Concepts associated with execution of large alteration of courses for larger vessels in Confined waters or in Harbour limits.

Alteration of courses has much significance during manoeuvring of ships anywhere in the world. Alteration of courses in open water is a minor or routine job by the navigator out at open seas. But execution of a perfect alteration of course in confined waters in proximity to navigational hazards is critical task. Though it is a routine and regular job for the pilots and seasoned ship handlers, the stakes involved during the process is very high - thus makes it a critical task to be carried out. The pilots usually carry out critical and large alterations of courses almost by the feel of the relative positioning of the vessel with the help of their highly alert senses and commendable reflexes!!! There is an appreciable processing of information happening in the feedback mechanism running across the minds of the pilots. Yet there is a certain degree of uncertainty always lies in the mind while executing large alteration of ships in confined waters especially in harbour limits.

During this process there may be some misinformation or mis-processing of information. This is very much on the cards. This causes the misplaced execution of the alteration of courses. As long as this misplaced alteration is within the tolerance limits of safety margin, the potential accidents are avoided. But when degree of misplace exceeds the safety margin, there occurs accidents - accidents with heavy claims of millions of dollars.

Alteration of course of a vessel in restricted waters with abundant navigational hazards in proximity is an art as well as a science. Its science because the handler needs to understand the existing forces and calculate their effect and at the same time apply correction in such a way that the alteration is smooth without any overshoot or landing in danger. It's a science as the understanding of the various forces acting on the vessel and best use of them is necessary to carry out a perfect turn. It's an art as it is perfected with experience to carry out a large and tight but smooth alteration of course without any stress on the vessel while avoiding the navigational hazards in proximity.

When a vessel alters her course while turning, there are various forces that act on the vessel to cause her to turn. To understand the dynamics of the turning the ship, we have to understand the following:

a. Relation between ROT and Speed
b. Paths traversed by bow, stern and pivot point
c. Relation between Heading and COG
d. Lateral Traverse (Xr & Xm) of the stern due to Inertia of rest and motion
e. References to be monitored during turning

a. Relation between ROT and Speed

In restricted waters or in harbours, the navigator has to follow a designed turning path. There is not much room to deviate from the designed path. The designated path is proximate to shallows and dangers. There is always a risk of running on to danger of getting aground and or collision.

For execution of a good turn in restricted waters, vessel has to keep right speed in proportion the right ROT.

Let's assume,

r = Radius of the turn,

V = Speed in m/s

@ = Turn Angle,

t = Time taken to complete the turn,

d = Distance travelled on a circular path

ROT = Rate of turn of vessel in degrees / second

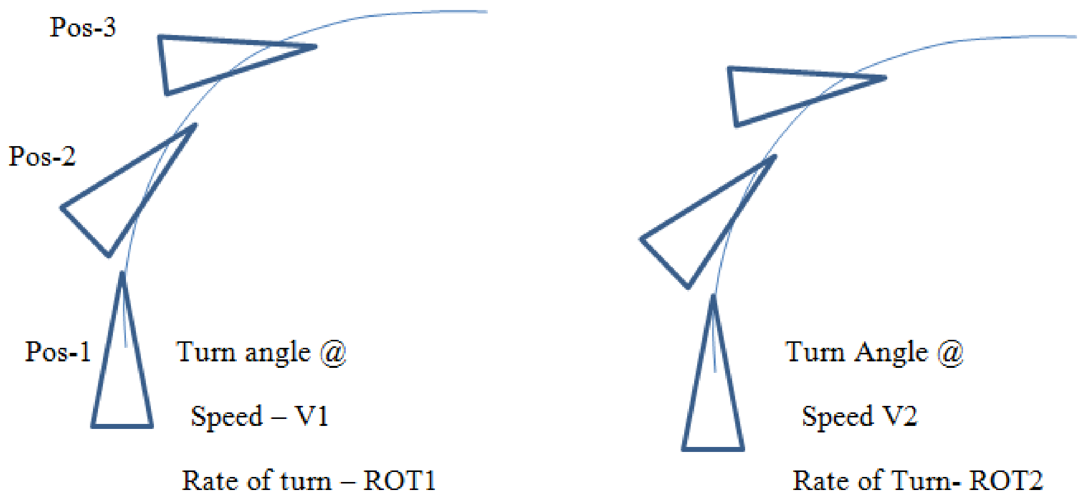
w= Distance from wheel over point to the point where vessel actually starts turning

Thus, ROT= @/t V= d/t, ➔ V/d = ROT/@ ➔ ROT= V@/d

Also, d=r@ ➔ ROT = @/t= d/r*t = V/r ➔ ROT=V/r

From above linear equations it is clear that the ROT is directly proportional to speed of vessel, V

If Vessel making a speed of V has to turn a angle of @ at a Rate of Turn - ROT, ROT has to be directly proportional to speed V. If a vessel is making more speed, her rate of turn has to be more and the vice versa.



When vessel moves from position-1 to position -2 the distance covered and angle turned by the vessel are the same in both the diagram. But the speed in one diagram is V1 and another is V2. So the ROT in one diagram should be different from other one.

V1 /V2 = ROT1 / ROT2 ➔ ROT2 = (V2/V1)*ROT1

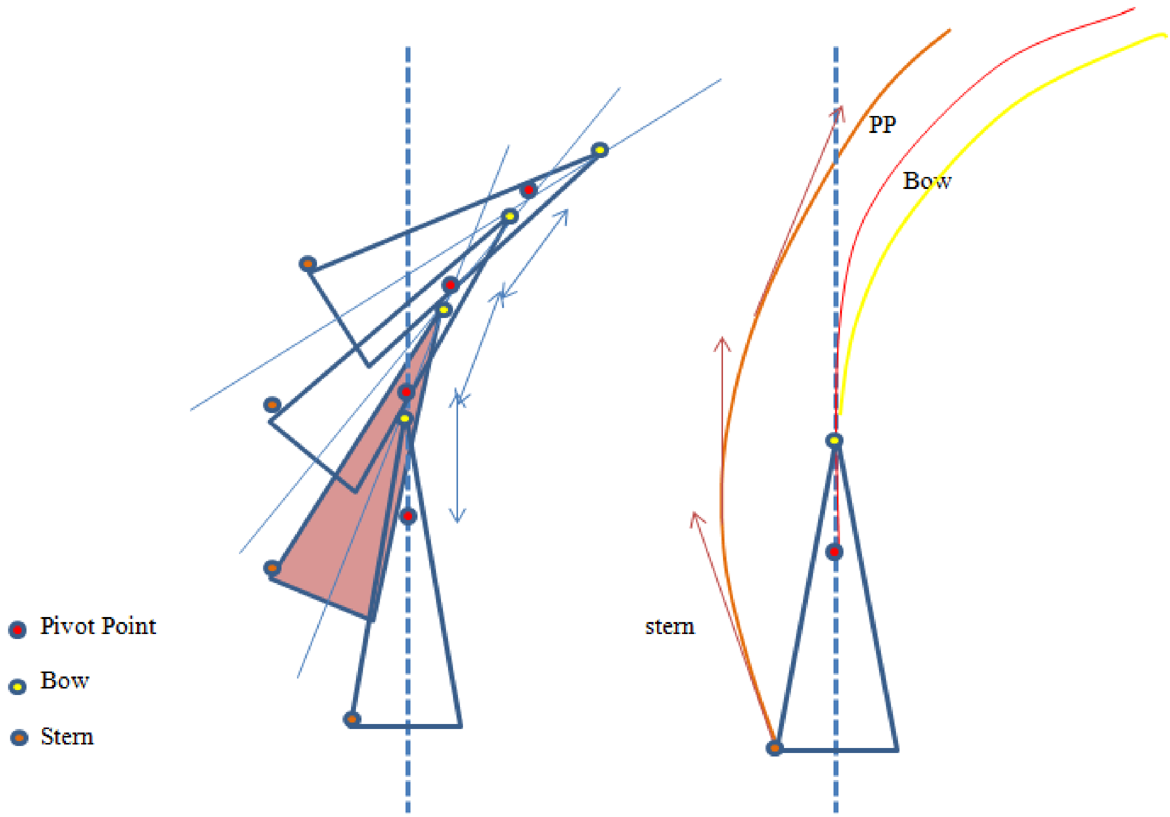
Thus to make a particular turning path, the ship handler has to adjust her speed and ROT accordingly to get a designated turning path. If the vessel is making a lesser speed the rate of turn (or Swing) has to be slower and if the sped is more the rate of turn has to be higher for the vessel to follow the planned path.

b. Paths traversed by Bow, Stern and Pivot Point

While vessel is making a turn in open waters with abundant sea-room, the paths traverse by the bow stern and pivot point matters a little to the ship handlers. But when the sea room is very less, in a range of few metres, it is very important to understand the difference in the paths traversed by bow, stern and pivot point.

At the beginning of the turn, the path of the stern is of much interest to the handler as the stern moves away from the path towards the probable danger at the stern. Bow is supposed to be in safe waters as the bow is turning towards the new course of the vessel.

However towards the end the alteration, the path of the bow is important as the bow would move away from the new course once she overshoots the course. The stern is still coming and yet to come to the new course.



Regarding the paths traversed by the Stern, PP and Bow, the following observations are clear from above diagram:

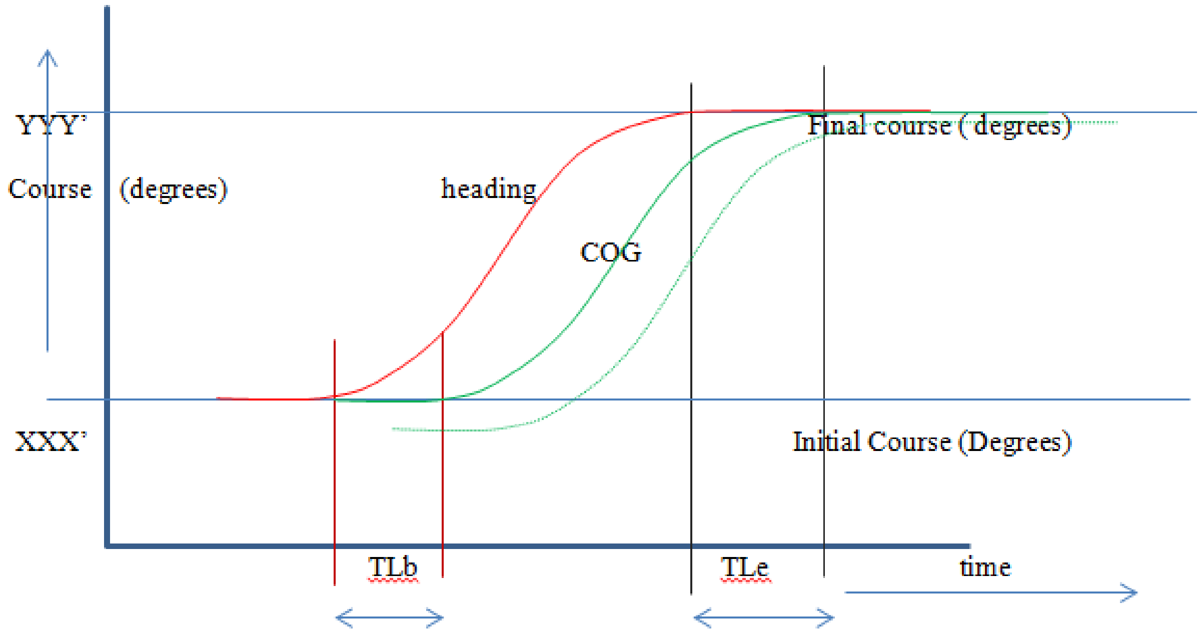
1. The stern starts moving away from the original path in opposite direction of the alteration of course for some time and then the stern starts moving in the direction of alteration.
2. PP keeps on moving on the same course for some time till the time the inertia of rest is overcome by the PP in her original course. After the inertia of the rest is overcome, the PP starts moving in the direction of alteration on a circular locus.
3. The bow immediately starts moving in the direction of the alteration away from the original course.

This helps the ship handler in minding where the bow or the stern exactly be landing while altering the course in a restricted waters. This helps the ship handler in preventing the bow or stern to come closer to any navigational hazard in proximity.

c. Relation between Heading and COG

Once the vessel gives wheel over to any side she starts turning to that side after the vessel overcomes her inertia of rest on her original course. There is a time and distance lag before she actually starts turning after wheel over is given. As the vessel starts turning, the heading starts changing as well as the COG (Course Over Ground); but the heading changes earlier than the COG. There is a time and angular lag between the Heading and the COG.

At the beginning of the turn as the vessel's heading starts turning to one side while the COG remains same as before and doesn't change right away. After some time the COG also starts turning to the same side. Let's assume, the time lag between the turning of heading and turning of COG is TLb. Similarly when the vessel's heading completes the turn and comes to new course the vessel's COG is still not settled down in the new course. At that time the COG is still changing towards the heading. Assume that the time lag between the settling of final heading and COG is TLe.



XXX' : Initial course

YYY': Final Course

TLb : Time Lag between Hdg & COG at the beginning of the turn

TLe : Time Lag between Hdg & COG at the end of alteration of Course

It is to be noted that TLb & TLe may not be the same.

What is the significance of TLb & TLe?

At the time of alteration when wheel over is given to one side, the stern moves in opposite direction from the original path. As vessel keeps on turning to one side the stern keeps moving onto opposite side. The **lateral traverse of the stern due to inertia of rest (Xr)** of the vessel keeps on increasing during the TLb till it reaches maximum. This happens due to "inertia of rest". As soon as the COG starts turning towards the heading the lateral traverse of the stern starts reducing from the maximum.

If there is ample sea room on the stern there is no issues. But if the stern-room is restricted, then the lateral traverse of the stern could cause it to touch the ground or smelling the ground. It could complicate the alteration process. This is critical while altering in the channel. If the white margin of the channel is less than the "maximum lateral traverse" of the stern, then there is risk of the stern being grounded or damage to the buoys if at the stern.

During the alteration of course, there is a continuous lag between the Heading and COG of the vessel.

Towards the end of alteration of course, once the vessel reaches her final course, there is still a lag exists between the heading and the COG. The stern still moves away from the settled new course of the vessel due to the "inertia of motion" away from the newly attained course. The stern keeps on moving from the new course within the period of TLe till it reaches maximum. This is **"lateral traverse of the stern due to inertia of Motion"(Xm)**. This would land the stern off the centre line of the course. If there is not much sea room available at the stern on the opposite side of the turn, this could cause a significant disaster if not controlled properly. **The classic example of a disaster due to this is the accident of container vessel M.V. Milano Bridge in the Port of Busan in Apr 2020.**

This "lateral traverse of the stern due to inertia of motion **(Xm**) during TLe is dangerous and pose serious threat to the vessel and environment in restricted waters, channels and harbours. This is due to following reasons:

1. The inertia of motion for large and loaded vessels is very high. This is even higher when moving at a higher speed. To control this inertia of motion possibly the handler may reduce speed in advance for loaded or larger vessels.
2. The time period of TLe is relatively unknown to the handler. The time period may be longer or shorter varies from vessel to vessel. During this period there is a degree of uncertainty in the position of the vessel as it continuously keeps on changing.
3. If there is effect of weather exists at the time of alteration, the amount of set generated by the external force e.g. current or wind etc. is unknown to the handler in the final course of the vessel. Though the direction of wind remains same relatively, the current may be different in the new course. And with the changed course, the relative direction and strength of the combined external forces with respect to the heading of the vessel would be quite different. Thus the amount of set is unknown to the handler. Though the pilot handles the vessels regularly and they can expect the amount of set on a new course. This varies with time in a diurnal range, month of the year, local disturbances in the weather system, strength and direction of tidal stream. There is a certain degree of uncertainty in this regard.
4. This set so generated due to external forces adds up the "lateral traverse of the stern due to inertia of motion" would cause a great amount of uncertainty on the positioning of the vessel in the new course.
5. The time to give correction is also very critical. If not acted swiftly vessel will land upon danger.

Due to above reasons it is very important to understand and take corrective action for this so as to keep the vessel in safe waters all the time during large alteration of courses in restricted waters.

Corrective action to Lateral traverse of Stern (Xm)

Corrective action involves 3 issues – displacement of vessel, speed of vessel and existing external forces causing set and/or leeway.

1. Handler can do nothing about the Displacement of vessel. Looking at the displacement of vessel handler may decide on what speed to keep during the alteration and ask for additional assistance of tug if necessary.
2. Speed is critical. Maintaining an optimum speed is the key. For high displacement vessels, it is preferable to reduce the speed in advance so that the inertia of motion would be lesser. For lighter vessel handler may choose to keep higher speed.
3. Regarding the existing weather creating set and/ or leeway, it is advisable to keep the heading towards the weather so that there is a little safe margin on the lee side of vessel during the period of uncertainty of TLe. If not heading to the weather side and there is no safe margin on lee side, if the set is more than expected and by the time handler realises it and vessel is drifted few metres onto the lee side. If not, she will be drawn to the edge of the channel and face consequent hazards.

   Even after the alteration, it advisable to alter few more degrees (+Cz') towards the altering side before she settles on the final new heading. This may be called as "Corrective Angle". This is +ve if altering to stbd side and –ve if altering to port side on the 3 digit notation of the course. Then give wheel hard over on opposite side so as to break the inertia of motion of the stern away from the new course. This would cause the COG to settle down quickly on the finally desired COG.

   The Cz' should further be increased or decreased depending of the direction of weather and consequent set of the vessel. This additional correction +/-Wz may be called as the "Weather correction". This is the resultant of the effects due to current, leeway and Tidal stream on the vessel

   Thus the final corrective angle may be called as **Weather Corrective Angle** (wCz')
   wCz = Cz +/- Wz

   Final heading = final charted course +/- wCz (+ for stbd side, - for port side)

Green dotted line in the above diagram of graph shows the path of COG if there is a current or weather exists on stbd side and vessel is having a set to port side. After alteration of course the set may not be the same as before alteration of course.

d. Lateral Drift of the Stern and the Bow while turning

When vessel is turning, though the heading of the vessel keeps on changing the COG of the vessel doesn't change appreciably till she settle on a new heading. Once she settles on a new heading her COG changes gradually and settles down near the heading with applicable set.

As the PP lies about $1/5^{th}$ of L from the bow, when a vessel turns to any side her stern moves in the opposite direction of the turn substantially and bow onto the direction of the turn lesser than the stern.

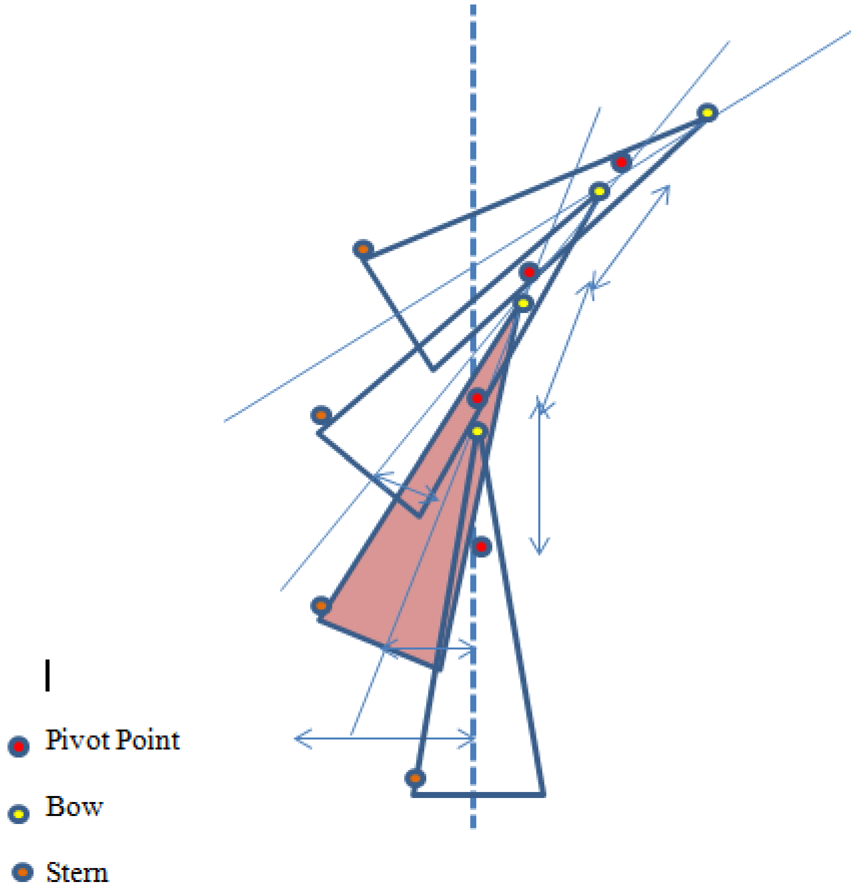
Let's examine how the bow and the stern moves from their original positions in the following diagram

For small alteration of course,

Lateral movement of stern = K+B/2 + (4/5)L tan@

Let's say,

ROT = r, Speed = v, Turn Angle =@ in the time period of TLb , Time taken = t (TLb), Distance travelled= d



At position P-1,

Lateral movement of stern = - (K+B/2 + (4/5)L tan@)

Lateral movement of Pivot Point = 0

Lateral movement of bow = + (B/2 + (1/5)L tan@)

At position P-2,

Lateral movement of stern = ((2L/3)- Xsec2@) tan2@ =

Lateral cross track of the pivot point, X = + d * tan@ → x"= (d+Xsec2@) tan2@

Lateral movement of bow = X + (B/2 + L tan2@)/3) = (L/3+ X sec2@) tan2@

Thus lateral movement of the stern follows function as below:

4L/5 * tan@

4L/5* tan 2@ - d*tan@*sec2@* tan2@

4L/5* tan3@ - (d+Xsec2@) tan2@*sec3@*tan3@

Above function shows that as soon as the PP starts moving on the circular path, the lateral traverse of the stern starts reducing after reaching the maximum value of 4L/5* tan@, where @ is the change in the heading of the vessel time lag at the beginning of the turn (TLb).

e. References while making tight turns

The most important tangible objective of the pilot is to keep vessel's position in safe depths so as to keep her always afloat at any given point of time during pilotage. The pilot mostly is aware and confident on the vessel's position except during alteration of course until she settles down on a new course.

While vessel alters her course, there is relative degree of uncertainty in the position of the vessel in the perception of the navigator as position continuously keeps on changing during the process. The navigator needs to actively observe vessel's change in position, rate of change of position as well as the position itself.

During this uncertainty, it is the physical references that come to the rescue of the ship handler. The ship handler should find 2 fixed land objects to understand the relative change in position and the rate of change position. The motion of the fixed land objects relative to one another shows clearly the change in position and rate of change in position.

Execution of Large but Unaided Alteration of Courses in Limited Sea rooms

Execution of large alteration of courses in limited and highly restricted sea rooms is as tricky as dangerous. The stakes are very high when executing a large alteration of course particularly in harbour limits or in close proximity to hazards of navigation or harbour structures. Many accidents has been recorded over history and in recent past also caused due to wrongly executed alterations of course.

All the concepts related to execution of turns have been discussed earlier in the chapter. Let's now see how to execute large unaided alterations of course safely and comfortably.

1. Large alteration with restricted sea room

When a large alteration of course is to be made in highly restricted waters, it may be executed in several smaller parts looking at the physical references. Though the alteration is a continuous process, it can be checked by the pilot with the physical references whether the alteration is going smoothly within the tolerable limits. If something is going beyond the limits, corrections may be given to control the alteration in tolerable limits.

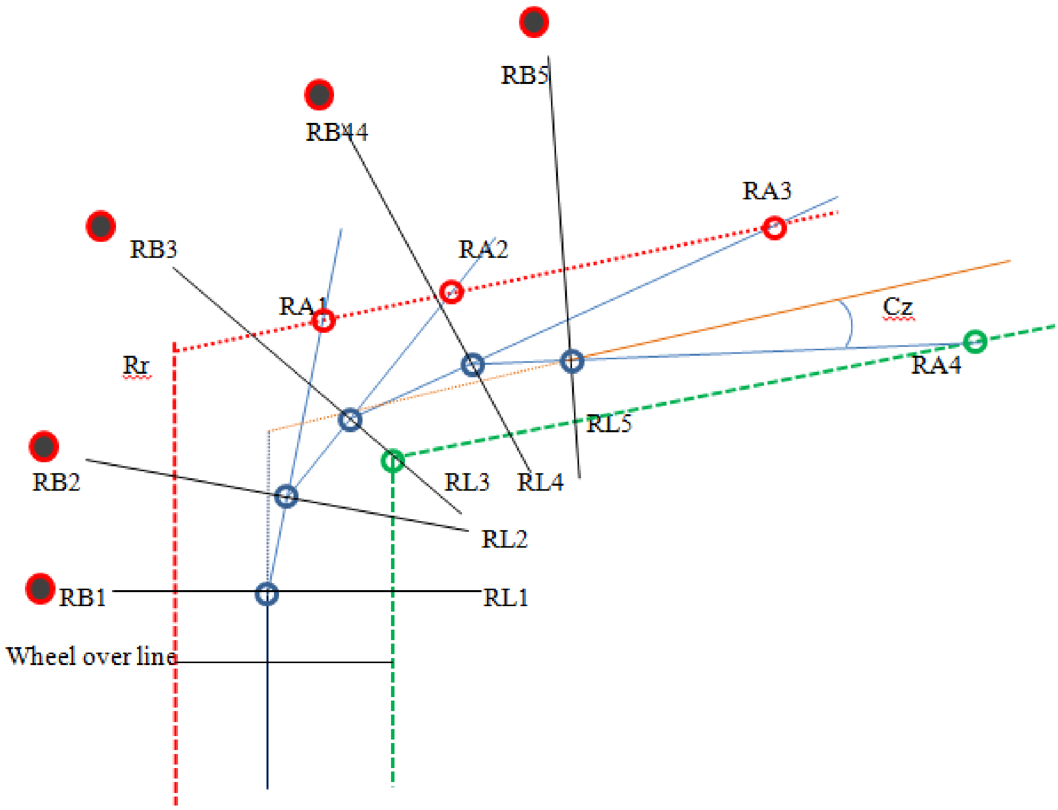
As shown in the figure below, the course is divided to 4 legs reference lines – RL1, RL2, RL3, and RL4. Their corresponding ahead reference points are RA1, RA2, RA3, and RA4. RL5 is the reference line at which the vessel already settled on her new course.

Thus while alteration of course the pilot need to check that when passing any fixed point on the reference line RL1, she should head towards Reference point ahead-RA1. The vessel keeps on swinging to starboard side under helm till she passes any fixed object along RL2. While passing RL2 vessel should head towards reference point RA2. Similarly the alteration would proceed till end.

There is no hard and fast rule on the dividing the course to how many parts. This may depend on following:

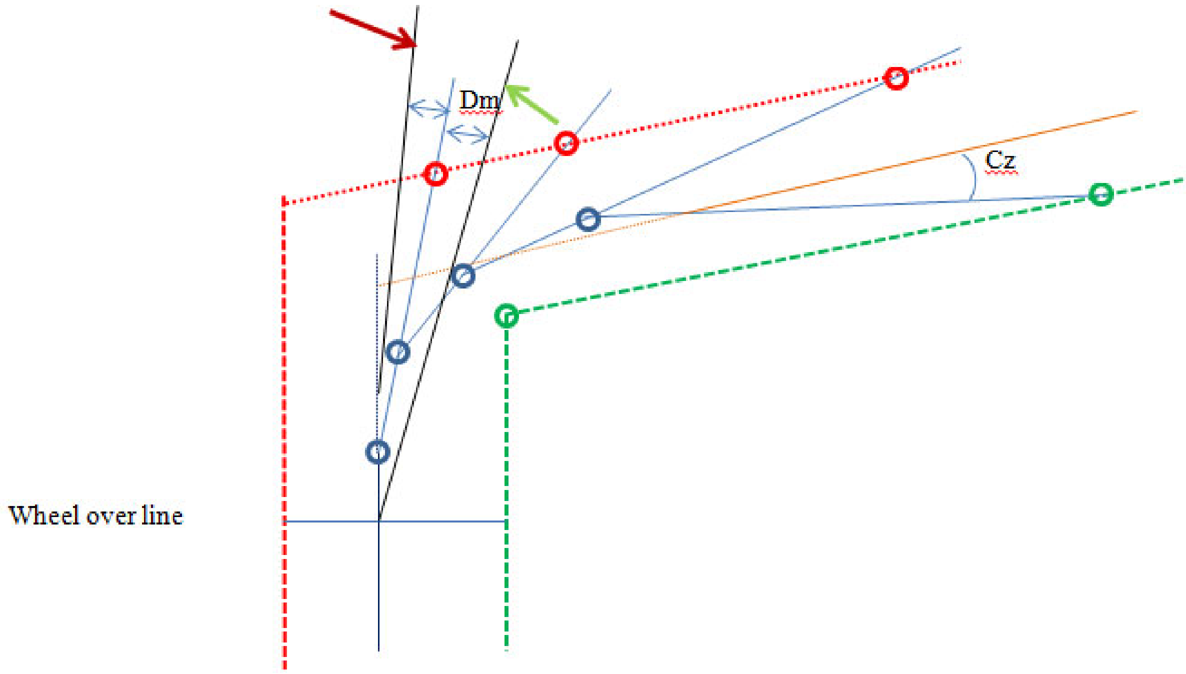
1. Number of available fixed reference points on the bow and corresponding reference points on the beam of the vessel.
2. Should not be in large numbers that it is difficult for the pilot to monitor them
3. Ideally 3-4 numbers depending on amount of alteration.

At any point if it is felt by the pilot that while passing a fixed land object at reference line RL, the corresponding reference pilot on the bow is not reached, then he may increase the swing (ROT) to catch the next reference point on time. Similarly at any time if it is felt that the bow reference point (RA) is overshoot while passing the corresponding reference line (RL), then the swing (ROT) of the vessel would be reduced to accordingly.



2. Large alteration with restricted sea room under External force

Similarly when there exists some external force like wind or current to cause set and drift or leeway on the vessel, the alteration of the course may be carried out little early or late depending on the direction of the set.



In the figure given above, if the from stbd side (green), then the course should be altered early so that while passing reference line RL1, the corresponding reference object on bow is already passed on to her port bow. Similarly the alterations would be executed further while passing subsequent RL.

If the Force is from port side (Red), then the course should be altered little late so that while passing reference line RL1, the corresponding reference object on bow is not yet crossed, thus be visible on her stbd bow. Similarly the alterations would be executed further while passing subsequent RL.

This ensures the vessel has a margin of safety due to drift (Dm) at the beginning of alteration. Same maintained regularly. At any time if this Dm becomes excess or reduced due to unpredictable wind or current, it must be corrected in the next RL.

Conclusion

As pilots execute large alterations of fairly larger vessels within harbour limits at appreciable speed the momentum of vessel involved is fairly large. If not properly executed alterations within very narrow sea room, the potential risks to the vessel as well as the harbour infrastructures are very high. Such improper alterations would damage the vessel as well as the port infrastructure with loss amounting to millions of dollars. Off late it has been observed that many accidents are happening while such alterations of couse in harbour limits. Thus it is advisable the ship handlers and pilots must understand the theory behind the alteration of courses in harbour limits. I hope this would help them in execution of alterations with much ease and confidence with reduced risks to the property and life on board!