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Course Description

Blast-Resistant Design of Steel Buildings

Part 2

March 24, 2016

This lecture will introduce the process for blast-resistant design of steel buildings. General design approaches and assumptions will be presented. The lecture will walk through the steps for blast design of steel components from determining the blast load and the component response to checking the demand against strength. A variety of component types will be explored including connections.

Learning Objectives

- Become familiar with types general design approaches, assumptions, and criteria for blast
- Understand general design steps for blast design of steel buildings
- Determine load demand and capacities for a variety of steel building components and connections
- Become familiar with design approaches for frames and building systems

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Blast-Resistant Design of Steel Buildings Part 2: Blast-Resistant Analysis and Design

March 24, 2016

Presented by
Aldo McKay, P.E.
Principal
Protection Engineering Consultants
San Antonio, Texas

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BLAST-RESISTANT DESIGN OF STEEL BUILDINGS

Part II: *Blast-Resistant Analysis and Design*

March 24, 2016

Kirk Marchand, P.E.

Aldo E. McKay, P.E

Protection Engineering CONSULTANTS

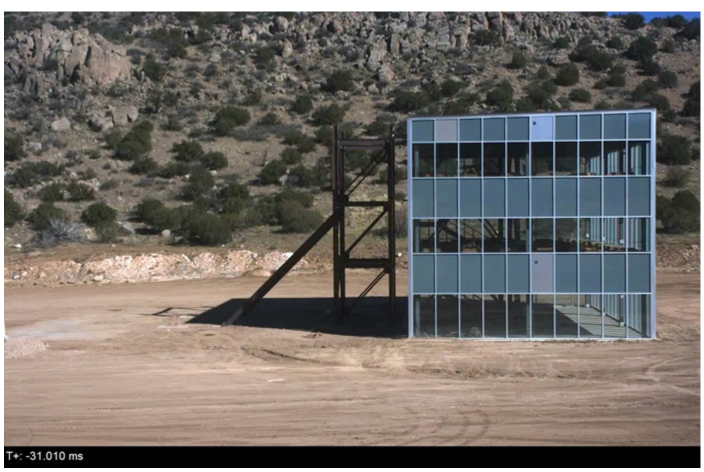
Outline

- General design approaches and assumptions in blast design
- Design Criteria and Reference Documents
- General design steps
- Blast design of components
  - Application of blast loads
  - The SDOF approach
  - Response limits
  - Shear and connections
  - Examples (SBEDS SDOF workbook for steel components)
- Frames and building systems

Glossary

- ATFP – Antiterrorism and Force Protection
- DOD – Department of Defense
- FOUO – For Official Use Only
- ISC – Interagency Security Committee
- LOP – Level of Protection
- PDC – Protective Design Center
- SBEDS – Single-Degree-of-Freedom Blast Effects Design Spreadsheet
- UFC – Unified Facilities Criteria

Steel Building Under Blast Loads



Video

General Design Approaches

- Closed-form Energy Solutions
  - Accuracy depends if component is in the applicable response realm
- Chart Solutions
- Single-Degree-Of-Freedom (SDOF)
  - use time-stepping numerical solutions to solve the basic equation of motion
  - standard design approach by blast designers
  - combines an explicit consideration of the dynamic structural response, and design simplicity

$$\sum F = M\ddot{y}$$
$$F(t) - R(y) = M\ddot{y}$$
$$M\ddot{y} + R(y) = F(t)$$

General Design Approaches, Cont'd

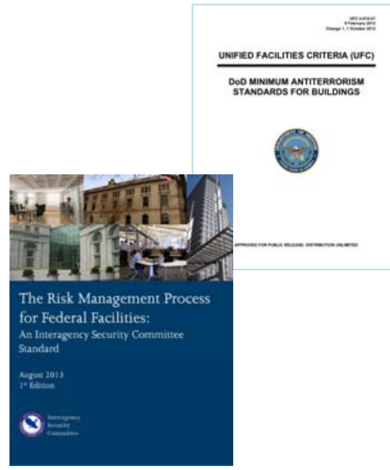
- Equivalent Static Load (ESL)
  - used for connections and other stiff members including bracing and framing components
  - more accurate when dynamic load is applied slowly compared to the component response time (limited inertial effects)
- Dynamic Finite Element Method
  - non-linear material properties and non-linear geometry should typically be used
  - numerous applicable commercial codes for various types of blast design problems

Basic Design Assumptions

- Material yield strengths increased for strain-rate effects
  - fast response causes high strain-rate and corresponding higher yield strength (10% to 20% increase)
- Component ultimate capacity used for blast design
- Yielding in ductile response mode is typically assumed
  - strengthen non-ductile response modes so they don't control response, if possible
- Design based on allowable deflection rather than allowable stress

Design Criteria and References

- Design Loads and Performance Limits for Different Industries
  - DOD ATFP Criteria - UFC 4-410-01
  - Federal projects - Interagency Security Committee (ISC) The Risk Management Process and appendices
  - ASCE Design of Blast Resistant Buildings in Petrochemical Facilities
  - VA Physical Security Design Manuals



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Design Criteria and References, Cont'd

- Comprehensive Guidance for Analysis and Design
  - UFC 3-340-02 "Structures to Resist the Effects of Accidental Explosions" (Chapter 5 for steel design)
  - UFC 3-340-01 "Design and Analysis of Hardened Structures to Conventional Weapon Effects" (Chapter 10 for steel design, FOUO (for official use only)
    - intended primarily for more robust blast hardened military structures
  - SBEDS Methodology Manual distributed with SBEDS program

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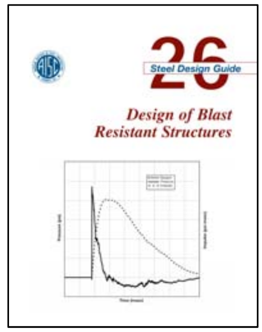
Design Criteria and References, Cont'd

- Good General Guidance
  - AISC Design Guide 26: Design of Blast Resistant Structures
  - ASCE/SEI Blast Protection of Buildings (ASCE/SEI 59-11)
  - AISC Facts for Steel Buildings Number 2 – Blast and Progressive Collapse
  - AISC Steel Construction Manual
    - tables useful for compression members and bolts
    - LRFD tables give ultimate component capacities with ϕ factor



General Design Steps for Blast Design of Steel Buildings

1. Blast Analysis of Building Envelope
2. Blast analysis of exposed structural members
   1. Using SDOF approach
   2. Using ESL
3. Frame system analysis

Blast Design of Steel Components

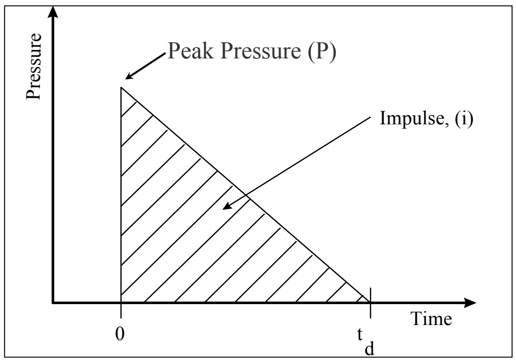
1. Determine the blast load
2. Select member type and geometry (*Typically obtained from conventional design*)
3. Use SDOF analysis (or other approach) to determine component response
4. Compare calculated peak response to design response criteria, iterate as necessary
5. Check shear demand against component shear strength
6. Design component connection against reaction demand

Determine Blast Load

- Specified as pressure-impulse pair
- May be calculated based on explosive weight and standoff
  - angle of incidence of blast loading
  - clearing effects on reflected blast load
  - Re-entrant corners
- Use of dynamic reactions coming from connecting members
- More complex, accurate approaches used as necessary

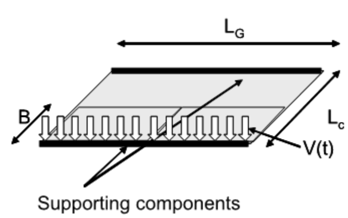
Simplified Design Blast Load Shape

- Peak pressure and impulse are calculated and used to define simplified load shape

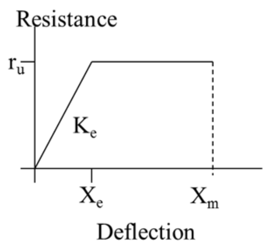


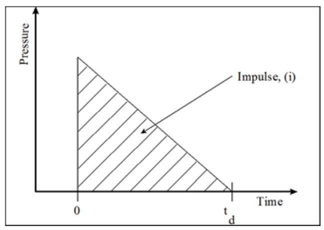
Framing Component Loads

- Direct blast load over tributary area
  - simpler approach than dynamic reaction load
- Dynamic reaction
  - generally has about same impulse as direct blast load
  - often lower peak pressure and longer duration
  - Dynamic reaction may be less conservative especially when ultimate resistance of supporting component > supported component



Use Energy Solutions for Max Deflection (X_m)





Impulse Sensitive Response

Kinetic Energy = Strain Energy

$$\frac{i^2}{2K_{LM}M} = r_u X_m - \tfrac{1}{2} r_u X_e$$

$$X_m = \frac{i^2}{2K_{LM}Mr_u} + \tfrac{1}{2} X_e$$

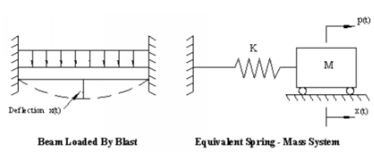
Pressure Sensitive Response

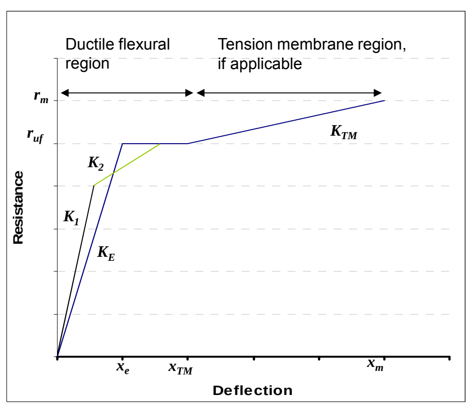
Work Energy = Strain Energy

$$PX_m = r_u X_m - \tfrac{1}{2} r_u X_e$$

$$X_m = \frac{X_e}{2(1-\frac{P}{r_u})}$$

Design using SDOF Approach





SDOF
- Perhaps this is the most common method of blast analysis
- Resistance vs. Deflection curve, commonly known as the component **"Resistance Function"**

General Resistance-Deflection Relationship for Steel Components

- The spring in SDOF system represents the stiffness and strength of blast-loaded component
  - **usually component has flexural response to blast load**
- (K) Stiffness relates mid-span deflection to applied static load
  - use standard beam deflection equations to solve for (w/Δ)
  - depends on component geometry and boundary conditions
- (R_u) Ultimate resistance. Numerous factors affect the ultimate load capacity
  - response mode (usually flexural response assumed)
  - depends on component dynamic moment capacity
  - Use standard beam moment equations to solve for “w”

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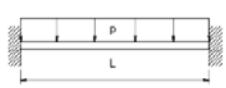
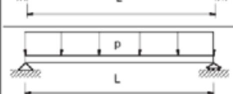
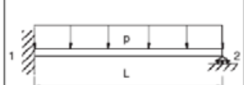
Terms Used in Resistance-Deflection Curve

Support Conditions and Loading Diagrams	Elastic Resistance	Ultimate Flexural Resistance	Stiffness		Equivalent Support Shears
			Bending[1,2]	Shear[3]	
	$r_e = \frac{12M_n}{L^2}$	$r_u = \frac{8(M_n + M_p)}{L^2}$	$k_e = \frac{384EI}{L^4}$ $k_{ep} = \frac{384EI}{5L^4}$ $k_E = \frac{307EI}{L^4}$	$k_e = k_{ep} = \frac{hE}{0.35L^2}$	$V = \frac{r_u L}{2}$
	$r_e = r_u$	$r_u = \frac{8M_p}{L^2}$	$k_e = k_E = \frac{384EI}{5L^4}$	$k_e = \frac{hE}{0.35L^2}$	$V = \frac{r_u L}{2}$
	$r_e = \frac{8M_n}{L^2}$	$r_u = \frac{4(M_n + 2M_p)}{L^2}$	$k_e = \frac{185EI}{L^4}$ $k_{ep} = \frac{384EI}{5L^4}$ $k_E = \frac{160EI}{L^4}$	$k_e = k_{ep} = \frac{hE}{0.35L^2}$	$V_1 = \frac{5r_u L}{8}$ $V_2 = \frac{3r_u L}{8}$

M_N = Negative Moment, M_P = Positive Moment (*From SBEDS Methodology Manual*)

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Dynamic Material Properties

$$f_{dy} = acf_y$$

where:

f_{dy} = dynamic design yield strength
f_y = minimum static yield strength
c = dynamic increase factor (DIF)
a = average static increase factor (SIF)
Note: a is also referred to as an average strength factor (ASF)

Dynamic Strength Increase Factors (Default Design Values)

Material	Minimum Static Yield Strength	Average Strength Increase Factor (SIF) (a)	Dynamic Strength Increase Factor (DIF) (c)
Cold Formed Panels, Beams	200 – 400 MPa (30,000 - 60,000 psi)	1.21	1.1
Steel	200 – 240 MPa (30,000 - 36,000 psi)	1.1	1.29
Steel	290 – 400 MPa (42,000 - 60,000 psi)	1.05	1.19
Steel	515 – 690 MPa (75,000 - 100,000 psi)	1.0	1.09

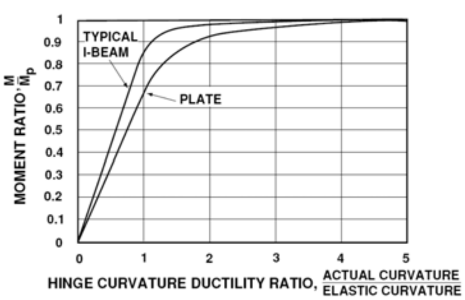
Plates - Hot Rolled Steel

- Plates typically used for blast doors, blast containment cells
- Steel plates are also effective for stopping high velocity fragments
- Fully plastic moment capacity is developed at curvatures of at least 5x the initial elastic curvature

Dynamic Moment Capacity- Plates

$$M_{du} = \left\{ \begin{array}{ll} f_{dy}\left(\frac{S+Z}{2}\right) & \mu \leq 7 \\ f_{dy}Z & \mu > 7 \end{array} \right\}$$

M_{du} = ultimate dynamic moment capacity per unit width
f_{dy} = dynamic yield strength of steel or aluminum beam
S = elastic section modulus per unit width
Z = plastic section modulus per unit width
μ = ductility ratio



Beams - Hot-rolled Steel

- Typically used for framing members
  - typical minimum static yield stress currently 36 – 50 ksi
- Usually respond in a ductile flexure response and have high inherent shear strength
- Only compact sections are recommended for blast design
- Compact beams with adequate compression flange bracing reach fully plastic hinge at lower ductility than plates

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Dynamic Moment Capacity - Hot-Rolled Beams

$$M_{du} = \begin{Bmatrix} f_{dy}\left(\dfrac{S+Z}{2}\right) & \mu \le 3 \\ f_{dy}Z & \mu > 3 \end{Bmatrix}$$

M_{du} = ultimate dynamic moment capacity
f_{dy} = dynamic yield strength of steel
S = elastic section modulus
Z = plastic section modulus
μ = ductility ratio

Note, dynamic moment capacity limited by lateral bracing based on equation below:

$$M_m = \left(1.07 - \frac{l_{bp}}{3160 r_y}\sqrt{f_{dy}}\right) M_{du} \le M_{du}$$

M_m = ultimate dynamic moment capacity accounting for effects of lateral bracing
l_{bp} = distance between lateral bracing points for compression flange provided to beam input separately in SBEDS for inbound and rebound response (mm)
r_y = radius of gyration of the member about its weak axis (in)
f_{dy} = dynamic yield strength of steel (ksi)

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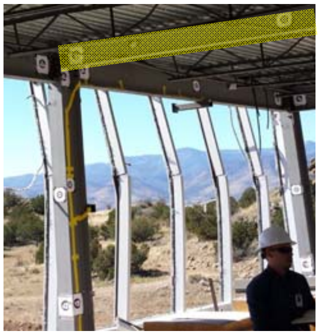
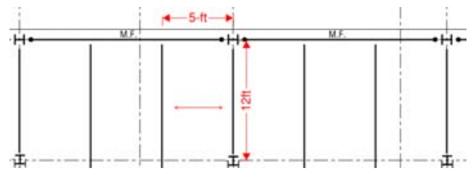
Hot-Rolled Beams, Example

Maximum displacement of a roof beam supporting a deck subjected to downward blast





The beam (W21x14) has the following properties:

- ASTM A992, F_y = 50 ksi (use dynamic yield stress F_{dy} = 62.5 ksi)
- Span, L = 12 ft (Simple-Simple)
- Beam Spacing, B = 5 ft
- Plastic Section Modulus, Z = 17.4 in.^{3}
- Moment of Inertia, I = 88.6 in.^{4}
- Supported Roof Cladding Weight, W_s = 5 psf

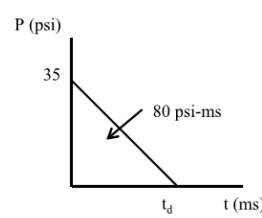
Hot-Rolled Beams, Example Cont'd

Energy Solution

Equivalent triangular load time duration

- Impulse, i = 80 psi-ms
- Peak Pressure, P = 35 psi

$$\mathrm{i} = \mathrm{impulse} = 0.5\mathrm{t_d}P$$
$$\mathrm{t_d} = \frac{2i}{P} = 4.57 \text{ ms}$$



Hot-Rolled Beams, Example Cont'd

Energy Solution
Mass

- Weight of beam per unit area, W_b = 14 plf / 5 ft = 2.8 psf
- Supported roof cladding weight, W_s = 5 psf
- Total weight

  $W_T = W_b + W_s$ = 7.8 psf = 0.054 psi
- Gravity, g = 386 x 10^{-6} in./ms^2

➢ **Component mass**

$$M = \frac{W_T}{g} = 140\ \frac{\text{psi-ms}^2}{\text{in.}}$$

Hot-Rolled Beams, Example Cont'd

Energy Solution
Stiffness

- Elastic stiffness for simply supported beam

$$K_e = \frac{384\,EI}{5BL^4}$$

- Modulus of Elasticity, E = 29 x 10^6 psi
- Moment of Inertia, I = 88.6 in.^{4}
- Span L = 12 ft = 144 in.
- Beam spacing, B = 5 ft =60 in.

➢ $K_e = \dfrac{384\,EI}{5BL^4} = 7.65\,\dfrac{\text{psi}}{\text{in.}}$

Hot-Rolled Beams, Example Cont'd

Energy Solution
Resistance

- Ultimate resistance for simply supported beam

$$R_u = \frac{8M_{du}}{BL^2}$$

- Dynamic moment capacity

$$M_{du} = F_{dy}\,Z = 1.088 \times 10^6 \text{ lb-in.}$$

➢ $R_u = \frac{8M_{du}}{BL^2} = 7.0 \text{ psi}$

Hot-Rolled Beams, Example Cont'd

Energy Solution

- Load-Mass Factor

K_{LM} **= 0.78 (elastic)**
= 0.66 (plastic)

- Natural Period

$$T_n = 2\pi\sqrt{\frac{K_{LM}\,M}{K_e}} = 2\pi\sqrt{\frac{0.78 \times 140}{7.65}} = 23.7 \text{ ms}$$

- Equivalent elastic deflection

$$X_e = \frac{R_u}{K_e} = \frac{7.0 \text{ psi}}{7.65 \text{ psi/in.}} = 0.915 \text{ in.}$$

Hot-Rolled Beams, Example Cont'd

Energy Solution (Impulsive Sensitive)

$$\frac{t_d}{T_n} = \frac{4.57}{23.7} = 0.19$$

Less than 1/3 – Impulse Sensitive

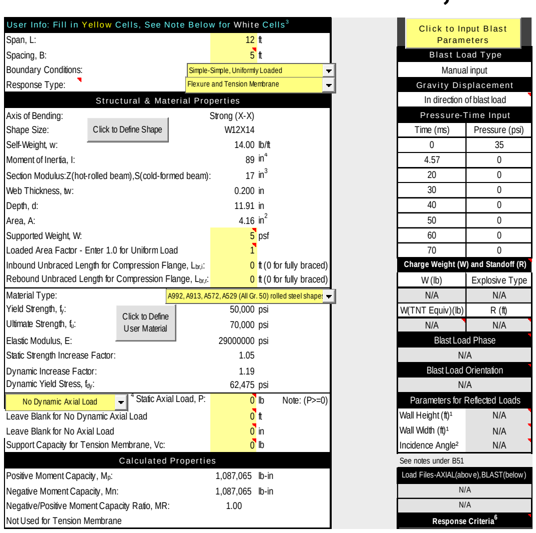
$$\text{Kinetic Energy} = \text{Strain Energy}$$

$$\frac{i^2}{2K_{LM}M} = r_u X_{\max} - \tfrac{1}{2} r_u X_e$$

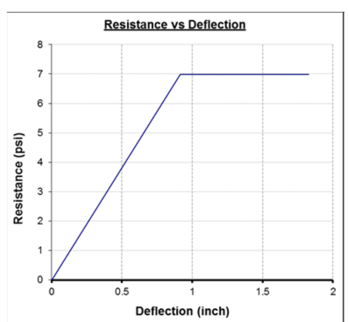
$$X_m = \frac{i^2}{2K_{LM}Mr_u} + \tfrac{1}{2} X_e$$

$$X_m = \frac{(80\text{ psi-ms})^2}{2(0.78)(7.0\text{ psi})(140\,\frac{\text{psi-ms}^2}{\text{in.}})} + 0.5(0.91\text{ in.}) = 4.64\text{ in.}$$

Hot-Rolled Beams, Example Cont'd

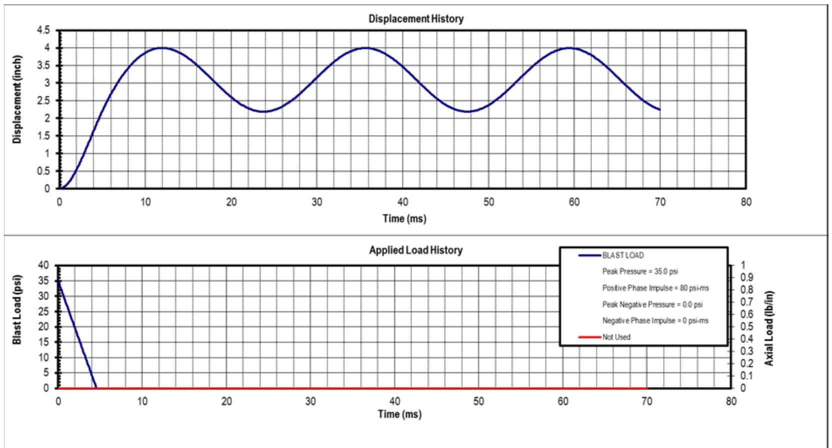


SBEDS (SDOF Solution)



Hot-Rolled Beams, Example Cont'd

SBEDS (SDOF Solution), Cont'd



Columns

- Column supporting a blast loaded beam (subject to axial loading only)
  - Load demand based on equivalent static reaction of supported component
  - capacity equal to ultimate column capacity with dynamic yield strength
  - AISC LRFD column capacities can be used without ϕ factor (or ASD capacity multiplied by 1.7)

Columns, cont'd

- Columns loaded by lateral blast loads (Beam-columns)
  - combined axial and lateral stresses
  - P-delta effects
- Is very common in steel construction to have cladding and façade elements not directly connected to the column. Thus, reduced blast loads are applied
- Recess steel column baseplate in concrete slab if possible

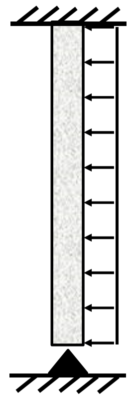
Column Connection Failure

Steel column connections not recessed in slab are very susceptible to bolt shear failure

Column weak axis and connection failure

Blast Loaded Beam-Columns

- Steel components per Chapter H of AISC Specification for Structural Steel Buildings
- Interaction equation set equal to 1 and solved to determine available dynamic moment capacity
- ***Design example discussed later***



Beam-Column Design

For hot-rolled beams

$$If \quad \frac{P}{P_{cr}} < 0.2 \qquad M_{duA} = M_m\left(1 - \frac{P}{2P_{cr}}\right)$$

$$Else \quad M_{duA} = M_m\left(1 - \frac{P}{P_{cr}}\right)\frac{9}{8}$$

Equation 6-19

$$P_{cr} = 0.658^{\lambda_c^2} f_{dy} A \quad if \quad \lambda_c \le 1.5 \quad where \quad \lambda_c = \frac{KL}{r\pi}\sqrt{\frac{f_{dy}}{E}}$$

$$P_{cr} = \frac{0.877}{\lambda_c^2} f_{dy} A \quad if \quad \lambda_c > 1.5$$

Equations from SBEDS Methodology Manual, derived from Chapter H of AISC Specification for Structural Steel Buildings

Response Criteria

- Response limits based on **deflections**
  - calculated deflection is compared to applicable criteria
  - criteria represents given damage levels or acceptable design values based on testing and engineering judgment
  - typically design criteria is one-half failure criteria, which provides a design safety factor
- Response criteria are material- and component-type dependent
- Different sets of response criteria have been published in various blast design manuals

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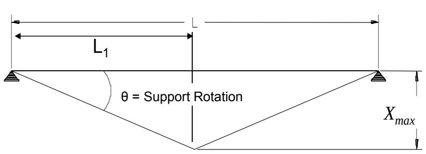
Response Parameters

- Maximum deflection is used to calculate two response parameters:

  1) Maximum support rotation (θ)



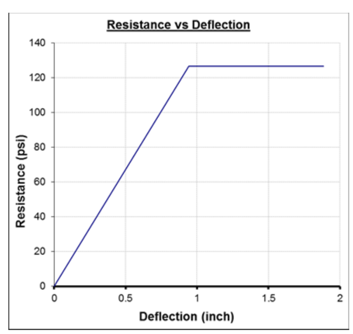
$$\theta = \tan^{-1}\left(\frac{X_{\max}}{L_1}\right)$$

L_1 equals minimum distance from support to yield location.

  2) Ductility Ratio (μ)

$$\mu = \frac{X_{\max}}{X_e}$$

X_e = deflection at yield of structural component



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Response Criteria for Steel Components

- PDC TR 06-08 "Single Degree of Freedom Structural Response Limits for Antiterrorism Design" is the most commonly used
  - DoD, VA and ISC
- Additional response limits found in
  - Design of Blast Resistant Buildings in Petrochemical Facilities
  - UFC 3-340-02, "Structures to Resist the Effects of Accidental Explosions"
  - UFC 3-340-01, "Design and Analysis of Hardened Structures to Conventional Weapons Effects"

Response Criteria for Steel Components, Roof Beam Example

Check roof beam from previous example against level of response B2 per PDC TR-06-08. **Use energy approach results.**

$$ductility\ ratio\ (\mu) = \frac{X_m}{X_e} = \frac{4.64in}{0.915in} = 5.07$$

$$Support\ Rotation(\Theta) = \tan^{-1}\left({}^{X_m}\!/_{0.5L}\right) = 3.69\text{ deg}$$

PDC Response Criteria for Hot-Rolled Steel – Roof Beam Example

Member		B1		B2		B3		B4	
		μ	θ	μ	θ	μ	θ	μ	θ
Flexure	Compact or seismic member	1	-	3	3°	12	10°	25	20°
	Non compact member	.7		.85		1.0		1.2	
	Plate [2]	4	1°	8	2°	20	6°	40	12°
Combined Flexure & Compression	Compact or seismic member[2]	1	-	3	3°	3	3°	3	3°
	Non compact member [3]	.7		.85		.85		.85	
Compression [4]		0.9		1.3		2		3	

Not OK!

1 - See paragraph 4-2 for information on selection of Flexure or Combined Flexure & Compression limits.
2 - Flat plate bent about weak axis.
3 - Assumes perimeter column base plates are buried in the concrete slab or the columns are continuous into a basement so that the column bears horizontally against the ground floor slab. If a shear plane through the anchor bolts connecting the column bearing plate to the foundation exists the response should not exceed the B1 value regardless of required component damage level. The ultimate resistance in this case should be based on the lesser of the shear capacity of the anchor bolts or the shear capacity of the column-to-baseplate connection.
4 - Not analyzed by SBEDS. These limits would typically be used for interior columns supporting roof members. Ductility ratio for pure compression is the ratio of total axial shortening to axial shortening at the elastic limit.

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PDC Criteria for Combined Flexure and Compression

- Consider combined compression and flexure when $P > 0.2\,P_{du}$
  - P is axial compression load based on the ultimate resistance (r_u) of the supported roof members plus dead load (DL) and 35% design live load (LL)
  - P_{du} is ultimate dynamic axial compression capacity

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Shear and Connection Design

- "Equivalent Static Reaction"

$$V_s = r_{uf}\, b\, L\, K_s$$

V_s = Maximum shear force in beam-type component, or in unit width "b" of panel component
r_{uf} = ultimate flexural load capacity
K_s = 0.5 for span with both ends fixed or both ends simply supported
= 0.625 at fixed end of span with other end simply supported
= 0.375 at simply supported end of span with other end fixed

- Use V_s to check shear strength of component and design connections for component

Shear Strength of Members

- Shear strength controlled by *h/t* ratio of web member, shear failure caused by elastic buckling instability
  - simple shear or combined shear and bending stress
  - Typically, shear strength is calculated as

$$f_{dv} = 0.55 f_{dy} \quad for \quad \frac{h}{t} \le 2.45\sqrt{\frac{E}{f_{dy}}}$$

(available procedures in UFC 3-340-02 for h/t outside this range)

Shear Strength - Example

W10x100 - ASTM A992

$f_y = 50 \text{ ksi}$

$t_w = 0.68 \text{ in.}$

$d = 11.1 \text{ in.}$

$$\begin{aligned} f_{dv} &= 0.55\, f_{dy} \\ &= 0.55\, f_y\; a\; c \\ &= 0.55(50)(1.05)1.19 = 34.4 \text{ ksi} \end{aligned}$$

$$V_n = d\, t_w\, f_{dv} = 11.1 \text{ in.}\,(0.68 \text{ in.})\,34.4 \text{ ksi} = 259 \text{ kip}$$

AISC 360, Section G2.1

Connection Design

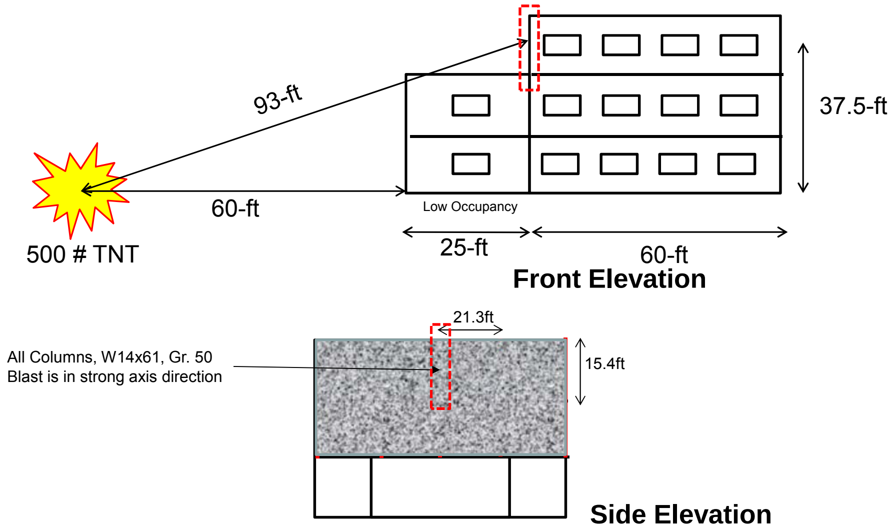
- Design strength of connection must resist reaction of component (V_s)
  - V_s can be based on equivalent static reaction or maximum dynamic reaction force
- Tensile membrane force may need to be considered
- Combined tension and shear forces can occur (especially for buildings subject to internal blast)
- Rebound forces must be considered
  - 50% rule
  - conservatively, rebound force assumed equal to V_s

Connection Capacities

- Approach varies
- Components - recommend using LRFD connection strengths
  - ESL is treated as fully factored design load
  - Strong connections is the most effective way to add protection
  - May increase material strength
    - » Static Increase Factor
    - » Dynamic Increase factor (depending on failure mode)

Components with Under-Designed Connections

Example Problem



Example Problem, Cont'd

Project Information:

- LLOP primary component per PDC TR 06-08 criteria
- Use SDOF with SBEDS v5
- Axial load includes equivalent static reaction from roof members plus 1.2D+0.5L
- Cladding weight is approximately 10 psf and spans horizontally between columns

SBEDS Inputs

$\theta := \text{atan}\left(\frac{37.5\text{ft}}{85\text{ft}}\right) = 23.806\,\text{deg}$ angle of incidence

Use fixed-simple support conditions. Column is continuous, therefore, bottom end is "fixed"

Response type is flexural

$L := 4.7\text{m} = 15.42\,\text{ft}$ Floor to floor span

$B := 6.5\text{m} = 21.325\,\text{ft}$ Grid spacing

$P := 300000\text{N} = 67442.7\,\text{lbf}$ Axial load

$SW := 49\,\frac{\text{kgf}}{\text{m}^2} = 10.036\,\text{psf}$ Supported Weight

Example Problem, Cont'd

Define Load

Blast Load Selection

Blast Load Input Type: Charge Wt (W) & Standoff (R)

Gravity Displacement: None (vertical component)

Explosive Type: TNT

TNT equiv. Factor: 1

W(lb): 500

R(ft) (Note 1): 93

Blast Load Phase: Positive phase only

Blast Load Type: Reflected without Clearing

Incidence Angle[2]: 23.8 (0-90 degrees)

Define Element

User Info: Fill in Yellow Cells, See Note Below for White Cells[3]

Span, L:	15.4	ft
Spacing, B:	21.3	ft
Boundary Conditions:	Fixed-Simple, Uniformly Loaded	
Response Type:	Flexural	

Structural & Material Properties

Axis of Bending:	Strong (X-X)	
Shape Size: (Click to Define Shape)	W14X61	
Self-Weight, w:	61.00	lb/ft
Moment of Inertia, I:	640	in^4
Section Modulus:Z(hot-rolled beam),S(cold-formed beam):	102	in^3
Web Thickness, tw:	0.375	in
Depth, d:	13.89	in
Area, A:	17.90	in^2
Supported Weight, W:	10	psf
Loaded Area Factor - Enter 1.0 for Uniform Load	1	
Inbound Unbraced Length for Compression Flange, $L_{br,i}$:		ft (0 for fully braced)
Rebound Unbraced Length for Compression Flange, $L_{br,r}$:	15.4	ft (0 for fully braced)
Material Type:	A992, A913, A572, A529 (All Gr. 50) rolled steel shapes	
Yield Strength, f_y: (Click to Define User Material)	50,000	psi
Ultimate Strength, f_u:	70,000	psi
Elastic Modulus, E:	29000000	psi
Static Strength Increase Factor:	1.05	
Dynamic Increase Factor:	1.19	
Dynamic Yield Stress, f_{dy}:	62,475	psi
No Dynamic Axial Load / [4] Static Axial Load, P:	67443	lb Note: (P>=0)
Leave Blank for No Dynamic Axial Load		ft
Eccentricity for Axial Load, e:	6	in

Example Problem, Cont'd

SBEDS SDOF Properties and Resistance Function

Calculated Properties

Positive Moment Capacity, M_p:	6,171,898	lb-in
Negative Moment Capacity, Mn:	5,437,100	lb-in
Negative/Positive Moment Capacity Ratio, MR:	0.88	
Ratio of Axial Load to Axial Load Capacity	0.06	

Model as "beam"

Response Criteria[6]

Flexure - compact section	
LOP/Type	LLOP/Primary
θ (deg)	μ
3	3

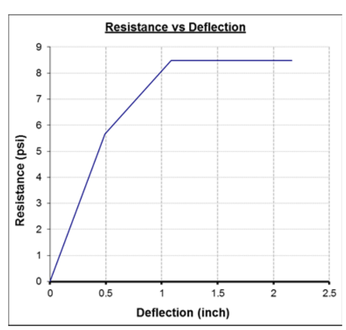
Set response limits

Solution Control

Inbound Natural Period:	24.86	ms
Rebound Natural Period:	24.86	ms
Max Recommended Time Step	0.10	ms
Time Step:	0.10	ms
% of Critical Damping:	3	%
Initial Velocity:		in/ms

SDOF Properties

Property	Inbound	Rebound	Units
Mass, M	231.2	231.2	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	11.52	11.52	psi/in
K_2	4.78	4.78	psi/in
K_3	0.00	0.00	psi/in
Resistance, R			
R_1	5.66	-4.98	psi
R_2	8.48	-7.47	psi
Yield Displacement, x			
x1	0.49	-0.43	in
x2	1.08	-0.95	in
Equiv Yield Defl., X_E	0.85	-0.75	in



Example Problem, Cont'd

Results Summary and Plots

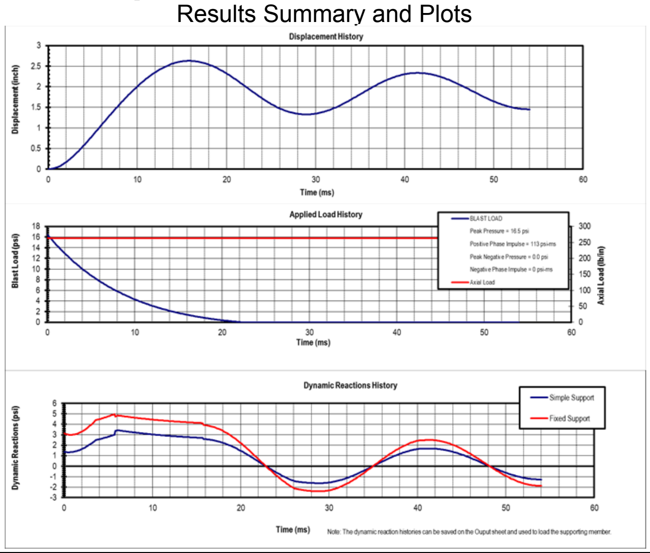
Results Summary						
θ_{max} = 1.63 deg.		Design Criteria:	LLOP/Primary			
μ = 3.09		Response DOES NOT MEET input design criteria				
X_{max} Inbound =	2.63	in	at time =	15.80	msec	
X_{min} Rebound =	0.00	in	at time =	0.00	msec	
R_{max} =	8.49	psi	at time =	15.80	msec	
R_{min} =	-5.58	psi	at time =	28.90	msec	
Shortest Yield Line Distance to Determine θ:				92.4	in	
Equivalent Static Reactions*						
Peak Reactions Based on Ultimate Flexural Resistance: Vu						
Vu at fixed support =				250,483	lb	
Vu at simple support =				150,290	lb	
Shear Capacity						
Shear Capacity: V_s =				178,979	lb	
Results for Shear Check				Shear is Not OK		

Not OK for flexural response

Change component, or design upgrade

Example Problem, Cont'd

Results Summary and Plots



SBEDS SDOF Workbook for Steel Components

- SBEDS analyses of steel beam-columns, corrugated panels, plates, composite steel beams, metal studs, open web steel joists using procedures in presentation
- Analyzes tension membrane response (when suitable support conditions exist) and axial compression on beam-columns
- User inputs applicable response criteria for comparison to maximum calculated deflection or uses PDC criteria
- Equivalent static and dynamic reaction loads can be calculated
  - SBEDS compares equivalent static shear forces to component shear capacity
- More details in SBEDS Methodology Manual

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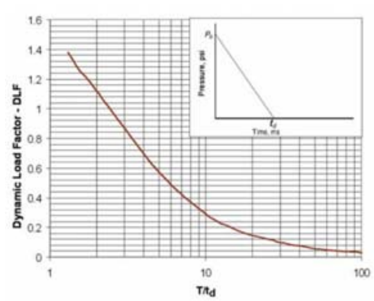
Frames and Building Systems

- Lateral systems and foundations on many large buildings will resist short duration energy from blast. For many government codes, no explicit design is required
- In some cases, overall response of building lateral load resisting system and foundation is considered as necessary
  - smaller building with very long duration blast loads are more of a concern (Petrochemical Projects)



From Steel Design Guide 26

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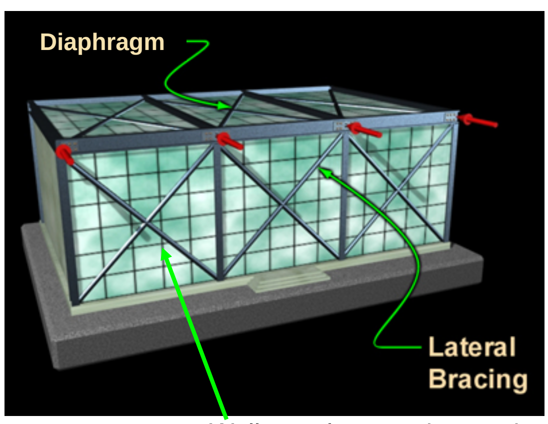
Building System Design Approaches

- SDOF of individual components with equivalent static load (ESL) used to design stiff components near end of load path
  - ESL based on ultimate resistance of "last" dynamically responding component along load path
  - Ultimate static design capacity of component must exceed ESL (diaphragms, shear walls, bracing, foundation)
- Or, building system is analyzed dynamically
  - Simple frames can be analyzed SDOF
    - one or two-story frames with simple geometry, pre-engineered frames and frames with standard I-beams
  - More complex frames typically done using Nonlinear Dynamic structural analysis software

Building System – ESL Approach



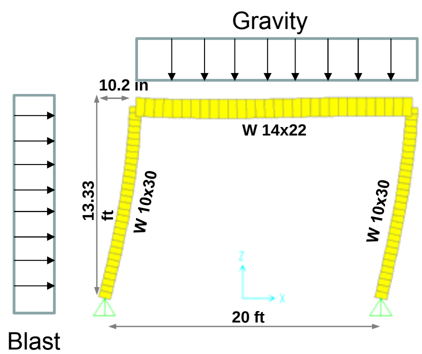
Wall panels spanning vertically

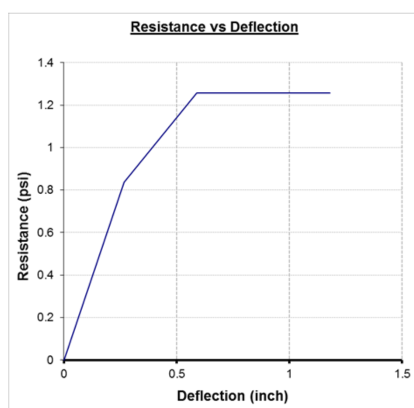
Note: Lateral bracing needed on all sides of building or shear walls, or moment resisting frames

Overview of Frame SDOF Analysis Procedure

- Frame sway and individual girder and column responses are analyzed with separate SDOF analyses
- Frame sway analysis method
  - Manually calculate SDOF parameters (Ru, K, Mass)
  - Use structural analysis software to perform pushover analysis and obtain SDOF parameters
    - Ultimate resistance = max load at collapse mechanism
    - Stiffness = ultimate resistance divided by yield deflection
    - Mass = effective mass over blast loaded area

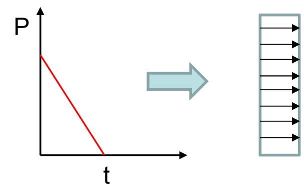
SDOF Properties from NLS Output



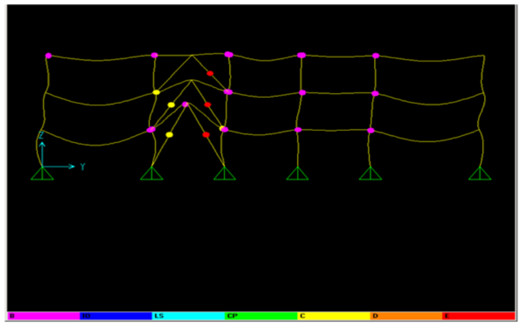


Need to include mass!

Non-linear Dynamic Analysis



Blast Load



Questions?

- Feel free to contact us at:
  - kmarchand@protection-consultants.com
  - amckay@protection-consultants.com

Protection Engineering CONSULTANTS
San Antonio
One Castle Hills
1100 NW Loop 410, Suite 300
San Antonio, TX 78213
512.380.1988
https://www.linkedin.com/company/protection-engineering-consultants

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Within 2 business days…

- You will receive an email on how to report attendance from: registration@aisc.org.
- Be on the lookout: Check your spam filter! Check your junk folder!
- Completely fill out online form. Don't forget to check the boxes next to each attendee's name!

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CEU/PDH Certificates

Within 2 business days…

- Reporting site (URL will be provided in the forthcoming email).
- Username: Same as AISC website username.
- Password: Same as AISC website password.

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There's always a solution in steel.

Thank You

Please give us your feedback!
Survey at conclusion of webinar.