Barge Impact Analysis for Rigid Lock Walls ETL 1110-2-563

John D. Clarkson, Huntington District

Robert C. Patev, New England District

Typical US Locks and Dam

Barge Impact due to loss of control

Topics

- Background on ETL
- Rigid Wall Guidance ETL
- Continuing efforts

Vessel Impact Task Group Members

- Headquarters
  - Don Dressler
  - Anjana Chudgar
- Districts
  - John Clarkson, Huntington
  - Bob Patev, New England
  - Joe Kubinski, Detroit
  - Andy Harkness, Pittsburgh
  - Terry Sullivan, Louisville
  - Mark Gonski, New Orleans
- ERDC
  - Bob Ebeling, ITL
  - Bruce Barker, ISD

Why write a new ETL?

- ETL 1110-2-338 rescinded in 1999
  - Method was felt too conservative for design
  - Uses permanent deformation of barge
  - Issued interim guidance letter
  - Yielded unexpected results

Why write a new ETL?

Innovations for Navigation Projects (INP) R&D Barge Impact Efforts

- Full-scale experiments
  - 4-barge (Prototype – Pittsburgh - ERDC/ITL Technical Report ITL-03-2)
  - 15-barge (Full-scale – RC Byrd - ERDC/ITL Technical Report ITL-03-8)
  - Crushing (New Orleans)

Full-Scale Experiments

- Primary goals:
  - Measure baseline response of barge corner
  - Measure actual impact forces normal to wall using load measuring devices
  - Investigate the use of energy absorbing fenders
  - Quantify a MDOF barge system during impact
  - Use results to validate/invalidate existing ETL model

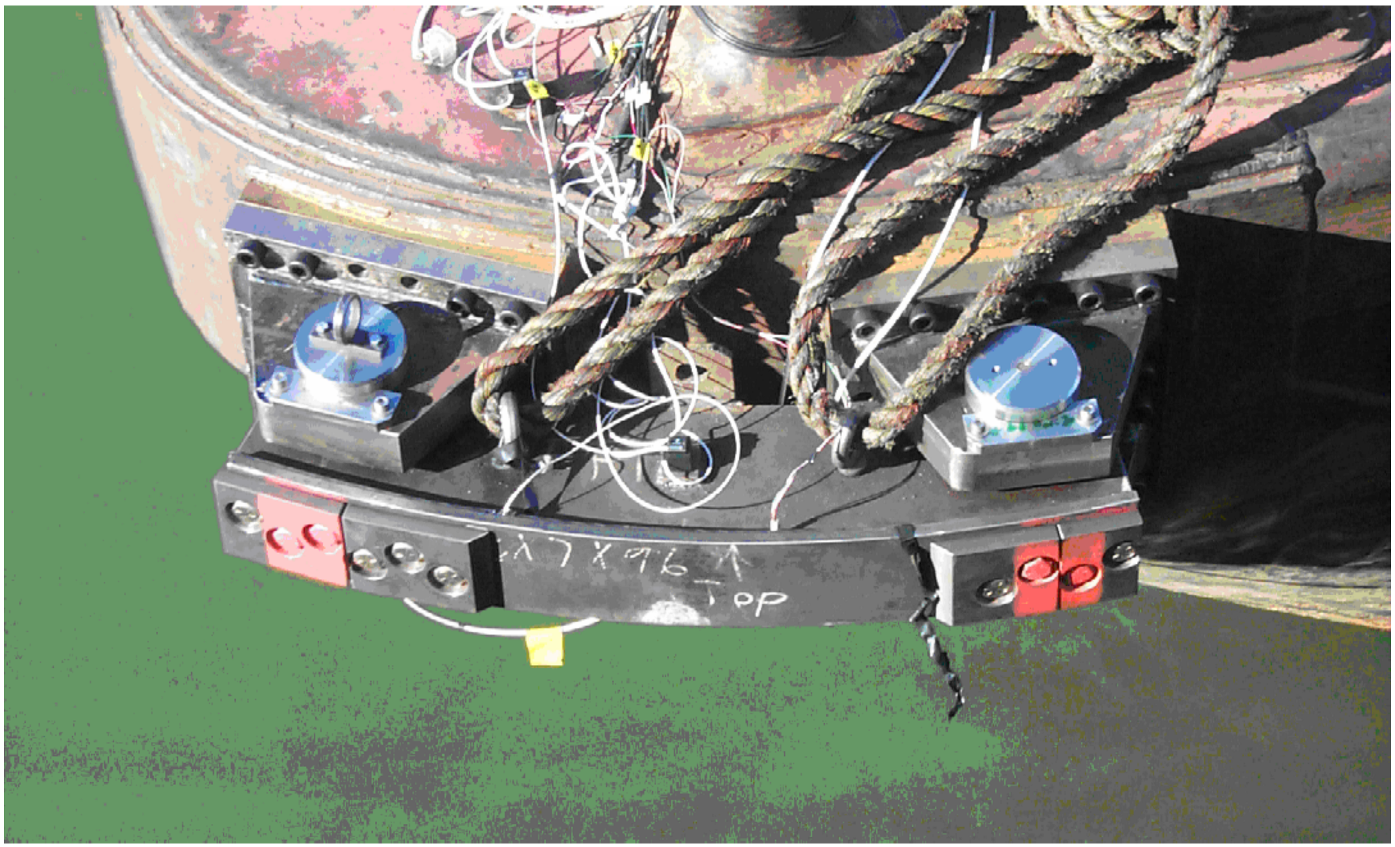
Full-Scale Experiments

Full-Scale Experiments

- Used a 15 barge commercial tow drafting at 9 feet
  - Mass of tow approximately 32,000 tons – 29,000 metric tons
- Impacts on
  - Upper guide wall
  - “Prototype” energy absorbing fendering system
- Successfully conducted 44 full-scale impact experiments
  - 12 baseline on concrete
  - 9 baseline on fendering system
  - 18 load measurement on concrete
  - 5 load measurement on fendering systems
- Impacts at:
  - Velocities from 0.5 to 4.1 feet per second
  - Angles from 5 to 25 degrees

Full-Scale Experiments

- Clevis Pin Load Beam

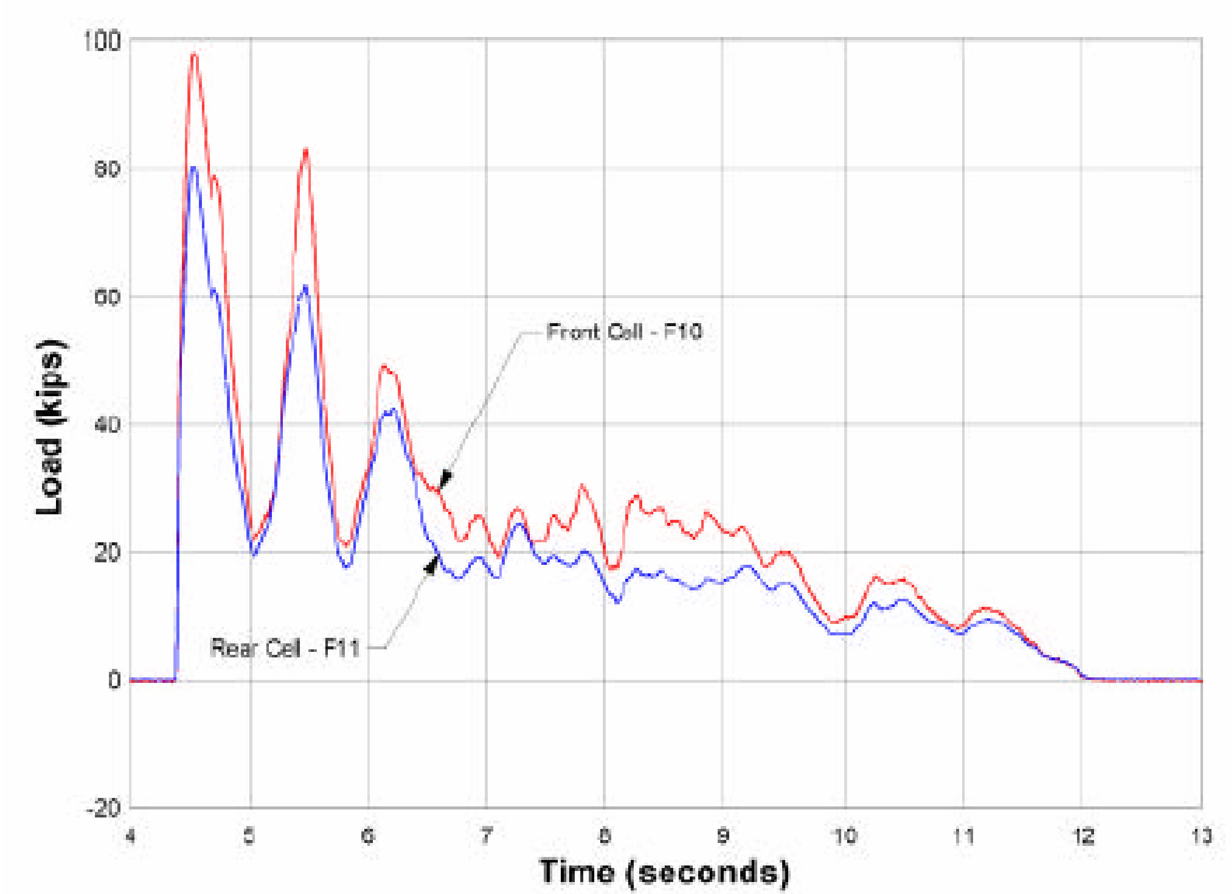


Full-Scale Crushing Experiments

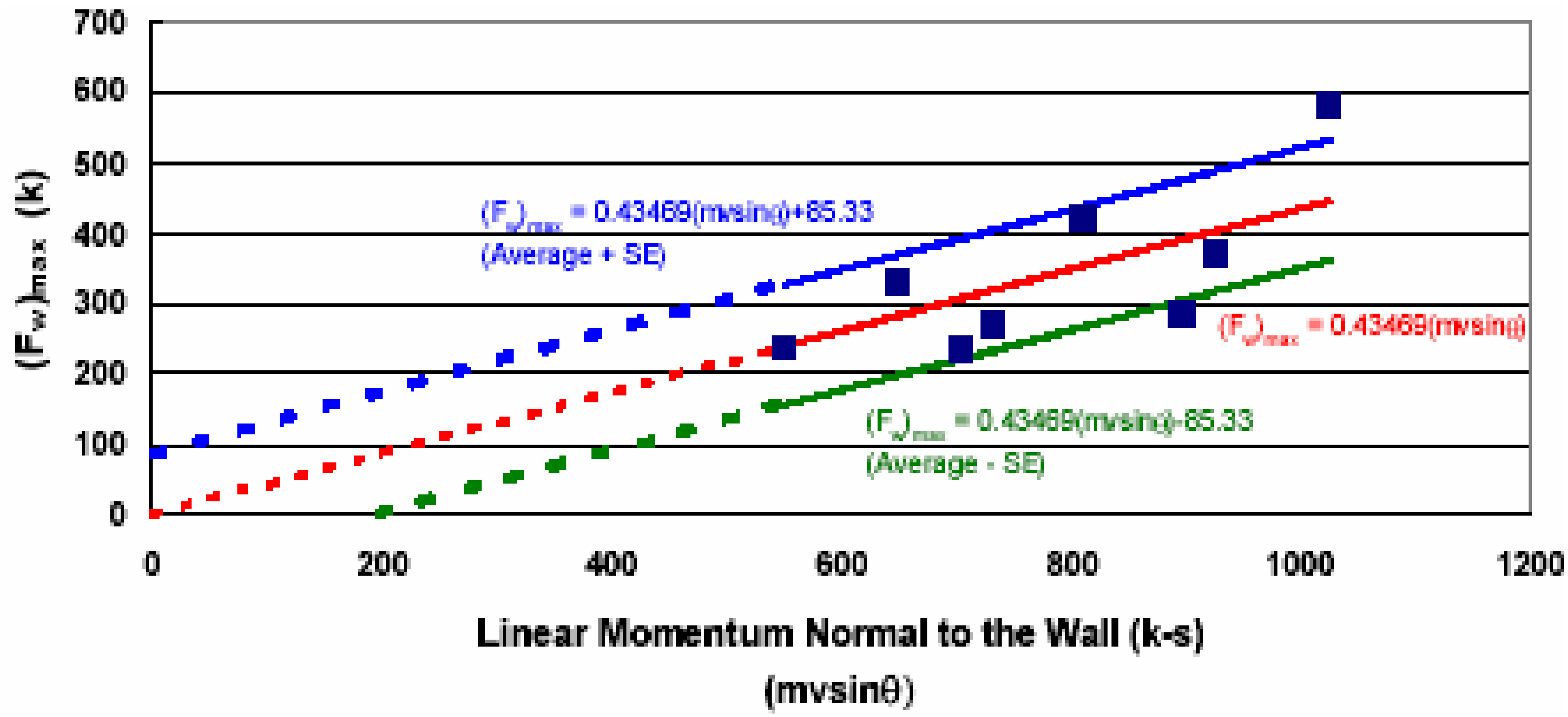
Full-Scale Experiments

- Experiment Data Reduction
  (ERDC/ITL Technical Report ITL-03-3)
  - Maximum normal force to wall from load beam measurements
  - Linear momentum of barge
    - Term “$mv\sin\theta$”
  - Develop empirical equation from experiments

Load Cell Data

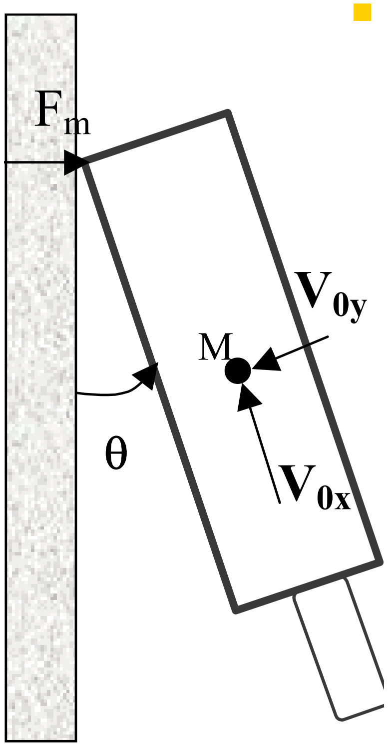


Force vs. Linear Momentum



Full-Scale Experiments

- Empirical Model
  - Limit (363 Metric Tons or 800 kips)



$$F_m = 0.435 \cdot m \cdot (V_{0x} \cdot \sin\theta + V_{0y} \cdot \cos\theta)$$

$$F_m \leq 800 \text{ kips}$$

where,

$m = \dfrac{W}{2g}$ W = weight of barge train, g = 32.2 ft/sec^2

V_{0x} = *initial* velocity of barge in x - direction (ft/sec)

V_{0y} = *initial* velocity of barge in y - direction (ft/sec)

θ = approach angle (degress)

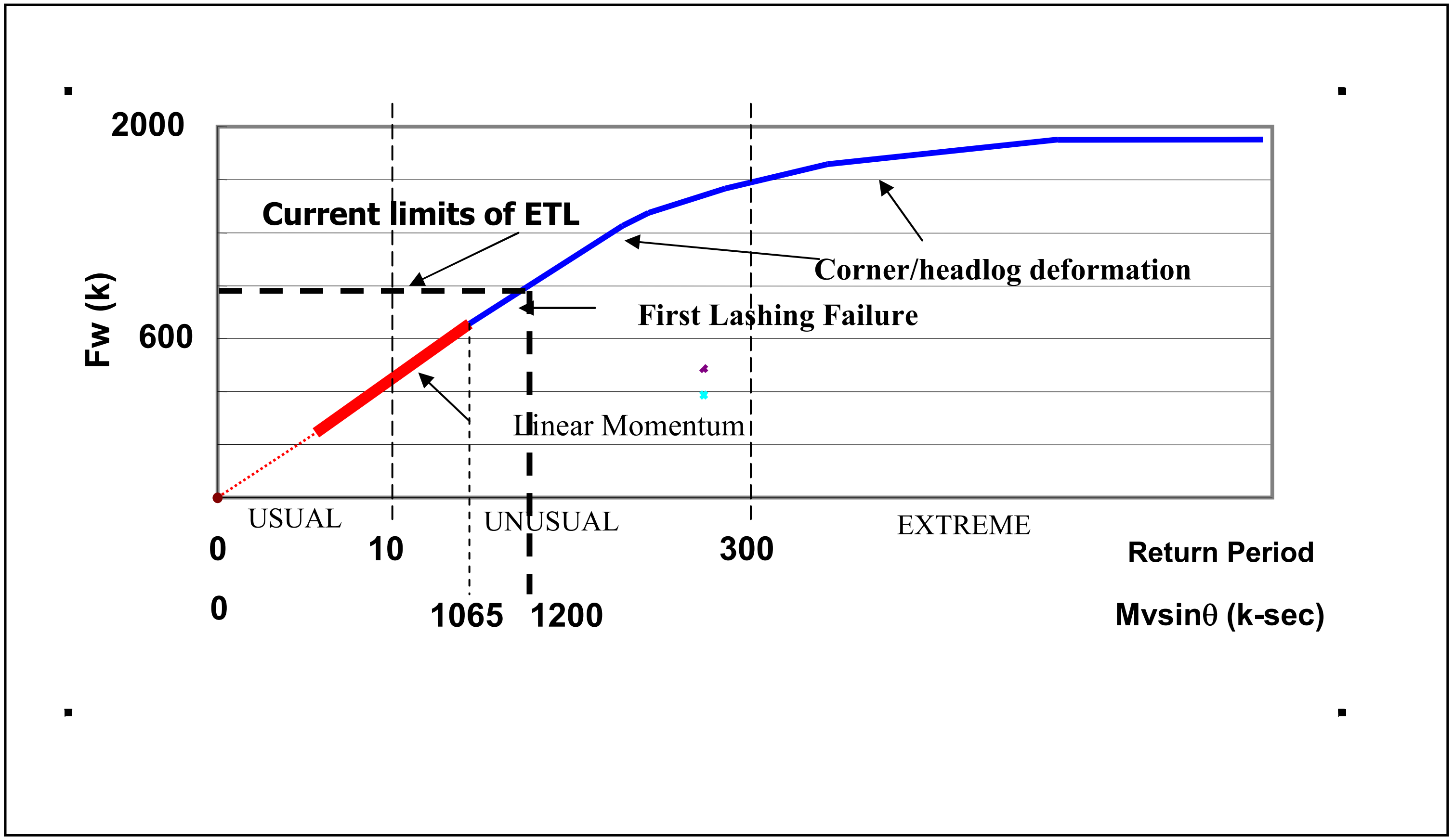
ETL 1110-2-563

- Goals of ETL 563
  - Provide an empirical model calibrated to the field experiments to assist in determining “realistic” impact forces
  - Provide guidance for input parameters to empirical model
  - Define return periods for barge impact
  - Provide methodology for determining return periods using probabilistic procedures

ETL 563

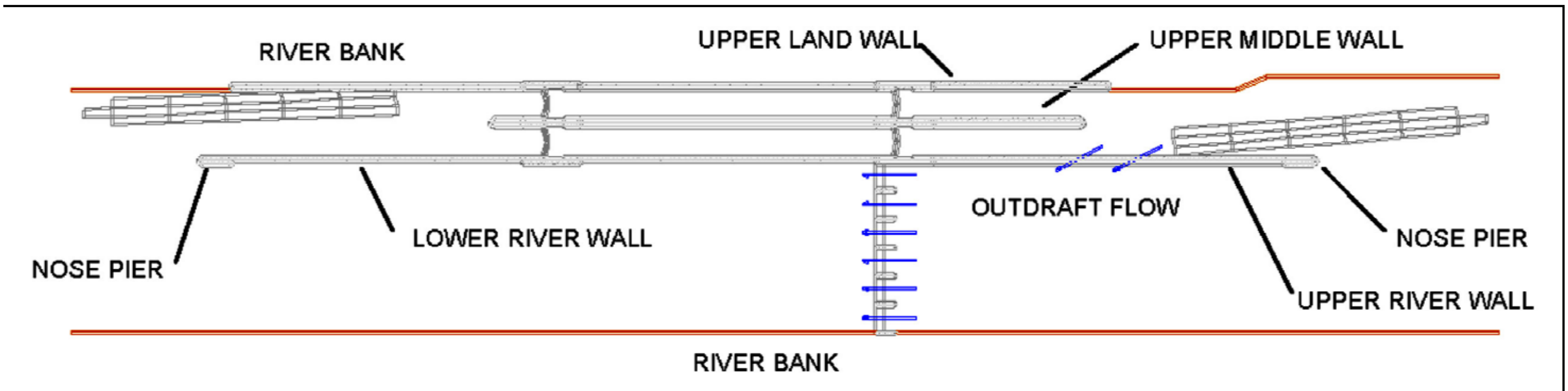
- Guidance complete but still a work in progress, works for most design requirements
  - Current model based on linear momentum of controlled impact experiments
    - Limitations of experiments
  - Future empirical or analytical models will account for:
    - Lashing Failures
    - Head-on Impacts
    - Flexible Walls

ETL 563 - Upper Limit



Barge Lashings

Typical Lock Structure



ETL 563

- Structure of ETL 563
  - HQ Guidance Letter
  - Appendix A – References
  - Appendix B – Design Guidance for Barge Impact Loads on Rigid Walls
    - Introduction
    - Empirical Barge Impact Model
    - Return Periods for Barge Impact
      - Probabilistic Barge Impact Analysis
    - Parameters for Barge Impact
    - Barge Impact Design for Rigid Walls

ETL 563

- Structure (cont’)
  - Appendix C – Data from Previous Studies
  - Appendix D– Examples of Probabilistic Barge Impact Analysis for Rigid Walls
  - Appendix E – Empirical Method for Barge Impact Analysis for Rigid Walls
  - Appendix F – Field Experiments
- Other issues addressed in ETL
  - Site constraints – limits angles and velocities
  - Drag and cushioning effects
  - Angular velocities
  - Added hydrodynamic mass

ETL 563

- <u>Definition of Return Periods</u>
  - *<u>Usual</u>* –
    - These loads can be expected to occur frequently during the service life of a structure, and no damage will occur to either the barge or wall. This typically corresponds to a 50 percent chance of being exceeded in any given year.
  - *<u>Unusual</u>* –
    - These loads can be expected to occur infrequently during the service life of a structure, and minor damage can occur to both the barge and wall. This damage is easily repairable without loss of function for the structure or disruption of service to navigation traffic. This typically corresponds to a 50 percent chance of being exceeded within a 100-year service life.
  - *<u>Extreme</u>* –
    - These loads are improbable and can be regarded as an emergency condition, and that moderate to extreme damage can occur to the wall and barge without complete collapse of structure (i.e., structure is repairable but with a loss of function or with an extended disruption of service to navigation traffic). This typically corresponds to a 10 percent chance of being exceeded within a 100-year service life.

ETL 563

Table 1 Preliminary Level Design Return Periods for Barge Impact		
Load Condition Categories	**Annual Probability of Exceedence**	**Return Period**
Usual	Greater than or equal to 0.1	1-10 years
Unusual	Less that 0.1 but greater than 0.00333	10-300 years
Extreme	Less than 0.00333	>300 years

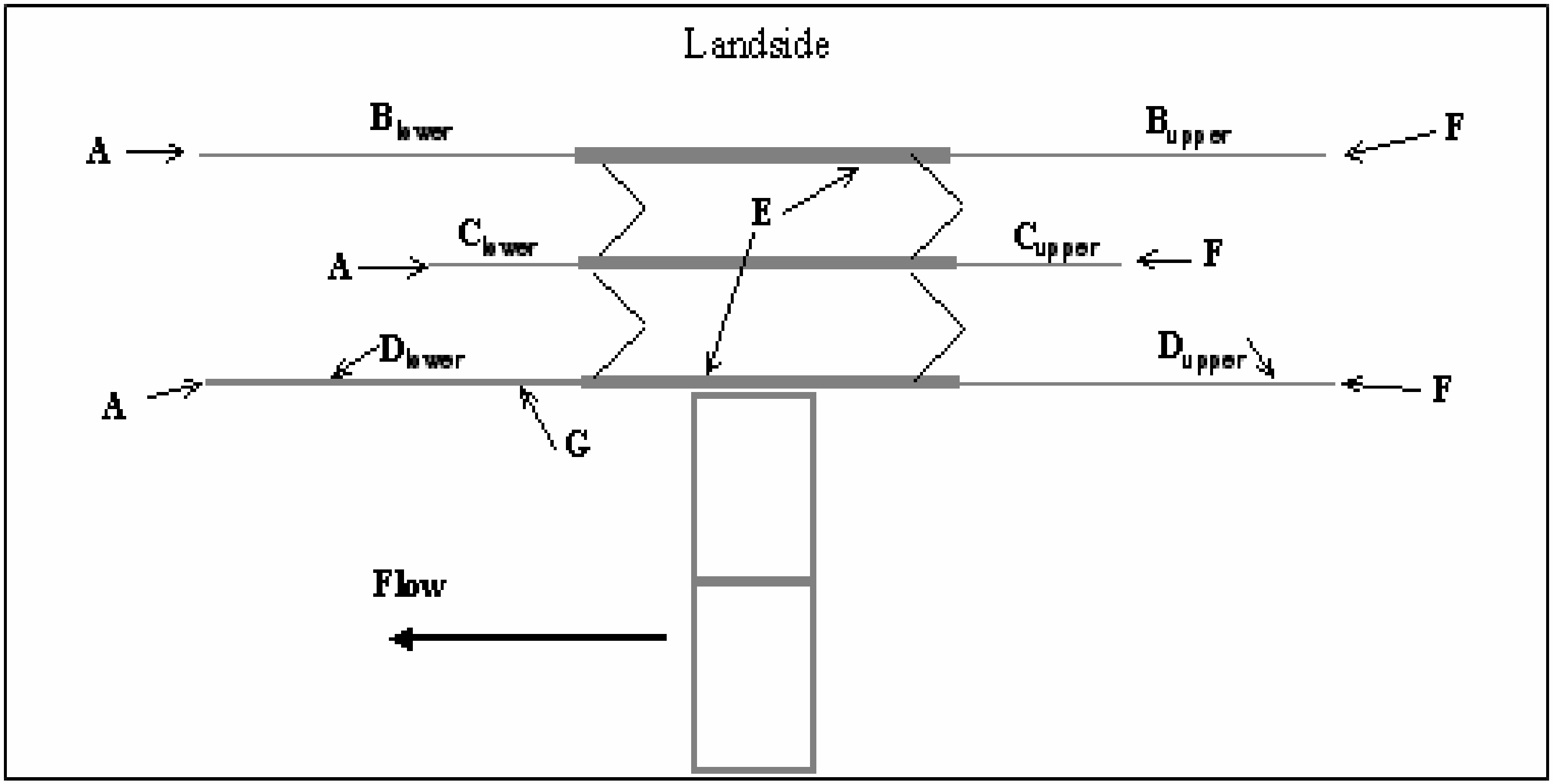
ETL 563

- Return periods

  - Probabilistic Barge Impact Analysis (PBIA)
    - Similar to Probabilistic Seismic Hazard Analysis (PSHA)
    - Uses annual probability distributions for velocities, angle and mass
    - Uses Monte Carlo Simulation to assists with determining the return period (RP) or annual probability of exceedance, P(E)

$$RP = 1 / P(E)$$

Examples of impact loads on lock structures



To convert kips to kilonewtons, multiply by 4.448

Table B-5
Example of Preliminary 9-Barge Design Impact Forces and Locations

Symbol (Figure B-10)	Location	Event	Impact Load, kips
A	Lower protection cell/bullnose	Extreme	1,000
B_{lower}	Lower land wall	Usual	150
		Unusual	250
		Extreme	350
B_{upper}	Upper land wall	Usual	300
		Unusual	500
		Extreme	700
C_{lower}	Lower middle wall	Usual	100
		Unusual	150
		Extreme	250
C_{upper}	Upper middle wall	Usual	200
		Unusual	300
		Extreme	500
D_{lower}	Lower river wall	Usual	200
		Unusual	300
		Extreme	400
D_{upper}	Upper river wall	Usual	400
		Unusual	600
		Extreme	800

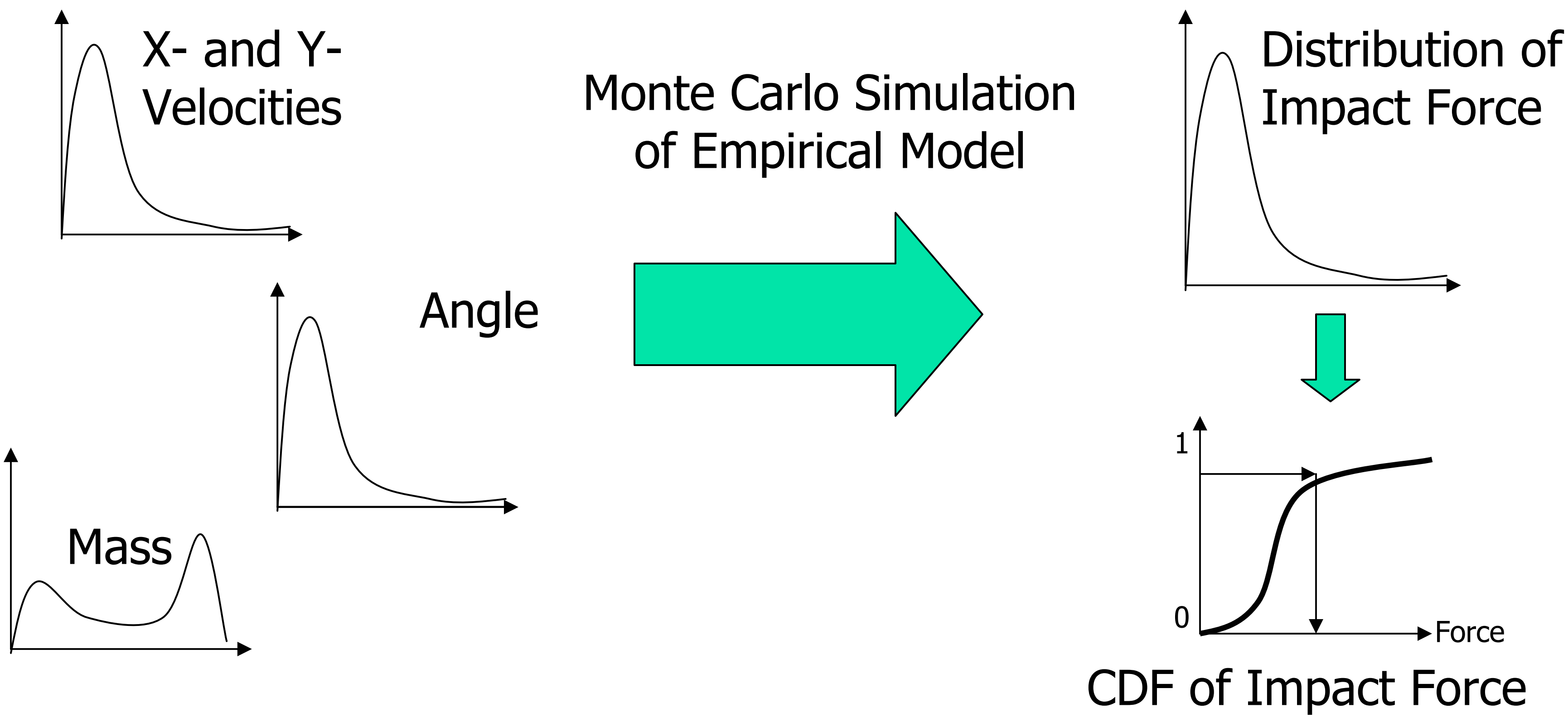
ETL 563

- Model Parameters
  - Velocity (x- and y-direction) and Angle
    - Scale model testing
    - Time lapse video
  - Mass
    - LPMS or WBC, Ship Logs
  - Site Examples in Appendix C

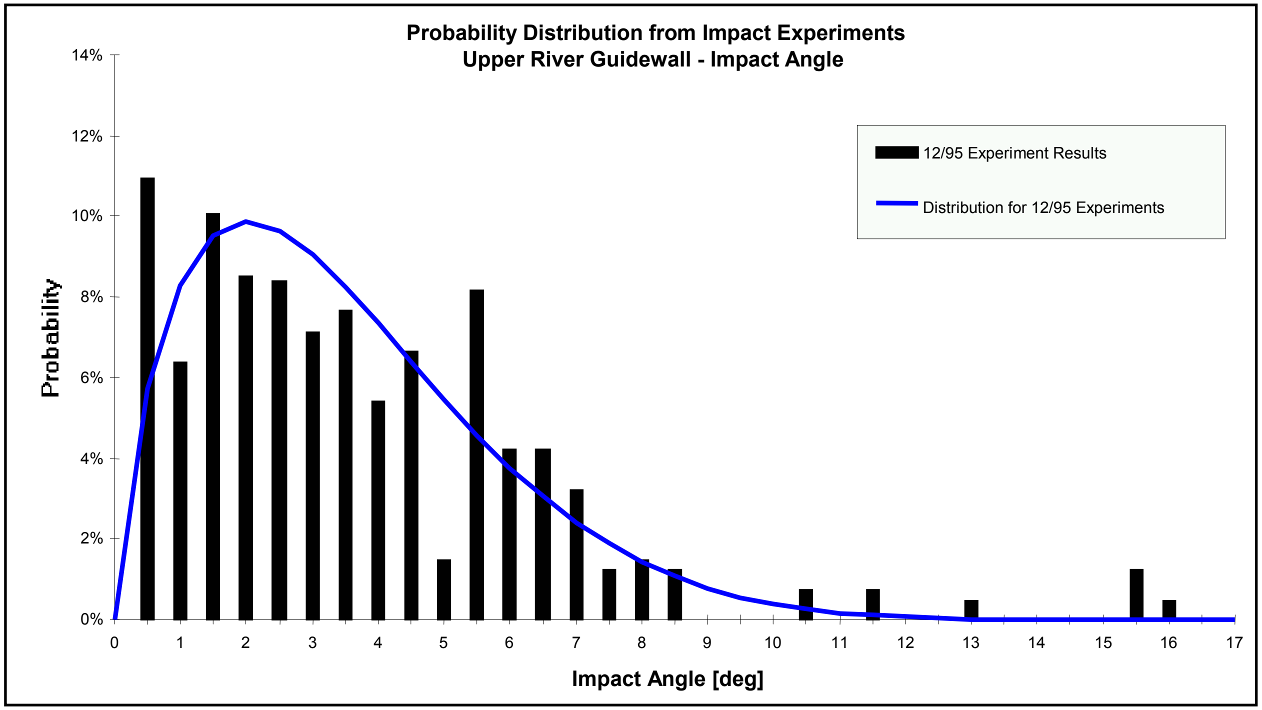
ETL 563

INPUTS

OUTPUT

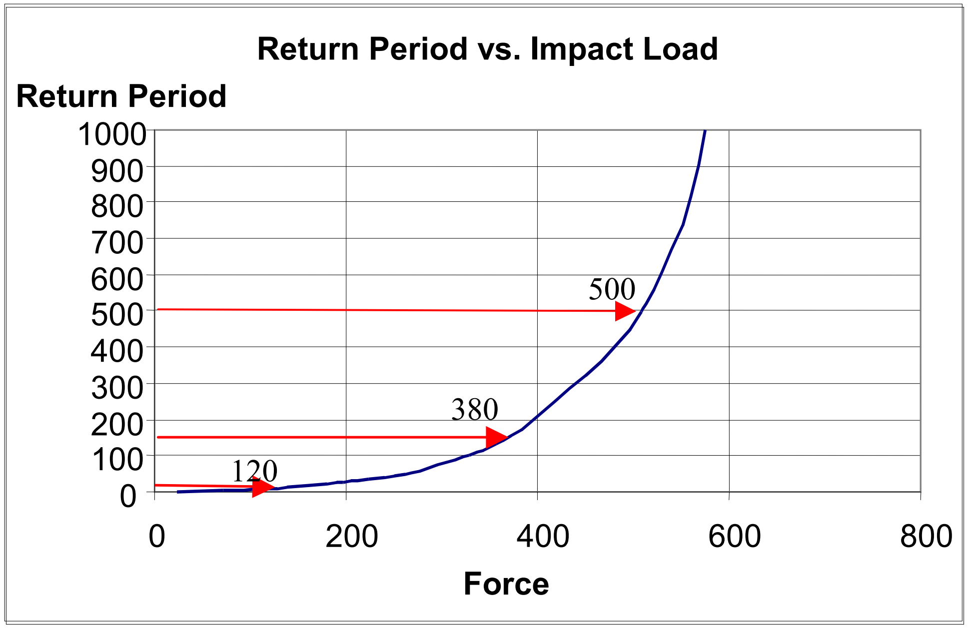


Example of Angle Distribution



Return period versus impact load for upper guide wall

- 120 Usual, 380 Unusual, 500 Extreme



ETL 563

- PBIA Example
  - Velocities and angles from scale model test results at ERDC
  - Mass distribution from LPMS or WBC data
  - Use Monte Carlo Simulation to generate distribution for impact load
  - Use Cumulative Distribution Function (CDF) of impact loads to determine return periods for design
    - No extrapolation to extreme distributions

Continuing Efforts

- Additional limit states
  - Lashing failures
  - Flexible Walls
  - Head-on impacts
    - Updates to ETL or new guidance
- Districts/Division-wide workshops
  - Hands-on training
  - Site specific analysis
- Computer programs
  - @Risk spreadsheet
  - Development of CASE Program

Barge Impact Analysis for Rigid Lock Walls

QUESTIONS

Robert.C.Patev@usace.army.mil

John.D.Clarkson@usace.army.mil