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TRANSPORT OF CONSTRUCTION MATERIALS UNSING A CRANE EQUIPPED WITH A CLAMSHELL GRAB

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ABSTRACT

This paper investigates the application of clamshell-grab portal cranes for the efficient handling and direct transfer of bulk construction materials—sand, gravel, soil, crushed stone—from barges or vessels to land-based transport. The study covers crane typology, grab design, workflow organisation, parametric 3D modelling of a clamshell-grab in Siemens Solid Edge, and finite-element validation of a heavily-loaded quick-change coupling. Operational and economic performance metrics are analysed, with emphasis on energy consumption, life-cycle costs, and carbon footprint.

KEYWORDS: *clamshell-grab crane, 3D modelling, carbon footprint.*

1. INTRODUCTION

A portal crane (also called a gantry crane) consists of a rigid portal frame (legs + cross-girder) that straddles the working area and supports a slewing or travelling super-structure carrying the hoisting gear.

Compared with tower or mobile cranes, portal cranes are optimized for repetitive loading cycles between a waterborne vessel or stockpile and a landside conveyor, rail-car, or truck.

1.1. Portal (gantry) cranes used for handling construction materials

Main features of these cranes are: structure,capacity and usage, mobility, lifting capacity.

The following are detailed characteristics for gantry cranes used for handling construction materials.

Table 1. Classification of portal cranes and rated capacity

Family	Typical Travel Gear	Boom/ Jib Type	Rated Capacity	Main Use-Cases	Notes
Rail-Mounted Portal Slewing Crane	Steel wheels on quay rails	Luffing or level-luffing jib that slews 360 °	10 – 63 t	Ports & river terminals; bulk and general cargo	Classic " port crane"
Rubber-Tyred Portal Crane (RTPC)	All-wheel rubber tyres; diesel-electric drive	Fixed horizontal girder with trolley	≤ 40 t	Yards where rails are impractical; stockpiles	Offers yard mobility at the cost of lower outreach stability.
Fixed (Static) Portal Crane	Anchored to a concrete foundation	Slewing luffing boom	20 – 100 t	Industrial plants, power stations	Lowest maintenance; ideal where working radius is
Semi-Portal / Half-Gantry Crane	One leg runs on ground rail, the other rides on an elevated runway	Girder with trolley	5 – 32 t	Pre-cast yards, fabrication shops	Saves floor space on the building side.
Floating Portal Crane (Crane Barge)	Pontoon or barge	Luffing slewing boom	25 – 200 t	Trans-shipment mid-stream	Enables ship-to-ship transfer where quays are absent

- Single-Leg (Monolegged) vs Double-Leg portals: double-leg frames give higher stability for heavy grabs, while a single leg frees quay space for vehicular traffic.
- Full-gantry versus semi-gantry: semi-gantry has one side supported by a building or trestle, reducing steel tonnage.
- Rigid vs Articulated Boom: level-luffing booms keep the grab vertical while luffing, permitting faster cycle times in confined vertical clearances.

Figure 1 Rail-Mounted Portal Slewing Crane

1.2 Power & Control Systems

Modern units integrate variable-frequency drives (VFDs), anti-sway algorithms, and laser or GPS positioning to cut cycle time and improve safety.

Table 2. Advantages and drive concept

Drive Concept	Advantages	Typical Applications
Diesel-Electric (gen-set + electric motors)	Self-contained, suitable for yards without shore power	RTPCs, floating cranes
All-Electric (grid fed)	Lower OPEX, regenerative braking possible, easy automation	RSPCs on modern deep-water terminals
Hybrid (battery-buffered)	Cuts fuel burn during idling, peak-shaves grid demand	Retrofit of legacy cranes

1.3 Duty classes & performance metrics

The following presents various tasks and performance indicators:

- ISO 4301/2 A6–A8: duty classes are common, supporting 1 000 000+ load cycles;
- Typical grab cycle: 45–120s including lowering, closing, hoisting, slewing, opening, and return;
- Throughput: 400–1000 t/h for sand or gravel with 8–15 m³ clamshell grabs on a 30t RSPC.

1.4 Advantages for bulk construction materials

The most important advantages for bulk building materials are:

- High throughput per footprint: a single portal crane can replace several wheel-loaders;
- Reduced double-handling: direct barge-to-truck discharge minimizes material degradation;
- Energy efficiency: electric drives plus regenerative lowering cut energy used by 20–30 % versus mobile equipment;
- Automation readiness: fixed rail path simplifies implementation of remote or fully automated operation modes.

2. CLAMSHELL (GRAB) BUCKETS

A grab consists of two (or more) articulating shells that close around loose material under an external or self-contained actuation force, hoist the load, and then reopen at the discharge point [3]. The energy needed to close the shells can be provided purely mechanically (via ropes), hydraulically (via cylinders), or electro-hydraulically (a hybrid of the two).

2.1 Primary classification by actuation method

The classification of clamshell grabs is presented in the table below.

.Table 3. Classification of clamshell grabs

Type	Typical Crane Interface	Key Components	Typical Capacity (m³)	Pros	Cons	Best-fit Materials
4-Rope Mechanical Grab	Two hoist ropes + two closing ropes (portal crane with twin-drum winch)	Lever system, sheaves, heavy-duty hinges	5 – 30	• Highest closing force (rock, boulders) • No onboard hydraulics → low maintenance	• Requires specialised 4-rope crane • More ropes to maintain	Dense, coarse or abrasive bulk (gravel, crushed rock, scrap)
2-Rope Touch-Down Mechanical Grab	Single hoist rope + single closing rope (2-drum crane)	Internal spring or ballast for re-opening	2 – 15	• Works on standard 2-drum quay cranes	• Lower closing force • Opening depends on gravity ⇒ slower cycles	Medium-density bulk, general cargo
Electro-Hydraulic Grab	Single hoist rope (hook) + electric power cable (400–690 V) OR battery pack	Built-in squirrel-cage motor, gear pump, cylinders	3 – 25	• Fits any single-hook crane • High grabbing force, precise control • Quick swap between vessels	• Requires power slipring or battery swap • Heavier dead weight	Damp or fine bulk (sand, fertilizer), mixed cargoes
Full-Hydraulic Grab	Crane provides twin hydraulic lines through a rotator	Cylinders mounted between shells	0.8 – 12	• Compact, light, inexpensive • Fast cycle time on excavator-based gantries	• Needs hydraulic swivels & hoses • Limited to ≤ 35 MPa system pressure	Small gantries, barge unloaders, soils

2.2 Geometry Variants

Table 4 presents some geometric variants.

Table 4. Shell Style and Application

Shell Style	Description & Application
Watertight / Closed	Continuous side plates; prevents loss of fine sand, cement, or silt.
Semiclosed (Perforated)	Slotted side plates allow for water drainage; ideal for dredged sand or wet gravel.
Skeleton (Rake)	Wide bars instead of plates; screens oversized rocks; used in quarry loading.
Orange-Peel (Multi-Petal)	4–8 interleaved jaws; excells in coarse scrap or rubble where penetration is needed.
Dredging/Environmental	Extra seals + overflow valves for silt remediation; sometimes double-closing seal.

When portal cranes handle **construction aggregates**, the industry sweet-spot is a **closed two-shell clamshell** sized so that **loaded weight ≈ 70 % of crane's SWL**—this balances cycle time and fill factor.

2.3 Selection Checklist

The selection criteria for the grapple drive are presented in table 5.

Table 5. Selection based on material

Criterion	Practical Rule-of-Thumb
Material Bulk Density	≥ 1.6 t m⁻³ → choose smaller, reinforced shells; ≤ 1.2 t m⁻³ → larger volume possible.
Moisture Content / Flowability	Wet, cohesive soils benefit from higher closing forces (4-rope or electro-hydraulic).
Cycle Time Target	If < 60 s, prioritize high closing speed (hydraulic or electro-hydraulic) and auto-greasing hinges.
Crane Drum Arrangement	4-drum crane → mechanical grab is the most economical; 2-drum or hook-only → electro-hydraulic.
Power Availability on Quay	Shore power present → electro-hydraulic (plug-in) is viable; off-grid → diesel-hydraulic or battery.
Maintenance Regime	Remote ports often prefer rope grabs (no pumps, seals) to minimize spare-parts inventory.

2.4. Performance Metrics

Performance values are:

- Filling Factor (η): 85 – 95 % of nominal volume for free-flowing aggregates; 60 – 75 % for cohesive clays.
- Closing Force: 100 – 350 kN for mid-size (11 m³) mechanical grabs; electro-hydraulic units of similar size generate up to 250 kN.
- Wear Life: High-hardness (HB 400+) wear strips add ~3 × shell life in sand and gravel duty.
- Energy Use: Regenerative lowering on electric cranes saves ~1.5 kWh per 100 t handled versus diesel excavator feeding a hopper.

3. EFFICIENCY & ECONOMY OF PORTAL CRANE + GRAB SYSTEMS

The efficiency and economy of gantry and overhand crane systems are presented in a summarized form below.

Table 6. Used energy for different grabbers

Configuration	Typical specific electricity use	Where the figure comes from
4-rope mechanical grab on rail-mounted portal crane	0.25 – 0.32 kWh	Full-scale measurements on a 25 t quay crane handling coal (0.27 kWh t)
Electro-hydraulic grab on single-hook crane	0.30 – 0.45 kWh	Manufacturer & port-operator data; extra 8-12 % due to onboard motor losses
Same crane fitted with a regenerative inverter	-15 … -30 % vs. above	VFD regen drive suppliers & trade press

3.1 Illustrative Cost-of-Energy Calculation

Assume a 25 t rail-mounted portal crane unloading sand at 500 t/h for 3 000 h/year.

Table 7. Economy with a regen-unit retrofit

Item	Without regen	With regen (-20 %)
Specific energy	0.27 kWh t	0.216 kWh t
Annual tonnage	1.5 Mt	1.5 Mt
Annual kWh	405 MWh	324 MWh
Romanian industrial tariff (Dec 2024) ≈ €0.14 kWh	€56.7 k	€45.4 k
Energy saving		≈ €11 300 per year

A regen-unit retrofit for this power class costs €40 000 – €60 000; pay-back ≈ 3 – 5 years at the electricity prices above.

3.2 Life-Cycle OPEX Comparison of Grab Types

In the following part, we present different values of the operational costs over the life cycle of the types of clamping devices.

Table 8. Operation expenses

Cost driver (per 11 m³ grab)	4-rope mechanical	Electro-hydraulic	Hydraulic
Rope / sheave wear	€6 – 9 t handled	none	none
Hydraulic seals/oil changes	none	€2–4 t	€4–6 t
Downtime for repairs	low (simple)	medium (motor + pump)	high if hoses damaged
Cycle time (s)	65–80	55–70 (more grabs h)	50–65
Net kWh t (incl. fill factor)	0.27	≈ 0.32 (5 % more energy but 10 % more throughput)	0.30–0.35

Result: Where a 4-drum crane already exists, the mechanical grab delivers the lowest €/t.

In mixed-cargo terminals, the electro-hydraulic grab's 8–12 % productivity gain offsets its higher energy use after ~18 months of service.

3.3 Carbon footprint perspective

Carbon footprint perspectives are:

EU-27 average grid intensity 2023: 0.242 kg CO_2 kWh.

Baseline emissions: 0.27 kWh/t × 0.242 kg kWh ≈ 0.065 kg CO_2/t.

A 20 % regen cut therefore saves 13 g CO_2/t → 19 t CO_2 yr for the example crane (1.5 Mt).

This improves the terminal's ESG score while cushioning against future carbon-pricing.

3.4 Capital Expenditure / Operation Expenditure for a Mid-Size Aggregate Terminal

The following table presents the Capital Expenditures / Operating Expenditures for a medium-sized aggregates terminal.

Table 9. Costs of 4 rope mechanical grab vs Electro-hydraulic

Item	Unit	4-rope mech. grab	Electro-hydraulic grab
Purchase price (CapEx)	€	110 000	130 000 (motor-pump package)
Annual depreciation (10 yr)	€/year	11 000	13 000
Grab-specific OpEx (ropes / seals, servicing)	€/year	35 000	42 000
Specific energy demand	kWh/t	0.27	0.32
Romanian industrial power tariff	€/kWh	0.14	0.14
Annual energy cost (1.5 Mt)	€/year	56 700	67 200
Total annual cost	€/year	102 700	122 200
Cost per tonne	€/t	0.068 €/t	t

4. PARAMETRIC 3D MODELLING OF A 11 M³ CLAMSHELL GRAB

Grapples are highly versatile working devices with automatic loading and unloading, designed to pick up bulk materials, such as earth, sand, gravel, but also other types of materials such as metal scrap or large fragments of rocks, logs or semi-finished products. Taking into account the drive mode, they can be operated with: cable (one, two or four control cables), with an electric motor and a hydraulic on. The construction of the buckets differs from one type to another depending on their destination.

An 11 m³ clamshell grab is modelled here using modern CAD/CAE/CAM technologies widely applied in mechanical engineering.

The CAD environment covers 3D product design; CAM modules drive CNC machine tools directly from the CAD geometry, while CAE tools simulate the virtual product under various environmental and operating conditions.

The geometric values of the cup are given in table 10.

Table 10. Geometric values of the cup

Parameter	Value
The volume of the cup	11 m³
Cup length	2650 mm
Bucket width	~2400 mm
Cup height	~1900 mm
Grapple's own weight	8,3 t
Sand density	1,6 t/m³
Grab arm length	2000 mm
Cable diameter	Ø 30 mm
Joint bolt diameter	Ø100 mm
Distributed linear load	10 t
Cup plate length	2600 mm
Lifting height	15 m

Three-dimensional design software offers a modern and highly efficient route to creating, managing, and executing large-scale projects by providing engineers with a clear holistic view that supports cost optimisation and resource allocation.

4.1 Advantages of Solid Edge for 3D Modelling

For the parametric modelling of the grab, we employed Siemens Solid Edge, a Windows-based 3D CAD system offering solid and assembly modelling as well as drafting capabilities [2].

Thanks to its Synchronous Technology, advanced sheet-metal tools and integrated simulation, Solid Edge is widely adopted across mechanical, aerospace, automotive, and consumer-goods industries.

2021.

4.2 3D Modelling of a Clamshell Grab

The 3D grab model was initiated in the **Sketch** environment, with the frequent use of the **Line, Circle,** and **Trim** commands.

Solid bodies were subsequently generated using **Revolve, Extrude,** and **Hole** features.

Within the **Assembly** module, the **Flash Fit** tool enabled rapid constraints and quick planar or axial alignment.

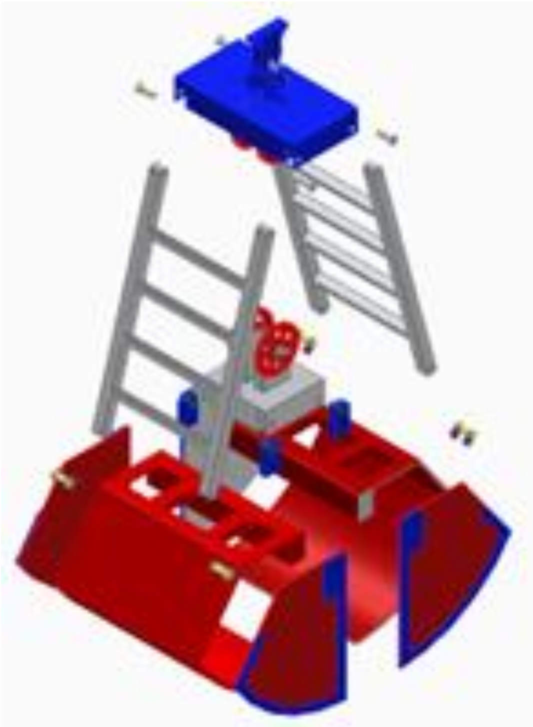

Figure 2 3D grapple model

4.3 Finite-Element Analysis of the Quick-Change Coupling Finite-Element Analysis of the Quick-Change Coupling

A detachable chain-type coupling—subject to the highest mechanical loads—was meshed and loaded with 400 kN (≈ 40 tf) [4].

Von Mises stress distribution and displacement plots confirm a safety factor >1.6 with no plastic deformation (Figures 3 and 4).

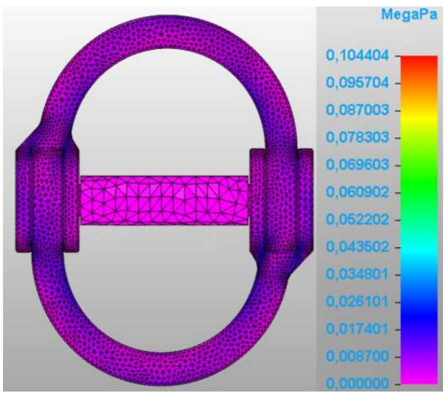

Figure 3 Stress distribution

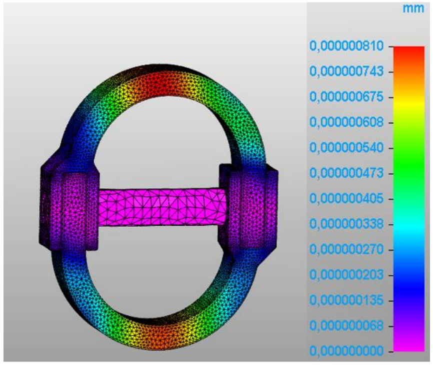

Figure 4 Maximum and minimum displacements

4. CONCLUSIONS

As a result of the study, we reached the following conclusions:

- Gantry cranes with mechanical clamshell grabs offer the most efficient quay handling of construction aggregates, achieving 400–1.000 t/h while avoiding material-damaging transfers;
- The "4-drum gantry crane + 4-rope grab" setup offers the lowest cost (~€0.068/t) thanks to no hydraulic oil use and low maintenance, while a single-hook electro-hydraulic grab raises costs to ~€0.081/t.
- Installing a regenerative inverter can reduce energy consumption by ~20%, saving around €11.300 and avoiding ~19 t of CO_2 emissions per year for a 25-ton crane unloading 1.5 Mt of aggregates annually. The estimated payback period is 3–5 years;
- Finite Element Analysis of the quick coupler confirms a safety factor > 1.6 under a 400 kN load, validating the structural integrity under intensive operation (A6–A8 duty class, i.e., over 1.000.000 cycles) without any risk of plastic deformation;
- The parametric 3D modeling of the 11 m³ grab in Siemens Solid Edge enables fast geometry iteration and direct CAM export, reducing engineering time and allowing volume adjustments for bulk densities between 1.2–1.6 t/m³ without redesigning from scratch;
- From an ESG perspective, the regenerative electric drive system with mechanical grab improves sustainability through low emissions, low energy consumption, and high reliability - crucial aspects for future carbon policies and for competitiveness in bulk cargo handling.

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