

Comparison of Q-D Standards for ECMs in Various National/International Manuals

9 August 2018

www.bakerrisk.com



D. Bogosian, Baker Engineering and Risk Consultants, Inc.



J. Chrostowski, ACTA, Inc.

Context and Motivation

- Tasked to evaluate Canadian long-span ECMs
 - *Needed to determine conformance to Q-D standards*
 - ◆ 7-bar
 - ◆ 3-bar
 - ◆ Undefined
 - *But whose standards?*
 - *And which standards?*
 - ◆ Separation distance
 - ◆ Blast loading
- Must satisfy one, or both?*
- Led to research of published standards
 - *Which led to comparisons...*
 - *Which led to confusion...*



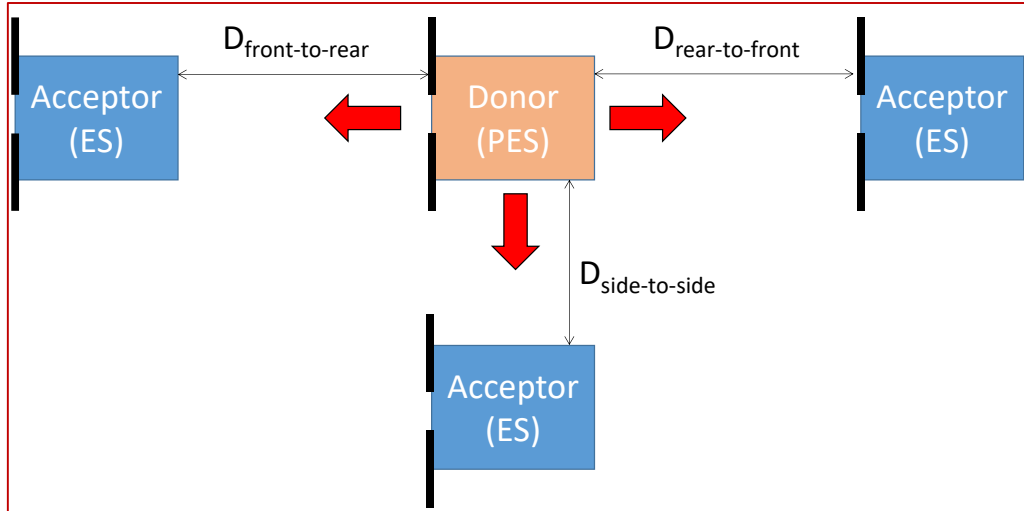
Standards Identified and Evaluated

- **US: DoD 6055.09-M & TP 17**
- **UK: JSP 482**
- **UN: IATG 02.20 & 05.20**
- **NATO: AASTP-1 & -4**
- **Canada: C-05-009-0021**

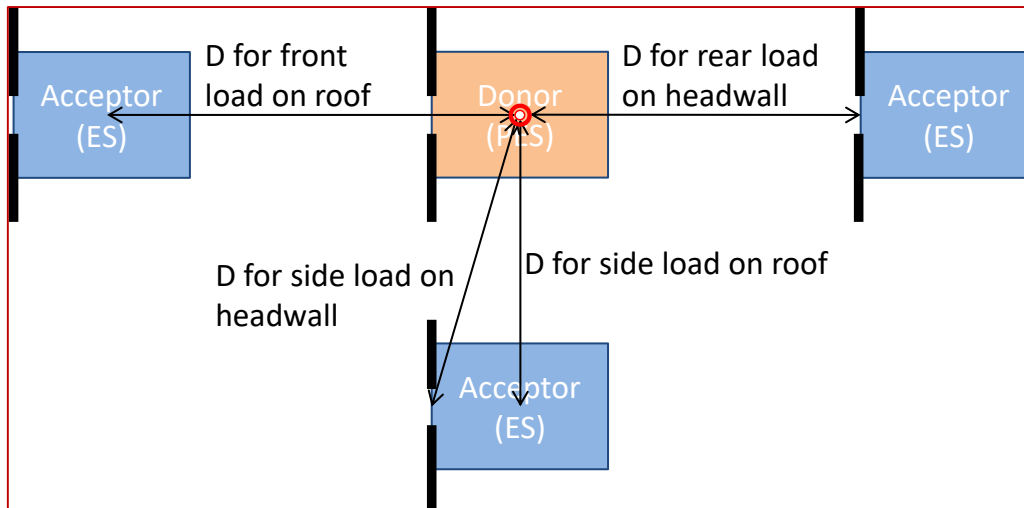
(Detailed references provided in paper)



Definitions



Separation distances



Distances for calculating load



Prescribed Separation Distances [m/kg^{1/3}]

| Receptor (PES) ECM Type | Direction | US | UK | UN | NATO | Canada |
|-------------------------|---------------|-------------------|------------------|------------------|------------------|------------------|
| Undefined | Side-to-side | 0.79 ^a | 1.8 ^c | 1.8 ^c | 1.8 ^c | 1.8 ^c |
| | | 0.50 ^b | 0.8 ^d | 0.8 ^d | 0.8 ^d | 0.8 ^d |
| | Rear-to-front | 2.38 | 2.4 ^e | 2.4 ^e | 2.4 ^e | 2.4 ^e |
| | Front-to-rear | 0.79 | 1.8 ^c | 1.8 ^c | 1.8 | 1.8 |
| 3-bar | Side-to-side | 0.5 | 0.5 | 0.5 | 0.5 | — |
| | Rear-to-front | 1.79 | 0.8 | 1.8 | 1.8 | 1.8 |
| | Front-to-rear | 0.79 | 0.8 | 0.8 | 0.8 | 0.8 |
| 7-bar | Side-to-side | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| | Rear-to-front | 0.79 | 0.8 | 0.8 | 0.8 | 0.8 |
| | Front-to-rear | 0.79 | 0.8 | 0.8 | 0.8 | 0.8 |

(a) for NEQ < 113,400 kg

(b) for NEQ > 113,400 kg

(c) for virtually complete protection

(d) for high degree of protection (no primary explosives, no items vulnerable to spall)

(e) assuming the ES has a headwall and hardened door; high degree of protection



Prescribed Separation Distances [m/kg^{1/3}]

| Receptor (PES) ECM Type | Direction | US | UK | UN | NATO | Canada |
|-------------------------|---------------|-------------------|------------------|------------------|------------------|------------------|
| Undefined | Side-to-side | 0.79 ^a | 1.8 ^c | 1.8 ^c | 1.8 ^c | 1.8 ^c |
| | | 0.50 ^b | 0.8 ^d | 0.8 ^d | 0.8 ^d | 0.8 ^d |
| | Rear-to-front | 2.38 | 2.4 ^e | 2.4 ^e | 2.4 ^e | 2.4 ^e |
| | Front-to-rear | 0.79 | 1.8 ^c | 1.8 ^c | 1.8 | 1.8 |
| 3-bar | Side-to-side | 0.5 | 0.5 | 0.5 | 0.5 | — |
| | Rear-to-front | 1.79 | 0.8 | 1.8 | 1.8 | 1.8 |
| | Front-to-rear | 0.79 | 0.8 | 0.8 | 0.8 | 0.8 |
| 7-bar | Side-to-side | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| | Rear-to-front | 0.79 | 0.8 | 0.8 | 0.8 | 0.8 |
| | Front-to-rear | 0.79 | 0.8 | 0.8 | 0.8 | 0.8 |

(a) for NEQ < 113,400 kg

(b) for NEQ > 113,400 kg

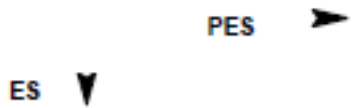
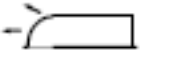


(c) for virtually complete protection

(d) for high degree of protection (no primary explosives, no items vulnerable to spall)

(e) assuming the ES has a headwall and hardened door; high degree of protection



Canadian Table

|  <p>ES ▼ PES →</p> |  <p>Building with earth on the roof and against three walls. Directional effects through the door and headwall are away from an ES.</p> <p>(a)</p> |  <p>Building with earth on the roof and against three walls. Directional effects through the door and headwall are perpendicular to the direction of an ES.</p> <p>(b)</p> |  <p>Building with earth on the roof and against three walls. Directional effects through the door and headwall are towards an ES.</p> <p>(c)</p> |
|----------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>5. Igloo, designed IAW Volume 8 (TBI) and with a headwall designed for 3 bar, with the door facing perpendicularly to the direction of PES.</p> | <p>Virtually complete protection</p> <p>Refer to Part 3, Section 2, paragraph 34. – No primary explosives</p> | <p>Virtually complete protection</p> <p>Refer to Part 3, Section 2, paragraph 34. – No primary explosives</p> | <p>Virtually complete protection</p> <p>Refer to Part 3, Section 2, paragraph 34. – No primary explosives</p> |
| <p>6. Igloo, designed IAW Volume 8 (TBI) and with a headwall designed for 3 bar, with the door towards a PES.</p> | <p>Virtually complete protection</p> | <p>Virtually complete protection</p> | <p>High degree of protection</p> <p>Refer to Part 3, Section 2, paragraphs 31. – Effect of high velocity projections</p> <p>Refer to Part 3, Section 2, paragraphs 32. and 33. – Effect of lobbed ammunition</p> |

?

Top of row cut off

Proper row



UK Standard for 3-bar Rear-to-Front

- Possible unintended consequence of ambivalently worded text
 - Receptor is “a standard UK igloo designed in accordance with Chapter 6”
 - Text does not distinguish between 3-bar and 7-bar designs
 - Both are covered in Chapter 6

| Receptor (PES) ECM Type | Direction | US | UK | UN |
|-------------------------|---------------|----------------------------------------|--------------------------------------|------------|
| Undefined | Side-to-side | 0.79 ^a 0.50 ^b | 1.8 ^c 0.8 ^d | 1.8 0.8 |
| | Rear-to-front | 2.38 | 2.4 ^e | 2.4 |
| | Front-to-rear | 0.79 | 1.8 ^c | 1.8 |
| 3-bar | Side-to-side | 0.5 | 0.5 | 0.5 |
| | Rear-to-front | 1.79 | 0.8 | 1.8 |
| | Front-to-rear | 0.79 | 0.8 | 0.8 |
| 7-bar | Side-to-side | 0.5 | 0.5 | 0.5 |
| | Rear-to-front | 0.79 | 0.8 | 0.8 |
| | Front-to-rear | 0.79 | 0.8 | 0.8 |

Same?



Prescribed Separation Distances [$\text{m}/\text{kg}^{1/3}$]

| Receptor (PES) ECM Type | Direction | US | UK | UN | NATO | Canada |
|-------------------------|---------------|----------------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|--------------------------------------|
| Undefined | Side-to-side | 0.79 ^a 0.50 ^b | 1.8 ^c 0.8 ^d | 1.8 ^c 0.8 ^d | 1.8 ^c 0.8 ^d | 1.8 ^c 0.8 ^d |
| | Rear-to-front | 2.38 | 2.4 ^e | 2.4 ^e | 2.4 ^e | 2.4 ^e |
| | Front-to-rear | 0.79 | 1.8 ^c | 1.8 ^c | 1.8 | 1.8 |
| 3-bar | Side-to-side | 0.5 | 0.5 | 0.5 | 0.5 | — |
| | Rear-to-front | 1.79 | 0.8 | 1.8 | 1.8 | 1.8 |
| | Front-to-rear | 0.79 | 0.8 | 0.8 | 0.8 | 0.8 |
| 7-bar | Side-to-side | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| | Rear-to-front | 0.79 | 0.8 | 0.8 | 0.8 | 0.8 |
| | Front-to-rear | 0.79 | 0.8 | 0.8 | 0.8 | 0.8 |

(a) for NEQ < 113,400 kg

(b) for NEQ > 113,400 kg

(c) for virtually complete protection

(d) for high degree of protection (no primary explosives, no items vulnerable to spall)

(e) assuming the ES has a headwall and hardened door; high degree of protection



Design Loads

| Metric | Donor (PES) ECM Type | Acceptor (ES) Component | US | UK | UN | NATO | Canada |
|-------------------------------------|----------------------|-------------------------|-----|-----|-----|------|--------|
| Pressure [kPa] | Undefined | Head wall | — | — | — | — | — |
| | | Roof | 745 | — | — | — | — |
| | | Side wall | — | — | — | — | — |
| | 3-bar | Head wall | 300 | 300 | 300 | — | — |
| | | Roof | 745 | 600 | 600 | — | — |
| | | Side wall | — | 300 | 300 | — | — |
| | 7-bar | Head wall | 700 | 700 | 700 | 700* | — |
| | | Roof | 745 | 600 | 600 | — | — |
| | | Side wall | — | 300 | 300 | — | — |
| Impulse [kPa-ms/kg ^{1/3}] | Undefined | Head wall | — | — | — | — | — |
| | | Roof | 170 | — | — | — | — |
| | | Side wall | — | — | — | — | — |
| | 3-bar | Head wall | 100 | 100 | 100 | — | — |
| | | Roof | 170 | 100 | 100 | — | — |
| | | Side wall | — | 100 | 100 | — | — |
| | 7-bar | Head wall | 123 | 200 | 200 | 200* | — |
| | | Roof | 170 | 100 | 100 | — | — |
| | | Side wall | — | 100 | 100 | — | — |

(*) for NEQ ≤ 75,000 kg



Design Loads

| Metric | Donor (PES) ECM Type | Acceptor (ES) Component | US | UK | UN | NATO | Canada |
|-------------------------------------|----------------------|-------------------------|-----|-----|-----|------|--------|
| Pressure [kPa] | Undefined | Head wall | — | — | — | — | — |
| | | Roof | 745 | — | — | — | — |
| | | Side wall | — | — | — | — | — |
| | 3-bar | Head wall | 300 | 300 | 300 | — | — |
| | | Roof | 745 | 600 | 600 | — | — |
| | | Side wall | — | 300 | 300 | — | — |
| | 7-bar | Head wall | 700 | 700 | 700 | 700* | — |
| | | Roof | 745 | 600 | 600 | — | — |
| | | Side wall | — | 300 | 300 | — | — |
| Impulse [kPa-ms/kg ^{1/3}] | Undefined | Head wall | — | — | — | — | — |
| | | Roof | 170 | — | — | — | — |
| | | Side wall | — | — | — | — | — |
| | 3-bar | Head wall | 100 | 100 | 100 | — | — |
| | | Roof | 170 | 100 | 100 | — | — |
| | | Side wall | — | 100 | 100 | — | — |
| | 7-bar | Head wall | 123 | 200 | 200 | 200* | — |
| | | Roof | 170 | 100 | 100 | — | — |
| | | Side wall | — | 100 | 100 | — | — |

?

(*) for NEQ ≤ 75,000 kg



Design Loads

| Metric | Donor (PES) ECM Type | Acceptor (ES) Component | US | UK | UN | NATO | Canada |
|-------------------------------------|----------------------|-------------------------|-----|-----|-----|------|--------|
| Pressure [kPa] | Undefined | Head wall | — | — | — | — | — |
| | | Roof | 745 | — | — | — | — |
| | | Side wall | — | — | — | — | — |
| | 3-bar | Head wall | 300 | 300 | 300 | — | — |
| | | Roof | 745 | 600 | 600 | — | — |
| | | Side wall | — | 300 | 300 | — | — |
| | 7-bar | Head wall | 700 | 700 | 700 | 700* | — |
| | | Roof | 745 | 600 | 600 | — | — |
| | | Side wall | — | 300 | 300 | — | — |
| Impulse [kPa-ms/kg ^{1/3}] | Undefined | Head wall | — | — | — | — | — |
| | | Roof | 170 | — | — | — | — |
| | | Side wall | — | — | — | — | — |
| | 3-bar | Head wall | 100 | 100 | 100 | — | — |
| | | Roof | 170 | 100 | 100 | — | — |
| | | Side wall | — | 100 | 100 | — | — |
| | 7-bar | Head wall | 123 | 200 | 200 | 200* | — |
| | | Roof | 170 | 100 | 100 | — | — |
| | | Side wall | — | 100 | 100 | — | — |

(*) for NEQ ≤ 75,000 kg



Worst-Case Loads

| Metric | Component | QD Standards for 7-bar ECM | | QD Standards for 3-bar ECM | |
|--------------------------------------------|-----------|----------------------------|----------------------|----------------------------|--------------|
| | | Value | Source | Value | Source |
| Pressure [kPa] | Head wall | 700 | US / UK / UN / NATO* | 300 | US / UK / UN |
| | Roof | 745 | US | 745 | US |
| | Side wall | 300 | UK / UN | 300 | UK / UN |
| Impulse [kPa- ms/kg ^{1/3}] | Head wall | 200 | UK / UN / NATO* | 100 | US / UK / UN |
| | Roof | 170 | US | 170 | US |
| | Side wall | 100 | UK / UN | 100 | UK / UN |

(*) Limited to NEQ \leq 75,000 kg

- The US is most conservative in the roof loads;
- The UK and UN are most conservative in the side wall loads;
- And with the exception of the US, all agree on the head wall loads.



Qualitative Consistency

- US roof loads = 745 kPa, 170 kPa-ms/kg^{1/3} for all types

- *Yet separation distance varies from type to type*
- *Roof is probably governed by side-to-side*

| Receptor (PES) ECM Type | Direction | US |
|-------------------------|---------------|----------------------------------------|
| Undefined | Side-to-side | 0.79 ^a 0.50 ^b |
| | Rear-to-front | 2.38 |
| | Front-to-rear | 0.79 |
| 3-bar | Side-to-side | 0.5 |
| | Rear-to-front | 1.79 |
| | Front-to-rear | 0.79 |
| 7-bar | Side-to-side | 0.5 |
| | Rear-to-front | 0.79 |
| | Front-to-rear | 0.79 |



Qualitative Consistency

- UK 3-bar headwall load is lower than 7-bar
 - Yet another reason why the 3-bar rear-to-front separation distance should be corrected

| Metric | Donor (PES) ECM Type | Acceptor (ES) Component | US | UK |
|-------------------------------------|----------------------|-------------------------|-----|-----|
| Pressure [kPa] | Undefined | Head wall | — | — |
| | | Roof | 745 | — |
| | | Side wall | — | — |
| | 3-bar | Head wall | 300 | 300 |
| | | Roof | 745 | 600 |
| | | Side wall | — | 300 |
| | 7-bar | Head wall | 700 | 700 |
| | | Roof | 745 | 600 |
| | | Side wall | — | 300 |
| Impulse [kPa-ms/kg ^{1/3}] | Undefined | Head wall | — | — |
| | | Roof | 170 | — |
| | | Side wall | — | — |
| | 3-bar | Head wall | 100 | 100 |
| | | Roof | 170 | 100 |
| | | Side wall | — | 100 |
| | 7-bar | Head wall | 123 | 200 |
| | | Roof | 170 | 100 |
| | | Side wall | — | 100 |

(*) for NEQ ≤ 75,000 kg

| Receptor (PES) ECM Type | Direction | US | UK | UN |
|-------------------------|---------------|-------------------|------------------|-----|
| Undefined | Side-to-side | 0.79 ^a | 1.8 ^c | 1.8 |
| | | 0.50 ^b | 0.8 ^d | 0.8 |
| | Rear-to-front | 2.38 | 2.4 ^e | 2.4 |
| 3-bar | Front-to-rear | 0.79 | 1.8 ^c | 1.8 |
| | Side-to-side | 0.5 | 0.5 | 0.5 |
| | Rear-to-front | 1.79 | 0.8 | 1.8 |
| 7-bar | Front-to-rear | 0.79 | 0.8 | 0.8 |
| | Side-to-side | 0.5 | 0.5 | 0.5 |
| | Rear-to-front | 0.79 | 0.8 | 0.8 |

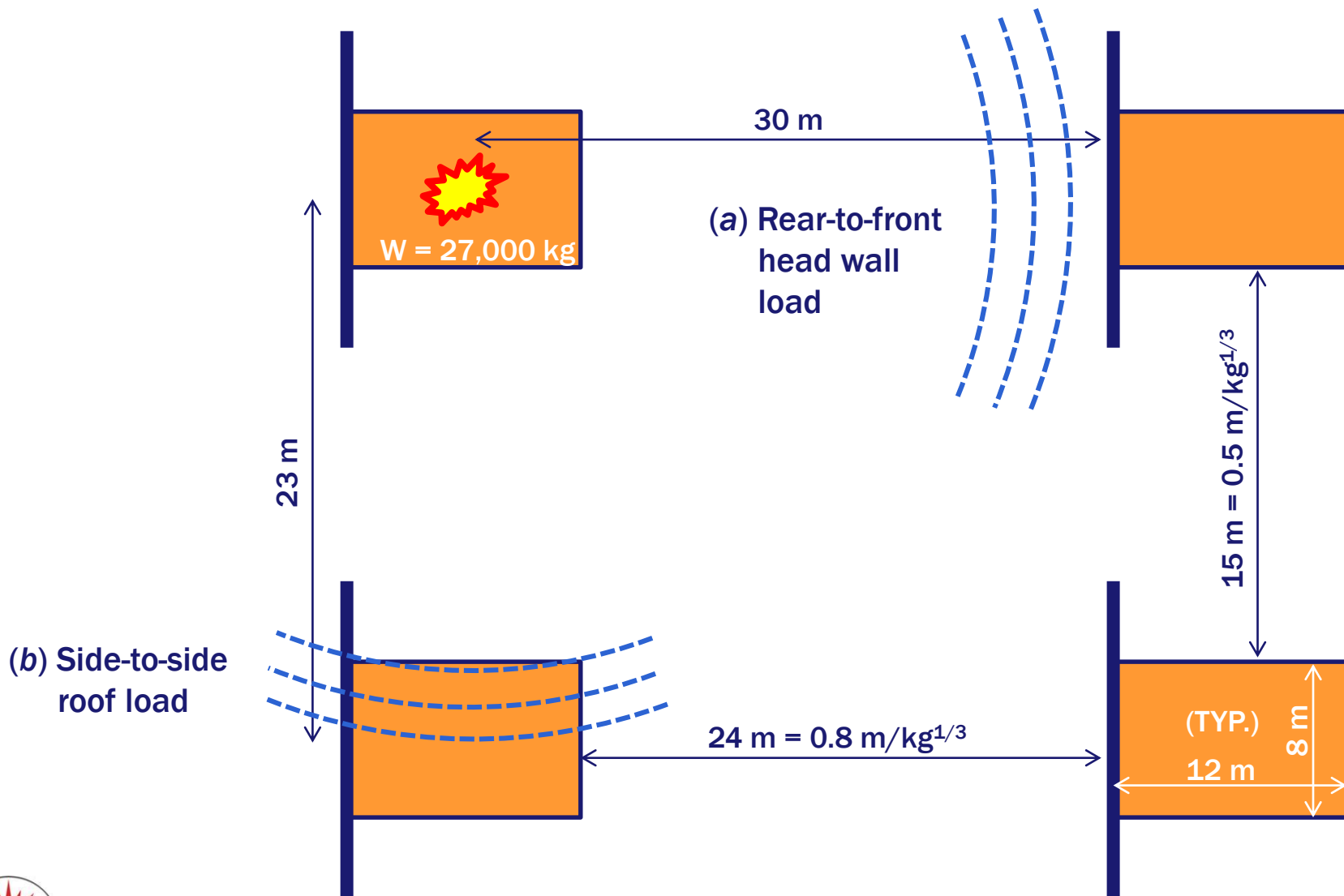


Quantitative Consistency

- Loading model exists in two sources
 - *AASTP-4*
 - *TP 17 = BEC v.7*
- Provides loads in three directions from ECM donor
- Curve fits to large body of experimental data, all scaled to a common parameter
- Model can be used in conjunction with Q-D separation distances to compute loads



Sample Problem



Results of Sample Problem

| | | BEC | US | UK/UN/NATO |
|-------------------------------------------|-------------------------------------|------------|-----------|-------------------|
| (a) Rear-to-front headwall reflected load | Pressure [kPa] | 1009 | 700 | 700 |
| | Impulse [kPa-ms/kg ^{1/3}] | 222 | 123 | 200 |
| (b) Side-to-side roof incident load | Pressure [kPa] | 412 | 745 | 600 |
| | Impulse [kPa-ms/kg ^{1/3}] | 109 | 170 | 100 |

- ***BEC generally closer to UK/UN/NATO than to US***
 - ◆ Especially on impulse
- ***No consistent trend regarding conservatism***
 - ◆ BEC can be high by 45%
 - ◆ BEC can be low by 45%



Recommendations

- **Fix the simple things**
 - *Canadian table*
 - *UK reference*
 - *Add interpretive graphics to explain distances*
- **Discuss the complicated things**
 - *Rethink logic behind standards*
 - *Consider harmonization*

