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# Design loads on floating solar photovoltaic system based on ASCE and DNV standards

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## ABSTRACT

Unlike the ground-mounted solar photovoltaic (PV) system, the floating solar PV system is subject to additional environmental loads. Especially, loads induced by waves and earthquakes should be necessarily considered. However, research on the design load and load combination of floating solar systems is insufficient at this point.

In this study, we present the design loads and load combinations for the floating solar PV system. Environmental loads such as wind, wave, snow, and earthquake are considered as the design loads based on ASCE 7-16 (ASCE/SEI, 2016), which is used as the minimum design loads and criteria. In addition, the load combinations for the floating solar PV system are presented using ASCE 7-16 (ASCE/SEI, 2016) and DNVGL-OS-C201 (DNV, 2015). The load combinations for the allowable strength design (ASD) are suggested.

## 1. INTRODUCTION

Solar energy is one of the clean energy to replace fossil energy, but the construction of large-scale solar power plants inevitably causes ecological damage. To solve the problem, the concept of floating solar photovoltaic (PV) system installed on calm water, such as reservoirs or offshore, has emerged. Cool temperatures allow the panels to generate power with higher efficiency, and shade reduces water evaporation.

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Unlike solar PV systems that are installed on the ground, floating PV systems (Fig. 1) must be able to withstand loads from wave and water level changes as well as wind. Design rules and codes for ground-mounted solar PV systems have been developed for decades, but yet there are no systematic design rules for floating solar PV system.

Fig. 1 A floating solar photovoltaic system (Cazzaniga 2018).

In this presentation, we suggest design loads and their load combinations. Based on existing building construction codes and design requirements of floating structures, brief calculation methods are suggested. Load combinations for ASD are also suggested.

## 2. DESIGN LOADS

In this section, we briefly introduce four environmental loads as external design loads: wind load, wave load, snow load, and earthquake. The environmental loads can be simulated and calculated from their environmental conditions, and those environmental conditions should be based on the observation data. If the observed data is insufficient, stochastic models such as DNV-RP-C205 (DNV, 2010) can be used to estimate the values.

Wind load can be simply calculated using ASCE 7-16 (ASCE/SEI, 2016), which provides the minimum design loads and criteria. Among the code, the floating solar panels can be considered as 'Main Wind Force Resisting System (MWFRS)', and 'directional procedure' should be applied since the direction of wind pressure varies along the direction of the wind. Parameters regarding gust, wind direction, height and angle of the panel, and normalized wind area are used. Since the floating solar PV system can be regarded as a rooftop structure with a very low height, section 29.4.3 can be applied. In detail, the basic wind speed is determined via the 'risk category' of the structure; then, the velocity pressure is derived with the help of the wind load parameters. The wind pressure of solar PV panels is determined by considering not only the velocity pressure but also the placement of the panel.

Wave loads cannot be obtained with simple relation due to the complexity of the platform. Advanced simulations such as CFD, SPH, and BEM or experiments are required to calculate the wave load of a given platform and environmental conditions. Wave conditions can be expressed using parameters such as significant wave height, peak period, and wave spectrum, which should be observed or stochastically derived. Using appropriate wave theory (Airy, Stokes) combined with energy spectrum (PM, JONSWAP), sea states can be simulated. The well-known code DNV-RP-C205 (DNV, 2010) provides detailed procedures above.

Snow can generate a weight load, which sometimes cannot be ignored. Section 7.4 of ASCE 7-16 (ASCE/SEI, 2016) deals with the sloped roof snow loads, which can be used to calculate snow load on solar panels. The tilt angle of the panel, thermal factor, importance factor, and terrain roughness of the installation site are required to obtain the wind load.

Earthquakes do not directly induce loads on the floating structure, due to the mooring system and inertia of the system. However, tsunami or sloshing can be triggered on the shore or in reservoirs, respectively, which both induce sudden changes in buoyancy and mooring tension. The stochastic process or historic observation for evaluating long-term event potential risk should be conducted.

## 3. LOAD COMBINATIONS

In this section, the load combinations considering wave load are briefly discussed. Because ASCE 7-16 (ASCE/SEI, 2016) is used when designing buildings or land structures, ASCE 7-16 (ASCE/SEI, 2016) does not consider wave load. However, wave load should be considered because the floating solar PV system is floating on the water. To present the load combinations considering wave load, the standards of DNV is used. In ASCE 7-16 (ASCE/SEI, 2016), the load combinations for ASD are also utilized. Thus, we present the load combinations for ASD.

In the case of ASD, DNVGL-OS-C201 (DNV, 2015) is utilized because DNVGL-OS-C201 (DNV, 2015) is a standard used when designing offshore structures for ASD. Following “For units unmanned during extreme environmental conditions, the usage factor $h_0$ may be taken as 0.84 for loading condition b).” on Table 1 of section 4.4.4 in DNVGL-OS-C201 (DNV, 2015), 0.84 is considered as the load factor for the wave load. Table 1 gives the load combination considering the wave load for ASD.

Table. 1. Load combinations for ASD

| | Load combinations |
|---|---|
| 1 | D |
| 2 | D+L |
| 3 | D+S |
| 4 | D+0.75L+0.75S |
| 5 | D+0.6W+0.84F |
| 6 | D+0.75L+0.75(0.6W)+0.75S+0.84F |
| 7 | 0.6D+0.6W+0.84F |

D : dead load, L : live load, S : snow load, W : wind load, F : wave load

## 4. CONCLUSIONS

We present the design loads and load combinations for the floating solar PV system. Four environmental loads are considered as external loads, and their calculating methods and considerations are suggested based on ASCE 7-16 (ASCE/SEI, 2016). Wave load is included in the load combinations based on ASCE 7-16. Using DNVGL-OS-C201 (DNV, 2015), the load combinations for ASD are presented. As a result, a new guideline for floating solar PV systems is presented. In the future, this work can be used for preliminary design.

## ACKNOWLEDGEMENTS

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## REFERENCES

DNV (2010), “DNV-RP-C205: Environmental conditions and environmental loads”, Det Norske Veritas.

DNV (2015), “DNV-OS-C201: Structural Design of Offshore Units”, Det Norske Veritas.

ASCE/SEI (2016), “ASCE 7-16: Minimum design loads and associated criteria for buildings and other structures”, American Society of Civil Engineers.

Cazzaniga, R., Cicu, M., Rosa-Clot, M., Rosa-Clot, P., Tina, G. M., and Ventura, C. (2018), "Floating photovoltaic plants: Performance analysis and design solutions." *Renew. Sust. Energ. Rev.*, **81**, 1730-1741.

KAIST (2021), “Recommended Design Rules for Floating Photovoltaic System”, Hanwha Energy Corporation.