Civil Structural Solutions for Power Storage

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The events of 2021 Storm Uri highlight the need for resilience in the Texas power grid. More broadly, increases in power generation from renewable energy sources such as wind and solar energy have increased the need for power storage solutions. Power storage at the point of renewable energy generation allows peaks in power generation to be shifted from times of abundance to times of high demand with increased revenue for the generator. Power storage at selected locations on the grid reduce transmission congestion by averaging the power flow and power storage at the point of consumption allow consumers to either store and later consume their own excess location power generation or moderate their power demand during times with high power rates, or simply to add resilience to their operations.

Energy storage can be achieved by a multiple of means. The highest density short-term and reversable energy storage mediums include synthetic fuels such as hydrogen, electrochemical solutions in the form of batteries, thermal energy and mechanical energy. Mechanical energy includes kinetic and potential energy storage.

Civil engineers have a significant role in the traditional potential energy storage in the form of pumped storage hydropower (PSH). Water is pumped from a lower to a higher natural or constructed reservoir to store energy and when needed it is allowed to reverse flow to recovers most of the stored energy when needed. Civil engineering requirements include dams, levees and underground construction.

A PSH with 100m elevation change has stored energy of 1 MJ/m^3 which is low compared to Lithium-Ion batteries with 1,400 MJ/m^3 energy density. PSH makes up for the low energy density at large scale and has high round-trip efficiency.

Unlike current battery storage, PSH and other forms of potential energy storage are not time limited. That is, energy may be stored long term unlike batteries that dissipate the stored power over a period of hours. Long-term storage of at least 4 hours and ideally 12 hours or longer provides the ability to shift solar generation from day to early evening or wind power from evening to morning. Much longer-term storage is possible to provide for resilience in the face of extreme upset conditions.

Several developers are investigating the potential of non-site-specific solutions that work on a similar principle to PSH by elevating ballast masses to store energy and lowering the masses to recover energy. Round trip efficiency may approximate that of PSH. Provided the ballast cost and indirect costs are manageable elevating ballast masses, known as gravity storage, can be an attractive solution.

Civil, structural and geotechnical engineers and materials scientists all have a significant role in PSH and gravity storage solutions. Sites must be located; development permissions must be obtained and in the case of gravity storage optimal solutions conceived.

Despite the large number of Federal Energy Regulatory Commission (FERC) permitted PSH locations in the USA, relatively few new PSH schemes have been progressed in recent years. Local regulatory permitting processes, long construction schedules and high initial cost are barriers to development. Gravity storage may be in the form of masses lifted from ground level to a height, or masses that are centered below ground and lifted. The principles are the same as PSH and follow the theoretical equation:

$$Work\ Done\ (in\ Joules) = mass\ (m)\ x\ gravity\ (g) x\ height\ change\ (\Delta h)$$ **Equation 1**

$$Energy\ Stored\ (in\ Watts) = Work\ done\ per\ unit\ time = \frac{m.g.\Delta h}{second}$$ **Equation 2**

This can be expressed in conventional power units of Watts per hour.

$$Power\ Stored\ (in\ Watt - hours) = \frac{m.g.\Delta h}{3{,}600}$$ **Equation 3**

If we are to target a reasonable energy storage capacity, then either significant masses need to be deployed or significant changes in height of the lifted or lowered mass is needed as shown in Table 1.

Table 1 Example Power Storage Parameters

Target Capacity	Round-trip Efficiency	Mass (metric tonnes)	Change in height (m)
0.5 MW-hour	0.8	20,000	14
5.0 MW-hour	0.8	30,000	94
50 MW-hour	0.8	140,000	201

It follows the civil engineering team has a significant role to play in the selection of ballast material with appropriate density while still being cost effective. The structural and geotechnical engineer have a significant role in defining and documenting a suitable structure for the vertical and lateral support of the ballast masses in their travel from low to high elevation.
Amongst other proprietary solutions the author will present on the solutions being conceived by Arup in Houston for non-site dependent application. An example of such a solution is illustrated in Figure 1.

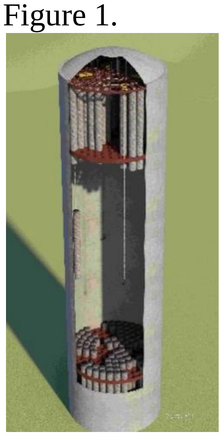

Figure 1 Arup Concrete Gravity Energy Storage Solution

The field is ripe for innovation and will benefit from the contribution of passionate civil engineering methods to refine the gravity storage solution. The author foresees a significant global market for long-term energy storage solutions and opportunity for the best of the forms of solution described in this paper.