GBS LNG AS A NEAR SHORE CONCEPT FOR LNG DEVELOPMENT

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In a blooming LNG market, driven by increasing demand and global warming concerns, Oil & Gas Companies are looking for affordable development schemes for monetizing gas reserves and supplying LNG.

Onshore Liquefaction plants are numerous and a few FLNG will be on production in the coming years. Although the concept is not new, the Gravity Based Structure (GBS) with Natural Gas Liquefaction Plant has not yet materialized. TOTAL has conducted extensive studies on different uses of concrete structures. The NKOSSA barge, producing gas condensates since 1996, off the coast of Congo Republic, is an illustration.

The GBS used for storage and offloading facilities coupled to an onshore LNG Plant or a complete LNG Plant on top of GBS, are among concepts that TOTAL has investigated. Through that comprehensive analysis over the last years, we are able to identify their technical and economical drivers.
GBS LNG as a near shore concept for LNG development.

In a blooming LNG market, driven by increasing demand and global warming concerns, Oil & Gas Companies are looking for an affordable development scheme for monetizing gas reserves and supplying Liquefied Natural Gas (LNG).

Onshore LNG plants are numerous and remain up to now a conventional solution when required by onshore or offshore gas field development.

An alternate onshore LNG plant using a floating barge strategy for construction purposes in harsh Arctic conditions, was used by the SNOVHIT project. The liquefaction steel barge was built and equipped in the Cadiz shipyard (Spain), dry-towed, docked and settled like a GBS as part of the MelkØya Island extension (Norway). All storage capacities are built on reclaimed land.

For offshore gas fields, a few Floating LNG vessels (FLNG) have been built and some are already producing: PETRONAS PFLNG Satu off the Sarawak coast (Malaysia) produces since 2017 and GOLAR Hilli Episeyo off the Kribi coast (Cameroon) started producing in 2018. The FLNG concept enlarges the range of solutions offered to LNG production facilities. Nevertheless, the FLNG concept needs adequate sea conditions for ship to ship LNG transfer. It may require a protected harbour or a breakwater for an acceptable offloading jetty availability.

Although the concept is not new, the Concrete Gravity Based Structure (GBS) is not widespread in LNG industry unlike the offshore oil & gas segment where GBS infrastructures are common since the early 70s for oil production. The Adriatic LNG re-gasification Terminal, located 14 km off the coast of Rovigo – Italy in 29m water depth, is the first of its kind for LNG Industry, in operation since 2009. Despite that realization, the stand alone GBS based Natural Gas Liquefaction plant (GBS LNG) has not yet materialized.

TOTAL has conducted extensive studies on the various uses of concrete structures in offshore environment.
TOTAL operates the NKOSSA Floating Production Unit (FPU) “NKP” located 60km offshore of Pointe Noire, Republic of Congo. It is the first mono-hull and largest pre-stressed concrete barge in the world, of 220m long, 46m wide, 16m high, with a draft of 10.5m, weighing 33000 T, producing condensate and LPG since 1996. The side by side LPG transfer, from the Floating Storage and Offloading (FSO) vessel “NKP-II” to LPG carriers, in open sea conditions, is also a valuable experience for TOTAL LNG Business Line and is a recognized expertise in marine operations.

In 1998, TOTAL has conducted a study for the KAKINADA GBS-based LNG import Terminal, on the East Coast of India.

The following year, the GBS concept was again investigated as part of the value engineering process for the YEMEN LNG. The objective was to reduce the cost of a conventional jetty in a costal environment where the sea bed has a steep slope requiring large steel structures. The alternate concept assessed was based on a rock filled rubble mound with a GBS sitting on top, at 15m below Mean Sea Level (MSL). The GBS is made of a monolithic concrete structure of 321m long and 60m wide containing 2 LNG tanks of 125 000 m³ each resting on 8.50m height bottom ballast compartments.

Recently, NOVATEK has been promoting a GBS concept for the North Siberian Gydan gas liquefaction project at the Ob river mouth. The ARTIC LNG2 project has ended the FEED phase and is expected to be launched soon.
Early 2018, TOTAL signed an agreement with NOVATEK with the aim of acquiring a direct 10% stake in ARTIC LNG2.

In recent years, TOTAL has undertaken several assessments of the use of GBS for gas liquefaction plants, either as a near-shore standalone unit or as a supporting structure for storage and offloading means. The aim was to understand its cost and schedule drivers as well as the interferences between GBS structural design, tank configuration, and topside modules layout and integration method. Means to build the GBS were also assessed.

**GBS concept with LNG and condensate storage, offloading facilities and Boil Off Gas (BOG) compression**

The onshore-based LNG Plant delivers LNG and condensate products through a subsea bundle (with cryogenic pipes) to offshore storage tanks built on GBS settled at 20m water depth at 2km distance from shore. The “I” shape terminal is made of 3 aligned shoe box type GBS. The three GBS constitute a breakwater and mooring support for carriers. Marine Loading Arms (MLA) are set on a cantilever platform. GBS-1 & GBS-3 are loaded each with 2 land based standard cylindrical LNG tanks while GBS-2 supports 2 condensate hull tanks. A compression platform located on GBS-2 top slab returns the BOG to onshore liquefaction units via the subsea bundle pipe.

The onshore liquefaction plant with near-shore GBS storage concept leads to a small 2% reduction in costs, compared to the base case with onshore tanks. Given the accuracy of estimate, we can conclude that the cost cuts are not significant. The newly built dry dock cost totally offsets the gain due to the subsea bundle over the 2km trestle and run down piping. This concept should be interesting cost-wise either with a rental of existing dry dock facilities or with an alternative construction method of GBS with floating dock. However, land acquisition issues, soil...
conditions not fit for land storage, environmental impact, reduction of energy consumption due to long run-down pipe to jetty during holding mode, may justify the use of this concept.

GBS LNG - an alternative approach to onshore LNG Plant.
The GBS concept extends the onshore site selection potential to the near shore and doubles the opportunities. Land acquisition, legal permitting and community objection, logistic access for construction, extended footprint and site preparation in a protected environment, harsh environmental conditions, lack of local skilled labour or expensive work force, or soil improvement requirements can hamper onshore site selection. Moreover, if the sea floor has little slope, a long run-down pipe on a jetty or an immersed cryogenic pipe for LNG transfer to the offloading quay is required up to a suitable water depth for LNG carriers. All these can increase project costs. A coastal onshore location not fit for plant erection can be a headache although the selected spot is an optimized location for pipelines costs in the overall upstream – midstream architecture of the project. The GBS overcomes such hurdles if sea floor characteristics are fit to bear the load of concrete structures and the GBS LNG plant concept is an alternative to consider.

Near shore characteristics are of primary importance prior to selecting the GBS LNG concept. A whole range of criteria are to be assessed like legal permitting, geotechnical survey and core samples characteristics, silting rate, bathymetry survey, presence of shallow gas, probability of occurrence of natural hazards like hurricanes, earthquakes and tsunamis.

GBS as a breakwater
For our case study, tanker operability for the selected site was assessed for a QFLEX moored in 18m water depth, positioned against the main wave as a baseline case for different mooring lines tension criteria and MLAs displacement. Then, the operability study was pursued with the tanker protected alongside a breakwater designed to obtain the best efficiency.

Local environmental conditions related to waves (distribution of periods, heights and directions), sea currents (distribution of velocity and directions), wind (distribution of velocity and directions), tide level variations are inputs to the waves hydrodynamic study around the GBS. According to the minimum availability required for offloading quay (95% in our study), GBS shape, minimum length and width are determined.
Without breakwater, the operability is lower than the 95% targeted. Stand-by of a QFLEX per annum for metocean conditions can last up to 12 days and could occur 27 times per year. With a breakwater, efficiency raises to 99% and the number of non-operable windows and their duration are significantly reduced.

<table>
<thead>
<tr>
<th>Model</th>
<th>Criteria</th>
<th>Operability</th>
<th>Operable consecutive days</th>
<th>Inoperable consecutive days</th>
<th>Number of inoperable windows</th>
</tr>
</thead>
<tbody>
<tr>
<td>With GBS</td>
<td>50% MBL, +/-1m at connection</td>
<td>99.2%</td>
<td>117.4</td>
<td>1.9</td>
<td>7</td>
</tr>
<tr>
<td>Without GBS Q Flex</td>
<td>50% MBL, +/-1m at connection</td>
<td>89.1%</td>
<td>101.2</td>
<td>11.7</td>
<td>27</td>
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<tr>
<td>alone</td>
<td>50% MBL, +/-1.5m at connection</td>
<td>89.7%</td>
<td>101.2</td>
<td>9.5</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>100% MBL, +/-1.5m at connection</td>
<td>95.4%</td>
<td>117.3</td>
<td>7.2</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 1: Breakwater efficiency for given metocean hind cast data with designed GBS

**Settling depth of GBS**

The LNG carriers have a 13m draft. With some margin GBS can be settled in a minimum water depth of 15m. The real settling depth of GBS will depend on breakwater height and operational dredging requirement.

Minimum size and shape are determined by breakwater efficiency. The topside layout will provide the top slab area required while the GBS height is ruled by the storage capacity with the minimum settling depth and height of bottom ballast compartments constraints.

The GBS settling depth should allow for a minimum air gap, to avoid waves overtopping at high tides.

Overtopping protection panels above the top slab can be used to reduce the GBS height, but will impact mooring configuration and offloading quay and may trigger potential complications for module skidding on the top slab.

The air gap of the GBS may impact the displacement allowed for MLAs. If necessary, a cantilever platform will be required with mooring dolphins alongside the GBS.

In our case, the GBS is settled at 20m water depth. The GBS height provides protection against overtopping and mooring bollards are positioned on the top slab. Standard MLAs operational displacements are within authorized
limits. The selected depth avoids operational dredging for LNG and condensate carriers approach on the protected side of the breakwater.

**LNG process**

Any existing liquefaction process can be customized for implementation on a GBS top slab. As an offshore-operated plant, it is recommended to reduce the process complexity to ease start-up and keep the maintenance cost lower. An SMR process is used in our case for a 5 MTPA capacity plant with 4 trains.

**fig.4: Process Block Flow diagram of GBS LNG plant**

For cooling media options, sea water pumping in shallow water will be problematic. Air cooling is selected to overcome the environmental impact of reject water temperature in shallow water and as per World Bank EHS recommendations.

Water cooling would be more efficient for the GBS LNG in terms of energy consumption, plant footprint and thus costs, but this option was left aside for potential optimization with water intake and reject issues to be solved. Another critical point to be checked is mixed refrigerant condensation with air cooling, particularly with ambient air as high as 35°C.

**Plant modularization and Topsides layout**

The GBS LNG concept requires modularization of process units for integration on the GBS top slab at construction yard. The layout needs 2 GBS blocks settled side by side, aligned on their width. The four liquefaction modules with their associated air coolers bays for SMR are grouped on one GBS to limit cryogenic leak hazard. The remaining modules for gas and condensate treatment, utilities including offloading station are on the second GBS. To limit hazard escalation from the GBS to LNG carriers, the offloading quay is on the air coolers' bay side, opposite to liquefaction compressors and drivers and the main cooling heat exchangers. Moreover, modules are spaced along the GBS length with a safety gap for escalation prevention. The GBS top slab is designed to resist blast overpressure occurring from Topside modules.
Flares and Living Quarter are located on opposite sides of the breakwater, flare mast being downwind of the prevailing wind direction. They will be installed on a jacket and a tripod linked by bridges to the GBS. This arrangement allows using the full GBS hull volume for LNG and condensate storage. Moreover, the flare tripod and LQ platform are offset to GBS alignment to prevent collision with carriers during berthing and un-berthing manoeuvres.

The GBS top slab is almost free of equipment except in the offloading area with MLAs and metering. The main deck is the process deck located above the GBS top slab. This configuration provides room on the top slab for lifting the retractable LNG pumps from the hull storage for maintenance, and for installing the main pipe rack with the 42” LNG run-down pipe to tanks.

**GBS structural description**

Each GBS is a shoe box type structure with 2 levels. The bottom level is made of ballast cells which will be filled with water and sand. The top level is made of several hull tanks in the middle, surrounded by peripheral ballast compartments. Lateral ballast compartments will be filled with sand and water up to mean sea level. Vertical walls of the bottom and lateral ballast, regularly spaced, act as stiffeners. GBS levels are separated by 3 horizontal pre-stressed slabs: the bottom slab above a steel skirt, the intermediate slab separating the 2 levels and the top slab.
The following loads are applied on the top slab for the GBS design:
- a uniform load for Topsides operational weight
- an accidental load resulting from an explosion in a process module.

A free flat external area is a prerequisite for safe circulation of staff on board, for handling operations, and for liquid spill drainage. LNG tanks with flat ceilings are the preferred option for membrane installation thus a flat pre-stressed without protruding beams, is selected.

**Hull tanks configuration**

Vertical walls running across the width or the length were also examined for making GBS hull tanks. The impacts of these configurations were checked during topside modules integration on the GBS top slab. Due to high hangover across the GBS width, longitudinal wall partitions are required to handle dynamic loads during the integration of modules.

The layout of the LNG plant with a configuration of 3 modules setup width-wise needs more than one hull partition longitudinal walls. Therefore, each GBS hull is organized with 3 rows of tanks with condensate tanks in the middle and LNG tanks on the side (fig.6). An inspection corridor is set between 2 rows. The corridors’ walls help to decrease the hangover across the width of the GBS and bear the dynamic load of topside modules during the skidding process.

Some operational constraints are taken into account including availability, integrity and maintainability of hull tanks:
- the availability of condensate tanks is ensured with a minimum of 2 tanks
- an off-spec tank for condensate is provided
- the availability of LNG tanks is ensured with a minimum of 2 tanks
- Access corridors make easier the inspection of tanks’ external walls. They offer the possibility to repair cracks and maintain the heat tracing system for LNG tanks.

- The access corridors allow for safe interventions inside an LNG tank due to no common walls with tanks in operation (mainly for membrane repair).

- All external walls and underneath of tank bottom slabs, on ballast compartments side, can be made accessible for inspection.

**Cost & Schedule of GBS LNG concept**

There are 2 main packages:

- The first one is related to the LNG Plant with the integration of modules on the GBS, onshore and offshore hook-up, onshore and offshore commissioning and operations readiness for start-up.

- The second one includes the GBS construction starting from dry-dock establishment (casting basin and offsite), bulk material procurement and logistics, GBS construction itself, membrane installation in LNG tanks, offshore Site preparation, GBS towing and ballasting on site.

Dry dock establishment is on a critical path of the concept, followed by the GBS delivery date to Topsides Contractor. However, project duration is mainly due to the fabrication of the Main Cooling Heat Exchanger (MCHE), followed by liquefaction train modularization process: it extends the standard onshore stick built project duration of circa 50 months to around 62 months. The project schedule was established assuming a newly built dry dock.

The GBS LNG cost was estimated for Q4-2017 economic environment with a class V, as per AACEI recommended practice. The estimate accuracy is -30% / +50% for a preliminary level study.

Figures below represent the cost distribution for the overall project and within the two main contracts.

![Fig.7: GBS LNG Plant cost distribution with a newly built dry-dock.](image-url)
The cost of the standalone GBS LNG concept is lower than a new stick built onshore plant with a 12% reduction. However with the accuracy of the estimate, it is comparable to an onshore LNG plant cost. Further cost optimization of the GBS LNG concept have been identified in the case study to drive down the overall cost and make it significantly lower than for onshore plants.

The main breakthrough of the concept comes from the optimization of the transfer pipelines costs between the upstream gas and condensate producing installations near the well pads and the costal liquefaction plant and offloading jetty. The onshore site selection in the case study requires lengthy transfer pipelines of 42" for the feed gas up to liquefaction units and 12" for the condensate up to offloading jetty. The GBS LNG concept enhances site selection opportunities; in the case study, it could reduce the pipelines length by 250 km and save less than a billion dollars.

**GBS LNG concept with caissons.**

The bare cost of the dock establishment is around 450 MUS$ including casting basins, batching plants, marine offloading facilities, offices and offsite. The dock establishment will be for a single use and may not benefit to the project’s host country. Within a tight schedule, the GBS Contractor has to find the right spot to build the dry dock with adequate soil characteristics, not far from the GBS LNG installation site, with convenient towing routes within a favourable weather window. Furthermore, ideally, a quarry for aggregates and a soft water reservoir should be in the vicinity. Availability of manpower and camps will be part of the quest.
Most of these uncertainties can be offset by using a floating dock familiar to the Civil Works Sector. A newly built floating dock cost is less than 30 MUS$. It could be moored along a quayside in a harbour. Manpower, logistics and bulk material supply could be easier. Caissons (small GBS) once built and pulled out from the floating dock, can be equipped with membranes for LNG tanks at a work station alongside a quay, then parked moored in offshore area. They will then be assembled on site to form the breakwater. For the case study, more than a dozen of caissons are required; most of them are for LNG tanks, a few for condensate and 2 are ballast caissons installed on each end of the breakwater. Each caisson contains ballast compartments and a single hull tank in the middle. Assembling the caissons will give a breakwater of a few hundred meters length in around 20m water depth.

![Fig.10: Caisson](image)

![Fig.11: GBS cost distribution with a newly built floating dock](image)

The main problem with this option is that topside modules integration will start in offshore conditions after the breakwater construction. Assuming that the sheltered side of breakwater allows lifting operations most of the time, there is still a limitation in module size. A heavy lift crane barge needs to operate in transit draft mode in 20m water depth which causes stability problems. The offshore integration, hook up and commissioning work will take longer than the integration process in dry dock and will penalize the project.

A jack-up barge solution moored alongside the GBS could be used to lift heavy modules up to 12 000 T (weight of one liquefaction train in the study case) from barge level to the top of the caissons. Then, modules will be skidded
to their final position. This process could reduce the number of modules from around 30 to 10 and save time in offshore work with a cost impact. The main handicap of GBS concepts – the dry dock establishment – can be overcome through coupling a floating dock and a jack-up barge. The LNG business would benefit from such a floater if it was proposed by Contractors in the future.

Fig.12: Jack-up barge sheltered behind breakwater for heavy modules lifting in offshore condition

Acknowledgements
The authors would like to thank TOTAL E&P technologists and the LNG Business Line Group for their support and contributions. We acknowledge the contribution of Contractors SETEC, PRINCIPIA, OLAV OLSEN and SAIPEM for this publication, more specifically, we thank Cécile PRATZ (SETEC) and Marie-Christine ROUAULT (PRINCIPIA).