Navigation Channels Considerations for Marine Terminals: Minimizing Risk

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**AECOM at a Glance: Integrated Solutions**

We provide the entire suite of services for virtually all types of terminals – Petroleum/petrochemical; LNG; liquid/dry bulk; container; break-bulk; military; offshore moorings – around the world

- Front End/Planning/Environmental/Feasibility/Economics/FEED
- Field Investigations
- Process engineering, pipeline, infrastructure
- Modeling and Simulation
- Conceptual, Preliminary, Final Engineering Design
- EPC/EPCM/Self Perform Construction Services/Fabrication

- 99,000 employees, 500+ offices in 150 countries around the world, $19 Billion revenue 2014
- **ENR #1 Ports & Marine, Transportation, Environmental, others**
- Global marine design centers; Gulf Coast in Houston, New Orleans
Topics

• Why you should have some level of knowledge
• Fundamentals of Channel Design
• Environmental & Permit Issues
• Dredging and Dredged Material Placement
• Managing Risk: Operational and Contractual
• Project Example: Port of Columbo, Sri Lanka

This presentation is meant as an introduction to navigation channels; Details are site dependent
Why should you understand this topic?

• Gateway to your marine terminal
• Navigation Safety, security of terminal
• Critical path item in terminal development; long “lead time”
• High initial cost and ongoing O&M; specialized market

*Who should know: Anyone involved in the development or operation of a marine terminal*
Development Process

- We will touch on these main topics
  - Design guidelines through PIANC and USACE
  - Environmental - site specific
- Concept Design
  - Location & Needs
  - Feasibility & Economics
  - Environmental regs
  - Metocean and channel
  - Go/No-Go
- Detailed Design
  - Environmental permits
  - Technical studies
  - Marine Safety
  - Other site specific
- Approvals and construction
Channel Design: Determining Geometry

- ID System components: Entrance, main channel, turning basins, berths…
- Existing bathymetry
- Obstructions
- Design vessels, other users
- Sub bottom condition – pipelines, etc.
- Calculated design is not absolute; practical/commercial issues considered
- From this you have a pretty good idea of your channel alignment

Photos: Bayport (PHA); channel connects to HSC w/wideners for arrival and departure
Field Investigations: These are critical tasks

- Bathymetry – Accuracy CRITICAL
  - Single vs. Multi Beam (preferred)
  - Offshore disposal areas
  - Areas for mining sand/fill
- Side scan, sub-bottom, magnetometer for utilities, pipelines, wrecks
- Soil Investigations: CRITICAL
  - Sufficient number of borehole sites
  - Correct sample # and tests
  - Probes useful to find hard material
  - Stable platform (jack up for rock or offshore/unprotected)
- Met-ocean
- Others depending on site (locating pipelines, archaeology, seismic, tsunami, etc.)

NOT THE PLACE TO CUT COST!
# Field Investigations, Typical Dredge Project

<table>
<thead>
<tr>
<th>Bathymetric or topographic survey</th>
<th>Detection of seabed obstructions (UXO, wrecks, boulders, ...)</th>
<th>Geological and geotechnical investigation</th>
<th>Hydraulic morphological and meteorological data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single beam survey</td>
<td>Side scan sonar</td>
<td>Geophysical seismic</td>
<td>Hydraulic Data</td>
</tr>
<tr>
<td>Multi beam survey</td>
<td>Multibeam sonar</td>
<td>• Reflection seismic</td>
<td>• Waterlevels</td>
</tr>
<tr>
<td>Land survey</td>
<td>Magnetometer survey</td>
<td>• Refraction seismic</td>
<td>• Tide</td>
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<td></td>
<td>• Geolectric survey</td>
<td>• Current</td>
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<td></td>
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<td>Sampling methods</td>
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<td></td>
<td></td>
<td>• Borehole</td>
<td>Sediment transport / Turbitidity</td>
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<td>• Vibrocore</td>
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<tr>
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<td>• (Jet)probe</td>
<td>Meteorologic Data</td>
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<tr>
<td></td>
<td></td>
<td>• Grab sample</td>
<td>• Waves</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Test pit</td>
<td>• Ice</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Fog</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Seismic Data</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Earthquake risk</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• Tsunami risk</td>
</tr>
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</table>

*Schematic chart of data required for a site investigation, adapted from Hydraulic Fill Manual.*
Channel Design: Width

- One way or two way
- Range of vessel characteristics
- Alignment – Straight, bends...
- Vessel “behavior” under design conditions, sailing/maneuvering
- Conceptual Width = Vessel beam + consideration for maneuvering + passing + bank clearance + other (turns, etc.)
- Often expressed as a factor of beam
- Practical/commercial factors considered – HSC Bayou Reach Example
Channel Design: Depth

- Direct calculation
- Three “levels” to consider above/below waterline
- Sea level factors – waves, tides, etc.
- Vessel factors – Draft, trim, list, squat, heel, etc.
- Bottom and seabed factors (hardness, uncertainties)
- Practical/commercial factors are considered
- Often expressed as factor of vessel draft
Channel Design: Other Aspects

• Turning radius
• Passing lanes
• Wideners
• Turning basins
  – Length X Factor
• Anchorage
  – Length X Factor
• Air draft: Can limit vessel size, alter channel design
Channel Design: Numerical Modeling

- Coastal engineering: Waves, currents, sedimentation, etc.
- Navigation models:
  - Fast time: SHIPMA, DynaSim
  - Real time simulators: PMI, MITAGS, Star Center, etc.
- Pilots, operators, other users involved
- Berthing and Mooring analysis, effect of passing vessels
  - OPTIMOOR, others
- Verify channel design, safety

Use results to ID areas of concern, modify design; an iterative process
Channel Design: Safety

- Channel suitability studies (as with LNG Waterway Suitability Assessment)
- Navigational risk analysis
  - Sea conditions
  - Channel arrangement
  - Traffic analysis, vessel encounters
  - Proximity to SPM, dangerous cargo
  - Risk of accident
- Modeling – Vessel traffic simulations
- Tug assists, #tugs and specifications
- Vessel Traffic Systems - USCG
- ATON
- Other site-specific items
Environmental & Permitting

• Typically Issued through Federal, State, Local authorities
• Conditions highly dependent on locality, resources, regulators
• Some typical resources/issues:
  – Coral, “hard bottom”
  – Sea grass, wetlands
  – Endangered species
  – Marine mammals
  – Fish and wildlife
  – Turbidity/water quality
  – Contaminated sediment
• Mitigation or improvements may be needed

Top: Bolivar Marsh, HGNC
Bottom: Sonoma Wetlands, CA
Environmental & Permitting: HGNC

*Example: HGNC Deepening and Widening (~$700MM) – Creation of habitat/confined disposal of dredge material*

- Dredge material was once pumped overboard into Galveston Bay; habitat loss, WQ degradation
- Mandate beneficial use of dredge material, contain all dredge matl
- Inter-tidal marsh; habitat islands; reefs; DMPA improvements
- Agencies involved: USACE; PHA; EPA; NMFS; USFWS; TXPWD; GLO; NOAA, TCEQ
- How? Multi-year effort between PHA and consultants (AECOM-GBA JV); USACE, agencies (Beneficial Use Group)
Environmental & Permitting: HGNC

- New Work w/USACE cost share; follow USACE guidelines
- Reconnaissance (in National Interest); Feasibility (cost/ben); Congressional Authorization & Funding; LRR/EIS, Sect. 404 & Sect. 10 of CWA, Sect. 408/Title 33 of US Code, 203/204 assumption of maintenance under WRDA….strong local sponsor in PHA
- Broken up into multiple projects; marshes, islands, offshore reefs, habitats, monitoring, etc. – Model project
Dredging and Dredged Material Disposal

• *Avoid it if you can! If not, minimize it to extent possible*

• Three primary equipment types, used individually or in combination
  – Cutter Suction Dredger (CSD)
  – Trailing Suction Hopper Dredger (TSHD)
  – Mechanical Dredge (Bucket or Backhoe)
Cutter Suction Dredger

- Many different configurations: kW, pumps, discharge, pontoon…
- Can be designed to cut most material, incl. soft rock (~50 MPa)
- Rotating “cutterhead” agitates material; dredge swings across channel, pump slurry material via pipeline to final disposal (~70% H2O or more)
- High production rates, limitations include sea state, pump distance
Trailing Suction Hopper Dredger

- Cuts softer/looser mud and sand; water jets/teeth for firm matl.
- Self propelled vessel; suction pipe with “draghead” lowered to seabed, material sucked from bottom and deposited in hopper
- Sizes vary <5k to 40k M³, can work offshore, sail in “S” pattern
- High production rates, needs wide open areas and sufficient depth; production limited by transit distance to disposal site, material type
Mechanical Dredge

- Cuts many different types of materials, incl. soft/shot rock
- Fixed barge on spuds/anchors – mechanically dig material from bottom, load into barges, tow to offshore disposal
- Sizes range by crane type: Up to 50 CM bucket
- Relatively low production rates, can dredge in restricted areas
Placement/Disposal of Dredged Material

- Offshore; upland (CDF); reclamation; beneficial use (marsh, beach restoration)
- CDF is a contained area nearby channel to contain material; weirs to control water and drain facility
- Offshore & CDF most common, also reclamation
- Mechanical dredge nearly always offshore disposal; TSHD primarily offshore but many have pump-off capability; CSD nearly always upland, reclamation, beach, marsh
Placement/Disposal of Dredged Material
Production and Cost

• Most dredges are unique/custom designed and built
• Costs are relatively stable: Relatively few variable costs
• The variable is production - M³/Net Operating Hour
• Efficiency is constant focus: Small increase in production = large cost and schedule savings
• Production limited by: Cutting (strength of material), area coverage, or transporting/pumping material
• Production calculated with:
  – Volume of material, size of area, average depth
  – Type and consistency of material
  – Workability (the % time dredging)
  – Other project specific factors, environmental, etc.
  – And of course the dredge’s capabilities
Basic Estimating Considerations – Production

• Production: Sometimes difficult due to “custom” nature of equipment
  – Dredges of similar dimensions will not have same productions; Software available
  – Look at similar projects, historical averages, input from contractors
  – Do a “sensitivity” analysis
  – Can develop an algorithm

• Volume calculated by subtracting survey surface from template

• Calculated as M3 per net operating hour; deduct down time
  – CSD workability ~60% - 75%
  – TSHD workability ~75% - 90%
Basic Estimating Considerations - Cost

- Assume details of project are known and bid items determined
- Determine dredge volumes: Survey surface vs. channel template
- Determine the equipment spread required
  - Suitable dredge + attendant plant – tugs, anchor barges, etc.
  - Pipeline, valves, joints, anchors, pontoons, moorings, and so on
  - Land/Dry plant required for fill – loaders, excavators, dozers, crew, other
- Equipment costs consist of:
  - Ownership costs: Value, depreciation, interest, repair, insurance
  - Operating costs: Consumables, repair, wear parts, labor
  - Allowance for ownership, operating, factors, and utilization
  - Utilization = working months per year to recover cost (9 to 10 months)
- Other ancillary costs

*CIRIA Guide to Cost Standards for Dredging is a great resource*
## Cost Estimate Example

- **TSHD** 7,600 CY capacity
- **Pump** 4,200 CY/NOH
- **Offshore disposal** 8 NM
- **Material** is soft clay/mud
- **Load factor** 30%
- **Production cycle includes** loading, turning, sailing, discharge
- **Volume removed includes** pay + unpaid
- **Volume/Production = Time**
- **Time X Unit Cost = Total**
- **Add Mobilization costs (get to/from site)**

### EXAMPLE PROJECT SUMMARY SHEET

#### HOPPER DREDGE CONCEPTUAL ESTIMATE

<table>
<thead>
<tr>
<th>Volumes</th>
<th>Grade</th>
<th>OD</th>
<th>Total</th>
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<tbody>
<tr>
<td>13-OR</td>
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<td>629,041</td>
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</tr>
<tr>
<td>12. 11. 9</td>
<td>796,605</td>
<td>602,918</td>
<td>1,399,523</td>
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<tr>
<td>Total</td>
<td>796,605</td>
<td>1,231,959</td>
<td>2,028,564</td>
</tr>
</tbody>
</table>

Removed: 796,605, 1,231,959, 2,028,564 (Assume pay plus unpaid = total available)

**Assumptions:**
- Generic Hopper Dredge: 7,600 CY Hopper Capacity (Water)
- Load ratio (hopper to soft clay): 30%
- Mud capacity/hopper: 2,280 CY
- Mud production rate: 4,200 CY/NOH (33" suction diameter)

#### Production Details:

- **Loading**: 33 Minutes
- **Turning**: 2 each, 5 min, 10 Minutes
- **Sail Loaded**: 8 mi, 10 mph, 48 Minutes
- **Sail Light**: 8 mi, 12 mph, 40 Minutes
- **Discharge/Washout**: 10 Minutes
- **Total Cycle**: 141 Minutes

\[ \frac{141 \text{ minutes}}{60 \text{ minutes/hour}} = 2.3 \text{ hours} \]

#### Production (Net):

\[ 973 \text{ CY/NOH} \]

#### Efficiency (NOH):

90% of 22 Hours/Day = 20 Hours/Day

\[ \frac{20 \text{ hours}}{24 \text{ hours}} = 0.8333 \text{ or } 83.33\% \]

**Total Production/Day (Net):** 21,020 CY/Day

### Cost Details:

- **Daily Cost (Dredge):** $78,000 Per Day
- **Supervision/Field OH:** $8,000 Per Day
- **Survey Vessel:** $1,200 Per Day
- **Subtotal:** $87,200 Per Day
- **Markup:** 24.4% $21,277 Per Day

**Total Cost/Day:** $108,477 Per Day

**Total Cost/CY:** $5.16

- **Mob/Demob:** 4 Days
  - **Dredge Cost:** $108,477
  - **Total Cost:** $433,907

**TOTAL COST, HOPPER DREDGE:** $10,902,367
Managing Risk: Contractual and Operational

- Many projects are part of EPC; dredger is a subcontractor
- Contract form: FIDIC or equal, T&Cs generally understood; modifications for specific items
- Simple projects - IFB (lowest price, responsive contractor)
- Contractual Risk Items – Technical Specifications:
  - Scope of work not clearly defined/customized to project
  - Bid items and/or schedule of prices
  - Insufficient/inadequate field investigations (i.e. rock)
  - Contractor lacks proper experience, equipment, staff
  - Pricing – LS vs. Unit Price (prefer UP for complex projects)
  - Environmental risks not adequately accounted for
  - Others depending on project

*Consulting engineer must be experienced with all aspects of work*
Managing Risk: Contractual and Operational

• Complex projects should be RFP (best value)
  – Prequalification: Contractors with proven equipment, experience, staff, resources, financial, etc.
  – Detailed scope of work – Take a bit of risk to reduce costs

• Key items in the RFP:
  – Equipment spread and specifications
  – Dedicated PM and key staff qualifications
  – Detailed project experience, references, safety record, etc.
  – Detailed Project approach
  – Detailed work plan, environmental protection, contingency
  – Logistics plan (if applicable)
  – Detailed bid tab, delineated by risk items, break in work

Significant thought, preparation, and attention to detail pays off – only as good as the Specifications
Managing Risk: Contractual and Operational

• Operational risks often due to environmental restrictions
  – Contaminated sediment
  – Turbidity – Miami River example
  – Stress/destroy coral reefs, vegetation
  – Nesting seasons
  – Injure/kill protected species
  – Work “windows” that drastically reduce schedule (Pacific NW)
  – Public perception/opposition
  – Government/political issues

• Substantial production issues/differing site conditions (i.e. rock)

• Persistent equipment problems/inadequate equipment, under-qualified management and/or staff

• Safety issues/injury/fatality

• Delays starting/mobilizing

• Schedule risk (weather, accidents/repairs to equipment)
Managing Risk

• Exhaustive, detailed up-front work/Pre-FEED/FEED
• Detailed, well thought out scope of work, best-value RFP for complex projects
• Vet/prequalify contractors thoroughly
  – Many are clearly qualified – GLDD, Jan de Nul, Boskalis, etc.
  – Is proper team in place? Experience working with contractor?
  – Early Contractor Involvement is often a great idea
• Early Contractor Involvement: Part of planning and design
  – Can offer ideas that fast-track project and reduce risk
  – Can verify design and construction means
  – Become stakeholder, responsible; develop risk analysis at all stages
  – Can be a competition through conceptual/early design, budgetary cost
Relevant Project Examples
Example: Port of Columbo, Sri Lanka

- AECOM developed design for expansion of this major transshipment port
- Included 6 km of breakwater and a new two-way approach channel
- Design to accommodate deep draft (16m) container vessels + future demand
Example: Port of Columbo, Sri Lanka

- New Approach Channel (blue); North Entrance (red); Existing Harbor Entrance (green)
- Existing entrance relatively narrow, sharp turn
- Poorly sheltered during SW monsoon
- Increasing ship traffic in existing port
- Design Vessel: 400 m length; 55 m beam; 16 m draft
- Petroleum pipeline crosses channel limit
- Dredge material needed for reclamation
- New ATON
Example: Port of Columbo, Sri Lanka

- SE approach chosen to avoid sharp bend and clearance to petrol SPM
- Dredge material suitable for reclamation
- Offshore wave environment = 1.25 factor for depth: $1.25 \times 16m = 20m$
- Breakwater required due to seas; seasonal wave climate developed

<table>
<thead>
<tr>
<th>Hs (Swell) (m)</th>
<th>Oct-Nov</th>
<th>Dec-Feb</th>
<th>Mar-April</th>
<th>May-Sept</th>
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<tbody>
<tr>
<td>Up to 0.6</td>
<td>46/38</td>
<td>83/69</td>
<td>82/63</td>
<td>8/3</td>
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<td>0.6 - 1.0</td>
<td>52/30</td>
<td>14/23</td>
<td>18/19</td>
<td>39/32</td>
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<tr>
<td>1.0 - 1.2</td>
<td>2/26</td>
<td>2/7</td>
<td>-/9</td>
<td>19/31</td>
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<tr>
<td>1.2 - 1.4</td>
<td>-/7</td>
<td>1/2</td>
<td>-/4</td>
<td>14/18</td>
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<td>1.4 - 1.6</td>
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<td>-/-</td>
<td>-/4</td>
<td>17/10</td>
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<tr>
<td>Over 2.0</td>
<td>-/-</td>
<td>-/-</td>
<td>-/-</td>
<td>1/1</td>
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</tbody>
</table>
Example: Port of Columbo, Sri Lanka

- PIANC Guidelines used for channel design
- Vessel speed of 10 knots = squat between 0.5 to 0.8m; wave induced motion ~1m; heave, pitch/roll, tide range, bottom type, maintenance dredging, water density considered.
- Final calculation resulted in -19.2 m channel offshore, rounded to -20m; reduced to -18m inside
- Two way channel; width calculated at 10.4 X vessel beam = 570 m width
- Bend radius calculated at 3,400m; increased channel width to 790m at bend
- Turning circle 1.5 times vessel length + clearances = 820m minimum; actual basin 1,300m X 1,500m for safety factor
- Channel modeled for navigation safety and marine traffic
Example: Port of Columbo, Sri Lanka

- Model results – Encounter densities (below) and plot of arriving/departing vessels (right)
Example: Port of Columbo, Sri Lanka

- Dredging volume 15m $M^3$ initially, small infill of 100,000 $M^3$ per year

- CSD and TSHD evaluated, TSHD used for dredging and reclamation because of high workability

<table>
<thead>
<tr>
<th>Dredger</th>
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<th>Dec-Feb</th>
<th>Mar-April</th>
<th>May-Sept</th>
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<td>Large CSD</td>
<td>66</td>
<td>88</td>
<td>63</td>
<td>11</td>
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<tr>
<td>8,000 m$^3$ TSHD</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>86.5</td>
</tr>
<tr>
<td>5,000 m$^3$ TSHD</td>
<td>96</td>
<td>98</td>
<td>90</td>
<td>48</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Dredger Size (m$^3$)</th>
<th>Bottom Discharge (m$^3$/wk)</th>
<th>Pump or Rainbow Ashore (m$^3$/wk)</th>
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</thead>
<tbody>
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<td>340,000</td>
<td>228,000</td>
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<tr>
<td>8,000</td>
<td>494,000</td>
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<tr>
<td>228,000</td>
<td>195,000</td>
<td>267,000</td>
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</tbody>
</table>
Example: Pedra de Ferro Terminal, Brazil

Final Layout
Thank You

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