TRANSNAV
http://www.transnav.eu
the International Journal
on Marine Navigation
and Safety of Sea Transportation
Volume 7
Number 4
December 2013

DOI: 10.12716/1001.07.04.10

The Propagation Characteristic of DGPS Correction Data Signal at Inland Sea - Propagation Characteristic on LF/MF Band Radio Wave

S. Okuda, M. Toba & Y. Arai
Marine Technical College, Japan

ABSTRACT: User at the Inland Sea requires high position accuracy which is 5 m (2drms) or less. Therefore the position accuracy of standalone GPS is insufficiency. Consequently it needs to use DGPS for navigator sailing the Inland Sea. We executed numerical simulation of the propagation characteristic on the extended line of bridge pier at opposite side from DGPS station, and already confirmed that bit error in DGPS correction data signal occurs, and that correction data could not form by bit error. Furthermore, we carried out numerical simulation of the propagation characteristic of DGPS correction data signal received at sailing through center of the bridge, and solved receiving condition of DGPS correction data signal before and after passing through the bridge. In this paper, we executed to inspect mutually results of electric field intensity simulation for oversea and overland propagation on some sea area of the Inland Sea and measuring results of electric field intensity for DGPS correction data signal, and evaluated the possibility of abnormal propagation comprehensively.

1 INTRODUCTION

Navigator who sails narrow channel at the Inland Sea requires high accuracy of fixed position which is 5 m (2drms) or less. In FRP 2008 (DoD, DoH.S. & DoT 2008), the requirement of position accuracy is 2-5 m for the inland waterway phase. Therefore the position accuracy of standalone GPS is insufficiency. Consequently it needs to use DGPS (Differential GPS) for navigator sailing the Inland Sea.

Decreased reliability of fixed position using GPS means that the reliability of GPS signal information decreases and there is a possibility of abnormal propagation of DGPS correction data signal, and such case occurs in the Inland Sea. Decreased reliability of GPS signal information means that there is decreased reliability of transmitting signal including satellite condition and some changes of GPS receiving condition around user including GPS receiver. Decreased reliability of transmitting signal should be compensated by RAIM (Radio Autonomous Integrity Monitoring) which is able to confirm it automatically. However, if abnormal propagation of DGPS correction data signal occurs, it is possibility to be affected by it. In this paper, we research as part of investigating received condition in the Inland Sea, but sailing circumstance in Europe where there are many river ports, large ships sailing on river around the Great Lakes have common receiving condition same as the Inland Sea. It considers that changes of GPS receiving condition are caused by incident of multi-path wave by not only sea reflection but also large offshore structures or other ships. In this paper, the main subject is to analyze the propagation characteristic of DGPS correction data signal, so to analyze changes of GPS receiving condition is future task.

Abnormal propagation of DGPS correction data signal is caused by single or multiple actions which are increase of propagation loss by overland propagation and/or some effects by offshore structure such as a big bridge. In previous papers at ITM 2011 and ITM 2012 (Okuda et al. 2011 & 2012), we executed numerical simulation of the propagation characteristic on the extended line of bridge pier at opposite side from DGPS station, and confirmed that bit error in DGPS correction data signal occurs. We also confirmed that there is a possibility that correction data could not form by bit error. In this paper, we carried out numerical simulation of the propagation characteristic of DGPS correction data signal received at sailing through center of the bridge that was future task in previous paper, and solved receiving condition of DGPS correction data signal before and after passing through the bridge. This simulation calculated a variation of signal strength by composition of superior reflection wave and surface wave. When the trail ship approaches from opposite side of using DGPS station, around just under the bridge reflection and/or scattering wave of bridge girder become to be superior, and signal strength increases because it is combined with surface wave. After passing through the bridge, signal strength increases and decreases according to combined phase because reflection wave from the bridge is combined with surface wave. Furthermore, we investigated validity of numerical simulation by checking the result of electric field measurement and also investigated effects of oversea and/or overland propagation by measuring electric field intensity every adequate distance at the Inland Sea on November 2010 and July 2012.

2 DGPS IN JAPAN

DGPS detects pseudorange error between GPS satellite and the reference station whose position is known, converts the error into correction data, and broadcasts the correction data to user on board around the reference station. Each user on board receives the correction data using MF beacon receiver. Position accuracy is improved by fixed calculation using the correction data. At present nominal position accuracy by standalone GPS is 9 m (2drms) in FRP 2008, on the other hand JCG (Japan Coast Guard) announces that position accuracy by DGPS is 1 m (2drms) or less. When using differential system, accuracy decreases depending on distance from the reference station. Then it is appropriate that position accuracy by DGPS is 1-5 m (2drms) depending on distance. DGPS has not only a function of improvement of position accuracy but also a function of integrity monitor. A function of integrity monitor informs some changes of GPS satellite healthiness or decreasing accuracy of pseudorange measurement to user quickly and break off use of the satellite data. This system is exactly the same as DGPS operated by USCG (United Status Coast Guard).

At present in Japan there are 27 DGPS stations which is the reference station, and the coverage is all coastal area except a few isolated islands. Table 1 shows DGPS specification operated by JCG. JCG calls user's attention concerning DGPS coverage (JCG DGPS center).

1 Exception of some area at Inland Sea about 200 km coverage.
2 Existence of difficult case to use by effect of terrain etc.

However JCG make no mention about an area or a phenomenon concretely.

Table 1. DGPS Specification in Japan

transmission rate	200 bps
transmitting power	75 W
coverage	200 km from DGPS station
transmission format	ITU-R M.823-1(RTCM SC-104)
message type	Type 3,7,9,16

Next, we describe about the present condition for integrity monitor. Each header of DGPS message includes operating condition of DGPS station. If position accuracy of the DGPS station becomes to be 1.5 m or more, DGPS system demands to change DGPS fix into standalone GPS fix. In Type 9, DGPS system demands to break off to use on fix calculation when correction value is 8 m or more.

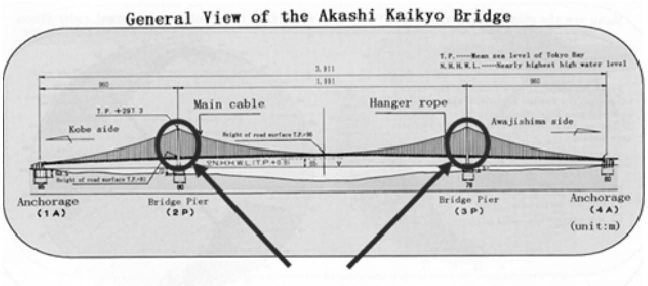
Before now, it was reported about an effect of interference between nighttime ionospheric scatter propagation wave and surface wave of MF beacon wave for DGPS (Yagitani et al. 2004). They discussed some effects about distance from DGPS station and other station transmitting the same frequency, but it is different from our subject.

In this study, one of triggers is the phenomenon that transmission of differential correction value was interrupted because of propagation trouble on specific area. At present DGPS in Japan broadcasts Type 3, 7, 9, 16 based on RTCM-SC104 format (Kalafus et al. 1986). Update rate for all satellites in view is 4-5 seconds so that number of satellites in view varies. When bit error of transmission data occurs by propagation trouble and the correction data is not completed, it is shown that differential correction data is not update in the case of one time data lost.

3 ANALYSIS FOR PROPAGATION CHARACTERISTIC

3.1 *In Case of Bridge Pier*

In previous paper, we analyzed the propagation characteristic of DGPS correction data signal nearby a big bridge in order to investigate abnormal propagation of MF beacon signal for DGPS. Structure around bridge pier of big bridges at the Inland Sea is regarded as metal screen (Araki 1977) shown in Fig. 1, transmittivity around there is a little over 1 %. Electric field intensity on propagation path from DGPS station to big bridge is obtained in case of oversea and overland independently because of complex terrain (Nishitani 1980). In addition, there is diffraction loss that bridge pier is regarded as knife edge (Shinji 1992) shown in Fig. 2, and the diffraction loss is 10dB or more depending on distance from bridge pier.



Metal Screen

Figure 1. Structure of metal screen

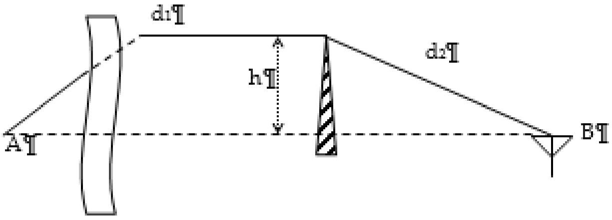


Figure 2. Knife edge diffraction

Table 2. Total electric field intensity

bridge	DGPS station	distance (km)	electric field intensity (*)	diffraction loss (*)	total intensity (*)
Kanmon kyo	Wakamiya	118.2	56	10.2	45.8
Kanmon kyo	Seto	130.8	55	10.3	44.7
Akashi-Kaikyo	Oohama	195.6	50	12.3	37.7
Akashi-Kaikyo	Muroto-Misaki	170.4	52	12.1	39.9

(*): dBμV/m

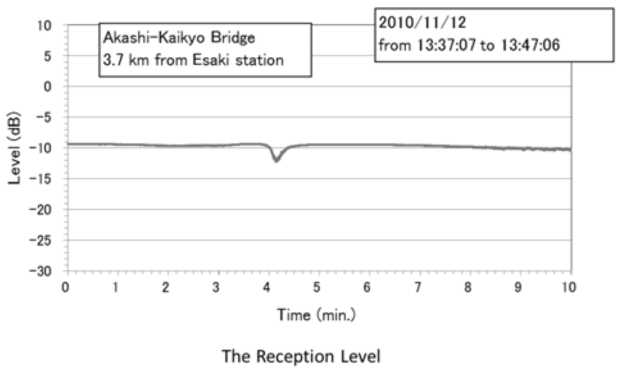


Figure 3. Electric field intensity when passing through the bridge (level down case)

Modulation system of MF beacon wave for DGPS is MSK (Minimum Shift Keying). Electric field intensity is needed 40 dBμV/m not to occur twice bit error per 1 word that bit error correcting cannot work (Saito 1996). Table 2 shows calculation results of electric field intensity nearby bridge pier. In the case of Akashi-Kaikyo Bridge, if beacon receiver uses DGPS station in Table 2, electric field intensity is 40 dBμV/m or less and always there is a possibility that DGPS correction data is missed one time.

In previous paper, there is a possibility that DGPS correction data signal causes bit error, and it is confirmed that there is a possibility that adequate position accuracy cannot be obtained (Okuda et al. 2011). Fig. 3 shows measuring data of electric field intensity measurement nearby Akashi-Kaikyo Bridge on November 2010. It was measured approximate 3dB decrease data at passing through the bridge. Because measured signal from Esaki station which is very near from Akashi-Kaikyo Bridge has large intensity, 3dB reduction does not occur some problem. However, when Esaki station signal is not utilized by some reasons which is missing to transmit etc., in case of using Muroto-Misaki station signal user's ship sails on the extended line of bridge pier, so that it may be occurred some problem to fix position. These relationship and directions of transmission from DGPS stations are shown in Fig. 4.

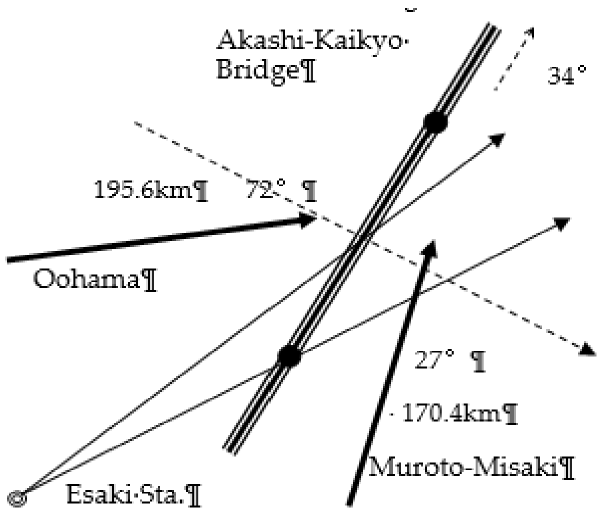


Figure 4. Geometric relation with DGPS station and Akashi-Kaikyo Bridge

3.2 *In Case of Center of Bridge*

Now, we analyze the propagation characteristic nearby a center of the bridge that was unsolved in previous paper (Okuda et al. 2011). In order to simplify this problem, it is assumed that in addition surface wave the superior reflection wave which reflects at structure of the bridge exists. Fig. 5 shows outline of direction of Minami Bisan-Seto Bridge and Oohama DGPS station used on this simulation, and trial ship sailed eastward. Fig. 6 (a) and (b) show plane view and side view respectively indicated propagation path of reflection wave. Fig. 6 (c) shows an aspect of reflection around under the bridge. Antenna height of trial ship used this simulation is 10 m and bridge girder of Minami Bisan-Seto Bridge is 65 m above sea level. Fig. 7 show one of numerical simulation results for relative value of composite signal strength (corresponding to electric field intensity) with surface wave (0dB) and reflection wave on a condition shown in Fig. 6. It was calculated that reflection coefficient was 0.5.

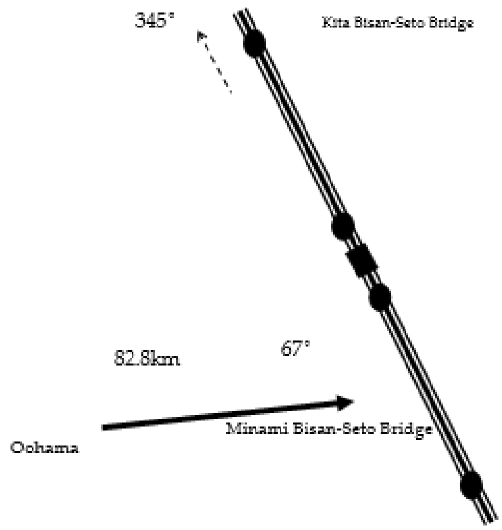


Figure 5. Bisan-Seto Bridge and direction of transmission

Relative value of signal strength to exceed 0 dB means that electric field intensity becomes to be large (to increase signal gain). Less than 0 dB means that electric field intensity becomes to be small (to decrease signal gain). If it is assumed that all of reflection wave work as noise, maximum signal to noise ratio is 6 dB. In this case, it is satisfied with advice by ITU which requires that signal to noise ratio is 7 dB or more inside DGPS coverage.

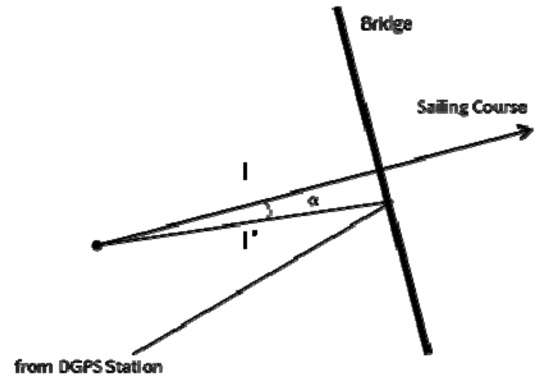


Figure 6(a). Propagation path of reflection wave (plane view)

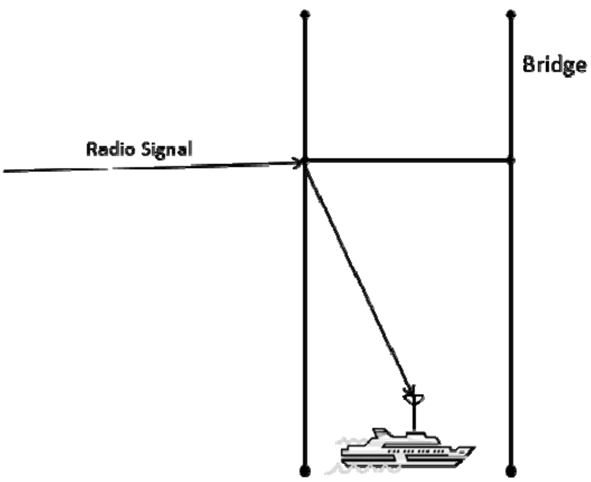


Figure 6(b). Propagation path of reflection wave (side view)

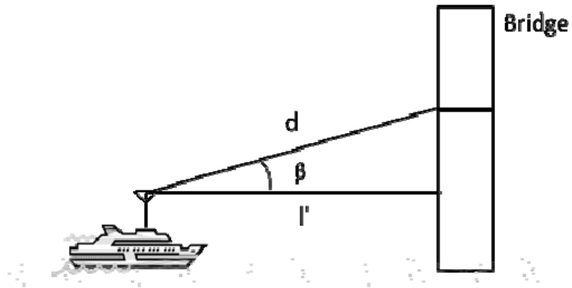


Figure 6 (c) Propagation path of reflection wave under the bridge

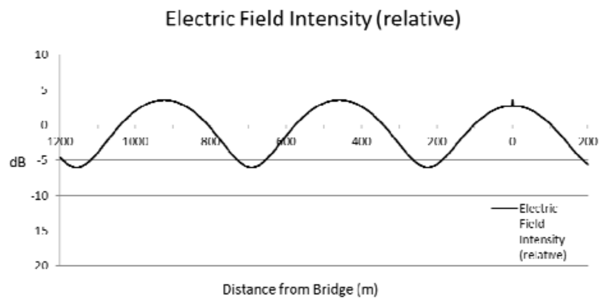


Figure 7. Result of calculation for electric field intensity (relative value) near the bridge

In fact, reflection point is not one place. There is not only mirror reflection, and effects of reflection wave decrease depending on increase of distance from the bridge. If it is assumed that there are these phenomena, it is considered that composite signal strength has some variation shown in Fig. 8.

Fig. 9 (a) shows measuring data of electric field intensity measurement whose situation is the same as this simulation. Ship to collect data sailed eastward on South Bisan-Seto Traffic Route. It was observed that signal strength increased and decreased at the front of the bridge, and signal strength increase 5 dB above minimum value around under the bridge. This simulation calculated using single reflection wave, so that measured data indicated the same tendency. To summarize, in case of sailing passing through a center of the bridge, it is observed some variation of electric field intensity around the bridge. However, when magnitude of the variation is less than 7 dB against received surface wave directly, there is no possibility that bit error occurs.

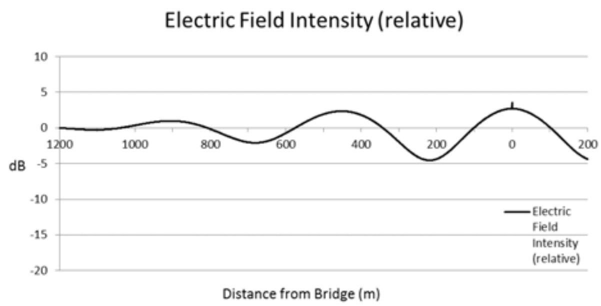


Figure 8. Corrected result of calculation for electric field intensity (relative value) near the bridge

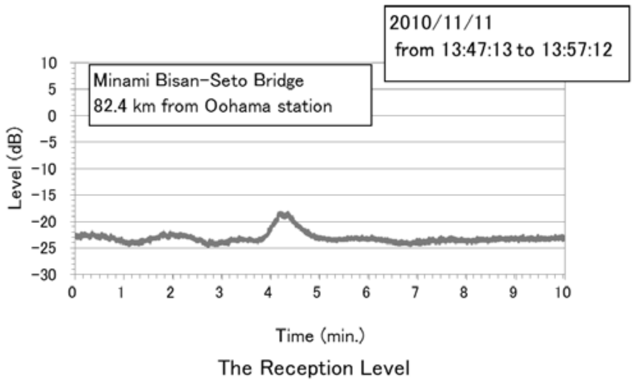


Figure 9 (a). Electric field intensity at passing through the bridge (Minami Bisan-Seto Bridge, using Oohama station signal)

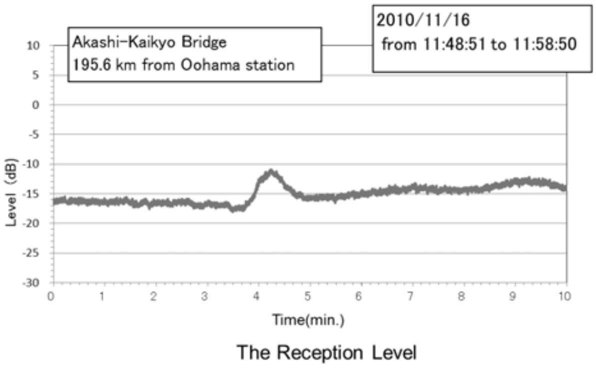


Figure 9 (b). Electric field intensity at passing through the bridge (Akashi-Kaikyo Bridge, using Oohama station signal)

As more examples, Fig. 9 (b) shows that ship sailed westward on Akashi-Kaikyo Traffic Route, distance from Oohama DGPS station became to be close after passing through the Akashi-Kaikyo Bridge. However, compared with Fig 9 (a), periodic variation of electric field intensity was not remarkable. It might be the boundary distance as DGPS MF radio beacon wave.

3.3 *Situation of Oversea Propagation*

We investigated electric field intensity per distance to research an effect of relationship with oversea and overland propagation. We measured electric field intensity every adequate distance during sailing on traffic route or waterway. So, its propagation was almost oversea. Fig. 10 shows that it was appeared a relationship with distance to intensity although difference at 4-90 km places from DGPS station was smaller than reference (Nishitani 1980). In future study, we will collect electric field intensity included overland propagation, and try to characterize an effect of overland propagation.

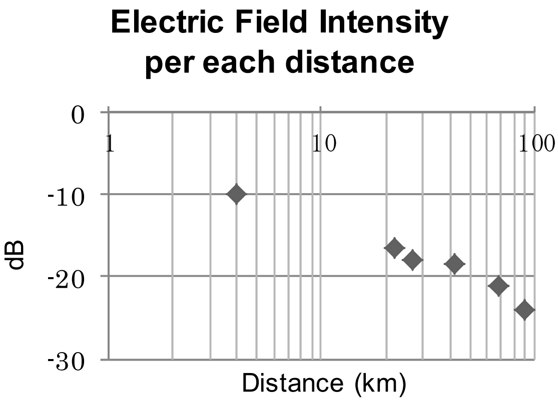


Figure 10. Electric field intensity per each distance

3.4 *Discuss for Other Bridge*

First, we discuss about nearby Kanmonkyo Bridge. In the vicinity of Kanmonkyo Bridge which locates midway between Wakamiya station and Seto station. DGPS user utilizes either of these stations. Wakamiya station is 12 km closer than Seto station from Kanmon-Kyo Bridge. Fig. 11 shows that in case of using Wakamiya station on westward sailing and in case of using Seto station on eastward sailing there is a possibility that a problem occurs on the extended line of bridge pier. Electric field intensity of DGPS correction data signal is over 40 dBμV/m required by DGPS system according to estimation in previous paper, but there is a possibility to occur bit error when overlapping each other factor.

Next, we discuss about nearby Kurushima-Kaikyo Bridge. In case of using Oohama station which is very close from Kurushima-Kaikyo Bridge, there is no problem even if diffraction loss by bridge pier exists. Consequently, when it cannot be used Oohama station, there is a possibility that same problem occurs in case of using Seto station or Esaki station.

It is considered that above-mentioned some effects of the big bridge are same as DGPS operated by USCG which is the same system in Japan. Existence of big bridge, complex terrain etc., details of DGPS operated by USCG is not clear, but it is considered that the Golden Gate Bridge and the Bay Bridge in San Francisco Bay may be existed the same problem.

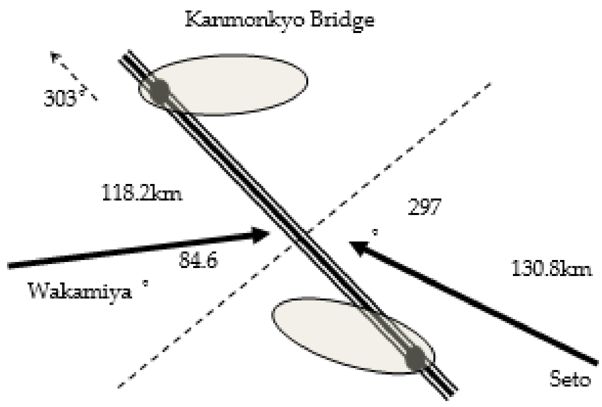


Figure 11. Geometric relation with DGPS station and Kanmonkyo Bridge

3.5 *Effect of Overland Propagation and Multi-path Signal*

Experimental navigation using our training ship Kaigi-Maru in July 2012 could be collected some electric field intensity data including overland propagation. 12-13 % of propagation path are on land, which are about 6 n.m. against 50 n.m. which are all of propagation path. In the case of 300 KHz band, if all of propagation path is land, it is estimated that electric field intensity of 50 n.m. path decreases about 10 dB (Nishitani 1980). Because decreasing electric field intensity regarding obtained data by experimental navigation is approximately 1 dB, normal sailing on traffic route is no problem.

It was compared with data for mooring at Fukae pier of Kobe port and sailing on Kobe airport off, so it was observed that electric field intensity decreased about 2 dB and data fluctuation is slightly large on mooring at Fukae shown in Fig. 12(a), (b). It is considered that 2 dB decreasing of electric field intensity are to be 5 n.m. distance longer than Kobe Airport off from Esaki station which was used station of DGPS and ratio of overland propagation are 59 %, that includes 80 % urban area. But data fluctuation at Fukae is a little less than 3 dB because there is no large construction near Fukae pier. Nearby Kanmon-Kyo, electric field intensity of Diffraction loss generated area 44-6 dBμV/m shown in section 3.1 and Table 2. Consequently, if there are some effects of multi-path signal, then electric field intensity becomes to be less than 40 dBμV/m, so that bit error occurs and data of DGPS will have a trouble to receive by occurring bit error. There is a possibility to be large effect of multipath by gantry crane at container yard except an effect of big bridge. In the case of inside port, there are some problem when pier docking and undocking. However, investigating minutely of effect of multi-path by calculation for intensity ratio of direct and reflection signal is physically impossible. In the case of existing multi-path, it is considered that receiving signal level is more than 1 Hz frequency, so we need to review methods for data collection and analyzing, and then they are future tasks.

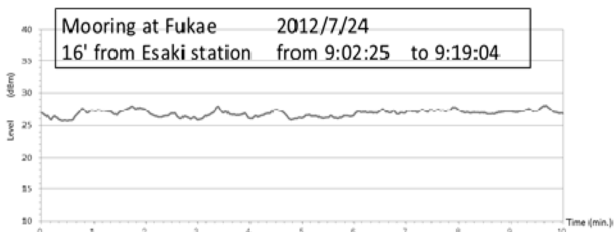


Figure 12(a) Sample of Including Much Overland Propagation

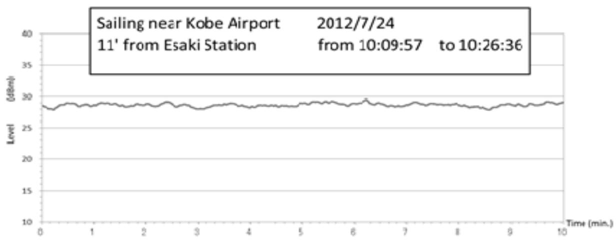


Figure 12(b) Sample of Normal Sailing

4 CONCLUSION

We leaded to the propagation characteristic around a center of the bridge to apply simplified reflection wave. The result almost corresponds to measuring data of electric field intensity. To utilize this simulation results and some effects of diffraction loss by bridge pier becomes to be able to examine receiving condition of DGPS station. When DGPS user cannot utilize the DGPS station which is close and has sufficient signal strength, or when to obtain position is insufficiency from the beginning, it is confirmed that to enter on the extended line of bridge pier is that bit error may occur and there is a possibility that it cannot fix accurate position. Furthermore we measured electric field intensity at every each distance from DGPS station to research an effect of overland propagation.

Finally, as stated above, there is some possibility that DGPS correction signal have been occurred bit error caused by decreasing electric field intensity and level fluctuation by multi-path, etc. nearby large construction such as big bridge including overland propagation, so there are some case that normal DGPS position accuracy cannot obtain. Hereafter, high accuracy position fix on pier docking and undocking is essential to execute safety and efficiently navigation for navigator using DGPS. Consequently, we have to clarify these phenomenon and consider countermeasures. In this paper, it is suggested that there are not only effect of big bridge but also effect of large construction near pier, and we show necessity to investigate minutely an effect of multi-path.

REFERENCES

Araki, T. 1977, Denji Bougai to Bousi Taisaku, Tokyo Denki University Press, 138-139

Department of Defense, Department of Homeland Security and Department of Transportation: 2008 Federal Radionavigation Plan, 2008

Japan Coast Guard DGPS center, http://www.kaiho.mlit.go.jp/syoukai/soshiki/toudai/dgps/menu.htm

Kalafus, R. M., Dierendonck, A. J. VAN & Pealer, N. A. 1986, Special Committee 104 Recommendations for Differential GPS Service, The Institute of Navigation, Global Positioning System Volume III, 101-116

Nishitani, Y. 1980, Hakuyou Denshi Kougaku Gairon, Seizann-Do, 174-175

Okuda, S. & Arai, Y. 2011. The Position Accuracy of DGPS Affected by the Propagation Characteristic on MF Beacon Wave, 2011 International Technical Meeting, 718-724 January 24-26

Okuda, S., Toba, M. & Arai, Y. 2012. The Propagation Characteristic of DGPS Correction Data Signal in Japan – Propagation Characteristic near Big Bridge -, 2012 International Technical Meeting,1383-1389,January 29-31

Shinji, M. 1992, Musen Tsuushin no Denpa Denpan, The Institute of Electronics, Information and Communication Engineers, 25-49

Saito, Y. 1996, Digital Modulation Techniques for Wireless Communications, The Institute of Electronics, Information and Communication Engineers, 70-107

Yagitani, S., Nagano, I., Tabata, T., Yamagata, K., Iwasaki, T. & Isamu Matsumoto, I. 2004, Nighttime Ionospheric Propagation of MF Radio Waves Used for DGPS – Comparison between Observation and Theory -, IEICE Transactions on Communications, Vol. J87-B, No. 12, 2029-2037