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LONG-TERM STRAIN MONITORING DATA OF JACKET-TYPE OFFSHORE STRUCTURE FOR TIDAL CURRENT POWER GENERATION UNDER SEVERE TIDAL CURRENT ENVIRONMENTS

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ABSTRACT: Structural strain responses of the jacket-type Uldolmok tidal current power plant structure under severe tidal environments were analyzed using long-term measurement data from construction to normal operation. From the measured data during construction, it was found that there were significant changes in strain responses at the steps of jacket lifting, weight-block loading, pile ejection and insertion. Strains due to permanent and tidal current loads were analyzed during removal work on one among six jacket legs, and it was found that the strains due to permanent load were much significantly changed after removal of on jacket leg. From the measurement data during normal operation, it was observed that strain responses were obviously fluctuated with M2 and M4 tidal periods and also with relatively short period of about 11 min due to the peculiar tidal characteristics in the Uldolmok strait.

Keywords: Tidal current power plant jacket structure, strain long-term measurement, measurements in construction and operation, tidal effects.

INTRODUCTION

The Korean southwest coastal area has long been considered as a highly attractive candidate for power generation from tidal currents. Among the possible sites in the southwest coastal area, the Uldolmok strait is known as the most promising site owing to the distinctive tidal currents with very high speeds up to 4-5 m/sec. Recently, the Uldolmok tidal current power plant (TCPP) was built as a pilot plant to promote research and development investment and speed up the commercialization of TCPPs (KORDI, 2011). Uldolmok TCPP is located between Jindo Grand Bridge and Byeokpa Port in the east-west direction and also between the towns of Jindo and Haenam in the north-south direction as shown in Fig. 1. Water depth at the jacket structure is 19 m below approximate lowest low water and total platform height and submerged platform height in water are 25.0m and 23.5m, respectively. Uldolmok TCPP was designed, fabricated, constructed, and operated according to the design guidelines for offshore steel jacket platform structures, in order to maintain the structure safely and economically under very high levels of tidal current loading. It is nevertheless very important to monitor structural responses to ensure structural integrity and also to establish load and response databases for further design of a commercialized TCPP farm (shown in Fig. 1 as commercialized TCPPs).

In this study, strains of the Uldolmok TCPP under severe tidal environments were measured using long-term measurement system and these data were analyzed. From the measured data during construction, it was found that there were significant changes in strain responses at the steps of jacket lifting, weight-block loading, pile ejection and insertion. Strains due to permanent and tidal current loads were analyzed during removal work on one among six jacket legs, and it was found that the strains due to permanent load were much significantly changed after removal of on jacket leg. From the measurement data during normal operation, it was observed that strain responses were obviously fluctuated with M2 and M4 tidal periods and also with relatively short period of about 11 min due to the peculiar tidal characteristics in the Uldolmok strait.

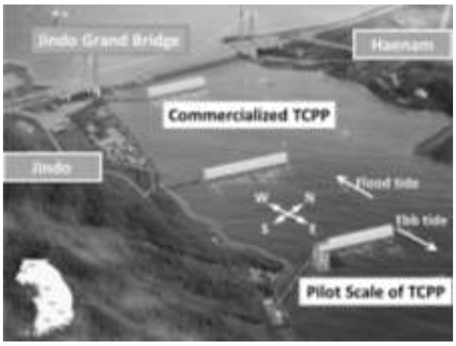

Fig. 1. Location of Uldolmok TCPP

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CONSTRUCTION AND MEASUREMENT

Main Construction Phases

Figure 2 shows the main construction stages for Uldolmok TCPP; (1) lifting both of the jacket and upper deck structures, (2) installing the jacket structure at the power plant site, (3) loading a weight block of 480 ton for increasing the stability against sliding and overturning under severe tidal current, (4) drilling seabed ground with a reverse circulation drilling (RCD) equipment, (5) inserting inner piles and pouring grout-concrete for combining jacket legs and inner piles, and (6) fabricating the house structure and power plant facilities and finally connecting the jacket structure with land-side office by truss-type catwalk (KORDI 2011).

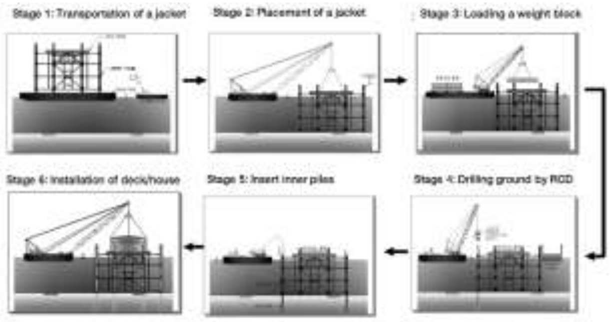

Fig. 2. Main Construction Stages

Long-Term Measurement System

The Uldolmok TCPP measurement system tracks three categories of data: (1) power-related data including rotational speed and torque at the side of turbine; (2) structural responses including strain, acceleration, and dynamic tilts; and (3) environmental data including tidal current and temperature, as shown in Fig. 3. This study focuses solely on the strain data, which were used to evaluate the tidal load levels using strain data under severe tidal environments.

Eight (8) strain gauges were installed at the bottom of jacket legs (DL-18m) based on the design drawing and structural analysis results as shown in Fig. 4. The gauges were installed inside of the structure with specialized protecting cases for protecting the gauges and cables from the tidal current loadings and also from unexpected impacts by small and/or medium scale floating objects. Considering the main tidal current directions, i.e. east and west directions, six (6) strain gauges (i.e. GS-W-E, SG-NW-E, SG-SW-E, SG-NE-W, SG-SE-W, and SG-E-W) were attached for measuring ε_{yy} , while two (2) strain gauges were attached to measuring ε_{xx} . The portable handy-type data loggers (i.e. TC31k) with batteries were used to measure strain responses every 30 minutes during construction works, and the static data logger with an external power was utilized to measure the strain every 1 minute after completion of construction work.

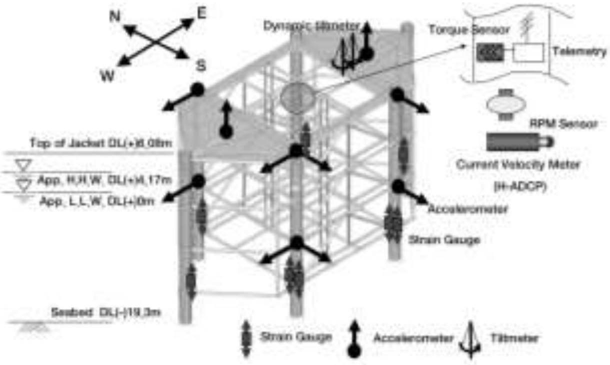

Fig. 3 Layout of Uldolmok TCPP measurement system

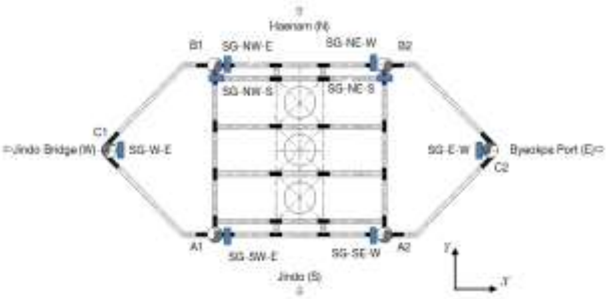

Fig. 4. Installation Points for Strain Gauges

ANALYSIS OF STRAIN DATA

Measurement Data at Lifting Phase

Strain gauges instrumented after construction are generally able to measure relative strains based on the strain under permanent loading and/or initial loading conditions. Strain gauges can be also instrumented during construction work, for example, strain gauges can be embedded with rebar in concrete structure cases. However, the accurate strain measurement cannot be guaranteed even in such a case, because the initial loading condition cannot be ideally zero. Therefore it is more practical to install the sensors after construction work and the initial strain level under permanent loading can be numerically evaluated and added into the measured strain data in most cases.

In this study, strain gauges were installed when the jacket structure was laid in the land-side fabrication yard near the installation site. The jacket structure was first stand, lifted and temporally free hanging by a floating crane. The numerical simulation could be more accurately carried out because the supporting conditions became clearer than the free-standing condition. When the structure was hanging by a floating crane, the connecting points became roller supports. The jacket structure was eventually being under tension-only state by self-weight. If strain gauges were installed at the utmost bottom of jacket legs, then strains must be measured as zero when the structure was hanging. But strain gauges were installed in just lower parts of jacket legs due to interferences with many horizontal members; hence somewhat extent of tensile strain can be expected at the hanging condition. Figure 5(a) shows the measured stain data during lifting operation by a floating crane, and it can be observed that the strains were significantly increased under hanging condition. In other words, the members became under tension-governing state. After the structure was temporally fixed on the barge ship for transportation, the strains were reduced again. It is also noteworthy that the strains were not perfectly recovered after fixing on the barge ship because of the different supporting condition at the bottom of jacket legs; hence, free standing condition before lifting and fixed condition by strut tie after fixed on the barge ship.

The numerical model was indirectly investigated by comparing the differences in measured and analyzed strains under free standing and hanging conditions. For the modeling of the jacket structure under free standing condition, six (6) points at the end of jacket legs were considered as hinge supporters, while the top of four jacket legs (i.e. A1, A2, B1 and B2) were considered as roller supporters because the crane cables cannot resist the horizontal forces as shown in Fig. 6.

Fig. 7 shows the numerically evaluated strains under both of free standing and hanging cases. In the cases of four (4) jacket legs (i.e. A1, A2, B1 and B2), the compressive strains at the free standing case were evaluated as about -80 $\mu\varepsilon$ and those were changed as about 20 $\mu\varepsilon$ at the hanging case after lifting operation, i.e. strain levels were totally increased as amount of about 100 $\mu\varepsilon$. In the cases of C1 and C2 jacket legs (i.e. SG-W-E and SG-E-W), the strain levels were evaluated as relatively lightly changed than other cases, which is because the upper deck and load block weights were not directly transferred through these two jacket legs,. The measured and analyzed results were compared in Fig. 8. In the cases of strain differences in SG-SE-W and SG-NE-W, the differences were almost identical as about 100 $\mu\varepsilon$, however the differences for SG-E-W and SG-WE-S are quite big, which is caused from the problem related to supporting condition, i.e. the bottom parts of jacket legs, in the case of free standing condition. In the case of general steel structures like Uldolmok TCPP, the geometric and material properties can be reasonably obtained by design drawings, therefore these errors originated from the modeling errors on assumed supporting conditions, and these discrepancies can be overcome by numerical model updating using by measured responses.

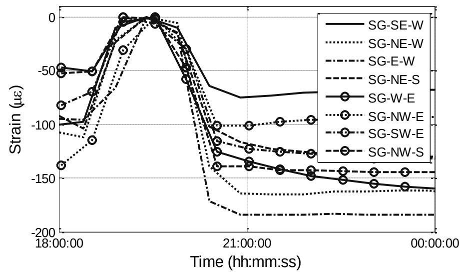

Fig. 5. Measured strain during lifting operation

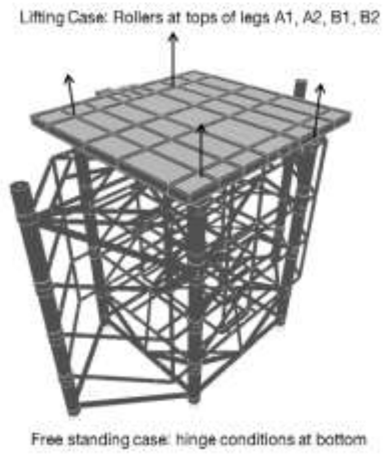

Fig. 7. Supporting conditions for free-standing and hanging cases

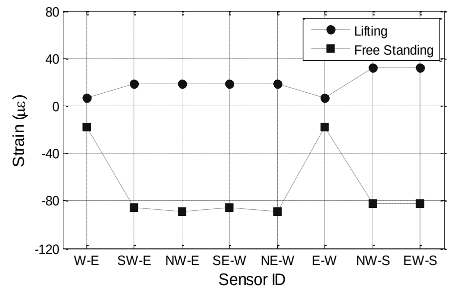

Fig. 7. Numerically evaluated strains for free-standing and hanging cases

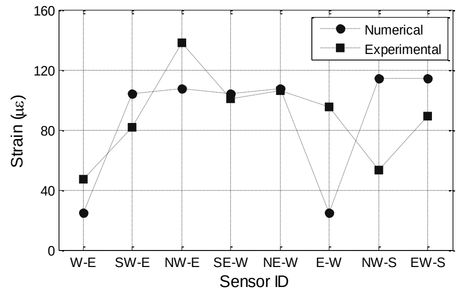

Fig. 8. Comparison of measured and analyzed strain changes from free-standing to hanging cases

Measured Strain during Removal of a Jacket Leg

The Uldolmok TCPP was structurally modified by removing one of six jacket legs (i.e. C2 jacket leg) to enhance the quality of incident tidal current such as turbulent intensity from January 1 to March 25, 2010. Fig. 9 shows the measured strain from February 1 to April 30, 2010 during removal work, and it can be obviously observed that the strains were significantly changed in the cases of SG-SE-W and SG-NE-W which were measured at the jacket legs relatively nearer to the removed jacket leg, C2. And it can also observed that the mean level by permanent load were changed a lot while the amplitudes were not severely changed because the tidal current loading level, which is a major live load, is almost same for the cases before and after removing one jacket leg.

Strain during Normal Operation

Fig. 10 shows the measured strain with tidal height and tidal current speed for three days from September 5 to 7, 2010. The measured strains for about 12 hour per day (from 5am to 11am, from 5pm to 11pm) were obviously fluctuated, while the other 12 hours' responses (from 11am to 5pm and from 11pm to 5am) were slowly and consistently changed without severe fluctuation. These observations were compared with tidal data for the same period, which showed that the periods with the smaller fluctuations were ebb tide conditions, and the others were flood tides. Therefore, the fluctuations were larger in flood tides, and smaller in ebb tides. These fluctuations were originated from severe fluctuation in tidal current speed and also relatively higher tidal speed as shown in the graph in the middle of Fig. 10. The maximum speed was up to about 1.6 m/sec in the flood tide while that is just up to about 1.0 m/sec in the ebb tide. It is caused that the main stream rapidly passes away along the center line after the Jindo Grand Bridge which can be observed from the Uldolmok Strait. It can be also observed that the strain is still deviated from mean levels even in still water conditions, and it means the tidal current speed is not zero along the water depth.

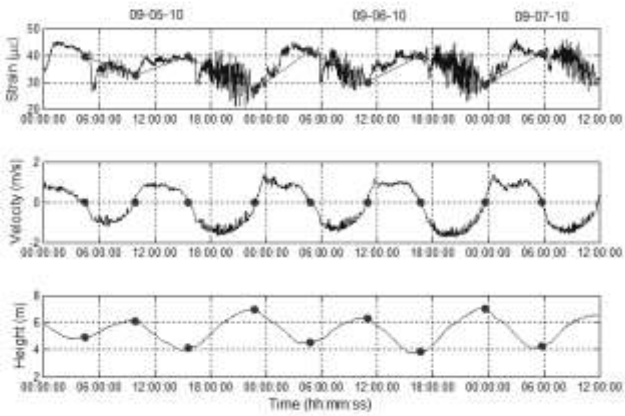

Fig. 10 Measured strain data from September 5 to 7, 2010. (circles denote times at still water)

The changes in measured strains were analyzed in the frequency domain to identify the main frequency components. Figs. 11 and 12 show the frequency components of the measured strain data for two frequency ranges, i.e. 0.5-5 cycles/min for Fig. 11 and 0.04-0.2 cycles/min for Fig. 12. From Fig. 11, it can be observed that strains were fluctuated with constant cycles of 0.001343 cycles/min (for the case of the first and main peak) and 0.002686 cycles/min (for the case of the second and lower peak), which corresponded to cycle lengths of 12.412 hour and 6.206 hour, respectively. The value of 12.412 hour is almost identical to the tidal M2 component of 12.42 hour, and the value of 6.206 hour is also very close to the M4 period of 6.21 hour. The measured strains were therefore strongly related to the

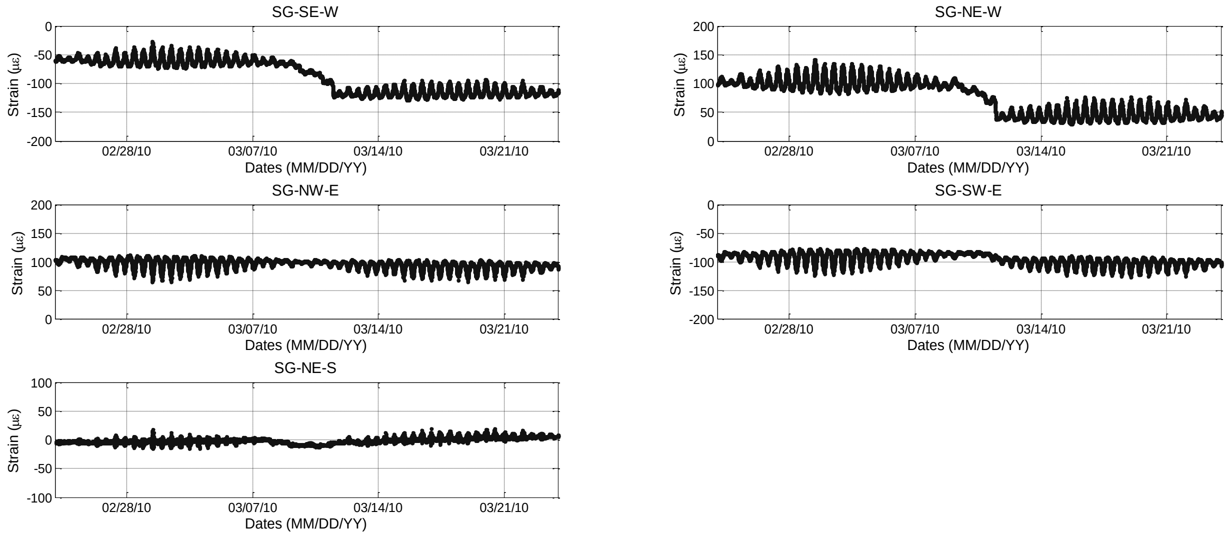

Fig. 10. Measured strain data during removal of one jacket leg (C2)

tidal changes as expected. From Fig. 12, it can be known that the short period of fluctuation was existed with 11.25 min of period, which is originated from a peculiar characteristics of Uldolmok strait.

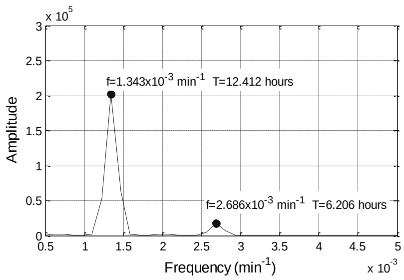

Fig. 11. Frequcny component of measured strains: 0.5-5 cycles/min

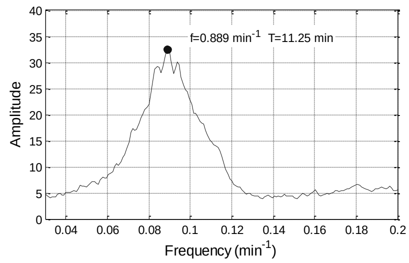

Fig. 12. Frequcny component of measured strains: 0.04-0.2 cycles/min

CONCLUSIONS

In this study, structural strain responses of the jacket-type Uldolmok TCPP were measured under severe tidal environment and analyzed using measured data from fabrication and installation to normal operation. The following conclusions are made; (1) there were significant changes in strain responses at the steps of jacket lifting, block loading, pile ejection and insertion, (2) the strains due to permanent load were much significantly changed after one jacket leg removal, (3) strain were fluctuated with M2 and M4 tidal periods and also relatively short period of about 11 min due to the peculiar tidal characteristics in the Uldolmok strait.

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REFERENCES

Korea Ocean Research and Development Institute (KORDI). Development of utilization technique for tide and tidal current energy. Final Report submitted to the Ministry of Land, Transport and Maritime Affairs, 2011.