Foundation engineering for offshore gravity structures

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Abstract: Gravity based structures are in play from early times. Numerous structures are being installed around the globe. These structures had shown a rigid face towards the harsh conditions/situation in the offshore environment. The key factors for sustainability are geotechnical design and the sub soil survey. These structures are used for collection, transport and also for temporary storage of crude gas and oil. These structures serve as a bridge between the much need fuel and the modern world. The installation of GBS involves major wings of modern engineering i.e. Mechanical, Structural, architecture and Geotechnical engineering because these structures are a great challenge as considering the harsh and hard off shore conditions. These structures are having a much importance apart from its features i.e. from the point of economy, as the oil prices are touching the heights, it influences construction of GBS. Now a days most of the multinational companies are focusing towards the construction of offshore GBS, as well as paying much attention on research work off these structures because to make huge profit. In this paper an effort has been made to understand the different aspects which are related to GBS i.e. pre-construction operations, soil investigation, construction, installment and some of the safety aspects as considering it one of the most focused topics now and in future.

Keywords: gravity based structures, offshore structures, installation.

1 INTRODUCTION:

An erection which is clutch by gravity at a spot is known as offshore gravity structure. Gravity structures plays a crucial role into days contemporary world, As these structures are not hold up by any means i.e. piles etc. but by the means of gravity, these structures are taken in consideration as a substitute for traditional pile foundation and pile brace structures. Mainly these types of structures are seen in North Sea. GBS construction largely depends upon the type of soil and its conditions as to instate hefty structure for oil and gas plants. Some of the times it becomes really onerous because of the below soil conditions on the other hand it can be used well for deep offshore down the water constructions near the shore. It can be adopted for storage of oil on need basis into it. These structures can get moved from one spot to another by the means of applying the water at very high pressure under the settled plates of the structure and by deballasting the platform to zero submerged weight. Offshore structures are having top priority
from the perspective of economic as well as from technical points. As because of increasing oil and gas demand as well as prices many of the offshore constructions got started as reviled by the studies around the globe. The design and construction is a fusion between steel structure scheme and harbor design, the design of offshore structures mainly depends upon the fact how the load such as gravity load, wind load, wave load, current load and other loads will get applied and how much in quantity. These structures facilitate drilling; compressing, storing etc. And also gets utilized by sulphur industries, see fig 1.

![Sulphur industries](image)

**Fig 1:** Sulphur industries [1]

### 1.1. Types of offshore platforms:

Offshore gravity structures are having variety of types, these different types depends upon the type of soil bed and other conditions: Well shielding platform, Platforms for tender, Separate platforms, Platforms for productions and Auxiliary platforms [1]

GBS has a very vast application field as we have seen that how it is used in current scenario in different aspects. It has been used at many locations for the purpose of collecting, extracting and storing crude gas and oil. It serves as a bridge between the need of energy fuels and the modern world. As this structure is self-installing, removable as well as it can be relocated. It proves to be more economical in installation. GBS has been used successfully in various countries like: Italy, UK, Us, Norway, Denmark, Europe etc [2]–[4].
2 Pre-Constructional Operations

Ordinarily, a pre-development stage comprises of various known focuses. Nonetheless, extra deterrents take temporary worker's consideration when executing a seaward structure, by and large spinning around two focuses: A geotechnical investigation of the dirt. And Seabed leveling work prior to setting the gravity based structure.

Principally, the dirt on which the development works is to be performed must go through a cautious report, at that point decide regardless of whether the dirt is fitting to the principles needed to oblige the structure. On account of the presence of any contaminations that crack the execution of the venture, further treatment is performed to the sand. In any case, all together that the cycle of sand treatment not to surpass its allocated spending plan, the profundity of sand evacuation arrives at just 10 m, with the guide of seaward instruments and ships to convey them alongside work laborers, this is because of the idea of the site. [5]

3 GBS Construction

Offshore structure construction is based on 15 stages.

- **Stage 1: Basin construction**
  The basin must be constructed in such a way that it is able to be dewatered carefully against highest tide in addition to the storm burst. In new constructions, the base course beneath the base slabs must allow free drainage. This can be achieved with the help of punched pipes or vitrified drains that are generally installed beneath the crushed rock base. The surface can be made of concrete which is prepared with suitable bleed holes if there is increase in the water table. The side slopes must be secured against erosion by providing drains, dewatering systems etc.

- **Stage 2: Base raft construction**
  After the construction of base, raft of GBS is constructed. The first step is the installation of skirts that are made up of various materials like steel or concrete depending upon the nature of soil. It encircles the delicate layer of the soil and transfer the load to deep and stronger level. Gullfaks C was the first type of concrete skirt installation [6]
  After this concrete base slabs are laid that is generally 1-2m in thickness. These normally give rise to a large amount of heat of hydration which produces thermal augmentation. Because of alternate heating and cooling cracks may develop. To minimize the effect of this problem, various methods are adopted based on thermal analysis and the slabs are laid in checkerboard pattern.
  Lower raft walls are then erected which are capable of building essential shear during the floatation of the base raft.
  After this, mechanical apparatus are installed which comprises of under base grouting system, drainage systems, skirt venting etc.

- **Stage 3: Float out**
  When the structure is ready to be displaced in water, ultimate checks are done on the weight and dislocation to make certain that the floatation is carried within the limits. Least underkeel clearance of about 05m is normally provided. Air cushions are provided underneath the skirts to minimize draft.
Stage 4: Securing at site of deep water
When the base raft is buoyed in water it is harbored with the help of chains to secure it from displacing. Air cushions are still restrained within the skirts and the discharge of air is carried out very precisely to make certain that it is safe against overstressing. During buoying operation there are chances of air deprivation under various skirt sections so the sub sections must be thoughtfully adopted. For submerging the base raft in water chains are run across it and fastened to iron legs. Uninterrupted mooring is done with float bracing in the centre, from base raft to anchor, minimizing the chances of tilt in base rafts.

Stage 5: Constructing in deep water
Rest construction takes place within the deep water but the structure must be secured from sudden and unexpected flooding. For concrete GBS structures transportation and installation of steel, concrete and other materials must occur in considerable volume.

Stage 6: Construction of shaft
In this stage shaft construction is done that may be 1 to 4 in count. The shafts are generally narrow so that slip forms are used conveniently. These slip forms are able to whirl and are just like chimneys. The uprightness is managed by lasers. During the construction phase, constructional elevators are used to provide the approaches which are sideways braced at intervals. The post-tensioning of the shaft is generally conveyed from the gallery. At this phase, gallery is completely immersed in water and is thus subjected to high pressures occurring due to water.

Stage 7: Dragging to deep water pairing site
In the 7th stage structures are pulled to separate locations for deck coupling as it needs water at greater depths than that at final installation region. The structure will continue to glide with water mark almost at the top of base caisson. The location for deck coupling should be opted to give adequate depth so that the structures provide good resistance against winds and other phenomena.

Stage 8: Deck structure construction
The integrated deck structure is constructed during the assembling of substructure. This is carried out in girders, shipyards etc. The deck is assisted by number of short term supports as it is very heavy and during the application of loads there are chances of twisting. Steel pads are generally used for permitting shear distortion and rotation.

Stage 9: Transportation of deck
After constructing the deck it is then carried with the help of huge barges. These are then debased so that sea fastening supports are fastened between the barge and deck girders. The fixture of connections, like pinned, free joint etc. requires cautious analysis. After debasing the barges and fastening the fixtures, barges are slowly deballasted until liftoff.

Stage 10: Submerging substructures
The substructures are subjected to two tests: standard inclination experiment and ballasting and deballasting. After conducted these tests the substructure is then immersed stepwise by examining the weight of the ballast water vs resultant daft.
During the process of submergence the structure undergoes various hydrostatic forces thereby increasing the stress.

- **Stage 11: Deck pairing**
  In this process deck operations are carried out keeping weather prediction in consideration. The water traffic around the site is restricted and the density of water is measured at various depths. Then the substructure is counterbalanced so that only 3 to 5m of the shaft increases above the water mark. During this complex phase the substructure begins to elevate the deck. Due to the weight of the deck caissons starts to lower down. This is the most crucial stage and the life of the structure also depends on it.

- **Stage 12: Hook up**
  This process needs at least 3 to 4 months for completion. In this stage the foot place is deballasted so as to lift it from its initial position where forces on the cells are minimized and approach is provided to the shaft. After this process, hook up of the instruments is done. This operation is time consuming and may need a number of working days for completion.

- **Stage 13: Hoisting to installation site**
  Now the structure is ready to be laid under tow to the site. The distortion may range from hundreds to thousands of tons. The structure is equipped for tow with sailing viaduct, wireless for communication purpose, firefighting equipments etc. During the process of towing, strength is likely governed by various controlling factors.

- **Stage 14: Installation at specific position**
  The structure is ballasted onto the sea floor. Various guidelines are given which have to be followed during the operation. These include positioning and inclination, perforation of dowel, ballasting and dewatering, skirt piercing, seating of base slab, and underground grouting.

- **Stage 15: Installation of conductors**
  This is the last operation to be conducted at site. The conductor sleeves are precasted in the base slab and after that it is made waterproof to restrict the entry of water. The conductors are directed and drilled into the required location. The wells are allowed to move in the vertical direction.

A Variety of points need to be taken in consideration when going for construction of GBS structures i.e.:

- Analysis of structures needs to be done.
- Need to check the degree of plastic reaction.
- Prior phase of construction.
- Deformation and Disturbance of structure need to get checked.
- Issues regarding withdraw [5]

Further construction needs to be done on a dry dock which has to be prepared for the huge and heavy structure for its construction and installation. There are various more aspects which need to be considered in order to ensure that construction meets requirements demanded by the method of execution i.e.
a. Depth of skirt foundation.
b. Base area of dock.
c. Bearing capacity.
d. Drainage system at the base.
e. Material properties at the base of the dock if GBS is casted directly on the base of the dock.
f. A number of gate dock designs are to be opted.
g. If gravel is present then sheet piling is to be done, sullary wall s need to be constructed in case of sand and detachable walls of concrete, see figure 2.

Figure 2: Construction of GBS platform.

4 Soil Investigation

Soil Investigation is considered as one of the important step in terms of GBS construction. Soil investigation is split into many aspects; the first drive is touch-on as that of prior reconnaissance which is generally a geophysical, bathymetry survey and inspection of the sea bed. The other steps which are taken into consideration depend upon the results of the survey done in first step. In-addition to these investigations some of the in-situ tests are to be done from where more specific reports can be prepared, which will help sustainable GBS construction which includes Cone penetration test.

4.1. Cone Penetration Test:

CPT is defined as one of the in-situ test which is being used to spot the different types of soil layers. In the regards to GBS it can be done into two ways i.e. either by less weight equipments penetrating to a finite depth or by adding extra solid tools to infiltrate more depth. In case of sampling in less weight equipments test can be done by using earlier phase by taking the help of vibro-core. On the other hand if sampling is required for heavier equipments then it will go under more and precise detailed investigation [7].

Remarkable advances have taken place in terms of CP deployment systems and now numerous ways to perform the experiments in a variety of water depths, from nearshore to more than 3000m are there. CPT
based techniques offer more accurate predictions for a wide variety of soil parameters in pure sands and clays [8].

Some of the parameters for soil investigation which needs to take in consideration for safe and sustainable construction of GBS are as under:

- a. The location and the number of boreholes.
- b. To identify the layers of the soil.
- c. Weight of the structure corresponding to the in-situ conditions.
- d. Application of load.

5 Installation

See Figure – 3, these structures are being constructed on a dry dock and then these are being transferred to the located site by the means of pulling with the high power ships. This structure is having huge dimensions and bottom weight, which makes to sustain in the harsh and cruel conditions. Once it reaches to the spot it is being lowered and the settlement is being done by installing the rocks and also by the process of grouting. The installation procedure of GBS depends upon some of the parameters including: Size and outline of the platform, Depth of water, the tolerance of positioning which is required in all the six freedom degrees, in all the formats it should be stable, differential tolerance on ballast levels and Methods of penetration and the skirt design. [7]
6 Safety Aspects

It should be indicated whether the site is hazardous or non-hazardous. A plan of safety devices and tools should be made, which includes fire extinguishing, route to escape, life-saving equipment and appliances, fire protection, life-saving drugs and essential medicines and also strong way to communicate [9].

7 Literature Review

[10] Concluded that GBS is used for various renewable projects in both deep and shallow water bodies. They also revealed that the properties of soil on which these structures are being constructed play a major role in the structure stability. Major emphasis was laid on scour as it affects the stability of foundation to a great level. [11] studied revealed that for constructing GBS support systems, dry docks, floating pontoons and onshore land areas are the three potential sites. It was also concluded that count and weight of support systems, demand for load out, transportation and installation process, etc. are the salient points that are to be taken into account in choosing the best location for system manufacturing. [12] Conducted elastic rocking vibration model for studying the stiffness and dynamic behavior of foundations of the gravity structures. It was found that foundations with porous sides were having lower dynamic amplitudes compared to non-porous surfaces. [13] revealed that the vibrations caused during offshore structures reduces the platform productivity, affects the serviceability, and also the structure is liable to number of accidents. Number of vibration control methods like conventional method, passive method etc. were examined and it was found that passive constrained layer damping method could be used in jacket structures only while as other methods could be applied for other offshore structures including jacket structures also. [14] Presented hydrodynamic simulations utilizing mechanical couplings for installation of complicated offshore structures. [15] figured that 1993 provisions of American Petroleum Institute describes the environmental load and design specifications for offshore structures. It was also concluded that to understand the structure mode behavior for secure design, software like SAP2000 V20 are used. [16] Focused on hydrodynamic response modeling of flexible upright surface penetrating cylinder that was placed under uni-directional waves in Morison loading regime.

8 Conclusion and Future Scope

1. Offshore gravity based structures plays a crucial role in today’s modern and highly communicating world. GBS are being used in such a way that it becomes a medium to collect and transfer the raw oil and gas.
2. These structures are to be installed in the water bodies to explore the sites which are having gas and oil in them. As because of GBS the most essentials which are required for modern life are possible to be.
3. GBS helps in collection, extraction and also temporary storage of crude gas and oil as well as helps in sustaining the requirements however there are certain few aspects in which GBS is lagging i.e. to coup up with the high velocity due the flow of water and some of the times it has to coup up with the tides which occur due the movement of moon, seismic motions with high standards, weather conditions etc.
4. Materials need to have long life as it is not convenient to change or repair as taking the stability of the structure in consideration. In coming future times it can become an essential tool to boost the economy of the country as well as can help in self-dependency of the particular area if it can be engineered well with minimum to zero drawbacks.
Although offshore engineering has been around for a long time, it still poses a number of issues for geotechnical engineers. One of the main limitations of offshore structures is that the geological disturbances cause foundation settlement to increase. With the increase in depth, the cost increases rapidly. Offshore gravity structures require more steel than steel jacket structures and these structures are exposed to seafloor scour.

8.1. Future Scope

- Offshore gravity structures have a promising future in the offshore development plans. From previous projects records must be retained for future work, and with these parameters, various case studies such as effectiveness of offshore structures as an economic case, seismicity potential, etc. should be analyzed.
- Efforts should be made to minimize the scouring caused to the offshore structures.
- As these structures prove to be uneconomical with large depths, ways should be found to make it less costly.

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