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Title:

Design of Standardized Vessels for the National Waterway 1 in India

Abstract:

The Inland Waterways Authority of India (IWAI) is improving the inland waterways sector through strategic development to ensure efficient and effective movement of goods within the country and for in-bound and out-bound destinations. National Waterway 1 (NW-1) is the most important Indian waterway and runs from Haldia (Sagar) to Allahabad across the Ganges, Bhagirathi and Hooghly river systems. It is 1,620 km (1,010 mi) long and is of prime importance amongst all the national waterways considering its locational advantages.

A key element for development of inland waterway transport (IWT) on NW-1 is the design of specific vessels that are well adopted to the navigation on this waterway. DST was contracted for the design of suitable IWT ship types, in different dimensions and for different types of cargo. These vessels should offer the best results in terms of high transport volumes, low transport cost, high safety level and low environmental footprint.

In order to work out standardized vessel concepts, vessel types had to be defined. In first line, the prevailing and/or expected operation conditions on NW-1 had to be considered, but also the experience of vessel design and operation on other international inland waterway networks. It appeared soon that the European scheme for ship dimension could not be applied.

The first step was to define a pattern of main dimensions based on the dimension of the infrastructure and the properties of the waterway. Using the DST database that contains the performance data of inland waterway vessels, the payload and operation cost of the vessels was assessed for the navigation on the waterway NW 1. This assessment considered, among others, the seasonal changes in fairway depth of the waterway. With the results, different business cases for vessel operation could be calculated.

For vessel design, the available water depth is a key parameter and, in the case of NW 1, these are quite low and also subject to large seasonal changes. It appeared also that the lowest part of the waterway can be almost considered as open sea, with specific requirements on strength and freeboard of the vessels. As next step, the hull forms for these vessels were elaborated, using the same setup of the propulsion system for all vessels. Following the requirements of standardized vessel design, other common features for equipment, accommodation and construction were defined. The design concepts were finally worked out for the different vessels and published as data sheets that compiled the most relevant data and features of the vessels.

In a CFD study, the stern tunnel shape was systematically varied by modifying the transom wedge angle in the stern region along the longitudinal plane within stern tunnel. A set of five variants of the stern tunnel geometry was developed from the base model. Numerical investigations were carried out in Star CCM+ for minimum viscous pressure drag at full load draft and complete water entrainment in the tunnel at ballast draft for design speed.

A comprehensive model test project carried out at DST was the next step. For three different hull types, performance in shallow water navigation was determined, including manoeuvring tests. Three basic designs of standardized inland waterway vessels for NW-1 in different main dimensions have been tested in order to assess their manoeuvring properties.

Design of Standardized Vessels for the National Waterway 1 in India

Operating conditions

From the navigation point of view, NW-1 consists of 7 operation zones, each with different properties, resumed in Table 1.

Table 1: Description of main operation zones

Sector	Length	LAD	Sharp bends	Wave influence	Navigation zone according to IR Class
Haldia to Diamond Harbour		> 3.0	none	Yes, up to 2 m	Zone 1
Diamond Harbour to Tribeni		> 3.0	none	Yes, tidal bore	Zone 3
Tribeni to Farakka	351 km	3.0	Yes, with R=300 m	none	Zone 3
Farakka to Barh	347 km	3.0	none	none	Zone 3
Barh to Ghazipur	287 km	2.5	none	none	Zone 3
Ghazipur to Varanasi	133 km	2.2	none	none	Zone 3
Upstream of Varanasi	236 km	Natural depth	Yes, with R=700 m	none	Zone 3

The available water depth on NW-1 has to be considered in the vessel concepts. As a guideline, the following least available water depth (LAD) is considered:

The optimised “Option 2 Navigation Channel” has the following LAD[1]:

a) 3.0 m LAD from Haldia to Barh;
b) 2.5 m LAD from Barh to Ghazipur, and;
c) 2.2 m LAD from Ghazipur to Varanasi.
d) Natural depths would be available upstream of Varanasi.

As the draught of a river vessel has to be considerably smaller than the available water depth, we assume the following draught parameters in function of the operation range:

- The under keel clearance (UKC) of a river vessel should be at the least 0.40 m, in order to maintain navigation at an acceptable speed and safety level. Without sufficient UKC, the risk of grounding is high and only low speed over ground is possible in upstream condition.
- Design draught (T_D): Average operation conditions, hull form and propulsion designed for optimum performance at this draught.
- Maximum draught (T_{max}): With sufficient water depth, the vessel is operated with maximum payload; still safety regulations are fully met.
- Minimum draught (T_{min}): At low water depth, the vessel remains in operation with reduced payload.

At present time, strong seasonal variations of the water depth have to be considered, see Figure 1. It is evident that vessels will be facing in many seasons water depth below the indicated LAD, and this in all reaches upstream of the Farakka lock. For this reason, the minimum draught (T_{min}) of the vessels has to be considerably lower than for, as example, a vessel designed for the River Rhine.

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[1] HOWE, page 28

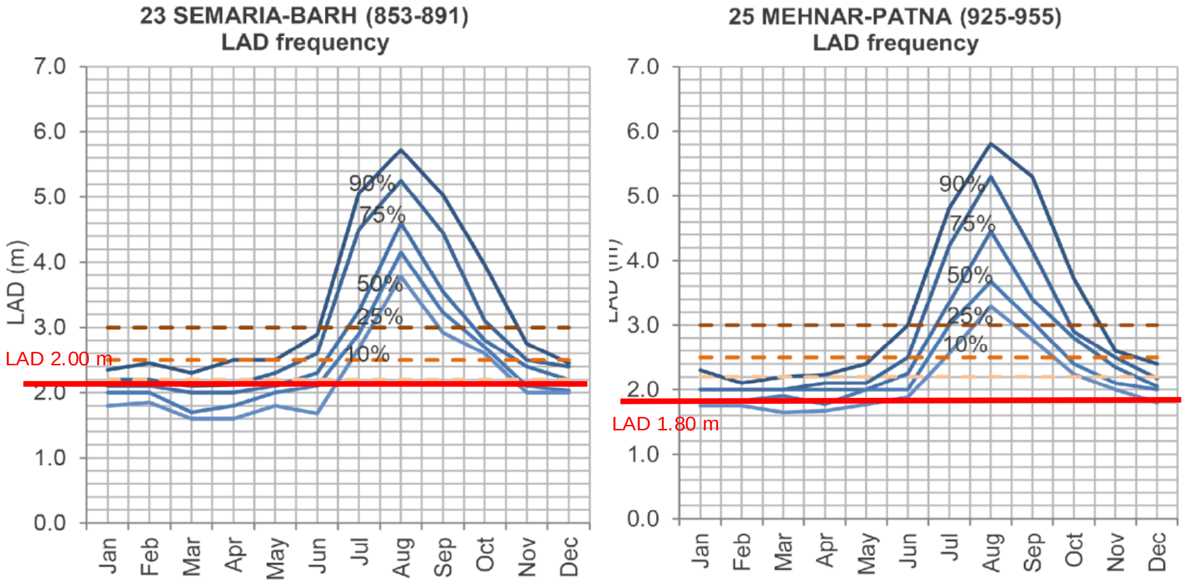


Figure 1: Waterdepth data for different sectors of NW-1

In waterways with limited water depth, only the increase in length and breadth of the vessel will improve the payload. Considering the requirement of low freight rates, the vessel main dimensions are therefore always selected close to the maximum allowable limit dimensions.

On order to define advantageous main dimensions, several limiting side conditions have to be assessed:

- Influence of limited fairway breadth
- Increased propulsion power demand
- Size limitations of infrastructure, in this case the Farakka lock
- Draught and freeboard of the hull
- Hull strength requirements

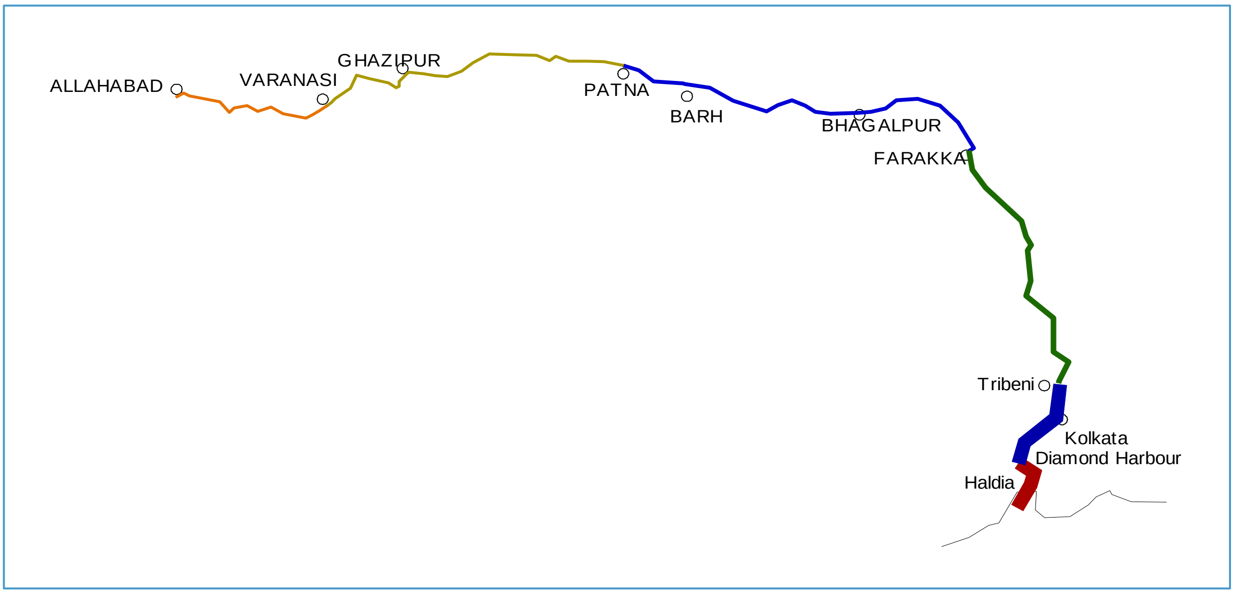


Figure 2: Sketch of different navigation sectors

What is the appropriate strategy to define vessel types, considering the navigation conditions and shallow water depth? Different alternatives can be discussed:

- For different navigation zones, specific vessels with different properties are used, each optimised for the specific navigation conditions.
- Vessel should be able to operate in all zones of NW-1.
- Vessels should be able to operate in all zones of NW-1, but with modified operation schemes for the service in Zone 1 (Haldia to Diamond Harbour) and the last zone upstream of Varanasi.

Option a) has the advantage that each of the vessels will be optimised for the specific navigation zone. Shortcut is the necessity of frequent cargo transfer from one vessel to another during the voyage, and transport cost will be too much affected by the cost and delay of these transhipments.

For option b), there are conflicting technical requirements that are difficult to meet. Deep water and wave influence at Haldia would require hulls with high freeboard and heavy construction, whilst the shallow water conditions in the upper reaches of NW-1 call for light construction and low freeboard. A part of the vessel designs will be suitable for navigation in all zones.

For the other designs, the option c) will be considered. This means that in seasons with foul weather and high waves in the coastal waters of the Haldia range, the NW-1 vessels will have transhipments at Diamond Harbour and/or Tribeni.

Also, in seasons with low LAD in the reaches upstream of Farakka, the vessels will use additional dump barges to reduce draught and maintain the high payload.

The main dimensions of these vessels will follow the pattern discussed in the preceding chapter. For the service in the shallow water reaches, all vessels have to remain operational at a minimum draught of 1.30 m.

Standardized vessel design

The standardization of the vessels should be at a high level, including hull form, steel structure and propulsion devices, but also manoeuvring devices, crew accommodation and deck equipment. Standardization will help to obtain low production and maintenance cost for the vessels and facilitate the training of the crews. This design strategy will make it possible to have many parts in common for the vessels, but to make also sure that the each vessel meets best the particular operation conditions on NW-1.

Aiming at standardized vessel design, only one propulsion layout will be used for all vessels: Ducted propeller, diameter 1.45 m. on horizontal shaft in combination with a reversible gearbox and a combustion engine of 500 kW in rating A (heavy, uninterrupted duty). The propeller nozzle and the rudders are covered by a plate. This propulsion layout can be used in vessels having a minimum draught of Tmin = 1.30 m. All NW-1 vessels will have twin propulsion.

Excellent manoeuvring properties are a key asset for navigation on NW-1. State-of-the-art devices have to be employed, as they are largely in utilisation on other waterways and have proved to be efficient and fail-safe.

On the different types of NW-1 vessels, these will be:

- Double rudders behind each propeller
- Bow thrusters, driven by combustion engines of 150 to 200 kW, to be used in ports and during manoeuvres with the stationary vessel.

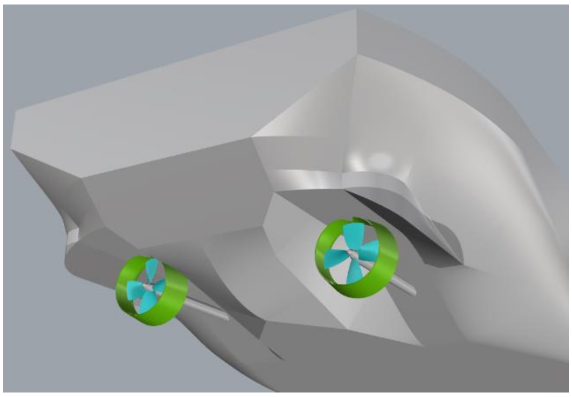
Vessel types

Referring to the terms of the contract attributed to DST , concepts for the following vessel types have been worked out:

l	Cargo type	Short Name	L	B	D	Tmax	Payload at Tmax	Navigation Zone
1a	Dry Bulk	B1	80.0 m	12.0 m	3.7 m	2.5 m	1579 t	Zone 1
1b	Dry Bulk	B2	110.0 m	12.0 m	4.3 m	2.8 m	2515 t	Zone 1
1c	Dry Bulk	B3	92.0 m	12.0 m	3.7 m	2.8 m	2105 t	Zone 1
2a	Tanker	T1	110.0 m	12.0 m	3.7 m	2.8 m	2434 t	Zone 1
2b	Tanker	T2	80.0 m	12.0 m	3.4 m	2.5 m	1524 t	Zone 1
3	RoRo	RoRo	70.0 m	14.5 m	2.8 m	1.7 m	757 t	Zone 3
4a	Container	CO1	80.0 m	12.0 m	3.4 m	2.5 m	1590 t	Zone 1
4b	Container	CO2	110.0 m	12.0 m	4.3 m	2.6 m	2140 t	Zone 1
5a	LNG Barge	LNG1	90.0 m	14.5 m	4.2 m	2.3 m	1037 t	Zone 1
5b	LNG Barge	LNG2	92.0 m	12.0 m	3.7 m	2.1 m	618 t	Zone 1
6a	Push Boat	PB	26.0 m	12.0 m	2.4 m	1.8 m	64 t	Zone 3
6b	Dumb Barge	DB	42.0 m	8.0 m	2.8 m	2.5 m	585 t	Zone 3
7	Car Carrier	CC	90.0 m	14.5 m	3.1 m	1.8 m	847 t	Zone 1
8	Dry Bulk	B_LNG	110.0 m	12.0 m	4.3 m	2.8 m	2452 t	Zone 1

CFD Study

The standardized vessels designed for NW-1 are to ply in full load condition and ballast condition during its upstream voyage and downstream depending upon cargo availability. Therefore, the study of full propeller immersion in the tunnel at ballast loading condition is crucial. A transom wedge to the stern tunnel is a solution to overcome air entrapment in the stern tunnel. An investigation is carried out at IIT Kharagpur for the performance of different stern tunnel configurations with the base hull form. The stern tunnel allows for propeller of large diameter with water entrainment capabilities inside the tunnel when stern tunnel and propeller are partially immersed during ballast voyage. Figs. 1(a) and (b) show the 3D perspective view of the stern tunnel configuration with the ducted propeller and line diagram of the stern wedge angle for the variants, respectively.



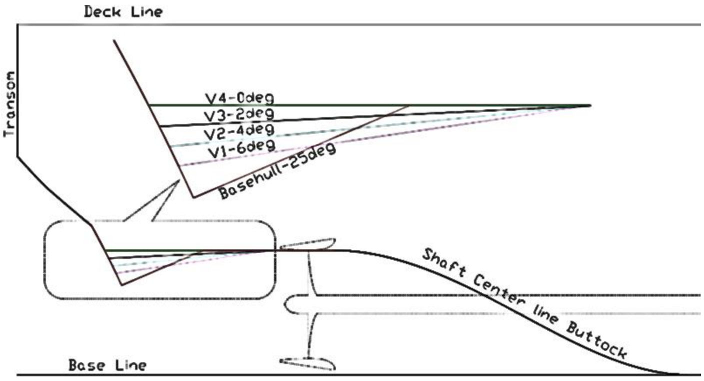


Fig. 3(a) Stern tunnel configuration with ducted propeller Fig. 1(b) Line diagram of variants

The aim of this investigation is to minimise viscous pressure in full load condition and avoid air entrapment during ballast arrival condition, thereby improve propeller efficiency and decrease fuel consumption. Different stern configurations, as shown in Fig. 1(b), are investigated with the help of numerical simulation carried out in Star CCM+. Hull form variants, without the ducted propeller, are investigated to understand the stern tunnel's water entrainment capability as a function of its geometry. A total of five variants are studied by systematically varying the aft transom wedge angle along the propeller shaft centerline as shown in Fig 1(b).

All the variants are investigated for viscous resistance in the fully loaded condition at 9 knots speed using simple double body analysis, neglecting wave-making resistance due to low Froude number. It is observed that the variation of frictional resistance component is nominal for all variants, whereas viscous pressure resistance decreases from base hull to a minimum for variant V4. The transom wedge angle has an influence on viscous pressure resistance component.

Subsequently, all the variants are further investigated for water entrainment into the stern tunnel in ballast condition using Volume of Fluids method (VOF) to track the air-water interface. The influence of stern wedge shape on resistance in ballast condition is negligible. Therefore, in ballast condition water entrainment capability in the tunnel is the governing criteria for the stern variants. In deep water, base hull form and V2 shows good water entrainment capability in the tunnel, V3 has the partial water entrainment capability and V4 is completely incapable of drawing water into the tunnel. The water entrainment capability of stern tunnel variants in shallow waters is better compared to deep water due to the increase in local water velocity past hull. Except for V4, all the other variants perform better in shallow waters in terms of water entrainment in the tunnel a requirement for propeller operation.

Model tests at DST

A comprehensive model test project carried out at DST was the next step. For three different hull types, performance in shallow water navigation was determined, including manoeuvring tests. Three basic designs of standardized inland waterway vessels for NW-1 in different main dimensions have been tested in order to assess their manoeuvring properties. The following conclusions have been obtained:

- Model tests with captive models have shown sufficient stopping ability of the vessels.
- For stopping in downstream direction and backward speed, the vessels should use the bow thruster during the manoeuvre in order to maintain the vessel on a straight course backwards.
- Turning circle tests have shown the capacity of the convoy to navigate at moderate speed the sharp bends of NW-1 in downstream direction.
- The access to the Farakka is by far the sharpest bend on the waterway NW-1. This turn will be handled by all types of the new designs of the NW-1 vessels, at least as slow manoeuvre with little or zero advance speed of the vessel, probably assisted by the bow thruster.
- Hydrodynamic manoeuvring coefficients for the different vessel types in their largest dimension have been obtained with captive manoeuvring tests.
- Bow rudder test have shown strong manoeuvring forces with the vessel navigating at moderate speed in shallow water.
- All test results are valid for navigation in shallow water with water depth ranging between h = 3.0 m and h = 5.0 m.

Conclusion

As IWAI is making much progress with the aim to promote the inland waterway transport on NW 1, the construction of some of the vessels is planned for the next years.