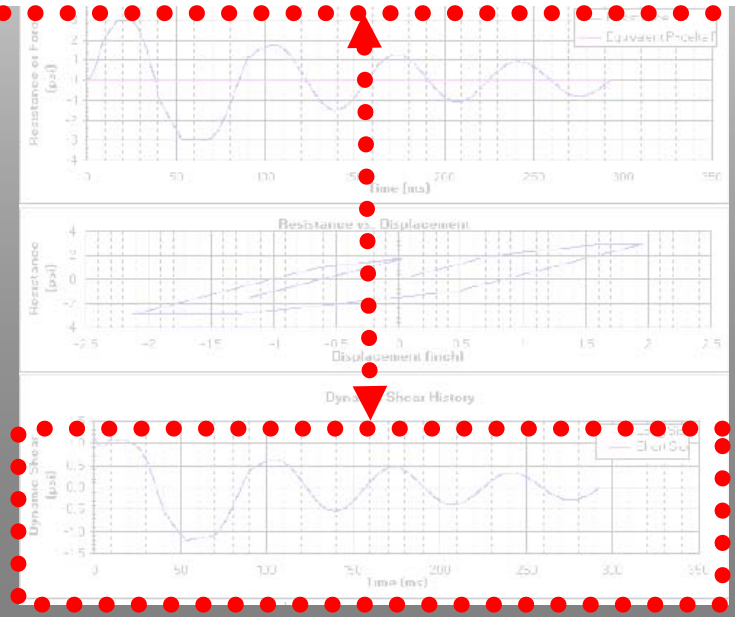
Dyanmic Shear History





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SBEDS Availability

- **Distribution Statement A – Approved for public release; distribution is unlimited**
- **https://pdmcx.pecp1.nwo.usace.army.mil/software/sbeds/index.php**
- **Registration required (Armadillo protection)**
- **Government users and their contractors have access to online support / CoP**

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Questions