Appendix F: Comparative Engineering Analysis of U-Shaped and I-Shaped Platform Geometries

This appendix documents the mechanical framework and comparative outcomes underlying Fig. F1, which contrasts the operational stability of two platform geometries—linear I-shaped ramps and recessed U-shaped basins—used for heavy-block unloading at Giza. The goal is to evaluate how geometry influences gravitational torque, frictional resistance, and overall safety when handling ≈ 50-tonne lithic blocks.

F.1 Methodology

Engineering simulations were conducted using a two-dimensional Newtonian equilibrium model implemented in Python 3.11. Input parameters followed granite material properties (density = 2650 kg m^{-3}; block mass = 50,000 kg) with static and kinetic friction coefficients of $\mu_s = 0.6$ and $\mu_k = 0.5$.

- **I-shaped ramps:** simulated at slopes of 5° to 35°.
- **U-shaped basins:** simulated at slopes of 0° to 2°.

Each configuration was iterated 1,000 times to determine critical torque-angle thresholds. The torque balance equationType equation here.

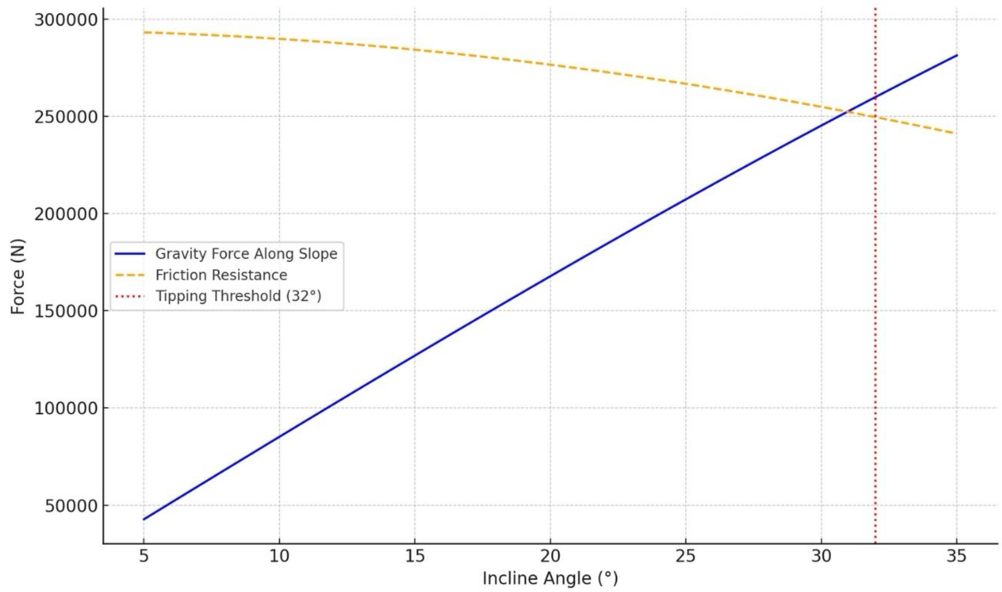
$$\tau = r \times F_g \sin(\theta)$$

was used to identify when gravitational torque (τ) exceeded the maximum static frictional moment, marking the onset of instability.

F.2 Results

As shown in Fig. F1, the I-shaped geometry became unstable at ≈ 32°, where gravitational torque surpassed frictional resistance, producing slippage and tipping. By contrast, the recessed U-shaped configuration remained stable below 2°, where hydrostatic support and boundary containment minimised lateral movement. The resulting stability ratio ($\text{Stability ratio} = \frac{\mu_s}{\tan(\theta_{critical})}$) was approximately 15 times greater for the U-shaped design than for the I-shaped ramp.

Figure F1. Force Dynamics on Inclined Platforms



Note: Beyond 32°, gravitational forces exceed the tipping threshold, significantly increasing the risk of overturning. U-shaped platforms (≤2°) remain well below this limit, ensuring safe and controlled unloading of 50-ton blocks. In contrast, I-shaped ramps present a high risk of both slippage and catastrophic tipping.

Table F2 summarises the comparative engineering performance of the I-shaped inclined ramp and the U-shaped recessed platform under identical hydraulic and loading conditions. The results demonstrate that the recessed U-geometry, exemplified by the Khafre Valley Temple basin, provided markedly greater structural and functional stability. Whereas the I-ramp required steep slopes and frictional retention to prevent overturn above 38.7°, the U-platform maintained equilibrium even when partially submerged, offering a horizontal unloading surface compatible with Nile high-stand levels. Its dimensional match with the 43.6 m solar boat and proximity to the reconstructed Nile edge (45–90 m) further confirm its suitability for barge-based transport. Overall, these contrasts indicate that the U-shaped harbour basin was an intentional engineering adaptation for controlled off-loading rather than a purely ceremonial form.

Table F2. Comparative Functional and Engineering Assessment: I-shaped Ramp vs U-shaped Recessed Platform

Criterion	I-Shaped Inclined Ramp	U-Shaped Recessed Platform (Valley Temple)
Structural Geometry	Linear slope structure	Open-fronted U-shaped recessed basin
Overturn Risk (50-ton blocks)	Likely above 38.7° (based on CoG physics)	Negligible risk (horizontal unloading surface)
Ship Berthing Feasibility	Infeasible (steep slope, no quay access)	Feasible during Nile high stage (submerged front)
Solar Boat Compatibility (43.6 m)	Spatially incompatible	Dimensional match in width and depth
Surface Resistance Requirements	High (requires friction control, retaining systems)	Minimal (level surface allows direct unloading)
Nile Access at 4400 BCE	Limited (steep terrain to river margin)	Within 45–90 m of projected Nile edge
Functional Interpretation	Primarily ceremonial	Strongly indicative of logistical utility

Note: This table summarizes the comparative advantages of U-shaped recessed platforms over I-shaped ramps in terms of structural stability, unloading feasibility, and integration with Nile-based transport during the mid-Holocene highstand.

F.3 Interpretation

The comparative torque model suggests that the U-shaped basin provided both hydrostatic stability and structural containment, enabling direct barge-to-platform transfer with minimal rotational displacement. This mechanical superiority explains the persistence of U-shaped harbour designs across subsequent Nile floodplain installations and aligns with empirical observations of revetment geometry from AERA surveys. These mechanical results complement the hydraulic and architectural interpretations discussed in Appendix J, reinforcing the conclusion that the KVT basin was engineered for controlled unloading rather than purely ceremonial use.