Applications of GPS for Maritime Construction Work in Japan and Further Plans

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ABSTRACT

RTK-GPS is most suitable for maritime construction work among all systems. The requirements of reference stations for maritime construction work are high-power radio waves, high-speed data transmission rate, and high reliability. Maritime GPS Promoting Solutions provides services that satisfy these requirements. The maximum service range of Maritime GPS Promoting Solutions is 10 -15 km from a reference station. That covers most of the maritime construction sites.

GPS has been spread in all kinds of maritime construction work at present according to the enlarging scale of construction that requires high efficiency. There are some reasons why GPS is popular in maritime construction work in Japan. One of them is the necessity of high accuracy for specific construction work such as soil improvement work. The other reason is that common coordinate of GPS enables positioning with no relative error among many work vessels. Vertical positioning has been also introduced to measure ground level of reclaimed land in construction work of offshore airports lately.

RTK-GPS is now being introduced into the other areas. One of the most important approaches is GPS wave measuring buoy. It measures wave height by the motion of the buoy floating offshore with GPS. As GPS is able to measure the absolute height, it is able to detect long period waves including tsunami. It enables early escape from the hazard caused by tsunami. As GPS wave measuring buoy is desirable to be located as far from the coast as possible, the accuracy of vertical positioning, service area, and long-term durability and reliability of GPS devices on the buoy are critical factors. An experiment considering small boat as buoy is carried out using time-sharing method. The result shows excellent perspectives.

Keywords: RTK-GPS, common coordinate, time-sharing method, vertical positioning, GPS wave measuring buoy.

INTRODUCTION

GPS is classified into two main types. One is stand alone GPS that is known as car navigation equipment. The other is differential GPS such as RTK-GPS and D-GPS that utilizes correction data from reference stations to raise the precision of positioning. Only RTK-GPS can be used for maritime construction work because of its capability of real-time positioning and high accuracy. GPS means RTK-GPS in this paper except as otherwise noted.

ADVANTAGES OF GPS FOR MARITIME CONSTRUCTION WORK

Maritime construction sites are located far from the coast whereas land construction sites are located on land. The positioning range for maritime construction work must be much longer than that for land construction work.

In early days, work vessels were positioned by crew onboard with sextants and three-arm protractors or navigated by operators onshore with transits. Efficiency of positioning was not sufficient because it was done by human labor. Positioning error using those instruments was not also sufficient because it depended on the operators' skill.

Consequently, positioning was mechanized by ranging devices using radio waves. One pair of frequency is needed for one ranging device. It means when some number of work vessels are working in the same construction sites, twice number of frequencies is necessary to prevent mutual interference. In addition, positioning error of this device is about one meter that is considerably large. On the contrary, optical ranging devices have high precision and are automated with automatic tracking capability. However, disadvantage of optical ranging device is that positioning range is rather short and measurement is possibly interfered by fogs and rains. Positioning is occasionally impossible because of weather conditions.

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Positioning range of GPS is much longer than that of optical ranging devices because correction data for GPS from reference stations is transmitted through radio waves that propagate longer distance and signals from GPS satellite can be received anywhere on the sea. Positioning by GPS is possible under any weather conditions.

From the point of view of the location of ranging devices, almost all optical ranging devices are located on land and reflectors are located on the work vessels. Positional data transmitters from land to the work vessels are required. Meanwhile, GPS receivers are located on the work vessels and reference stations are located on the coast. Positional data is obtained onboard.

The other advantage of GPS is that it needs no unmoving place to where ranging device is attached. GPS is favorable for work vessels floating on the sea. Advantages of GPS indicate it is most suitable for maritime construction work among all ranging devices.

REQUIREMENTS FOR REFERENCE STATIONS OF GPS

Characteristics of GPS are suitable for maritime construction work, however it is required to build reference stations of high performance, appropriate management, and proper maintenance for actual operation. In other words, requirements are wide service range, transmission of additive data such as operation control data in addition to correction data, and uninterruptible transmission to reduce operation-time loss of work vessels of expensive charter fee.

As a result, the requirements of reference stations for maritime construction work are high-power radio waves, high-speed data transmission, and high reliability. Maritime GPS Promoting Solutions provides services that satisfy these requirements. Specifications of reference stations of Maritime GPS Promoting Solutions are shown in Table 1.

Table 1. Specifications of reference stations of Maritime GPS Promoting Solutions.

Item \ Mode	RTK-GPS	D-GPS
Service Area (radius)	10-15km	30km
Precision (horizontal) (vertical)	1cm+2ppm x D 2cm+2ppm x D (D : distance)	about 1m -
Service Hours	24 hours a day, every day of the year	
Data Format of Correction Data	RTCM-SC104 version 2.0, 2.1 Type1 : correction data for DGPS Type3 : coordinate value of reference station Type22 : correction data for coordinate value of reference station Type18 : observed carrier phase (raw) Type19 : observed pseud range (raw)	
Frequency	229MHz band	
Power	10W	
Data Transmission Rate	9,600 bpm 14,400 bpm	
Data Update	every single second	

The maximum service area of Maritime GPS Promoting Solutions is 10 -15 km from a reference station. Most of the maritime construction sites are covered with one reference station. It is because the power of radio waves is 10W that is much larger than those of other organizations. Maritime GPS Promoting Solutions has widest service areas and provides many advantages for maritime construction work. Seventeen reference stations are placed on the port areas in Japan by GPS Promoting Solutions shown in Figure 1.

Figure 1. Seventeen reference stations of GPS Promoting Solutions.

SPREAD OF GPS

Horizontal positioning by GPS was introduced in conventional maritime construction work more than ten years ago in Japan. GPS has been spread in all kinds of maritime construction work at present according to the enlarging scale of maritime construction that requires high efficiency. It covers not only construction work itself such as dredging, pile driving, soil improvement work, and so on, but also investigation such as bathymetry and operational control of work vessels. General view of utilizations of GPS in various maritime construction work is shown in Figure 2.

Figure 2.General view of utilizations of GPS in various maritime construction work.

Bathymetry

Bathymetry consists of water depth measurement and survey boat positioning those are carried out simultaneously on the sea. It takes most important part in estimating the completion of maritime construction work.

The most popular way of bathymetry at present is automated data- collection from echo sounder and GPS into computer, followed by data processing by special survey software. It is enabled by popularization of GPS, digitalization of echo sounders, and advance of computers.

Multi-beam echo sounder has also been introduced because it is able to emit fan shape ultrasonic beam and obtain water depth data not only just under the survey boat but also certain area as if a number of sharp single beams are emited at a time.

Dredging

Dredgers are classified into various kinds such as cutter suction dredgers, trailing suction hopper dredgers, grab bucket dredgers, backhoe dredgers, soft mud dredgers, and so on. A grab bucket dredger equipped with GPS is mentioned herein as a typical example. Figure 3. shows one example of grab bucket dredger.

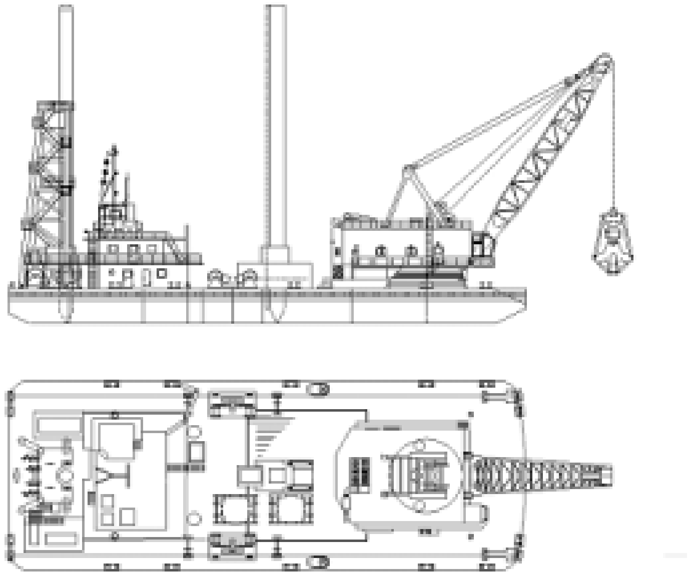

Figure 3. Grab bucket dredger.

As the most of grab bucket dredgers have full-slewing cranes and hoist up and down the grab buckets by wire ropes, dredging water depth are very deep. GPS is used for control the position of grab bucket. As the crane is slewing on the barge, relative position of the barge and boom top is not constant. It is necessary to measure the relative position during operation. Figure 4. shows an arrangement of GPS antennas equipped on a grab bucket dredger.

Figure 4. Arrangement of GPS antennas on a grab bucket dredger.

The position and direction of the barge are measured by two GPSs equipped on the barge. The position of boom top is measured by another GPS equipped on the crane. Slewing angle and tilting angle of the crane are calculated by those three values and shown on PC screen.

At first, a grab bucket dredger is navigated with main window of according to the procedure of execution. Next, the grab bucket is moved to the predefined position by slewing of the crane and tilting of the boom with the window switched for crane manipulation. During the movement of the grab bucket, position of the barge is being measured at every moment and the slewing center of the crane is shown correctly following the motion of the barge.

After finishing navigation of the barge, the grab bucket will be navigated to the predefined position with the widow switched for grab bucket manipulation. The predefined position and the actual position of the grab bucket are shown on the window at the same time. Crane operators just manipulate the crane to match the actual position to the predefined position by seeing the PC screen. Operation is easy with graphical display. Navigation window for grab bucket dredger and navigation window for grab bucket manipulation are shown in Figure 5, 6 respectively.

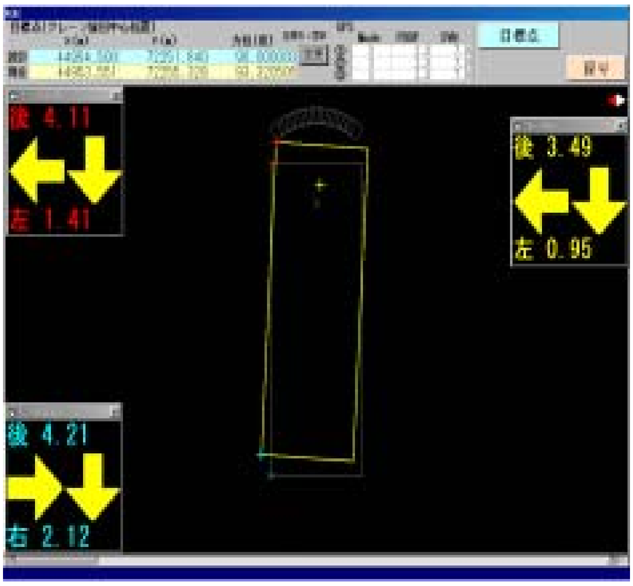

Figure 5. Navigation window for grab bucket dredger.

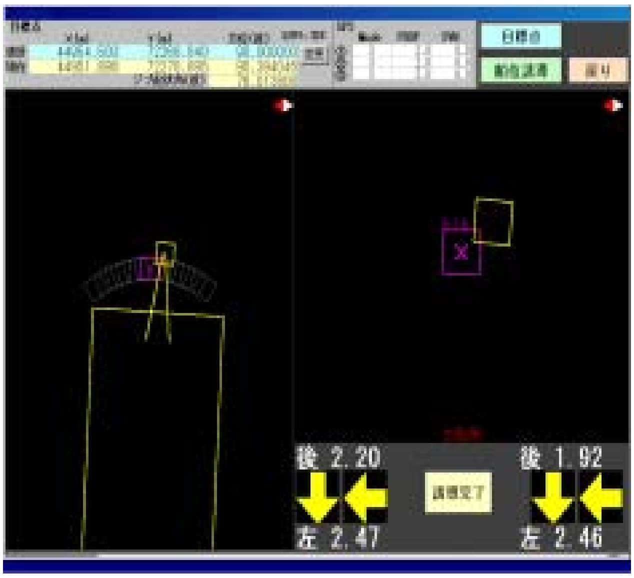

Figure 6. Navigation window for grab bucket manipulation.

Pile Driving

Floating pile drivers are classified into two types. One is slewing type and the other is inclining type.

Slewing type is also called multi-purpose floating crane because it is able to be used for hoisting and dredging by removing attachment. It allows easy positioning of piles by slewing, however ballasting-up is troublesome. Inclining type has a mast that is able to be tilted forward and backward by hydraulic cylinder attached at the derrick that hold the leader. Slewing type floating pile driver is shown in Figure 7 and inclining type floating pile drivers is shown in Figure 8.

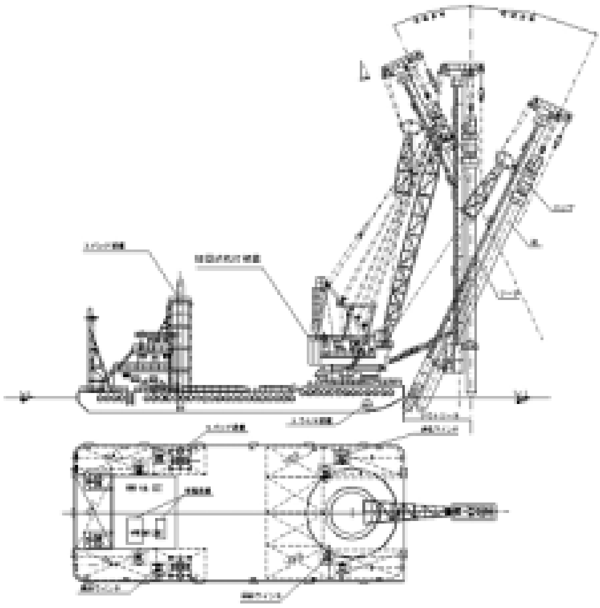

Figure 7. Slewing type floating pile driver.

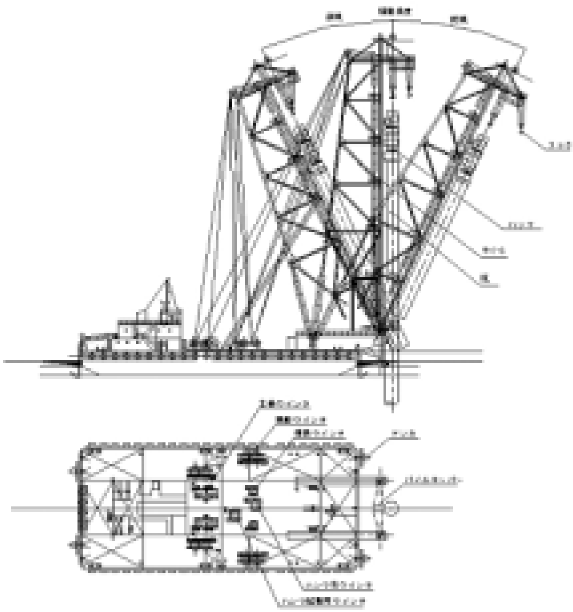

Figure 8. Inclining type floating pile driver.

Slewing type is favored lately responding to complicated maritime structure such as combination of vertical and inclined piles, and responding to larger and longer steel piles than before.Fig.9 shows a schematic view of GPS equipped floating pile driver.

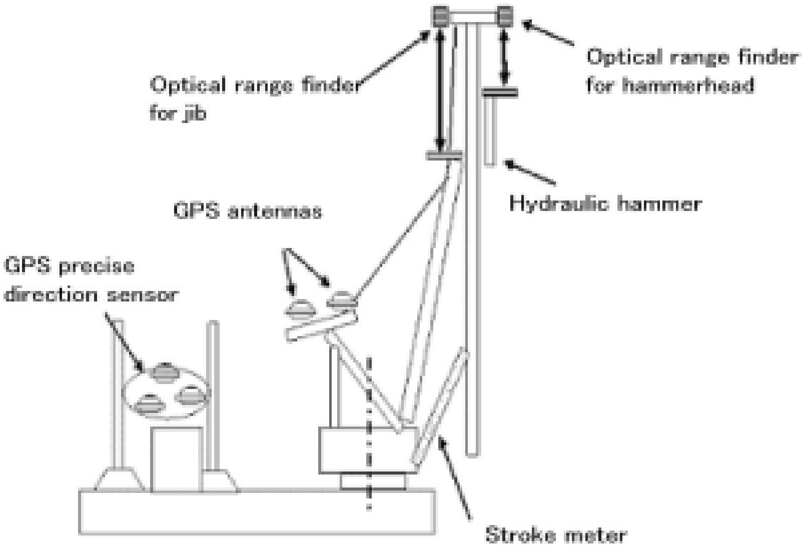

Figure 9. Arrangement of GPS antennas on a grab bucket dredger.

The advantage of this system is precise position control of both the crane and the barge, which are mechanically independent to each other, enabled by data communication link in-between. The coordinate value of slewing center is calculated with position and direction of the barge. Direction is measured with the direction sensor equipped at the stern. Then the coordinate value of pile top is calculated with data from some other sensors.

REASONS FOR SPREAD OF GPS IN MARITIME CONSTRUCTION

There are some reasons why GPS has been so popular in maritime construction work in Japan. Some of them are mentioned in "ADVANTAGES OF GPS FOR MARITIME CONSTRUCTION WORK". The other reasons are as follows.

Demand for High Accuracy in Execution

High accuracy is demanded in specific construction work such as soil improvement work because precise execution enables the saving of the amount of sand and cement milk for consolidation of soil.

One Reference Station for Multiple Work Vessels

One of the most important advantages of GPS is that multiple work vessels in the same sea area are able to share one reference station. Common coordinate enables positioning with no relative error among work vessels. This is inevitable especially in the large-scale project that needs rapid execution.

Figure 10. shows soil improvement work with six work vessels. Up to six work vessels were engaged in soil improvement work in this site at a time. This is a typical example of precise positioning and rapid execution in large-scale construction work in Japan.

Figure 10. Soil improvement work with six work vessels.

VERTICAL POSITIONING IN PRACTICAL USE

Vertical positioning by GPS has also been introduced to measure the ground level of reclaimed land in construction work of offshore airports lately in addition to horizontal positioning used in conventional construction work and operation control. Real-time vertical positioning that is enabled by RTK-GPS is introduced in slope maintenance, leveling by bulldozers, compaction with vibrating rollers, subsidence measurement of offshore airports, and work progress control. Figure 11 shows a bulldozer equipped with GPS for leveling work. Figure 12 shows a vibrating roller equipped with GPS for compaction work.

Figure 11. Bulldozer equipped with GPS.

Figure 12. Vibrating roller equipped with GPS.

OPERATION CONTROL OF WORK VESSELS

Positional data measured by onboard GPS is used mainly for positioning and navigation by the crew onboard the work vessels. Positional data is also used for operation control of multiple work vessels by sending them to the operation control center on land through radio waves. There are two types of operation control method.

Conventional Method

Positional data is transmitted to the operation control center with radio waves of which frequency is different from that transmit correction data from the reference station to prevent jamming. Then this method needs additional radio frequency. This method is called one-way transmission method. It has been introduced in the second stage construction work of Kansai International Airport. Schematic view of one-way transmission method for operation control is shown in Figure 13.

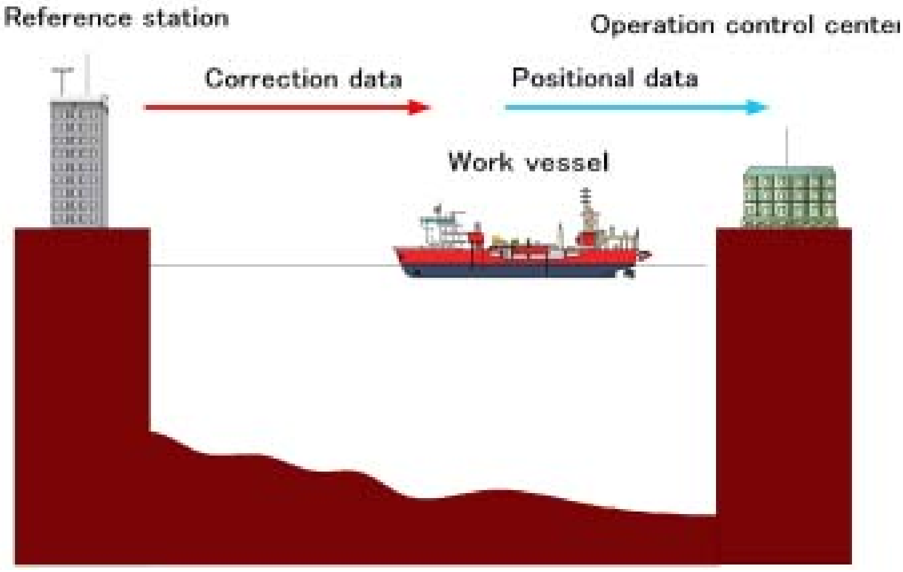

Figure 13. One-way transmission method for operation control.

Time-Sharing Method

Newly developed time-sharing method is introduced for operation control of soil carriers employed in Naoetsu Energy Port Project. Each soil carrier receives correction data from the reference station in the former half of one second. The data such as name, position, and ongoing work of each soil carrier are sent back to the reference station in the latter half of one second. Time-sharing of radio waves of one frequency enables this method.

The advantage of time-sharing method is that no additional radio is needed for operational control. Correction data transmitter is used as positional data receiver in the reference station. Correction data receivers are used as positional data transmitters on work vessels. This method is called two-way transmission method. Schematic view of two-way transmission method for operation control is shown in Figure 14.

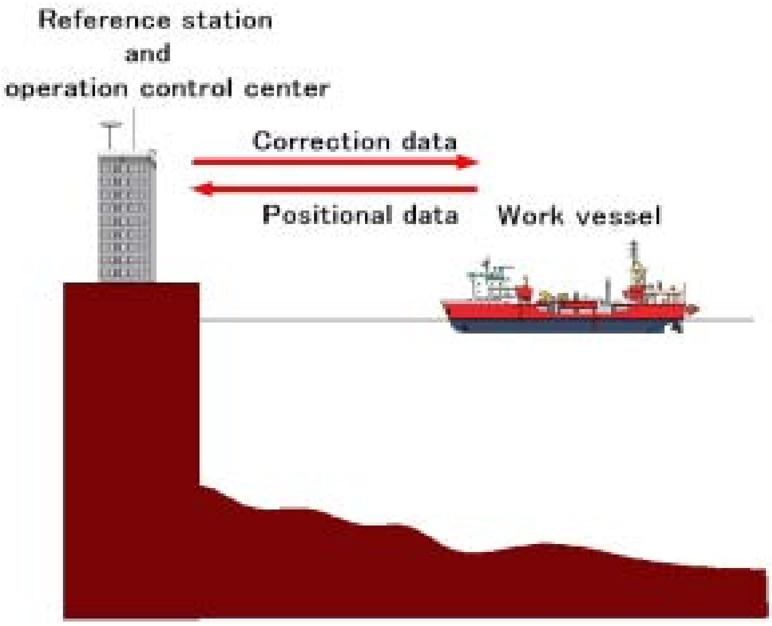

Figure 14. Two-way transmission method for operation control.

The disadvantage of time-sharing method is that it needs considerably high data transfer rate. This system is realized successfully by the use of radio waves that is shown in Table 1. This system can be applied into up to fourteen soil carriers simultaneously. Working situation is shown in Figure 15.

Figure 15. Working situation in Naoetsu Energy Port Project.

COOPERATIVE WORK AMONG DIFFERENT KINDS OF WORK

GPS is used for not only single kind of work but also cooperative work among different kinds of work. One typical example is removal work of sunken pieces of destroyed structure. It is a cooperative work of investigation work and removal work.

In 1892-1921, Japanese government constructed The Third Fort in Tokyo Bay for the defense of the capital. However, it was destroyed in the Great Kanto earthquake of 1923, and now is a reef causing stranding of ships. Removal work of sunken pieces of The Third Fort has been started for the safety of the ships cruising in Tokyo bay. Removal work is very difficult because sunken pieces are spread over wide areas. Then, removal work has been carried out in four steps as follows.

In the first step, position, size, and configuration of sunken concrete blocks are investigated with survey boat and divers. Position is measured in the common coordinate with GPS.

In the second step, all the data of sunken pieces including position, size, and configuration is gathered to construct a database.

In the third step, database is constructed and total removal plan is arranged using the database.

In the forth step, removal work is carried out according to the removal plan. The grabs developed specifically to remove sunken pieces and conventional floating cranes are navigated by GPS according to the positional data in the database. Navigation window of floating crane is shown in Figure 16.

Working efficiency was satisfactory compared with that when GPS is not introduced, since there is no relative error between investigation work and removal work.

Figure 16. Navigating window of floating crane.

FUTURE VIEW

GPS is now being introduced into the new areas other than conventional maritime construction work. One of the most important approaches is GPS wave-measuring buoy. It measures wave height by the motion of the buoy with GPS. As RTK-GPS is able to measure the absolute altitude, it is able to detect long period waves including tsunami. On the contrary, conventional wave-measuring buoy with accelerometer is not able to measure long period waves because of drift.

The water level measured by conventional wave measuring equipment needs to be compensated by tide. The water level measured by GPS wave measuring buoy needs no compensation because GPS measures the water level from the ellipsoid directly. The height from the ellipsoid is transformed into water level by geoid map.

GPS wave measuring buoy is desirable to be located as far as possible from the coast in order to enable early escape of people from the disaster caused by tsunami. Accuracy of vertical positioning, service area, and long-term durability and reliability of GPS devices on the buoy are critical factors.

Experimental GPS wave measuring buoy was built and placed on the sea 13 km from the coast shown in Figure 17. It introduces unique GPS system that works with one-way radio wave transmission from buoy to coast.

Figure 17. Experimental GPS wave measuring buoy.

The problem of experimental GPS wave measuring buoy is that control of buoy from the coast is impossible by the restriction of one-way transmission. It means that there is no means to maintain equipment onboard the buoy when embarkation on the buoy by boat is impossible because of severe weather condition. From the viewpoint of reliability, one-way transmission is totally unsatisfactory for practical GPS wave measuring buoy because it relates direct to a number of human life and property.

GPS wave measuring buoy with time-sharing method to send measured wave height from buoy to reference station is proposed by Maritime GPS Promoting Solutions on the experience of operation control at Naoetsu Energy Port Project. Experiment considering a small boat as a buoy using time-sharing method was carried out. Schematic view of experiment is shown in Figure 18 and a small boat equipped with RTK-GPS for the experiment is shown in Figure 19.

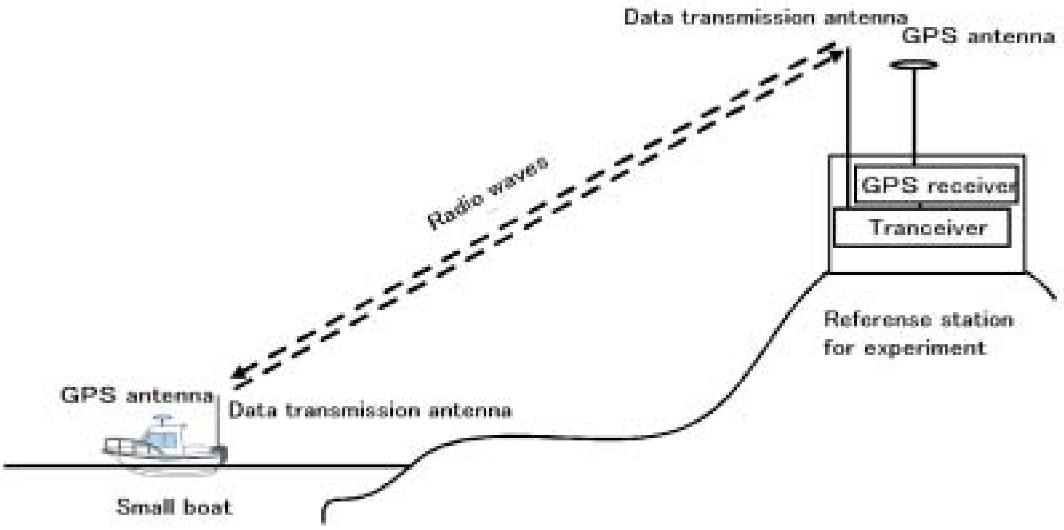

Figure 18. Small boat equipped with RTK-GPS.

Figure 19. Small boat equipped with RTK-GPS.

Vertical motion of the boat obtained in the experiment is shown in Figure 20. The other data is similar to this. It is recognized that vertical motion of small boat is measured correctly. Experimental result shows excellent perspectives for GPS wave measuring buoy using time-sharing method.

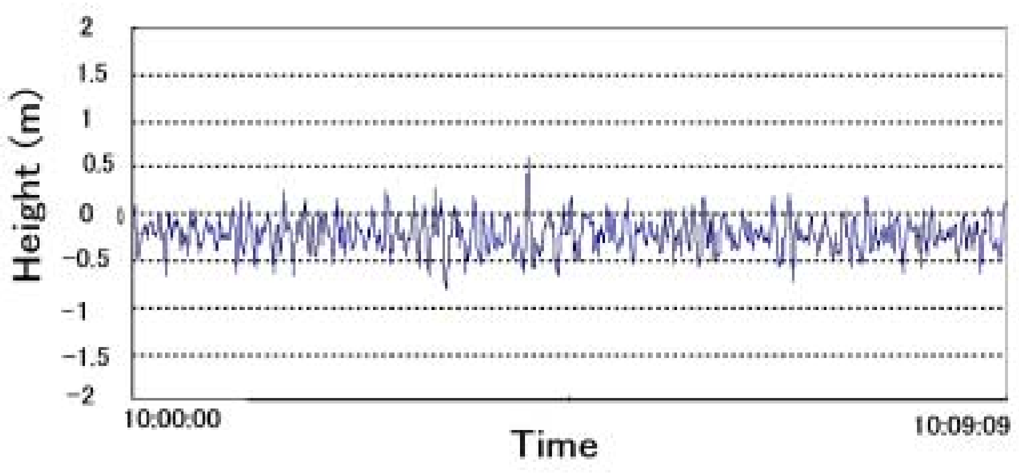

Figure 20. Vertical motion of small boat.

CONCLUSIONS

Tex The spread of GPS in maritime construction work in Japan shows that GPS is more suitable for maritime construction than land construction. The utilization of vertical positioning in various kind of execution shows the perspectives of GPS in other areas than construction work. One of the most important areas is disaster prevention. GPS wave measuring buoy is expected to save lives from tsunami.

Maritime GPS Promoting Solutions has been playing most important role in introduction of GPS into maritime construction work in Japan. We will continue to support future applications of GPS into more broad areas than before.

REFERENCES

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