Journal of Building Technology, 2024, Volume 6, Issue 2
DOI: 10.32629/jbt.v6i2.2745
ISSN Online: 2717-5103
ISSN Print: 2705-1390

Conceptual Design of Gravity Battery and Gravity Electric Station

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Abstract: The article aims to describe the technical criteria for the conceptual design of a gravity-based battery or accumulator solution. It introduces a technology derived from the 1380 mm descent of a four-story reinforced concrete building, managed by the author. The methodology follows the author's doctoral thesis and is applied in his professional practice and scientific-technical articles. The description outlines the design criteria for a 100 kWh per discharge cycle solution, addressing the challenge of storing electrical energy using mechanical means while minimizing the carbon footprint, all achieved with European technology and raw materials. The industrial development of this solution requires significant investment beyond the author's reach, so this article serves to make the concept known to the scientific and technical community, with wishes for success to prior developments by companies like Gravitricity and Energy Vault.

Key words: heavy lifting; gravity battery; gravity stack; electric station

1. Introduction

The purpose of this article is to describe the technical criteria for the conceptual design of a solution of batteries or accumulators by gravity. This invention is a technology derived from the 1380 mm descent of a four-story reinforced concrete building, whose design and construction management was carried out by the author (Aparicio García, Method for the descent or ascent of a four-story building. Derived applications, 2020) The methodology followed is the one referred to by the author in his doctoral thesis and which he applies continuously in his professional practice and in all the scientific-technical articles developed (Aparicio García, Roadway joints in bridges: proposal of integral joint in abutments (JIE), 2016). All prices given for the economic analysis are approximate and non-binding.

2. Current Situation

The need for electrical energy storage is promoting research in all areas, from hydrogen to the various electrochemical batteries. A gravity accumulator or battery (or pile) is one that stores surplus electrical energy in potential energy and returns it in electrical energy on demand. The known and technologically mature forms of gravity energy storage are reversible hydroelectric power plants. The new forms of storage that are being developed are proprietary technologies. Their engineering is attached to private initiatives that finance their development and serve as a fundamental reference for this work. Both developments store energy by lifting heavy weights and return electrical energy as they descend. We wish them both every success, as they are technologies that decarbonize energy production.

2.1 Vault Energy

The project developed by Energy Vault (Energy Vault, 2022) is the first source of inspiration for the solution to be proposed. Potential energy is stored with discrete weights, of 35 tons each, materialized in concrete blocks that are stacked with the surplus energy. When the blocks are unstacked, the potential energy is transformed into electrical energy to the grid through winch-alternators, as required by the system. The potential energy is transformed into mechanical energy, so the yields are very high. At least that is what is indicated in the proof of concept already executed.

The sources are public, and provide data that happens to contrast with the following self-explanatory table that summarizes the reverse engineering that audits the proposal. (Energy Vault, 2019).

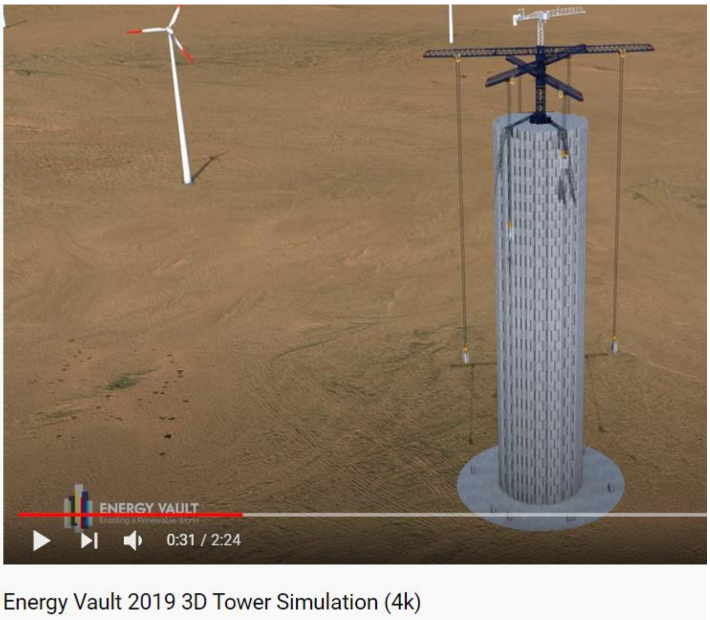
Table 1. Reverse engineering of the stackable block solution

Energy Vault					
Ref	Pilot test	Expected	Ud	Formula	Comment
Data from youtube feeds					
HG	120	120	m	Source data	Crane heights
bg	6	6	nº	Source data	Crane arms
Pb	35	35	ton	Source data	Weight of concrete blocks
d	2,700	2,700	kp/m^3	Source data	Density
V	13.0	13.0	m^3	V=Pb×1000/d	Block volume
h	3.0	3.0	m	Estimated	Estimated floor height
nºH	40	40	nº	nºP=HP/h	Number of floors
S	4.3	4.3	m^2	S=V/h	Estimated floor area
L	2.1	2.1	m^2	L=S^0.5	Side of square in block floor plan
Ef	85%	90%	%	Source data	Efficiency
nºB	5,000	5,000	nº	Source data	Number of blocks
ri	175,000	175,000	ton	ri=nºB×Pb	Gravity pile weight
Occupancy check at the plant					
VP	64,814.8	64,814.8	m^3	VP=ri/d	Strict pile volume
HP	120	120	m	Estimated	Estimated pile height
SP	540.1	540.1	m^2	SP=VP/HP	Strict floor area
LP	23.2	23.2	m^2	LP=SP^0.5	Side of square in strict plan
Nominal source power data					
En	35	35	MWh	Source data	Nominal energy
Potential energy testing per piston cycle					
g	9.81	9.81	m/s^2	Data	Gravity
dh	60	60	m	dh=HP/2	Average stroke of the mass nucleus
Epi	10,3005,000,000	103,005,000,000	J	Epi=g×ri×dh×1000	Cumulative potential energy
Epi	28613	28613	kWh		Cumulative potential energy
Epi	28.6	28.6	MWh	Epi<En	Cumulative potential energy
Source economic data: cost of gravity battery					
T	30	30	years	Source Data	Estimated useful life
P_pg	7,000,000.00 €	8,000,000.00 €	€	Source Data	Estimated cost of the plant
G	Alternators	Alternators		Source Data	Generation similar to hydro turbines

T0	2019	2019		Source data	Project
TF	2020	2020		Source data	End of construction
CIA	tata power	tata power		Source data	Power partner in INDIA
P_BE	70,000,000.00 €	80,000,000.00 €	€	P_BE=P_BG×10	Estimated cost of equivalent chemical batteries
Economic data of the source					
c	60	60	€/m³	Estimated data	Cost of concrete
Ch	3,888,888.89 €	3,888,888.89 €	€	Ch=c×VP	Estimated cost of concrete costs
Ci	3,111,111,11 €	4,111,111,11 €	€	Ci=P_pg-Ch	Estimated cost of other facilities

From the table above, a control of the accumulable potential energy with the gravity pile is made and a lower accumulable energy per cycle is inferred than that indicated in the public videos promoting the solution. The control number performed gives an accumulable potential energy of only 81% of that indicated in the commercial data. But it could be higher for the same volumetric dimensions if a higher density material is used, such as concrete with embedded metal plates. In other words, a greater number of stackable elements of smaller dimensions by achieving apparent densities of 30-40 kN/m^2 based on scrap. The installation cost is of the same order of magnitude as the cost of concrete blocks. The solution is protected by a family of patents of which one of them stands out (USA Patent No. US20200025182A1, 2020).

Figure 1. Vault energy gravity pile. Proof of concept executed in Switzerland (Energy Vault, 2022).



Energy Vault 2019 3D Tower Simulation (4k)

Figure 2. Vault energy gravity stack (Energy Vault, 2019).

The solution, which can only operate with six concrete blocks at a time, does not seem capable of supplying much current to the grid. The wind and cable capacity issues seem to be limitations of the solution, which I am sure are solved or in the process of being solved by the engineers. It is important to recognize that the construction of the gravity pile is already underway, so it must have expected feasibility.

2.2 Gravitricity

Another form of gravity stack developed by the company Gravitricity has been found. The website describes the solution (Gravitricity, 2022).

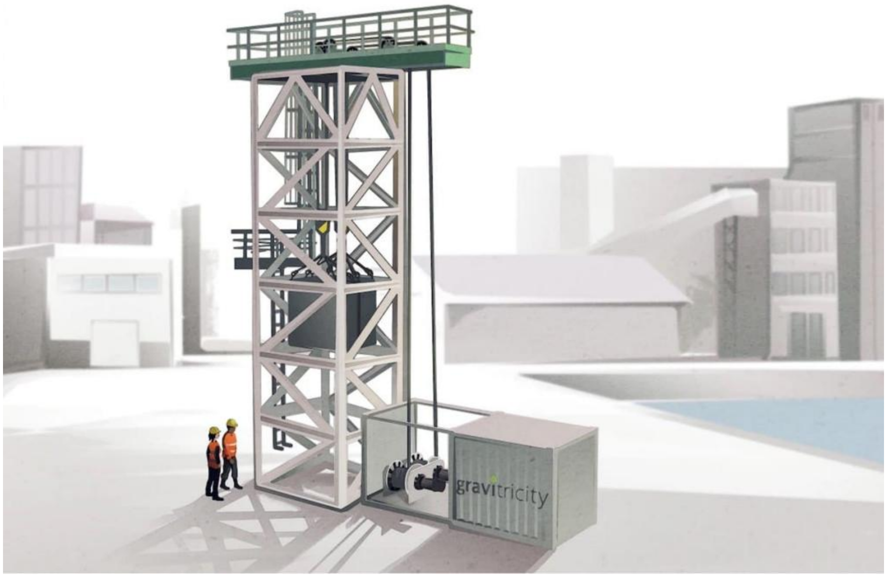


Figure 3. Gravity pile. Proof of concept. Gravitricity.

The above infographic describes the proof of concept already executed in Scotland. As with the previous solution, it is technically audited based on the public data provided in the following self-explanatory table.

Table 2. Reverse engineering of block solution in mine shafts. Gravitricity

Gravitricity				
Ref	Pilot test	Ud	Formula	Comment
Source data				
HG	14.5	m	Source data	Lifting height
bg	1	nº	Source data	Crane arms
Pb	25	ton	Source data	Weight of concrete blocks
d	2,300	kp/m^3	Source data	Density
V	10.9	m3	V=Pb×1000/d	Block volume
h	1.5	m	Estimation	Estimated floor height
nºH	2	nº	nºP=HP/h	Number of floors
S	7.2	m2	S=V/h	Estimated floor area
L	2.7	m2	L=S^0.5	Side of square in block floor plan
Ef	85%	%	Source data	Efficiency
nºB	2	nº	Source data	Number of blocks
ri	50	ton	ri=nºB×Pb	Gravity pile weight
Potential energy testing per piston cycle				
dh	7	m	Source data	Average stroke of the mass nucleus
Epi	3,433,500	J	Epi=g×ri×dh×1000	Cumulative potential energy

Gravitricity				
Ref	Pilot test	Ud	Formula	Comment
Epi	0.95	kWh		Cumulative potential energy
Technical data of the prototype				
P_pg	1,160,000.00 €	€	Source data	Estimated cost of the plant
T	25	años	Source data	Estimated useful life
TF	2021		Source data	End of construction
Pp	250	kW	Source data	Peak power
tc	11	s	Estimation	Discharge cycle time
Epi_r	0.76	kWh	Epi_r=tc×Pp/3600	Estimated real potential energy at peak power
h	80%	%	h=Epi_r/Epi	Yield
Large-scale estimation				
Epi	24.4	MWh	Source data	Potential energy per cycle
Epi	24,400	kWh		Returnable potential energy per cycle
P	10	MW	Source data	Estimated power to be supplied
tc	2.44	h	tc=Epi/P	Discharge cycle time
nºc	730	nº/año	Source data	Number of cycles per year
nºcd	2	nº/día	nºcd=nºc/365	Number of cycles per year
E	17,812	MWh/año	E=Epi×nºc	Upper limit of energy produced per year
pe	0.112	€/kWh	Estimate	Price of electricity
T	50	años		Lifetime
ET	890,600,000	kWh	ET=Epi×nºc×T	Lifetime production
pa	1,994,944.00 €	€/año	1.53	Annual production/TIR
PA	99,747,200.00 €	€/T	PA=Epi×nºc×T×pe	Lifetime production
hi	80%	%	Source data	Lower efficiency
hs	90%	%	Source data	Higher efficiency
Epi0_s	30.5	MWh	Eps0_s=Epi/hi	Higher potential energy to be delivered per cycle
Epi0_i	27.1	MWh	Eps0_i=Epi/hs	Lower potential energy to be delivered per cycle
Estimation of megascale data in mine shafts				
hc	300	m	Source data	Depth of well
ri	12,000	ton	Source data	Dead load
ri/b	500	ton	Source data	Weight per massif
nºB	24	nº	nºB=ri/ri/B	Number of blocks or clumps
nºcb	8.0	nº	Estimate	Number of winches per massif
c/cb	62.5	ton/cb		Load per winch
Epi	35,316,000,000	J	Epi=g×hc×ri×1000	Potential energy per cycle
Epi	9,810	kWh		Potential energy per cycle
Large-scale cost estimation				
ca	171.00 €	€/MWh	ca$=1.0×ca€	Gravity battery production cost
CA	3,045,852.00 €	€/pila	CA=ca×E	Cost of gravity battery

It is important to cite the estimated relative costs for each type of electrical energy storage. They are summarized in the figure below and are extracted from the outstanding work of the Gravitricity team.

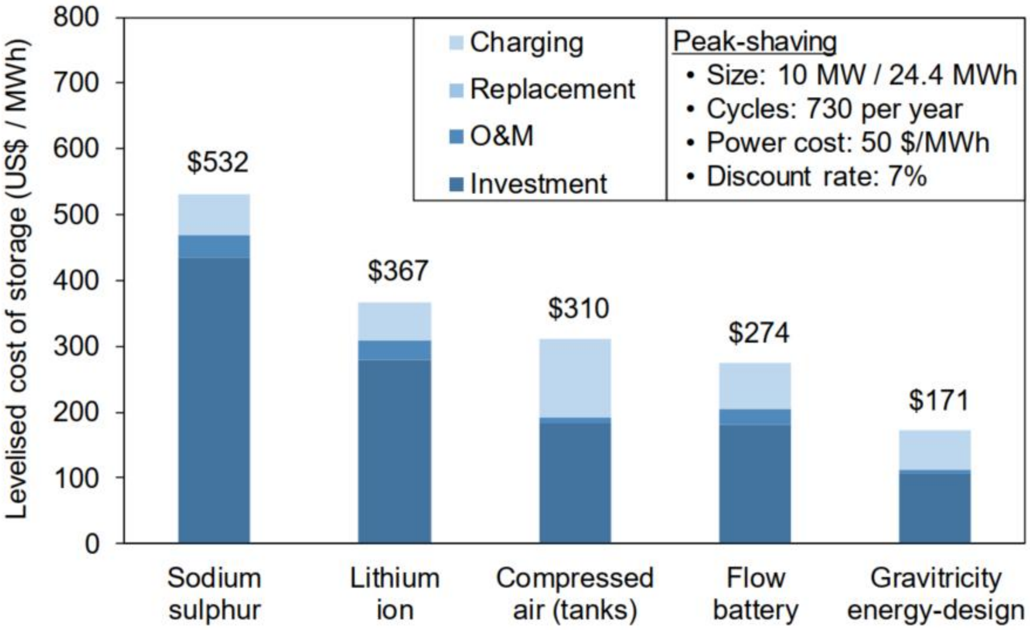


Figure 4. Relative storage cost of Gravitricity-type gravity pile compared to competing technologies (Gravitricity, 2022).

The solution is protected by a family of patents of which the latest one stands out (UK Patent No. WO2020260596A1, 2020).

3. Piston Cells or Gravity Batteries or Accumulators

Currently, there are two ways of storing surplus energy in valley periods with mature technology:

- Recuperar potential energy by rising water back to the reservoir with hydroelectric utilization, which has no noticeable environmental problems, i.e. by reversible hydroelectric power plants. Special mention in the technical-economic defense of its hybrid implementation with solar photovoltaic and wind energy is worth mentioning the engineer Mr. José Rebollo Pericot.
- Electric accumulator, batteries or rechargeable batteries. An urgent solution for electric cars, but requiring extensive mining for the raw material and with a high environmental cost for decommissioning.

The following outlines the minimum technical and economic criteria for the exploration of this new technology at the beginning of its learning curve:

- For the previously controlled Swiss and Scottish gravity piles, a Spanish solution has now been proposed.

The proposed alternative solution is the so-called piston battery or gravity battery or rechargeable battery. Linear pre sizing was performed for practical applications. The approximate dimensions of elevatable piston buildings of a certain height will be justified, but with particular attention to a case that can be executed by means of a suitable construction project.

The surplus energy from other sources is transformed into potential energy by means of hydraulic elevators, hydraulic climbing jacks with great efficiency in the ascent. The potential energy is returned transformed into electrical energy through alternators and multipliers. The first idea that amalgamates the technical solution is to convert high-density waste from landfills into raw material. The dead weight or clump can be configured in any high-density material.

To increase the density of the dead weight, aggregates or fillers of high specific weight can be used, resulting in smaller volumes than those corresponding to a typical concrete. In any case, it is the technical economic study that would determine the executive solution. The following figure was one of the first conceptual sketches.

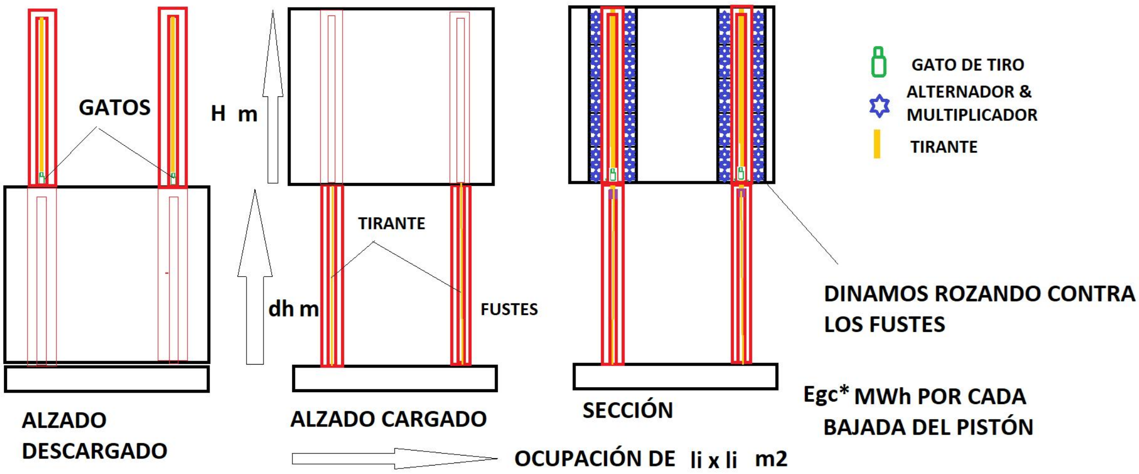


Figure 5. Conceptual diagram of piston pile.

The gravity stack is loaded when the dead weight is raised and unloaded when it is lowered. The dead weight is lifted by a climbing jack attached to the dead weight. The climbing jack lifts the mass by a fixed but easily replaceable tie rod, between the top head beam and the foundation. This is the fundamental value of technological uniqueness of the solution by not bending the steels. The top beam is supported on reinforced concrete shafts embedded in the foundation.

When the solid is released, rotors or dynamos, anchored internally to the dead weight, engage with metal racks that are solidly connected to the concrete supports. These rotors connected to multipliers and these to dynamos or alternators, generate electricity. From here the design methodology is described.

3.1 Initial data for gravity electrolyzer station

The prototype is intended to be a proof of concept of a marketable solution. To this end, the battery is sized so that it can charge a 100 kWh storage battery per discharge cycle in 15 minutes. From this a priori, one of the fundamental applications is inferred and described with an example: a solar farm of n photovoltaic panels can feed a gravity battery during the time when there is no car for recharging, so that the first vehicle that requires it is ready for rapid recharging. The applications derived for the reduction of contracted power at electric stations, if over-power pulses can be guaranteed with this type of batteries on demand, is another fundamental application. The large-scale solution is a technical alternative to hydroelectric or combined cycle power plants. Only economic viability, if proven, can launch the new industry.

Table 3. Starting data for the sizing of an electrolyzer station

Gravity battery for fast electrolyzer station				
Ref	Pilot test	Ud	Formula	Comment
Fundamental data				
BT	100	kWh		Tesla battery capacity
hc	0.25	h	Data to be established with prototype	Full cycle descent hours
ri	1,750	t	Data	Minimum module tons
d	3,000	kp/m^3	Data	Average dead density

3.2 Approximation to the dimensions and cost of the solid

The following table describes, by simplifying volumes, the dimensions of the high-density concrete mass to be installed.

Table 4. Dimensions and cost estimate of the massif

Geometrical definition of annually executable battery unit				
vi	583	m^3	vi=1000×ri/d	Dead volume
H	4.05	m		Dead height
si	144.03	m^2	si=vi/H	Floor area
li	12.00	m	li=si^0.5	Dead side
cr	30	€/m^3	Estimation	Cost of backfill with compaction treatment
crt	17,500.00 €	€	crt=cr×vi	Total cost of fill

3.3 Approximation to the dimensions and cost of the foundation

The following table describes, by simplifying volumes, the dimensions of the reinforced concrete foundation slab to be provided. The importance of the foundation should be emphasized, because it can be an important technical limitation as deep foundations or high bearing capacity substrates may be required.

Table 5. Dimensions and estimated foundation cost

Piston battery foundation slab				
el	0.80	m	Estimation	Thickness of foundation slab
vlc	115.23	m^3	vlc=el×li^2	Volume of foundation slab
cl	60	€/m^3	Estimation	Reinforced concrete foundation cost
ccl	6,913.58 €	€	cci=vlc×cl	Cost of foundation
Estimation of the required soil bearing capacity				
st	12	t/m^2	st=d×H/1000	Average design stress of the soil
sa dm	50	t/m^2	Land data	Permissible soil stress

From the table above, we can infer the need to take into consideration the geotechnical criteria for this type of solutions. The settlements could be greater than those allowed in the standards for this type of structure, as long as they are uniform. If there is inclination of the base slab, the verticality of the shafts must be taken into account, although this tolerance could be given or corrected with piles, preloads or adequate shaft embedment details.

3.4 Potential energy per cycle

The following table describes, based on the above data, what is the maximum cumulative potential energy. Each down cycle returns energy to the system. The number of cycles per day is a limitation of the system.

Table 6. Potential energy per cycle

Potential energy per piston cycle				
g	9.81	m/s^2	Data	Gravity
dh	36	m	Data	Mass core race
Epi	**618,030,000**	J	Epi=g×ri×dh×1000	Potential energy per cycle
Epi	**172**	kWh		Potential energy per cycle
Epi	**0.172**	MWh		Potential energy per cycle

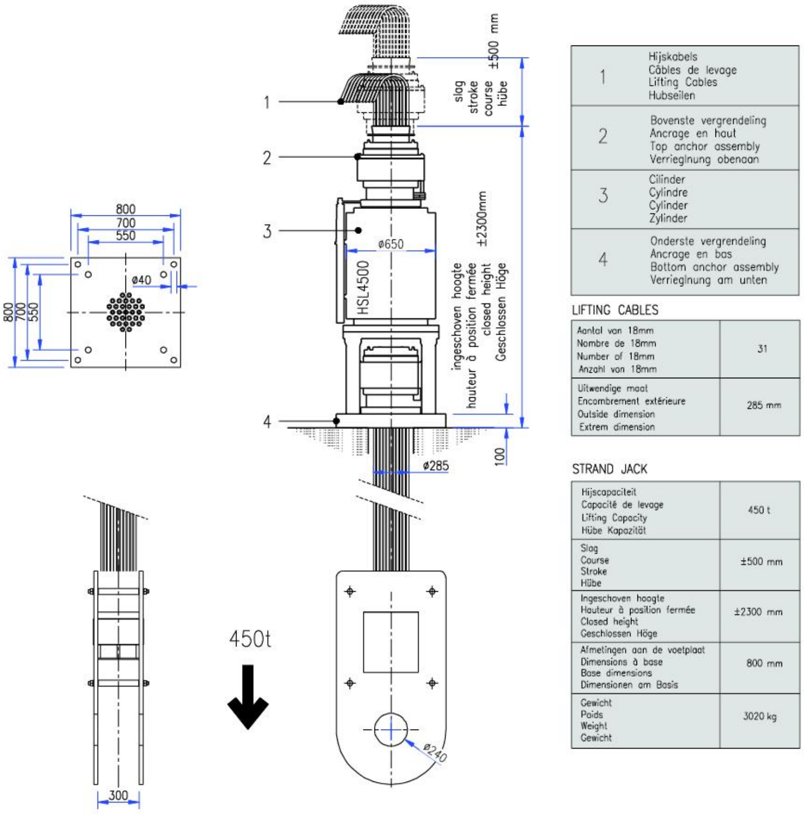
3.5 Dimensioning of the necessary jacks and their cost

The following table describes, based on the above data, how many and of what load capacity jacks are required.

Table 7. Number of climbing jacks and cost

Sizing of the necessary jacks				
st	36.01	m^2	st=si/nºg	Taxable area per cat
cg	0.50	m	Data	Cat stroke
hg	2.50	m	manufacturer's data	Cat height
nºg	4	ud		Number of jacks
rig	438	ton	rig=ri/nºG	Reaction per cat
cg	12,000	€/gato	Estimation	Cost per jack unit
ceg	48,000.00 €	€	ceg=cg×nºg	Lifting cost per jack

From the above table, it should be noted that the jacks can be of the VSL (VSL, 2022), Sarens or similar type. The dimensions of the jacks are not negligible. It is important to know the speed at which the loads are lifted.



1	Hijskabels Câbles de levage Lifting Cables Hubseilen
2	Bovenste vergrendeling Ancrage en haut Top anchor assembly Verrieglnung obenaan
3	Cilinder Cylindre Cylinder Zylinder
4	Onderste vergrendeling Ancrage en bas Bottom anchor assembly Verrieglnung am unten

LIFTING CABLES

Aantal van 18mm Nombre de 18mm Number of 18mm Anzahl von 18mm	31
Uitwendige maat Encombrement extérieure Outside dimension Extrem dimension	285 mm

STRAND JACK

Hijscapaciteit Capacité de levage Lifting Capacity Hübe Kapazität	450 t
Slag Course Stroke Hübe	±500 mm
Ingeschoven hoogte Hauteur à position fermée Closed height Geschlossen Höge	±2300 mm
Afmetingen aan de voetplaat Dimensions à base Base dimensions Dimensionen am Basis	800 mm
Gewicht Poids Weight Gewicht	3020 kg

Figure 6. Example of Sarens type climbing jack (Sarens, 2022).

Table 8. Limitation of climbing speed for climbing jacks

Upload speed limit for uploads				
dh	36	m	Datum	Massive core stroke
Rk	10,350	kN	Datum; between 5 and 10 m/s	Maximum jacking load
v	10	m/h	Datum; between 5 and 10 m/s	Load rise speed
ts	3.6	h	ts=dh/v	Rise time
car	0.5	m	Sarens data	Pulling jack stroke
t_car	0.1167	h	7 minutes per stroke	Load lifting speed per stroke
v	4.29	m/h	Datum; between 5 and 10 m/s	Load lifting speed
cd	6.67	nº	cd_max=24/ts	Cycles per day

The climbing speed of the jacks in load is between 5 m/h and 10 m/h, which limits the number of cycles to six per day with current technology, with no learning curve. The climbing brace must be made of post-tensioned cables, as bars require couplers every 12 m and prevent the passage of the jack. It also allows substitution. The above table summarizes the main current technological limitation, which is found in the climbing speed of the climbing jacks, which must be used more quickly.

3.6 Dimensioning of the tie rods or lianas and their cost

The following table describes, based on the above data, how many and of what dimensions tie rods are required.

Table 9. Number and type of suspenders or lianas and their cost

Dimensioning of the required bar tie rods				
fpk	18.7	t/cm^2	Steel Y1870	Characteristic strength of rebar
gp	1.10			Strength reduction coefficient
fpd	17.0	t/cm^2	fpd=fpk/gp	Ultimate strength of rebar
Ap	26	cm^2	Ap=rig/fpd	Required steel area
F	5.7	cm	F=2×(Ap/PI())^0.5	Equivalent bar diameter
Fc	6.5	cm	Fictitious as cables are needed	Diameter of commercial bar
AFc	33	cm^2		Area of commercial diameter
nºFc	1	nº		Number of commercial diameter bars
ptt	1,147.45	kp	ptt=AFc×7850×hf×nºFc	Total weight of a tie rod
cl	2	€/kp	Prestressing cable price	Cost of prestressing steel
ctb	9,179.57 €	€	ctb=cb×ptt×nºg	Total cost of bars

3.7 Sizing and cost of shafts or supports

The following table describes, based on the above data, how many and of what dimensions are the shafts or supports required. It should be noted that the header beam is not dimensioned and that the cost of the shafts includes the proportional part of these beams.

Table 10. Number and type of futures or supports and their cost

Dimensioning of shafts				
P	1,750	ton	P=ri	Weight of each piston
nºf	8	nº	nºf=nºg×2	Number of shafts
qf	219	ton		Load per shaft
fck	25,000	kN/m^2	Pp=pm×nºm/1000	Characteristic strength of concrete
gc	1.5	-		Strength reduction coefficient
fcd	14,167	kN/m^2	fcd=0.85×fck/gc	Reduced concrete strength
Ac	0.1544	m^2	Ac=10×qf/fcd	Concrete area
Lc	0.39	m		Equivalent shaft side
Lc×	0.60	m		Shaft side
hf	44.05	m	hf=dh+H+hg+cg+1	Shaft height
I	0.010800	m^4	I=Lc×^4/12	Rectangular section inertia
l	254	-	l=hf/(I/(Lc×)^2)^0.5	Slenderness
vlf	127	m^3	vlf=hf×nºf×(Lc×)^2	Volume of shafts
cf	180	€/m^3		Cost of reinforced concrete of shafts
cft	22,835.52 €	€	cft=cf×vlf×nºf	Total cost of shafts

The shafts must be of high-capacity precast concrete and 12 m sections that are easy to join to combine easy transportability with easy prefabrication; or prefabricated on site.

3.8 Down time of each cycle and rotor diameter

The following table describes, based on the number of rotor turns per meter of massif descent, the rotor diameter, which will be critical to determine the rotor's resistance capacity.

Table 11. Determination of required rotor diameter

Descent time of each cycle and rotor diameter				
hc	0.25	h	Data to be established with	Full cycle downhill hours
cr	36	m	cr=dh	Descent stroke
v	2.400	m/min	v=cr/cr/60	Descent speed
nºv	8.0	nº/m		Number of turns per meter of descent
u	0.125	m	u=v/nºv	Rotor turn perimeter
F	0.040	m	F=u/PI()	Diameter of each rotor

The piston will descend at a slow speed, to minimize losses in kinetic energy and to avoid impact problems. In principle, a speed of 36 m/15 min = 2.40 m/min is chosen. It is therefore necessary to provide multipliers to accelerate the rotor to feed the generators, to admit kinetic energy losses and to provide neoprenes for partial energy recovery and for solid support during maintenance. The resistance capacity of the rotors is another technological limitation, which is shown in the following table.

Table 12. Checking the bearing capacity of the rotors

Dimensioning of rotor resistance capacity				
nºr	14		nºr=naf	Number of rotors
fsk	3.6	t/cm^2	Steel 480	Characteristic strength of steel
gs	1.82		1.05×3^0.5	Strength reduction coefficient
fsvd	2.0	t/cm^2	fsvd=fsk/gp	Ultimate strength of steel
ga	1.50			Coefficient of load increase
Asrv	166	cm^2	As=ga ×ri/fsvd/2	Required shear area per rotor
A(F)	12	cm^2	A(F)=PI()×(F2×100/2)^2	Rotor round area
nºF	13		nºF=Axv/A(F)>nºr	Number of rotors required

3.9 Multipliers, alternators and their cost

The following table describes the estimated number of low-revolution alternators and multipliers and their cost.

Table 13. Multipliers and alternators and their cost

Zodiac Aerospace Alternator				
M	300	rpm	See prototype	Revolutions after applying the multiplier
Ppa	8	kW	Zodiac Data	Peak alternator power
Eg	2	kWh/c/g	Eg=Ppa×hc	Power generated per cycle and generator
Epi	172	kWh		Potential energy per cycle
ef	61.8%		View alternator	Power generation efficiency
Egc×	106	KWh	Egc×=ef×Egc	Power generated per cycle
nºAl	53	nº	nºAl=Epi/Eg	Number of alternators at low operating RPM
Cai	500.00 €	€/alt	Estimation	Cost per alternator
cal	26,502.33 €	€	cal=Cai×nºAl	Total cost of alternators
naf	14	ud/fuste	naf=nºAl/nºG	Number of alternators per shaft
One multiplier for each low rpm alternator				
cmult	300.00 €	€/mult	Estimated	Cost per multiplier
cmu	15,901.40 €	€	cmu=cmult×nºAl	Total cost of multipliers

3.10 Electroline station cost, production over its lifetime

The following table summarizes the cost of an electrolyzer station and production based on current technology with no learning curve for a 100-year lifetime.

Table 14. Cost of electrolyzer station and production in its useful life

Material execution budget				
PEM	146,832.39 €	€	8.47046	Cost of each piston/TIR in years
Production				
hp	365	h	hp=365×hc×cd	Production hours
cdmax	96	nº	cdmax=24/hc	Maximum cycles per day
cd	4	nº		Feasible cycles per day
cp	1460	ciclos	hc hour cycles cp=365×cd	Piston cycles per year
Epi"	106	kWh	Epi"=Epi×ef	Potential energy return per cycle
pe	0.112	€/kwh		Electricity price
T	100	years		Lifetime
Epi"a	154,774	kWh	Epi"a=Epi"×365	Potential energy returnable per year
PA	1,733,464.28 €		PA=Epi×a×pe×T	Lifetime production

3.11 Fundamental technical hypotheses to be checked

The following table summarizes the fundamental technical keys to be checked in terms of feasibility, since the civil part of raising and lowering heavy weights is mastered, but not the industrial part of feasibility and suitability of alternators and multipliers, and how to design them ad hoc for the invention; nor the prices.

Table 15. Key starting hypotheses to be tested with a prototype

Key starting hypotheses				
Epi	0.172	MWh	Objective data	Cumulative potential energy
nG	95%		Key to check	Performance of hydraulic jacks to accumulate energy
Eex	0.181	MWh	Esx=Epi/nG	Energy supplied by renewables for storage
nA&M	65%		Key to check	Performance of alternators plus multipliers
E0	0.112	MWh	E0=nA&M×Epi	Energy returned per cycle
ef	61.8%		see losses	Battery efficiency

Also important are the times in which a piston cycle is discharged and the number of cycles that can be transmitted for consumption per day. It should be noted that if, instead of electric filling stations, large plants are proposed, the scale factor can reduce costs. The loading speed of the piston cannot be the same as the unloading speed, but since hydraulic jacks are used, the lifting energy can be perfectly discontinuous, which also makes it possible to store tidal energy, which is already very irregular.

4. Added Environmental, Social or Legal Values.

For the realization of this type of gravity batteries, the high density waste material is reused, heating part of the waste and avoiding its storage in landfills. The bureaucratic management savings are important, because they are installations that can be executed in any space, with industrial activity permits already in place. An investment can be made by the private sector, even outside the network, which means that the rigidity of public law must be reduced, and it could not be otherwise, since public law regulates everything that is allowed and private law everything that is not prohibited. It makes staggered and sustainable investment, and generates new industry and jobs. The exploitation and opening of new mines for batteries, the technology it competes with, will be reduced. It reduces the need to build reservoirs for reversible hydroelectric power plants, which is the other technology against which it competes. The investment can be made anywhere, encouraging an auxiliary industry for the use, separation and classification of waste, or reactivating mining operations such as mercury. Waste land is valorized.

The beneficiary industry associated with these batteries and which will be the supplier of the components is listed below:

- Industry for the manufacture of low rpm alternators.
- Industry for the manufacture of x300 rpm multipliers
- Reinforced concrete foundations
- Prefabrication of reinforced concrete shafts
- Armed earth containment technologies
- Post-tensioning ropes/rods for elevation
- Ad hoc high capacity hydraulic jacks industry

Specifically, in the automotive auxiliary industry sector, a new line of business is offered. This solution allows the associated internationalization, if the technology is developed with patents and adequate intellectual protection. It would be copying the Danish technical-industrial model of development of the wind turbine industry. A paradigmatic example of the methodology of industrial protection of a key technology is Freyssinet, which the author has already developed on a historical basis in a previous article (Freyssinet, 2022) (United States Patent No. US2080074, 1937) (Fance Patent No. FR680547, 1928) (Aparicio García, Corte de soporte o pilar sin gatos. Post-tensioning for steel structure: wedge-wedge method; derived technology, 2019). All the technology and raw materials necessary for its development are located in Europe.

5. Graphical Definition of the Electroline Station

That's all for the theory in this paper. Next, the prototype to be built, defined using the methodology described above, can be repeated in columns for its parametric and technical-economic study. Without its execution, neither its feasibility nor its learning curve can be foreseen.

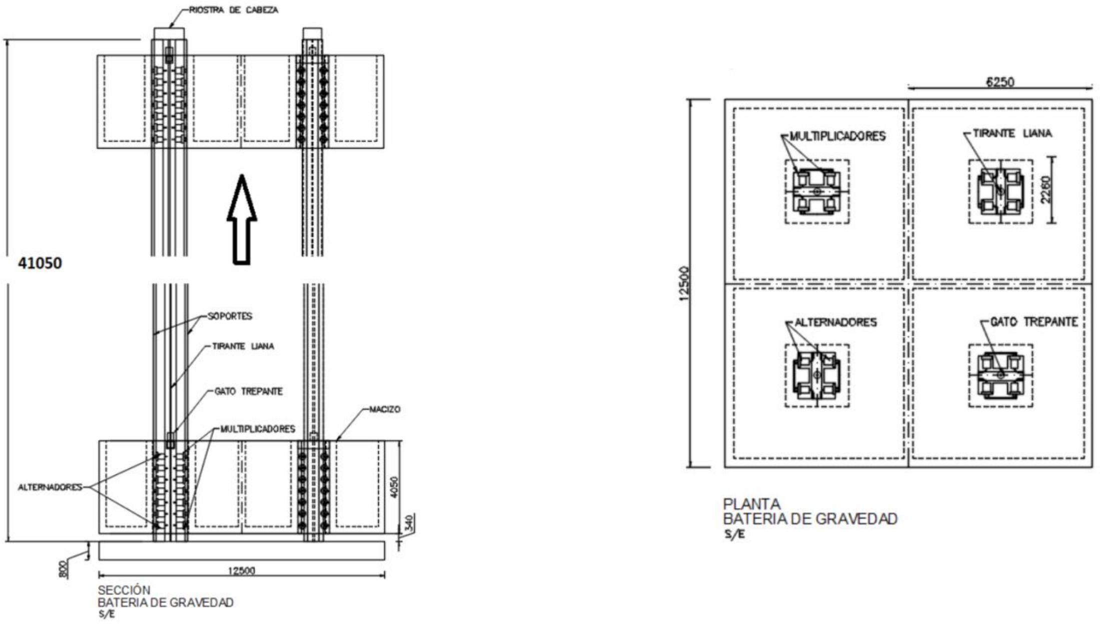


Figure 7. Gravity electroline station.

6. Conclusions

The description outlines the technical criteria for the approximate and conceptual design of a solution involving batteries or accumulators operated by gravity, as embodied in the scheme of a 100 kWh per discharge cycle. Its purpose is to address the challenge of storing electrical energy using mechanical means, while minimizing the carbon footprint; all achieved with European technology and raw materials. The industrial development of this solution, apart from intellectual protection, prototype execution, and experimental validation of the initial hypotheses, requires a significant financial and entrepreneurial investment that is beyond the author's reach. Therefore, this article serves to make the concept known to the scientific and technical community. We wish the utmost success to the prior developments of companies such as Gravitricity and Vault Energy.

Acknowledgments

In this document the ideas learned from the following technicians are fundamental: José María Martínez Gutierrez, Abraham Olano, Carles Cots, Antonio Roldán, José Miguel Liquete, Carlos Alonso, Juan José Arenas, Julio Martínez Calzón, Juan Lima and Patrick Ladret; but especially from all the technicians involved in the previous gravity battery solutions.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] Andrea Pedretti, B., & William Gross, P. 2020. USA Patente nº US20200025182A1.

[2] Aparicio García, J. 2016. Juntas de calzada en puentes: propuesta de junta integral en estribos (JIE). Tesis doctoral, 32-33. Santander, Cantabria, España: Universidad de Cantabria. Obtenido de http://hdl.handle.net/10902/8357

[3] Aparicio García, J. 2019. Corte de soporte o pilar sin gatos. Postesado para estructura metálica: método cuña-contracuña; tecnología derivada. *Hormigón y Acero*, 70(288). https://doi.org/10.33586/hya.2019.002

[4] Aparicio García, J. 2020. Método para el descenso o ascenso de un edificio de cuatro plantas. Aplicaciones derivadas. *Hormigón y Acero*, 71(292). https://doi.org/10.33586/hya.2019.2035

[5] Energy vault. 2019. Energy Vault 3D Simulation. Obtenido de Energy Vault 3D Simulation: https://www.youtube.com/watch?v=itbwXMMkBQw

[6] Energy vault. 2022. Energy vault. Obtenido de ENERGY VAULT: https://www.energyvault.com/

[7] Franklin, m., & Fraenkel, p. 2020. UK Patente nº WO2020260596A1.

[8] Freyssinet. 2022. Freyssinet españa. Obtenido de FREYSSINET ESPAÑA: http://www.freyssinet.es/freyssinet/wfreyssinetsa_sp.nsf

[9] Freyssinnet, E. 1937. United States Patente nº US2080074.

[10] Freyssinnet, E., & Seailles, J. 1928. Fance Patente nº FR680547.

[11] Gravitricity. 2022. Gravitricity. Obtenido de GRAVITRICITY: https://gravitricity.com/

[12] Sarens. 2022. Sarens. Obtenido de SARENS: https://www.sarens.com/equipment/strand-jacks.htm

[13] VSL. 2022. VSL. Obtenido de CSL: https://vsl.com/home/technologies/heavy-lifting/