The 2018 World Congress on
Advances in Civil, Environmental, & Materials Research (ACEM18)
Songdo Convensia, Incheon, Korea, August 27 - 31, 2018

Keynote Paper

New concepts for ocean nuclear power plants

*Phill-Seung Lee[1)], Chaemin Lee[2)], Kang-Heon Lee[3)], Jaemin Kim[4)], Kihwan Lee[5)]

[1), 2)] *Department of Mechanical Engineering, KAIST, Daejeon 34141, Korea*
[3)] *SMART System Design Division, KAERI, Daejeon 34057, Korea*
[4)] *Samsung C&T Corporation, Seongnam-si, Gyeonggi-do 13530, Korea*
[5)] *Offshore Engineering Research Department, HHI, Ulsan 44032, Korea*

[1)] *phillseung@kaist.edu*

ABSTRACT

We present recently developed new concepts for ocean nuclear power plants (ONPPs) using gravity-based structures (GBS) and tension leg platforms (TLP) [1-3]. For GBS-type ONPPs, the large nuclear reactor (APR 1400) and the small and medium nuclear reactor (SMART) are mounted, respectively. For a TLP-type ONPP, SMART is mounted. We introduce basic design concepts including new general arrangements (GAs) obtained through a modularization method. In order to evaluate their safety and stability, a fully coupled seismic analysis considering GBS-seawater-soil interaction is performed for GBS-type ONPP. Hydrostatic and dynamic analyses are conducted for the TLP-type ONPP. We believe that ONPPs are the next generation nuclear power plants with enhanced safety useful for mankind.

1. INTRODUCTION

As an effort to safely use nuclear power, the concept of ocean nuclear power plants (ONPP) has emerged. Various types of ONPPs have been proposed such as a submerged type ONPP, named Flexblue, developed by France [5], a barge type ONPP, named Akademik Lomonosov, developed by Russia [6] (see Figure 1), and a spar-type ONPP developed by Massachusetts Institute of Technology (MIT) [7] (see Figure 2).

In this presentation, we introduce our concepts for ONPPs using gravity-based structures (GBS) and tension leg platforms (TLP), which are called GBS-type (see Figure 3) and TLP-type ONPPs (see Figure 4), respectively [1,2].

In the following sections, we explain the design concepts of the GBS- and TLP-type ONPPs. Then, we show the results of fully coupled seismic analysis considering GBS-seawater-soil interaction for the GBS-type ONPP, and hydrostatic and hydrodynamic analyses for the TLP-type ONPP.

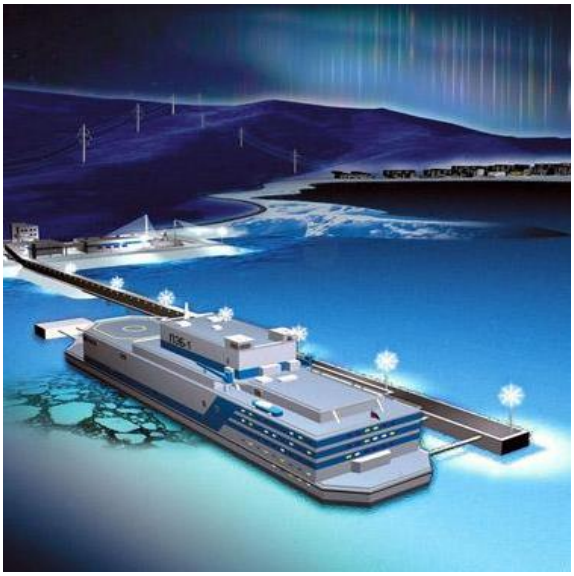

Figure 1. Akademic Lomonosov.

Figure 2. Spar-type ONPP.

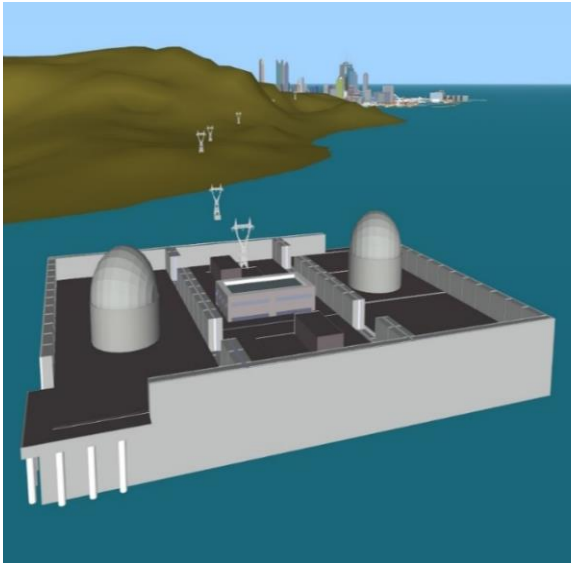

Figure 3. GBS-type ONPP.

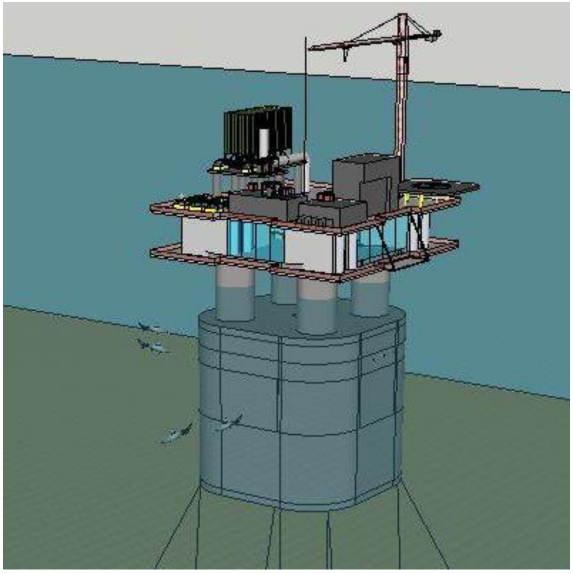

Figure 4. TLP-type ONPP.

2. GBS-type ONPP

The gravity-based structure (GBS) is one of the typical offshore structures, which is held in place by gravity. The biggest advantage of using GBS is that it enables to provide similar environmental conditions as on land. Thus, already developed nuclear facilities can be easily adopted in ocean environment without major design changes.

We use the system-integrated modular advanced reactor (SMART) and the advanced power reactor 1400 (APR 1400) developed by the Korea Hydro & Nuclear Power (KHNP) Co., Ltd., with minimum modification of the general arrangement (GA), safety features, and design parameters.

We use the modularization method to place nuclear facilities into the GBS modules. Physical connections and fluid circulations among the facilities are mainly considered. We divide the module of the facilities and buildings into seven groups, as shown in Table 1.

Table 1. Modularized groups [2].

Group	Facilities and buildings
1	- AAC D/G building - Aux. boiler and oil storage building - Fresh water storage tank
2	- Turbine generator building - Main transformer - Unit Aux. transformer - Standby Aux. transformer - Excitation transformer - Spare unit Aux. transformer - Other spare transformers
3	- Reactor make-up water tank - Hold-up tank - Boric acid storage tank - EDG building - CO2 Storage tank - Other storage tanks
4	- Reactor building - Aux. building - Compound building
5	- Operator's office - Guard house - Accommodation - Main control building - Refuge - Fire pump and water - Wastewater treatment building and facilities
6	- ESW/CW Intake structure - Chlorination building - CCW HX building - Discharge pond and facilities
7	- N2 and H2 storage cylinder area

Using SMART, the single GBS type design was first developed, which supplies 100MWe of output from a single unit, and later expanded to double and triple GBS designs which supply 200MWe of output, as shown in Figure 5.

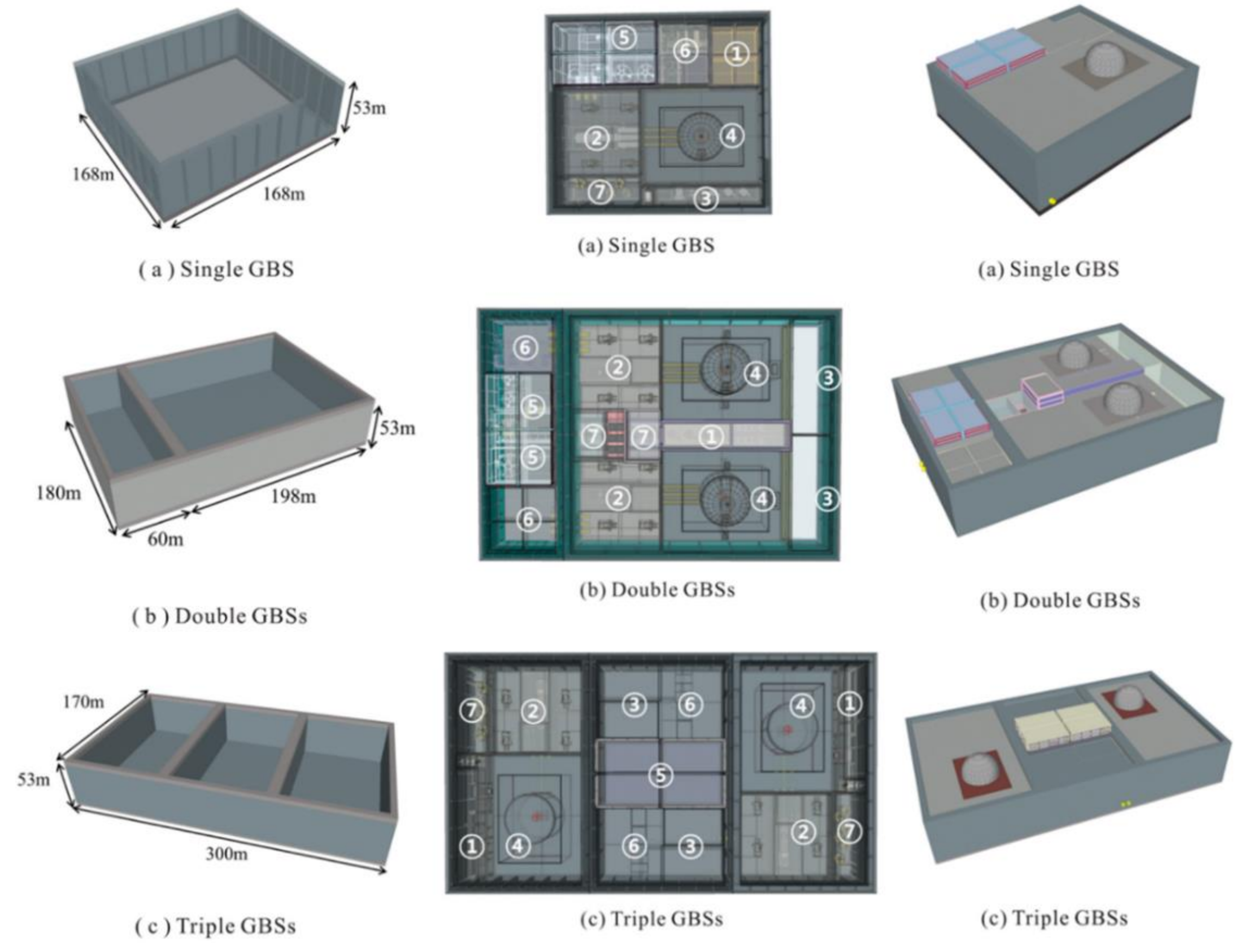

Figure 5. Three GBS-type ONPPs [2].

For evaluating the safety of GBS-type ONPPs, we conduct a fully coupled seismic analysis of soil-GBS-seawater system using the commercial software, ADINA. The acceleration time history of the El-Centro earthquake is applied. By changing the amount of ballasting water, we investigate how the weight of GBS-type ONPP affects its responses.

The finite element model of the soil-GBS-seawater system is shown in Figure 6. The horizontal acceleration of the GBS-type ONPP is shown in Figure 7. Through case studies, we observed that as the unit weight is decreased, the horizontal acceleration response is reduced. This is because, when the weight is lighter, horizontal sliding movement occurs and thus the transferred earthquake acceleration is reduced.

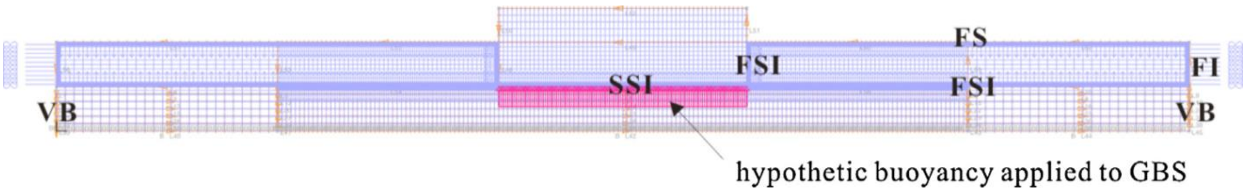

Figure 6. Finite element model of soil-GBS-seawater system [2].

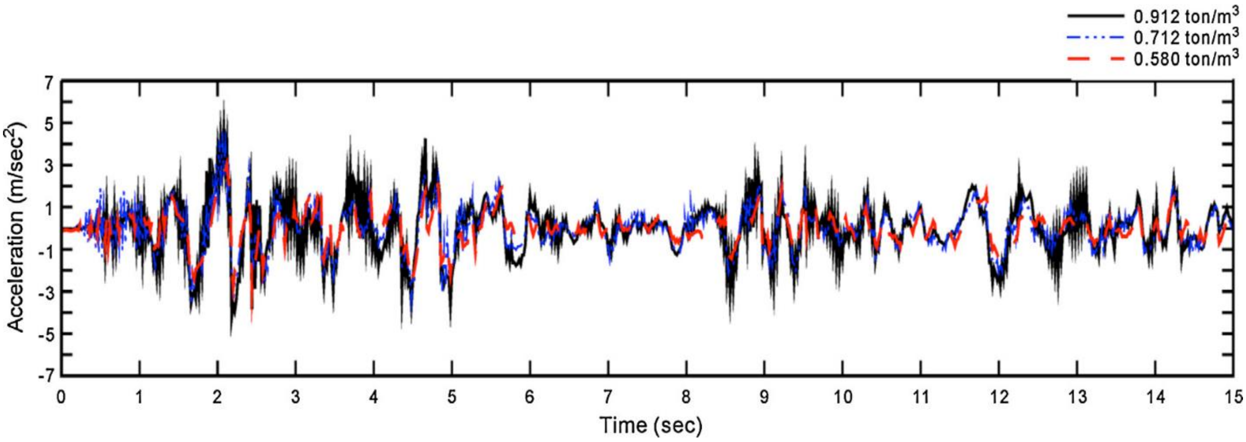

Figure 7. Horizontal acceleration response of the GBS-type ONPP [2].

3. TLP-type ONPP

The tension leg platform (TLP) is a buoyant unit connected to a fixed foundation by pre-tensioned moorings. It has very good seakeeping performance among various floating offshore structures, especially for vertical motions such as heave, roll, and pitch. For this reason, TLP is the proper platform for developing new floating-type ONPP. We mount SMART for the TLP-type ONPP. As for the GBS-type ONPP, we use the modularization method to place nuclear facilities into the TLP modules. The design of the moorings is performed based on the DNV-OS-E301 rule.

When designing the GBS-type ONPP, the consideration of earthquake is essential. On the other hand, for the TLP-type ONPP, we need to perform hydrostatic and hydrodynamic analyses [8-12].

As a result of the hydrostatic analysis, we have obtained positive values of righting arm (GZ), as shown in Figure 8. This means that the platform is in a stable equilibrium state. Wave conditions for hydrodynamic analysis are selected based on the sea state. We consider from the sea state 3, which means relatively calm state, to sea state 8, which means extreme state. The commercial software ANSYS AQWA is used for the hydrodynamic analysis. Accelerations and tilt angles occurring in the structure can be predicted. Figure 8 shows the tilt angles for the sea state 7. In conclusion, we have confirmed that accelerations and tilt angles occurring in the structure satisfies the rule for nuclear merchant ship proposed by the GL in all the sea states considered.

4. Conclusions

In this presentation, we introduced the GBS-type ONPP. It has a great advantage, that is, existing nuclear facilities can be used with minimal design changes. A new GA for the GBS-type ONPP obtained using the modularization method is presented. A fully coupled seismic analysis of soil-GBS-seawater system is conducted using commercial software ADINA. It was observed that the relation between the unit weight of the GBS-type ONPP and its horizontal acceleration during earthquake. Next, we introduced the TLP-type ONPP. It requires more design changes of the nuclear facilities for development than that for the GBS-type ONPP. However, it has the advantage of being almost free from Tsunami, and also there is less physical limitation to its installation site. Through the hydrostatic analysis, we confirmed that the structure is in static equilibrium state. Performing the hydrodynamic analysis, accelerations and tilt angles are obtained and we confirmed that the TLP-type ONPP is safe when compared with the GL rule even in extreme sea state. We believe that ONPPs are the next generation nuclear power plants with enhanced safety useful for mankind.

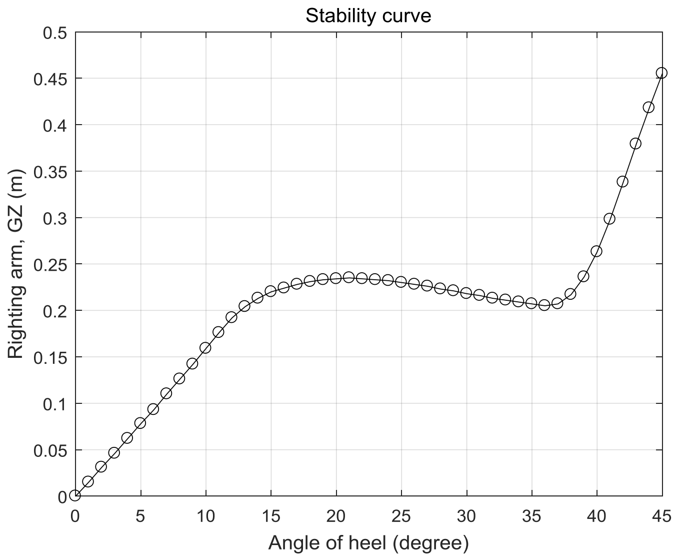

Figure 8. Stability curve of the TLP-type ONPP.

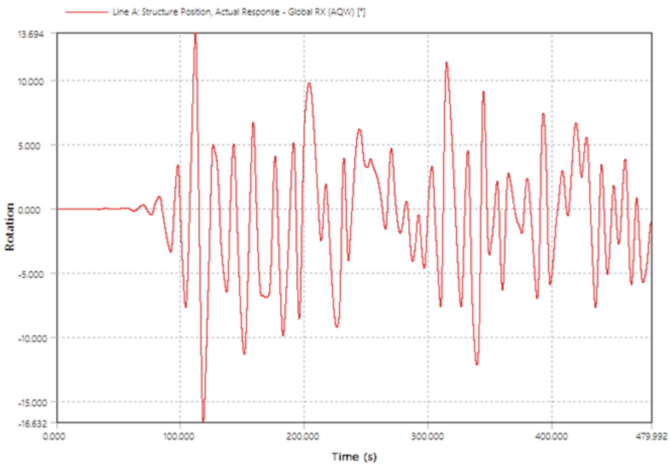

Figure 9. Tilt angles for sea state 7

REFERENCES

Lee K, Lee KH, Lee JI, Jeong YH, and Lee PS. (2013), "A new design concept for offshore nuclear power plants with enhanced safety features", *Nuclear Engineering and Design*, **254**, 129–141.

Kim MG, Lee KH, Kim SG, Woo IG, Han JH, Lee PS, and Lee JI. (2014), "Conceptual studies of construction and safety enhancement of ocean SMART mounted on GBS", *Nuclear Engineering and Design*, **278**, 558–572

Lee KH, Kim MG, Lee JI, and Lee PS. (2015), "Recent Advances in Ocean Nuclear Power Plants", *Energies*, **8**(10), 11470–11492.

Buongiorno J, Jurewicz J, Golay M, and Todreas N. (2016), "The offshore floating nuclear plant concept", *Nuclear Technology*, **194**(1), 1-14.

Kolmayer A. (2011), "Blue Submarine; The Flexblue® Offshore Nuclear Reactor," *Power Engineering International*, **19**, 126-131.

Fadeev Y. (2011), "KLT-40S Reactor Plant for the Floating CNPP FPU," IAEA international workshop on advanced nuclear reactor technology for near-term deployment, Vienna, Austria.

Jurewicz J, Boungiorno J, Golay M, Todreas N. (2014), "Offshore Floating Nuclear Plant (OFNP) with Spar-Type Platform Design," Transactions of American Nuclear Society winter meeting, USA.

Kim KT, Lee PS, Park KC. (2013), "A direct coupling method for 3D hydroelastic analysis of floating structures," *International Journal for Numerical Methods in Engineering*, **96**(13), 842-866.

Yoon JS, Cho SP, Jiwinangun RG, Lee PS. (2014), "Hydroelastic analysis of floating plates with multiple hinge connections in regular waves," *Marine Structures*, **36**, 65-87.

Lee KH, Cho S, Kim KT, Kim JG, Lee PS. (2015), "Hydroelastic analysis of floating structures with liquid tanks and comparison with experimental tests," *Applied Ocean Research*, **52**, 167-187.

Lee KH, Lee PS. (2016), "Nonlinear hydrostatic analysis of flexible floating structures," *Applied Ocean Research*, **59**, 165-182.

Yoon JS, Lee PS. (2017), "Towards hydro-elastoplastic analysis of floating plate structures," *Journal of Fluids and Structures*, **71**, 164-182.