Andrew JIP- Phase II

Hurricane Andrew - Effects on Offshore Platforms

Final Project Meeting
June 21-22, 1995

PMB Engineering, Inc.
San Francisco, California

Agenda - June 22, 1995

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■ 8.00 AM	Introductory Remarks	DKD
■ 8.15 AM	Calibration Approach	RKA
■ 9.00 AM	Calibration Details	CAC
■ 9.45 AM	Break	
■ 10.00 AM	Calibration Results	RKA
■ 11.15 AM	Use, Comments, and Status	
	- Bias factors	CAC
■ 11.30 AM	Conclusions and Recommendations	DKD
■ 11.45 AM	Discussion	

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Calibration Approach

Calibration Methodology

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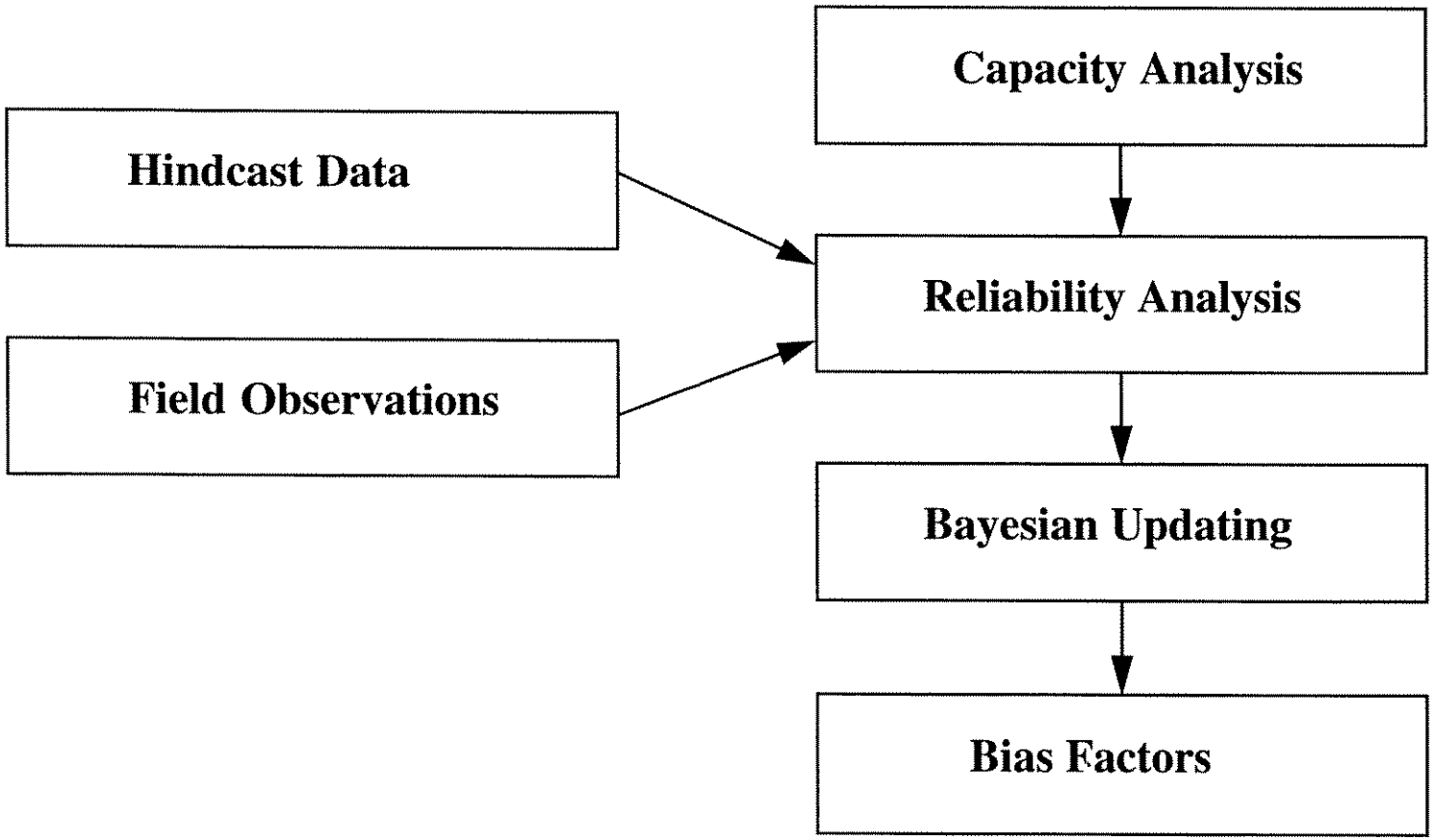

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Bias Factor (B)

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- **Where to Introduce ?**
  - **On Resistance** (R)true = (B) (R)predicted
  -
  - **On Loads** (S)true = (B) (R)predicted
  -
  - **On Safety Margin:** (R/S)true = (B) (R/S)predicted

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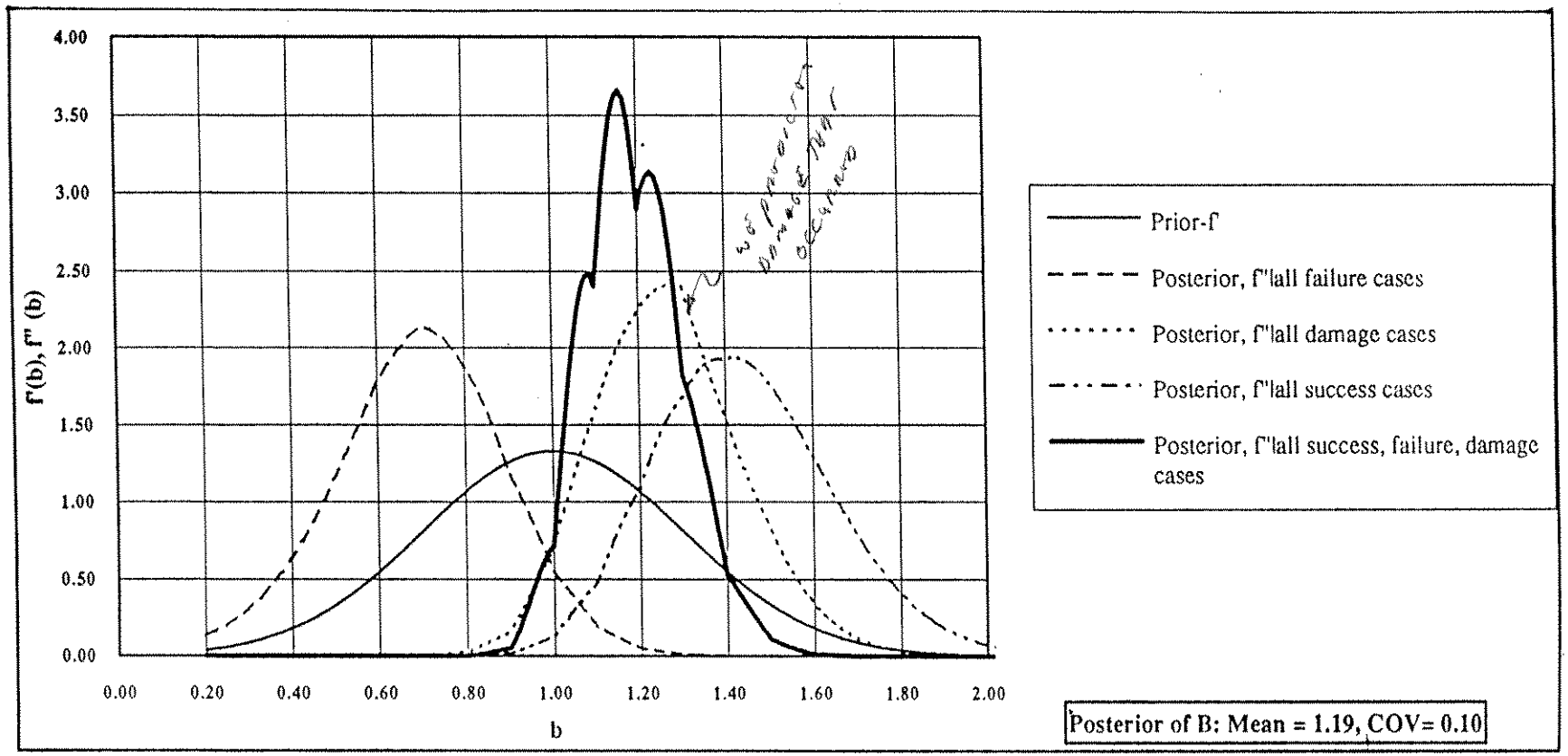

Posterior Distribution of Bias Factor (B)

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Calibration

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- **Three Different Bias factors for Platforms**
  - **Bias in the Jacket Superstructure** **Bss**
  - **Bias in Foundation Lateral Capacity** **Bfl** – From Caisson PMB Report 94-81
  - **Bias in Foundation Axial capacity** **Bfa**
- **Andrew JIP - Phase I**
  - **Bias Factor B - All Failure Modes Included**
- **API/MMS Foundation Study**
  - **Bias Factors Bfl and Bfa**
- **Andrew JIP - Phase II**
  - **Joint Distribution of Three B's**
  - **Marginal Distributions of Three B's**

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Foundation Lateral Capacity

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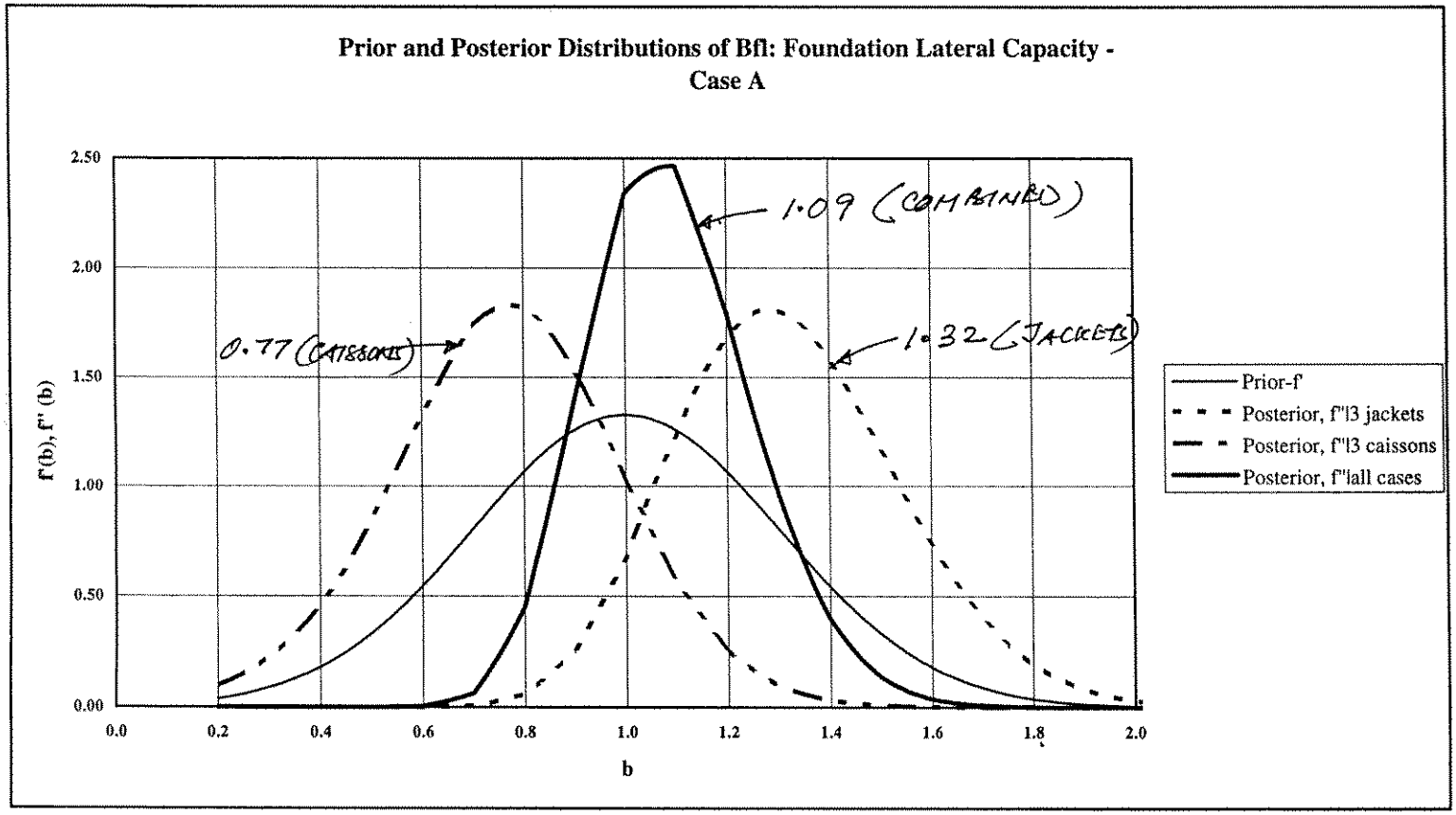
- **Very Small Pilehead Displacements**
- **Case A: Fully Plastic Section Event did not Occur in the First Pile**
- **Case B: Fully Plastic Section Event did not Occur in Several Piles**
- **Case C: Fully Plastic Section Event did Occur in One Pile**

API/MMS Foundation Study

Andrew JIP- Phase II



Posterior of Bfl - Jacket Platforms & Caissons

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API/MMS Foundation Study- Summary

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- **Foundation Lateral Capacity**
  - **API Static p-y Curves/ Springs**
  - **Prior Bias Factor of 1.0**
  - **Posterior Bias Factor - Jacket Platforms**
    - **1.32 for Case A** — First plastic hinge
    - **1.26 for Case B** — multiple plastic hinges
  - **Calibrating at First Pile Hinge of Multiple Pile Hinge does not Result in Significant Difference in Bias Factors**
  - **Case-C of Calibrating Assumed Observed Hinge Event Result in No Shift in Bias Factor**
  - **Posterior Bias Factor for Caissons Alone - 0.77**
  - **Including Jacket and Caisson Cases Reduces the Lateral Foundation Bias Factors to 1.04 - 1.09**

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Foundation Axial Capacity

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- **Very Small Pilehead Displacements**
- **Case D: Pullout/Plunging Event did not Occur in the First Pile**
- **Case E: Pullout/Plunging Event did not Occur in Several Piles**
- **Case F: Pullout/Plunging Event did Occur in One Pile**

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API/MMS Foundation Study

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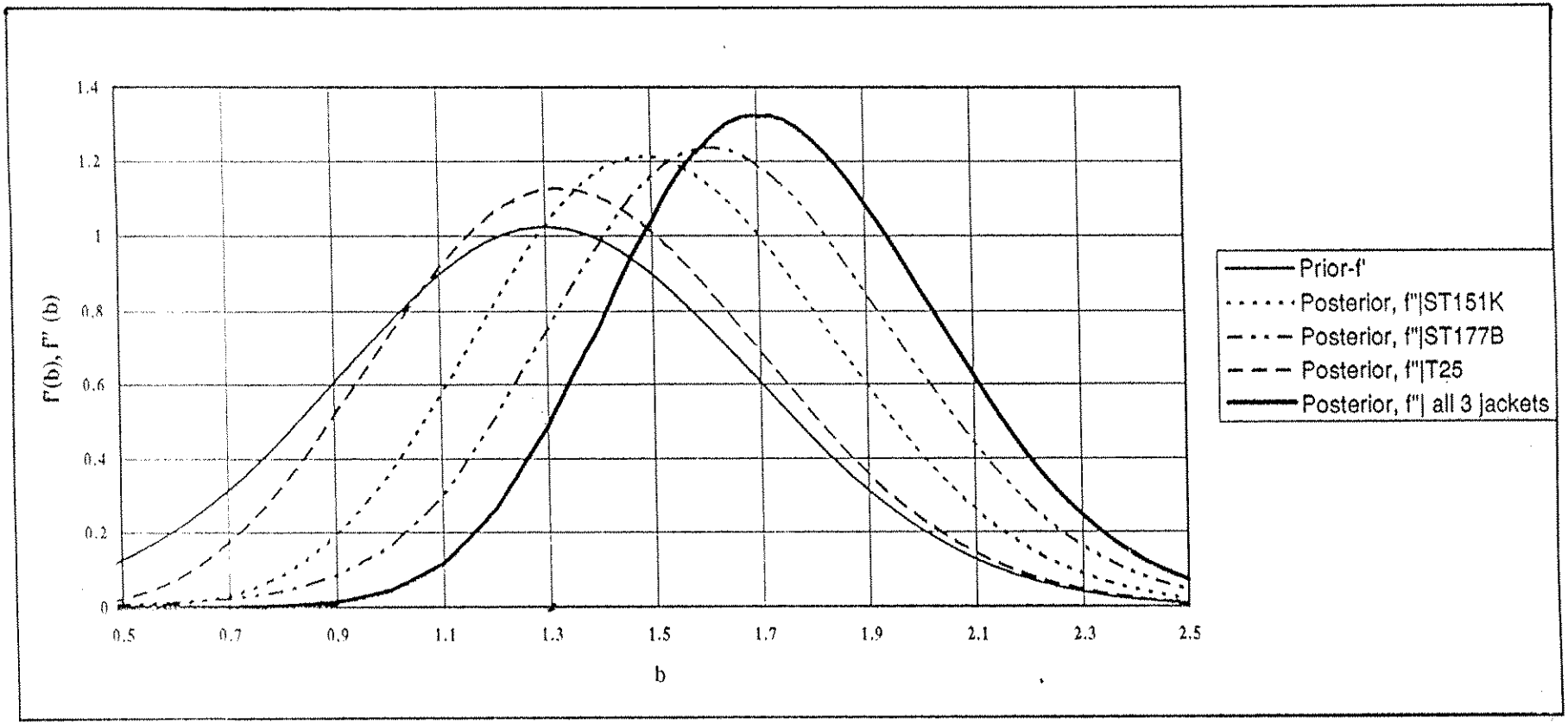

Prior and Posterior of Bfa - Jacket Platforms - Case D

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API/MMS Foundation Study - Summary

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- **Foundation Axial Capacity**
  - **API t-z Curves/ Springs with No Degradation**
  - **Prior Bias Factor with Mean of 1.3 and COV of 0.3.**
  - **Posterior Bias factor - Jacket Platforms**
    - » **1.73 for Case D**
    - » **1.66 for Case E**
  - **Calibrating at Predicted First or Several Pile Pullout/Plunging Events does not Result in Significant Difference in Bias Factors**
  - **Case-F of Calibrating Assumed Observed Pile Pullout/Plunging Event Result in Lower Shift in Bias Factor to 1.53**

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Calibration Procedure - Phase I

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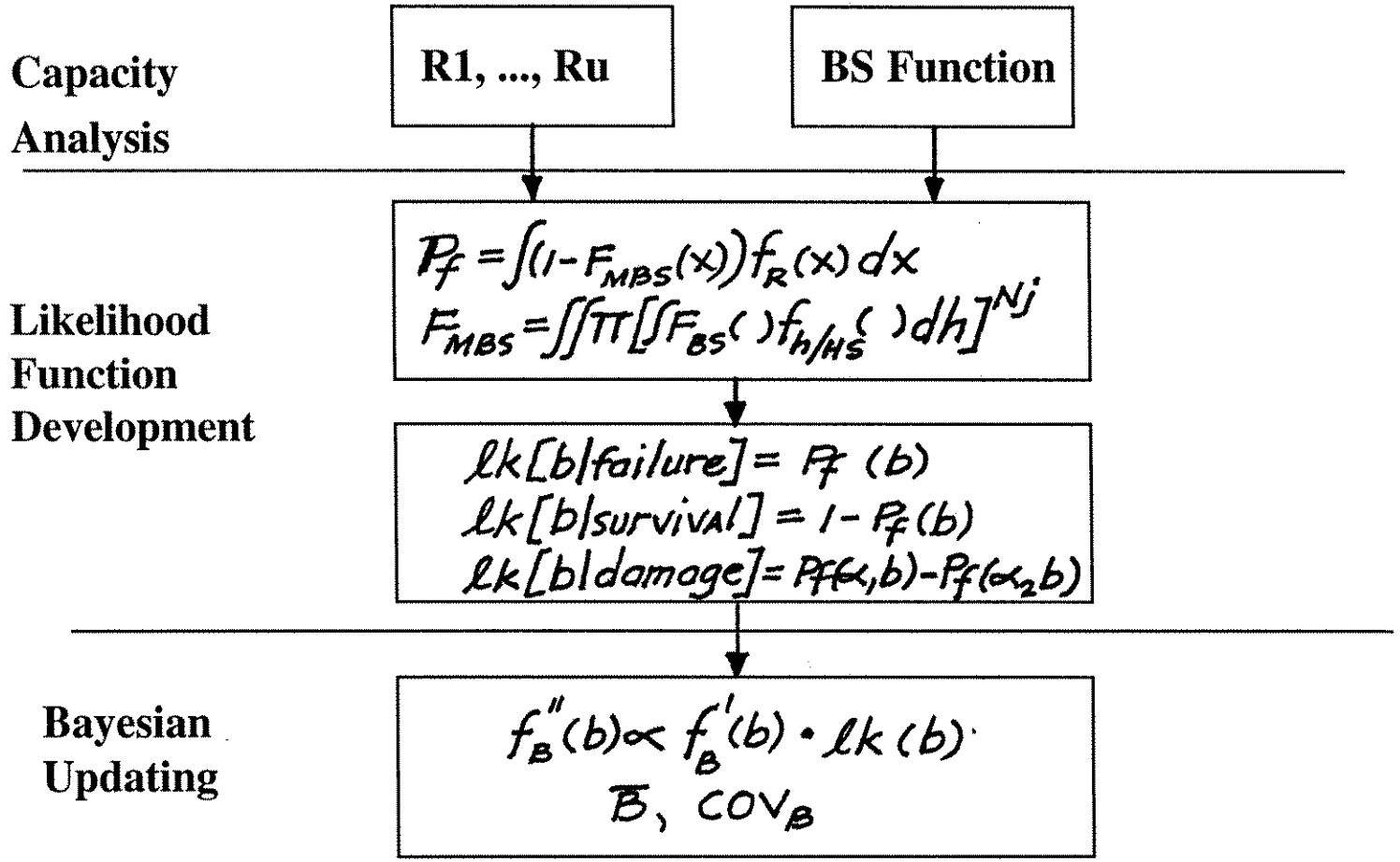

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Calibration Procedure - Phase II

Andrew JIP- Phase II

Capacity Analysis

R1, ..., Ru

BS Function

Likelihood Function Development

Model Failure $P_{fi}(b_i) = P\left[\frac{b_i R_i}{S_i} < 1\right]$

System Failure $P_f(b_1, b_2) = P\left[\left(\frac{b_2 R_1}{S_1} < 1\right) \cup \left(\frac{b_2 R_1}{S_2} < 1\right)\right]$

SYSREL / FORM / SORM

$$lk[b_1, b_2 \mid failure] = P_f(b_1, b_2)$$

Bayesian Updating

$$f''_{B_1,B_2}(b_1,b_2) \propto f'_{B1,B2}(b_1,b_2)\, lk\, b_1, b_2 \mid new\ inf.]$$

$$f''_{B_1}(b_1) = \int_{b_2} f''_{B1,B2}(b_1,b_2)\, db_2$$

$\bar{B}_1$, COV$_{B1}$

$\bar{B}_2$, COV$_{B2}$

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Phase II Work Presentation

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Multiple B's

- Introduction to Likelihood Functions: Encoding Observed Behavior of Platforms?
- Failure Probability Formulation
- Multiple Components, System Organization
- Likelihood Functions Development
- Prior Distributions of B's
- Bayesian Updating
- Bias Factors - Joint and Marginal Distributions
- Applications of Bias factors

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Calibration Details

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Introduction to Likelihood Functions

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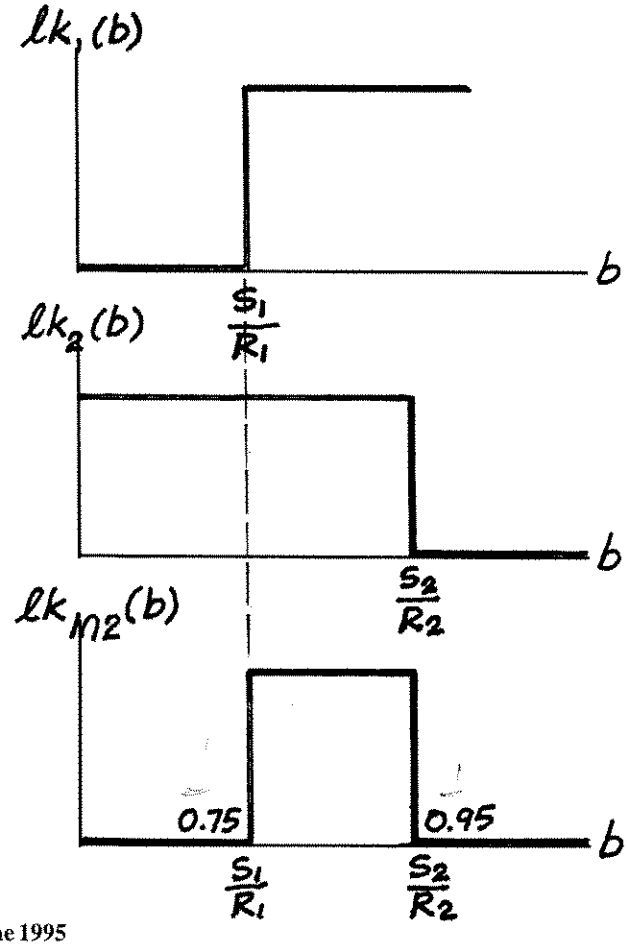
Deterministic Likelihood Functions - Single Failure Mode



SURVIVAL $b\frac{\hat{R}_1}{S_1} > 1.0$ (CAPACITY / LOADS)

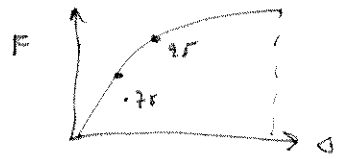
$b > \frac{S_1}{R_1}$

FAILURE $b\frac{R_2}{S_2} < 1.0$

$b < \frac{S_2}{R_2}$

DAMAGE $0.75 < \frac{bR}{S} < 0.95$

$\frac{S}{R_1} < b < \frac{S}{R_2}$



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Introduction to Likelihood Functions

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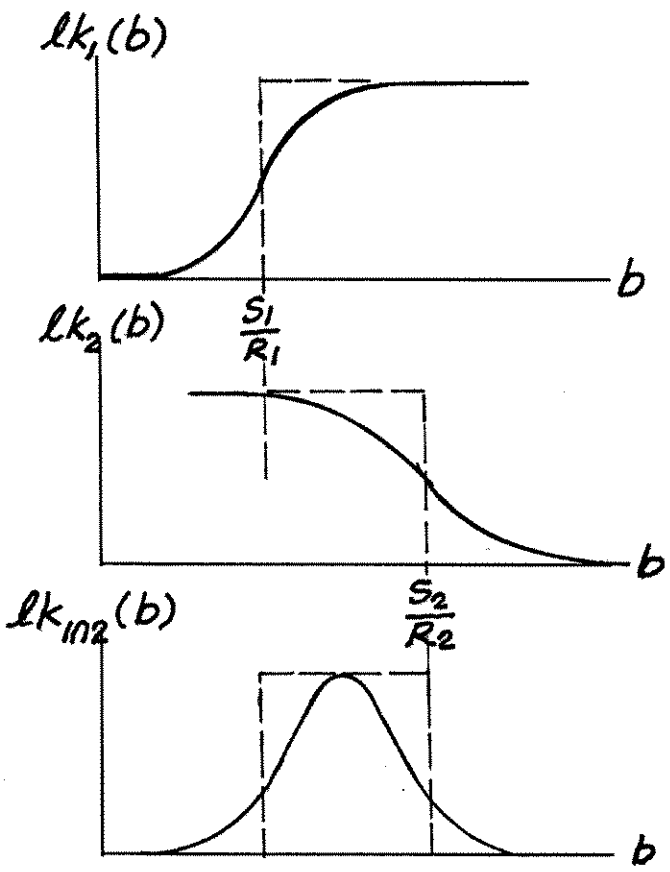
Probabilistic Likelihood Functions- Single Failure Mode



THIS IS A MEASURE OF THE UNCERTAINTY OF S AND R

SURVIVAL:

$$lk_1(b \mid \text{SURVIVAL}) = P\left[b_1 \frac{R_1}{S_1} > 1\right]$$

FAILURE:

$$lk_2(b \mid \text{FAILURE}) = P\left[b_1 \frac{R_2}{S_2} < 1\right]$$

DAMAGE:

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Introduction to Likelihood Functions

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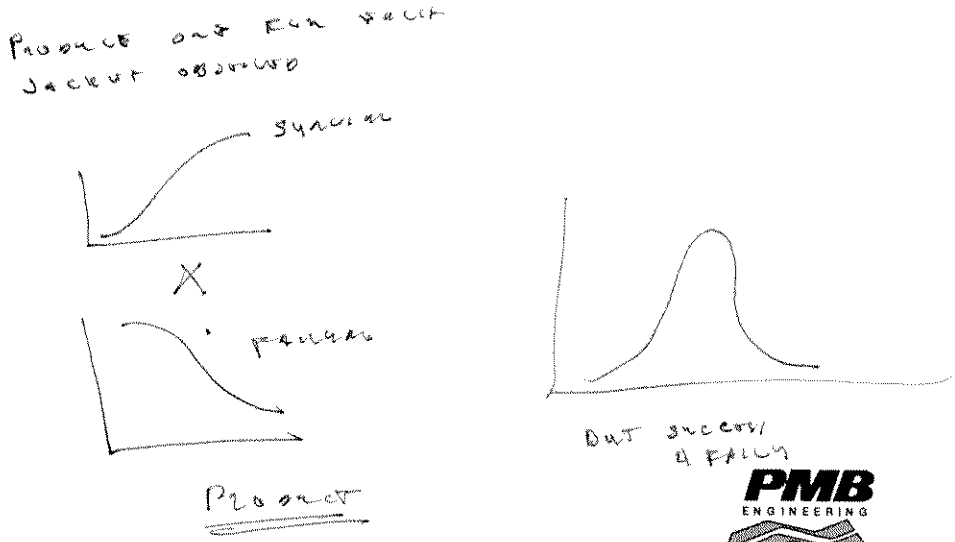
Multiple Structures

$$lk(b \mid n\ observations) = \prod_{platform}^{n} [lk(b \mid observations)]$$



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Introduction to Likelihood Functions

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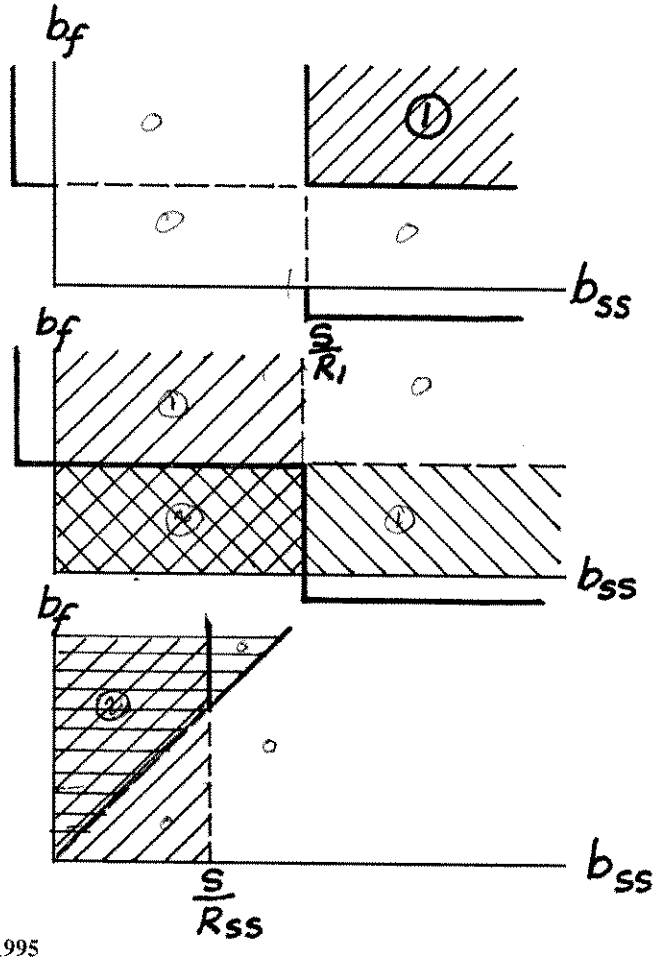
Joint Likelihood Functions - Two Failure Modes



Both Failure Modes Survived

$$P\left[\left(b_{ss}\frac{R_s}{S}>1\right) \cap \left(b_f\frac{R_f}{S}>1\right)\right]$$

AND

Structure Failed (Unknown Failure Mode)

$$P\left[\left(b_{ss}\frac{R_s}{S}<1\right) \cup \left(b_f\frac{R_f}{S}<1\right)\right]$$

OR

Superstructure Fails & Foundation Does Not

$$P\left[\left(b_{ss}\frac{R_{ss}}{S}<1\right) \cap \left(b_f\frac{R_f}{S}>1\right)\right]$$

$$\text{OR } P\left[\left(b_{ss}\frac{R_{ss}}{S}<1\right) \cap \left(\frac{b_f}{b_s}\cdot\frac{R_f}{R_{ss}}>1\right)\right]$$

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Introduction to Likelihood Functions

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Individual Likelihood Functions from Joint Likelihood Function

- **Marginal Likelihood Function**
  - $lk(bs) = \int lk(bs, bf)\, dbf$
  - $lk(bf) = \int lk(bs, bf)\, dbs$
- **Conditional Likelihood Functions**

  For example:
  - $lk'(bs) = lk(bs \mid bf = 1)$
  - $lk'(bf) = lk(bf \mid bs = 1)$
- **In General, $lk(b_s, b_f) \neq lk(b_s) \times lk(b_f)$**
  - **It will happen if and only if, Logical Separation (e.g., Survival of Both Modes) and Probabilistic Independence of the Events (e.g., No Common R.V.'s) Exist. We don't have either in most cases.**

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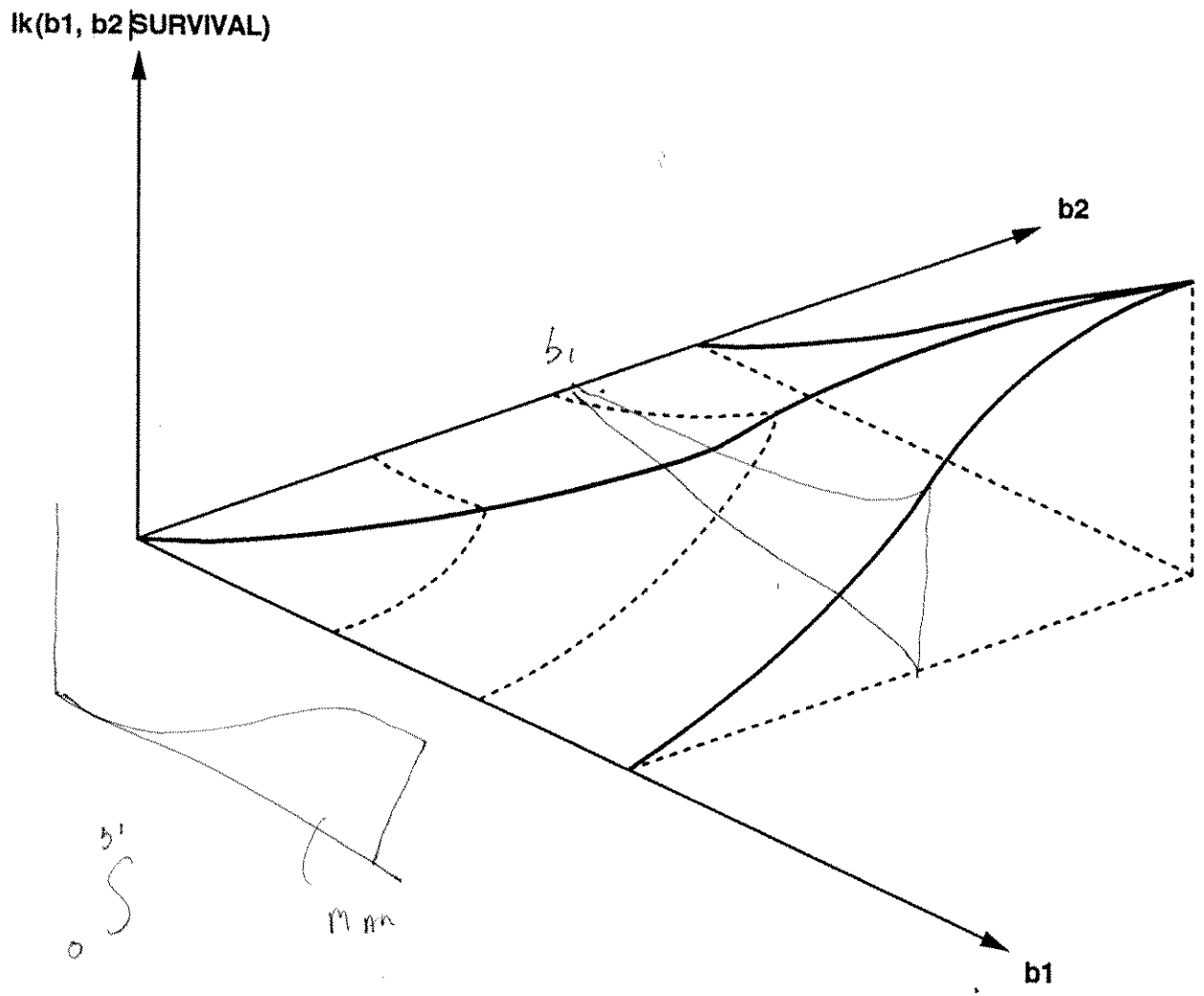

LIKELIHOOD FUNCTION - SURVIVAL CASE

PHASE II

Probability of Failure Equations

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- **Single B Factor - Andrew Phase I**

$$P_f = \int_0^\infty \left\{ 1 - F_{\substack{MBS \\ Andrew}}(x) \right\} f_R(x)\, dx$$

$$F_{MBS}(x) = \prod_{\substack{Hour \\ j}} \left\{ \int F_{BS}(x \mid H=h, U_j=u) \cdot f_{H/Hs}(h/Hs_j = hs)\, dh \right\}^{Nj}$$

$$F_{BS}(x \mid H=h, U_j=u) = \Phi\left[\frac{\ln x - \ln\left\{C_1 (h + C_2 u)\right\}^{C_3}}{\sigma_{\ln \epsilon_o}} \right]$$

$$BS = C_1 \left[h + C_2 u \right]^{C_3} \epsilon_o$$

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Probability of Failure

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Assumed Distributions for Load and Capacity Parameters

Item	Distribution	Expected	COV
Capacity, R	Log-Normal	per Analysis	0.15 (Jacket) 0.2 (Foundation - lateral) 0.3 (Foundation - Axial)
Indiv. Wave Height, (h/Hs)	Forrestall	per Hindcast	per Formula
Error in Hs	Log-Normal	1.0	0.10
Error in Current, U	Log-Normal	1.0	0.15
Error in Base Shear	Log-Normal	1.0	0.25 (wave-in-Deck) 0.20 (wave-below-deck

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Probability of Failure

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- **Probability of Occurrence (Failure or Survival) for a Single Structure in a Single Storm**
- **Multiple Storm Hours Effect Included**
- **Capacity Estimates Corresponding to Three Failure Modes Adjusted to Field Observations**
  - **Platform Survived (No Damage to Any Mode)**
  - **Platform Damaged - SuperStructure (but Foundation O.K.)**
  - **Platform Failed**
    - » **Failure Mode Unknown**
    - » **Failure in SuperStructure (and Foundation O.K.)**

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Probability of Failure

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- **Used RELACS (Risk Engineering, Inc.) Software to Compute Likelihood Functions**
- **Multiple "Components" Representing Probability of Occurrence (Failure or Survival) During:**
  - **Different Failure Modes**
  - **Different Storm Hours**
- **System Probability of Occurrence of Post-Andrew Field Observations Determined for a Range of "b" Values**
  - **Conditional distributions of b's**
  - **Joint Distributions of b's**
  - **Marginal Distributions of b's**

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Calibration Results

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Bayesian Updating

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- Assumed Prior Distributions of Bss, Bfl, and Bfa
- Likelihood Functions Corresponding to Field Observation for a Platform
- Posterior Distributions
  - Joint Distribution of B's for Individual Platforms
  - Joint Distribution of B's for All 9 Platforms
  - Marginal distributions of Three B's
- Mean and COV of Posterior Distributions of Bss, Bfl, and Bfa
  - Joint Distributions
  - Marginal Distributions

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Prior Distributions of B's

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- **Prior of SuperStructure, Bss** — **N(1, 0.3)**
- **Prior of Foundation Lateral, Bfl** — **N(1, 0.3)**
- **Prior of Foundation Axial, Bfa** — **N(1.3, 0.3)**
- **Joint Distribution of Three Priors**
  - **Mutually Independent**
  - **Product of Three Distributions**

$$f'(b_{ss}, b_{fl}, b_{fa}) = f'(b_{ss}) * f'(b_{fl}) * f'(b_{fa})$$

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Pile Axial Capacity

Andrew JIP- Phase II

- **API t-z Curves Would vary Due to Following:**
  - **Loading Rate or Strain Rate Effect**
  - **Cyclic Loading**
  - **Reconsolidation (Time Effect)**
  - **Compressibility (Pile Length Effect)**
  - **Pile Aging**
- **No Increase in t-z Capacity Considered in Capacity Analysis**
- **Used API Design t-z Curves**

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Pile Axial Capacity

Andrew JIP- Phase II

- **Per API PRAC 86-29B (Tang, 1988)**
- **Overall Bias**

	Mean	COV
– API 16th Edition	1.3 to 3.7	0.32 to 0.53
– API 17th Edition	1.5 to 3.0	0.30 to 0.40

- **Individual Effect Bias**

	Mean	COV
– Loading Rate	1.56	0.04
– Reconsolidation	1.27	0.04
– Compressibility	0.96	0.03

- **Used Prior of 1.3 with a COV of 0.3**

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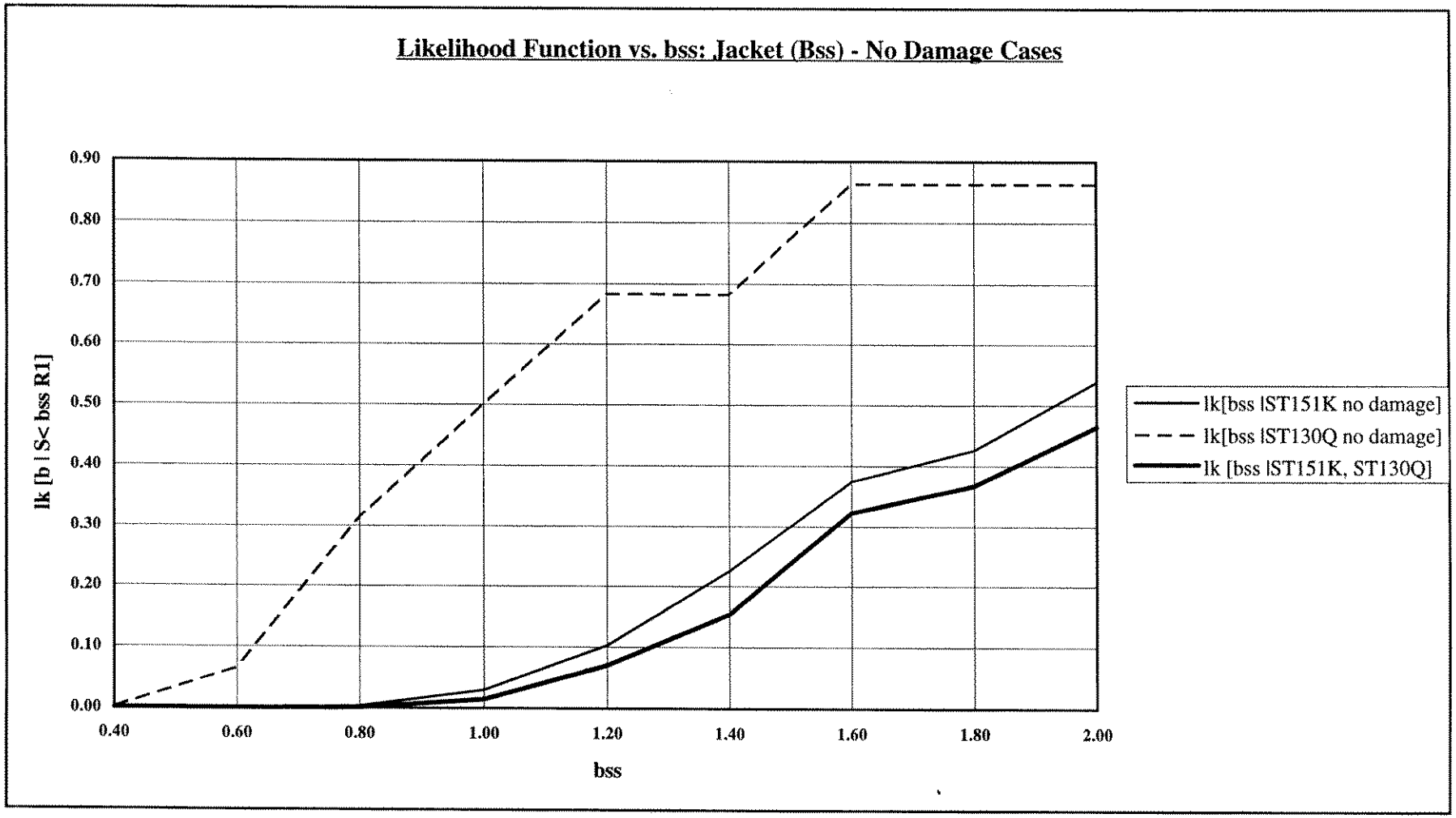
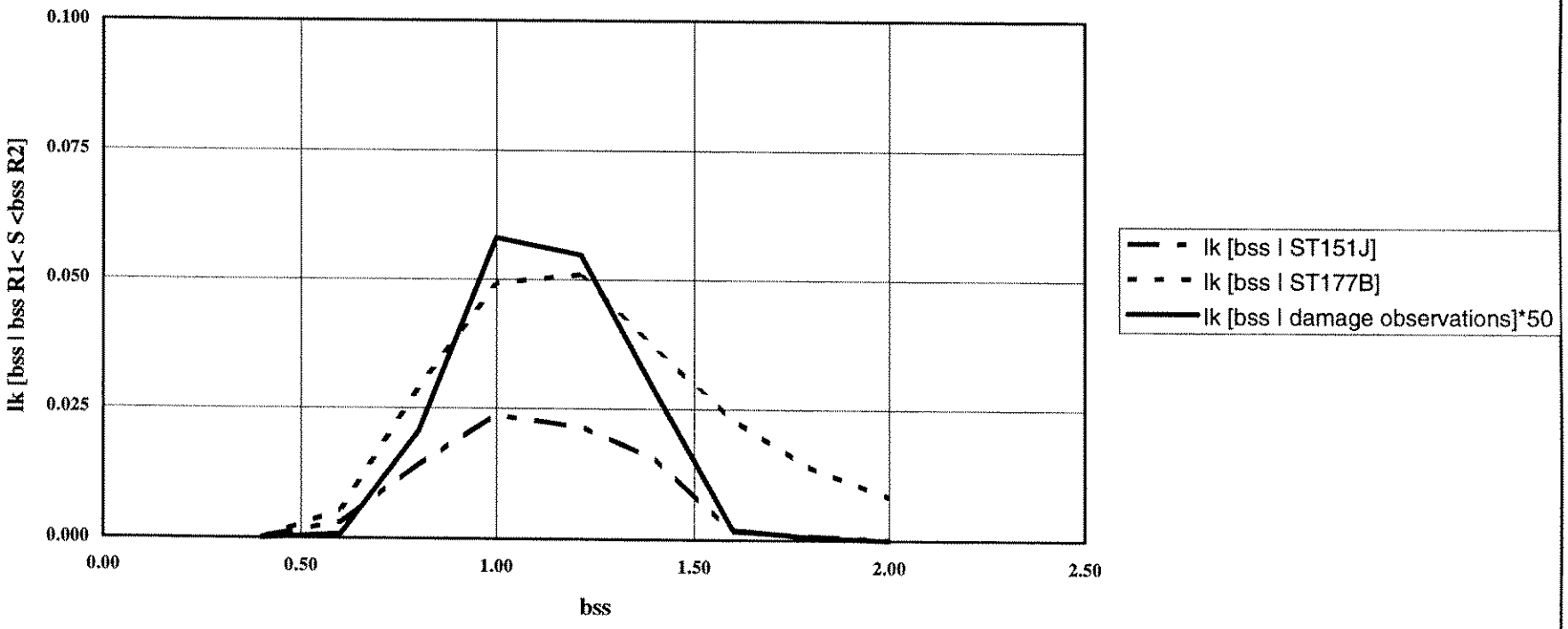
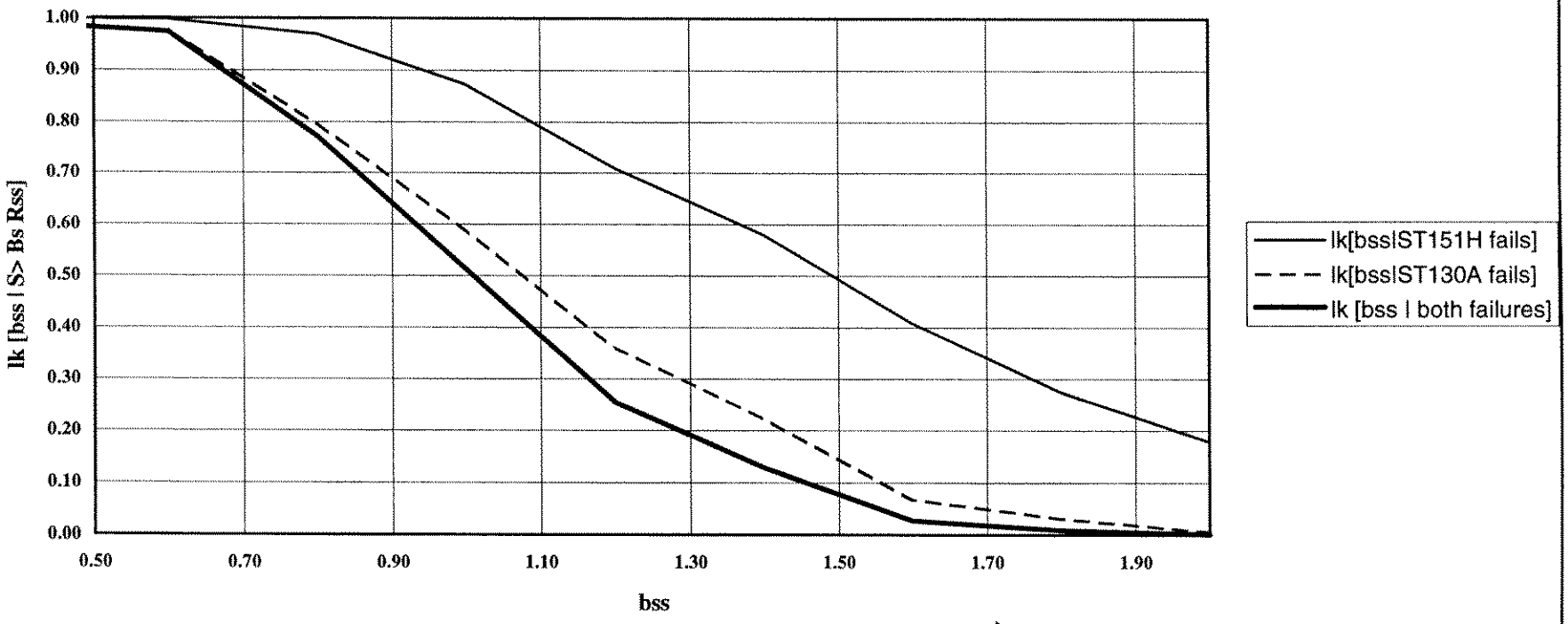
Likelihood Function vs. bss: Jacket (Bss) - No Damage Cases

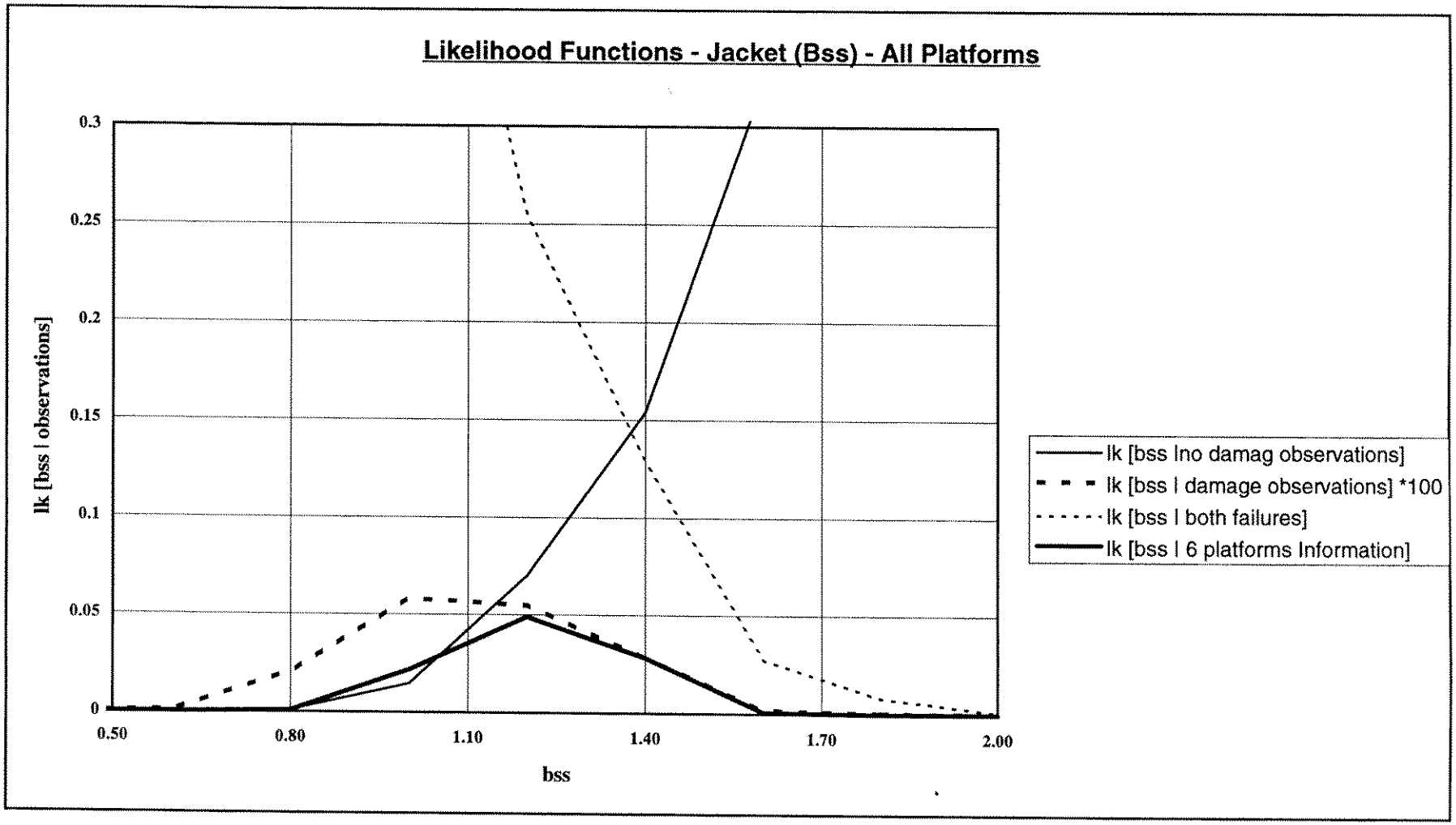


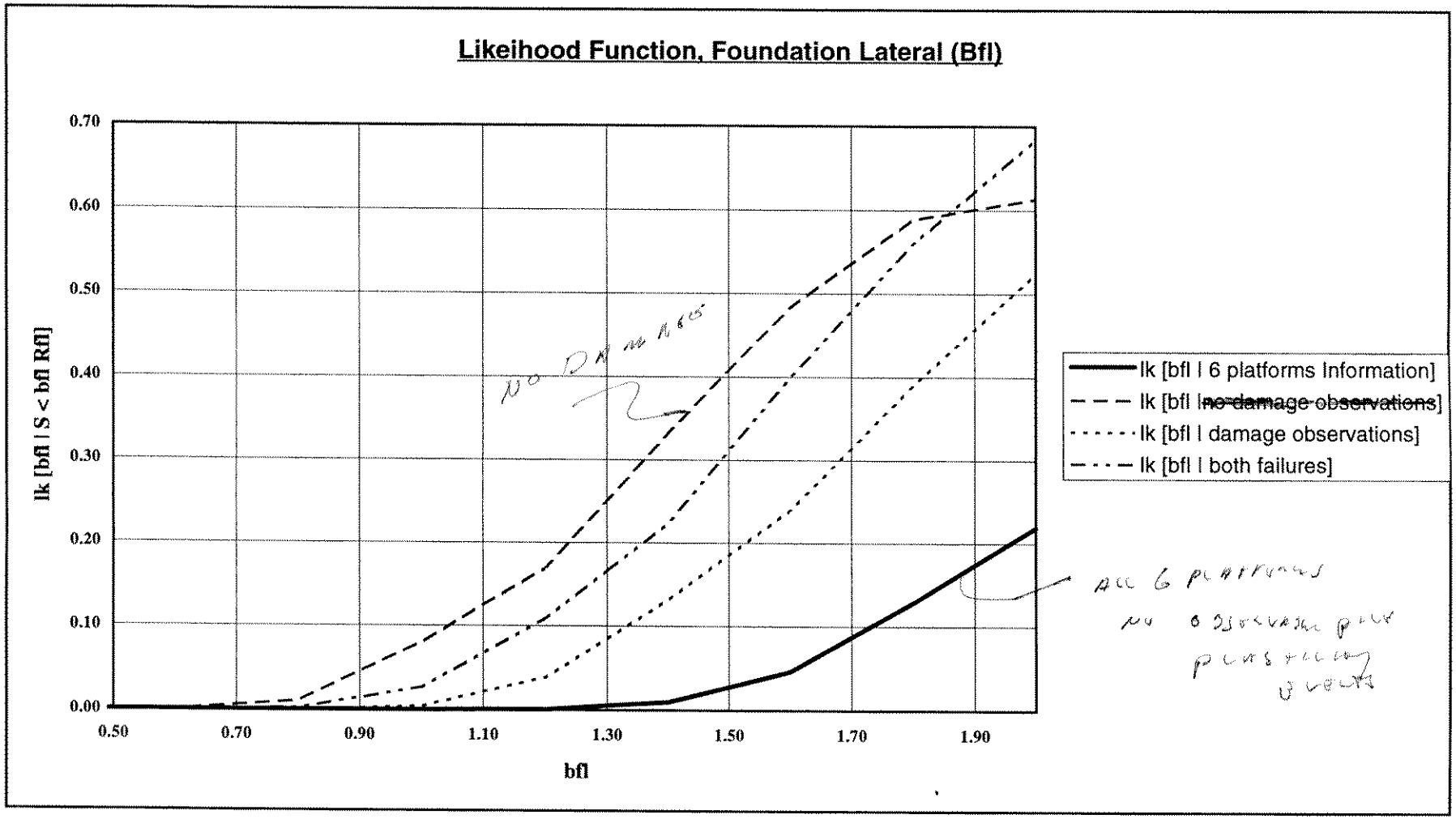
Likelihood Functions - Jacket (Bss): Damage Cases

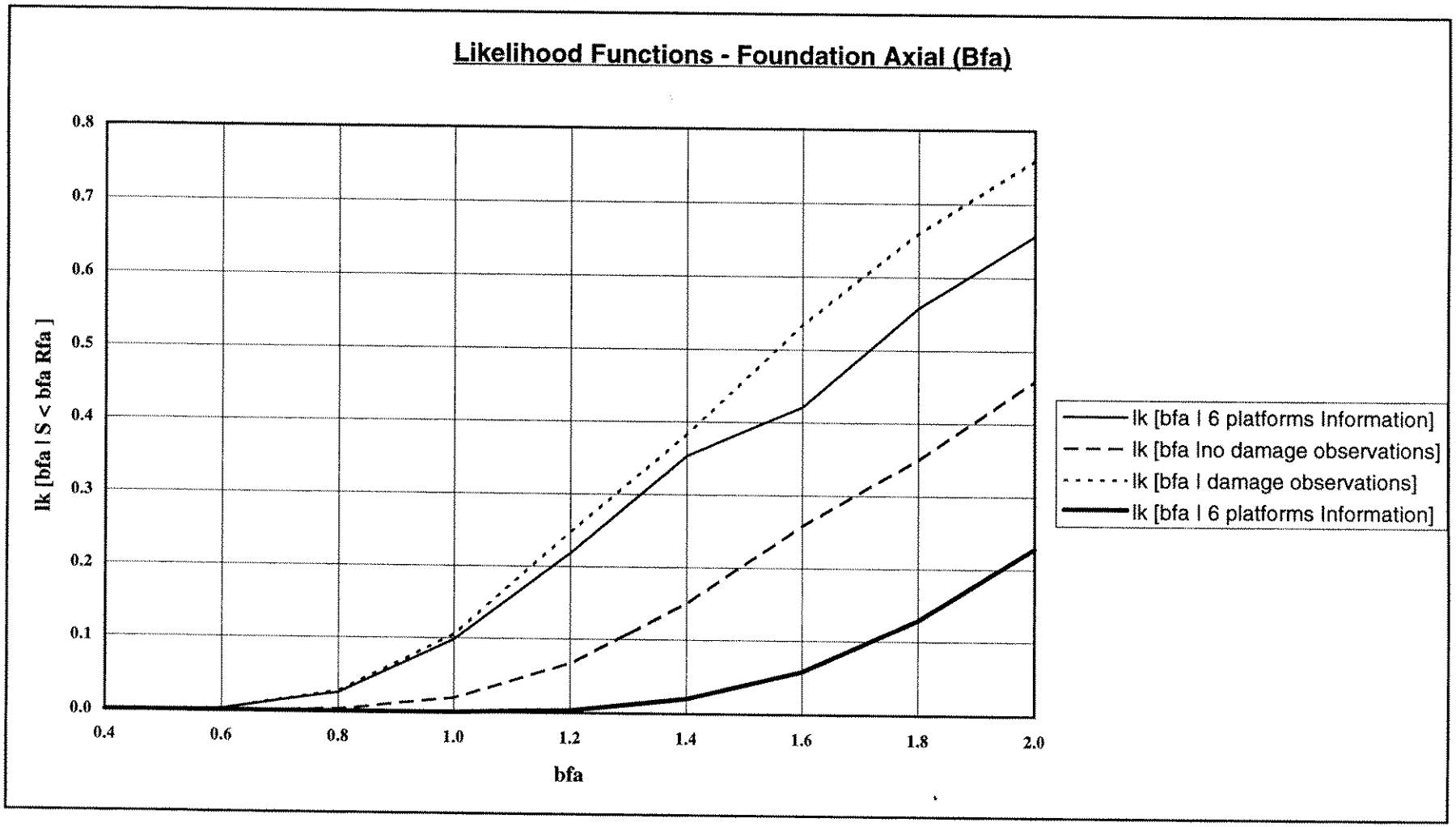


Likelihood Function - Jacket (Bss): Failure Cases




Likelihood Functions - Jacket (Bss) - All Platforms
lk [bss I observations]
0.3
0.25
0.2
0.15
0.1
0.05
0
0.50
0.80
1.10
1.40
1.70
2.00
bss
lk [bss Ino damag observations]
lk [bss I damage observations] *100
lk [bss I both failures]
lk [bss I 6 platforms Information]


Likeihood Function, Foundation Lateral (Bfl)
lk [bfl I S < bfl Rfl]
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0.50
0.70
0.90
1.10
1.30
1.50
1.70
1.90
bfl
lk [bfl I 6 platforms Information]
lk [bfl I no damage observations]
lk [bfl I damage observations]
lk [bfl I both failures]


Likelihood Functions - Foundation Axial (Bfa)
lk [bfa I S < bfa Rfa]
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
bfa
lk [bfa I 6 platforms Information]
lk [bfa Ino damage observations]
lk [bfa I damage observations]
lk [bfa I 6 platforms Information]

Posterior Distribution of B's (Phase I)

Andrew JIP- Phase II

Prior - N(1,0.3)

Posterior - Mean = 1.19, COV = 0.10

	Mean	COV
❑ No Damage	1.44	0.14
❑ Damage	1.26	0.13
❑ Failures	0.69	0.27

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Posterior Distribution of B's (Foundation JIP)

Andrew JIP- Phase II

- **Foundation - Lateral 'B_{fl}' Prior N(1,0,.3)**

Posterior:	Mean	COV
– Case A	1.32	0.17
– Case B	1.26	0.18
– ST151K	1.19	0.21
– ST177B	1.20	0.21
– T25	1.14	0.22

- **Foundation - Axial 'B_{fa}' Prior N(1,3,.3)**

Posterior:	Mean	COV
– Case D	1.73	0.17
– Case E	1.66	0.18
– ST151K	1.52	0.21
– ST177B	1.63	0.20
– T25	1.37	0.25

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Posterior Distribution of B's (Phase II)

Andrew JIP- Phase II

	Mean	COV
o Jacket 'B_j' N(1,0.3)	0.82	0.10
– No Damage	1.06	0.12
– Damage	0.78	0.13
– Failures	0.67	0.22
❑ Foundation - Lateral 'B_{fl}' N(1,0.3)	1.57	
– No Damage	1.30	
– Damage	1.30	
– Failures	1.41	
❑ Foundation - Axial 'B_{fa}' N(1.3,0.3)	1.69	0.12
– No Damage	1.50	0.18
– Damage	1.57	0.15
– Failures	1.50	0.17

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Summary - Posterior Distributions
All Studies (Phase I, II and Foundation)

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	Bias	Mean	COV
❑ **Andew Phase I**			
	'B'	**1.19**	**0.10**
❑ **Foundation Study**			
	'B_{fl}'	**1.30**	**0.17**
	'B_{fa}'	**1.70**	**0.17**
❑ **Andew Phase II (Preliminary)**			
	'B_j'	**0.82**	**0.10**
	'B_{fl}'	~~**1.30**~~ 1.57	~~**0.17**~~
	'B_{fa}'	**1.70**	~~**0.17**~~ 0.12

Over prediction Mo capacity
or
Under prediction Mo Load

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Use, Comments and Status

Example Use of Bias Factors

- **DETERMINE PREDICTIVE PROBABILITY OF FAILURE**

  - $Pf \iint f''_{B1,B2}(b_1, b_2)\, db_1, db_2$

  - $Pf\,[b_1, b_2] = P\,[(g_1<0)(g_2 < 0)]$

    $g_1 = (b_1 * R_1 / S) - 1$

    $g_2 = (b_2 * R_2 / S) - 1$

    or $Pf = P[g'_1 < 0 \cup g'_2 < 0]$

    with $g_1 = B_1R_1 / S\text{-}1$

    $g_2 = B_2R_1 / S\text{-}1$

Example Use of Bias Factors

- **EVALUATION OF ANNUAL PROBABILITY OF FAILURE**
  - Establish Annual Maximum Seastate Data
  - Determine Coefficients to Define Base Shear
  - Determine Ultimate Capacity of Platform
  - Determine Probability of Failure versus "b"

- **DETERMINE UPDATED PROBABILITY OF FAILURE (Single B; as in Andrew I)**
  - $Pf = P[S > R]$ [Bias not considered]
  - $Pf' = \int P[S > Rb \mid b]\, f_B'(b)\, db$ [Prior]
  - $Pf'' = \int P[S > Rb \mid b]\, f_B''(b)\, db$ [Posterior; Post Andrews]

    Still Applies to Individual Mode.

Conclusions and Recommendations

Work to Do

Andrew JIP- Phase II

- **Update Likelihood Functions**
- **Complete Bayesian Updating**
- **Develop an Example Application**
- **Issue Draft Report**
  - **July .....**
- **Participants Comments**
  - **1 month after Submittal of Draft Report**
- **Release Final Project Report**

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