Available online at www.sciencedirect.com

ScienceDirect

Solar Energy 108 (2014) 13–27

SOLAR ENERGY

www.elsevier.com/locate/solener

Design and installation of floating type photovoltaic energy generation system using FRP members

Young-Geun Lee [a,1], Hyung-Joong Joo [b], Soon-Jong Yoon [a,*]

[a] Department of Civil Engineering, Hongik University, Seoul 121-791, Republic of Korea
[b] ISIS E&C Co., Ltd., Seoul 121-842, Republic of Korea

Received 13 May 2014; received in revised form 24 June 2014; accepted 26 June 2014

Communicated by: Associate Editor Mukund Patel

Abstract

In this paper, we present the result of investigations pertaining to the development of floating type photovoltaic energy generation system. For the floating structure, durable and light-weight materials such as a pultruded FRP composite material are essential. Pultruded FRP has superior mechanical properties and excellent corrosion–resistance compared with those of conventional structural materials. In the paper, we discussed the development concepts of the floating type photovoltaic energy generation system briefly. The mechanical properties of the FRP structural member used in the structural system are investigated through the tensile and shear tests. Test results are used in the finite element analysis and design of the system. Link system which is composed of pultruded FRP, used tire, and PE rope is also analyzed by the finite element method. Finally, floating type photovoltaic energy generation system is designed, fabricated, and installed successfully at the sea site in Korea. In addition, the energy production of floating PV energy generation system is measured and compared with that of land type plant. Energy productions of floating type from June to August are significantly higher, but the energy productions from September to October are lower.

Keywords: Floating type PV energy generation system; Pultruded fiber reinforced polymeric plastic; Finite element analysis; Design and installation

1. Introduction

Recently, environmental problems associated with the excessive use of fossil fuel are issued throughout the world. Enforcement of the Kyoto protocol ensures that renewable, sustainable energy sources are a priority for national governments (Hollaway, 2013). As an alternative energy resource, the importance of renewable energy is continuously rising. Moreover, the demands for facilities to generate renewable energy are also rising. To satisfy such demands, a large number of photovoltaic (PV) energy generation systems is constructed and planned in a large scale. However, since these facility zones are mostly located on land, some problems such as an increase in total construction cost due to high cost of land use, environmental disruption such as devastation of ecological system have occurred. To solve or mitigate such problems, floating type PV energy generation system is studied and developed (Nam, 2010).

The PV panel temperature is a parameter that has great influence in the behavior of a PV system, as it modifies system efficiency and output energy (Nishioka et al., 2003). It depends on the PV panel encapsulating material, its thermal dissipation and absorption properties, the working

* Corresponding author. Tel.: +82 2 320 1479; fax: +82 2 3141 0774.
E-mail addresses: esdras1981@gmail.com (Y.-G. Lee), hj5898@hanmail.net (H.-J. Joo), sjyoon@hongik.ac.kr (S.-J. Yoon).
[1] Tel./fax: +82 2 3141 0774.

http://dx.doi.org/10.1016/j.solener.2014.06.033
0038-092X/

point of the PV panel, the atmospheric parameters such as irradiance level, ambient temperature and wind speed (Lasnier, 1990) and the particular installing conditions (Garcia and Balenzategui, 2004; Teo et al., 2012). To decrease the temperature on the PV panel, various air cooling and water cooling techniques have been studied and developed (Tonui and Tripanagnostopoulos, 2007; Dubey et al., 2009; Agrawal and Tiwari, 2011). The floating type PV energy generation system may decrease the temperature naturally. Temperature of the PV panels in the floating type PV energy generation system is lower than the land type due to relatively low temperature of the sea site.

The advantages of floating type photovoltaic energy generation system compared with the system installed on land may be considered as below.

– Environmental problems such as devastation of ecological system may be eliminated or mitigated.
– Because the system uses water surface, the land can be used for other purposes and no need to make access road.
– Energy generation efficiency may be increased because the ambient temperature on water is relatively low.
– Evaporation from the water surface may be reduced when installed in a reservoir (ex: Photovoltaic floating cover system (Ferrer-Gisbert et al., 2013; Santafé et al., 2013)).

According to the previous research (Trapani and Redón Santafé, 2014), installations of the floating type PV energy generation system are totally 19 from 2007 to 2013 in worldwide. First floating PV power plant is installed in Aichi, Japan. And then various types of floating PV power plants are installed in USA, Italy, Spain, France, Korea, etc. In addition, installation of the tracking type floating PV generation system was installed recently in Korea (Choi, 2014; Kim et al., 2014). In 2014, 1 MW class floating PV energy generation system was constructed at the cooling water intake channel in the thermoelectric power plant in Dangjin, Korea.

In 2009, we have developed the floating type PV energy generation system using pultruded fiber reinforced polymeric plastic (PFRP) members (Choi et al., 2010a, 2010b; Lee et al., 2010) at the sea site. PFRP has superior material properties compared with those of conventional structural materials. Especially, PFRP has light weight and excellent corrosion–resistance (Babero, 1998; Bank, 2006) which is highly appreciated for the design and fabrication of the floating type photovoltaic energy generation system. Strictly speaking, FRP materials are non-corrosive material. However, strength and stiffness of the FRP are known to be decreased by the moisture absorption (Smith, 1990, 2001). In order to consider the rate of moisture absorption when the FRP structure is designed, adjustment factors are recommended by 0.8–0.9 (ASCE, 2010). According to Strongwell's corrosion resistance guide (2014), PFRP structural shape composed of glass fiber and polyester resin has a sufficient corrosion resistance in sea water.

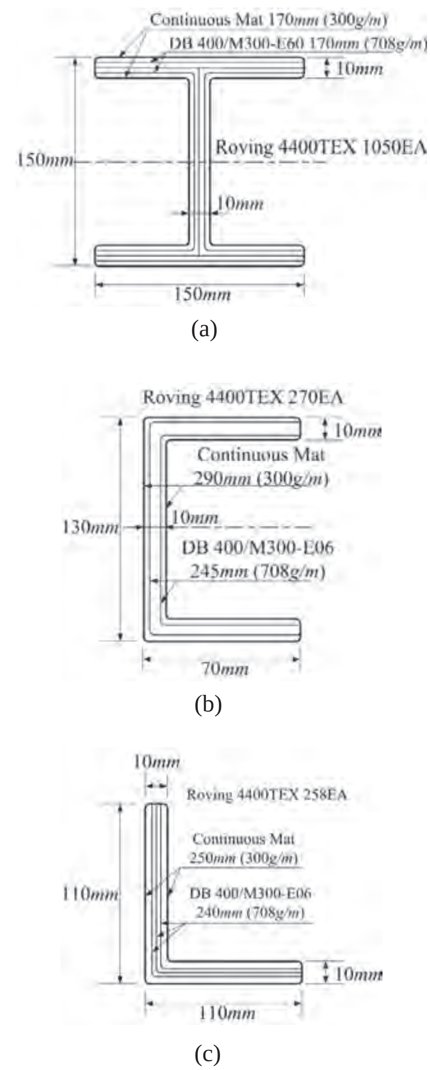


Fig. 1. Arrangement of reinforcing fiber used for manufacture and dimension of cross-section of PFRP member. (a) I-shape; (B) channel and (c) angle.

In this paper, we discuss the design and fabrication of the floating type photovoltaic energy generation system briefly. The mechanical characteristics of PFRP members used in the fabrication of the floating type photovoltaic energy generation system are presented. Mechanical properties of PFRP members are also measured by the tensile and shear tests. The finite element analysis of the floating type photovoltaic energy generation system is conducted using mechanical properties test results. In addition, we present the result of investigations pertaining to the development of links between unit modules of the floating type photovoltaic energy generation system. The link system installed between the unit modules is made of PFRP, recycled used tire, and polyethylene synthetic fiber rope. The link system is also analyzed by the finite element method. The floating type photovoltaic energy generation system which is consisted of unit modules connected by the link

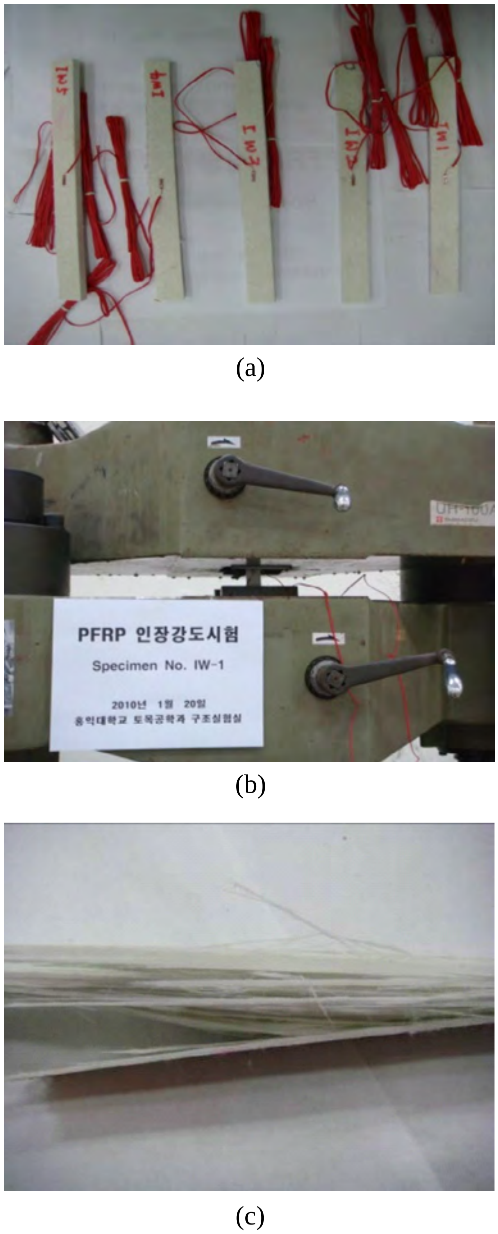


Fig. 2. Tensile strength test. (a) Specimens; (b) test and (c) failed specimen.

Table 1
Average tensile test results.

Shape	Young's modulus (GPa)	Strength (MPa)	Poisson's ratio
Angle	38.17	521.53	0.36
Channel	34.49	564.88	0.32
I	30.76	415.31	0.29

system is installed at the sea near land. The energy production of energy generation of the system is measured and analyzed.

Table 2
Average shear test results.

	Shape	Shear modulus (GPa)	Strength (MPa)
Angle	Axial	6.30	87.31
	Transverse	6.15	61.53
Channel	Axial	6.76	93.54
	Transverse	5.72	67.31
I	Axial	5.40	76.30
	Transverse	6.33	41.41

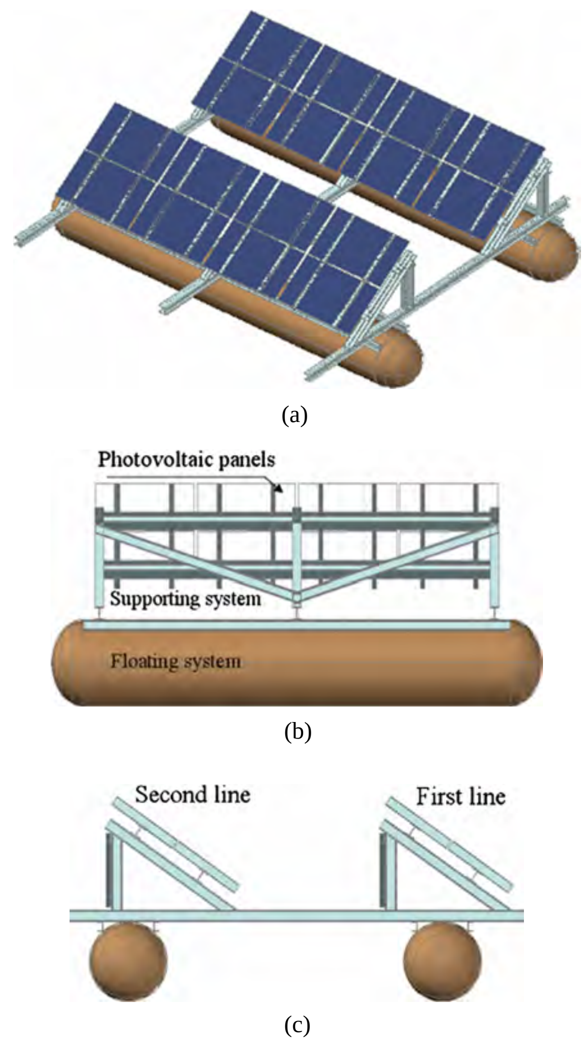


Fig. 3. The floating type photovoltaic energy generation system. (a) Unit module; (b) rear view and (c) side view.

2. Mechanical properties of PFRP members

2.1. PFRP members

PFRP members produced for the structure fabrication have shapes such as angle-type, channel-type, and I-type cross-section which are widely used as a general steel

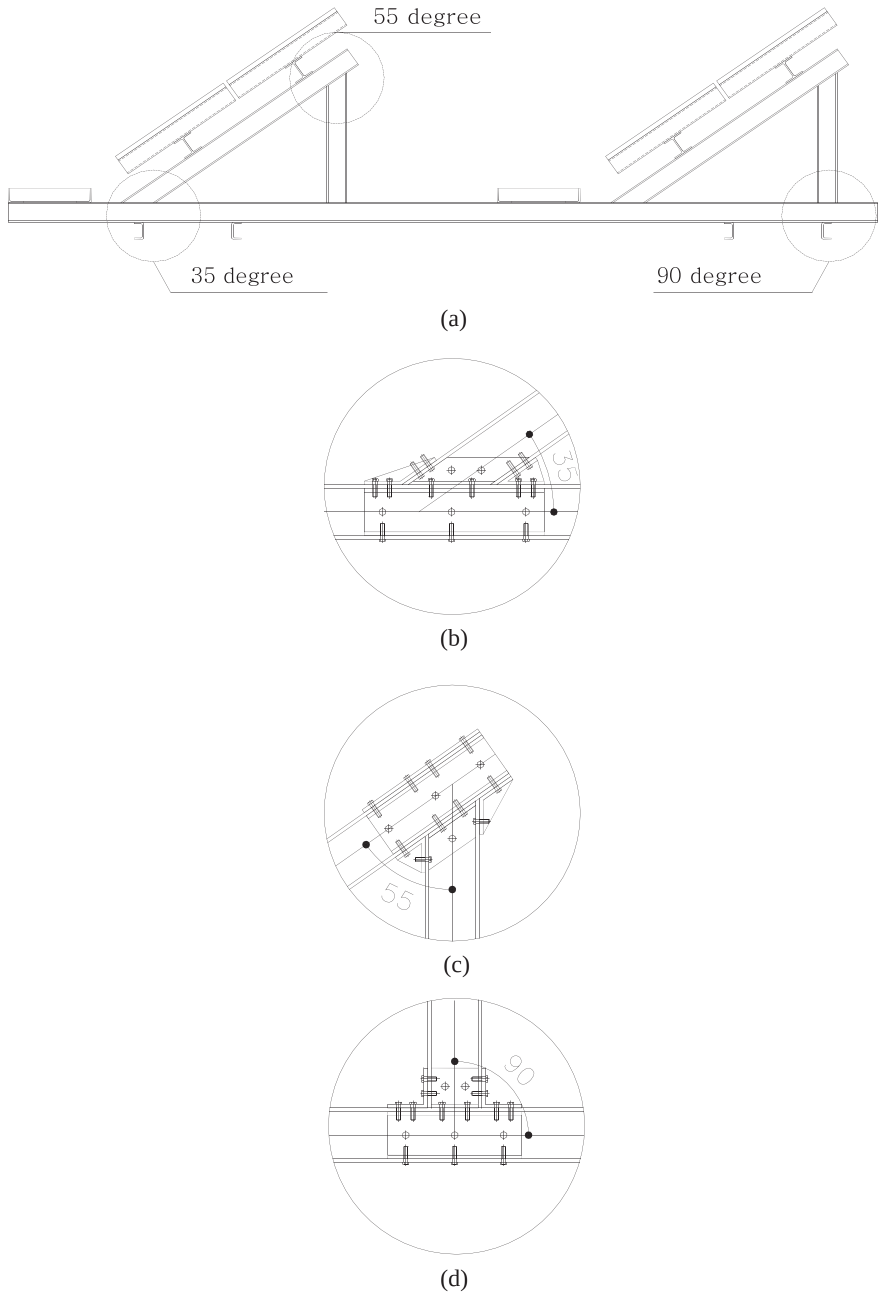


Fig. 4. Details of connection part. (a) Connection, (b) 35°, (c) 55° and (d) 90°.

structural member. The reinforcing fibers for those members are E-glass fibers and the matrix material for the member is polyester resin. Schematic view of arrangement of reinforcing fibers within the cross-section for each type of the member is shown in Fig. 1. Roving was longitudinally arranged due to the characteristics of the pultrusion process of structural member and chopped strand mat (CSM) was used at the near surface of the members. In addition, non-directional arrangement of both double bias mat (roving cross, ±45°) and short E-glass fiber, about 50 mm, in the direction of ±45° for the angle-type, channel-type, and I-type members to achieve stiffness in longitudinal as well as transverse directions are also used in the manufacturing process.

2.2. Tensile test

The tensile test specimen was taken along the longitudinal direction (i.e., member axis direction) of the member according to ASTM D 3039-08. For testing tensile strength, the specimen was installed and loaded using the universal testing machine with 1000 kN capacity. The specimen was loaded up to failure with a loading speed of 3 mm/min according to the displacement control

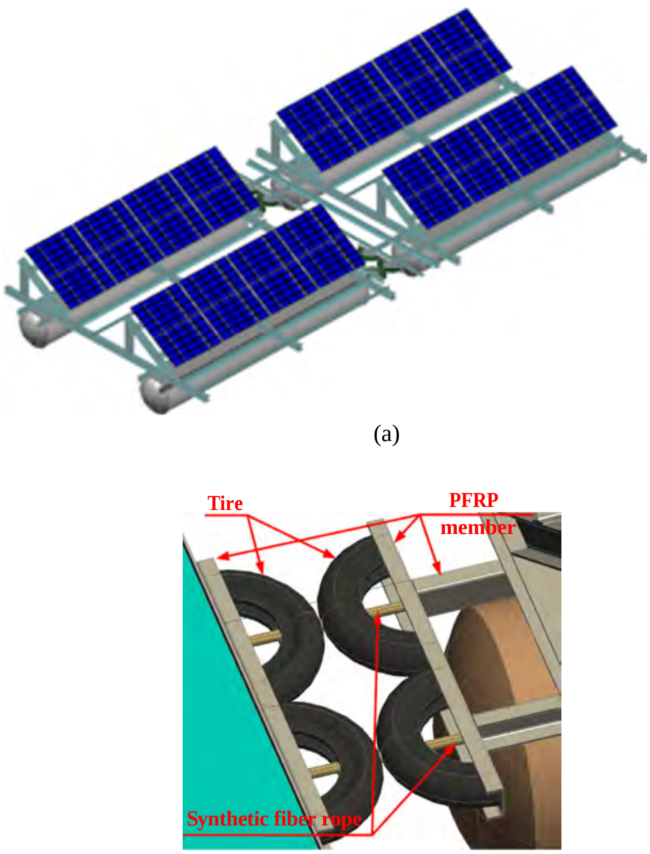


Fig. 5. Connection between unit structures. (a) ISO-view and (b) detailed view.

Table 3
Safety factors for the FRP structural member (AASHTO).

Strength	Member type	Safety factor
Flexural	Beam	2.5
Shear	Beam	3.0
Compressive	Column or truss	3.0
Tensile	Tie or truss	2.0
Bearing	Joint or connection	N/A

method. Mechanical properties along the longitudinal direction of the member are measured by tensile tests using the specimens shown in Fig. 2(a), and a test set-up and one of the failed specimens are also shown in Fig. 2(b) and (c), respectively. Table 1 gives the summary of average tensile test results.

2.3. Shear test

Shear strength tests were performed on the total of 30 specimens, 10 specimens taken from each structural shape made of PFRP. Shear strength tests for the PFRP were performed on the specimens to reach specimen breaking at the center of specimen by shear according to the method

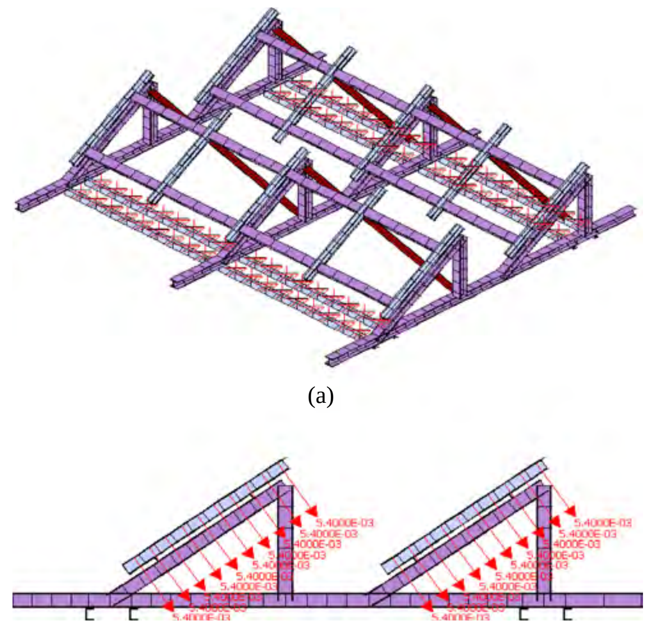


Fig. 6. Boundary and loading conditions. (a) Boundary conditions (all hinges) and (b) loading conditions.

Table 4
Check for safety of structural member.

	Member	Maximum stress by FEM (MPa), ①	Ultimate strength/safety factor (MPa), ②	①/②	Remark
I	Flextural	52.66	185.40	0.284	OK
	Compressive	8.44	154.50	0.055	OK
	Tensile	12.08	231.76	0.052	OK
	Shear	22.80	26.37	0.865	OK
C	Flextural	73.91	162.54	0.455	OK
	Compressive	1.52	135.45	0.011	OK
	Tensile	3.11	203.18	0.015	OK
	Shear	20.62	31.18	0.661	OK
A	Flextural	3.33	194.52	0.017	OK
	Compressive	0.00	162.10	0.001	OK
	Tensile	0.96	243.15	0.004	OK
	Shear	0.04	29.10	0.001	OK

suggested by ASTM D 5379-12. The loading speed of 1.27 mm/min was applied according to the displacement control method. The shear test results are briefly summarized as given in Table 2.

3. Design of floating type photovoltaic energy generation system

3.1. Design of unit module

In the floating type PV energy generation structure, 16 PV panels are installed and each PV panel has the

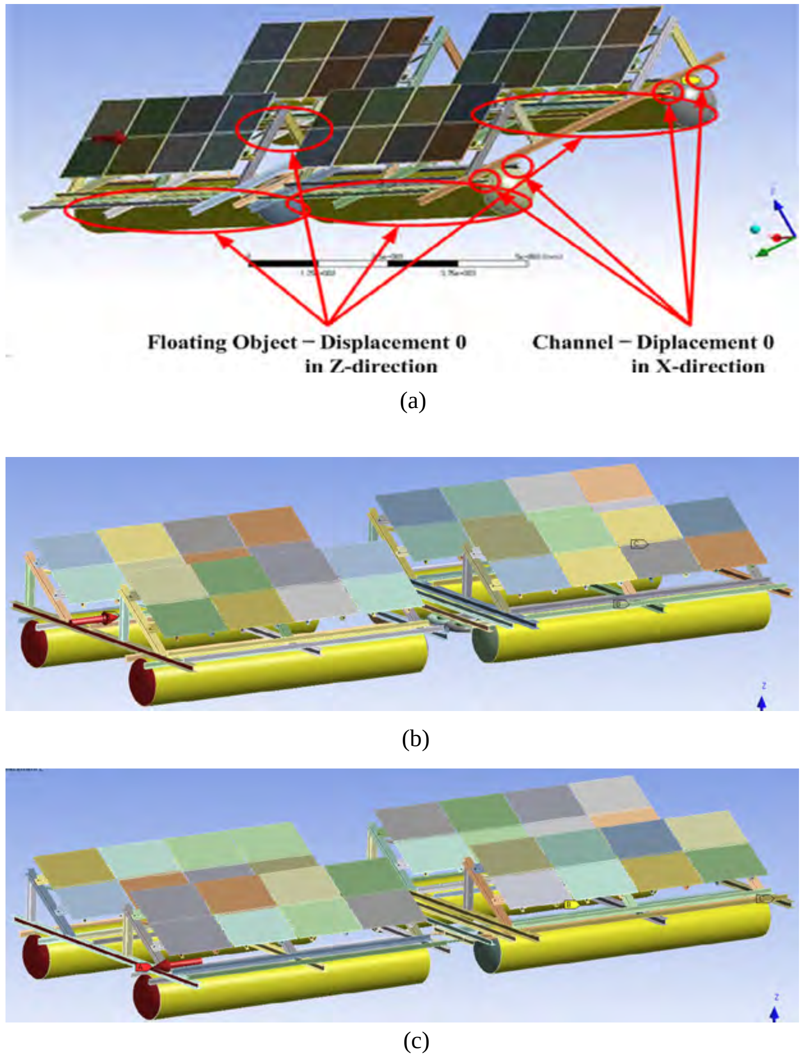
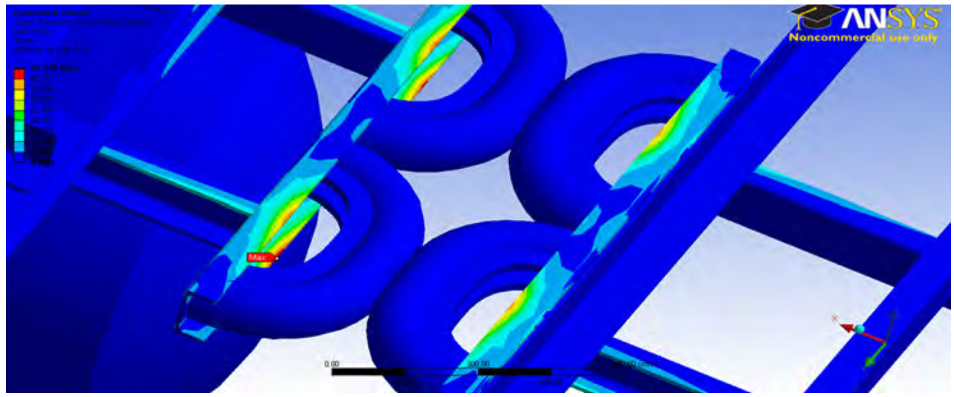


Fig. 7. Boundary and loading conditions of the connection part between modules. (a) Boundary conditions of the connection part between modules; (b) Case 1 – loading condition (compression) and (c) Case 2 – loading condition (tension).

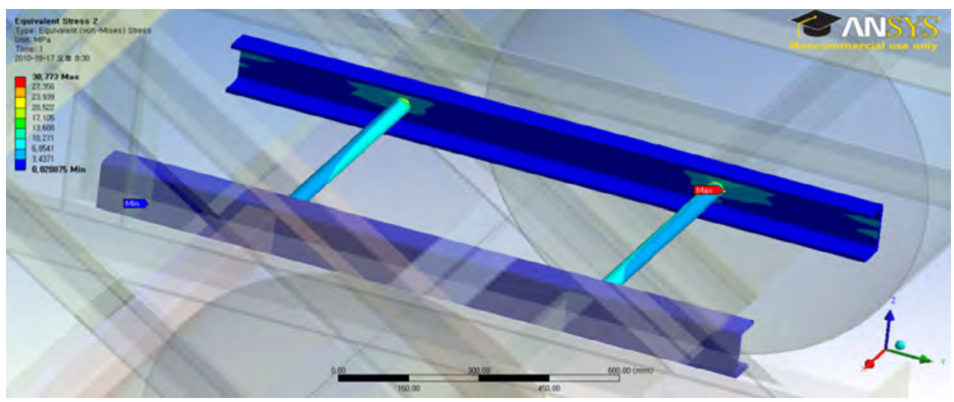
Table 5
Check for safety between connection parts.

Case	Member	Maximum stress by FEM (MPa)	Ultimate strength (MPa)	Remark
1	Channel (PFRP)	45.8	564.9	OK
	Tire	2.80	50.0	OK
2	Channel (PFRP)	12.06	564.9	OK
	Polyethylene rope	30.77	120.0	OK

dimension of 1619 mm × 980 mm × 35 mm and a capacity of about 230 W. As shown in Fig. 3, the overall outside dimension of the unit module structure was designed as 6630 mm × 7000 mm × 2685 mm to support 16 PV panels so that total energy generation capacity could be 3.68 kW considering fabrication, installation, workability, etc. As shown in Fig. 3, the structure is composed of two parts. One is the supporting structural system that supports the PV panels. As mentioned earlier, all of the pultruded FRP (PFRP) members are designed to be connected by the stainless steel bolts as shown in Fig. 4. There are three types of connections which are 35°, 55°, and 90° as shown in Fig. 4(a). Details of each connection are shown in Fig. 4(b)–(d). All of bolts, nuts, and washers are made of stainless steel to prevent from corroding on the salty water environment. The other is the floating system located under the supporting system. The floating system is made of the filament winding E-glass reinforced polyester plastic (GFRP) pipe produced commercially. GFRP pipe is cut to a certain length and then the inside of the pipe is filled with Styrofoam which is used to prevent the loss of buoyancy of the floating object when the pipe is damaged. Finally, the FRP end plates made by the hand lay-up process are used to close both sides of the GFRP pipe.

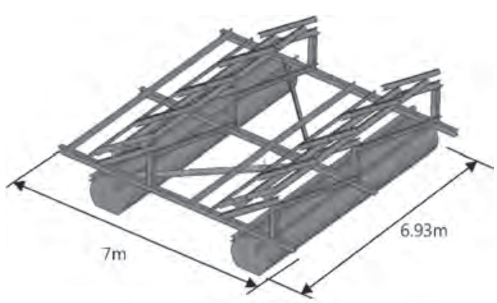


(a)

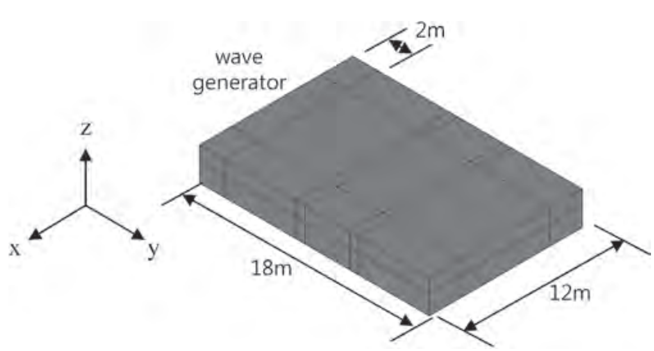


(b)

Fig. 8. Analysis results for the connection part between modules. (a) Case 1 and (b) Case 2.



(a)



(b)

Fig. 9. Geometries of structure and fluid model. (a) Floating structure and (b) fluid.

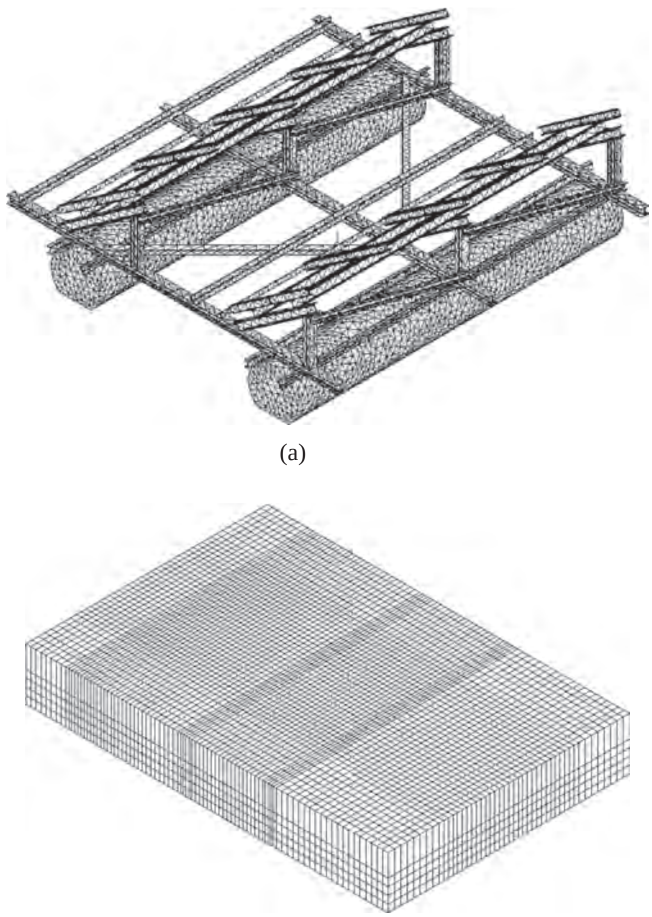
3.2. Connection between modules

We discussed the development concepts of connection between unit module structures made of PFRP, steel plate, recycled used tire, and synthetic fiber rope and the details are shown in Fig. 5.

3.3. Design method for the structure system

The allowable stress design method and the strength design method are mainly used as design methods for the structures. The design method specifically applicable for the PV energy generation structures is not available at this time. Hence, in general, the required members have been selected and used according to designer's choice based on the allowable stress design method.

Differently from metal materials which are considered to be an isotropic material, the PFRP material is typical materials which have anisotropic material property, and the strength and stiffness of materials differ significantly depending on the quantity and reinforcing direction of fibers and the matrix material used. So it is very difficult to determine the member size by simply applying the design method.



(a)

(b)

Fig. 10. Generated mesh of structure and fluid. (a) Floating structure and (b) fluid.

In this study, the allowable stress design method which is widely accepted in the construction industries is basically used. Table 3 gives the safety factor for the member which is recommended by America Association of State Highway and Transportation Officials (AASHTO).

3.4. The finite element analysis

3.4.1. Modeling

The finite element analysis (FEA) was performed to check structural safety of the designed floating type PV energy generating structure. In the finite element analysis, GTSTRUDL Ver. 29 was used. The element used for modeling of a PV panel is the SBHQ6 which is a stretching and bending hybrid quadrilateral element with 6° of freedom for each node. All the members for the supporting system were modeled with 3D-frame element. The mechanical properties of materials used in the analysis are the results obtained from the experiment as mentioned earlier.

The analysis was performed based on the assumption that the structures were simply supported on 4 bottom channel members that are assembled with the cylindrical shaped floating object which is installed on the water surface.

Load was applied according to the guideline specified in the IEC 61646: 2008. This guideline specifies the maximum load on the PV panel as 5400 Pa and also specifies that there must have no problems with respect to the electrical use as well as the structural safety when the load is applied. The guideline also specifies the load of 2400 Pa which is calculated if the safety factor of 3 for the gale at the wind speed of 130 km/h (equivalent to wind speed 36 m/s = 800 Pa) and the load of 5400 Pa is used for the durability against heavy snow or ice loads. It is a large amount of load as much as two times of combined load in the extreme conditions suggested by the general structural design codes. In the finite element analysis, load was applied by combination of 5400 Pa and dead load when the structures are installed on the water surface. Details on the loading and boundary conditions are shown in Fig. 6.

3.4.2. Results of the finite element analysis

Maximum flexural stress, maximum compressive stress, and maximum shear stress in the member of the structure are briefly summarized and the result of the safety check of the member is given in Table 4.

3.4.3. Connection between unit structures

Structural analysis was performed to verify the safety of the connection between unit module structures. For the connection of unit module structures, structural behaviors are examined through FE analysis. Program used for the analysis is ANSYS 11.0 SP1 which is a general purpose structural analysis commercial program. Boundary and loading conditions are shown in Fig. 7. Load is applied according to the guideline specified in IEC 61646 (2008). This guideline specifies the maximum load on the PV module as 5400 Pa as mentioned. There are two cases of loading conditions, compressive case (Case 1) and tensile case (Case 2). In both cases, the wind load is applied to the projected area in the plus (+) or minus (−) horizontal direction on unit module structure. The mechanical properties of materials used in the analysis are the results obtained from

Fig. 11. Schematic of numerical model for wave generation.

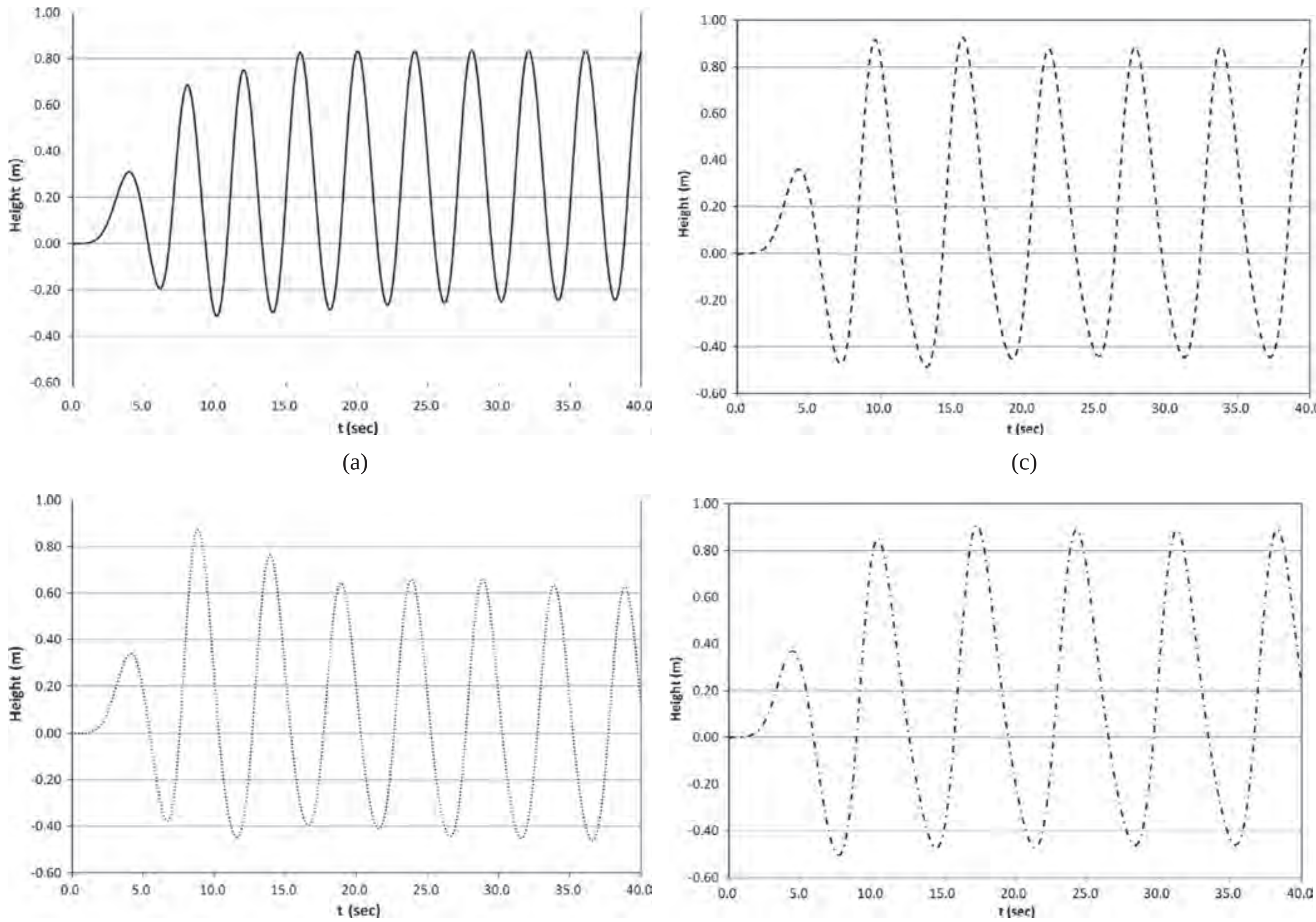


Fig. 12. Numerical results of wave generation. (a) $T = 4$ s; (b) $T = 5$ s; (c) $T = 6$ s and (d) $T = 7$ s.

Table 6
Characteristic of generated wave.

Case	T (second)	Wave height (m)
I	4	1.09
II	5	1.12
III	6	1.33
IV	7	1.35

the experiment. From the result of the analysis, the maximum stresses at the recycled used tire, rope, and channel member of connection part are found. As a result, more than 3 of safety factors in all connection parts are confirmed. The results of analysis are briefly summarized in Table 5 and shown in Fig. 8, respectively.

4. Hydrodynamic–structural analysis of floating type photovoltaic energy generation system

We conducted the hydraulic and structural analysis of floating body using ADINA system (ADINA R&D INC., 2012) which can solve the fluid–structure interaction (FSI) problems. Wave periods and wave heights were selected as the main independent parameters in this study and the characteristics of responded stresses were investigated such as the location and magnitude of the maximum stress (Kim et al., 2010).

4.1. Modeling

The supporting structural system that supports the photovoltaic panels is made of pultruded FRP. The floating system is made of polystyrene foam product (Styrofoam). The geometries of structure and fluid are shown in Fig. 9. Detailed each shape of mesh for structure and fluid, respectively, is also shown in Fig. 10 (Kim et al., 2010).

4.2. Wave generation

The idea for generating wave in fluid flow domain was similar to that in laboratory experiments, moving the vertical wall in either side of fluid domain. As the boundary

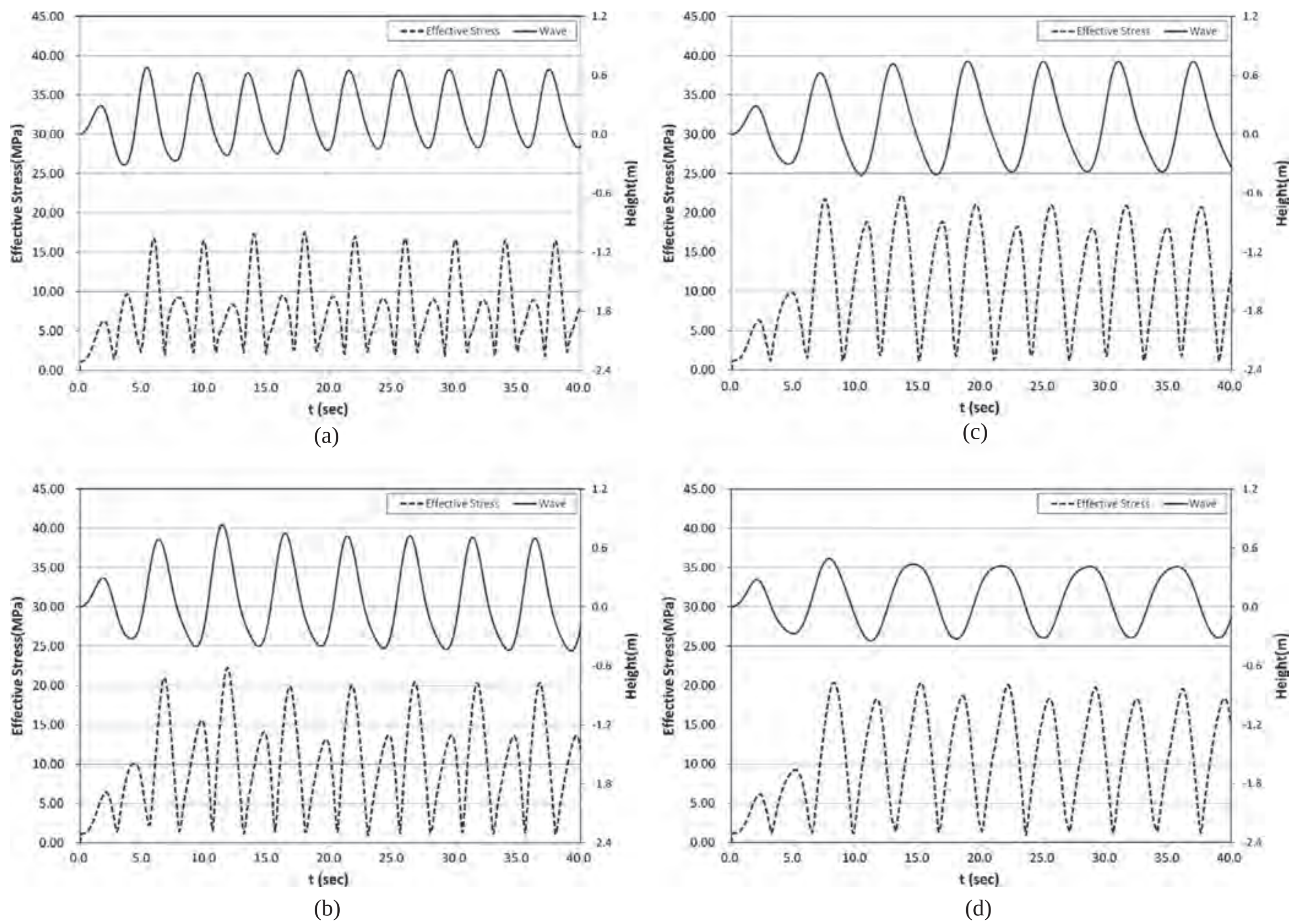


Fig. 13. Maximum effective stress in floating body for wave propagation. (a) $T = 4$ s; (b) $T = 5$ s; (c) $T = 6$ s and (d) $T = 7$ s.

Table 7
Maximum effective stress when structure located at crest and trough.

Case	Effective stress (MPa)			
	I	II	III	IV
Crest	16.38	20.33	20.76	19.53
Trough	8.93	13.44	18.43	18.24

condition in ADINA system, moving wall was used to generate specific waves by changing the movable range of wall as shown in Fig. 11. The wave period was varied from 4 to 7 s. In cases for several wave periods, the initial time of 20 s, at least, is required to obtain stable wave motion as shown in Fig. 12. It was also found that wave generated by the moving wall had the same wave period of wave generator and wave heights became higher when the kinetic time of wave generator became longer, which might be caused by the increment of contact time between water and wall and the transmission of more energy for longer contact time. Characteristics of generated wave in this study are presented in Table 6 (Kim et al., 2010).

4.3. Results of the hydrodynamic–structural analysis

When the effective stress in floating body for wave propagation combining with the water surface fluctuation was investigated as shown in Fig. 13, the maximum stress for each case was detected at the crest of wave and the difference between crest and trough became smaller when the wave length was longer. Maximum effective stresses when the structure located at crest and trough are briefly summarized in Table 7. Maximum effective stress results of all of the cases are less than the allowable stress (Kim et al., 2010).

5. Fabrication and installation

5.1. Production of PFRP member

In this study, structural members supporting the PV panels are manufactured by the pultrusion process to fabricate the floating type PV energy generating structure. The PFRP members for the structure have 3 different cross-sectional shapes including I, angle, and channel. For the pultrusion process, a mold to maintain the shape of

(a)

(b)

(c)

Fig. 14. Member production by the pultrusion process. (a) Fiber supply and impregnation; (b) pulling; (d) hardening.

cross-section for each member is required and molds need to manufacture for each structural shape, respectively. A process to produce pultruded FRP member is shown in Fig. 14.

5.2. Fabrication and installation of floating type PV energy generation structure

A floating type PV energy generation structure may be fabricated as 6 step processes. Fabricating steps are shown in Fig. 15. A floating type PV energy generation structure is installed at the Buksin Bay, Tongyeong-si, Gyeongsangnam-do, Korea, in December, 2009. Installation site is presented in Fig. 16. Installation process of the floating type PV energy generation structure on the water surface is shown in Fig. 17.

5.3. Connection between unit structures and mooring

Connection between unit structures is done after moving unit structures to the installation site using a motor boat. The unit structures are fixed by using a rope. Between both sides of the structure, to ensure the safety of the structure, recycled used tires are inserted (Nam, 2010). Fig. 18(a) and (b) shows connection installed between unit structures and mooring state, while Fig. 18(c) shows floating type PV energy generation structures whose installation and mooring are completed.

6. Energy production of PV energy generation of the system

The monthly energy production of the floating type PV energy generation system is compared with that of PV generation system installed on land. The monthly energy production of floating type PV energy generation system is expected to have several advantages. Especially, difference of temperature of the seawater and land is expected to increase the energy generation efficiency. According to the temperature data presented by Korea meteorological administration, the difference of temperature measured in the seawater and land near Tongyeong-si region is approximately 2 °C during summer (Lee et al., 2010). This system has 16 PV panels (230 W × 16 = 3.68 kW). However, measurement of energy production in the floating type PV energy generation system is conducted at only 4 PV panels (230 W × 4 = 0.92 kW) due to lack of capacity of converter. PV plant on land is a part of the commercial plant which has 20 kW capacity. Measured energy production data of floating type PV energy generation system is compared with that of PV energy generation system on land as given in Table 8. As can be seen in Table 8, energy productions of floating type system from June to August are significantly higher than land type system. However, energy productions of floating type system from September to October are lower than land type system. This phenomenon may be related to malfunction due to condensation of the switchboard after the typoon DIANMU had passed over Tongyeong-si region in August 11, 2010. Accordingly, to get more reliable data for the efficiency, many years of continuous measurements are needed.

7. Conclusion

In this paper, we present the study result of design, fabrication, and installation of the floating type PV energy generation system. First of all, basic design of the floating type PV energy generation system was performed according to the design concept such as unit module structure with appropriate handling size considering safety, easy of fabrication, installation, handling, etc.

Fig. 15. Fabrication of floating type PV energy generation structure. (a) Fabrication of vertical unit member; (b) fabrication of horizontal unit member; (c) connection between vertical and horizontal unit members; (d) fabrication of vertical bracing and guide; (e) assemble PV panels and (f) attach floating object.

The structural design is conducted by using the PFRP members to prevent corrosion of the structure. To obtain the mechanical properties of PFRP members, tensile test and shear test are conducted. These mechanical properties test data were used to determine the allowable stress of PFRP materials with safety factors suggested in AASHTO (2001). Safety check for the floating type PV energy generation system was performed by comparison with the result of the finite element analysis. It was found that the unit module structure and connection part between unit structures could resist external loads successfully with the sufficient safety. In addition, we conducted the fluid–structure interaction analysis of the floating type PV energy generation system using ADINA system which can solve the fluid–structure interaction (FSI) problems. The maximum stress obtained in the analysis is much less than the allowable stress of PFRP materials.

In this study, we suggest the method to fabricate and install floating type PV energy generation structures efficiently and it was noted that most of processes could

Fig. 16. Installation site of the floating type PV energy generation structure.

(a)

(b)

Fig. 17. Installation of floating type PV energy generation system on the water surface. (a) Lifting and (b) installation on the water surface.

be easily conducted by plain worker. For more rapid and efficient work, it is necessary that perforation of bolt holes should be conducted systematically with the machine at the production factory, rather than by worker. In addition, selection of a drill blade suitable for the mechanical characteristics of the FRP material would likely be important.

As discussed at the introduction, the PV energy generation structures require a large amount of area of land for the PV energy generation plant. The economic benefit per investment is low because of high cost of land use, so it is one of the reasons to make people reluctant to construct the PV energy generation plant on land. Since the floating type PV energy generation structures suggested in this study uses an idle water surface, it was expected that the expenses for purchasing the required land for the suggested PV system could be minimal in comparison with the PV energy generation plant on land. However, since expenses of the floating object were added for installation on the water surface, more economical design of structures is needed to develop. Moreover, the design of the floating type PV energy generation structures was attempted first time. Accordingly, the optimum design and fabrication of the structures considering the structural characteristics of FRP member should be further developed. In addition, it was also considered to be extremely important that the long-term observation for the developed structures is needed in relation to the durability and efficiency of the system.

(a)

(b)

(c)

Fig. 18. Floating type PV energy generation structures installed at the sea site. (a) Connection; (b) mooring and (c) completion of installation.

Table 8
Comparison of the monthly energy production between the floating type and land type system.

Month	Floating (0.93 kW) (①, kW h)	Land (20 kW) (②, kW h)	②/(20 kW/0.93 kW) (③, kW h)	①/③
June (21–30)	20.4	313.0	15.33	1.3
July	52.6	931.0	45.6	1.2
August	55.8	1042.0	51.1	1.1
September	46.5	1124.0	55.1	0.8
October (1–10)	12.2	397.0	19.5	0.6

Finally, increment of the energy production of floating type system is not clear compared with that of land type system. To get more reliable data for the evaluation of efficiency, many years of continuous measurements are needed.

Acknowledgements

This research was supported by the grant (code F20833209H1400 00110) funded by Korea Institute of Marine Science & Technology Promotion of Korean government. The financial support provided by the above institution is acknowledged.

References

AASHTO, 2001. Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals. AASHTO, Washington, D.C..

ADINA R&D Inc., 2012. ADINA Theory and Modeling Guide. ADINA R&D Inc., Watertown, Massachusetts.

Agrawal, S., Tiwari, G.N., 2011. Energy and exergy analysis of hybrid micro-channel photovoltaic thermal module. Sol. Energy 85, 336–370.

ANSYS, 2008. 11.0 User's Manual, ANSYS Inc., Pennsylvania.

ASCE, 2010. Pre-Standard for Load & Resistance Factor Design (LRFD) of Pultruded Fiber Reinforced Polymer (FRP) Structures. ASCE, Virginia.

ASTM D 3039/D 3039 M-08, 2008. Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials.

ASTM D 5379/D 5379 M-12, 2012. Standard Test Method for Shear Properties of Composite Materials by the V-notched Beam Method.

Babero, E.J., 1998. Introduction to Composite Materials Design. Taylor & Francis Inc, Pennsylvania.

Bank, L.C., 2006. Composites for Construction: Structural Design with FRP Materials. John Wiley & Sons, New Jersey.

Choi, H., Joo, H.J., Nam, J.H., Kim, K.S., Yoon, S.J., 2010a. Structural design for the development of the floating type photovoltaic energy generation system. Mater. Sci. Forum 654–656, 2803–2806.

Choi, H., Joo, H.J., Nam, J.H., Yoon, S.J., 2010b. Development of the floating type photovoltaic energy generation system. J. Korean Soc. Adv. Compos. Struct. 1 (1), 16–26.

Choi, Y.K., 2014. A study on power generation analysis of floating PV system considering environmental impact. Int. J. Software Eng. Its Appl. 8 (1), 75–84.

Ferrer-Gisbert, C., Ferrán-Gozálvez, J.J., Redón-Santafé, M., Ferrer-Gisbert, P., Sánchez-Romero, F.J., Torregrosa-Soler, J.B., 2013. A new photovoltaic floating cover system for water reservoirs. Renewable Energy 60, 63–70.

Garcia, A., Balenzategui, J.L., 2004. Estimation of photovoltaic module yearly temperature and performance based on nominal operation cell temperature calculations. Renewable Energy 29, 1997–2010.

GTSTRUDL, 2007. GTSTRUDL User Reference Manual. Georgia Institute of Technology, Georgia.

Hollaway, L.C., 2013. Advanced fibre-reinforced polymer (FRP) composite materials for sustainable energy technologies. In: Bai, J. (Ed.), Advanced Fibre-reinforced Polymer (FRP) Composites for Structural Applications. Woodhead Publishing Limited, UK, pp. 737–779.

IEC 61646, 2008. Thin-film Terrestrial Photovoltaic (PV) Modules – Design Qualification and Type Approval.

Kim, S.H., Lee, Y.G., Seo, S.H., Joo, H.J., Yoon, S.J., 2014. Structural design and installation of tracking-type floating PV generation system. Compos. Res. 27 (2), 59–65.

Kim, S.Y., Choi, E.S., Yoon, S.J., Lee, S.O., 2010. Three dimensional hydrodynamic–structural analysis of floating type photovoltaic composite structure. in: Proceedings of AIMM'10, Jeju, Korea.

Lasnier, F., 1990. Photovoltaic Engineering Handbook. Adam Hilger, UK.

Lee, Y.G., Joo, H.J., Nam, J.H., Yoon, S.J., 2010. Modified design of floating type photovoltaic energy generation system. J. Korean Soc. Adv. Compos. Struct. 1 (4), 18–27.

Nam, J.H., 2010. Development of Floating Type Photovoltaic Energy Generation System Using the Pultruded Structural Members. Ph.D. Thesis, Hongik University, Seoul, Korea.

Nishioka, K., Hatayama, T., Uraoka, Y., Fuyuki, T., Hagihara, R., Watanabe, M., 2003. Field test analysis of PV system output characteristics focusing on module temperature. Sol. Energy Mater. Sol. Cells 75, 665–671.

Santafé, M.R., Ferrer Gisbert, P.S., Sánchez Romero, F.J., Torregrosa Soler, J.B., Ferrán Gozálvez, J.J., Ferrer Gisbert, C.M., 2013. Implementation of a photovoltaic floating cover for irrigation reservoirs. J. Cleaner Product. 66, 568–570.

Smith C., 2001. Environmental testing on pultruded structural shapes. in: Proceedings of COMPOSITES 2001. Tampa, Florida.

Smith, C.S., 1990. Design of Marine Structures in Composite Materials. Elsevier Applied Science, UK.

Strongwell, 2014. Corrosion Resistance Guide: Industrial Products. Strongwell, Virginia.

Dubey, S., Sandhu, G.S., Tiwari, G.N., 2009. Analytical expression for electrical efficiency of PV/T hybrid air collector. Appl. Energy 86, 697–705.

Teo, H.G., Lee, P.S., Hawlader, M.N.A., 2012. An active cooling system for photovoltaic modules. Appl. Energy 90, 309–315.

Tonui, J.K., Tripanagnostopoulos, Y., 2007. Air-cooled PV/T solar collectors with low cost performance improvements. Sol. Energy 81, 498–511.

Trapani, K., Redón Santafé, M., 2014. A review of floating photovoltaic installation: 2007–2013. Prog. Photovoltaics Res. Appl..