Preface.

Korean Investigation Authority has published the report about accident of 360 meters long container vessel "Milano Bridge" on April 6th 2020 in Busan. The report confirms that the accident caused by excessive speed during manoeuvring and the underestimated effects of the ship in ballast, such as partially submerged propellers and rudder blades with limited maneuverability, are considered to be the causes of this serious accident.
Milano Bridge was ballasting at the time, having departed from Zhoushan Shipyard in China, after undergoing repairs entered the port with about one-third of its propeller exposed above the water surface..

KMST noted that Milano Bridge sailed towards the pier at a speed of 8 knots, which was higher than the usual speed of 6 knots when berthing. Wind speed at the time was 5 to 8 metres per second, which is considered normal. The accident could have been avoided if Milano Bridge had slowed to less than 7 knots when approaching the pier by the report.

CHAPTER 2 Milano Bridge case in Busan

In another opinion of this case is “The ship could not manoeuvre as planned/hoped, mainly because she was ballasted to an aft draft of 6.90m instead of the needed 10.27m.” When briefly calculating the immersed area of the rudder with a draft aft of 6.9 meters based on the general arrangement (G/A) of Milano Bridge, it is presumed to be 54 m^2 , or about 64% m^2 of 85m^2, the total rudder area.

If a vessel does not use tugs or bow thrusters, she can make a turn with a moment created by rudder force only in 1st stage as we discussed in chapter 1. This rudder force, which creates a moment to push her stern to either side, is proportional to the rudder area, the square of the velocity of the water past the rudder, and the sine of the rudder angle. A vessel can increases her rudder angle or increase her main engine RPM to improve rudder effectiveness when altering course.
The force worked on the rudder area, is calculated as follows: $Fn = K \cdot A \cdot v^2 \cdot \sin$ (A: rudder area, Θ V: velocity of water inflow to rudder, and Θ: rudder angle).
By the formula force on Rudder, we can see the variables have 1. Rudder Area A, and 2. Speed (Square of Vessel Speed V^2) are both mentioned in their opinion. The main difference of their concern is: for ship operator, the propeller immersion rate is controllable in vessel operator’s end before a maneuvering begin.

For pilot association member, the approaching speed is controllable in their end although ship operator have the obligation to monitor their process in speed control. However vessel turning is a continuous process as we stated in chapter 1. It is consisted of an accelerating process in the beginning (stage 1 and 2) then a decelerating process in the end (3 and 4 stage). The sequence of these maneuvering just follow up one by one without any pause. It will need a throughout knowledge to understand which force set in which stage, and great skill to properly exert those forces one by one to perfect the maneuvering. It is a laboring try even for an experienced pilot. However, we will go through every and each details to cultivate our intuition in turning maneuvering.

Key Words: rate of turn；approaching speed；propeller immersion rate；rudder effectiveness；flow velocity；**rudder cycling**

Terms used:

1. Approaching speed : The speed vessel made good over ground while berthing.
2. Flow Velocity : Is the water flow over rudder plate which cause by vessel’s movement and propeller expel water on it.
3. Rate of Turn: vessel turning Degrees per minute.
4. Propeller Immersion Rate : the ratio of the distance between water line and propeller blade tip to propeller diameter.
5. Rudder Effectiveness : The effective of forces worked on rudder while vessel turning.
6. Head Reach : The distance vessel reached along her original course line while turning.
7. HORSE captain is the captain use Hard Over Rudder and Small Engine which is good in speed and course control.
8. MORIE captain is the Captain use Moderate Rudder and Increased Engine to handle the situation in slow steaming.
9. Coasting: Case where Rudder is hard over and Engine RPM put into Zero
10. Stern swing: ship’s stern swing to either side when she develop a drift angle while turning rate is increased.

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1 Inevitable incident in deceleration stages

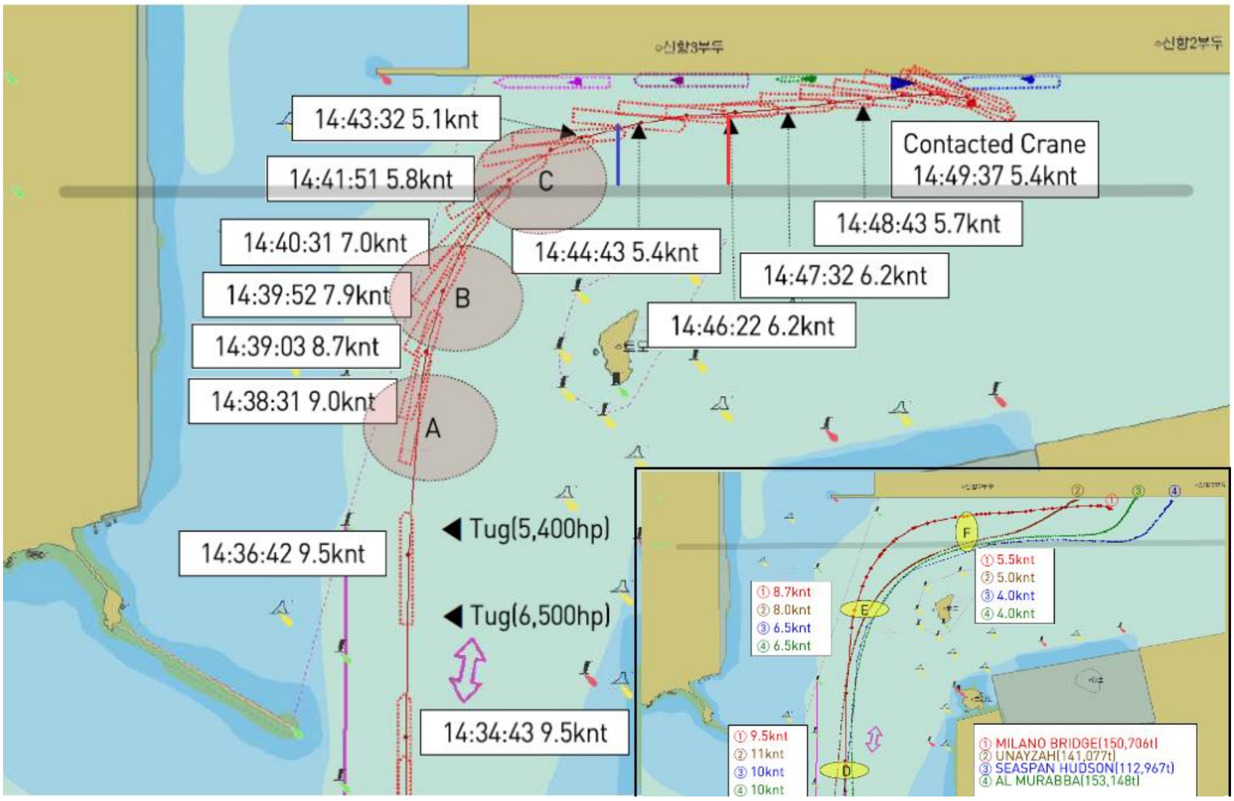

Figure 2 – 1 Different Vessel track in approaching

1.1 General inbound and berthing maneuvering.

For inbound container vessels, usually they will complete 90 degrees turn to parallel with the pier line at position F (Right Bottom) then go to do parallel berthing. To check ship's position after this 90 degrees turn in ship's heading, there is a range line marked by two green beacons at portside terminal to check vessel's head reach (grey line in figure 2 – 1). Remaining abeam distance to berth (about 360 meters) is for mariner to arrange following parallel berthing, please refer to Figure 2 – 1 : 3 other vessel tracks (No. 2 to No. 4)

1.2 Particular circumstance at time of incident.

- Milano Bridge finished 3rd stages turn (90 degrees turn) at position F when her head reach had advanced 240 meters more than normal turning, comparing with 3 other vessel's track in figure 2 - 1. This 240 meters distance is estimated from her ship's length (360 meters) ratio. In figure 2 – 1, the beam distance to grey range line is the orange color line segment vertical to grey range line in figure 2 – 1 at position F).

- The tail wind blew from 164° to 199° at about 5 to 9 m/s (Beaufort wind scale 4 to 5), tidal current flowed south at about 0.1 knots, and waves were no higher than about 0.5 meters in Busan New Port at the time of the accident.
- immersed area of the rudder with a draft aft of 6.9 meters based on the general arrangement, it is presumed to be 54 m^2 , or about 64% of whole rudder area.
- Propeller immersion rate is partially submerged by 6.5 meters draft.

1.3 Possible remedy after turning too late:

When Milano Bridge's turning had delayed to point C, the remedy maneuvering are like chapter 1 Figure 1 - 5 demonstrated have 4 situations to consider. If mariner

A. Use Situation 1 skill in figure 1 - 5,
   Milano Bridge at point C in figure 2 – 1 should steady the heading to 090^0 degrees (to parallel with pier line) without increase main engine RPM, the Course Over Ground COG will still go 075^0 degrees (drift angle 15 degrees). The beam distance to berth is already very narrow (2 ship's beam width) only.
   - plus there are 3 vessels at berth already which took out one vessel's beam width distance from Milano Bridge's current position.
   - The COG will come back to 090^0 degrees slowly as per figure 1 – 5 situation 1 illustrated which will need one more vessel's beam distance before vessel COG come to 090 degrees lately.
   - Vessel is on abnormal draft condition 6.5 meters aft which will set even more than normal 10.5 meters draft. make Milano Bridge in position C have no more room to set to North direction.

   Berthed vessel occupied One beam width and ownship need another one beam distance to set to North in normal 10.5 meters draft situation. Milano Bridge is with less draft of 6.5 meters now, her submerged ship's hull, propeller, and rudder area all are partial which make her setting to North more unpredictable. This option to steer heading 090^0 degrees with same speed in not available in this incident. Figure 1 – 5 situation 1 is not applicable.
B. Increase speed to rectify COG difference (15 degrees) with ship's heading as soon as possible. Can Milano Bridge increase speed to narrow the abeam setting to North (half vessel's beam distance as in Figure 1 – 5 situation 2 demonstrated) ?
   - In situation 2 increase speed can reduce abeam setting distance but the head reach will increase proportional to the speed. Within this 2 ship's length head reach distance, vessel need to eliminate the 15 degrees drift angle.
   - The berth for Milano Bridge is now 2 ship's length ahead (we can use ship's shape in ECDIS while berthing to estimate the distance to berth, this is also part of our graphical awareness training).

- Mariner had increased speed to steady the heading. Main Engine had ordered to increase to Navigation Full at point C (after it had already increased to Maneuvering full in point B).
- Current situation is vessel already in Maneuvering Full engine RPM. Increase RPM from Maneuvering Full to Navigation Full may reduce COG setting to berth a little. But the head reach distance in heading 090 degrees will increase by excess speed.
- Also considering current speed is 5.1 knots, it may hard to stop in time. And, very light draft 6.5 M will cause more windage, not enough water resistance to effectively stop the vessel.

Situation 2 increase speed in not a very good option in this case.

C. The approaching speed had a critical point for bow thruster and tugs to be useful. Bow thrusters and tug boats are generally ineffective at speed over water more than 3 to 5 knots.

- If Milano Bridge reduce speed to make full use of thruster and tugboat assistance, the rudder effect will decrease immediately and thrusters/tugboats will need another 1 or 2 minutes to be at its best push/pull force. This is a normal maneuvering when vessel is one or two NM from the berth.
- Now vessel is 120 meters beam distance to berth, there is no time to reduce speed and wait.
- In condition 3 reduce speed will set vessel to North immediately and make situation even more harsh.

Situation 3 reduce speed and RPM is not applicable when vessel us very close to dock.

D. Condition 4 in figure 1 – 5 seems the only solution when vessel is in position C.

- As we discussed in chapter 1 the stern will swing out by drift angle 15 degrees and COG will need one more ship's length to reach her 090^0 degrees turn.
- The decision to do rudder cycling must be earlier then position C to take vessel out of her original North head reach which is 120 meters now and our first priority.
- Otherwise, it will not have enough space to do it.
- For easy reference, <u>mariner should make up his mind to do rudder cycling when ship's position passed assumed range line</u> (grey line). This is the awareness we need.
- To compare with Figure 2 – 2 Engine and Rudder order sequence in VDR, we can see at 14:42:44 hours (about position C) when vessel's heading is 080 degrees mariner had use full speed and Midship at the same time. This is the time, mariner should make up his mind to take vessel out of her approaching to North side as soon as possible. Use original turning rate to starboard side is a good idea but Mariner "midship the rudder" to reduce turning rate to starboard side.

- And at 14:45:04 hours, mariner further reversed the rudder angle to Port 10. It's a wrong move when vessel still set to North, heading is not where vessel will set to (COG is).

Mariner has no intention to reduce speed and setting to north by using rudder cycling may be because lack of necessary training and skill.

With very short period of Port Rudder angle used (both were 7 seconds in 14:45:04 and 14:46:41, figure 2 – 2 marked with two red squared), vessel COG still goes to port side. In KMST investigation report had added two contributed factor,

1.4 propeller immersion rate and wind speed. Quoted:

1. Under the same conditions, only the draft was changed, setting the vessel in full ballast where the propeller was 100% immersed (10.5 meters). The same rudder and engine orders were used just as recorded in the VDR (same as incident timing), while no decrease was made in propulsion forces and rudder effectiveness. As a result, the vessel turned out to be able to secure a safe distance from the pier as her tactical diameter was smaller than that it had been during the accident. (remark: Vessel will be able to turn to position F in Figure 2 – 1 bottom right).
2. Wind speed, reduced from 13 knots to 0. The vessel track in simulation getting farther away (clear) from Pier No.3, at a distance of 100-150 m, two or three times the ship's beam distance, compared with the track during the accident. That means the tail wind Milano Bridge faced before passing To Islet, further affected the ship's movement as the vessel speed reduced to 5 or 6 knots when making a large course alteration to starboard. The hull is presumed to be pushed as far as 100-150 meters toward the pier by the wind.

Unquoted

In the quotations above, we can see propeller immersion play the significant part as "100% immersion rate can get vessel back to original track" and "wind speed (force 4 or 5) can reduce about 2 or 3 ship's beam width distance head reach to the dock (150/360 = 42%)".

2 Bad decision in acceleration stages

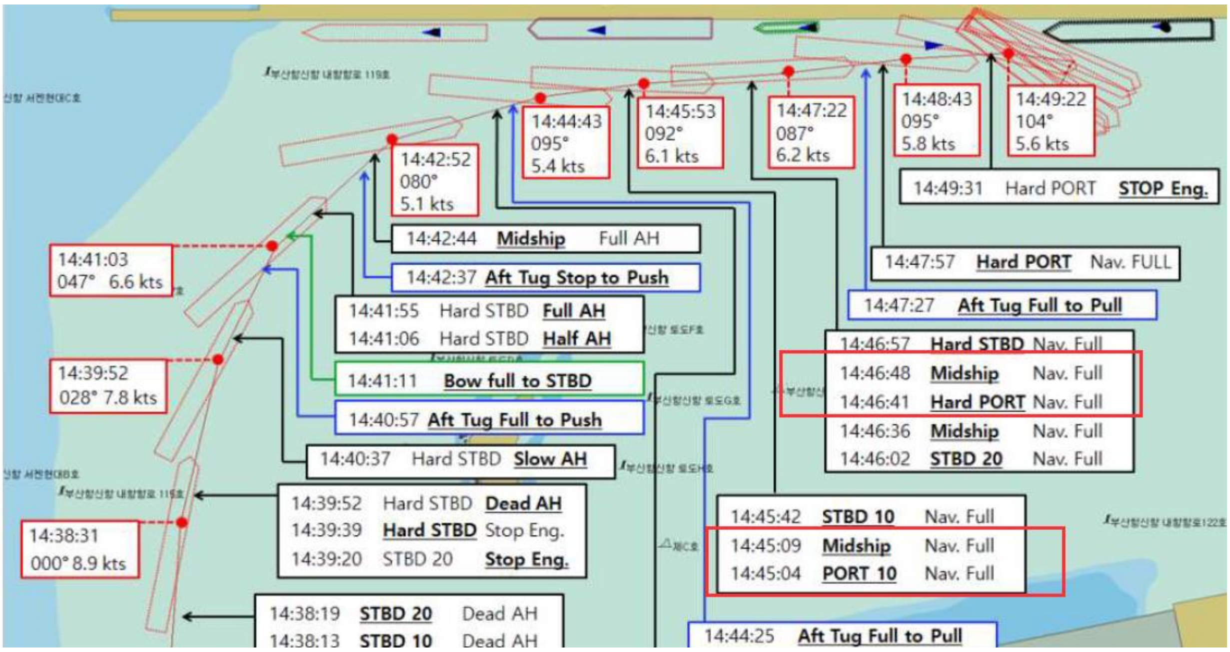

Figure 2 – 2 Engine and Rudder order sequence in VDR

2. 1 The reason of incident is **wheel over position delayed**.

With bad immersion of propeller and tail wind, Captain is just bad luck with bad decision made by pilot. The concern of approaching speed too fast at breakwater entrance is not relevant (discussed later). Before the maneuvering begin, mariner should check the situation of its propeller immersion and wind force. These two among others are force majeure (wind, current, draft, ship size…etc.,) need to be taken care of before every and each maneuvering. In traditional shiphandling, we can evaluate these force majeure effects by final position vessel will reach. This is the purpose of KMST simulation study to find out her final position will be. The results in different approaching speed and wind force and ballast draft condition discuss as below:

2.1.1.First is the wind from the South, although the wind force is not significant at the moment 14:50 hours (Beaufort wind scale 4 to 5). This is a light draft abnormal condition which make her windage increased in some way and push vessel head reach more to North (dock) than her normal 10.5 M draft situation. If the wind speed is 13 knots, <u>The hull is presumed to be pushed as far as 100-150 meters toward the pier by the wind (by investigation report).</u>

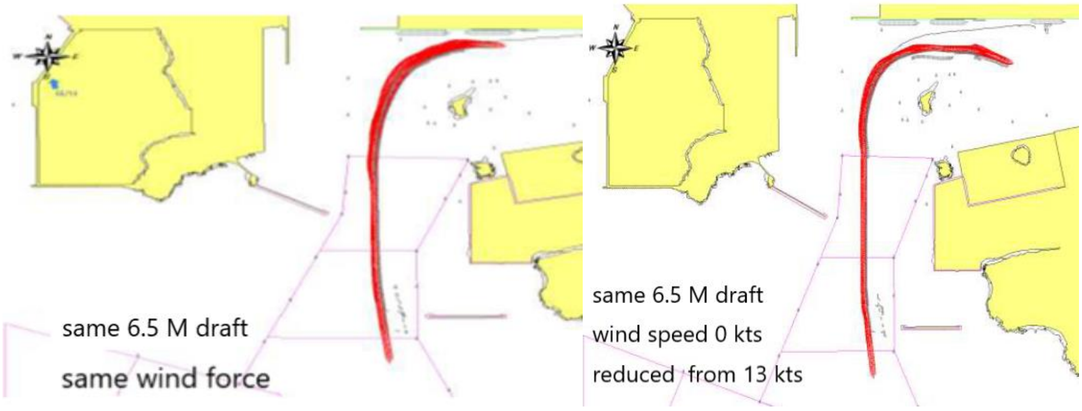

Figure 2 – 3 Simulator track with No wind force

2.1.2 Water resistance in 2nd stage is the braking force of ship's advance distance in figure 1 - 2. In Normal ballast draft 10.5 M as sea trial condition, the same rudder and engine orders were used just as recorded in the VDR, while no decrease was made in propulsion forces and rudder effectiveness. As a result, the vessel turned out to be able to secure a safe distance from the pier in figure 2 - 4 than her aft draft 6.5 Meters in the left drawing.

Ship hull submerged area had reduce from 10.5 meter to 6.5 meter about 40% less than her sea trial normal ballast condition. Water is almost a thousand times as dense as air. It provides far more resistance to stop the drift as a result. This explained why the immersion rate of shipside have more effect in reducing vessel advance distance.

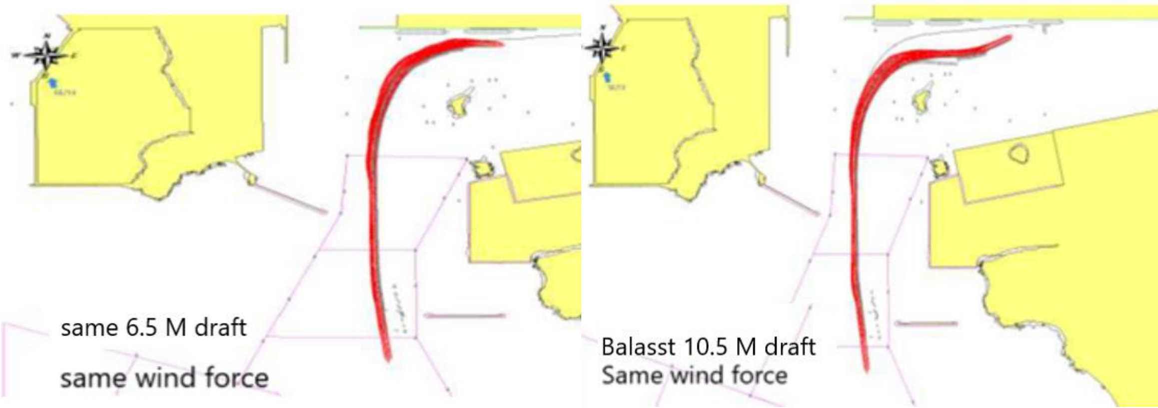

Figure 2 – 4 Simulator track with draft in 10.5 Meters

2.2 The problem is Milano Bridge began the 2nd stage turn too late.

In figure 2.5. quoted "In this simulation, when passing To Islet, the vessel reduced her speed to about 5 knots and made a turn to starboard as recorded in the VDR under the same weather and draft conditions. As a result, the vessel made a 90° change in heading at the mid-point between the quay and the islet."

"That means if Milano Bridge had reduced her speed to about 5 knots while passing the islet, she is presumed to have secured a safe distance from the quay as the vessel would

make a 90° change in heading at the mid-point between the quay and the islet, just as the track of the other similar vessels described in figure 2 - 6."
Unquoted.
The difference of our study from KMST is the way we separated the turning curve into 4 stages in this book to better analyses the details. The head reach distance is reduced to half in figure 2 -5 (mid-point between the quay and the islet) if we compared from the position abeam the small island (islet). KMST is to compare the head reach distance after 2nd stage had started with different speed from 8.7 knots to 5.0 knots. If figure 2 -5 both drawing are at same stage of turning when they abeam of small island, the draft (water resistance force proportional to her immerged ship hull) and wind force are the same, the difference of turning curve is because their different centrifugal forces are generated from different speed. However, from figure 2 -4 we know even the speed in 8.7 knots if the draft is 10.5 meters there will be OK. <u>This means the draft (immersion rate of ship's side area 100%) is more important than her approaching speed (50%)</u>. It means ship operator's responsibility to adjust ship's draft of this incident is more than over-speed maneuvering by the pilot.

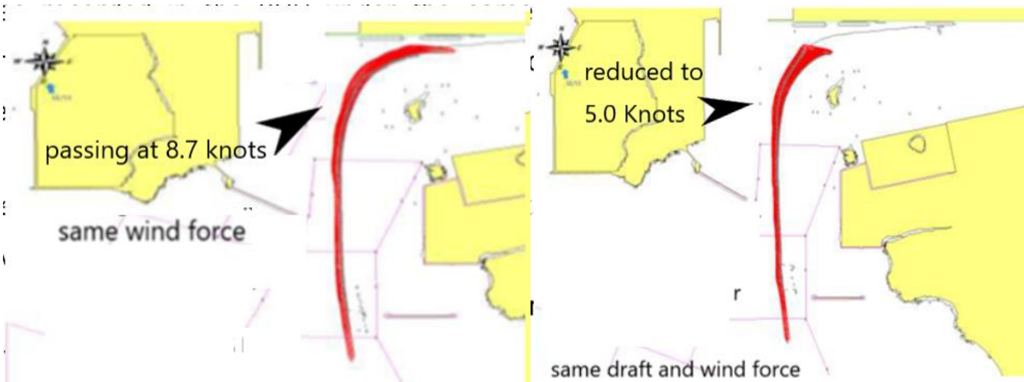

Figure 2 – 5 Simulator track with same wind/draft and different approaching speed

2.2.1. Water resistance will increase only after ship's heading had turned after 1st stage as we discussed in chapter 1.

2.2.2. Before 2nd stage of turn began, water resistance working to stop the vessel head reach is insignificant.

2.2.3. The excess speed in 1st stage is not the decisive factor of this incident. This can be referred to figure 2 – 6 M.V. UNAYZAH EXPRESS 141,077 T (No. 2 vessel about same size as Milano Bridge) speed at position D (Break Water entrance) is 11.9 knots which is more than Milano Bridge's 9.5 knots.

2.2.4. However this vessel started 2nd stage of turning (vessel heading turn to starboard side about 12-15 degrees) well before Milano Bridge as figure 2 – 6.

2.2.5. The different position of Milano Bridge starting 2nd stage with other vessels is represented by black arrow pointing south (where vessel departed her original course line, grey line in figure 2 – 6).

2.2.6. Milano Bridge started 2nd stage turn at pink line and other 3 vessels started 2nd stage at light green line position. This black arrow distance is about 400 meters (more than vessel's abeam distance difference at position F which is 240 meter as we summarized in the beginning).

2.2.7. Milano Bridge begin the 2nd stage turning 400 meter later than UNAYZAH EXPRESS. But the head reach difference of these two vessels in not 400 meters, only about 240 meters.

2.2.8. The reason of this 400 meters difference when 2nd stage start is not same as 240 meters difference when their heading reached 0900 degrees change in 3rdstage is because ,after 2nd stage began, Milano Bridge is turning more effective than UNAYZAH EXPRESS.

2.2.9. If we move the black turning curve of Milano Bridge down 400 meter to where UNAYZAH EXPRESS 2nd stage had begun, we can see the turning curve of Milano Bridge has much less turning radius.

2.2.10. So, turning has no problem after Milano Bridge started 2nd stage turning. The problem is Milano Bridge began the 2nd stage turn too late.

We need to find out the reason why with more details below.

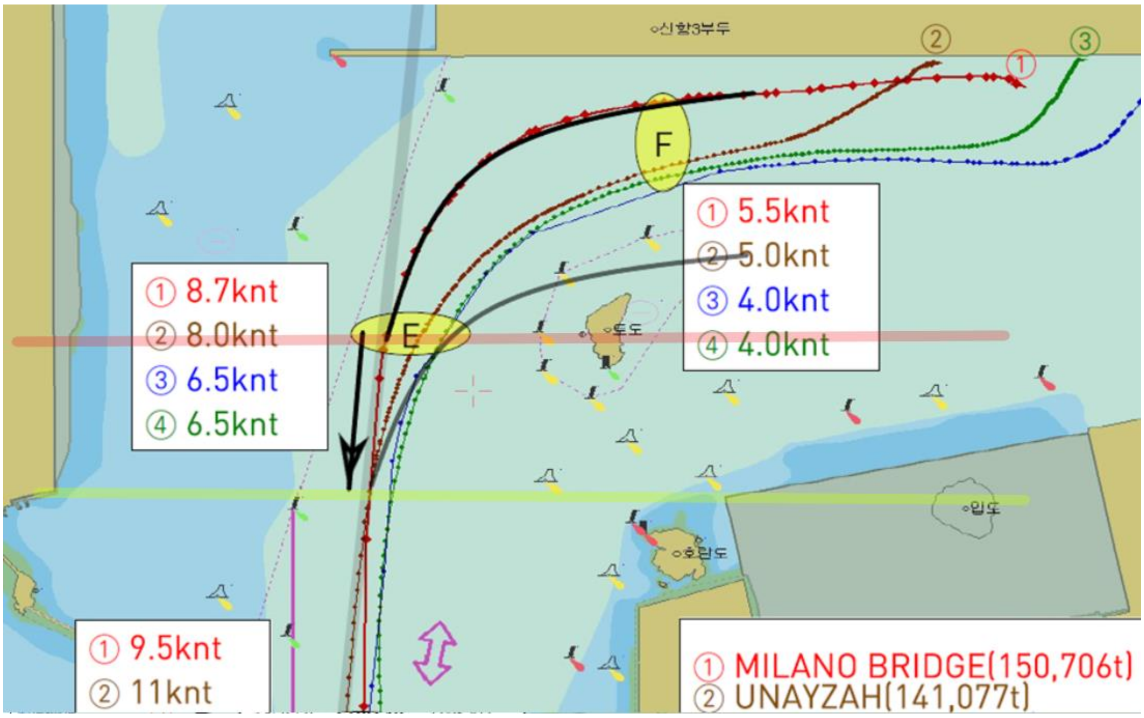

Figure 2 – 6 Delay of the 2nd stage of turn begin

2.3 What maneuvering Milano Bridge did in 1st stage?

Now the reason of this incident is clear: Milano started her 2nd stage of turning too late. Let's look into what caused the vessel heading change delayed in 1st stage. Please refer to figure 2 – 7 Engine order before 2nd stage begin.

2.3.1 14:34:31 - 14:36:35 “Full Ahead” , Rudder order “STBD 10”, COG 000^0 degree, SOG 9.5 Knots. vessel entered Break Water at 14:34:31 hours with “Full Ahead” speed, until this moment

2.3.2 14:36:35 hours reduced to “Half Ahead”. Heading due North 0000 degree had not changed yet.

2.3.3 14:36:39 “Slow Ahead” , Rudder order “STBD 10”, COG 0000 degree, SOG 9.4 Knots.

2.3.4 After 4 seconds time from 14:36:35, Engine RPM reduced to Slow ahead.

2.3.5 14:37:27 “Slow Ahead” , Rudder order “Midship”, COG 0000 degree, SOG < 9.4 Knots.

2.3.6 Rudder order “STBD 10” reduced to “Midship”. So, the turning had not started yet at this time 14:37:27. After 7 seconds from

2.3.7 14:37: 34 hours, Engine order reduced to “Stop Engine”. Mariner’s maneuvering is to reduce excess speed he felt, not to turn the vessel.

2.3.8 14:38:31 “Dead Slow Ahead”, Rudder “Midship” from 14:37:34 then ordered “Stbd 10” at 14:38:13 hours, wheel over time is now.

2.3.9 But the engine RPM reduce to zero after 18 seconds “Stbd 10” at 14:39:20 hours.

2.3.10 Mariner may lost orientation: cannot decide to reduce SOG Speed Over Ground first or to start the turn first (at 14:38:13 with “starboard 10”as he did 18 seconds ago).

2.3.11 We even cannot say 14:38:13 is the wheel over point when engine order is “Dead Slow Ahead” and Rudder order is “STBD 10” only. Then, mariner reduce RPM to Zero with “stop engine”.

2.3.12 14:38:31 The COG is 0000 degree and SOG is 8.9 knots. Vessel had not changed its heading

2.3.13 14:39:39 “Dead Slow Ahead” reduced to “Stop Engine” , Rudder order “STBD 20” Increased to “Hard Stbd”.

2.3.14 This is typical “coasting” case where Rudder is hard over and Engine RPM put into Zero which also known as “Titanic effect”.

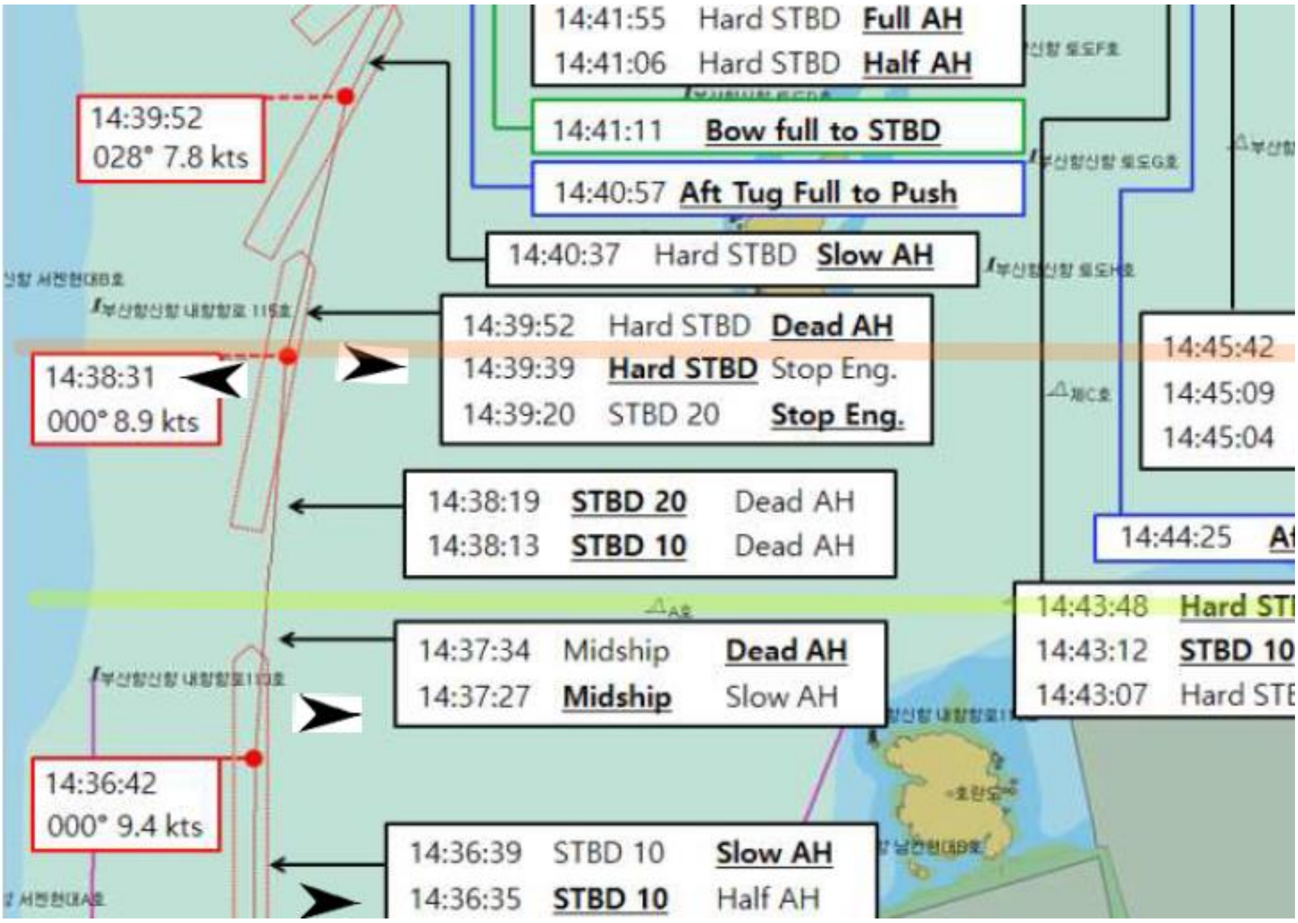

Figure 2 – 7 Engine Order before 2nd stage of turn begin

2. 4. Milano Bridge wheel over time is one minute delayed

After our time table analyses, we can see the wheel over time is 14:38:13 hours with "STBD 10" and the rudder order increased as routine.

⇒ However, the engine RPM is also reduced from 14:37:34 "Dead Slow Ahead" to 14:39:39 "Stop Engine" after the wheel over maneuvering had begun at 14:38:31 hours (68 seconds ago).

⇒ We don't know the rate of turning is how many? By estimation from 14:38:31 to 14:39:52 hours, COG change 28 degrees, Rate of turn is 20 degrees per minute, it seems normal in 1st stage maneuvering.

⇒ The head reach in this period 81 seconds (14:38:31 to 14:39:52) by @8.4 knots is 350 meters. The head reach if the average speed is 5.0 knots is 208 meters. The speed difference is 142 meters in her head reach (8.4 – 5.0 Knots difference).

⇒ There is 142 meters difference because approaching speed different from @8.4 knots to @5.0 knots. The black arrow in figure 2-6 is 400 meter long.

⇒ Compared with other 3 vessel's turning curve, there Pivot Point left original course line in turning curve are 400 meters earlier than Milano Bridge.

- ⇒ This is the main reason of Milano Bridge turning too close to the dock line, delayed in 1st stage maneuvering.
- ⇒ If we check Milano Bridge at wheel over time is 14:38:31 in figure 2-7 is green line position, we can see Milano Bridge position is abeam of South End of the Small island.
- ⇒ Other vessels had their turning in 2nd stage began when they abeam the south terminal (as red line position as figure 2 - 7 had shown).
- ⇒ If we use ship's shape of 360 meters long to measure the vertical distance of green line and red line, the distance will be about one ship's length.
- ⇒ 360 meters for 8.4 knots vessel will be 1.38 minutes run (83 seconds).
- ⇒ This is One Minute Law which means one minute delay caused incident.

It is obvious Milano Bridge's wheel over time is too late (one minute delayed or not decisive). Maybe mariner are distracted by other errands. To errs is human. So, we need to prepare more check points and remedy measures before it is too late.

3 More awareness in Milano Bridge case

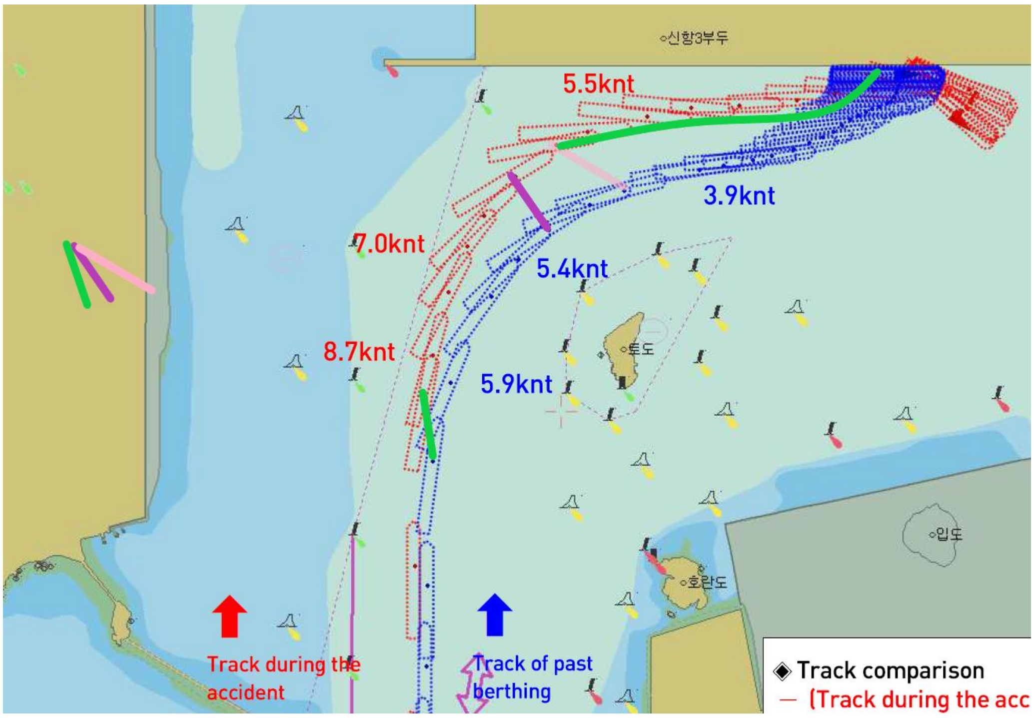

Figure 2 – 8 2nd stage of turn begin delayed whole turning curve

3.1 With rudder cycling to get out in 3rd stage?

In figure 2 -8, we connect two tracks same turning stages with a color bar. 2nd stage starting position is connected with Green Bar when vessel is 10 degrees away original heading 000 degrees. Purple Bar to connect two positions difference when vessel COG made 60 degrees turn to starboard side. Pink Bar is position difference when vessel COG made 80 degrees turn to starboard side. Green Curve is suggested maneuvering in this incident (coped from past success blue tracks). As discussion above, we can summarize as following:

3.1.1 The wheel over time is delayed about 1.35 minute (14:38:31 to 14:39:52) which in her average speed 8.4 knots, the head reach will be 350 meters difference.

3.1.2 This one minute delayed in turning is the same as human element principal " One Minute Law".

3.1.3 In figure 2 – 8, we compared the 2nd stage position difference in incident and past berthing as represented by green segment which is about 200 meters long.

3.1.4 In figure 2 – 8, we compared position difference when vessel COG made 60 degrees turn to starboard side in incident and past berthing as represented by purple segment which is about 250 meters long.

3.1.5 In figure 2 – 8, we compared position difference when vessel COG made 80 degrees turn to starboard side in incident and past berthing as represented by pink segment which is about 270 meters long.

3.1.6 In figure 2 – 8, we can see even the approaching speed is fast in incident case, their turning curve had not so much difference.

3.1.7 However the head reach is increase slowly due to the draft is less than normal loading situation. Another possibility is different engine and rudder order used by another Captain or Pilots in their past track approach and berthing.

3.1.8 After vessel COG had changed 80 degrees (pink bar) position, past track had reduced speed and done parallel berthing as required.

3.1.9 In the incident case, Milano Bridge SOG speed over ground is 5.1 Knots at 14:42:52 hours when COG had changed 0800 degrees, see figure 2 – 2.

3.1.10 After 15 seconds, Mariner order Engine RPM to Navigational Full at 14:43:07 hours when they found out position too close to dock.

3.1.11 This is a "jump out decision" which made bow thruster and tug boats useless in following maneuverings (over 5.1 knots as common sense knew).

3.1.12 The correct one is to go "rudder cycling" and keep COG more than 090 degrees away from the dock (green turning curve is suggested for safe berthing) when SOG is over 5.0 knots as we discussed in chapter 1.

3.1.13 If the SOG is below 5.0 knots, the safest way will be continue the turning to starboard side (SOG reach 090 degrees) and stop the engine immediately and take all headway out.

3.1.14 Stop the vessel first is the same principal as collision avoidance, no speed no collision, then arrange the parallel berthing with tugboats and bow thruster's help.

3.1.15 Possible berthing maneuvering is illustrated as figure 2 – 8 after vessel COG had changed 80 degrees at 14:42:52 hours with a green track assumed from her Pivot Point.

3.1.16 This green COG track is the exact copy from past track (blue track).

3.1.17 Although Milano Bridge turning too slow with more head reach distance after 80 degrees heading changed in the incident. She can use current position to reduce speed and stop the vessel with rudder cycling skill and proper understanding of ship's stern swing out problem to avoid it.

3.1.18 To keep COG more than 090 degree is the first priority after vessel heading change 80 degrees as now many adverse influences present as A. less draft, B. tail wind, C. over speed, and D. too close to dock already.

3.2 Situation Awareness in this turning

3.2.1 What awareness in Wheel over stage or 1st stage position:

- The wheel over position WOP has to set up before the maneuvering. This is a common sense for all members of bridge team.
- However, the actual wheel over position can be aware by using multiples of ownship shape's length or the speed vector length in Radar or ECDIS. This is an easy reference in different ECDIS chart scales or Radar range ring when ECDIS/Radar chart scale is under frequent changed.
- Traditional Wheel Over Point is memorized by land mark line or navigation aids. However, ocean going ship's captain have the problem to identify these navigational aids in each different port by visual. With the help of unified presentation in ECDIS and Radar screen, ship length or speed vector can be very convenient to be used by mariner.
- In this Busan port, the WOP is when vessel passed south island (see figure 2 – 6).
- This WOP position is about 4.5 times of Milano Bridge ship's length SL for a 90 degrees turn.
- 4.5 times of Milano Bridge ship's length is 360 x 4.5 = 1,620 meter.
- Most vessels entered west breakwater at 10 knots speed and reduced to 6.5 knots abeam the small island. We used the speed of 8.2 knots when vessel need to put wheel over for turning.
- 6 minutes speed vector in 8.2 Knots (= 1518.6 meters) is very close to 1,620 meters which can represent her 4.5 SL. If ship is over speed at WOP, 1600 meter distance is ? knots vessel's 6 minutes speed vector length. The answer is 8.64 knots.
- Over-speed vessel will make their 6 minutes speed vector have longer distance. Longer distance (Over-speed) vector will touch the dock earlier than her normal speed.
- When 6 minutes speed vector touched the dock, it will be the proper time for vessel to Put Wheel Over to turn in this case.

The morale of this study is "6 minutes speed vector length is a very good indicator for WOP" no matter what scale ECDIS chart layer is or whatever the range ring setting in Radar is, if the 6 minutes speed vector touched the dock ahead, It must be the wheel over time now.

- Too much approaching speed will cause 6 minutes speed vector longer and touch the dock earlier no matter mariner is checking at ECDIS or Radar.
- This is an example only. Mariner need to find out the relationship of their ship's length, speed over ground, head reach, turning ability etc.,
- The turning need 3.5 times of SL to finish a 90 degrees turn. Another one SL is saved for parallel berthing.

The maneuvering in WOP stage should be "Hard Over Rudder" to initial the turn which can serve two purposes. One is to increase the turning rate and other one is to use the drag of rudder (pull back force) to slow down the vessel (see figure 1 – 2). As past cases demonstrated, turning too slow is always the cause of later panic and incidents. The mariner use small rudder angle and full speed is called "MORIE " in book title BHRM Dynamic Navigation for Master (author Captain Gilbert Lee ISBN-13979-8323633081)

Slow steaming is the ultimate test of Master's shiphandling.

- **HORSE is the captain use Hard Over Rudder and Small Engine which is good in speed and course control.**
- MORIE is the Captain use MOderate Rudder and Increased Engine to handle the situation in slow steaming.

3.2.2 What awareness in 2nd stage Position?

- Keep this aware to know if the turning rate had not reached as we expected.
- In figure 2 – 6, the position other vessels begin their 2nd stage of turning is at green line's position. When ownship abeam of west terminal's south end and east terminal's north end at the same time, the Green line could be deemed as jointed line by these two points from ECDIS or Radar monitor for graphical awareness.
- When other vessels begin 2nd stage of turning, their head reach to dock line is about 3.5 ship's length of ownship length (360 x 3.5 = 1260 meter) and their speed estimated is 7.5 knots, their 6 minutes speed vector length should be 1,389 meters then.
- In 1260 meters (3.5 SL) before the dock line, vessel (of our own size as figure 2 – 6) have to start her 2nd stage there. 1260 meters is about 0.9 times of 1,389 meters (7.5 knots, 6 minutes speed vector length) now.
- The speed vector length should change to 3 minutes when the turning begin and the head reach had reduced. By the speed 7.5 knots, 3 minutes speed vector distance is 695 meters which is about 2 SL = 720 meters.
- How many ownship's length to the dock line can be estimated by our ECDIS ship's shape.
- The same techniques by using our finger span as divider to take one ship length distance then compare with the distance ahead of dock line to know how many distance remained ahead is a prudent skill.
- An advanced skilled mariner, he can estimate his vessel distance ahead of dock line by his mental comparison of ownship's shape against remaining head reach.

- A sharp heading change usually need at least 3 minutes to accomplish.
- If we stick in original theory of ship's position as 1st generation did, we will notice the final result is unfavorable almost when the turning had finished as in this incident.
- If we had practiced theory of rate of turn theory as 2nd generation did, we may notice the turning rate had not accelerating as usual in her 2nd or 3rd stage of turning. Maariner may decide to use other resources or means to increase turning rate at time of 2 or 3 minutes after WOP.
- If we fully understanded these 4 stages of turning theory and properly trained of how to aware of its each stage's turning rate, approaching speed, and position of each stage, mariner may have the awareness that 2nd stage of turn had not started in correct position as usual. Mariner may have the awareness at time of 1 minute after WOP.
- In Busan port's case, we can see 3 other vessel begin the 2nd stage just passed south end of west terminal in figure 2 – 6 green line position.
- If Milano Bridge mariner had checked their turning stage at this point, they will know his ship is turning too late.
- In figure 2 -2 14:39:39 hours, Milano Bridge position passed south end of TODO island had into 2nd stage of turn which is too late already.
- Mariner use "Hard starboard & Stop Engine" as HORSE style is to slow down the vessel first.
- However, with head reach distance remained for Milano Bridge is about 3.5 ship's length, there is no way she can stop before the dock. So, the priority should be turn the vessel as fast as possible. Mariner had wrong priority to slow down the vessel first.
- Turn the vessel as fast as possible will need the Kick Ahead skill to increase the Rate of Turning.
- As we knew, Kick Ahead need to use all reserved RPM to make it effective.
- In 14:39:39 hours, Milano Bridge want to turn into 2nd stage should use "Full Ahead" RPM to increase the Rate of Turn then stop the engine as required turning rate had reached.
- In 1st stage, rate of turn is always slow because only the rudder had turning force. However,
- one ship length distance advance in 1st stage is the distance vessel have to sail for a container vessel or fast speed vessel.

After 2nd stage of turning had started, we have to check the turning rate is increasing or not? How to estimated the rate of turning we needed? If we refer to figure 2 – 6,

- the distance is about 2.5 ship's length distance, from the green line (2nd stage started) to Point F where Heading had changed 90 degrees (although COG had not changed 90 degrees)
- The distance travelled by ship turning is about 2.5 ship's length = 900 meters

- the average speed from green line to position F is about 6 knots
- 900 meter in 6.0 knots needs 4.8 Minutes. The turning will need 90 – 15 = 75 degrees heading change from 2nd stage begin. 15 degrees is the heading change in 1st stage in one ship's length advance.
- Average turning rate required is 75 degrees / 4.8 minutes = 15.6 degrees in 2nd and 3rd stage of turning.
- Usually, container ship can finish 90 degrees turn within 3.5 shup's length during sea trial where the wind is light, draft is 100% immersed, and speed is navigational full.
- In deep sea water, most vessel can finish 90 degrees turn within 3.5 ship's length. This 3.5 SL minus 1 SL in first stage, remained 2nd and 3rd stage advance is 2.5 SL.
- In "Half Ahead" engine, vessel turning need 6 minutes to finish 90 degrees turn within 3.6 SL as vessel's sea trial data.
- In harbour area, the 90 degrees turning need to be finished with limited space not like sea trial executed in open sea.
- In harbour area, 3rd stage need a deceleration process to reduce the rate of turn to a controllable level.
- Steady the vessel in new course line with her COG same as her heading is her 4th stage of turning.

2.2.3. What awareness in 3^{rd} stage of turn:

- At 14:41:03 hours in figure 2 – 2 where her SOG is 6.6 knots & COG 047^0 degrees, the engine order is "Slow Ahead" and rudder is "Hard Starboard".
- This position should be the position Milano Bridge had finished 80 degrees turn already in her past track. Please review other vessels track in figure 2 -6.
- Mariner also sense the delay of turning. The turning rate now is <u>18.33 degrees per minute</u> (14:41:03 047^0 – 14:42:52 080^0). It is even slower than vessel did in 1^{st} stage as we calculate in figure 2 – 7 (14:38:31 000^0 to 14:39:52 028^0) rate of turning is <u>20 degrees per minute</u>.
- These two turning rate is more than we calculated in last paragraph average rate of turning is 15.6 degrees per minute.
- Exact rate of turning in different harbour of estuary may differ greatly.
- The specific rate of turn is not always the same in different waterway:
- in a moderate turn river, rate of turn may be 10 degrees per minute will be good (like EVER FORWARD grounded outside of the Craighill Channel.)
- In sharp turn and long riverway, rate of turn may need 20 degrees per minute at her maneuvering "Full Ahead" speed. (most difficult turn I knew is in Vietnam Cai Mei port)
- In a turning basin, the turning rate may need 30 degrees per minutes with near zero speed.

- In this stage, vessel turning should increase quickly by the water resistance and centrifugal force caused momentum in normal draft vessel.
- There is no tendency that turning rate is increased as required in this incident.
- It is caused by light draft and not enough water resistance to against centrifugal force.
- The tendency of turning rate increased or decreased is more important than the rate figure.
- Is it slower than 1st stage or increased quickly after 1st stage can give mariner a clear awareness of the turning is slower or progressed in good order?
- The rate of turn is a very good indicator of vessel's turning performance which can provide mariner extra awareness when we know how to check it periodically.
- How to correct this situation when turning rate is slow? To kick the engine haead to increase turning rate or to prepare further rudder cycling in 4 stages.

2.2.4. What awareness in 4th stage of turn: it is at 14:42:52 hours when COG is 080^0 (or heading 090^0) in figure 2 – 2.

- The beam distance to dock is about 220 meters and minus 60 meter occupied by berthed vessel's beam width. It will remain about 150 meter clearance in her abeam.
- The situation is clear. To keep away from the berth and other berthed vessel as far as possible, the way to secure this purpose will need to use Course Over Ground COG to monitor vessel's advance in North direction.
- COG is an indicator of vessel's present movement calculated from its GPS position's difference. It is take no account of all other factors affected ship's movement including wind force/direction, tidal current, draft, engine power, tug assistance, rudder, thruster used.
- All other factors worked on ship's hull will summarized by its speed vector over ground calculated from vessel's past position over ground.
- In current situation, vessel already too close to dock after 3rd stage of turning, the aim to avoid vessel moving further North is first priority.
- COG over ground will be a very good indicator for this purpose. The speed over ground SOG will need to put in second priority.
- There are two purposes in current situation. One is to parallel the dock which will need COG going no more to North (COG more than 090^0 degrees) and the second is to stop the vessel as soon as possible.

Rudder cycling is the only choice here in 4 stage. Use original speed 5.0 knots to continue the turn to starboard side and keep COG no less than 090^0 degrees.

4. Rudder Cycling:

emergency maneuvering in all emergency: collision, grounding or speeding

Rudder Cycling is to use 3 or 4 times hard over rudder to each side in turn to reduce ship's speed and retain control of ownship's heading. In this case:

4.1 Put rudder order "Hard Starboard" first to continue the turn to make COG more than 090 degrees no matter how many degrees ship's heading is. The difference in ship's heading and COG is her drift angle.

- As first chapter stated, when COG turned to 090^0 degrees ownship's stern may swing out by our drift angle.
- 366 meters SL x 3/4 (longitudinal distance aft PP swing outside turning curve, extra advance) sin 20^0 (drift angle) + 51.2 meters beam width x 1/2 (transverse distance from center of stern) cos 20^0 (drift angle) =93.9 + 10.4 = 104.4 meter
- In last paragraph of 4th stage awareness we know : It will remain about 150 meter clearance in her abeam.
- Keep COG to reach 090 degrees will swing her stern out 104.4 meter to the North.
- Keep proper turning control to avoid COG go too much to South to avoid stern swing too much to North is also a major concern we should have.
- It is always easy to make the calculation on the paper. For mariner, they have no time to check one by one. Anyway, if no discussion here mariner will not have proper awareness while they are at scene on the rush while their Adrenaline are flushing. It is always the purpose of my study.

4.2 Change the rudder order to portside fully when COG had reached 090 degrees. That is "Hard Port" after first rudder order "Hard Starboard".

- Vessel will need some time to stop the original turn to starboard side and COG going back to Portside. This over shooting to starboardside will cause ownship stern swing further out to north direction.
- As calculation the head reach to North when 4 stage begin had remained about 150 meters and the stern swing to North when COG is 090 degrees with 20 degrees drift angle will be 104 meter.
- Proper control the COG turning rate is also a good seamanship to avoid too much swing of stern.
- Steady vessel's swing or reduce the turning momentum as soon as possible is always the first priority in harbour maneuvering.

4.3 When the turning to starboard side is stopped, reduce the engine to "Slow Ahead" to take her headway out immediately.

- Maintain the engine RPM "Full Ahead" until the rate of turn to starboardside in 1st hard starboard effect is reduced to Zero for efficient rudder effect.

- After heading coming back to portside from the first "Hard Starboard" turn, reduce Engine RPM immediately as the turning to starboard is stopped and we don't want vessel come back to port side too strongly and/or the speed pick up after heading is steady (KICK ahead).
- Now, vessel's COG is over 090 degrees after "Hard Port " rudder used to stop the turn to Starboard side.
- Our first priority to keep COG more than 090 degrees had reached. Our concern should concentrate on the SOG control.
- Depends on COG return to 090 degrees tendency, if vessel begin the turning to portside with "Hard Port" and "Slow Ahead" is slow we may wait and see how many speed had dropped during this maneuvering "Hard Port" after "Hard Starboard"?
- If vessel begin the turning to portside with "Hard Port" and "Slow Ahead" very quickly, we will need to use "Hard Starboard" immediately to avoid the COG become less than 090 degrees.
- Usually after two Full rudder angle have used the speed will drop quickly by water resistance in 2nd stage of turn.
- Engine RPM should reduce immediately after heading control is gained .
- Wait vessel reduce below 5 knots to make full use of Tugboats assistance and Bow thruster to control vessel's side movement and reduce her speed to berth at the same time.

5. The most effective speed reduction stage

is at second stage of rudder cycling where the water resistance will help stopping ahead speed. It is prudent to decide the best practice for ownship in this rudder cycling process by captain experience to get a balance between reduce advance distance to dock and avoid losing control of ownship's heading at the same time.

Once again, all our fear is coming from uncertainties of our maneuvering. If Master had not practice "Rudder Cycling" before he will not have any idea of "how much overshooting she will be now?". Master knows the uncertainty (fear) of rudder cycling is normal unless he had learned or practiced before. Rudder cycling use "hard over" rudders in turn to reduce speed but may lost control of turning at the same time because vessel has lost speed at the same time which means no rudder effect.

Our situation awareness in rudder cycling is not only the degrees of course had changed or ship speed had reduced but also the environment factors which may affect ownship 's maneuvering. Which side is the upwind/stream side and turning quickly? Is the lee side rudder had more effect to turn and more hard to stop? Is the time to check the yaw of Portside need to be earlier than Starboard side?

Our attention on these details is cultivated from the learning experiences now: time/distance, rudder angle required, weather side, water depth, wind force changed, COG required direction, stern swing out distance, drift angle, rudder cycling all will affect ownship's response to our intention or our intuition in the future.