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SBEDS as a Tool For Computation of Blast Response for Explosives Safety

David Rodriguez, P.E.

Chuck Oswald, Ph.D., P.E.

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OVERVIEW/OUTLINE

1 Introduction

2 Analysis Approach

3 Results and Discussion

4 Conclusions

Introduction

Introduction

- Explosive safety design for U.S. Department of War facilities requires compliance with UFC 3-340-02 (UFC)
- UFC provides Single-Degree-of-Freedom (SDOF) systems for one-way and two-way slabs
- SDOF properties for two-way elements requires use of **32 charts** and **4 tables** to calculate
- “Hand” calculations are required for explosive safety submittals but are often inefficient and prone to human error

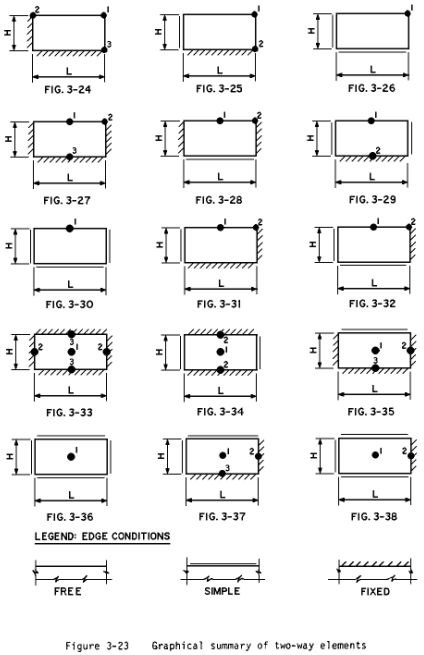
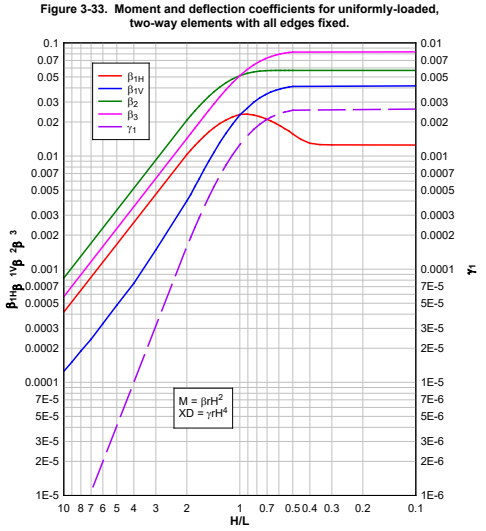
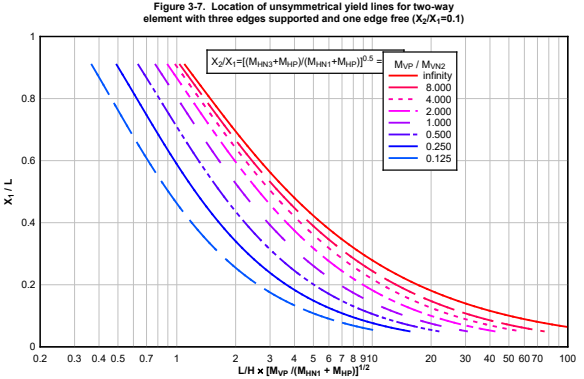


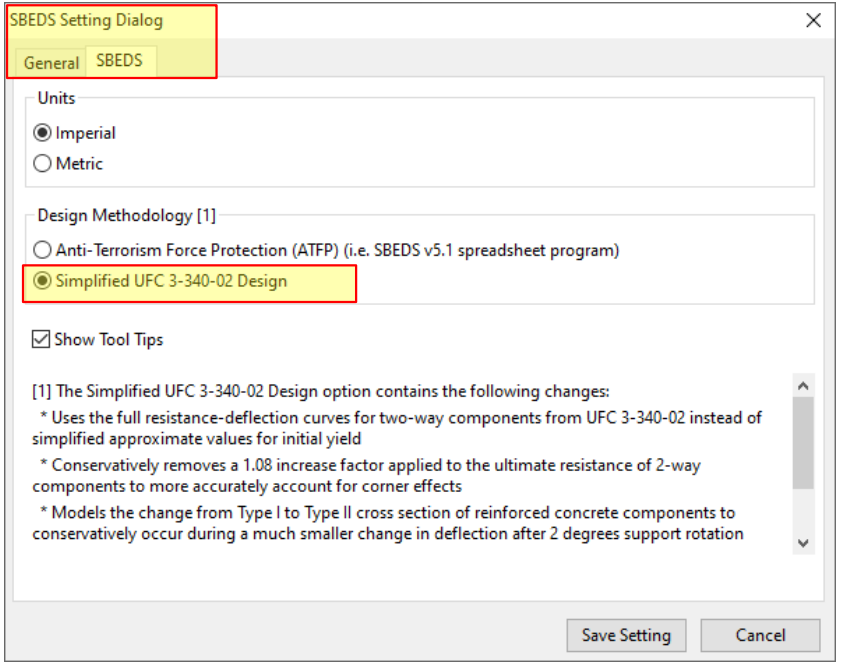
Figure 3-23 Graphical summary of two-way elements





SBEDS V6.2

- SBEDS V6.2[1] now includes design methodology to fully comply with UFC two-way slab methodology
- Independent Verification and Validation (IV&V) of SBEDS V6.2 for SDOF properties of one-way and two-way slabs per UFC for the following:
  - Resistance and stiffness
  - Load-mass factors
  - Shear forces at supports and distance “d” from supports
- New design methodology provides consistent, efficient, and cost-effective designs



[1]SBEDS V6.2 distributed by the U.S. Army Corps of Engineers Protective Design Center (USACE PDC)

Analysis Approach

Analysis Approach

- Structured into two phases
  - Phase 1: SDOF Properties (17 component test matrix)
    - Example of 11 of the 17 components tested in Phase 1 is shown to the right
    - 13 two-way and 4 one-way components assessed
  - Phase 2: SDOF Analysis (26 analysis case test matrix)
    - 13 two-way components from Phase 1 were analyzed with two-unique blast load shapes
    - Total of 26 analysis cases in Phase 2

Snapshot of Phase 1: Example of Test Matrix

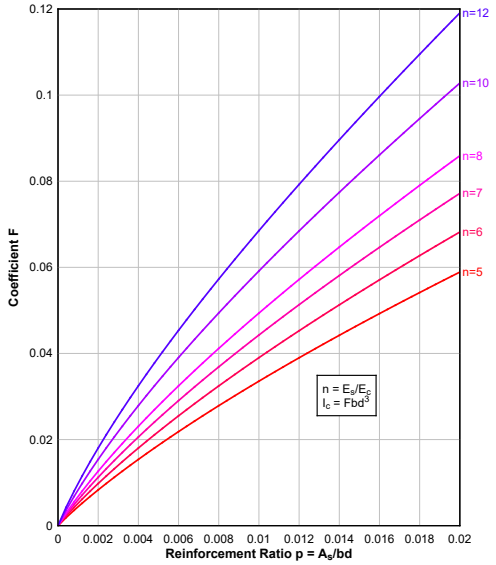
ID	BC	L (ft)	H (ft)	Hc (in)	Steel Reinforcement
C01	2-Way: Four Sides - All Fixed	10	9.5	6	Parallel to L: 0.20in^2 @ 12in O.C. E.F. Parallel to H: 0.20in^2 @ 12in O.C. E.F.
C02	2-Way: Four Sides - All Fixed	12	8	6	Parallel to L: 0.20in^2 @ 12in O.C. E.F. Parallel to H: 0.20in^2 @ 12in O.C. E.F.
C03	2-Way: Four Sides - All Fixed	15	12	12	Parallel to L: 0.20in^2 @ 12in O.C. E.F. Parallel to H: 0.20in^2 @ 10in O.C. E.F.
C04	2-Way: Three Sides - All Fixed	12	15	12	Parallel to L: 0.20in^2 @ 10in O.C. E.F. Parallel to H: 0.20in^2 @ 10in O.C. E.F.
C04a	2-Way: Three Sides - All Fixed	12	15	12	Parallel to L: 0.20in^2 @ 10in O.C. E.F. Parallel to H: 0.11in^2 @ 10in O.C. E.F.
C05	2-Way: Three Sides - All Fixed	20	14	15	Parallel to L: 0.20in^2 @ 11in O.C. E.F. Parallel to H: 0.20in^2 @ 11in O.C. E.F.
C06	2-Way: Fixed One Span, Simple Other Span	12	8	6	Parallel to L (pos): 0.20in^2 @ 12in O.C. Parallel to L (neg): None Parallel to H: 0.20in^2 @ 12in O.C. E.F.
C07	2-Way: Fixed One Span, Simple Other Span	15	12	12	Parallel to L (pos): 0.20in^2 @ 12in O.C. Parallel to L (neg): None Parallel to H: 0.20in^2 @ 10in O.C. E.F.
C08	2-Way: Two Adj. Sides - Both Fixed	12	15	12	Parallel to L: 0.20in^2 @ 10in O.C. E.F. Parallel to H: 0.20in^2 @ 10in O.C. E.F.
C09	2-Way: Two Adj. Sides - Both Fixed	12	8	6	Parallel to L: 0.20in^2 @ 12in O.C. E.F. Parallel to H: 0.20in^2 @ 12in O.C. E.F.
C10	2-Way: Two Adj. Sides - Both Fixed	12	15	12	Parallel to L (pos): 0.20in^2 @ 12in O.C. Parallel to L (neg): 0.41in^2 @ 12in O.C. Parallel to H (pos): 0.20in^2 @ 12in O.C. Parallel to H (neg): 0.41in^2 @ 12in O.C.

Analysis Approach (Cont'd)

- Phase 1: SDOF Properties (One-way and Two-way Slabs)
  - Assessed two-way/one-way boundary conditions, aspect ratios, material strengths, and steel reinforcement layouts
  - Compared calculated SDOF Properties from an independent Excel-based spreadsheet, termed UFC Method Spreadsheet (UMS), to SBEDS V6.2
  - UMS directly incorporates all the applicable equations and curve-fits for all graphs directly taken from the Dplot curves of UFC 3-340-02
- Phase 2 SDOF Analysis (Two-way Slabs Only)
  - SDOF dynamic analysis performed and SDOF results compared between UMS and SBEDS V6.2.
    - UMS used an independently developed constant-velocity numerical SDOF analysis that is similar to General SDOF Component in SBEDS V6.2
  - Analyses focused on Protection Category 1 – Personnel Protection (i.e., displacements less than 2 degrees support rotation)

Phase 1: SDOF Properties

- Gross moment of inertia and ultimate moment capacities calculated with UFC Sections 4-15 and 4-14
- First principles approach for cracked moment of inertia utilized in UMS and SBEDS V6.2 in lieu of UFC charted solution
  - Identical results when modular ratio, n, corresponds to discrete curve value (e.g., n=6, 7, etc.)
  - Deviations of up to 2% introduced when interpolating between curves when compared to first principles method
- Elastic and elasto-plastic stiffness and resistance calculated with UFC Section 3-12 and 3-13



UFC cracked moment of inertia chart

$$kd = \frac{\left[\sqrt{2dB\left(1+\frac{rd'}{d}\right)+(1+r)^2}-(1+r)\right]}{B}$$

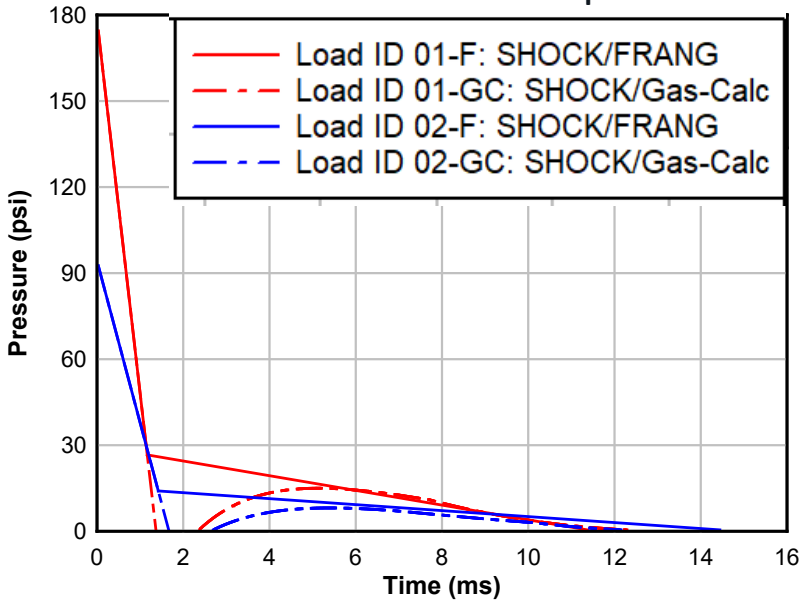
$$Icr = \frac{bk^3d^3}{3} + nA_s(d-kd)^2 + (n-1)A'_s(kd-d')^2$$

First principles cracked moment of inertia equations

Phase 2: SDOF Analysis

- Internal blast load shapes used for two-way component SDOF analysis
  - Explosive Operating Bay (EOB) 5.5 ft x 7 ft x 6 ft with front wall venting
  - 1.2 lb and 0.6 lb C4 charges placed at center of EOB and identified as Load ID 01 and Load ID 02, respectively
  - SHOCK V2 used to define shock loads
  - Both FRANG and Gas-Calc used to define two unique gas pressure histories for each C4 charge.
  - Combined shock and gas pressure histories are identified as with the respective Load ID as “-F” for FRANG and “-GC” for Gas-Calc

2 blast loads x 2 shapes each



Applied loads used for SDOF Analyses

Results and Discussion

Phase 1: SDOF Properties Results

- Comparisons of calculated properties between SBEDS and UMS for 2-way flexural components as follows:
  - Resistances, shear reactions at support, and shear at distance “d” from support are in good agreement with no more than a 2% difference
  - On average, elastic resistance, K1 and final elasto-plastic stiffness, K3, are in good agreement with a **discrepancy identified in the K2 stiffness region**
  - Elastic load-mass factor, KLM1, and first elasto-plastic load-mass factor, KM2, are good agreement with **significant discrepancies identified in the KLM3 region**
- Perfect agreement observed in all SDOF properties for 1-way components

SDOF Properties: Calculated Resistance Summary

	SBEDS / UMS Ratio		
	R1 (psi)	R2 (psi)	R3 (psi)
(Two-way components only) Average	1.00	1.00	1.00
Maximum	1.02	1.02	1.00
Minimum	0.99	0.98	1.00

Ratios of 0.98 to 1.02

SDOF Properties: Calculated Stiffness Summary

	SBEDS / UMS Ratio		
	K1 (psi/in)	K2 (psi/in)	K3 (psi/in)
(Two-way components only) Average	1.00	0.96	1.01
Maximum	1.14	1.00	1.05
Minimum	0.98	0.52	0.98

Ratios of 0.52 to 1.14

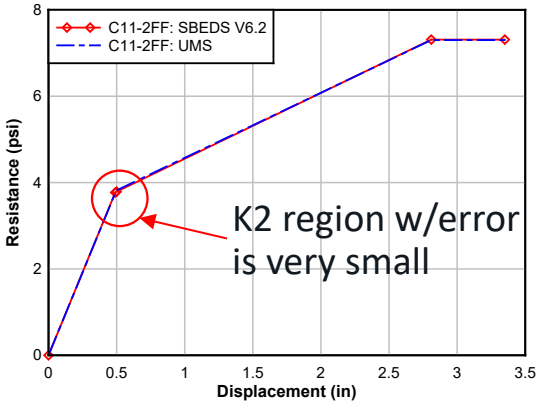
SDOF Properties: Calculated Load-Mass Factor Summary

	SBEDS / UMS Ratio		
	KLM1	KLM2	KLM3
(Two-way components only) Average	1.00	1.01	0.83
Maximum	1.01	1.03	0.99
Minimum	1.00	1.00	0.77

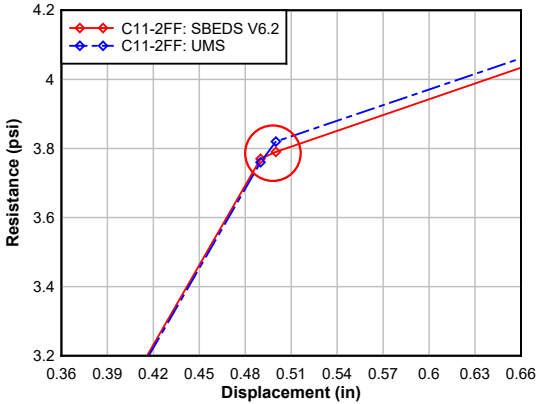
Ratios of 0.77 to 1.01

Phase 1: Stiffness Discrepancy

- Component with largest stiffness discrepancy, 52% difference, in K2 region was C11-2FF (two adjacent sides with fixed supports)
- This 52% difference was caused by small errors that were large compared to small baseline values for this stiffness region
  - Variation in R1 and R2 resistance values ~1%
  - X1 and X2 values up to the hundredths decimal place matched
  - Differences in thousandths decimal place calculations for X1 and X2 combined with ~1% R1 and R2 resistance values resulted in the 52% difference for this K2 region



Overall resistance-deflection curve



Enlarged curve at K2 region

Phase 1: Load-Mass Factor Discrepancy

- It was determined that SBEDS V6.2 preemptively switches to the plastic load –mass factor in the final elasto-plastic stage of response (i.e., KLM3)
- An additional Phase 2: SDOF Analysis was conducted after correcting KLM3 error
  - Two-way components SDOF properties calculated by SBEDS V6.2 were input into SBEDS General SDOF with same blast loads except KLM3 error was corrected

SDOF Properties: Calculated Load-Mass Factor Detailed Summary				
	ID	SBEDS V UMS Ratio		
		KLM1	KLM2	KLM3
	C01-2FFFF	1.00	1.02	0.81
	C02-2FFFF	1.00	1.01	0.79
	C03-2FFFF	1.00	1.02	0.82
	C04-2FFF	1.01	1.01	0.77
	C04a-2FFF	1.01	1.03	0.82
	C05-2FFF	1.01	1.01	0.77
	C06-2FFSS	1.00	1.01	0.99
	C07-2FFSS	1.00	1.02	0.99
	C08-2FF	1.00	1.00	0.79
	C09-2FF	1.00	1.00	0.82
	C10-2FF	1.00	1.00	0.79
	C11-2FF	1.00	1.00	0.82
	C11a-2FF	1.00	1.00	0.86
	C12-1FF	1.00	1.00	1.00
	C13-1FF	1.00	1.00	1.00
	C14-1FF	1.00	1.00	1.00
	C15-1FF	1.00	1.00	1.00
(Two-way components only) Average		1.00	1.01	0.83
Maximum		1.01	1.03	0.99
Minimum		1.00	1.00	0.77

Phase 2: SDOF Analysis Results

- Results for SBEDS V6.2 As-is
  - **Three cases** undercalculated (-8%) responses observed with **Gas-Calc load shape** and **five cases** overpredicted (+10%) with the **FRANG load shape**
  - Incorrect smaller KLM3 caused less severe SHOCK/Gas-Calc load shape to undercalculated max. deflection by up to 8% compared to UMS.
  - KLM3 was used in these analyses during **deceleration** phase (negative acceleration) of SDOF response
- Results for SBEDS V6.2 with Revised KLM3
  - **Good agreement** for calculated SDOF response observed after KLM3 was revised with **no more than a 2% difference** for θmax and *Xmax*

SDOF Analysis Results: SBEDS V6.2 As-is			
	SBEDS / UMS Ratio		
	θmax (deg)	μ	Xmax (in)
Average	1.00	1.00	1.00
Maximum	1.07	1.09	1.07
Minimum	0.93	0.93	0.92

$$\ddot{y}_i = \frac{F(t)_i - c\dot{y}_i - k_i y_i}{K_{LM\,i} M}$$

Acceleration at each SDOF time step

SDOF Analysis Results: SBEDS V6.2 with Revised KLM3			
	SBEDS / UMS Ratio		
	θmax (deg)	μ	Xmax (in)
Average	0.99	0.99	0.99
Maximum	1.01	1.03	1.01
Minimum	0.98	0.95	0.98

Conclusions

Conclusions

- Phase 1: SDOF Properties
  - Good agreement observed in all SDOF and shear related properties for all one-way flexural components
  - On average good agreement observed for all stiffness regions with negligible visual differences observed in the K2 region for two-way flexural components
  - SBEDS V6.2 preemptively switches to the plastic load –mass factor in the final elasto-plastic stage of response (i.e., KLM3) for two-way flexural components
- Phase 2: SDOF Analysis
  - SBEDS V6.2 As-is: Good agreement on average with observed overprediction and underpredicted of calculated SDOF response less then +/- 10%
  - SBEDS V6.2 with revised KLM3: Very good agreement on average, maximum, and minimum calculated SDOF response observed after KLM3 was revised with **no more than a 2% difference**
- Overall
  - Very good agreement was observed in the IV&V between SBEDS V6.2 and UMS after minor correction (to KLM3) in SBEDS V6.2

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QUESTIONS?

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CONTACT US

David A. Rodriguez Jr., P.E.

3330 Oakwell Ct #100
San Antonio, TX 78218 USA

+1.210.721.7327

@ drodriguez@bakerrisk.com

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