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# Comparative Analysis Hydrostatic and Stability Characteristics of Skeg Hull Shapes on Barge

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***ABSTRACT:*** *This study aims to determine and compare hydrostatic characteristic and safety levels of direct stability on a barge using two different stern configuration : Transom and Skeg. The analysis was conducted using numerical simulation based in the International Maritime Organization ( IMO ) criteria for cargo ship over 24 meters in length. The results showed that both models perfectly complied with all mandatory safety standards. However, the barge model utilizing a Transom stern demonstrated significantly higher primary stability value compared to the skeg model. The initial metacentric height ( Initial GM ) for the transom variant reached 32.196 m , whereas the skeg variant recorded 15.115 m. This indicates that stern share modification significantly influence the center of buoyancy and the righting levers under heavy cargo conditions.*

***Keywords***: *Hydrostatic, Stability, Skeg, Transom, Barge*

**NOMENCLATURE**

| **Symbol** | **Description** | **Unit** |
|---|---|---|
| *GM* | Gravity to Metacentra | *m* |
| *MB* | Metacentra to Bouyancy | *m* |
| *KB* | Keel to Bouyancy | m |
| *KG* | Keel to Gravity | *m* |
| w | Weight / Displacement | *Ton* |
| $S(x^0)$ | Momen (Degree ) | *Ton.m* |
| *G-G'* | Distance Gravity to new Gravity | *m* |
| *Lwl* | Length of Water Line | *m* |
| *B* | Breath | *m* |
| *T* | Draught | *m* |
| *CB* | Block Coefisien | |
| *L/B* | Ratio Length and Breath | |
| *B/T* | Ratio Breath and Draught | |
| | | |

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## I. INTRODUCTION

Maritime transport using barge play a crucial and strategic role in supporting economic growth and infrastructural development across the Indonesian archipelago[1], [2]. As a maritime nation encompassing thousand islands, the logistical distribution of massive material – such as large- scale precast concrete, bridges , and sea walls – heavily relies on the dependability of water transport [3]. Barges represent the preferred operational choice due to their expansive open deck cargo capability, low draft properties allow access to shallow waterways, and highly economical operating costs compared to conventional cargo vessels [4].

Nevertheless, the structural nature barges, which are generally non propelled horizontal box- shaped structures, poses distinct hydrodynamic and navigational safety challenges [5], [6]. Because their movement is entirely dependent on the towing force of a tugboat, the survival of these vessel relies heavily on their hull from stability. The hull must retain an upright position and secure valuable deck cargo loss not only trigger massive financial liabilities for logistics providers but also safety and threaten marine ecosystems with environmental contamination[7], [8].

The stern design stands out as a fundamental hull geometry parameter that dictates baseline hydrostatic properties, underwater volume distribution, and the subsequent formulation of the righting arm (GZ) curve [9], [10] . The geometric profile of the aft sector directly interacts with fluid flow dynamic and determines the position of the center of buoyancy, both vertical ( Vertical Centre Buoyancy – VCB ) and longitudinally ( Longitudinal Center of Buoyancy – LCB ) [11], [12], [13]. Minor modification to the aft angles or appendages can cause systematic cascading effects on static stability performance when the vessel encounters external heeling forces from strong wind and wave currents, see figure 1.

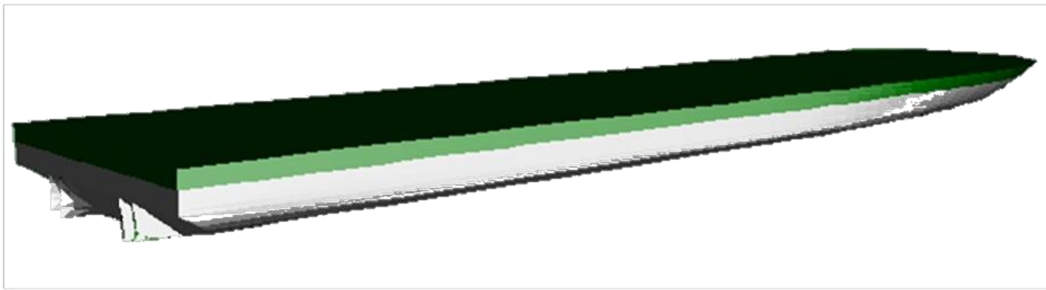


**Fig. 1 Model of barge ship**

Within practical shipyard design and construction frameworks, two primary aft configuration are frequently evaluated for operational effectiveness on barges : the conventional plumb stern ( transom stern) and the stern integrated with directional skegs (skeg) [14]. The transom typology preserves a district, flat stern profile to maximize aft hull volume at higher operational draft, thereby bolstering buoyancy forces at the rear[15]. Conversely, the implementation of skeg structure is primarily intended to minimize yawing or sustain directional stability while being towed by a tugboat. However, adding this appendage alters the volumetric fluid distribution at the stern, which subsequently modifies the static stability behavior of the vessel[16], [17].

Given the overriding importance of maritime safety, variation in hull geometry must be rigorously validated against stringent global standards. The definitive international baseline is established by the International Maritime Organization (IMO) criteria detailed within the International Code on Intact Stability. This regulation distance the minimum acceptable thresholds for intrinsic stability parameters, including the area under the GZ curve, initial metacentric height (initial GM), and the maximum heeling angle location. These criteria serve to guarantee that a vessel possesses a reliable righting moment to withstand serve weather condition at sea[18], [19].

To due, comparative research detailing the exact impacts of Transom versus Skeg stern configuration on deck-loaded heavy barges remains relatively limited. The majority of historical studies focus predominantly on resistance attributes and propulsion characteristics. Meanwhile, studies focus predominantly on resistance attributes and propulsion characteristics. Meanwhile, exhaustive assessments of hydrostatic metric involving LCB shift, KN cross-curves, and intact stability behavior for concrete pipe carriers require deeper numerical exploration [20]. Consequently ,this study focuses on simulation and comparing the hydrostatic performance and safety margins of these two district stern variations. The resulting technical recommendations aim to guide naval architects and fleet operators toward executing barge design that optimize structural safety alongside operational maritime efficiency.

## II. EXPERIMENTAL SETUP

The evaluation of hydrostatic characteristics and static stability curves in this study is executed utilizing a computer-based numerical simulation approach. Digital 3D geometric models of the barge hull were engineered across two stern variations : the first model utilizes a standard flat transom stern, while the second incorporates directional skeg appendages. The numerical evaluations were performed under completely uniform loading configurations, specially dense stack of solid cylindrical concrete pipes secured across the main deck surface.

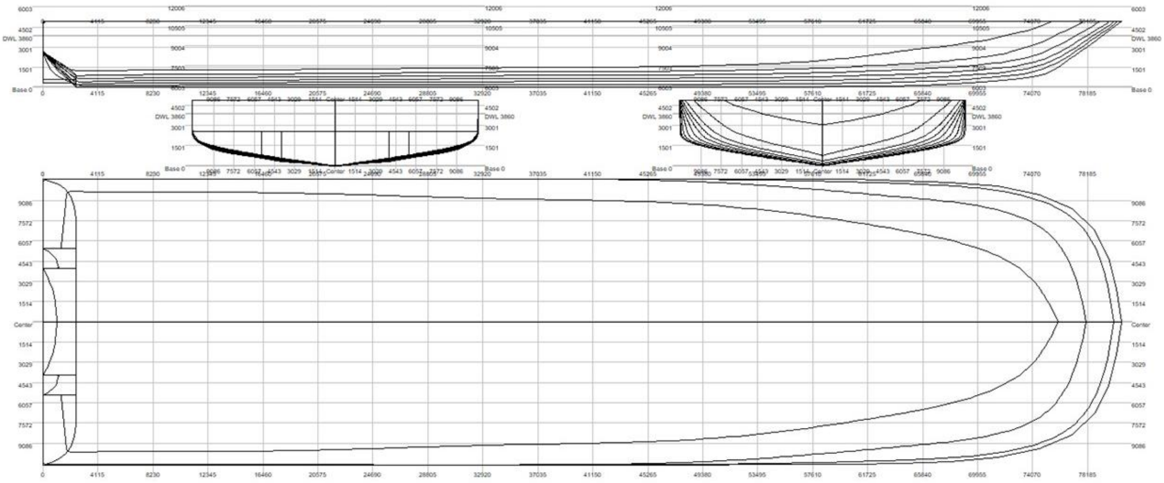


**Fig. 2 Lines plan of barge**

Static stability verification was carried out in strict accordance with mandatory IMO international regulations specified for cargo ship over 24 meters in length. Underwater hull hydrostatic parameters, including volumetric mass displacement and the longitudinal center of buoyancy ( LCB), were evaluated systematically across a gradient of operational drafts, ranging from the lightship condition (0,6 meters) up to the maximum fully – loaded operational limit (3,6 meters) , see figure 2.

## III. RESULTS AND DISCUSSION

### 1. Hydrostatic Characteristics (Displacement & LCB)

Numerical computation reveal that displacement metrics and LCB shift across both hull variations demonstrate linear and consistent transitions corresponding to changes in operational draft. This behavior occurs because the expanding volumetric profile of the submerged hull corresponds directly to an increase in upward buoyant forces [21], [22], [23].

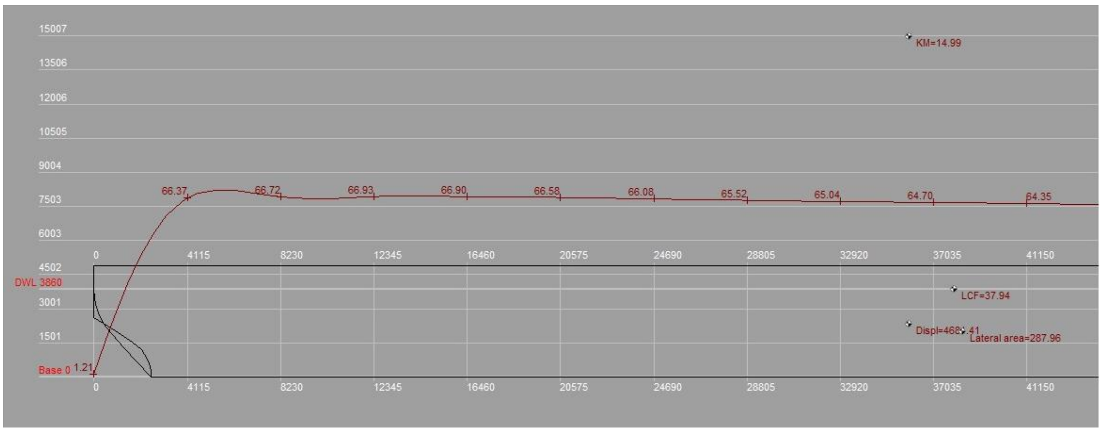



**Fig. 3 Model of barge ship without transom**

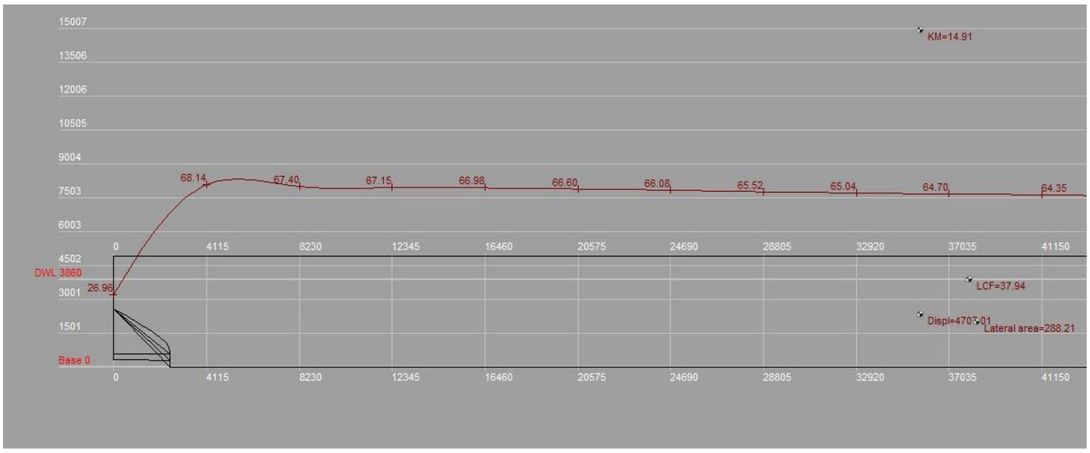



**Fig. 4 Model of barge ship use transom**

During the generation of the cross curves of stability, the potential righting lever value (KN sin φ ) was plotted across a displacement envelope spanning 500 to 4000 metric tons, under heeling angles ranging from $10^0$ to $90^0$. The transom-stern model exhibits slightly higher volume-moment distribution properties compared to the skeg model during the early stages of operational draft , see figure 3 & 4. The comparative numerical findings mapping mass displacement and LCB shift are detailed within figure 5 & 6 .

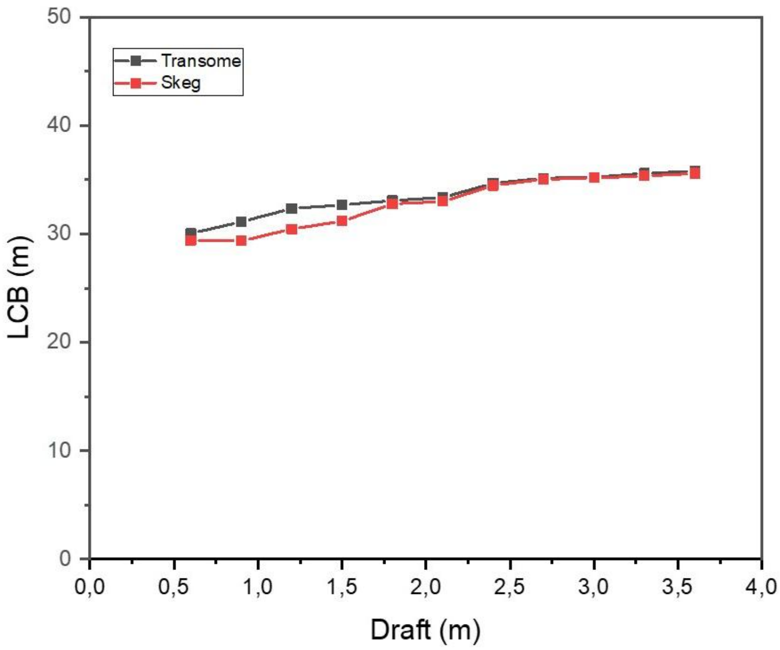



**Fig. 5 Comparison of LCB**

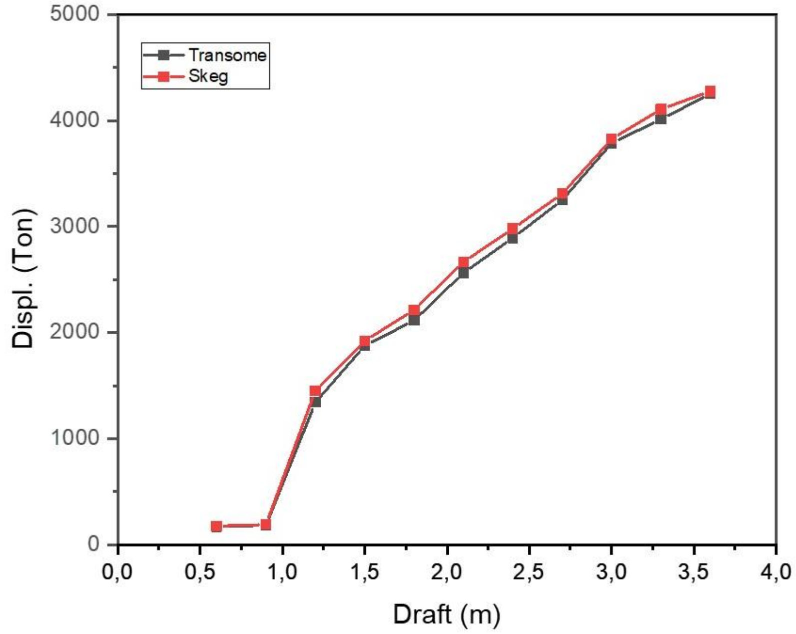



**Fig. 6 Comparison of Displacement**

**2. Static Stability Curve Assessment**

Evaluating the generated righting lever (GZ Righting Arm) curves against varying heeling angles demonstrates that both stern geometries successfully satisfy the minimum international safety criteria dictated by IMO framework, achieving absolute compliance status [24]. Although both hull design are verified as safe for operations , the transom-configured vessel exhibits primary stability performance that is distinctly stiffer, more rigid, and superior. The initial metacentric height (Initial GM) for transom variant reaches an exceptional 32,19 meters , markedly exceeding the skeg variant which registers at 15,115 meters , see figure 7 & 8 . Similarly, the maximum righting lever (Max GZ) attained at heeling thresholds pas $30^{0}$ show the transom model reaching 8.14 meters, substantially outperforming the skeg configuration which remains constrained at 3,61 meters see figure 9. Comprehensive compliance metrics across all tested IMO criteria are complied within Figure 10.

TRANSOM

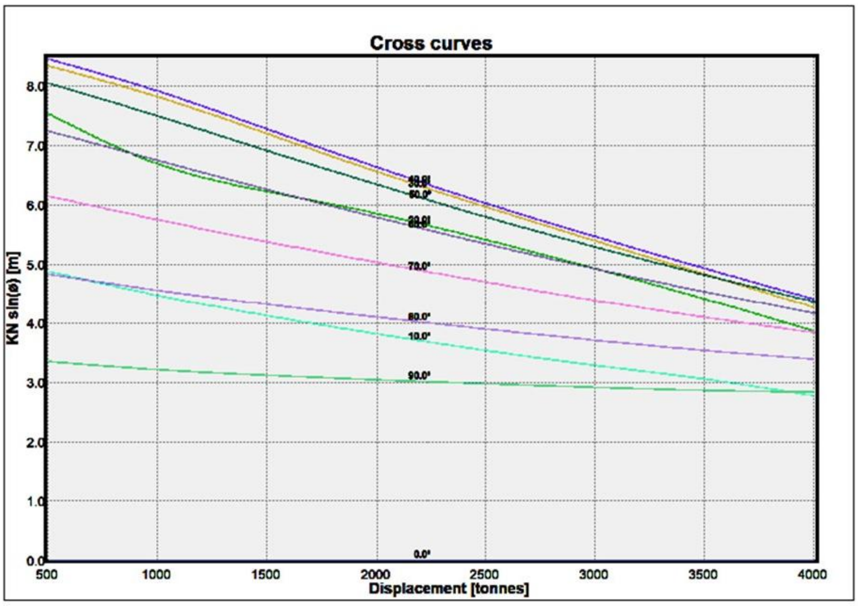



**Fig. 7 Cross curve of transom stern**

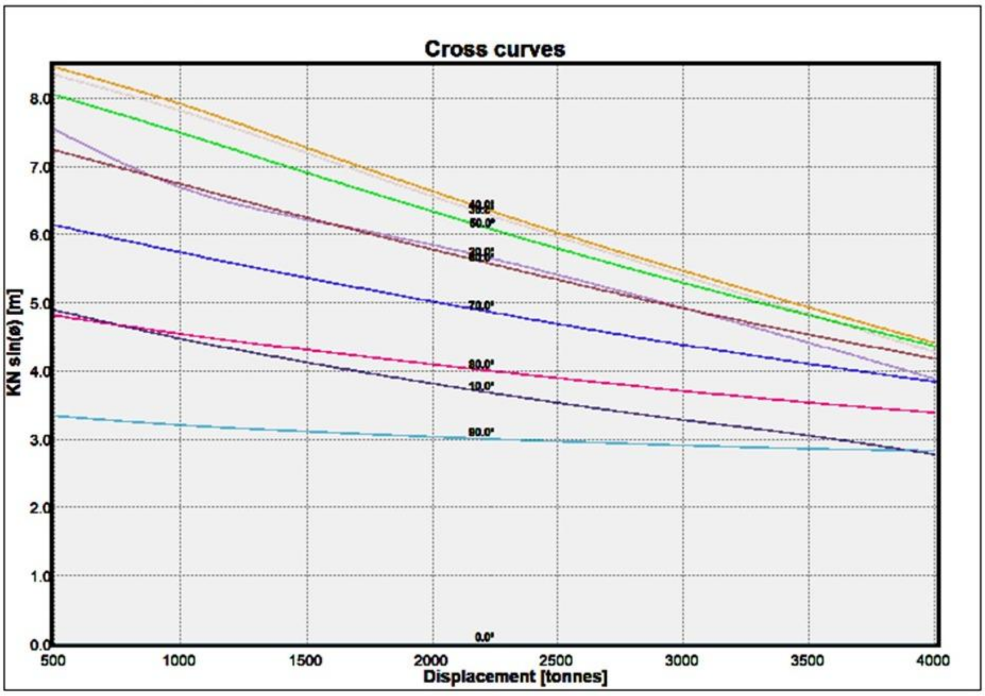
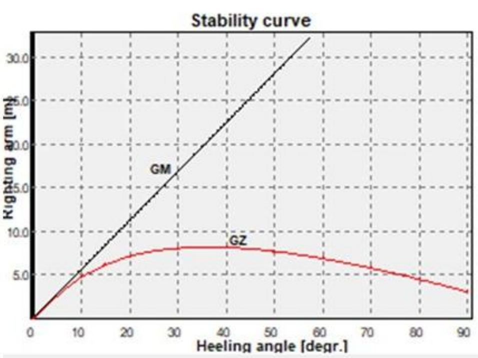
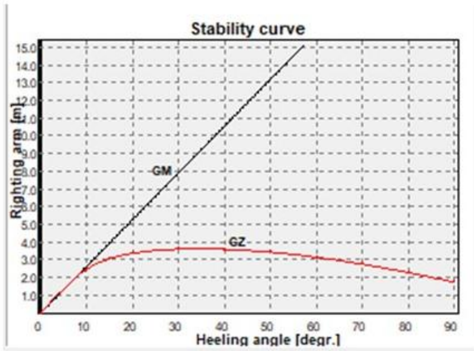



**Fig. 8 Cross curve of stern barge**




**(a)**




**(b)**

**Fig. 9 (a) stability curve stern barge ; (b) stability curve transom stern barge**

| Minimum design criteria applicable to all ships | | | | |
|---|---|---|---|---|
| Cargo and passenger ships of 24 m. in length and over. | | | | |
| Description | Criteria | | | Complies |
| Area 0 to 30 | 1.364 | >= | 0.055 | YES |
| Area 0 to 40 | 1.994 | >= | 0.090 | YES |
| Area 30 to 40 | 0.630 | >= | 0.030 | YES |
| Max. GZ at 30° or greater | 3.616 | >= | 0.200 | YES |
| Angle of maximum GZ | 34.355 | >= | 25.000 | YES |
| Initial GMt | 15.115 | >= | 0.150 | YES |
| Angle of heel due to steady wind | 0.000 | <= | 16.00 | YES |

**(a)**

| Minimum design criteria applicable to all ships | | | | |
|---|---|---|---|---|
| Cargo and passenger ships of 24 m. in length and over. | | | | |
| Description | Criteria | | | Complies |
| Area 0 to 30 | 2.806 | >= | 0.055 | YES |
| Area 0 to 40 | 4.221 | >= | 0.090 | YES |
| Area 30 to 40 | 1.414 | >= | 0.030 | YES |
| Max. GZ at 30° or greater | 8.140 | >= | 0.200 | YES |
| Angle of maximum GZ | 36.418 | >= | 25.000 | YES |
| Initial GMt | 32.196 | >= | 0.150 | YES |
| Angle of heel due to steady wind | 0.000 | <= | 16.00 | YES |

**(b)**

**Fig. 10 (a) Result criteria stern barge ; (b) Result criteria transom stern barge**

## IV. CONCLUSION

This study demonstrates that geometric alterations to a barge's stern structure assert a definitive impact on its baseline hydrostatic functions and its ultimate righting capabilities under high-load profiles. While both the skeg-appendage hull and the pure transom model demonstrate full adherence to international safety metrics, the transom-stern configuration delivers an initial metacentric height (Initial GM and GZ righting arm) attributes that are distinctly superior. This offers an elevated safety margin against open-sea capsizing vectors during heavy cargo transit operations.

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