Mooring Force Analysis
Methods
...with Application to Breakaways
Caused by Passing Vessels

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Dept of Naval Architecture & Ocean Engineering
U.S. Naval Academy
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Overview

- Purpose
- Background
- USCG MC Incident Data
- Findings from Actual Cases
- Discussion
- Conclusions
- Acknowledgements
Why Develop & Study Mooring Forces Methods?

- Design of Navigation Channels
- Reducing Marine Casualty Incidents (and Consequences)
  - Property Damage – Ship & Pier
  - Pollution
  - Injuries/Deaths
Motivation and Purpose of Project

Deep-Draft navigation channel congestion
- Traffic
- Blockage
- Ship berths in close proximity to transiting vessels

Tasked to investigate occurrences of vessel mooring breakaways due to passing vessels
- Frequency; Locations
- Characteristics & preliminary analysis of events
Mooring Force Analysis Methods

- Numerical
- Analytical
- Physical
  - Experimental / Model-Scale
  - Full-Scale
  - Evidentiary or “Forensic”
Background

Literature Review

- Navy
  - **MIL- HDBK 1026/4**: Mooring Design Handbook (repl. NAVFAC DM 26.4)
  - **MIL-HDBK 1025/1**: Piers and Wharves
  - **DM 26.6**: Mooring Design Physical and Empirical Data
  - **TR-6005-OCN**: ‘EMOOR’ - A Planning/Preliminary Design Tool for Evaluating Ship Moorings at Piers and Wharves

- USACE
  - **EM 1110-2-1100 (Part II)**: CEM Harbor Hydrodynamics
Literature Review (cont’d)

- Essential Reference
  - Guidelines and Recommendations for the Safe Mooring of Large Ships at Piers and Sea Islands, Oil Companies International Marine Forum (OCIMF)
  - Design of Marine Facilities, J. Gaythwaite, 1990
  - Port Engineering, P. Bruun
  - Handbook of Port & Harbor Engineering, G. Tsinker
Mooring Analysis Software

- Navy
  - E-MOOR, FIXMOOR, PASS-MOOR

- Commercial
  - Ship-Generated Hydrodynamics (SGH) – PI Engineering → MOSES
  - OPTIMOOR - Tension Technology
  - AQWA - WS Atkins
  - SHIP-MOORINGS – Alkyon
  - Others
Mooring Line Research

Deepwater Mooring Analysis
- Many Studies
- TAMU; MARIN
- Catenary; TLP

Pierside Mooring Line Dynamics
- Not much in literature
- Geometry much more complex
- Usually based on linear or non-linear elastic theory
Mooring Line Arrangements

OCIMF Guidelines ...
- Balanced load distribution
- Loads<55% MBL
- Line types
- Others
Typical Mooring Force Analysis: Begin w/ Hydrodynamic Model
(Example Shown: SGH)
Mooring Line Analysis

MOSES
Mooring Line Loads

0:36:05
...and Mooring Line Loads
Approach of this Study

- Investigated actual casualties
- Worked with USCG Office of Investigations and Analysis (G-MOA)
- Looked at ten-year window (1991-2001)
  - Searched for “Breakaway” cases
  - Reviewed cases individually
  - 50+ Breakaways recorded due to passing vessels
  - 20+ investigated in depth; preliminary analysis and comparison to empirical mooring force analysis
USCG MC Incidents

1991-2001 “Breakaways”
- 1,000’s of entries
- 50+ cases of passing vessel breakaways

Challenges

Data:

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Houston-Galveston Safety Advisory Committee  
Mooring Subcommittee  

Moored/Passing Vessel Interaction Questionnaire

The interaction of moored and passing vessels is a recurring predicament for vessels in Houston. Ships and barges have been pulled off docks causing line breaks, hose ruptures, and other damages. In an attempt to research the history and magnitude of vessels being pulled away from their moorings, Houston-Galveston Safety Advisory Committee (HOGANSAC) has developed a questionnaire for distribution within the Houston area ports. If you have records of incidents where damages have occurred from the interaction of passing and moored vessels, HOGANSAC requests that you take the time to complete the attached questionnaire.

HOGANSAC is interested in any information that amplifies the answers that you give in the questionnaire. If your company has conducted a report or investigation regarding the incident, you are encouraged to attach it. Submitting photos or a sketch of the mooring line arrangements, including the vessel, pier, and mooring securing points used on both the vessel and pier sides, may help HOGANSAC understand the forces at work at the time of the incident. Witnesses' observations of vessel motion and line condition at the time of the incident are extremely useful. A general description of the berth's construction (open/closed face, seawall, etc) and the hydrology around it is also useful, if known.

The “Other Factors” section of the questionnaire is designed for you to add factors affecting the incident that weren’t captured by the questionnaire. For instance, if an incident happened because a passing ship was forced closer than usual to the affected berth to avoid dredging operations, multiple ships passed causing increased interaction effects, or mooring fittings on the pier were inadequate for the vessel size, please include that information.

HOGANSAC will keep any information you provide confidential. If you have questions about the survey, please contact Mr. Alton Landry at (713) 678-7711. Please send the completed questionnaire and any accompanying documents to:

Marine Exchange of the West Gulf, Inc.  
Attn: Mr. Alton Landry  
111 East Loop North  
Houston, TX 77029  
Fax: (713)678-4839  
E-mail: marinemchangehou@aol.com

Thank you for your time and interest in making the Houston Ship Channel a safer place to operate.

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General Information

PLEASE COMPLETE ONLY THOSE ITEMS FOR WHICH YOU HAVE INFORMATION.
SEND OR FAX TO: Marine Exchange of the West Gulf, Inc.  
Attn: Mr. Alton Landry - 111 East Loop North - Houston, TX 77029  
Fax: 713-678-4839 - E-mail: marinemchangehou@aol.com

PLEASE REPORT ALL INCIDENTS IMMEDIATELY TO HOUSTON VESSEL TRAFFIC AT 713-671-5103, OR VIA VHF RADIO CHANNEL 5A.

Date/Time of incident: __________________________
Terminal name/location: __________________________
Nature of incident: __________________________
Wind conditions: __________________________ Tide information/current speed: __________________________
Depth of water along inboard length of tow/ship: __________________________
Bow: ______ Stern: ______
Center: ______ Other depths: __________________________
Geography of channel in vicinity of terminal: __________________________
Orientation of Dock to Ship Channel: (Alongside, Perpendicular, Other) __________________________
Specific hydrology issues (including pier construction and bottom conditions): __________________________

Moored Vessel Information

Vessel name: __________________________
Draft at time of incident: ______
Fore: ______ LOA: ______
Aft: ______
Beam: ______
Hos: ______ DWT: ______
Transfer conditions (circle one): Loading Unloading No transfer
Orientation of vessel on dock: (Alongside, Stern Te, Doublet Up, Single Wide): __________________________
Number and arrangement of lines required by vessel/facility: __________________________
Describe breakaway (stern pulled away from pier, upward surge, etc.): __________________________

Mooring line arrangement (please attach sketch, note number of lines and parts, material of construction, showing which lines parted, including angles that lines make with vertical)

Line Breakage Information (if applicable)

Parted Line location(s)(bowline, aft bow spring, etc.): __________________________
Length of line: __________________________
Number of Parts: __________________________
Line size/material: __________________________
Condition of lines: __________________________
Frequency of line inspections: __________________________
Time of last line inspections: __________________________
Description of line securing points used (chocks, tension winches, bits, pileings, etc.): __________________________

Passing Ship Information (estimated information is acceptable)

Ship name: __________________________ Loaded or Empty (Circle One)
Draught: ______ LOA: ______ Berth: ______ DWT: ______ Speed: ______
Closest point of approach of passing ship to berth: __________________________
Ship direction (inbound/outbound): __________________________

Other Factors/Events

What other factors contributed to the event? (Passing ship forced near the pier, etc.) __________________________
Vessel Critical Profile (VCP)
# Vessel Critical Profile

Name/ QUEENSLAND STAR  
Primary VIN/ 7226275  
Call/ MZBM7  
Flag/ UK

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<td>Operator</td>
<td>P &amp; O NEDLLOYD LTD</td>
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<tr>
<td>Owner</td>
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MC Investigation Reports

MCIR             MARINE CASUALTY INVESTIGATION REPORT           25JUL02
CASE NUMBER.../ MC00002693     INV INIT/ MOD     FORT/ WORKS   LAST UPDATE/ 19JUN00
CASUALTY TYPE: VESSEL/ X     PERSONNEL/     FACILITY/     POLLUTION/ MARPOL/
INCIDENT DATE/ 19FEB00       TIME/ 425       KNOWN/       ESTIMATED/ X REF CASE/
NOTIFY DATE/ 16FEB00         TIME/1521      REPORTER TYPE/PARTY, NEC
SUBJECT....../ M/V STAR IKEBANA; MAKING     LOCAL FILE REFERENCE/
LOCATION....../ MOBILE BAY     LOCAL CODE/
INCIDENT STATUS: VERIFIED/ NOT VERIFIED/ X VERIFIED, NOT REPORTABLE/
NOTIFY/ ACTION: CTX/X     RETURN/ (TO IAFFR)

--- VALIDATION AND ENDORSEMENT ---

BND/PWD       BND/CLS       RETURN   USER-ID       NAME       DATE
INVESTIGATOR: X       MCENERY       SUSAN MCENERY   19JUN00
UNIT COMMAND: X       MCENERY       SUSAN MCENERY   19JUN00
DIST REQ? : 
HQ REQ? :

--- GENERAL INFORMATION ---

CITY/ MOBILE     ST/ AL       WATERBODY/ MOBILE BAY
RIVER MILE/ .     LATITUDE/ N34-41.0   LONGITUDE/ W88-2.5
CAS SUMMARY: TYPE/ BREAKAWAY CLASS/ NONE
POSSIBLE DRUG INVOLVEMENT/? N     PUBLIC VESSEL/ BOATING/
DEATHS/ MISSING/     INJURED/ TOTAL DAMAGE/700
ENV IMPACT: MODE/     SEVERITY CATEGORY/     MATERIAL CATEGORY/
OSC/     EPA REGION/     CLEANUP REQ?
RESPONSE BY MSF/?     MSF TIME TO RESPOND/ HOURS
NOTIFICATION FROM NRC?.../ NRC CASE....
NOTIFICATION FROM APHIS/? N     APHIS PORT/

--- INCIDENT BRIEF ---

M/V ANNOLLA WAS TIED UP AT MCDUFFIES TERMINAL, WHEN THE M/V STAR IKEBANA
HEADING SOUTHBOUND ON THE MOBILE RIVER, CAME BY AND REPORTEDLY WAKED THE M/V
ANNOLLA CAUSING TWO LINES TO PART. NO OTHER DAMAGE OCCURED. INCIDENT COULD
NOT VERIFIED; CASE CLOSED TO FILE.
Narrative Supplement

SUBJ: WAKE DAMAGE OF THE DELTA QUEEN AT THE DOCK ON 09APR98.

On April 9, 1998 at approximately 1330, the Delta Queen was moored at the dock on the east bank of the Mississippi River near the greater new orleans bridge. The vessel was being piloted by master d. b. w. cap. the captain passed the delta queen through the breaking of warning lines, and rocking the stern gantry ramp and breaking two safety chains connected to the dock. The robin street wharf is located at mile 96.0 of the Mississippi River on the east bank just above the greater new orleans bridge. The captain passed the delta queen on her way up river and was reportedly getting ready to meet a down bound bulk ship.

The carrolton gauge was at 13.5 feet. The river was running at an estimated 3.5 miles an hour. Talking with the governor nicholls light operator, it is not uncommon for some ships to make 15 miles per hour or more against this current. There is a vessel that works at a fleet on algers point with video tape capability. Unfortunately, the tape has been erased. This may have been a way to determine the actual speed of the vessel.

The delta queen is 51 feet, 61 gross ton, 540 horsepower, uninspected river towboat of conventional design.

The amber is a 89,681 gross ton, panamanian registered freight ship built 1987. Communications, weather and fatigue are not factors in this case.

The apparent cause was a combination of excessive speed and close proximity on the part of the freight ship Amber in relation to the Delta Queen. A contributing factor may be the high river stage. A second contributing factor may be the meeting of the down bound ship. This case will be attached to the pilots IP for future reference. Case closed.
Analysis of Cases

- Used PASS-MOOR (Seelig, 2001)
  - Simple, requires little input parameters
  - Still required to infer several characteristics
    - Ship
    - Channel
    - Mooring

- Sensitivity Analysis

- Other tools reviewed/employed for conditions outside range of PASS-MOOR
PASSING SHIP EFFECTS ON MOORED SHIPS

by
William N. Seeig, P.E.

NFESC East Coast Detachment
Washington Navy Yard
1435 18th Street SE Suite 3000
Washington Navy Yard DC 20374-5063

20 November 2001

Prepared for:
Commander, Naval Facilities Engineering Command
Engineering Innovation & Criteria Office

Distribution Unlimited

Figure 2.1-1 DIMENSIONLESS PASSING SHIP FORCING ON MOORED SHIPS FOR DEEP WATER
(after Wang, 1975)
Figure 2.1-7. NON-DIMENSIONAL PEAK FORCE IN THE SWAY DIRECTION ON THE MOORED SHIP (after Wang, 1975) FOR DEEPWATER

Figure 2.2-2. SAMPLE SHALLOW WATER CORRECTION FACTOR FOR THE PEAK SWAY FORCE
The graph represents the applied forces to the moored ship (Fx and Fy) over time (sec). It shows two curves, one for Fx (green) and one for Fy (red), indicating the variation of forces over the specified time period.
Findings

- Usually larger vessel passing smaller
- In most cases, estimated forces from empirical analysis methods were much smaller than required for line breakage
  - Other factors attributable to breakage occurrence?
  - A few cases did indicate excessive line forces
- Results are highly dependent on
  - Vessel Velocity
  - Vessel Proximity
  - Current velocity
  - Channel and berth depths
Additional Factors

**Slack Lines**
- Snap-Loading
- May Increase Line Load by an order of magnitude

**Underkeel Clearance (UKC)**
- May Increase Added Mass values by factor of 2.0

**Shoaling of Channels / Channel Sides / Quays**
- Directly Affects UKC
- Also Impacts Hydrodynamics
Slack Mooring Lines and Snap Loading

“Slack Mooring Lines” were directly implicated in many of the cases studied.
Snap loading arises when a mooring line transitions suddenly from a slack condition to a taut condition.
May result in significantly greater force.
See, e.g.

Model Ship in Translation Under Constant Pulling Force

Discussion

Mooring Breakaway

- Hydrodynamics
  - Accelerations, Forces

- Other Forces (Internal & External)
  - Wind, Tug

- Vessel Data
  - Geometry of Moored Vessel(s) and Passing Vessel(s);
  - Vessel Speed, Relative Attitude

- Waterway Data
  - Bathymetry, esp.
    - Depth, Width, Channel Slope
  - Berth Characteristics

- Mooring Details
  - Geometry of Lines
  - Tensioning
  - Type of Lines, Connections
  - Condition
Conclusions

- Frequency of mooring breakaways due to passing vessels is significant
  - Reporting issues
  - Several per year (conservative)
- Mooring analysis methods
  - [Conventional] Environmental
  - Ship-Ship
  - Coupled effects
- Mooring force & response dynamics
- Limiting factors?
Selected Recommendations for Additional Work

- Slack Lines
  - Pierside Breakaway Dynamics
  - Pretensioning Technology
  - Alternative Mooring Designs

- Passing Vessel Effects on Vessels Moored *not* parallel to sailing line
  - More complex issue
  - Potential for higher forces & moments

- Impact of quay/pier construction and geometry
  - UKC effects
  - Hydrodynamics alongside [pierside of] vessel
Acknowledgements

Dennis Webb, USACE ERDC CHL (WES)
CDR Lyle Rice, USCG G-MOA-2
LCDR Al Blume, USCG
Bill Seelig, NFESC
Sovereign Maersk’s Stern Mooring Lines
(Photo: World Shipping Council)
--- COMMENTS --- 16MAR94, 0330/Welcome, LA: M/V TOPAZ broke loose from its moorings at Zen-Noh grain elevator and struck the ACBL Welcome Fleet. Statements from Zen-Noh stevedores, revealed that at 0130, the vessel's springlines were observed releasing and the vessel moving fore and aft as well as away from the dock. At 0215, the vessel's forward breast line parted. Stevedores tied a loop on the severed line and replaced the line on the dock's bollard, but noticed the ship's crew never took up the slack in the line, thus rendering the line ineffective. The vessel continued to work away from the dock. At 0245, TOPAZ requested the assistance of harbor tugs. The first tug arrived at 0300, after the vessel had broken away from the dock. The tugs appeared to move the ship's stern toward the dock, apparently causing the ship's bow to head out into the river several hundred feet. Four broken lines were found by Zen-Noh personnel. The remainder of the lines appeared to have spun off of their winches, since they were long and had no broken ends. Even the intact lines had splices. The vessel "warped" away from the dock until it was abreast the current. The vessel travelled downriver, not under command until it struck the ACBL Welcome barge fleet. Two assist tugs were damaged in the allision. At some point, the vessel dropped its port anchor. Whether the starboard anchor was released is unclear since statements conflict on this point. Only the port anchor was released when we arrived on scene. The gangway to the vessel, belonging to Zen-Noh, was smashed between the side of the ship and the dock. The dock sustained some broken wooden whalers on the dock structure. The anchor had dropped near a group of four natural gas pipelines. THIS ACTION PRESENTED A CONSIDERABLE HAZARD TO THE PORT. When I arrived on scene, the ship was stemming the current with a pilot in charge of the deck. I issued orders on behalf of the COTP to cut the rode to remove the danger of a potential natural gas release and explosion. I ordered the vessel to anchor or moor at the nearest safest anchorage or mooring. After cutting the anchor chain, the vessel anchored in Burnside Anchorage to await the return of its lines. LTJG T. J. SHOENFELT  Investigating Officer
--- COMMENTS --- Subject: The Barge Breakaway at Lucy Fleet on February 12, 1999. At approximately 0300 hours on February 12, 1999, the Tug Southern Star was conducting a routine fleeting operation at Lucy Fleet. He noticed that tier eleven was missing and informed the Lucy Fleet Tug Woody Dumas. The Woody Dumas determined that eight barges had broken away from Lucy Fleet. The Woody Dumas immediately notified river traffic of this incident and specifically alerted CGB Laplace. CGB Laplace is the next fleet down river from Lucy Fleet. At approximately 0300 the dispatcher of Triangle Fleet contacted the dispatcher for CGB Laplace fleet. He notified CGB that eight barges had broken loose from the fleet and were probably headed his way. The CGB dispatcher looked up river and saw the NAV lights on a couple of light boats up river headed his way. He did not see the barges yet but notified his fleet boats. The CGB fleet dispatcher made a general broadcast to his fleet boats about the breakaway. One of the CGB fleet boats (Miss Linda) was working barges at the wash dock. The wash dock is adjacent to the number one tier of CGB Fleet. The deckhands on the Miss Linda did not see the barges but heard a series of large crashes in the area of the #1 tier. They then observed running lights from several light boats coming down river. At the same time they observed the #1 tier at CGB drift out into the river. The eight barges that broke away from Triangle are OR1231, OR6242, LTD117, LTD 106, PC107, PMC9305, MEM2175 and MEM5114. After the collision with the barges from triangle fleet, tier #1 of CGB drifted down river colliding and breaking away the entirety of tiers #4 and #5. Over 230 barges were tied up in the fleet at CGB during the collision. It is estimated that 185 of these barges broke away. 88 empty barges and 97 loaded barges. CGB Laplace fleet reports all barges accounted for. 104 barges have received damage. One barge, the ET-414 sunk in the middle of the river at mile 120.6 just above Shell Norco. Several barges from the barge breakaway allided with and caused damage to the forepeak and starboard #1 Wing Void of the T/S Kriti Amber while moored at the Union Carbide dock located in Taft, Louisiana. A surveyor from the vessel's class society attended the vessel with Coast Guard Marine Inspectors. The cargo was offloaded and repairs made for the vessel to departing port. Case PS99017365. The MEM 5114 was the barge moored to the spud barge in tier eleven at Triangle Fleet. Pictures of the cable on this barge show a steel cable broken just below (less than a foot) the clamp used to form an eye in the cable. In the picture the eye is still around the bit of the barge MEM 5114. This barge is believed to have been the initial domino causing the break away. Fleet records/log indicate that the moorings were checked the previous evening at 1700 by an experienced hand. This Marine Casualty was not a major marine casualty in itself but a series of minor collisions or casualties that when grouped together become a Significant Marine Casualty in dollar amount. Human error, The RNA, communications and fatigue were not factors in this case. There was no pollution or injuries. The apparent cause of the casualty was equipment failure. The cable on the MEM 5114 parted starting a domino effect of barges going down the river. There is no regulation for these cables. They are usually cables that have served in another capacity such as on a crane. Once they are past the allowed service they are replaced and put to use in the fleets. A contributing factor may have been the high water of the river and a storm passing the area during the night. There are indications that a ship passed the fleet an hour before the breakaway. The surge caused by the vessel may have also been a factor. This would not be a cause because ships pass the fleet several times in a 24-hour period and should be able to stand up to the strain on the cable. Neither a 2692 nor a surveyor's report has been received from the T/S Kriti Amber damaged by the barges at TAFT. The ship lawyers have been contacted with negative results. Once obtained a separate case will be opened and attached to this case. Case Closed. M.D. White, CWO4