#510359 (16)

Computational Evaluation of Shipboard Cathodic Protection Systems

by V. G. DeGiorgi, E. D. Thomas III and K. E. Lucas

Mechanics of Materials Branch and Environmental Effects Branch
Naval Research Laboratory, Washington, DC, 20375, USA

A. Kee

Geo-Centers
Ft. Washington, Maryland, 20744, USA

ABSTRACT

Impressed current cathodic protection (ICCP) systems and computer modeling using boundary element techniques are independent established technologies. The application of boundary element methods to the design of ICCP systems will result in the development of more effective and more efficient ICCP systems. Three analyses are highlighted in the presentation. In two analyses, detailed comparisons are made between physical scale modeling (PSM) and computer modeling results. PSM results are defined as the baseline that computer modeling results are compared with to determine the applicability and accuracy of the technique. The first analysis performed uses U. S. Navy CG Hull Class and examines issues of mesh refinement and material characterization accuracy. In the second analysis, PSM and computer analysis for the CG Hull Class are directly compared with sea trial data. In the final analysis presented issues of scale and material characterization are examined using a model of a U. S. Navy CVN Hull Class ship.

Computational Evaluation of Shipboard Cathodic Protection Systems

NAVAL RESEARCH LABORATORY * * WASHINGTON, D.C. * *

Dr. Virginia G. DeGiorgi
Mechanics of Materials Branch

Mr. E. Dail Thomas III
Mr. Keith Lucas
Environmental Effects Branch

Mr. Anthony Kee
Geo-Centers, Ft. Washington, MD

The Naval Research Laboratory

Washington, DC

The Naval Research Laboratory (NRL) is the direct result of a proposal made in 1915 by Thomas Edison to the United States Government for the establishment of a government laboratory for research and development of military technologies. NRL was officially founded in 1923. In 1992 NRL was designated as the U. S. Navy's Corporate Laboratory. The research staff at NRL consists of nearly 1500, primarily civilian employees of the Navy. The main campus is located along the Potomac River at the southern tip of the District of Columbia.

Research is conducted at NRL in general science and technology, warfare systems and sensors, materials science, ocean and atmospheric sciences and space science and technology. The diversity of expertise available at NRL is an important asset in the formation of research teams. Access is provided by NRL to multiple super-computer facilities for state of the art computational analyses. Fully equipped fatigue and fracture laboratories, corrosion testing laboratories, a vacuum arc melting furnace for reactive metals, hot isostatic press and ultrasonic non-destructive testing laboratory are only a few of the facilities available at NRL.

More information on NRL may be obtained from it's World Wide Web Home Page at:

http://www.nrl.navy.mil/

Cathodic Protection

GOAL: Maintain material to be protected at electrical charge level which minimizes corrosion.

*Makes use of natural electrochemical response

*Sacrificial Anodes
- Zinc
- Aluminum
- Impractical for large ships

*Impressed Current
- External power source
- Electrical current source points - anodes
- Voltage read at reference cells
- Simple feedback loop
- -reference cell readings control power input

Approach/Description

Application of computer modeling capability to determine geometric, spacial and electrochemical interactions for use in system design and evaluation

Approach has been verified for a ship hull ICCP system

Using a Boundary Element Method (BEM) a ship hull ICCP system has been reproduced as a Computer Model:

* Precisely Duplicates Complex Geometries
* Precisely Duplicates Major Alloys
* Includes ICCP System Anodes as Part of Computer Model

Method Verification by comparison to:

* Physical Scale Model Tests
* Ship Trial Data

Physical Scale Modeling

Scale Dimensions

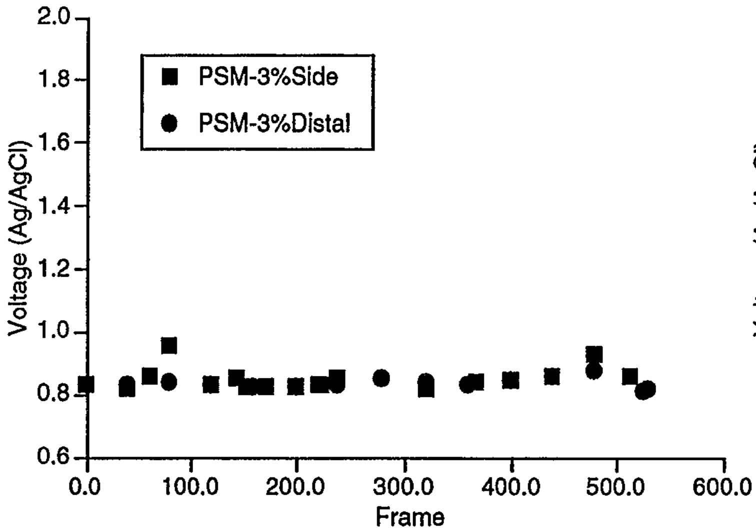
Scale Conductivity

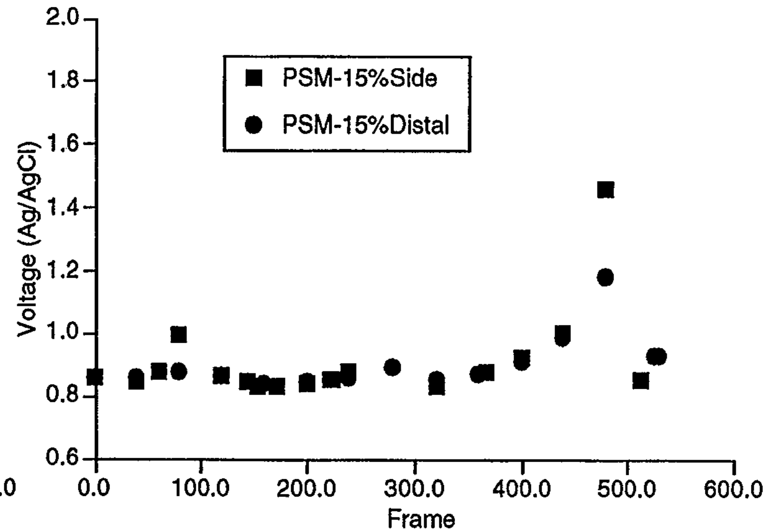
Reproduce Design as Scale Model
Precisely Duplicate Complex Geometries
Precisely Duplicate All Metal Alloys

Validated by Comparison with Sea Trails Data
USS Princeton
(CG-59)

Partial Coating System Applied to Princeton
Conditions Between Minimum and Maximum Damage Conditions

Physical Scale Model Data
Distal vs Side

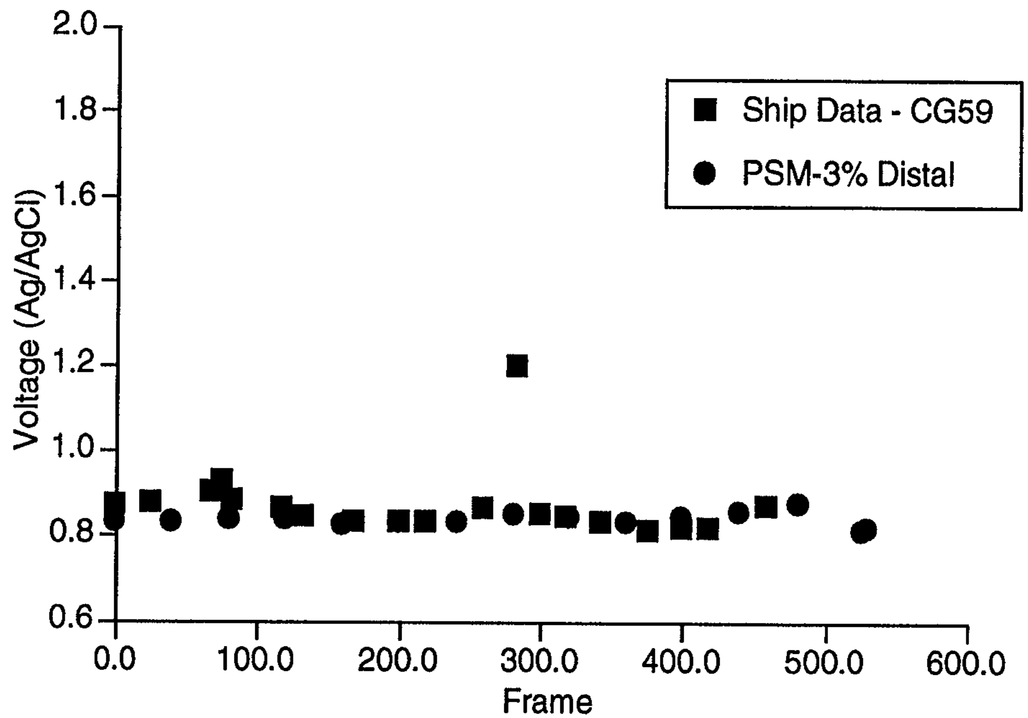




Demonstrates the similarity in readings. Distal readings correspond to real ship data. Side readings correspond to computer model data.

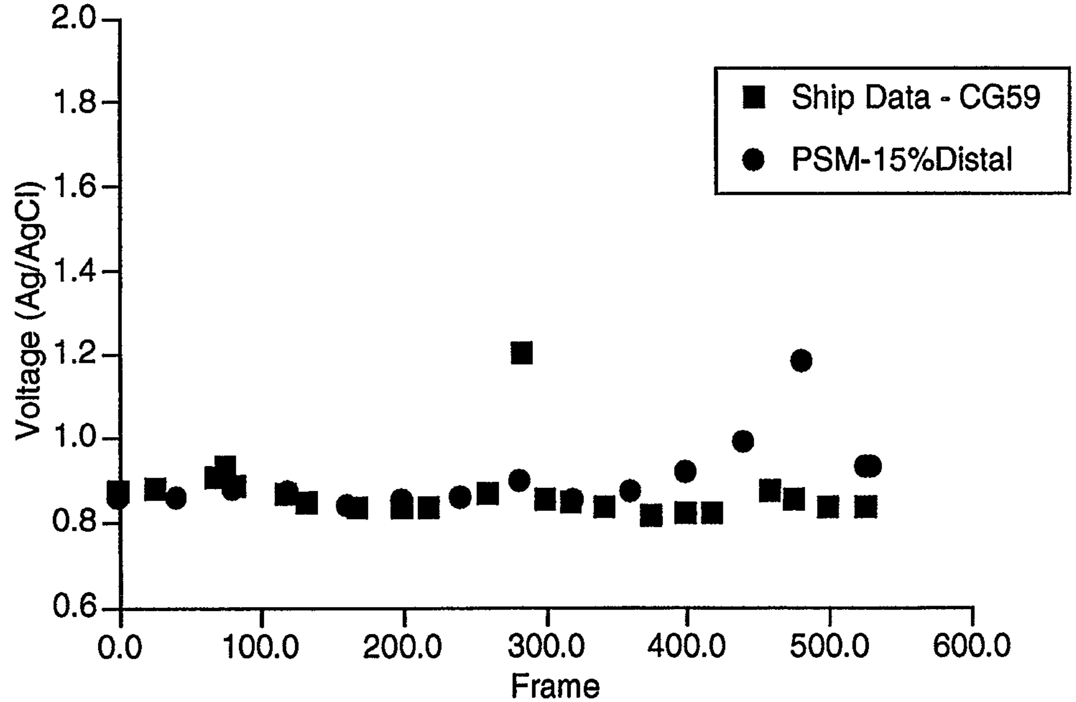
Comparison of Ship Data and Physical Scale Model Data

Beginning of Life Conditions for Modeling Results



Comparison of Ship Data and Physical Scale Model Data

End of Life Conditions for Modeling Results



Computer Modeling Approach

Boundary Element Method

LaPlace's Equation

$$\nabla^2\Phi = 0$$

Nonlinear Material Polarization Response

Constant Potential (i.e. Anode)

$$\Phi = c$$

Constant Current (i.e. Anode)

$$\frac{\partial\Phi}{\partial n} = c$$

Insulated (i.e. Painted Surface)

$$\frac{\partial\Phi}{\partial n} = 0$$

Results from Computer Modeling

* Potential Map of Entire Surface

* Current Density Map of Entire Surface

* Potential Map of Surrounding Electrolyte

* Access to Potential and Current Density Values at Point Locations

* Current Balance

Ship/System Geometry

CG-59 (6 anode/2 power supply zones)
CG-66 (7 anode/2 power supply zones)

Conditions Considered

Static -
Minimum (3%) Damage
Maximum (15%) Damage
Dynamic -
Minimum (3%) Damage
Maximum (15%) Damage

Open Water Polarization Response

Plate Velocity Polarization Response Study
NAB
Steel
20 Ohm-cm Seawater

CG Model Details

BEASY-CP Version 1.1
(revision date 22 July 1988)

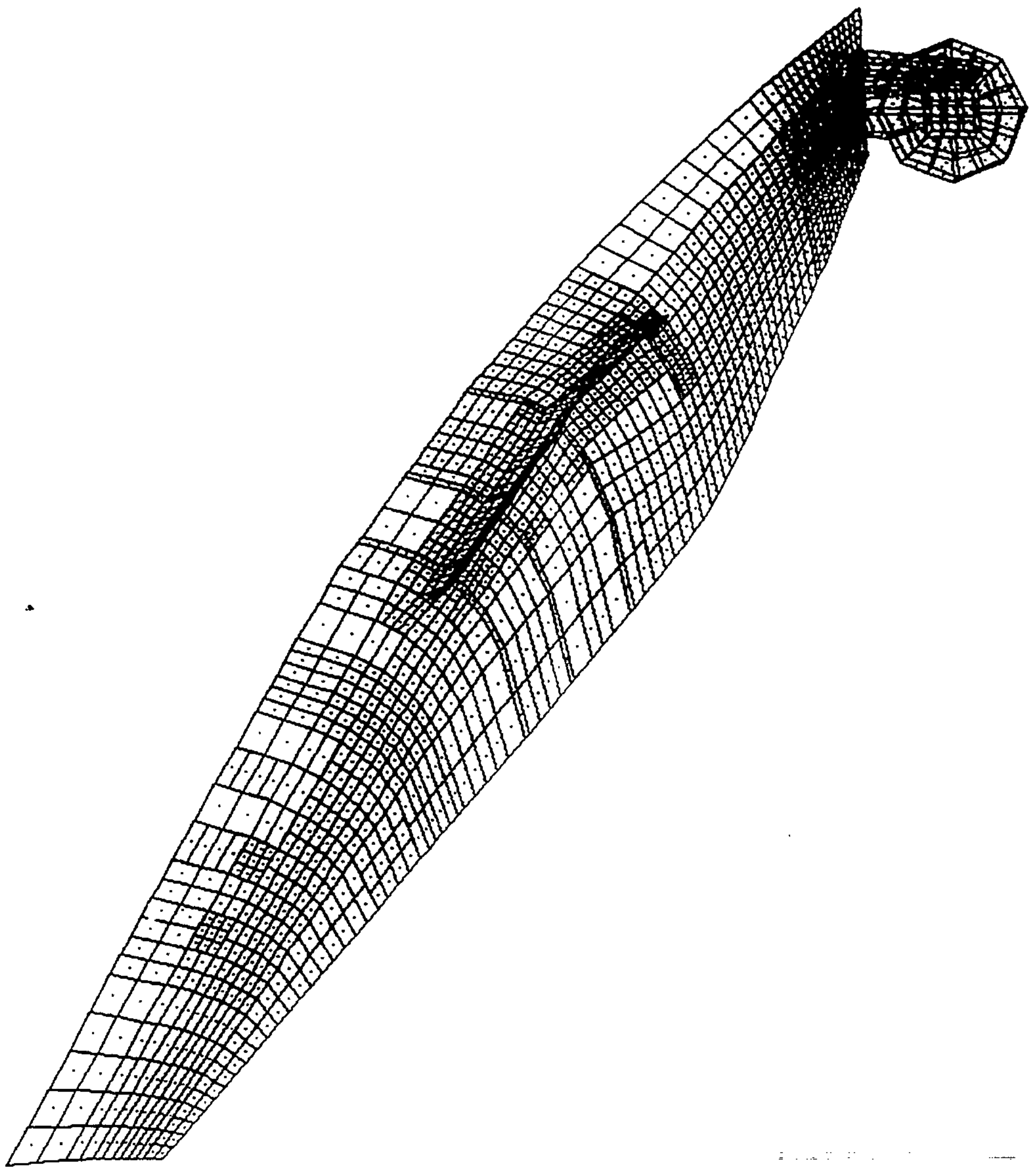
Linear Elements

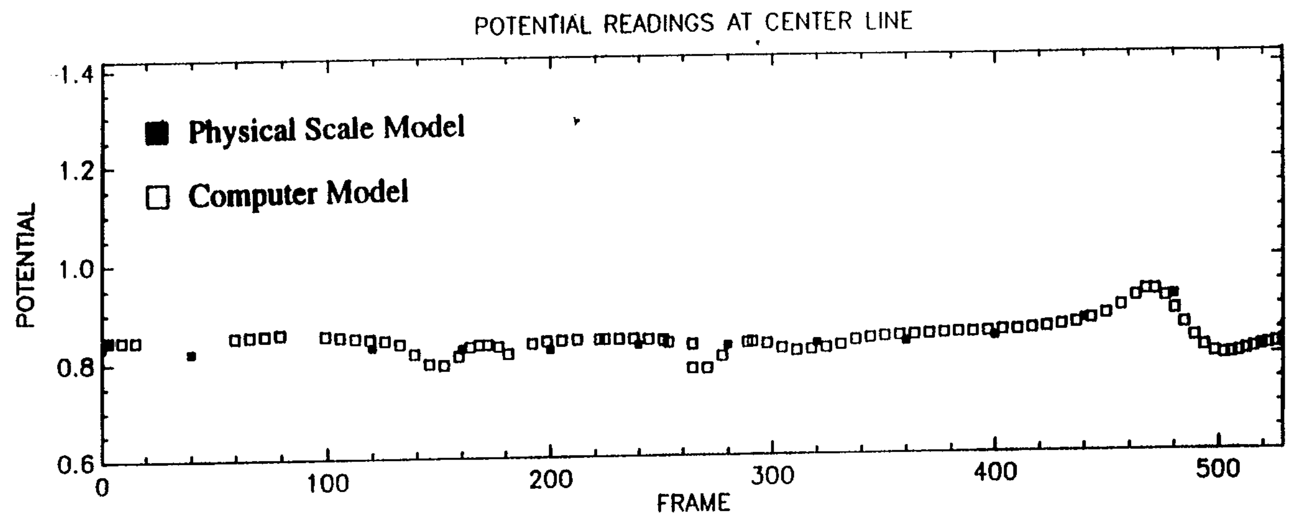
1583 Elements

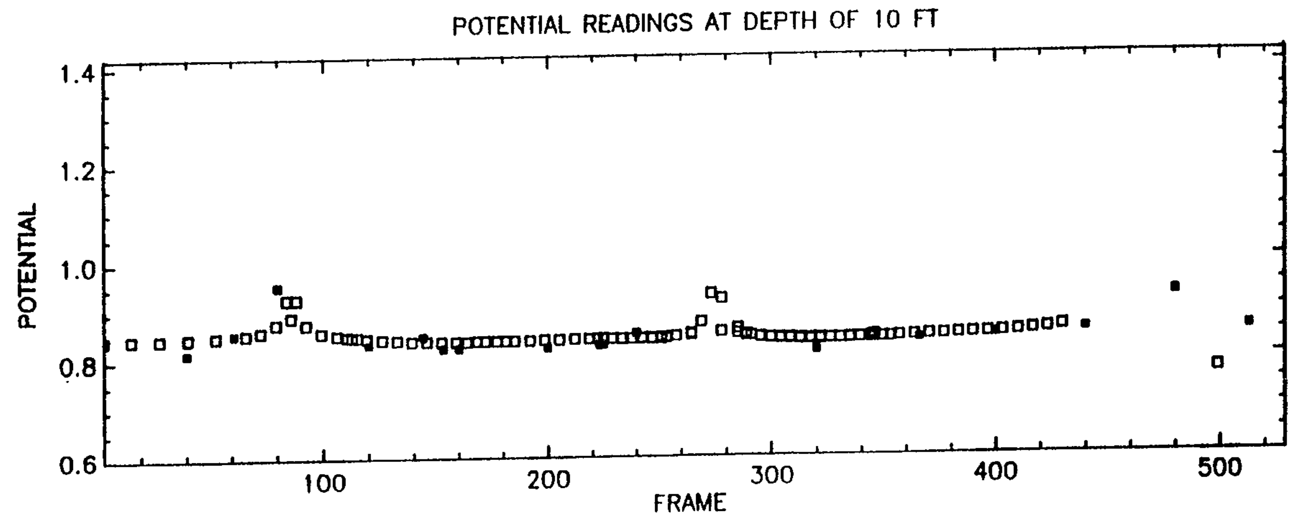
1876 Mesh Points

1 CPU Hour Cray YMP

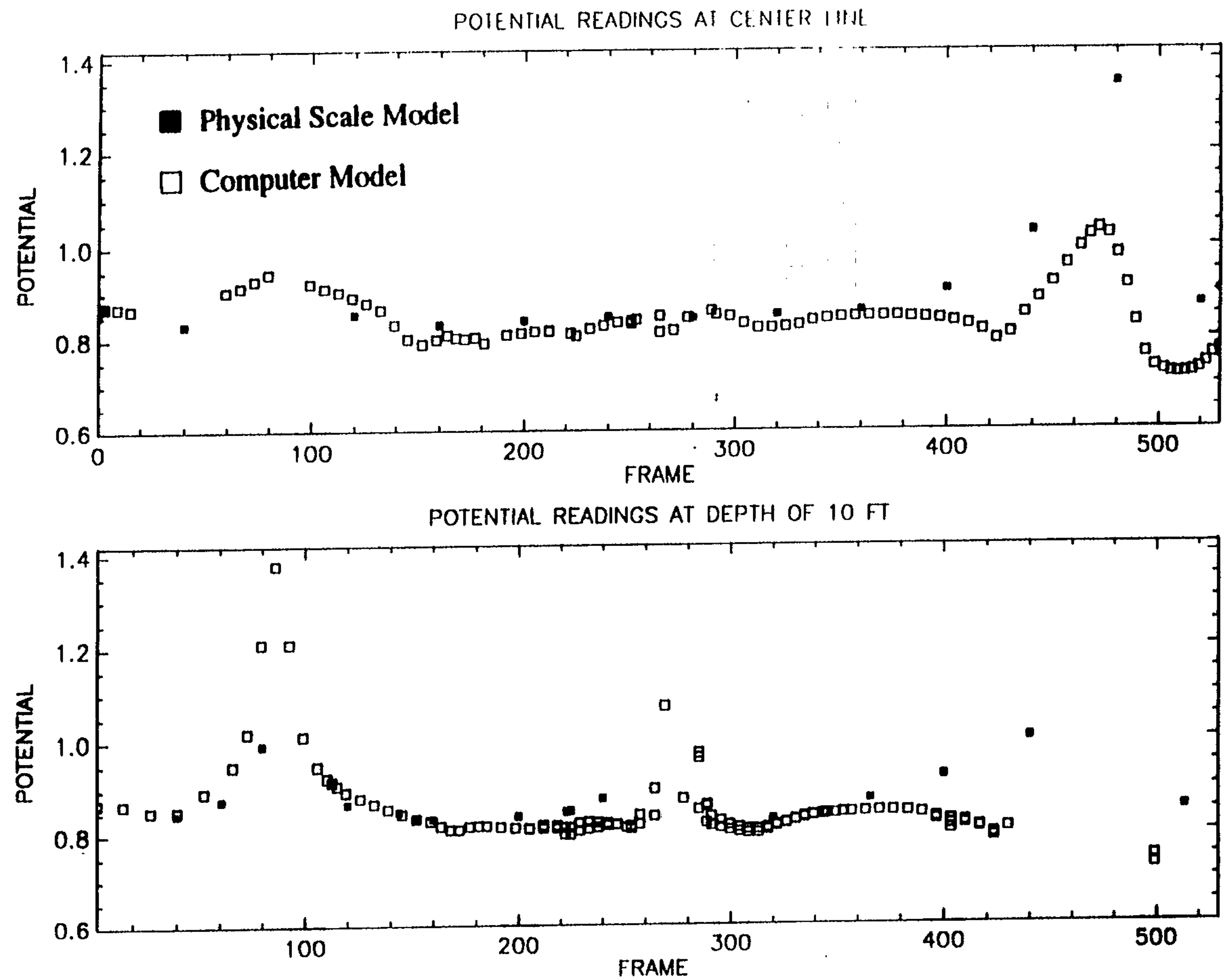
8 Megawords Memory







CG-59, Static - Minimum Damage



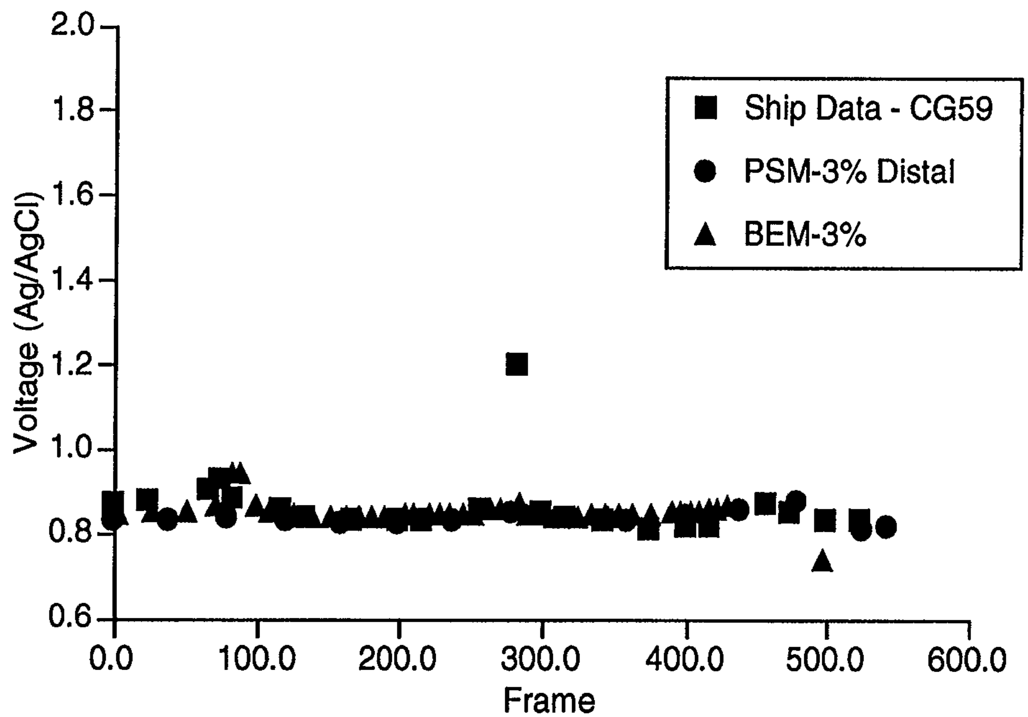
CG-59, Static - Maximum Damage

CG-59 Current Summary
6 Anodes/2 Power Supply Zones
Reference Cell = -0.85 V Ag/AgCl
(Amps)

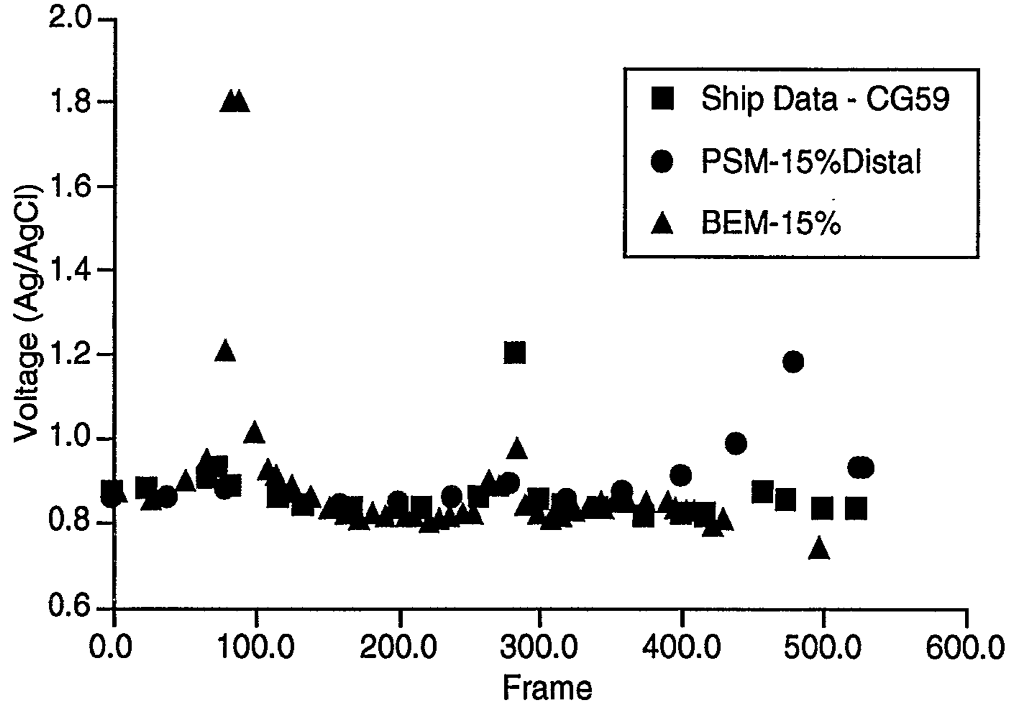
	Total	Steel	NAB
Static -			
Minimum (3%) Damage			
Computer	35.7	8.0	27.7
Physical Scale Model	33.6	7.3	26.3
Maximum (15%) Damage			
Computer	181.1	8.6	26.2
Physical Scale Model	172.6	7.6	22.0
Dynamic -			
Minimum (3%) Damage			
Computer	60.0	13.2	46.8
Physical Scale Model	52.6	9.5	44.1
Maximum (15%) Damage			
Computer	553.0	24.4	69.3
Physical Scale Model	604.2	15.7	112.3

Comparison of Ship Data, Physical Scale Model Data and Computer Analysis Data

Beginning of Life Conditions for Modeling Results



Comparison of Ship Data, Physical Scale Model Data and Computer Analysis Data
End of Life Conditions for Modeling Results



Ship/System Geometry

CVN

Upgrade System Design

(17 anodes/3 power supply zones)

Conditions Considered

Static -

Minimum (3%) Damage

Maximum (15%) Damage

Dynamic -

Minimum (3%) Damage

Maximum (15%) Damage

Tank Water Polarization Response

NAB

Steel

20 Ohm-cm Seawater

CVN Model Details

BEASY-CP Version 5.0_DEVELOP
(release date 15 Nov. 1992)

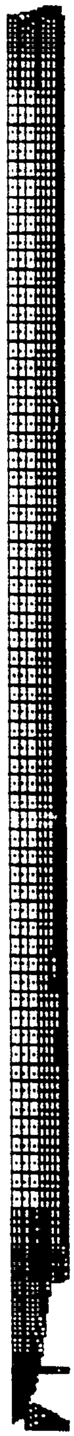
Linear-Quadratic Elements

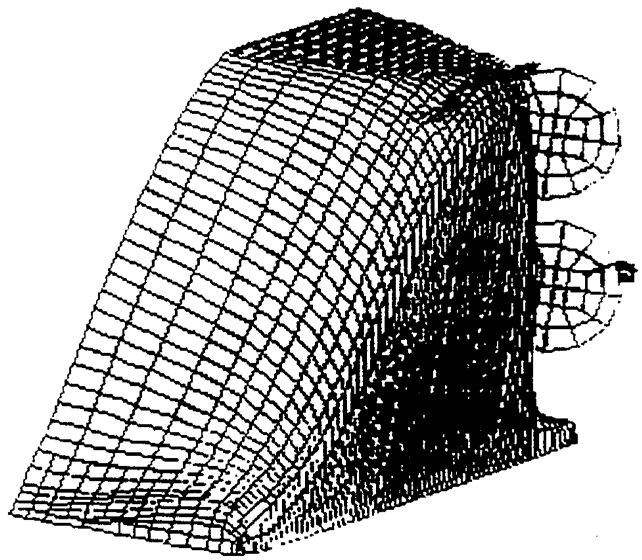
1884 Elements

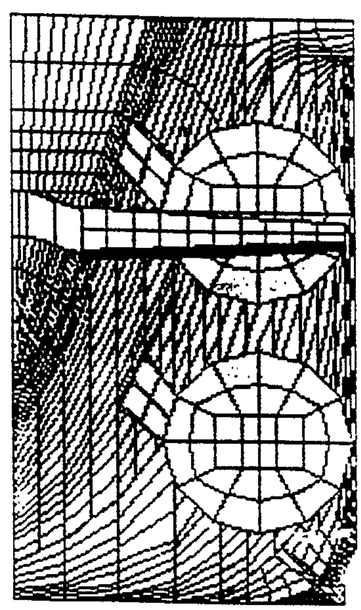
7996 Mesh Points

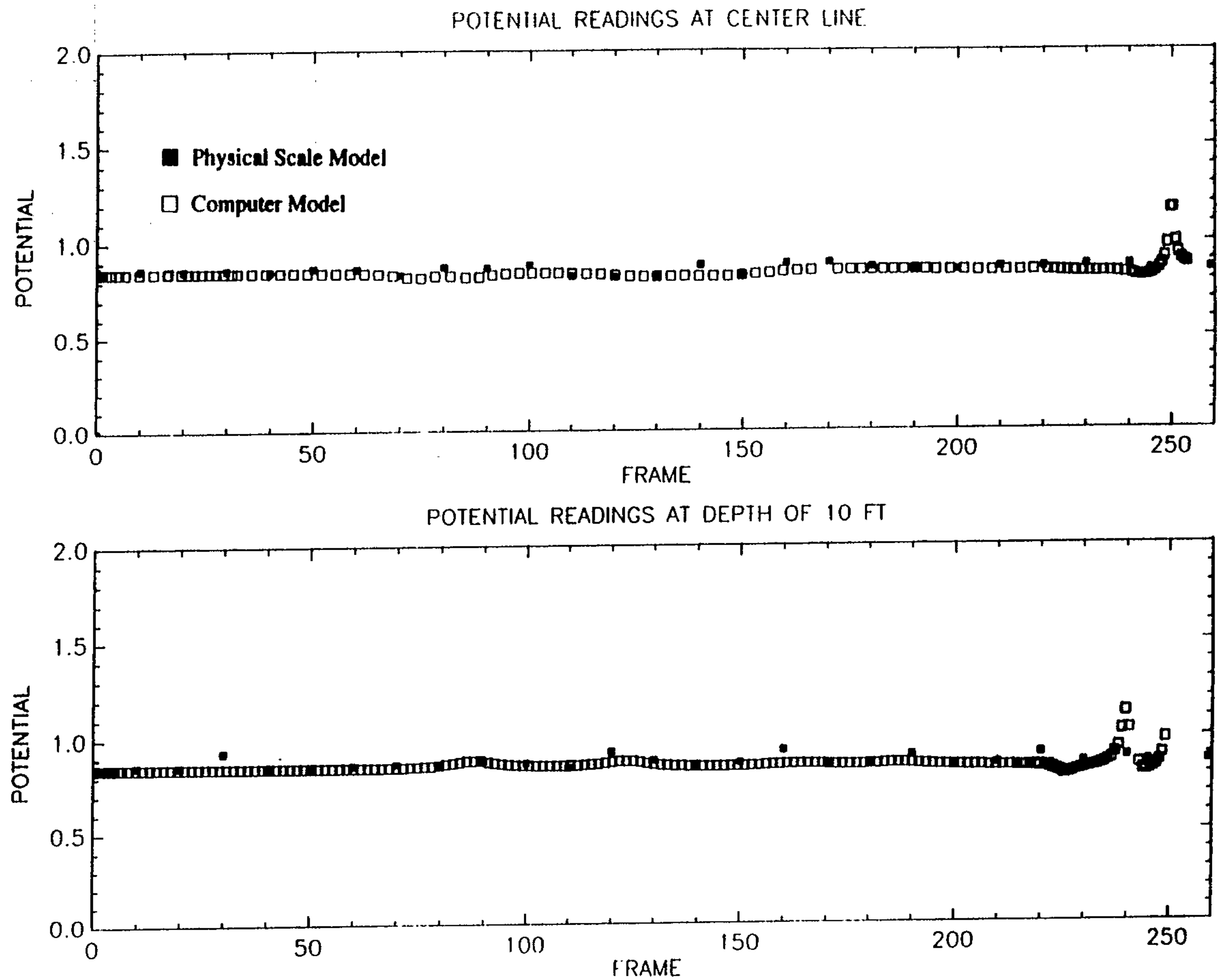
2 + CPU Hours Cray YMP

12 Megawords Memory

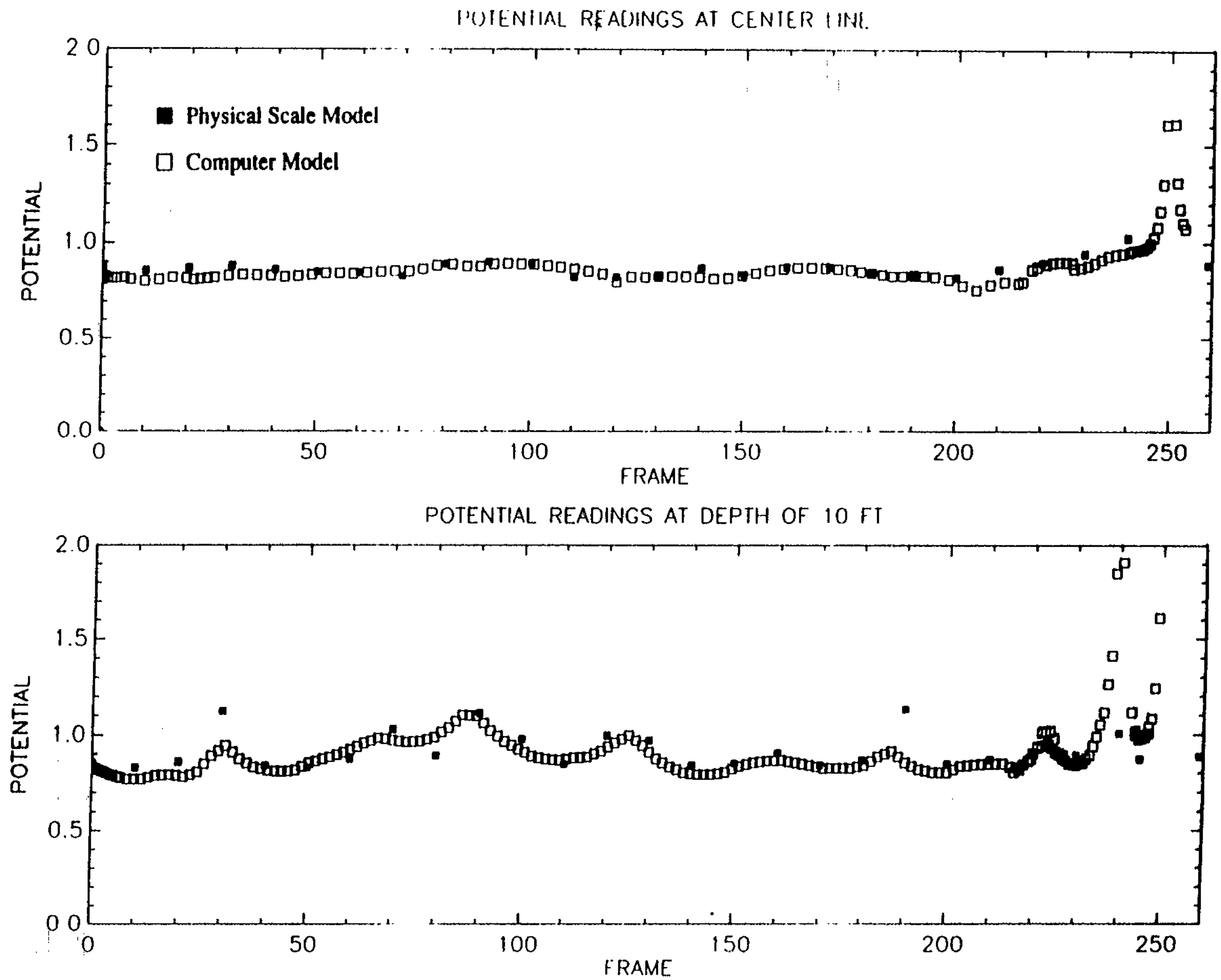








CVN-68, Static - Minimum Damage



CVN-68, Static - Maximum Damage

CVN Current Summary/Upgrade System
17 Anode/3 Power Supply Zones
Reference Cell = -0.85 V Ag/AgCl
(Amps)

	Total	Steel	NAB
Static -			
Minimum (3%) Damage			
Computer	91.6	29.8	61.8
Physical Scale Model	81.9	31.8	50.1
Maximum (15%) Damage			
Computer	605.1	527.7	77.3
Physical Scale Model	704.1	650.0	54.0
Dynamic -			
Minimum (3%) Damage			
Computer	190.6	71.7	118.9
Physical Scale Model	314.7	110.6	204.1
Maximum (15%) Damage			
Computer	1718.0	1528.2	189.8
Physical Scale Model	1837.7	1609.5	228.2

Mesh Refinement

Element Type
Computer Time/Cost

Element Size
Selective Refinement

Driving Forces
Size of Electrolyte Volume
Features to be Modeled

Material Properties/Polarization Response

Current Density vs. Potential
Nonlinear
Duplicate Service Conditions
Accuracy in Area Representation
Material Interactions

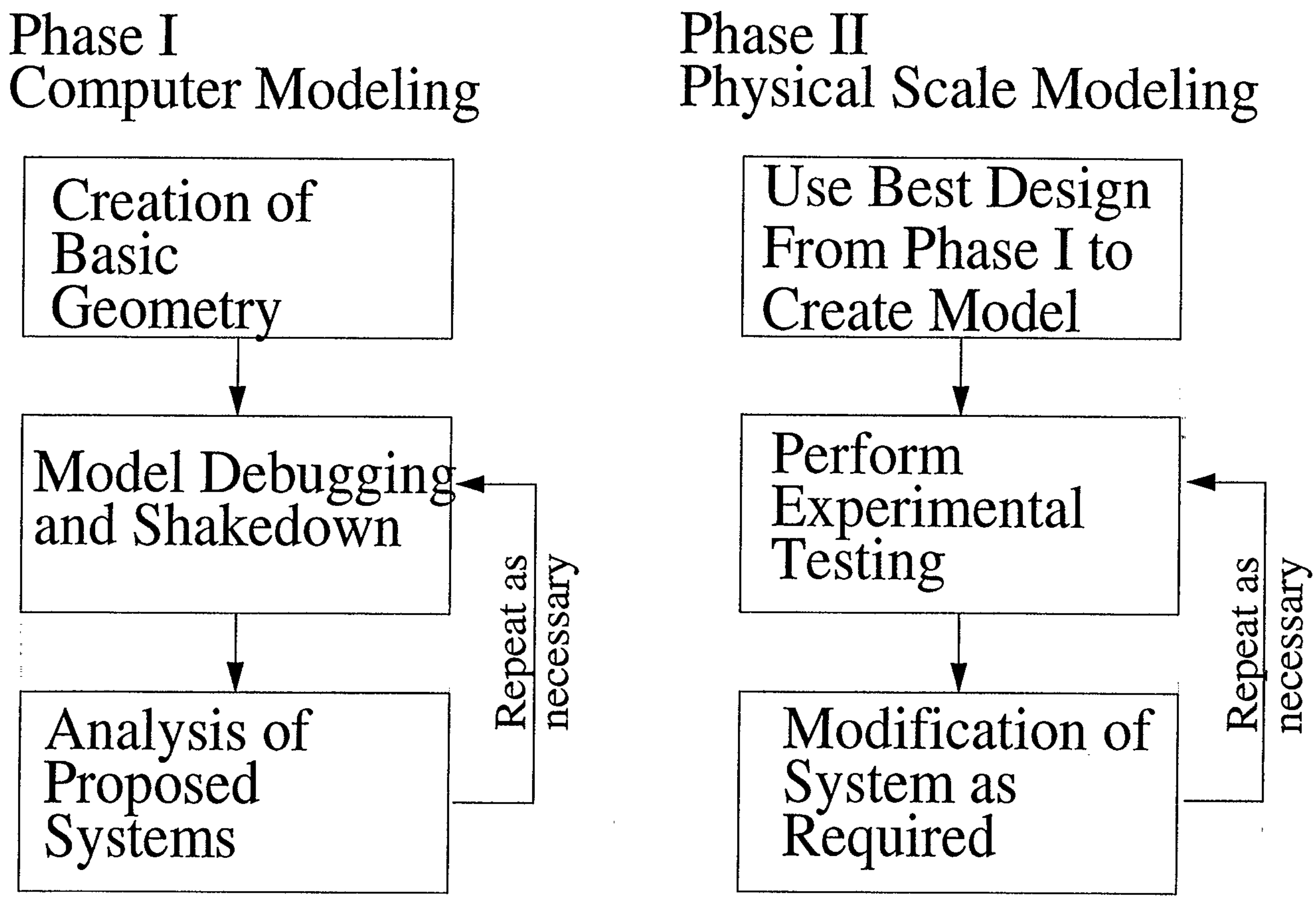
Proposed Design Procedure

Utilizes both Physical Scale and Computer Modeling

Computer Modeling -
Preliminary design
Able to perform many iterations in cost effective manner
Takes advantage of nature of computer modeling

Physical Scale Modeling -
Final design verification
Takes advantage of nature of physical scale modeling

Shipboard ICCP System Design Process



Summary

Completed detailed investigation into the feasibility of use of computer modeling for design and evaluation of shipboard ICCP systems

Identified sensitivity to and quantified modeling parameters: mesh refinement, material characterization, geometry sensitivity, spatial sensitivity and convergence criteria

Have successfully predicted shipboard ICCP system performance using a commercial boundary element code

Verification of physical scale modeling techniques by comparison with full size ship data

Developed design methodology which combines computer modeling and physical scale modeling methods for the design and evaluation of ICCP systems