Using the Boundary Element Method to calculate the electromagnetic signatures from ships due to corrosion.

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Contents.

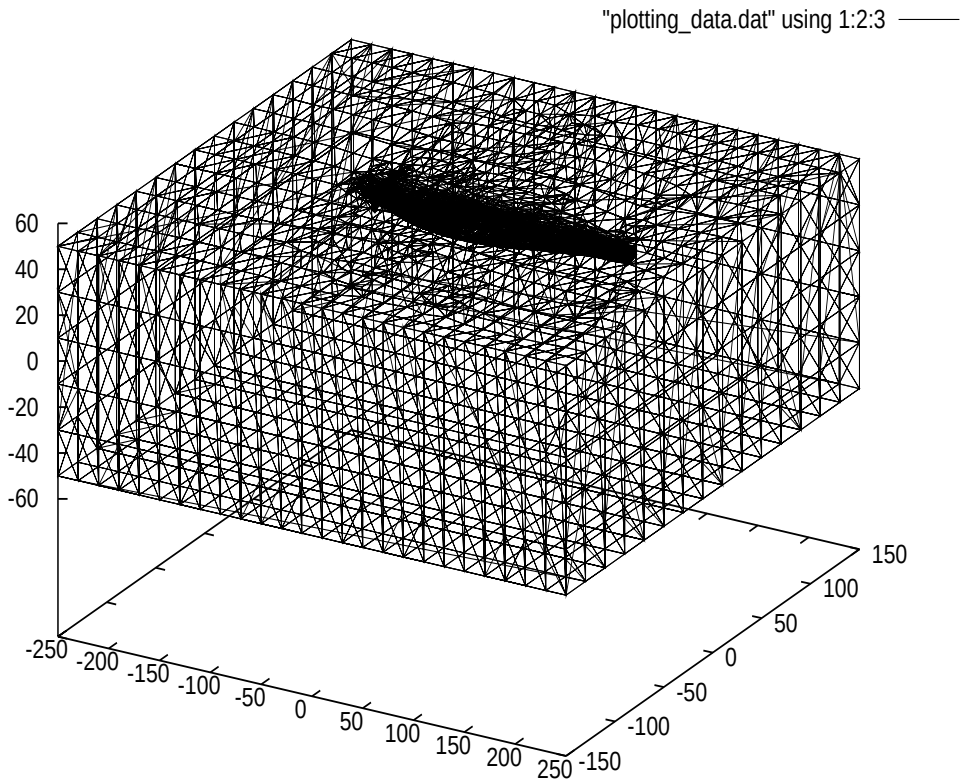
Introduction.

- A ship corroding in seawater is like a galvanic cell
- Level of corrosion dependent on many factors
  - paint protection
  - Cathodic Protection
  - Calcareous Deposits
- Corrosion currents in sea result in the ship's EM signature
- Aim - evaluate the electric potential at the interface between ship and seawater
- The potential about the ship allows evaluation of:-
  - corrosion protection
  - underwater **E** field signature
  - underwater **B** field signature

The Model.

- Ship floating in top surface of a tank of seawater.
- Boundary element method used to model the electric potential over surface of domain.
- Requires surface mesh - triangular, constant elements.
- Boundary conditions are complicated:-
  - sea has insulating boundaries where not in contact with the ship
  - on the ship boundary, the potential and its flux are related by a polarization relation
    - relation needs to be scaled to account for factors such as paint coatings.

Mesh of the Model.



The Boundary Element Method.

- Aim: To solve for the electric potential u and the outward normal derivative of the potential q on each element.
- BEM considers each element in turn as a source, evaluating the effect of the u and q of this element on all other elements.
- Governing equation is Laplace's Equation
  - Fundamental solution is $u = \frac{1}{4\pi R}$.
- BEM equation is

$$H\mathbf{u} = G\mathbf{q}.$$

- $G_{ij} \propto \int_{\Gamma_j} \frac{1}{R_{ij}} d\Gamma$ and $H_{ij} \propto \int_{\Gamma_j} \frac{\partial}{\partial \mathbf{n}} \frac{1}{R_{ij}} d\Gamma$.
- Localised coordinate system on 'field' element allows a power series expansion of $\frac{1}{R_{ij}}$

– numerical integration performed by forming a polynomial in a unique shape parameter α

$$\int_s \frac{1}{R} ds = \sum_{m,n=0}^{20} \left\{ X^{m+1} Y^{n+1} \frac{m!}{(m+n)!} \frac{d^n}{d\alpha^n} \sum_{r=0}^{m+n} d_r^{(m+n)} \alpha^r \right\} \Upsilon^{m,n}.$$

Solving the equations and field calculations.

- The Point Successive Over-relaxation Method is used to solve the BEM equation

$$\tilde{u}_i = u_i + \frac{r}{H_{ii}} \left((H\mathbf{u})_i - (G\mathbf{q})_i \right).$$

- Electric field at any point, p, within the domain can be calculated from

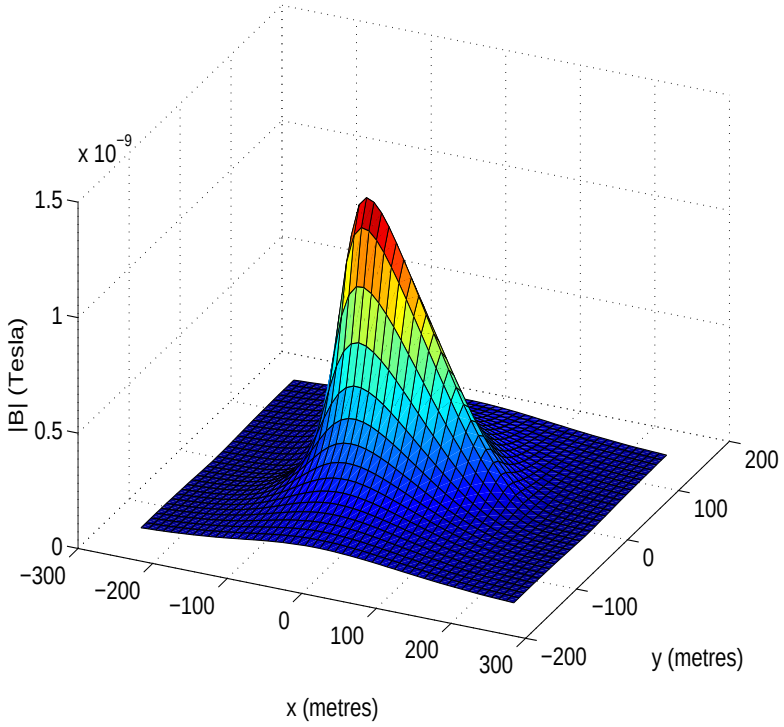
$$\mathbf{E}_p = -\nabla u_p.$$

- New method for calculation **B** - no volume mesh required
  - Magnetic field at any point within the domain can be calculated using

$$\mathbf{B}_p = -\frac{\mu_0}{4\pi}\sigma \int_s \frac{u}{R^3} d\mathbf{s} \times \mathbf{R}$$

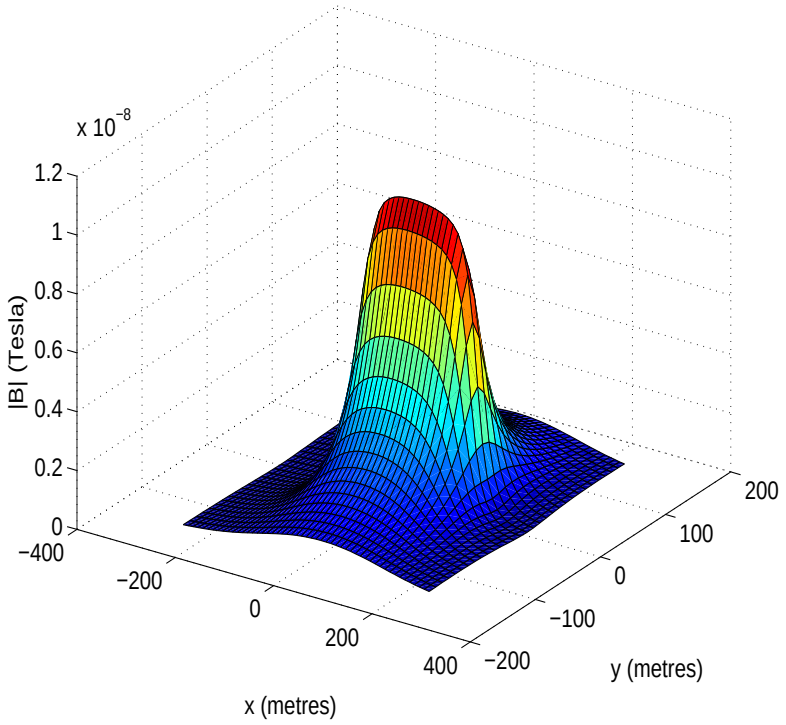
  - These 'u' values are the solutions of the BEM equation.

|B|-Perfect Paint.



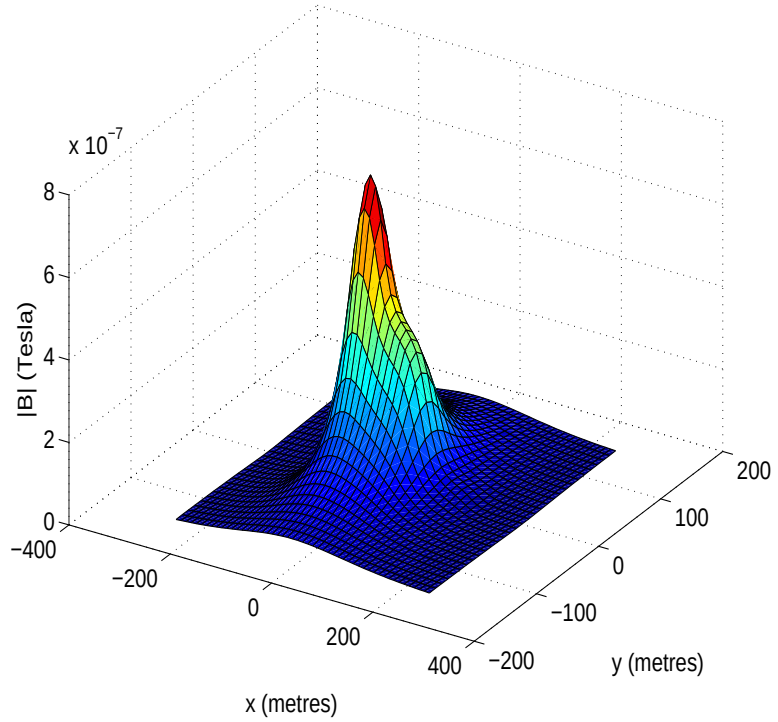
- Perfect Paint on hull ⇒ Little or no hull corrosion
  - corrosion occurs near propeller.

|B|-Damaged Paint



- Paint damage in region $133.8m \leq x \leq 153.8m$.

|B|-Damaged Paint, ICCP anodes on

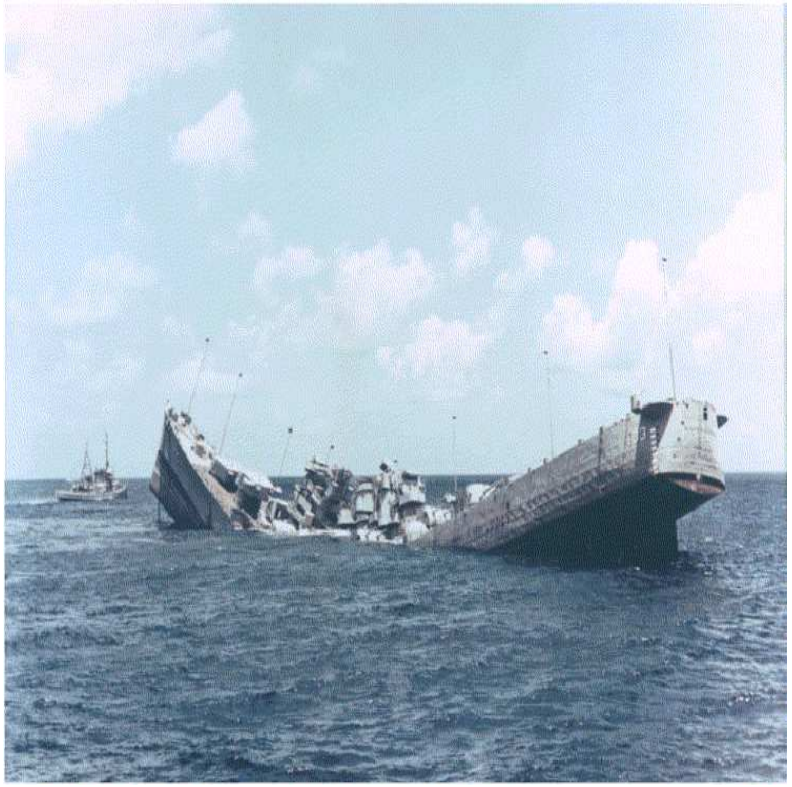


- Anodes supplying $1A$ are located either side of the hull at $x = -27m$ and $x = 60.67m$.

Conclusions.

- BEM can be used to evaluate the electric potential (and its outward normal derivative) on the surface of a corroding ship.
- New method developed for numerical integration based round the moments of the triangular surface elements.
  - Method required formation of polynomials in a shape parameter α, followed by subsequent differentiation
  - Accuracy of method was comparable to established methods
  - New method is a viable alternative to existing ones.
- BEM solutions allow EM signatures calculations.
  - New method for calculating the magnetic field, no volume mesh required
- Why are we interested in the EM fields?

Mine Countermeasures



Mine Countermeasures

Thanks.

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