CALCULATING WHEEL-OVER POINT

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The article consists of two parts. The first one presents a ship turning method in restricted waters that based on calculating the wheel-over point. The second part presents the method of ship's turning in shallow waters that taking into account the increasing radius of turning due to increase of resistance of water and large water masses.

Keywords: ship, turning, radius of circulation, wheel-over point, turning radius, shallow waters, restricted water maneuvers.

For safety sailing it is necessary for any vessel to take into account her ability to turn in restricted areas. A vessel cannot make a turning immediately and at one point. The simplest method is the method when the arc between a new course and an old one is drawn by a turning radius.

Entering point A_0 and pull out point B_0 of a turning circle are the points of an arc contact with previous and new courses (see Figure 1.1). But actually if a vessel begins starting a wheel-over at point A_0 she reaches a new course in point B_1 only.

For big-sized vessels distance B_0B_1 can reach a considerable value. This mistake can be worse if a vessel has a "dead interval" when ratio B_0B_1/RTR (TR – turning radius) becomes more than a unit. Besides, within the opening period a vessel has a shift from her initial course to the side opposite to the turning. But usually, this value is not more than some tens of meters. However, due to drifting the extreme aft point of a vessel with an extended hull deviates to a distance A_0A_0' which becomes commensurable with a fairway breadth. Therefore, safe maneuvering

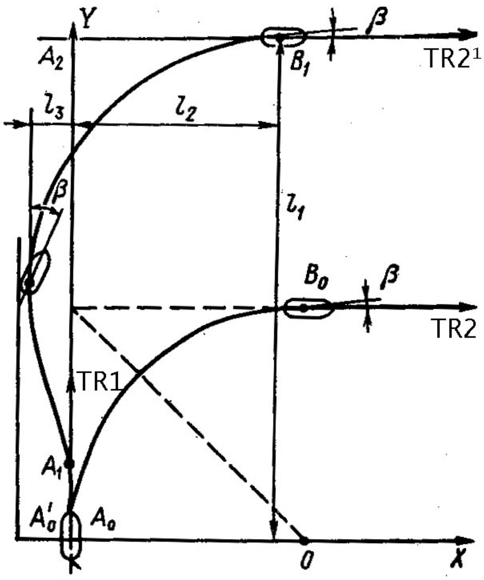

Fig. 1.1. Calculated and real circle

of big tonnage vessels in restricted areas can be obtained provided a seafarer has got full information about ship's ability to make a turn. A new method has been offered to find a wheel-over point while performing a turning circle through deep water. This method is based on using tangent to a turning circle trajectory.

Every vessel has the table of maneuvering characteristics for performing turning circles in deep water with 35, 20 and 10 degrees rudder position. Turning circles are drawn so, that point A_0 is the point of starting wheel-over. Figure 1.3 shows plotted TR1 (track 1) and TR2 (track 2) both of which cross at point C. Then a turning angle must be defined as the difference between TR1 and TR2 and marked as ΔTR.

Figure 1.2 shows the tangent drawn to the trajectory with a 20 degrees rudder position. Point C is the intercept of the tangent with the line of the ship's initial track which is measured in cables. Thus value A_0C is the advance whilst turning at angle ΔTR with a 20 degrees rudder angle.

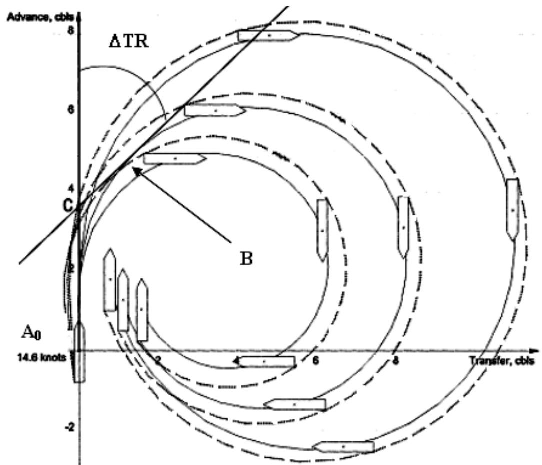

Fig. 1.2. Deep water turning circle with 35°, 20°, 10° wheel position

To find a starting wheel-over point on the TR1 (Figure 1.3) it is necessary to measure A_0C

(Figure 1.2) and to put the same value relevant to the chart scale on the TR1 (Figure 1.3) from the point C in opposite direction. The end of this segment is marked as point A_0 which is the starting wheel-over point. Thus wheel-over point A_0 is found through the turning circle which belongs to this vessel only.

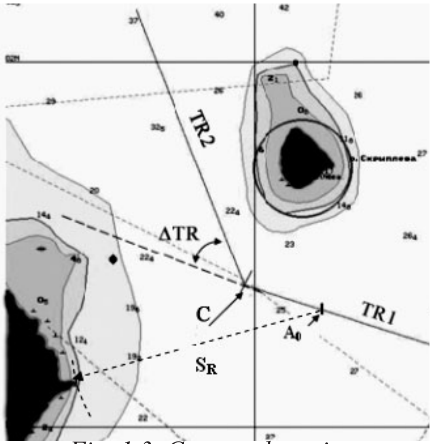

Fig. 1.3. Course alteration and wheel-over

To change position of a rudder angle to perform a turning it is necessary to draw the tangent to any of the three trajectories. The value A_0C will change the chosen trajectory. Accordingly, point A_0 will change its position on the TR1.

Suitable visual bearing or radar distance should be drawn toward point A0 to determine a moment when a vessel is in the wheel-over position.

Any trajectory of a turning is a moving vessel's center of gravity Figure 4 shows the vessel heading to the upper point of the trajectory which has value of 90 degrees plus β (angle drift). This trajectory is performed with the rudder in unchanged position all the time.

In realty at point A_0 rudder is put over at an indicated angle. At first a vessel begins moving according to the trajectory. Then at an appointed moment the rudder angle is reduced to an indicated value. The turning speed slowly begins to reduce and turning radius slowly to increase. The trajectory starts to change growing up.

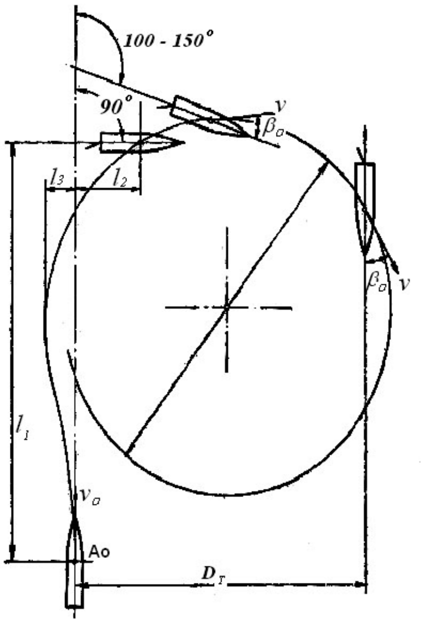

Fig.1.4. Vessel heading during turning

At the next appointed by a seafarer moment value of the rudder angle is changed in position straight or the turning has to be met the helm which in this case has position with the rudder angle to the side opposite to the turning. At this time turning speed quickly reduces and turning radius sharply increases. And at a moment when she begins proceeding her course turning radius grows up to for ever and ever.

To value the accuracy of a turning circle on a new course by a tangent method the mathematical model of the bulk carrier with next data is taken:

Displacement	33089 t
LOA in full load	182.9 m
LBP in full load	173.9 m
Breadth	22.6 m
Draft (bow)	10.1 m
Draft (stern)	10.7 m
Draft middle in full loaded	10.4 m

As an example the turns with the rudder in position starboard 20 degrees are examined. At first the turning circle is fulfilled. Turning data are written with the interval of five degrees. After that the turning circle is drawn.

A turning angle is decomposed and each of components answers its angle rudder position only. In general case ΔTR will be presented in form of

$$\Delta TR = \Delta TR1 + \Delta TR2 + \Delta TR3 + \Delta TR4$$

where ΔTR – turning angle

ΔTR1 – turning angle with the rudder in position 20 degrees

ΔTR2 – turning angle with the rudder in position 10 degrees

ΔTR3 – turning angle with the rudder in position straight

ΔTR4 – turning angle with the rudder in position 5 degrees to the side opposite to the turning.

Any turning angle ΔTR is calculated for turning trajectory with the rudder in position 20 degrees. Therefore all tangents are drawn to this trajectory. The turnings are fulfilled from 20 to 90 degrees at intervals of ten degrees.

To fulfilled turning at the appointed angle the rudder changes must be the following (see Table 1.1 at the end of the first part of the article):

1. a) If value of ΔTR is from 20 to 60 degrees the rudder has to be in position 20 degrees for ½ΔTR or this angle value answers value ΔTR1 and which is written in the first column.

b) If value of ΔTR is from 60 to 90 degrees the rudder has to be in position 20 degrees for ⅔ΔTR or this angle value answers value ΔTR1 and which is written in the first column.

2. On achievement of a turning with value of ΔTR1 the moment to start to change position of a rudder angle from 20 to 10 degrees the same board. The mathematical model continues turning until value which is 100 less than turning angle. At this time angle value is equal ΔTR1+ΔTR2 and is written in the third column.

3. a) When the turning reaches value ΔTR1+ΔTR2 and value of turning angle is 10 degrees less than set angle the rudder is changed in position straight. The mathematical model goes on turning before angle reaches appointed value. At this moment turning angle value is equal ΔTR1+ΔTR2+ΔTR3=ΔTR and is written in the fourth column.

b) When the turning reaches value ΔTR1+ΔTR2 and value of turning angle is 10 degrees less than set angle the rudder is changed in position straight. The mathematical model goes on turning before angle reaches value which is 5 degrees less appointed angle. At this moment turning angle value is equal ΔTR1+ΔTR2+ΔTR3 and is written in the fourth column.

4. a) When the turning angle reaches value ΔTR1+ΔTR2+ΔTR3 and value of turning angle is 5 degrees less than set angle the rudder is changed in position 5 degrees to the side opposite to the turning. The mathematical model goes on turning before angle reaches appointed angle value or turning speed is around zero. At this moment turning angle value is equal ΔTR1+ΔTR2+ΔTR3+ΔTR4=ΔTR and it is written in the fifth column.

b) When the turning angle reaches value ΔTR1+ΔTR2 and value of turning angle is 10 degrees less than set angle the rudder is changed in position 5 degrees to the side opposite to the turning. The mathematical model goes on turning before angle reaches appointed angle value or turning speed is around zero. At this moment turning angle value is equal ΔTR1+ΔTR2+ΔTR4=ΔTR and it is written in the fifth column. The movement parameters are written at each moment changing of the rudder position.

The turning angles are examined from 20 to 90 degrees at intervals in 10 degrees. The tangents are drawn for each turning angle.

A final turning angle is realized in three variants with different position of the rudder, therefore three turnings are made for each angle, three trajectories are drawn and three values are written in the Table 1.1 as a distance of each track between final turning point and the tan-gent.

Then to value the accuracy of turning on a new course by a tangent method the ma-thematical model of the tanker with next data is taken:

Displacement	77100 t
LOA in full load	242.8 m
LBP in full load	228.0 m
Breadth	32.2 m
Draft (bow)	12.5 m
Draft (stern)	12.5 m

At first the operations are fulfilled the same as for previous model. A turning angle is discomposed and each of components answers its angle rudder position only. In general case ΔTR will be presented in form of

$$\Delta TR = \Delta TR1 + \Delta TR2 + \Delta TR3 + \Delta TR4\ ,$$

where

ΔTR, ΔTR1, ΔTR2 − same as for previous model;

ΔTR3 – turning angle with the rudder in position 10 degrees to the side opposite to the turning;

ΔTR4 – turning angle with the rudder in position 15 degrees to the side opposite to the turning.

Then operations are fulfilled the same as for previous model with the exception that a final turning angle is realized in two variants and all data are written in the Table 1.2 (see at the end of the first part of the article).

Then to value the accuracy of turning on a new course by a tangent method the ma-thematical model of the RO-RO with next data is taken:

Displacement	25400 t
LOA in full load	184,2 m
LBP in full load	174,0 m
Breadth	30,6 m
Draft (bow)	8,2 m
Draft (stern)	8,2 m

Then all operations are fulfilled the same as for previous model of the tanker with the exception that all data are written in the Table 1.3 (see at the end of the first part of the article).

These way three mathematical models are taken to value the accuracy of a turning on a new course by tangent method. It is necessary to take notice that the final turning part differs from each other by the angle of rudder position. It is a necessity for this to stop turning speed.

All vessels are fulfilled turnings with different position of the rudder at final part. Part-ly turning speed reduced to zero when a vessel did not reach appointed course and data was written in a table. In others cases a vessel reached appointed course although she had some turning speed but data was written. But if this turning was continued angle value did not reach more than 3,5 degrees above appointed when the turning speed was zero. In this case a vessel had to return to her course and distance did not increase between a vessel and tangent. The values of whole distance are written in the Table 1.4 (see at the end of the first part of the article).

Table 1.1. Change of moving parameters mathematic model bulk carrier for turning

ΔTR	ΔTR1			ΔTR1+ΔTR2			ΔTR1+ΔTR2+ΔTR3			ΔTR1+ΔTR2+ΔTR3+ΔTR4			Point to trajectory distance	Point of contact with trajectory
	Change course, deg.	Linear speed, kt	Rotation speed, deg/min	Change course, deg.	Linear speed, kt	Rotation speed, deg/min	Change course, deg.	Linear speed, kt	Rotation speed, deg/min	Change course, deg.	Linear speed, kt	Rotation speed, deg/min		
20°	10.2	10.10	28.4	--	--	--	20.2	9.70	13.7	--	--	--	-3.0	32.7°
	10.6	09.99	28.7	--	--	--	15.3	9.82	18.5	20.1	9.72	6.8	2.0	
	10.6	09.99	28.7	--	--	--	--	--	--	20.0	9.74	4.1	4.0	
30°	15.6	09.76	30.9	20.4	9.56	26.1	30.3	10.31	13.9	--	--	--	-4.0	44.5°
	15.1	09.76	30.8	20.3	9.56	25.7	25.1	9.41	17.3	30.0	9.35	8.2	2.0	
	15.6	09.76	30.9	20.3	9.56	25.9	--	--	--	30.0	9.41	6.0	3.8	
40°	20.3	09.52	31.7	30.1	9.14	24.4	40.2	8.98	13.4	--	--	--	3.0	52.5°
	20.3	09.52	31.7	30.1	9.14	24.4	35.1	9.00	16.7	40.0	8.02	7.7	2.0	
	20.3	09.52	31.7	30.1	9.14	24.4	--	--	--	40.0	9.12	4.7	5.0	
50°	25.1	09.29	31.7	40.0	8.77	23.5	50.4	8.73	12.6	--	--	--	5.0	63.5°
	25.1	09.29	31.7	40.5	8.76	23.5	45.0	8.67	16.3	50.1	8.77	6.8	8.0	
	25.6	09.27	31.7	40.2	8.75	23.6	--	--	--	50.0	8.91	2.2	16.0	
60°	30.4	09.04	31.3	51.2	8.46	22.7	60.2	8.48	12.6	--	--	--	8.0	73.0°
	30.4	09.04	31.3	50.4	8.46	22.8	55.3o	8.44	15.2	60.0	8.59	5.8	8.0	
	30.4	00.04	31.3	50.1	8.48	22.8	--	--	--	59.6	8.86	-0.1	12.0	
70°	47.7	08.32	29.9	60.3	8.05	22.5	70.0o	8.20	10.8	--	--	--	10.0	83.5°
	47.7	08.32	29.9	60.3	8.05	22.5	65.0	8.05	14.5	70.0	8.32	4.8	13.0	
	47.7	08.32	29.9	60.3	8.05	22.5	--	--	--	69.5	8.59	-0.1	20.0	
80°	53.1	08.13	29.5	70.4	7.85	22.0	80.0	8.07	11.6	--	--	--	11.0	93.0°
	53.6	08.11	29.5	70.2	7.85	22.0	75.1	7.89	14.4	80.0	8.26	3.6	16.0	
	54.4	08.09	29.5	70.1	7.85	22.0	--	--	--	78.9	8.48	-0.1	24.0	
90°	60.0	07.91	29.2	80.2	7.72	21.6	90.1	7.99	9.7	--	--	--	14.0	102.0°
	60.0	07.91	29.2	80.3	7.72	21.6	85.1	7.78	14.1	90.0	8.20	2.9	20.0	
	60.0	07.91	29.2	80.2	7.72	21.6	--	--	--	88.6	8.33	-0.1	26.0	

Table 1.2. Change of moving parameters mathematic model tanker for turning

ΔK	ΔTR1			ΔTR1+ΔTR2			ΔTR1+ΔTR2+ΔTR3			ΔTR1+ΔTR2+ΔTR3+ΔTR4			Point to trajec-tory distance	Point of contact with trajec-tory
	Change course, deg.	Linear speed, kt	Rotation speed, deg/min	Change course, deg.	Linear speed, kt	Rotation speed, deg/min	Change course, deg.	Linear speed, kt	Rotation speed, deg/min	Change course, deg.	Linear speed, kt	Rotation speed, deg/min		
20°	10.2	13.35	17.4	--	--	--	20.0	13.06	3.2	--	--	--	10.0	31.0°
	10.2	13.35	17.4	--	--	--	--	--	--	18.0	13.80	-0.1	10.0	
30°	15.2	13.12	19.8	20.0	12.91	18.2	30.0	12.63	5.7	--	--	--	08.0	40.5°
	15.2	13.12	19.8	20.0	12.91	18.2	--	--	--	28.5	12.69	-0.1	18.0	
40°	20.0	12.89	21.2	30.0	12.42	18.6	40.0	12.21	7.0	--	--	--	08.0	51.0°
	20.0	12.89	21.2	30.0	12.42	18.6	--	--	--	39.3	12.30	-0.1	22.0	
50°	25.1	12.63	22.0	40.0	11.95	18.6	50.0	11.82	6.3	--	--	--	14.0	62.5°
	25.1	12.63	22.0	40.1	11.97	18.6	--	--	--	49.5	11.95	-0.1	28.0	
60°	30.3	12.36	22.5	50.1	11.57	18.4	60.0	11.49	7.1	--	--	--	16.0	71.0°
	30.1	12.36	22.5	50.2	11.55	18.4	--	--	--	59.6	11.64	-0.2	28.0	
70°	46.3	11.53	23.1	60.1	11.02	18.7	70.0	10.98	7.7	--	--	--	16.0	81.0°
	46.3	11.53	23.1	60.1	11.02	18.7	--	--	--	70.0	11.14	2.2	16.0	
80°	53.2	11.22	23.0	70.2	10.67	18.1	80.0	10.73	6.5	--	--	--	16.0	93.0°
	53.6	11.20	23.0	70.0	10.67	18.2	--	--	--	79.6	10.96	0.0	24.0	
90°	60.1	10.90	22.8	80.1	10.36	17.6	90.1	10.57	5.5	--	--	--	20.0	102.0°
	60.3	10.89	22.8	80.0	10.38	17.6	--	--	--	89.2	10.77	-0.2	32.0	

Table 1.3. Change of moving parameters mathematic model RO-RO for turning

ΔK	ΔTR1			ΔTR1+ΔTR2			ΔTR1+ΔTR2+ΔTR3			ΔTR1+ΔTR2+ΔTR3+ΔTR4			Point to trajec-tory distance	Point of contact with trajec-tory
	Change course, deg.	Linear speed, kt	Rotation speed, deg/min	Change course, deg.	Linear speed, kt	Rotation speed, deg/min	Change course, deg.	Linear speed, kt	Rotation speed, deg/min	Change course, deg.	Linear speed, kt	Rotation speed, deg/min		
20°	10.1	12.15	25.7	--	--	--	20.2	11.88	12.6	--	--	--	-2.0	29.0°
	10.1	12.15	25.7	--	--	--	--	--	--	20.1	11.89	8.6	-2.0	
30°	15.2	11.94	29.9	--	--	--	30.1	11.60	8.6	--	--	--	2.0	40.0°
	15.2	11.94	29.9	--	--	--	--	--	--	28.8	11.59	-0.6	4.0	
40°	20.4	11.70	33.0	25.4	11.53	32.2	40.1	11.29	8.6	--	--	--	5.0	51.0°
	20.4	11.70	33.0	25.4	11.53	32.2	--	--	--	38.3	11.29	0.0	8.0	
50°	25.0	11.57	35.0	35.2	11.16	32.7	50.1	10.98	9.4	--	--	--	8.0	60.0°
	25.6	11.57	35.2	35.2	11.14	32.7	--	--	--	49.2	11.00	-0.3	10.0	
60°	30.4	11.27	36.7	45.4	10.79	32.8	60.3	10.69	10.1	--	--	--	7.0	70.0°
	30.4	11.27	36.7	45.4	10.79	32.8	--	--	--	59.5	10.97	-0.8	12.0	
70°	35.4	11.06	37.9	55.6	10.46	32.3	70.0	10.44	10.8	--	--	--	14.0	80.0°
	35.4	11.06	37.9	55.1	10.48	32.4	--	--	--	69.0	10.54	-0.3	16.0	
80°	53.6	10.32	39.6	65.3	9.99	34.5	80.2	9.99	12.1	--	--	--	4.0	92.5°
	53.0	10.34	39.6	65.3	10.01	34.4	--	--	--	80.0	10.09	3.2	9.0	
90°	60.2	10.09	39.5	75.1	9.74	33.2	90.2	9.84	11.7	--	--	--	6.0	102.5°
	60.2	10.09	39.5	75.2	9.72	33.2	--	--	--	90.0	9.91	3.3	6.0	

Table 1.4.

Turning angle	Distance from point when the vessel is on appointed course to the tangent		
	Bulk carrier	Tanker	RO - RO
20°	-3.0		
	2.0	10.0	-2.0
	4.0	10.0	-2.0
30°	-4.0		
	2.0	8.0	2.0
	3.8	18.0	4.0
40°	3.0		
	2.0	8.0	5.0
	5.0	22.0	8.0
50°	5.0		
	8.0	14.0	8.0
	16.0	28.0	10.0
60°	8.0		
	8.0	16.0	7.0
	12.0	28.0	12.0
70°	10.0		
	13.0	16.0	14.0
	20.0	16.0	16.0
80°	11.0		
	16.0	16.0	4.0
	24.0	24.0	9.0
90°	14.0		
	20.0	20.0	6.0
	26.0	32.0	6.0

2. CALCULATING WHEEL-OVER POINT FOR SHALLOW WATER

The shallow water has considerable influence upon increase of a turning circle radius for account:

- Increasing resistance of water.
- Increase of large water masses.

In the circular letter IMO MSC/circ. 1053 adopted on the 5th December 2002 the deep, unrestricted water is determined as next: “The water depth should exceed four times the mean draught of the ship”. Therefore the deep water is water with the depth, which is equal to five and more draughts of the ship.

A new method to calculate a wheel-over point for any shallow water with using turning cir-cle for deep water is suggested.

At first the turning circle for the depth of 52 m (depth equal to 5 draughts of the ship) will be compared with the turning circle for the depth of 120 m (depth equal to 11, 5 draughts of the ship).

The turning circles for each of the above-mentioned depths are fulfilled with the position of the helm from 35 degrees to 10 degrees at intervals of 5 degrees. Then each movement trajectory is drawn.

After that the values of advances are calculated for turning from 20 degrees to 90 degrees at intervals of 10 degrees for both depths of 120 m and 52 m.

The values of the advances are written in the table below as follows:

- For each rudder position two turning circles (for depth 120 m and for depth 52 m) are made.
- For each turning angle two values of the advances (for depth 120 m and for depth 52 m) are written.
- Difference is found between two advances which are made for various depths but with the same rudder angle position and the angle of turning.

48 comparisons are received and only five of them exceed 0.05 cbl (9.1 m). The largest dif-ference reaches 0.09 cbl (16.38 m).

Received comparisons show that turning circles made at the depth of five draughts are the same as one made and it is possible to consider these depths as deep water. Therefore the depths will be accepted as

Table 2.1. Difference of advances in cables at depths of 120 m and 52 m for various positions of rudder and angle turning

Angle of turning	Rudder 35°			Rudder 30°			Rudder 25°			Rudder 20°			Rudder 15°			Rudder 10°		
	Advances at depth 120 m, cbl	Advances at depth 52 m, cbl	Difference advances, cbl	Advances at depth 120 m, cbl	Advances at depth 52 m, cbl	Difference advances, cbl	Advances at depth 120 m, cbl	Advances at depth 52 m, cbl	Difference advances, cbl	Advances at depth 120 m, cbl	Advances at depth 52 m, cbl	Difference advances, cbl	Advances at depth 120 m, cbl	Advances at depth 52 m, cbl	Difference advances, cbl	Advances at depth 120 m, cbl	Advances at depth 52 m, cbl	Difference advances, cbl
20	1,40	1,34	0,06	1,35	1,36	0,01	1,46	1,52	0,06	1,54	1,58	0,04	1,75	1,76	0,01	2,12	2,15	0,03
30	1,60	1,51	0,09	1,63	1,62	0,01	1,76	1,81	0,05	1,86	1,90	0,04	2,11	2,13	0,02	2,60	2,56	0,04
40	1,78	1,73	0,05	1,86	1,86	0	2,03	2,07	0,04	2,15	2,20	0,05	2,46	2,46	0	3,03	3,02	0,01
50	2,02	1,97	0,05	2,10	2,10	0	2,28	2,32	0,04	2,47	2,51	0,04	2,81	2,81	0	3,47	3,43	0,04
60	2,24	2,22	0,02	2,33	2,35	0,02	2,57	2,62	0,05	2,82	2,83	0,01	3,16	3,19	0,03	3,93	3,90	0,03
70	2,49	2,47	0,02	2,61	2,61	0	2,87	2,94	0,07	3,16	3,19	0,03	3,56	3,61	0,05	4,41	4,41	0
80	2,78	2,78	0	2,92	2,93	0,01	3,23	3,26	0,03	3,55	3,56	0,01	4,02	4,03	0,01	4,92	4,92	0
90	3,08	3,07	0,01	3,27	3,29	0,02	3,57	3,65	0,08	3,98	3,98	0	4,51	4,51	0	5,52	5,54	0,02

deep water if it is more than five draughts. But in reality a turning circle will be fulfilled at more deep water.

To calculate a wheel-over point at any depth which is less than five draughts for a definite turning angle and a rudder position it is necessary to find the advance with the help of a turning circle for deep water using the same rudder position. Then the advance for required shallow water must be calculated as follows:

1. To find the coefficient for the depth equal to five draughts (deep water) which is equivalent to the advance

$$\frac{T}{H_{5T}} = \frac{1}{5} = 0,2 \quad ,$$

where T – middle draught
H – depth equal to five draughts;

2. To find the coefficient for he depth accepted for calculation

$$k_1 = \frac{T}{H_{SH}} \quad ,$$

where k_1 – coefficient for the calculation depth,
H_{SH} – the depth less than five draughts (depth for calculation);

3. To find the coefficient of shallow water which defines the advance increasing of a deep water turning circle

$$k_2 = k_1 - 0.2 \quad ,$$

where k_2 – a coefficient of shallow water increasing the advance of a deep water turning circle;

4. To find the advance for shallow water (the coefficient of deep water advance is accepted as 1, then the coefficient of shallow water is added and the sum is multiplied by the advance of deep water)

$$S_{SHW} = S_{DW}\,(1+k_2) = S_{DW}[1+(k_1 - 0.2)],$$

where S_{SHW} – advance of shallow water,
S_{DW} – advance of deep water.

The final formula looks like this

$$S_{SHW} = S_{DW}\left[1+\left(\frac{T}{H_{SHW}}-0,2\right)\right]$$

To value accuracy of the coefficient the mathematical model of the bulk carrier is used with the following data:

Displacement		33089 t
Length full		182.7 m
Breadth full		22.1 m
Draught	fore	10.1 m
	aft	10.7 m
	mean	10.4 m

The following depths are taken for the turning circle:

120.0 m - deep water
32.1 m - the depth equal to three draughts
21.4 m - the depth equal to two draughts
18.0 m, 16.0 m, 14.5 m, 13.0 m - different depths

Six turning circles are made at each depth at the position of the helm from 35 degrees to 10 degrees at intervals of 5 degrees. 42 turning circles are made to starboard side and the same number is made to port side. All 84 turning circles are made according to this mathematical model.

At each turning circle the advance values are calculated for turning angles from 20 degrees to 90 degrees at the intervals of 10 degrees. Each calculated advance is compared with the advance received from the drawing (see Table 2.2 at the end of the article).

The Table 2.2 shows the comparison advances between those received from the turning circle calculated value on condition that the rudder is in position of 35 degrees starboard side.

The first column contains depths, which are accepted for turning circles. The depth of 120 meters is deep water and this line belongs to all turning angles. Other deeps are considered as shallow water with their data for each turning angle.

In the second column for the depth of 120 meters the upper value is the coefficient for deep water. The lower value is the coefficient for deep-water advance, which is accepted as 1. Other values belong to shallow water depths. For each shallow water depth upper value is a ratio of the draught to the depth which is at this line and it is the coefficient of this depth. The lower value is the coefficient for shallow water advance at this line.

Next columns keep data for turning angles, which were accepted for turning circles, and each of them has left and right parts. Upper left data indicate value of the advance in millimeters received from drawing but lower port data indicate the same value in cables. Lower starboard data are received as a result of multiplication of the deep water advance for this turning angle by the shallow water coefficient which is at this line. Two values are compared and if the difference is more than 0,3 cables this both cells are made gray. Other advances are calculated in the same way including a tactical diameter.

The Table 2.2 is made up for the rudder in position of 35 degrees only. The same tables are made up for each rudder position from 35 degrees to 10 degrees at the intervals of 5 degrees.

After all the tables are filled and comparisons values are made for following data are received:

- 483 values don not exceed the difference of 0.3 cable (55.5 m) between the calculated and the ones received from the drawing (88.6%).
- 66 values exceed difference 0.3 cables (55.5 m) between the calculated and the received ones from the drawing (11.4%).
- 27 values exceed the difference 0.4 cables (74.1 m) between the calculated and the re-ceived from ones drawing (4.7%).

For the depths equal to two and three draughts of the mathematical model the tactical diameters are more than 0.3 cables (55.5 m) in 3 out of 24. If a depth is less than two draughts a tactical diameters sharp increase and the calculated and measured values reach up to 3 cables.

To determine the value accuracy of the coefficient the mathematical model of the tanker is used with following data:

Displacement		77100 t
Length full		242.8 m
Breadth full		32.2 m
Draught	fore	12.5 m
	aft	12.5 m
	mean	12.5 m

The following depths are taken for a turning circle:

120.0 m - deep water,
38.0 m - the depth equal to three draughts,
25.2 m - the depth equal to two draughts,
21.0 m, 18.0 m, 15.0 m - different depths.

It is fulfilled operations the same as with the mathematical model of the bulk carrier and as a result of this the following data are received:

- 170 values don not exceed difference of 0.3 cables (55.5 m) between the calculated and received values from the drawing (70.8%);
- 70 values exceed the difference of 0.3 cables (55.5 m) between the calculated and received values from drawing (29.1%);
- 38 values exceed the difference of 0.4 cables (74.1 m) between the calculated and received values from the drawing (15.8%).

For the depths equal to two and three draughts of the mathematical model the tactical diameters are more than 0.3 cables (55.5 m) in 2 out of 12 values. If a depth is less two draughts a tactical diameters increase sharply and the difference between the calculated and measured values reach up to 4 cables.

After estimating the coefficient of the above-mentioned two mathematical models the particulars of the m/v "Norilsk" are used:

Displacement	30758 t
Length full	173,5 m
Breadth full	24,55 m
Draught fore	10,00 m
aft	10,70 m
mean	10,35 m

The deep water turning circle is drawn on basis of the real tests. However, there are no data are for drawing the turning circle in another scale. Therefore the turning circle is drawn in natural size (see Figure 2.1).

The turning circle for shallow water is drawn on the basis of calculation and for ratio of the depth to the draught equal to 1.25 (see Figure 2.2). Therefore the calculation could be made with some mistakes which would arise because of increase of the turn circle. And as a result it is received 8 caparisons between of calculated advances and advances received from drawings (see Table 2.3). The comparison results are as follows:

5 values exceed the difference of 0.3 cables;

4 values exceed the difference of 0.4 cables;

The maximum difference of 0.65 cable.

The advance calculation method is offered on the basis comparisons which are received as shown above. Thus is possible to find wheel-over point with the help deep water turning circle easily. But for using this method a vessel must have turning circles which are received at different rudder angles and fulfilled more exactly then m/v “Norilsk”.

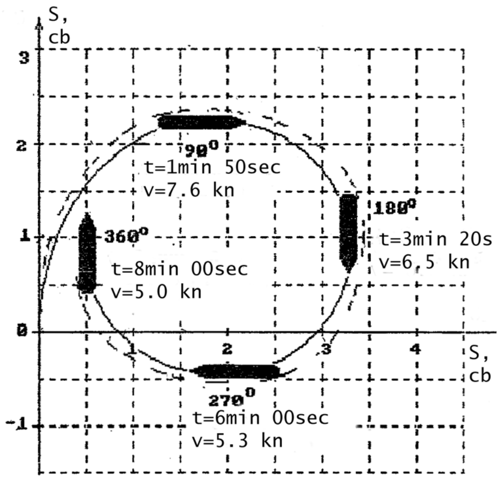

Figure 2.1. Deep water turning circle

M/V “NORILSK”

Turning circle was made up in loaded condition and in deep water (result of real tests). The turning circle was fulfilled of rudder position of 35° starboard side and with the following particulars:

Draught fore - 10.0 m,
Draught aft - 10.7 m,
Initial speed - 11.4 kt,
Rudder position - 35° S/side,
Advance - 2.2 cb,
Maximum diameter - 3.3 cb

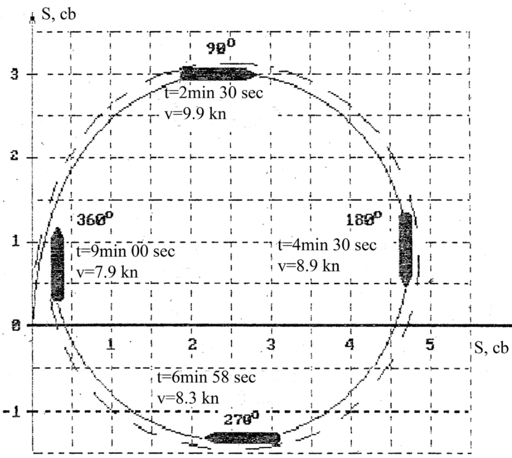

Figure 2.2. Shallow water turning circle

M/V “NORILSK”

Turning circle was made up in loaded condition and in shallow water (result of calculating). The turning circle was fulfilled at rudder position 35° starboard side and with the following particulars:

Draught fore - 10.0 m,
Draft aft - 10.7 m,
Initial speed - 11.4 kt,
Rudder position - 35° S/side,
Draught/depth ratio - 1.25,
Advance - 3.0 cb,
Maximum diameter - 4.7 cb

Table 2.2 The distance from crossing tracks to wheel-over point depending on turning angle and manoeuvring depth depending on turning angle and manoeuvring depth with rudder position of 35 degrees, starboard side

H	T/H k	Turning angle																	
		20°		30°		40°		50°		60°		70°		80°		90°		Tact. Diam.	
		a/dr	a/cal	a/dr	a/cal	a/dr	a/cal	a/dr	a/cal	a/dr	a/cal	a/dr	a/cal	a/dr	a/cal	a/dr	a/cal	a/dr	a/cal
		mm/cb		mm/cb		mm/cb		mm/cb		mm/cb		mm/cb		mm/cb		mm/cb		mm/cb	
120.0	0,200	65,0		74,0		82,5		93,5		103,5		115,5		128,5		142,5		160,0	
	1,000	1,40		1,60		1,78		2,02		2,24		2,49		2,78		3,08		3,46	
32,1	0,324	70,0		77,7		89,0		101,0		113,0		125,5		140,5		160,0		190,0	
	1,124	1,51	1,58	1,68	1,80	1,92	2,00	2,18	2,27	2,44	2,51	2,71	2,80	3,03	3,12	3,46	3,46	4,10	3,88
21,4	0,486	69,0		88,0		99,5		112,0		127,0		142,0		158,0		178,0		223,5	
	1,286	1,49	1,81	1,90	2,06	2,15	2,29	2,42	2,60	2,74	2,87	3,07	3,21	3,41	3,57	3,84	3,96	4,83	4,44
18,0	0,578	74,0		89,0		104,5		120,0		138,0		156,5		179,0		205,0		281,5	
	1,378	1,60	1,93	1,92	2,20	2,26	2,46	2,59	2,78	2,98	3,08	3,38	3,44	3,87	3,82	4,43	4,24	6,08	4,76
16,0	0,650	77,0		94,5		113,0		130,0		150,5		171,5		194,5		219,5		319,0	
	1,450	1,66	2,04	2,04	2,32	2,44	2,58	2,81	2,93	3,25	3,24	3,70	3,62	4,20	4,02	4,74	4,46	6,89	5,01
14,5	0,717	85,0		103		122,5		141,5		161,0		184,0		207,5		235,5		340,0	
	1,517	1,84	2,13	2,22	2,42	2,65	2,70	3,06	3,06	3,48	3,39	3,97	3,78	4,48	4,21	5,09	4,67	7,34	5,24
13,0	0,800	87,0		106,0		129,5		150,5		175,0		201,0		228,5		262,0		395	
	1,600	1,88	2,25	2,29	2,56	2,80	2,85	3,25	3,23	3,78	3,58	4,34	3,99	4,94	4,44	5,66	4,92	8,53	5,53
		-0,32										+0,35		+0,50		+0,42			
		-0,33														+0,74			
		-0,38																	
		-0,37																	

Bulk carrier, D = 33089 t, L = 182,7 m, Lw = 173,9 m, B = 22,6 m; 1 cb =46,3 mm ;T_F =10,1; T_A =10,7; T_M =10,4

Table 2.3 *The distance from crossing tracks to wheel-over point depending on turning angle and maneuvering depth at rudder position of 35 degrees, starboard side*

H	T/H k	Turning angle															
		20°		30°		40°		50°		60°		70°		80°		90°	
		a/dr	a/cal	a/dr	a/cal	a/dr	a/cal	a/dr	a/cal	a/dr	a/cal	a/dr	a/cal	a/dr	a/cal	a/dr	a/cal
		mm/cb		mm/cb		mm/cb		mm/cb		mm/cb		mm/cb		mm/cb		mm/cb	
Deep water	0,200																
	1,000	0,45		0,70		0,98		1,23		1,46		1,72		1,98		2,28	
12,94	0,800																
	1,600	0,66	0,72	1,02	1,12	1,36	1,57	1,52	1,97	1,98	2,34	2,30	2,74	2,61	3,16	3,00	3,65
			0,06		0,10		0,21		0,45		0,36		0,44		0,55		0,65

m/v "NORILSK", Δ = 30758 m, L = 173.5 m, Lw = 164.9 m, B = 24.55 m,
1 cb=40 mm, T_F=10.0, T_A =10.7, T_M =10.35
1. Turning circle in loaded condition (result of real tests).
2. Turning circle in loaded condition in shallow water (on the basis calculation).
3. Depth to draught ratio of the ship is 1,25

*H / T = 1,25; H / 10,35 = 1,25; H = 1,25 * 10,35 = 12,94*