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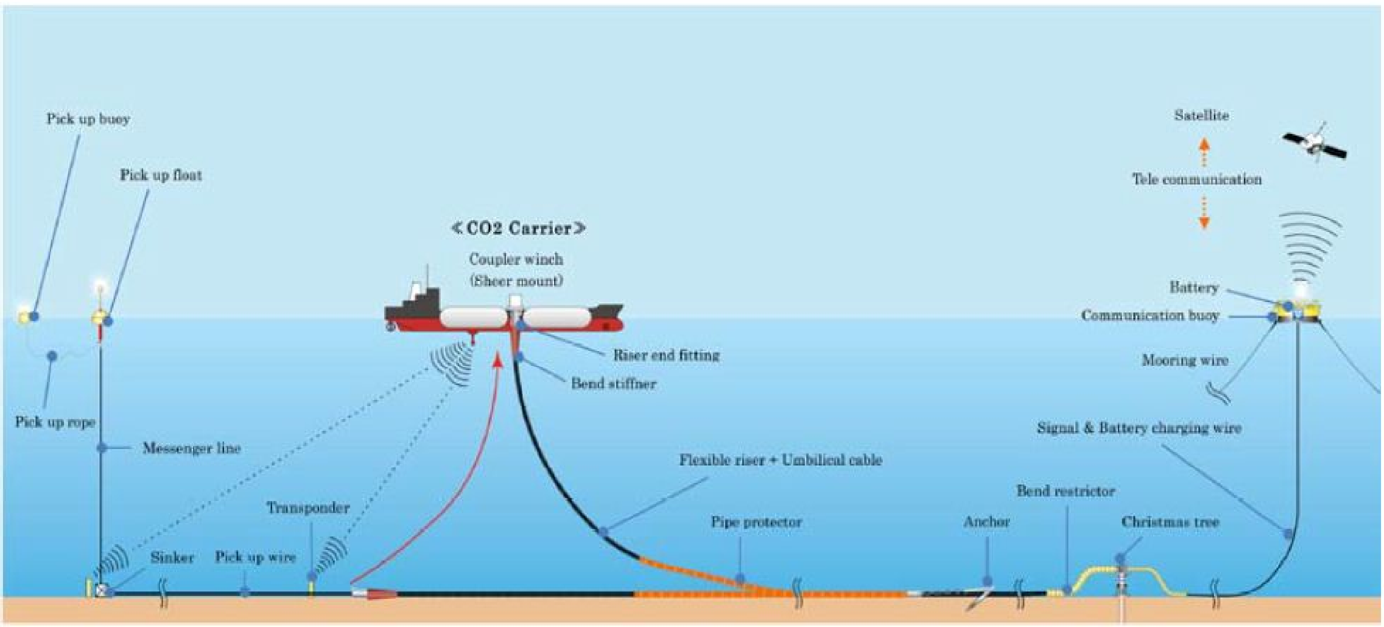
Preliminary Feasibility Study on CO_2 Carrier for Ship-based CCS



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CHIYODA CORPORATION

SUPPORTED BY GLOBAL CCS INSTITUTE

FINAL REPORT

Preliminary Feasibility Study
on
CO_2 Carrier for Ship-based CCS

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Contents of the Final Report
"Preliminary Feasibility Study on CO_2 Carrier for Ship-based CCS"

1. Overview

1.1 Transportation in the CCS chain

Transportation in CCS, particularly when applied to the "underground storage" concept as discussed in Chapter 5 of the IPCC Special Report on Carbon Dioxide Capture and Storage (2005), has not been addressed from the point of view of industrial research and development, because dedicated pipelines for carbon dioxide (CO_2) transportation exist in North America as a part of the infrastructure and the necessity for ship-based CO_2 transportation does not. Even in areas bordering the sea in Western Europe, the existing gas and oil pipeline networks are considered to be the way forward to transport CO_2.

If an emitter industry adjudges that the potential capacity for CO_2 storage in the neighboring area not so attractive, transportation of CO_2 by ship provides the opportunity to access distant storage sites. Industries dependent on overseas resources in their businesses are familiar with transporting bulk raw materials and fossil fuels by ships, and transportation of CO_2 by ocean-going vessels provides an attractive and viable alternative to overcome the limitations imposed by "sink-source matching condition" in carbon dioxide capture and storage (CCS).

Ship-based CCS provides flexibility in changing capture sites, storage sites and the transportation routes in a CCS project. The flexible selection of time, place and size of each project component in a CCS chain provides the robust strategy on the steps of decision-making by the stakeholders, and thus bring about a smooth introduction of a CCS scheme to a society. This is particularly pertinent in a country where the oil and gas industry is weak and, hence, is unable to take any strong initiative to create CCS projects. It is because the site selection step that strongly depends on oil and gas exploration data is a key to the actual CCS deployment.

The cost of transportation of CO_2 by ship has so far only been examined in generic comparisons with pipeline transportation under the "sink-source matching" conditions. The effect of scale and flexibility of ship-based CCS have not yet been carefully investigated and considered in detail based on ship design and existing regulations. Moreover, the potential attractiveness of a transportation network for ship-based CCS in East Asia has been neglected; ocean-side storage sites in this region at depths greater than 200m (where access by ship is easier than access by pipeline) might be shared and developed collaboratively by the carbon-intensive countries in this region.

1.2 Proposal of CO_2 carrier ship equipped with onboard injection facilities

The proposed ship transportation of CO_2 in this study has the key component of the ship as illustrated in Fig.1.2-1, which is equipped with the cargo tank of liquid CO_2 (LCO_2). The system design also features an onboard injection pump to deliver pressurized CO_2 directly from the ship to the seafloor wellhead of the injection well.

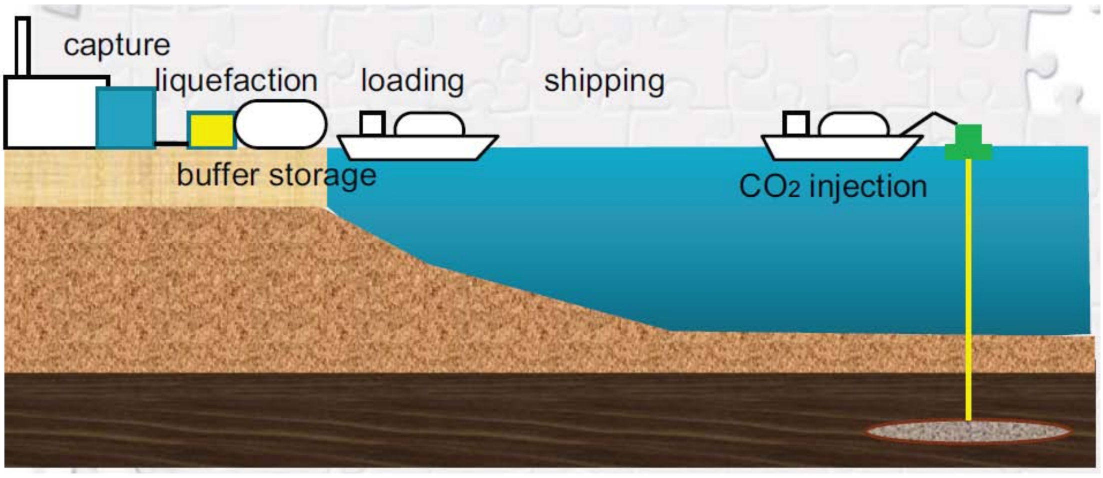


Fig1.2-1 Shuttle Ship and Socket Buoy

As schematically shown in Fig.1.2-2, the shuttle transportation using the proposed vessels enables CCS connection from multiple capture sites to multiple storage sites. Its merit includes:

- Relaxation of the "sink *vs.* source matching" requirement on CCS deployment;
- Direct access to the sub-seabed geological formation via CO_2 delivering pipe in the water column;
- Elimination of the large volume buffer storage tanks both onshore and offshore;
- Flexibility in changing a CCS project plan;
- Easy decommission, relocation and reuse of offshore facilities; and
- Thus securing the redundancy of the system.

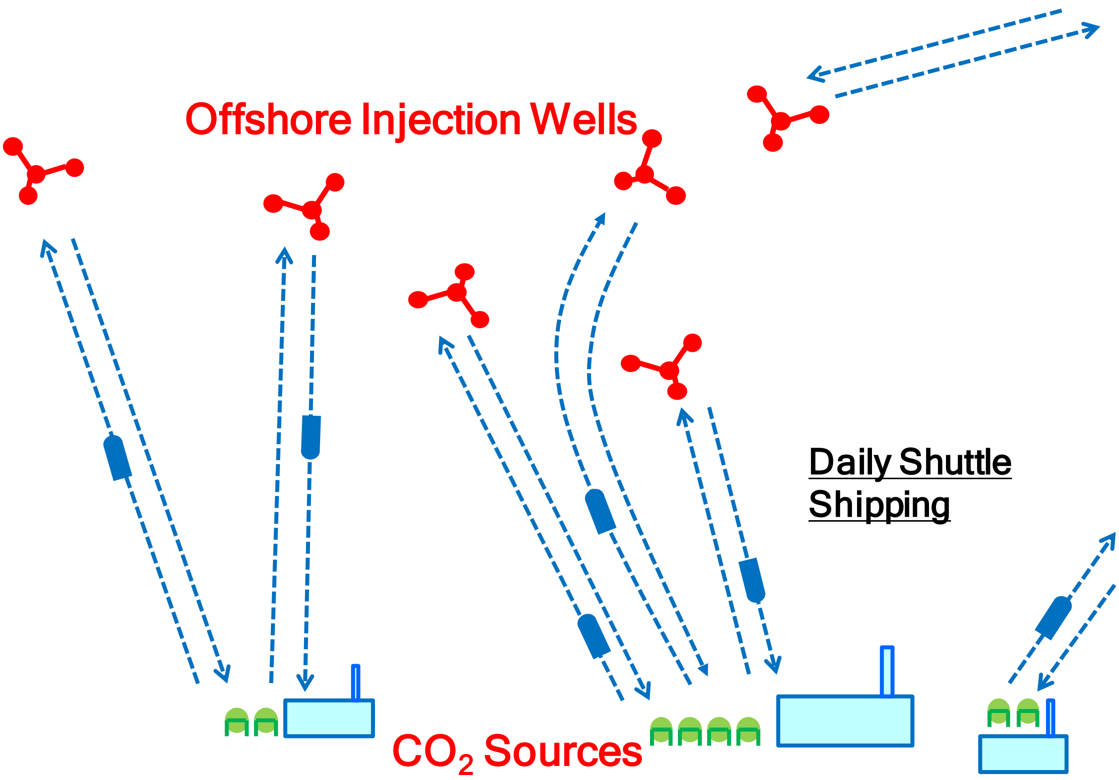


Fig1.2-2 CO_2 shuttle shipping application

The objectives of the study are to demonstrate the technical and economic feasibility of "the CO_2 shuttle tanker equipped with injection facilities".

The injection pump for transportation of CO_2 by pipeline could be located either onshore, on the offshore platform, or even on the sea floor (e.g. as a booster pump driven by power lines), but in the proposed scheme, each vessel conveying the cargo LCO_2 has its own onboard injection pump which is driven by the ship's engine and operated by ship personnel.

Manned platforms with accommodation for workers are not necessary in the proposed system of this study.

The transportation system proposed in this study is featured by the onboard injection facilities, and hence needs no ocean platform on which CO_2 buffer storage tanks will be installed.

1.3 Scope of works and Design bases

Fig.1.3-1 shows the work items of the study, and the scope of work is illustrated in Fig.1.3-2. The scope of works and design basis for the study is summarized in Table 1.3-1, brief explanations of which are presented in the following sections.

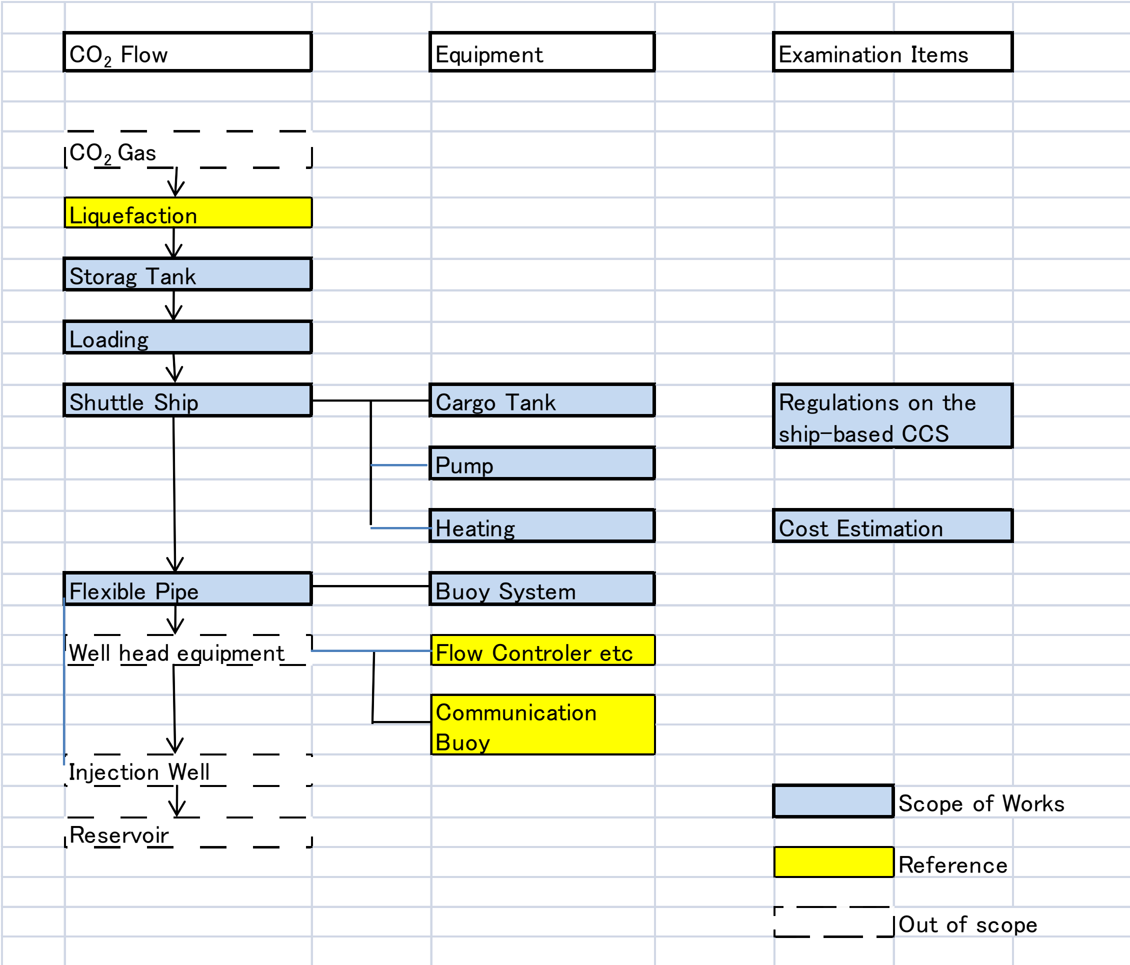


Fig .1.3-1 Scope of works

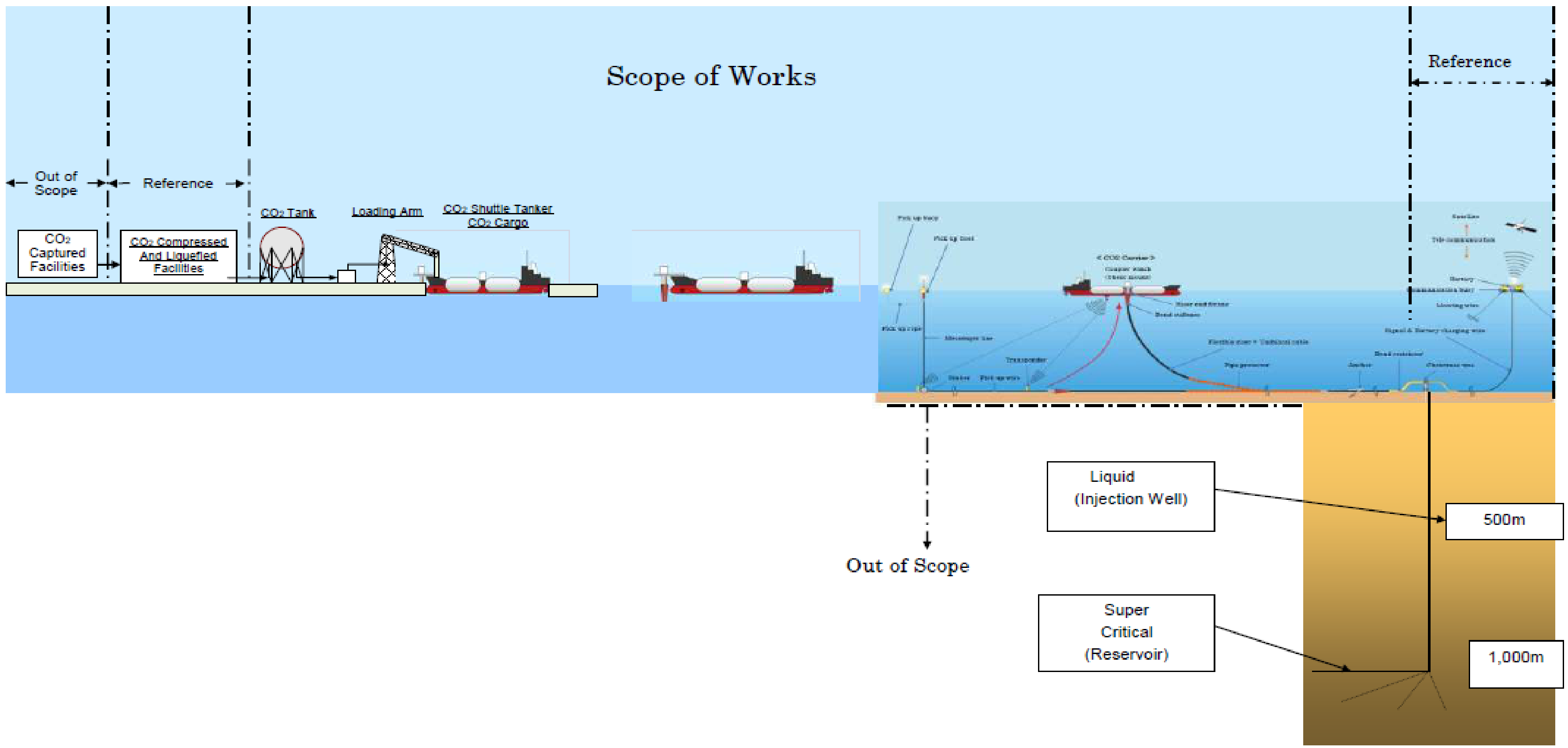


Fig.1.3-2 Scope of Wiorks

Table1.3-1 Design bases and condithons for "ship-based CCS" concepts

Item	sub-item	Design bases or Conditions	Remark
General		Shuttle type transport	
	Premise	No-manned Offshore Facilities	
Shuttle tanker			
	Cargo Tank	carbon dioxide conditions: minus10℃、2.86MPa capacity of a unit tank: $3000m^3$	
	Injection Pump	outlet pressure: 2.65MPa up to **10Mpa** flow rate: $3000m^3/22h$	
	Heater	securing the CO2 at the sea surface point above **0℃***	*Examination in terms of associated risks is required.
Socket Buoy System	w/ Moored Floating Structure	Applicability of TLP's	to clarify the applicability in terms of sea conditions, water depths etc.
	w/o Offshore Platform	Design of system using Flexible Riser Pipe	Base case for the study
Target Reservoirs for Storage	Total potential capacity	corresponding annual storage amounts: 0.3, 1.0 and 3.0 million tones	
	Injectivity of a well	0.05, 0.1,0.25 million tones per year	
	Locations	water depths : less than 500 m within Japan's EEZ	

1.3.1 General

1) Premise

(1) Shuttle-type transportation is to be used.

Refer to 1.1 regarding shuttle-type transportation

(2) Un-manned offshore facility is to be installed.

A manned offshore facility (such as a buoy) is not the preferred option because of the huge expense that would be incurred for facility construction and operation compared with an un-manned offshore facility.

1.3.2 Shuttle tanker

1) Cargo tank

(1) CO_2 is to be transported in liquid phase under the conditions at -10deg.C and 2.65MPa based on the reasons discussed in 2.1.

(2) About 3000m^3 of liquid CO_2 is loaded into the shuttle ship, which is equipped with two cargo tanks, each of about 1500m^3. Liquid CO_2 is then injected into the target reservoir via pipe and well at a rate of about 3000m^3/day (about one million t-CO_2 /year). Such injection rate is an international standard value for an experimental large-scale CCS project for treating flue gas.

2) Injection pump

(1) CO_2 injection rate is to be 3000m^3/22h.

(2)Liquid CO_2 is to be pressurized from the cargo tank at a pressure of 2.65MPa to 10MPa for injection.

3) Heater

Temperature of liquid CO_2 is being increased from -10 deg.C to 5 deg.C.

A temperature of 5 deg.C is to be used as a safe value to avoid freezing the seawater. The simulation study will be made with the CO_2 being in a liquid phase at the injection well bottom, using a radial well model to predict any reservoir pressure change caused by a change in the CO_2 condition from a liquid phase to a supercritical phase. This simulation will be conducted to make sure that the performance of a reservoir and seal formations underground are not affected by the low-temperature carbon dioxide.

After being heated, the CO_2 is to be injected through a flexible riser pipe into the seafloor well. Simulation study will also be made to estimate the temperature of the CO_2 at the well bottom.

1.3.3 Socket buoy system

An appropriate buoy system is to be selected from the following two cases through the examination of hydrographic conditions, operating conditions, cost and others.

1) With moored floating structure.

2) Without offshore platform.

1.3.4 Target reservoir for storage

1) Locations

Although an area less than 200m deep is targeted in the domestic potential investigation by RITE as a potential storage site, such locations would always have the potential to cause conflict with fishermen and cause a reparation problem under fishing rights.

Therefore, in the study, the CO_2 storage site is assumed to be at a depth shallower than 500m in an area of the sea within Japanese EEZ, as the cost of injection at that depth is not expected to be so high. No concrete storage site is to be examined in the study.

1.4 Study flow

As the study flow shown in Fig.1.4-1, its outline is as follows.

1) Scope of works and design bases <1.3>

The scope of works and design bases are discussed and the premise of the studied "shuttle-type transportation of CO_2 by ship" and presented.

The design bases are justified by the numerical analyses and the following two numerical analyses are conducted to confirm safety of injecting liquid phase CO_2. <3.2.2>

- Computation of change in the pressure and temperature throughout reservoir <Attachment B>
- Computation of change in the pressure and temperature through the flexible riser pipe in seawater and through the injection well under the seabed <Attachment C>

2) Shuttle ship

(1) Design of cargo tank <2.2>

The cargo tank to meet the following requirements is presented as a design basis.

- Capacity of liquid CO_2: 3000m^3

- Temperature of CO_2: minus 10 deg.C

- Pressure of liquid CO_2: 2.65Mpa

(2) Capability of DPS (dynamic positioning system) <Attachment A>

The proposed CO_2 carrier vessel performs two functions, the shuttle-type transportation and the injection for storage in the sub-seabed geological formations. After reaching the storage site offshore, the floating messenger line will be picked up and the end of flexible riser pipe is put onboard the shuttle ship, CO_2 is then delivered for injection. These operations are conducted safely and efficiently using DPS-controlled ship manoeuvring, even under severe weather or sea conditions at the hypothetical storage site M. Since the operation availability throughout the year will heavily influence the economy of the proposed system, more than 90% of operation availability is aimed for in the study.

The capability of DPS is analyzed by the simulation study using the literature data of the weather and sea conditions of the site M.

(3) On-board pump and heating system<3.2.1>

An onboard pump with a design pressure of up to 10 MPa and an associated heating system which can warm up the flowing liquid CO_2 from minus 10 deg.C to 5 deg.C, are selected.

(4) Design of carrier and cargo tank <2>

An arrangement of on board equipment such as the pump, the heating system, the DPS, and the flexible riser pipe operation system is made for the design completion of the proposed carrier vessel.

3) Flexible riser pipe

(1) Design of flexible riser pipe <3.3>

A flexible riser pipe is designed considering the required performance. The numerical analyses on its dynamic strength and long-term fatigue behavior were made under the weather and sea conditions of the hypothetical site M.

(2) Concept of pickup system <3.3.5>

A concept of pickup system, *i.e.* how to pick up the flexible rise pipe and put on the shuttle ship, is presented and evaluated.

4) Buoy system and offshore operation <3.4, 3.5>

(1) Rejection of the conventional socket buoy system <3.4.1>

(2) Adoption of a novel pick-up buoy system <3.4.2>

(3) Design of equipment for the flexible riser pipe operation <3.4.3>

(4) Mooring design of the pickup float<3.4.4>

Mooring of the pickup float is examined using hydrodynamic forces analysis.

(5) Offshore operation availability <3.5.2, 3.5.3>

The procedure proposed by this study is shown as follows -

a) The key factor of the vessel's operation availability is identified by the interview survey with captains of research vessels;

b) The response amplitude operator (RAO) of the proposed CO_2 carrier vessel in the moderate waves is calculated;

c) The estimations and evaluations on the offshore operational availability of the proposed CO_2 carrier vessel at offshore hypothetical site M are carried out by using the result of the above-mentioned a) and b), and the limiting sea condition on the vessel equipped with the DPS; and

d) The results of the estimation lead to the suggestion that the operation availability of the proposed CO_2 carrier vessel reach the target value of nearly 90% even in higher freeboard of a service platform required for the offshore buoy picking-up operations.

5) Law and regulatory consideration <4>

The international and domestic regulatory framework and HSE on the ship-based CCS are investigated.

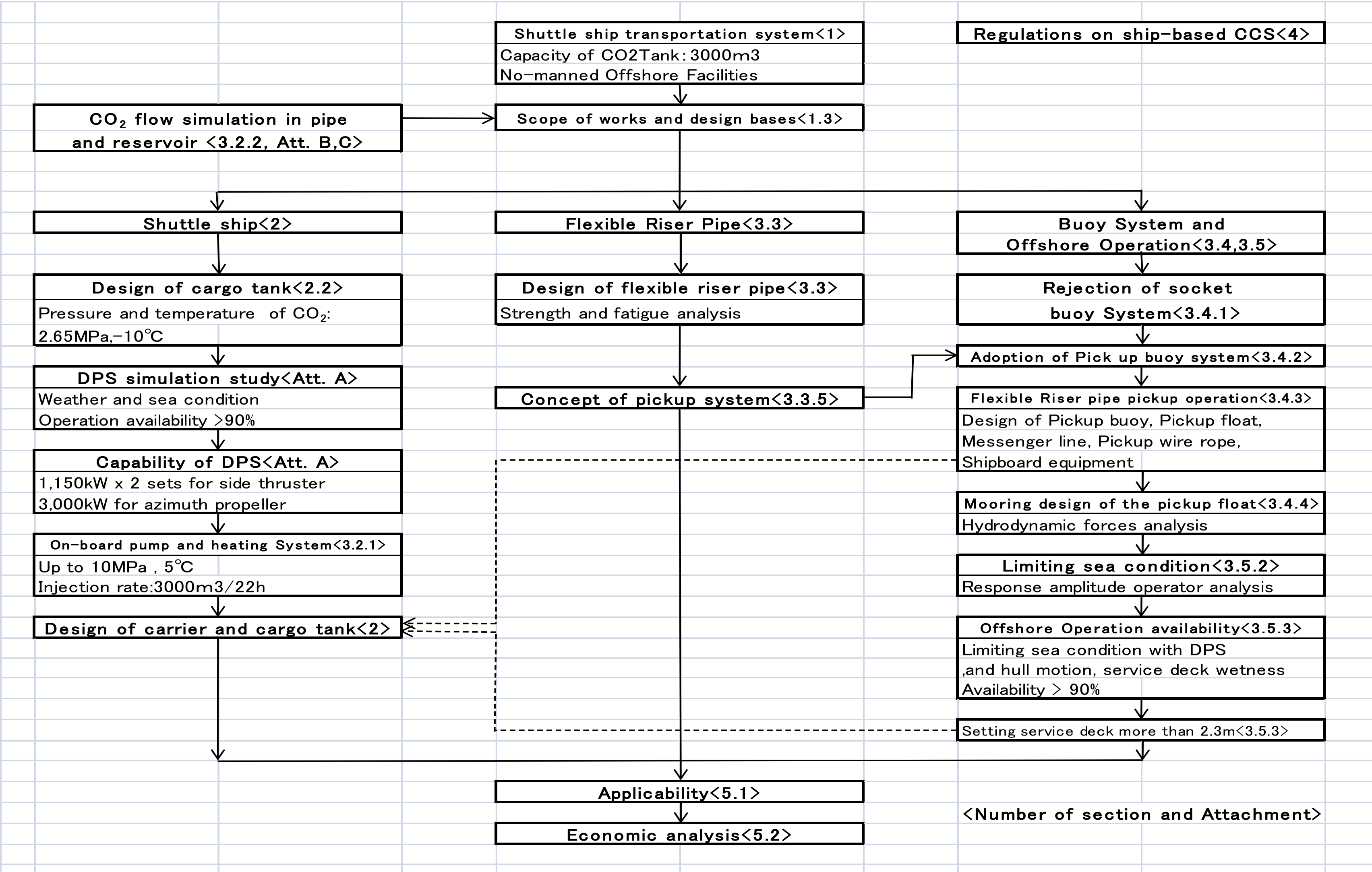
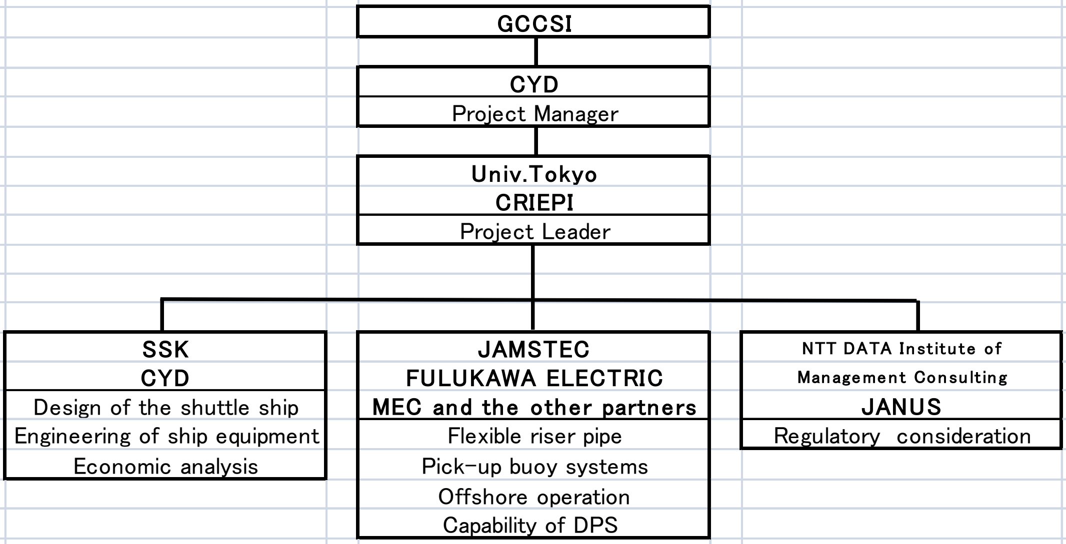


Fig1.4-1 Study flow of the project

1.5 Organization of project

Organization chart of the project is shown in Fig1.5-1.



CYD : Chiyoda Corporation
Univ. Tokyo : The University of Tokyo
CRIEPI : Central Research Institute of Electric Power Industry
SSK : Sasebo Heavy Industries Co.,Ltd
JAMSTEC : Japan Agency for Marine-Earth Science and Technology
FULUKAWA ELECTRIC : Furukawa Electric CO.,LTD
MEC : MEC Engineering Service Co.,Ltd
NTT DATA Institute of Management Consulting,Inc.
JANUS : Japan NUS Co,Ltd

Fig.1.5-1 Organization Chart of the Project

2. Liquid CO_2 Carrier and Cargo Tank

2.1 Outline of liquid CO_2 carrier

The ship is equipped with two units of storage tanks of liquid CO_2 (LCO_2), and the technical information of the storage tanks is described below.

The ship is kept in position at one point during the injection operation offshore using a Dynamic Positioning System (DPS), consisting of one azimuth propeller (ship aft) and two side thrusters (ship fore). To investigate a required capability of the DPS for the carrier ship with a cargo LCO_2 capacity of 3000 tons, a DPS simulation study was carried out under the combined disturbance conditions of wind, wave and current. From a marine and weather database for offshore locations, a site was arbitrarily chosen for the DPS simulation calculation. The investigation was conducted for seeking the requirement of the ship capability to assure the shipment efficiency above can perform above 90% in a yearly basis. The details of the DPS simulation are shown in Attachment A.

During cruising of the ship between the emission source onshore and the injection point offshore, the azimuth propeller acts as the main propulsion device. Electric power is supplied by either of two generators driven by diesel engines. Each generator can supply sufficient power to the azimuth propeller, so that one generator failure will not affect the power to sail the ship.

The following tables and figures show the principal particulars of the vessel and the ship profile and section.

Table 2.1-1 Principal particulars of the LCO_2 carrier

Hull					
	L (over all)	94,200 mm			
	L (pp)	89,600 mm			
	B (mould)	14,600 mm			
	D (mould)	6,900 mm			
	d (design)	5,600 mm			
Machinery					
	Side thruster (variable pitch)		1,150 kW	2 sets	
	Azimuth propeller		3,000 kW	1 set	(Main propulsion)
	Power generator (Diesel driven)		3,500 kW	2 sets	
Ship speed					
	NSR (90%)	15.0 knot			

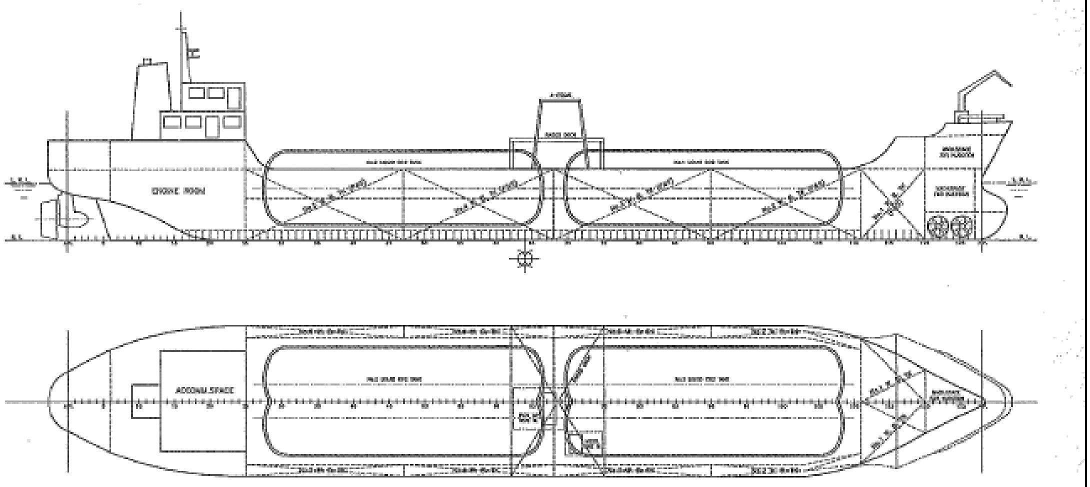


Fig. 2.1 -1 General arrangement plan

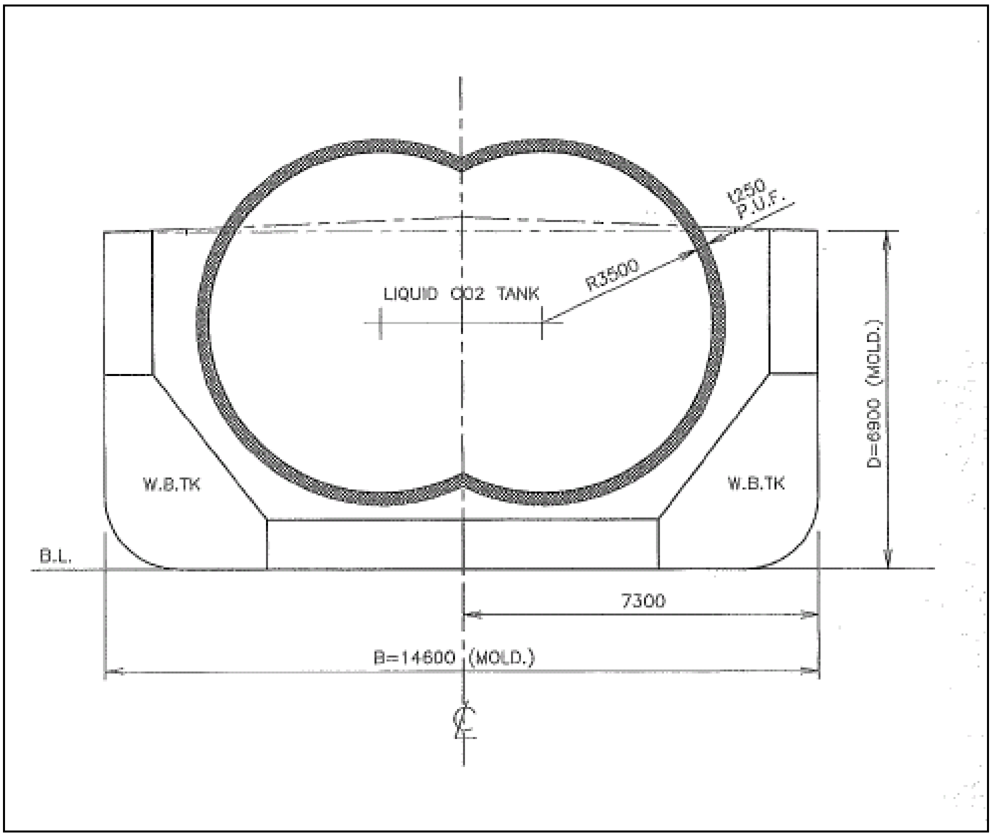


Fig. 2.1 -2 Midship section

2.2 Cargo tank design

The physical properties of CO_2, specifically the vapor liquid equilibrium properties of CO_2, are such that the design of a storage tank for the containment of liquid carbon dioxide is very similar to existing designs for intermediate pressure liquefied petroleum gas (LPG) containment systems. The design methodology for LPG cargo tanks is well understood and is regulated by international standards (specifically the "International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk"; IGC code) and Classification Societies (such as DNV, BV and LRS). The design methodology employed in this study which is for the marine transport of LCO_2 is exactly the same as described by the IGC code and subject to Classification Society rules. These design rules are well proven with literally hundreds of LPG carriers operating worldwide in an industry that has an excellent safety record since the advent of LPG bulk marine transport in the early 1960s.

2.3 Pressure and temperature condition of cargo LCO_2

Carbon dioxide is liquefied onshore and loaded onboard the vessel, and its state will be as follows:

Temperature of the liquid:	- 10 deg.C
Vapour pressure of the liquid:	2.65 MPa

	(corresponding to the vapor pressure of the liquid at -10 deg.C, which is the conditions for loading LCO_2.)
Rise of pressure* of the LCO_2:	about 0.1MPa after 3-day duration
	(for the ambient temperature condition of 45 deg.C)
Hence the maximum working pressure is:	2.8 MPa.

**Note: The LPG bulk marine transportation industry has proven designs capable of transporting LPG (at -48* deg.C*) and ethylene (at -104* deg.C*). The method of insulation is well understood in the industry as is the method of "affixing the tanks to the ship". There is nothing new in this design that is not well proven in the industry.*

2.4 Capacity and dimensions of tanks

The capacity and dimensions of tanks are listed below.

Number of tank:	two (2) units
Volume of tank:	about 1,500 m^3 (each)
Total volume of tanks:	about 3,000 m^3
Design temperature of the tank:	minus 10 deg.C
Design pressure of the tank:	3.10 MPa
	(equal to the pressure setting of the relief valve)
Dimensions of tank (one unit);	
Radius of single cylinder:	3.50 m
Total length of the tank:	26.96 m

2.5 Material

Quenched and tempered carbon steel for low temperature use

Tensile strength 795N/mm^2, Yield strength 685N/mm^2

According to JIS SHY685 (use at minus 10 deg.C)

2.6 Shape of pressure tank

Bi-lobe tank with heads at both ends, the outline is of torispherical shape as shown in Fig.2.6-1.

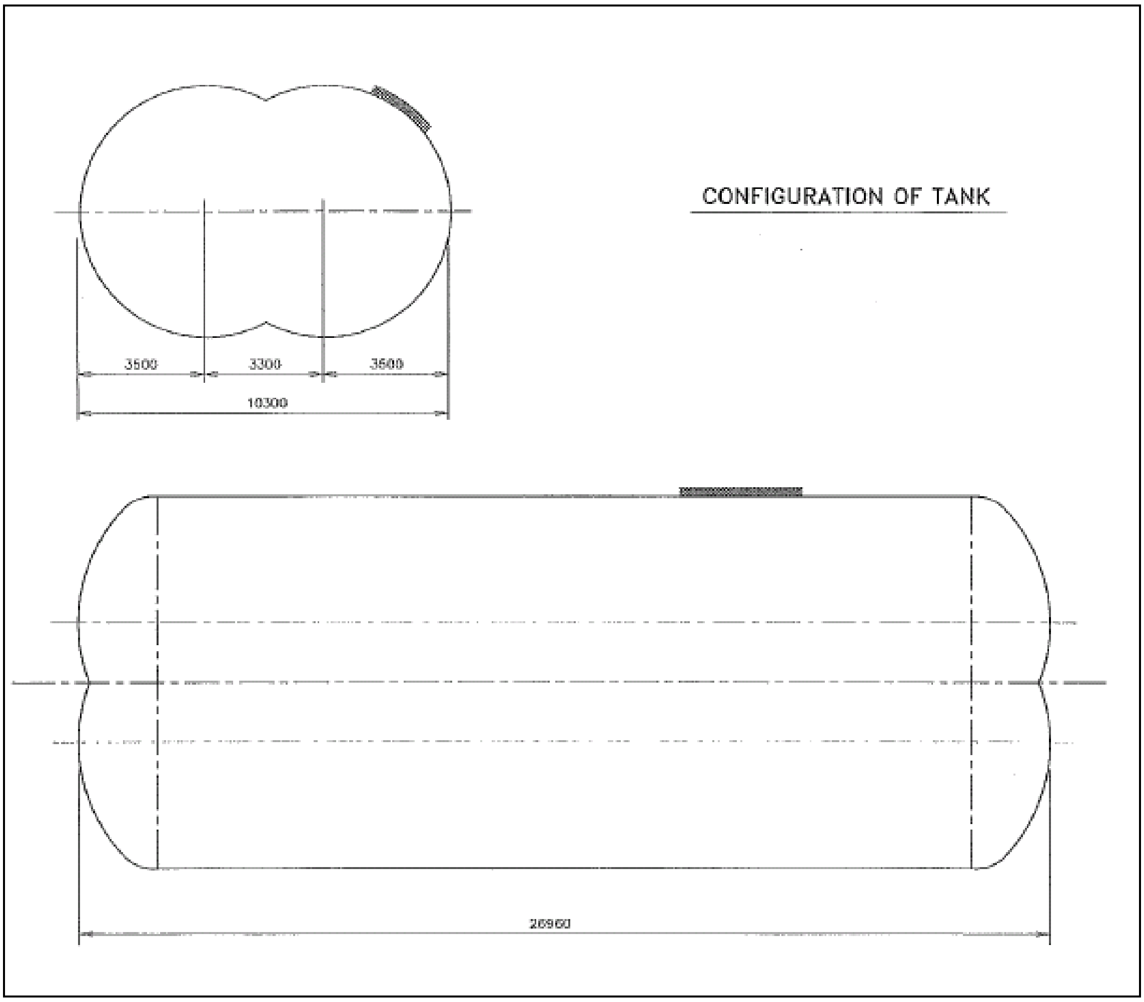


Fig. 2.6-1 Configuration of liquid CO_2 tank

2.7 Manufacturability

The tank shape is of a Bi-lobe type. Consequently the diameters of cylindrical tanks are considerably reduced and the thickness of the wall is also kept to minimum to avoid various requirements for thicker plates.

The liquid temperature is kept above minus 10 deg.C. The reduced thickness of the tank plate and the designated liquid temperature exclude the requirement of the heat treatment procedure after welding and assembling the tank parts.

2.8 How to decide the scantlings of tanks

2.8.1 Thickness of the tank plate

Normally the Classification Society requires the heat treatment after assembling the tank if the plate exceeds 40mm in thickness. And in case the liquid temperature is below - 10 deg.C, the anneal-purpose heat treatment (for relieving the tress) is also required after assembling the tank (refer to the IGC code 4.11 attached below)

> **4.11 Stress relieving for type C independent tanks**
>
> **4.11.1** For type C independent tanks of carbon and carbon-manganese steel, post-weld heat treatment should be performed after welding if the design temperature is below −10°C. Post-weld heat treatment in all other cases and for materials other than those mentioned above should be to the satisfaction of the Administration. The soaking temperature and holding time should be to the satisfaction of the Administration.

This is the reason why the bi-lobe shape is adopted to keep the plate thickness as thin as possible.

2.8.2 Design basis for cargo tank

The design of the cargo tanks is conducted in accordance with the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk; also known as the IGC code. This code has been used as the basis for the design of cargo tanks for liquefied petroleum gas (LPG) since the 1960s. The physical properties, more specifically the vapour liquid equilibrium properties of carbon dioxide above 0.6 MPa are remarkably similar to those of LPG and it is noted that the Classification Societies have already included considerations for carbon dioxide within their design rules. Hence the design undertaken here makes use of existing rules and standards from an established industry; that is the industry concerned with the marine transport of liquefied gases.

The choice of cargo tank design pressure is determined by the vapour pressure of carbon dioxide at -10 deg.C with operating and safety margins; to allow for pressure increase during voyage and additionally to allow for the operation of the cargo tank pressure relief valves. The initial design concept allows for approximately up to 3 days of voyage between loading and unloading of the carbon dioxide cargo. Using industry standards for insulation type and insulation thickness, it is possible to calculate the quantity of heat ingress to the cargo tanks during a 3 day voyage and determine that an insulation thickness of 250mm is sufficient to allow for a 3 day voyage during which the pressure rise is limited to less than 0.15 MPa. This determines the maximum working pressure of the cargo tanks to be an acceptable 2.8 MPa. By “acceptable” it is meant that at a cargo tank design pressure of approximately 2.8 MPa, it has been calculated that the required steel thickness for the cargo tank is commercially available and adheres to industry standards and hence the design will be viable. It is common industry practice to allow a safety margin of 10% for the operation of the safety valves and hence the design pressure of the cargo tanks is determined to be 3.1 MPa.

It is noted that the heat ingress to the cargo tanks is calculated with an ambient air temperature of 45 deg.C and an ambient sea temperature of 32 deg.C. These conditions are more stringent than the normal ambient conditions around the coast of Japan. The result of this investigation is a carbon dioxide carrier that will load at 2.65MPa and minus 10 deg.C, travel for up to 3 days during which heat ingress from the surroundings will cause the carbon dioxide to warm up leading to an increase in pressure of up to 0.15MPa and a resulting pressure of 2.8 MPa. The carbon dioxide will then be unloaded with sufficient margin between the maximum operating pressure and the safety valve relief pressure of 3.1 MPa. This design is viable and in accordance with existing standards for proven designs within the marine transport of liquefied gases industry.

3. Ship equipment and injection method

3.1 Loading

3.1.1 Outline of loading system

The CO_2 loading system is shown in Fig. 3.1-1. The scope of this Preliminary Feasibility Study is limited to only downstream of the CCS chain, hence, starting from the CO_2 buffer tank as shown in Fig.3.1-1. However, the related information on the CO_2 compression and liquefaction facilities is reported as reference.

CO_2 captured from various sources such as power plants, chemical plants, etc. is fed to the CO_2 compression and liquefaction facility, where CO_2 is compressed (up to 2.65 MPaA), dehydrated, liquefied (at -10 deg.C), and then stored in the CO_2 buffer tank. When a CO_2 shuttle tanker arrives at the berth, the CO_2 is pumped from the buffer tank and then loaded through the loading arm installed at the berth into the CO_2 cargo tanks on the tanker (see Fig. 3.1-2). Pressure and temperature inside the CO2 cargo tanks is controlled to 2.65 MPaA and -10 deg.C by connecting the pressure equalizing line to the CO_2 tank BOG cooler.

The CO_2 is then transported by the CO_2 shuttle tanker to the injection and storage site offshore.

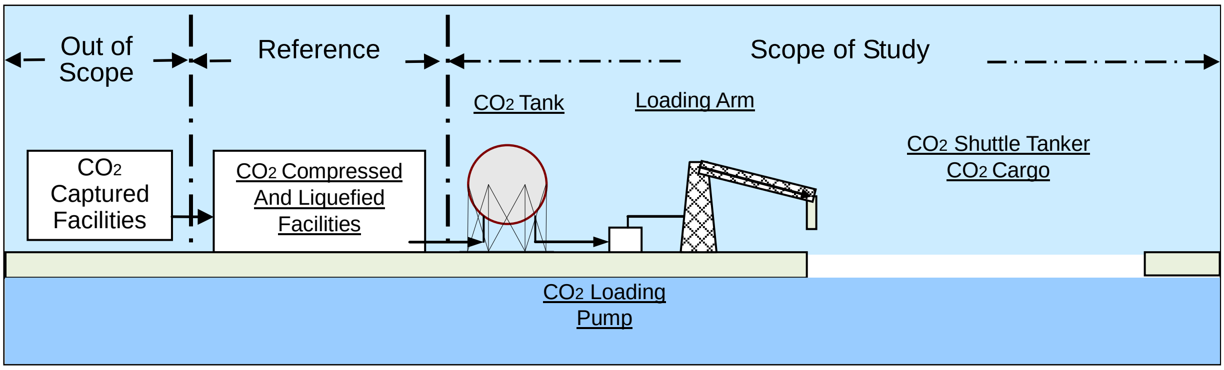


Fig. 3.1-1 CO_2 loading system

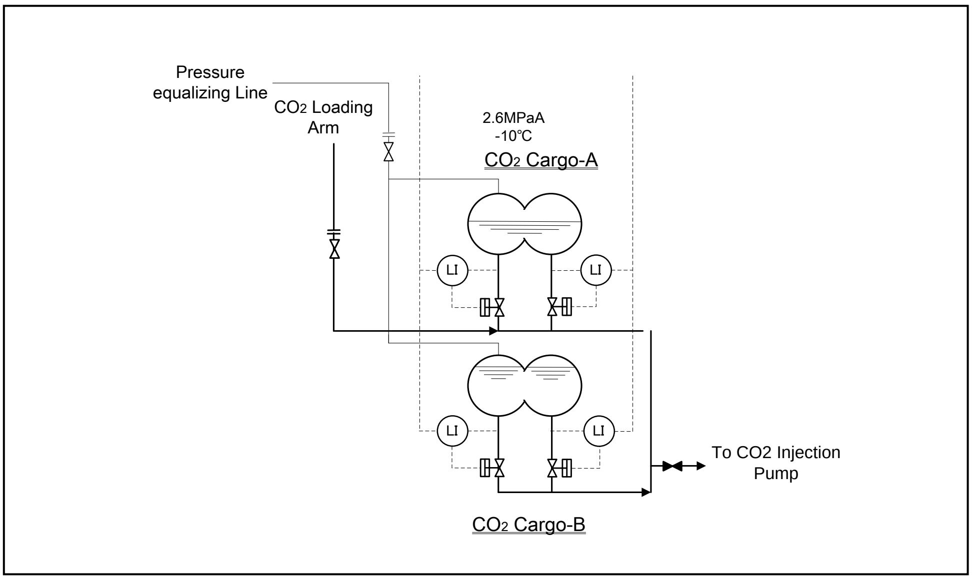


Fig. 3.1-2 CO_2 loading at the CO_2 cargo tanks

3.1.2 Scope of proposed CO_2 transportation system

The loading facilities in this Study include CO_2 buffer tank, CO_2 loading pump, CO_2 tank BOG cooler, loading arm and related equipment, whereas the followings are out of the scope of the Study:

- CO_2 compression and liquefaction facilities (although its related information is addressed as a reference in the Study;
- Berth (we think that an existing berth might be utilized);
- CO_2 capture facilities; and
- CO_2 gathering pipelines.

3.1.3 Loading capacity

The nominal capacity of CO_2 loading is 1 million tons/year, based on the following premises:

- Operation factor: 350 days/year
- Non-injection days caused by sea conditions: 15 days
- Scheduled shut-down period for maintenance is prescribed by Japanese regulations, *i.e.*, the maintenance will be executed on the plural set of the equipment, one by one, so there is no need to provide the special scheduled shut-down period.

3.1.4 Applied laws and regulations

In the examination of the system in this chapter, we supposed that the applied laws and regulations are High Pressure Gas Safety Act and Industrial Safety and Health Act of Japan. These laws are addressed in Chapter 4.

3.1.5 Major equipment

1) CO_2 tank: operating condition -10 deg.C, 2.65 MPaA
   430m^3 tank x 14sets (total capacity 6,000 tons; 2days stock)

2) CO_2 loading pump: capacity: 250 tons/hr, 2 sets + 1standby

3) CO_2 tank BOG cooler: utilizes cooling medium of CO_2 compressed and liquefied facilities

4) Loading arm: 500 ton/hr, 1set

5) Un-loading arm: 200 ton/hr, 1set (transfer CO_2 of CO_2 shuttle tanker in emergency

6) CO_2 vent stack: CO_2 release to atmosphere on emergency

3.1.6 Estimated construction cost

4,300 million Japanese yen (49.6 million AUD*)

Note: exchange rate=86.65yen/AUD TTM rate of 29 July 2011 Bank of Tokyo-Mitsubishi UFJ

3.1.7 Estimated facilities plot area

55m × 96m (5,200m^2)

3.1.8 Operating labor

2.0 operators (0.5 operators/team, 4 team x 3 shifts)

3.1.9 Utility consumption

Elec. power: 294,000kWh/year

3.1.10 Discharged CO_2

165tons/year @ 0.561kg-CO_2/kWh (Base on Japanese Ministry of Environment)

3.1.11 Reference information CO_2 compressed and liquefied facilities

1) Facilities capacity

- CO_2 loading nominal capacity: 0.94 million tons/year

- Operation factor: 330 days/year

  Non-injection days caused by the sea condition: 15 days

  Scheduled shut-down period for maintenance prescribed by Japanese regulation: 20 days

  Liquefied CO_2 will be supplied by another facility in the scheduled shut-down period for maintenance

2) Major equipment

- CO_2 compressor: 67,000m3/h 3stage 10,000kW, 1set

  (including lubricant system, suction drum, inter-stage knock-out drums, discharge drum, inter-stage coolers and discharge cooler)

- Dryer: 2set (including regeneration system)

- Refrigerator: 25 GJ/h, 1system

- CO_2 condenser: 125ton/h, 1set

- LCO_2 drum: 18m3 1set

3) Estimated construction cost: 3,800 million Japanese yen (49.6 million AUD*)
   Note: exchange rate = 86.65yen/AUD same as 3.1.4

4) Estimated facilities plot area: 30m x 30m (900m^2)

5) Operating labor: 6.0 operators (1.5 operators/team, 4 team x 3 shifts)

6) Utilities consumption

- Elec. power: 147,000,000kWh/year

- Cooling water: 8,000,000tons/year

- Waste water: 18.900tons/year

7) Discharged CO_2: 77.600tons/year @ 0.561kg-CO_2/kWh (same as 3.1.8)

3.2 Offshore delivery and Injection

3.2.1 On-board pump and heating

1) Outline of flow

The CO_2 injection flow is shown in Fig. 3.2-1. The loading arm of CO_2 shuttle tanker is connected to the CO_2 injection flexible riser pipe at the injection point, and the CO_2 stored in 4 (four) cargo tanks is sent to the CO_2 injection pump by each, and pressurized to the injection pressure (10 MPaA). The CO_2 is then heated to the injection temperature (5 deg.C) at the CO_2 heater (using sea water and hot water from the engine).

In the gasification plants for liquefied natural gas, the same kind of cooled seawater is being discharged to the environment. In the particular case of the proposed system, the affected area might be limited to nearby the carrier vessel, and the water depths of the CO_2 storage site are greater than those of LNG stations. Generally, the offshore area is oligotrophic, and hence has relatively low productivity and biodiversity. Anyway, its environmental impact can be assessed by the conventional methodology.

Temperature and pressure of CO_2 flow is shown in Fig. 3.2-2. The pressurized and heated CO_2 is sent through the CO_2 injection flexible riser pipe to the wellhead equipment installed on the seabed at the injection point. The CO_2 is then injected into the underground geological formation at the scheduled injection rate set for the individual wells, while the injection rates are controlled by flow control valves (electrically controlled) installed at the wellhead. Data signals on the flow rate are sent from the wellhead to the injection control system on the CO_2 shuttle tanker to monitor and control the injection condition.

The data related to the injection operation and the conditions of the injection wells are transmitted from the communication buoy to the CO_2 shuttle tanker and the injection control center (see Fig. 3.2-3).

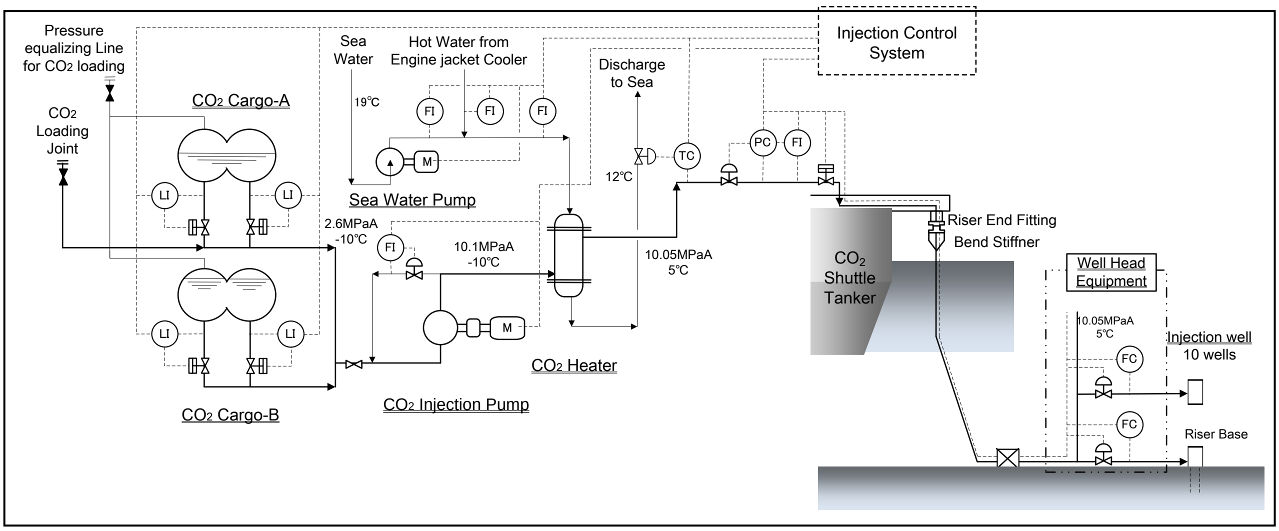


Fig. 3.2-1 CO_2 injection flow

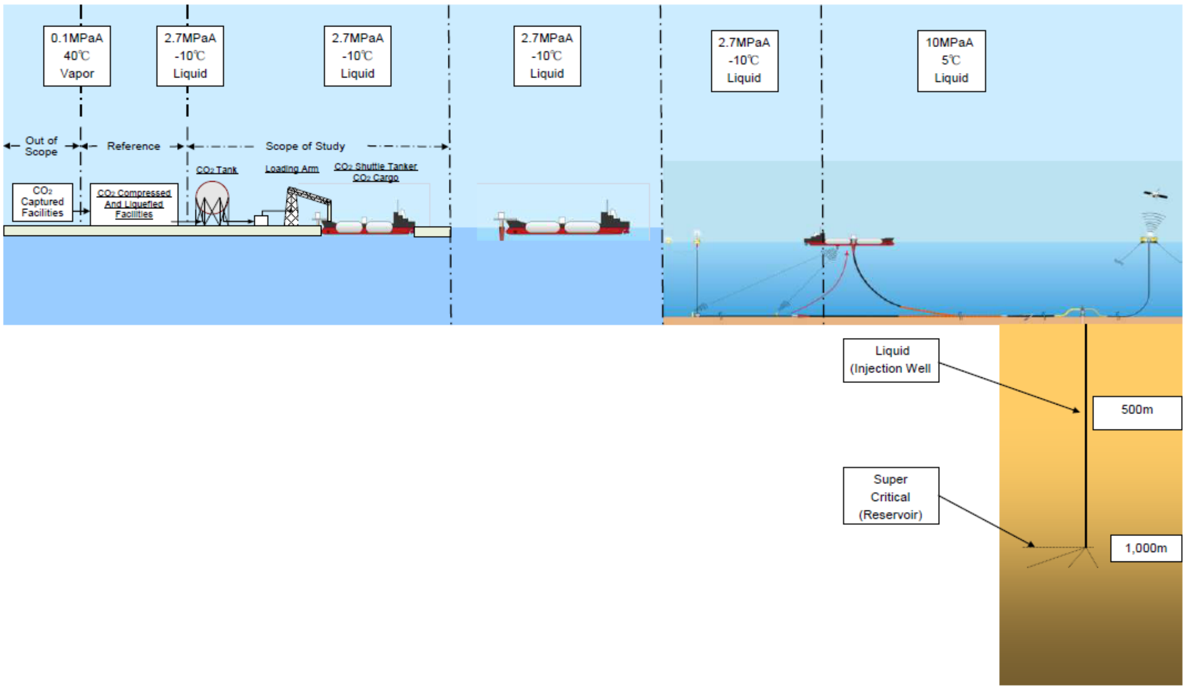


Fig. 3.2-2 Temperature and pressure of CO_2 flow

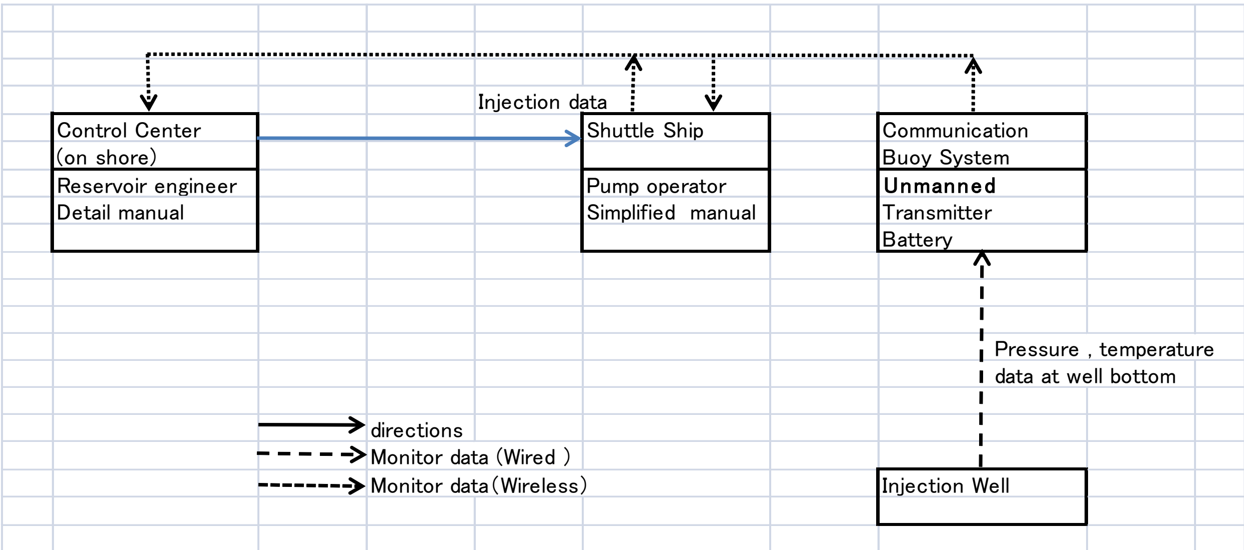


Fig. 3.2-3 Operation system

2) Major Equipment

(1) CO_2 injection pump: 150m^3/hr, 450kW 1set

(2) Sea water pump: 200m^3/hr, 18.5kW 1set

(3) CO_2 heater: Heating area=125m^2 1set

(4) Injection control system :

- Start up sequence control CO_2 injection pump and system;

- Switching sequence control on 4 (four) parts of the CO_2 cargo;

- Flow rate, pressure and temperature control of CO_2;

- Flow rate control of each injection well; and

- Shut down sequence control CO_2 injection pump and system.

3) Estimated facilities cost:

300 million Japanese yen (49.6 million AUD*)

Note: exchange rate=86.65yen/AUD TTM rate of 29 July 2011 Bank of Tokyo-Mitsubishi UFJ

4) Equipment layout in the hold of CO_2 shuttle tanker

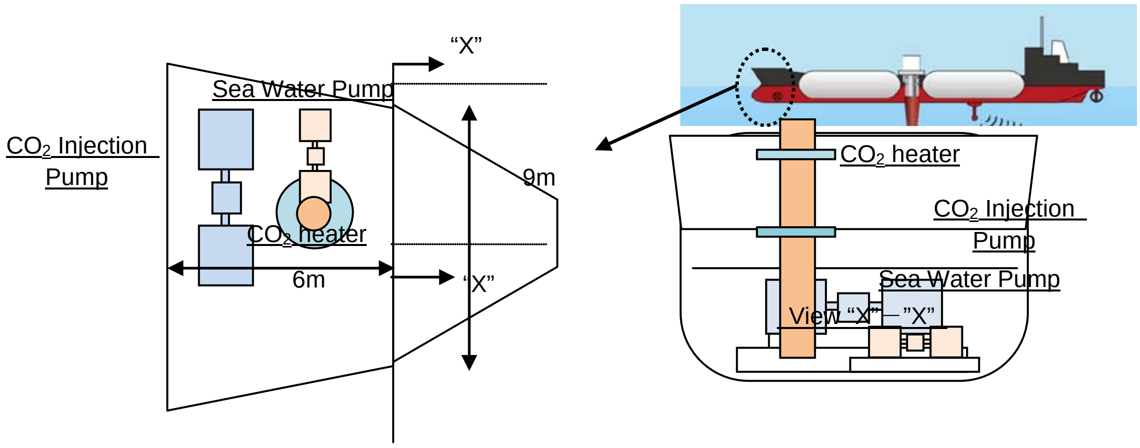


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Fig. 3.2-4 Equipment layout in the hold of CO_2 shuttle tanker

5) Utility Consumption

Elec. Power: 420kWh/hr (9,240kWh/day)

As fuel oil: 95L/hr (2.084kL/day)

6) Discharged CO_2

4.9 tons/day @0.561kg- CO_2/kWh (based on Japanese Ministry of Environment guidance)

7) Effect of low temperature seawater returned from the CO_2 heater

CO_2 injection is operated in the open sea, and the amount of cooled returned sea water is very small. Therefore, the effect of low temperature to ocean can be neglected.

3.2.2 Flow simulation study

1) TOUGH2 simulation study

In the proposed ship-based CCS scheme, a higher CO_2 temperature up to 5ºC at maximum is selected at the outlet point of the vessel for an energy saving purpose in a shuttle operation for the transportation. Being injected under such a condition, the CO_2 might be still in a liquid phase at the bottom of an injection well, whereas it will probably be in a super-critical condition in a reservoir after warmed up by heat flow from ambient. Under such circumstance, the reservoir pressure may increase much higher than the conventional case of injecting CO_2 under the super-critical conditions, causing some negative effects on the integrity of the confinement of CO_2, such as defects on a seal formation of the reservoir. Therefore, in order to investigate a reservoir pressure increase under CO_2 injection operation, a numerical model study was conducted by constructing a simplified reservoir model for both liquid CO_2 injection case and super-critical CO_2 injection case under the same injection rate condition.

The used software for analysis was TOUGH2 and ECO2N, whereas "TOUGH2 " is a basic simulator for nonisothermal multi-phase flow in fractured porous media based on the computational finite volume method, and "ECO2N" is CO_2 phase behavior analysis program included in the TOUGH2 software package.

The method of analysis and its results of the simulation study are shown in Attachment B.

The results of the study showed that the pressure difference between two injection cases with the same amount of liquid and super-critical CO_2, is quite small by less than 1% of the reservoir pressure in CO_2 flooded area. This suggests that there is no large risk on injecting CO_2 in liquid phase. However, in the actual site investigation for CCS project, it is necessary to evaluate rock properties of a reservoir and its cap rock based on the actual field data, and also to conduct numerical model studies. In addition, after starting CO_2 injection, the integrity of reservoir rock and cap rock need to be investigated through scheduled monitoring of the injection operation.

2) Pipe flow simulation study

Liquid CO_2 is pressured from 2.65Mpa up to 10Mpa by the on-board pump and warmed from minus 10 deg.C up to 5 deg.C by the heating system. Liquid CO_2 is then injected through the flexible riser pipe in sea-water and the injection well in rock to reservoir. The pressure and temperature change of liquid CO_2 in the flexible riser pipe and the injection well are simulated.

Method and the results of simulation study are shown in Attachment C.

The results of the study show that the temperature of CO_2 is warmed up in the flexible riser pipe and injection well ,and the fluid condition at the bottom of injection well is very near to the super critical conditions in the high injection rate case, and is super critical phase in the low injection rate case.

And when the depth of reservoir is more than 1000m, the on-board pump must compress the liquid CO_2 to more than 10Mpa.

The above-mentioned TOUGH2 simulation study is calculated under the condition that a low temperature of liquid CO_2 is injected at the injection well bottom to the reservoir. The result of this study shows that there is no large risk associated with injecting CO_2 in the liquid phase.

These two simulation studies show that the design bases of liquid CO_2 injection is almost real.

However, in the actual site investigation for a CCS project, it is necessary to evaluate sea conditions and rock properties and injection well properties based on the actual field data, and to also conduct numerical model studies.

3.3 Flexible riser pipe applicability

3.3.1 Basic design of flexible riser pipe

1) Specification

・Flow rate 3000 m^3/16hr (52 L/sec)

・Flow velocity 3m /sec

・Inner diameter 0.16m

The inner diameter of the flexible riser pipe was calculated as follows.

$$D = (4q / \pi v)^{1/2}$$

in which,

D ; Inner diameter of flexible riser pipe,

v ; Flow velocity,

q ; Flow rate

・Design pressure 20 MPa (Working pressure; 10MPa)

2) Pipe construction and its properties

The construction and the main properties of the flexible riser pipe designed by the in-house program of Furukawa Electric Co. are shown in Tables 3.3-1 and 3.3-2.

Table 3.3-1 Construction of flexible riser pipe

layer	thickness (mm)	outer diameter (mm)	material
Interlock carcass	5.5	163	stainless steel
Inner pipe	6.7	176.4	high density PE
Inner pressure armor	2.0 × 2	184.4	carbon steel
Tensile armor	2.0 × 2	192.4	sarbon steel
Buoyant layer	51.8	295	plastic tape
Outer sheath	7.0	309	high density PE

Table 3.3-2 Main properties of flexible riser pipe

Weight in air	79.0 kg/m	empty in inner pipe
Weight in sea water	20.0 kg/m	filled with CO_2
Burst pressure	76.7 MPa	
Axial stiffness (EA)	1.05E+05 kN	
Bending stiffness (EI)	94300 Nm^2	
Torsional stiffness (GJ)	8500 Nm^2/deg	
Minimum bending radius	2.5 m	3.75m for reel winding
Allowable tensile force	820 kN	

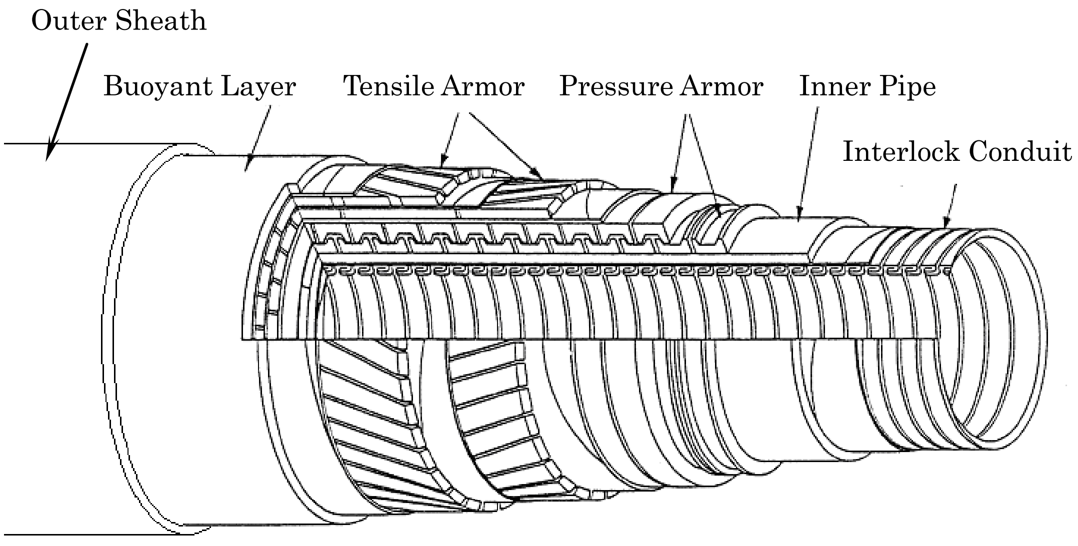

Fig. 3.3-1 Construction of flexible riser pipe

3.3.2 Static analysis for Flexible riser pipe

1) Assumption

- Water depth 200m & 500m
- Picked up pipe configuration Free hanging
- Excursion of DPS tanker ±15m
- Surface current 0.75 m/sec (declines by 1/7-th power law)
- Seawater density 1025kg/ m^3
- Drag coefficient 1.0
- Added mass coefficient 1.0

2) Applied software OrcaFlex Dynamics (Ver. 9.4)

3) Results

Results of 2D static analysis are shown in Tables 3.3-3 to 3.3-6.

Maximum tensile force at the upper end of the flexible riser pipe is low enough for the allowable tensile force in each case. The bending radius at the upper end and at the touch down point (TDP) are found to be kept larger than the minimum bending radius.

Table 3.3-3 Case-1 (water depth: 200m; current direction: 0deg)

Position		Near	Neutral	Far
Top	Tension kN	37	37	38
	Bending radius m	5.3	5.3	5.0
TDP	Bending radius m	6.2	7.9	24.9
	TDP movement m	- 11	—	19
Arc length of riser pipe m		210.5	212.5	216.5

Table 3.3-4 Case-2 (water depth:200m; current direction:180deg)

Position		Near	Neutral	Far
Top	Tension kN	45	48	51
	Bending Radius m	9.6	15.3	57.9
TDP	Bending Radius m	34.0	43.9	57.9
	TDP movement m	21	—	24
Arc length of riser pipe m		225.5	233.5	243.5

Table 3.3-5 Case-3 (water depth:500m; current direction:0deg)

Position		Near	Neutral	Far
Top	Tension kN	94	95	96
	Bending Radius m	3.4	3.3	3.2
TDP	Bending Radius m	9.2	13.3	20.0
	TDP movement m	-22	—	22
Arc length of riser pipe m		523.5	528.5	538.5

Table 3.3-6 Case-4 (water depth: 500m; current direction:180deg)

Position		Near	Neutral	Far
Top	Tension kN	123	126	130
	Bending Radius m	16.2	30.8	2300
TDP	Bending Radius m	6.2	7.9	24.9
	TDP movement m	-22	—	26
Arc length of riser pipe m		590.5	602.5	614.5

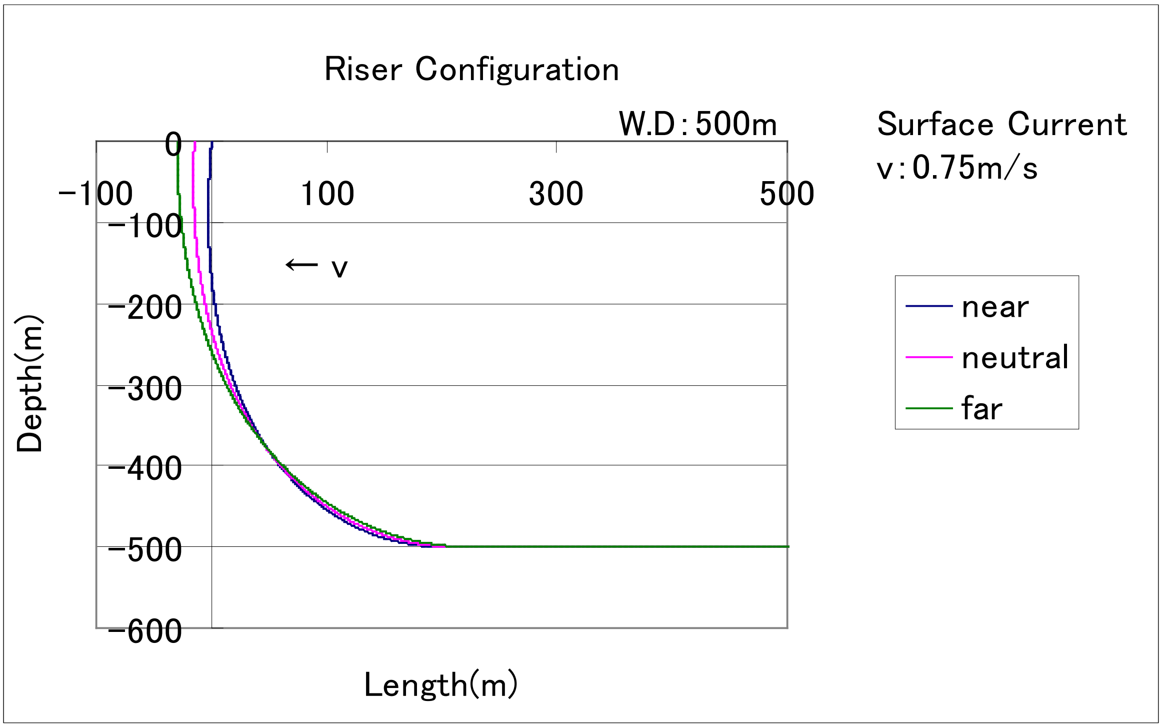

Fig. 3.3-2 Static configuration of flexible riser pipe (water depth: 500m) .

3.3.3 Dynamic analysis for flexible riser pipe

1) Assumption

- Water depth 200m & 500m
- Flexible riser pipe configuration Free hanging
- Significant wave height during operation 3.0m
- Significant wave period during operation 6.0sec &12.0sec
- Water spectrum Bretschneider
- Response amplitude operator See Table 3.3.7
- Connecting point of riser top See Fig. 3.3.3
- Surface current 0.75 m/sec (declines by 1/7-th power law)
- Applied software OrcaFlex Dynamics(Ver. 9.4)

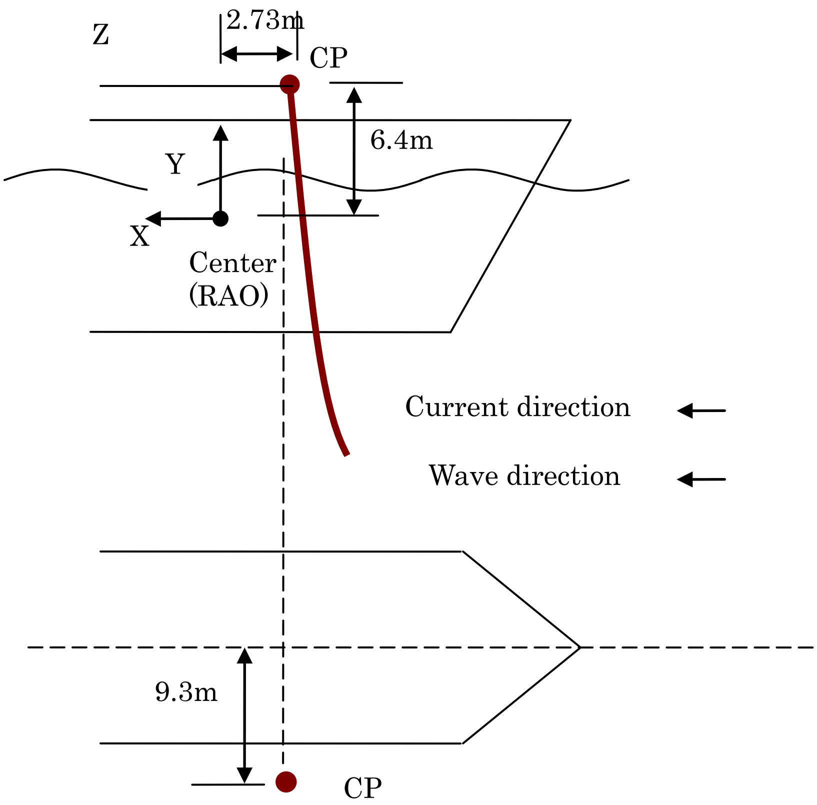

Fig. 3.3-3 Connecting point of the riser top.

Table 3.3-7 Response Amplitude Operator (RAO).

Wave direction =180 degree												
	SURGE		SWAY		HEAVE		ROLL		PITCH		YAW	
TW	AMP	PHASE	AMP	PHASE	AMP	PHASE	AMP	PHASE	AMP	PHASE	AMP	PHASE
(SEC)	(M/M)	(deg)	(M/M)	(deg)	(M/M)	(deg)	(D/M)	(deg)	(D/M)	(deg)	(D/M)	(deg)
2	1.89E-03	1.75E+02	1.18E-12	0.0E+00	1.13E-03	3.56E+02	6.71E-12	0.0E+00	2.56E-03	3.29E+02	2.28E-12	0.0E+00
2.5	3.04E-03	3.54E+02	1.80E-13	0.0E+00	1.08E-03	3.26E+02	6.24E-13	0.0E+00	4.84E-03	1.15E+01	2.42E-13	0.0E+00
3	8.14E-03	2.12E+02	3.46E-13	0.0E+00	1.85E-03	1.73E+02	5.04E-12	0.0E+00	4.11E-03	2.75E+02	7.89E-14	0.0E+00
3.5	1.68E-02	2.73E+02	2.91E-17	0.0E+00	5.03E-03	2.16E+02	1.61E-16	0.0E+00	1.26E-02	4.87E+01	6.27E-17	0.0E+00
4	2.82E-02	7.93E+01	2.36E-18	0.0E+00	7.04E-03	6.19E+01	1.32E-17	0.0E+00	3.06E-02	2.08E+02	5.74E-17	0.0E+00
4.5	4.42E-02	3.18E+02	1.64E-17	0.0E+00	3.43E-02	2.64E+02	1.14E-15	0.0E+00	5.88E-02	1.29E+02	6.85E-17	0.0E+00
5	5.85E-02	2.19E+02	4.16E-17	0.0E+00	3.28E-02	2.32E+02	4.16E-15	0.0E+00	1.75E-01	3.52E+02	7.96E-17	0.0E+00
5.5	8.61E-02	1.58E+02	2.48E-17	0.0E+00	1.18E-01	9.57E+01	6.06E-15	0.0E+00	3.64E-01	3.34E+02	5.30E-17	0.0E+00
6	1.09E-01	1.20E+02	1.69E-17	0.0E+00	2.91E-01	1.08E+02	3.46E-15	0.0E+00	3.12E-01	2.84E+02	1.82E-16	0.0E+00
6.5	1.00E-01	1.03E+02	4.70E-17	0.0E+00	2.59E-01	1.18E+02	1.19E-15	0.0E+00	8.52E-01	2.36E+02	3.73E-17	0.0E+00
7	3.80E-02	9.81E+01	3.00E-17	0.0E+00	1.65E-01	9.12E+01	1.04E-15	0.0E+00	1.57E+00	2.38E+02	2.03E-16	0.0E+00
7.5	7.10E-02	2.72E+02	3.95E-17	0.0E+00	1.87E-01	4.39E+01	2.57E-16	0.0E+00	2.06E+00	2.45E+02	1.12E-16	0.0E+00
8	2.00E-01	2.75E+02	4.04E-17	0.0E+00	2.83E-01	2.10E+01	4.73E-16	0.0E+00	2.29E+00	2.52E+02	1.26E-16	0.0E+00
8.5	3.22E-01	2.77E+02	2.75E-17	0.0E+00	3.90E-01	1.15E+01	2.70E-16	0.0E+00	2.31E+00	2.57E+02	9.04E-17	0.0E+00
9	4.26E-01	2.78E+02	2.64E-17	0.0E+00	4.89E-01	7.10E+00	2.95E-16	0.0E+00	2.22E+00	2.61E+02	6.94E-17	0.0E+00
9.5	5.11E-01	2.78E+02	9.23E-18	0.0E+00	5.74E-01	4.81E+00	1.60E-16	0.0E+00	2.09E+00	2.63E+02	2.11E-16	0.0E+00
10	5.80E-01	2.78E+02	1.52E-17	0.0E+00	6.46E-01	3.57E+00	1.71E-16	0.0E+00	1.95E+00	2.64E+02	1.23E-16	0.0E+00
10.5	6.36E-01	2.78E+02	4.25E-17	0.0E+00	7.05E-01	2.87E+00	2.32E-17	0.0E+00	1.81E+00	2.65E+02	1.74E-16	0.0E+00
11	6.83E-01	2.77E+02	2.01E-17	0.0E+00	7.53E-01	2.44E+00	1.49E-16	0.0E+00	1.68E+00	2.65E+02	1.16E-16	0.0E+00
11.5	7.22E-01	2.77E+02	6.42E-17	0.0E+00	7.92E-01	2.16E+00	2.44E-16	0.0E+00	1.55E+00	2.65E+02	1.70E-16	0.0E+00

12	7.55E-01	2.76E+02	8.25E-17	0.0E+00	8.24E-01	1.95E+00	3.38E-16	0.0E+00	1.44E+00	2.65E+02	1.86E-16	0.0E+00
12.5	7.84E-01	2.76E+02	2.89E-17	0.0E+00	8.50E-01	1.79E+00	1.36E-16	0.0E+00	1.34E+00	2.65E+02	6.02E-17	0.0E+00
13	8.08E-01	2.75E+02	7.66E-17	0.0E+00	8.71E-01	1.66E+00	8.32E-17	0.0E+00	1.25E+00	2.65E+02	2.93E-17	0.0E+00
13.5	8.29E-01	2.75E+02	6.01E-17	0.0E+00	8.89E-01	1.54E+00	9.95E-17	0.0E+00	1.16E+00	2.64E+02	4.54E-17	0.0E+00
14	8.47E-01	2.75E+02	4.11E-17	0.0E+00	9.04E-01	1.44E+00	3.27E-17	0.0E+00	1.09E+00	2.64E+02	7.72E-17	0.0E+00
14.5	8.62E-01	2.74E+02	5.78E-17	0.0E+00	9.16E-01	1.34E+00	1.78E-16	0.0E+00	1.02E+00	2.64E+02	2.60E-17	0.0E+00
15	8.76E-01	2.74E+02	1.11E-16	0.0E+00	9.26E-01	1.26E+00	1.36E-16	0.0E+00	9.55E-01	2.63E+02	2.21E-16	0.0E+00
16	8.98E-01	2.73E+02	3.81E-17	0.0E+00	9.43E-01	1.11E+00	1.07E-16	0.0E+00	8.45E-01	2.62E+02	1.29E-16	0.0E+00
17	9.15E-01	2.73E+02	4.59E-17	0.0E+00	9.55E-01	9.84E-01	2.25E-16	0.0E+00	7.52E-01	2.61E+02	2.37E-16	0.0E+00
18	9.28E-01	2.73E+02	7.72E-17	0.0E+00	9.64E-01	8.77E-01	1.06E-16	0.0E+00	6.74E-01	2.60E+02	1.31E-16	0.0E+00
19	9.39E-01	2.72E+02	5.65E-17	0.0E+00	9.71E-01	7.86E-01	1.03E-16	0.0E+00	6.08E-01	2.59E+02	3.04E-16	0.0E+00
20	9.47E-01	2.72E+02	1.19E-16	0.0E+00	9.76E-01	7.08E-01	2.63E-16	0.0E+00	5.51E-01	2.58E+02	1.17E-16	0.0E+00
21	9.54E-01	2.72E+02	2.18E-16	0.0E+00	9.80E-01	6.41E-01	1.55E-16	0.0E+00	5.03E-01	2.57E+02	1.16E-16	0.0E+00
22	9.60E-01	2.72E+02	9.02E-17	0.0E+00	9.83E-01	5.83E-01	7.08E-17	0.0E+00	4.61E-01	2.55E+02	4.11E-17	0.0E+00
23	9.65E-01	2.71E+02	7.05E-17	0.0E+00	9.86E-01	5.33E-01	1.70E-16	0.0E+00	4.25E-01	2.54E+02	7.75E-17	0.0E+00
24	9.70E-01	2.71E+02	1.62E-16	0.0E+00	9.88E-01	4.89E-01	2.50E-16	0.0E+00	3.93E-01	2.53E+02	2.71E-16	0.0E+00

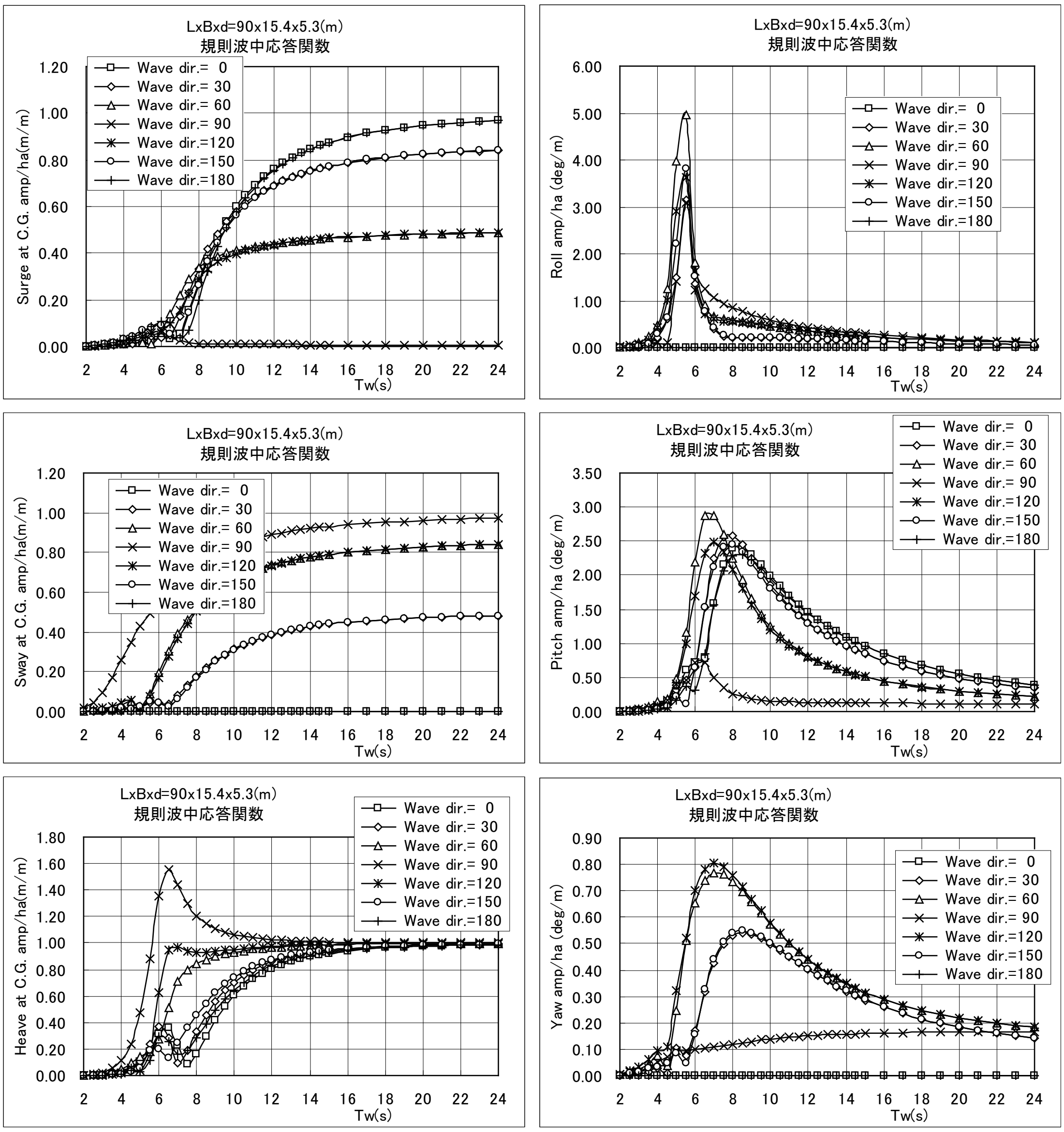

Fig. 3.3-4 Response Amplitude Operator (RAO)

2) Results

Maximum tension and minimum bending radius calculated from the results of the dynamic analysis are shown in Tables 3.3-8 and 3.3-9. Maximum tensile force at the connecting point (CP) of the riser top is lower 1/10 of the allowable tensile force (820kN). Minimum bending radius at the CP and the touch down point (TDP) are larger enough compared with allowable minimum bending radius (2.5m).

Table 3.3-8 Maximum tension & minimum bending radius (Water depth: 200m)

Wave period		sec	6.0	12.0
Top (CP)	Maximum tension	kN	72	73
	Minimum bending radius	m	8.5	14.1
TDP	Maximum tension	kN	15	21
	Minimum bending radius	m	64.8	46.7

Table 3.3-9 Maximum tension & minimum bending radius. (Water depth: 500m)

Wave period		sec	6.0	12.0
Top (CP)	Maximum tension	kN	173	177
	Minimum bending radius	m	12.8	20.0
TDP	Maximum tension	kN	45	59
	Minimum bending radius	m	77.9	48.1

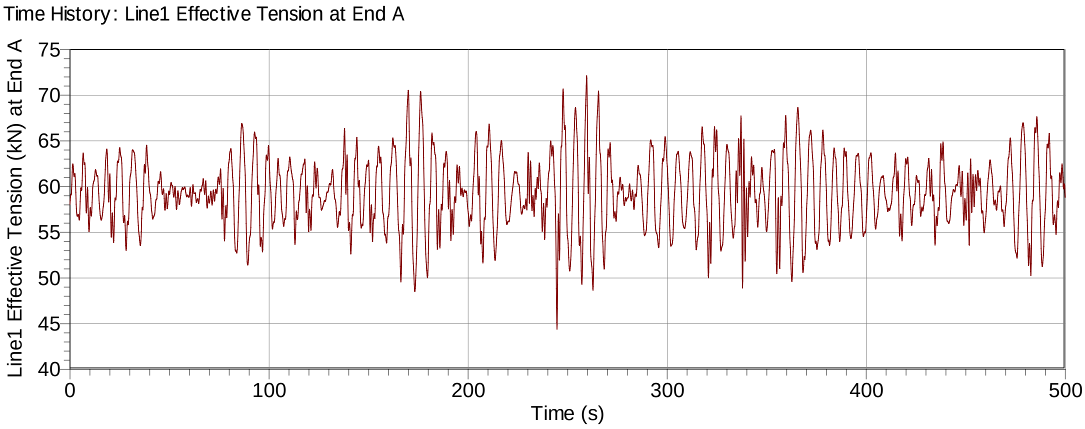

Fig. 3.3-5 Time history of the tension at CP. (W.D: 200m; W.P: 6.0 sec) .

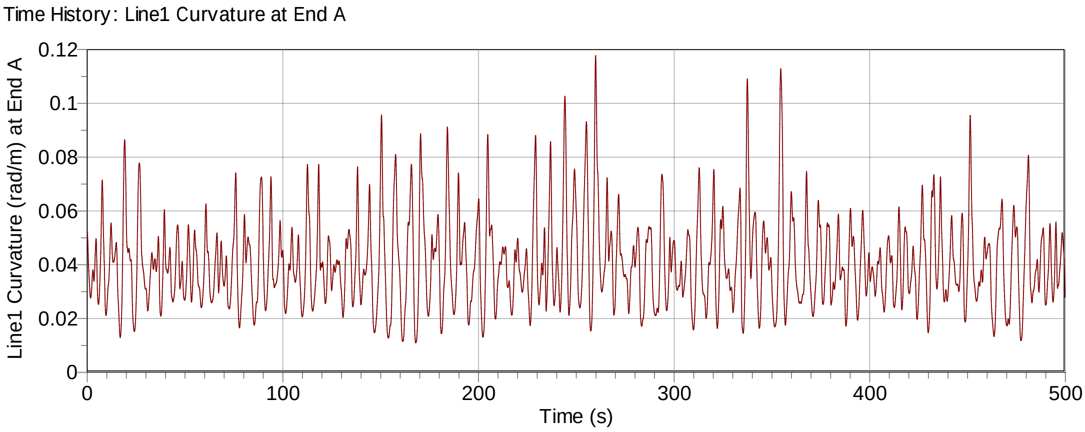

Fig. 3.3-6 Time history of the curvature at CP.
(W.D: 200m; W.P: 6.0 sec).

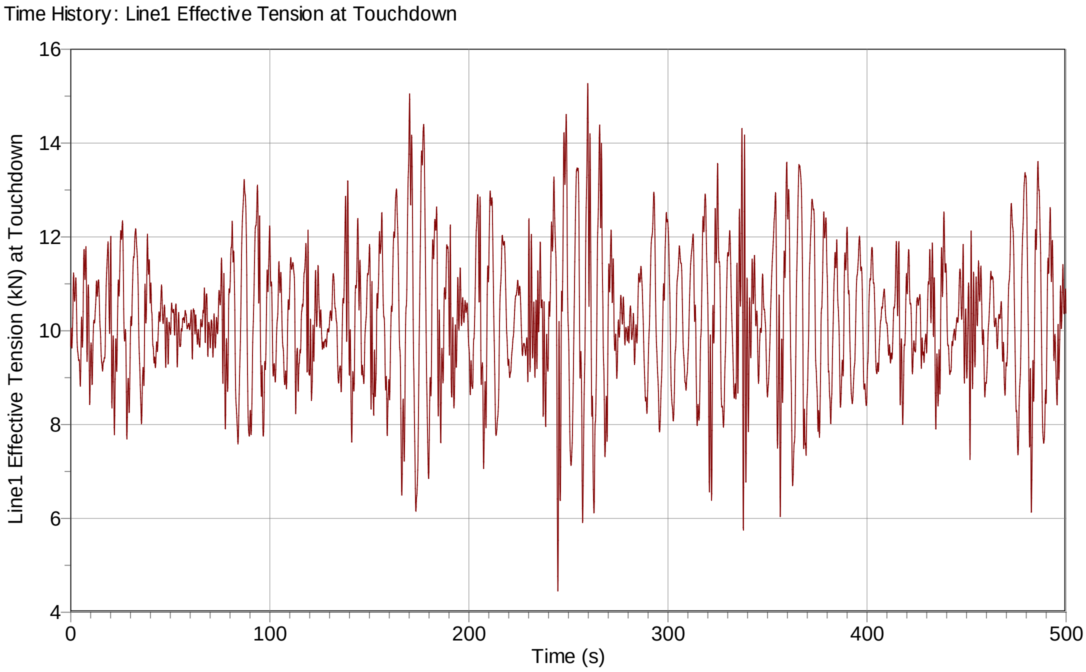

Fig. 3.3-7 Time history of the tension at TDP.
(W.D: 200m; W.P: 0.6 sec)

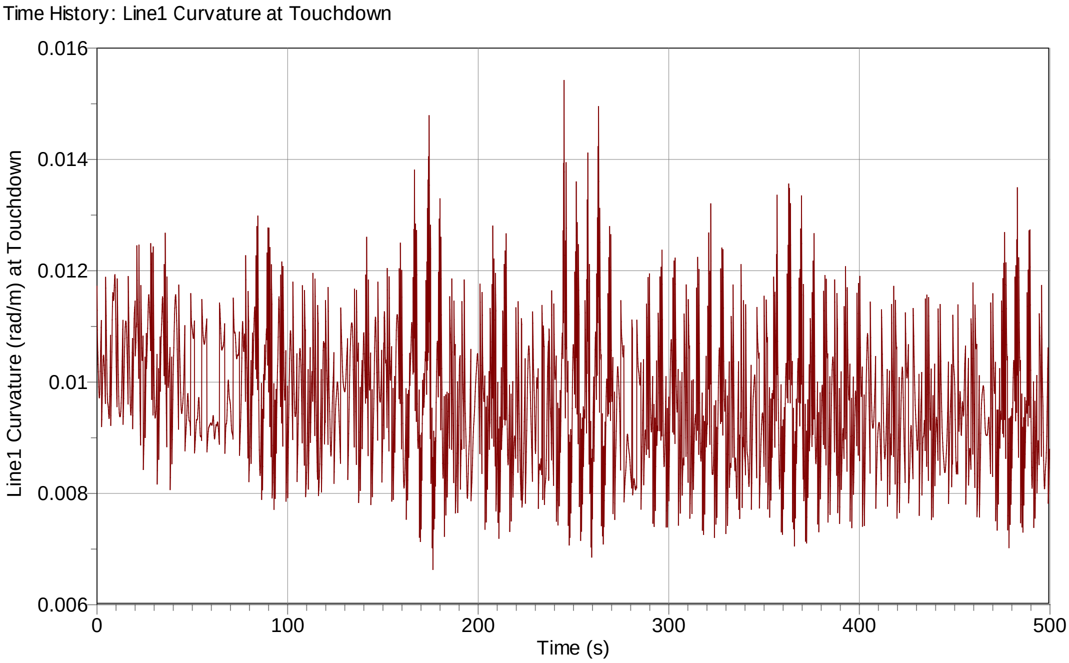

Fig. 3.3-8 Time history of the curvature at TDP.
(W.D: 200m; W.P: 6.0 sec)

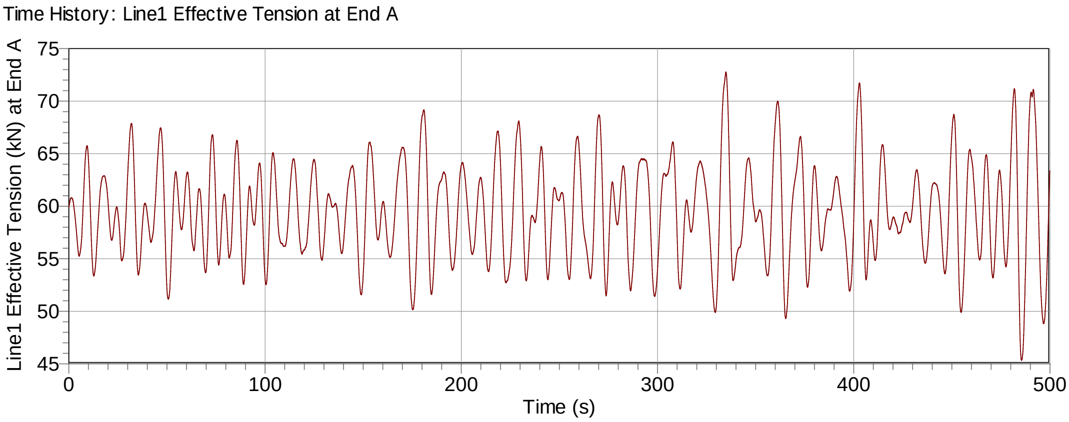

Fig. 3.3-9 Time history of the tension at TDP.
(W.D: 200m; W.P: 12.0 sec)

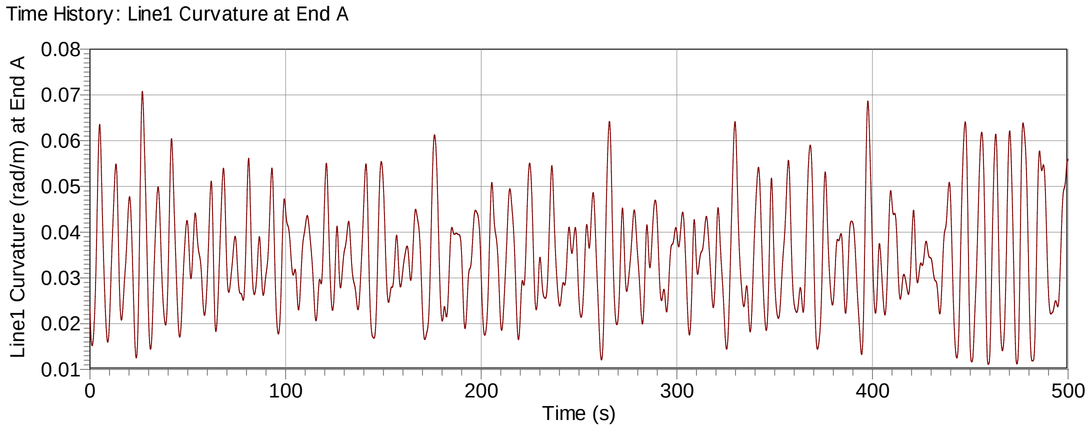

Fig. 3.3-10 Time history of the curvature at TDP.
(W.D: 200m; W.P: 12.0 sec)

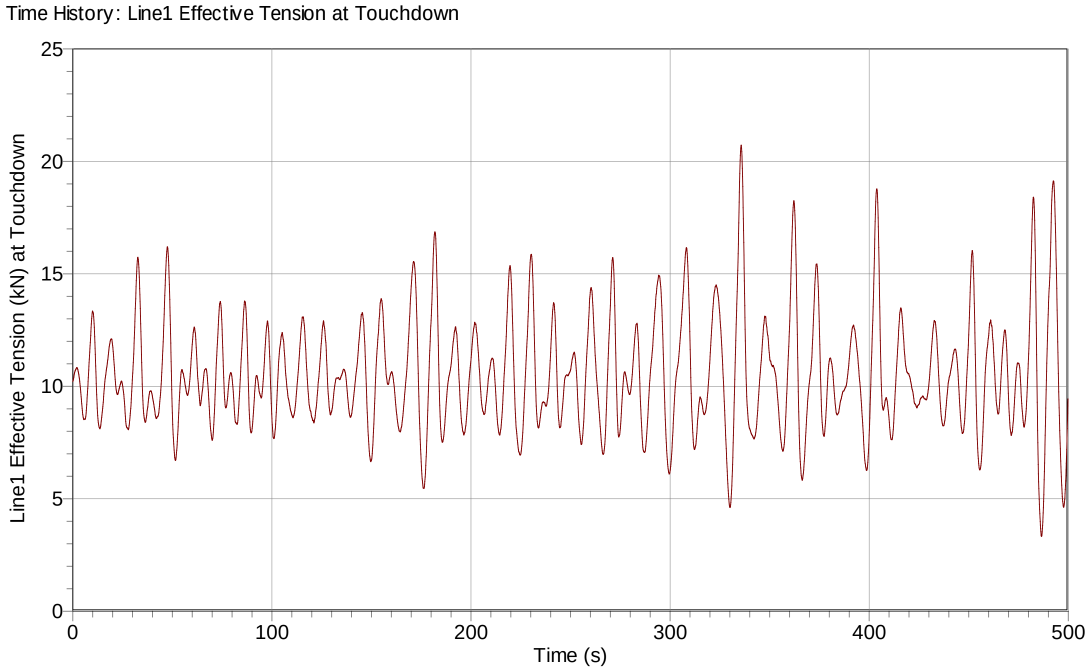

Fig. 3.3-11 Time history of the tension at TDP.
(W.D:200m, W.P:12.0 sec)

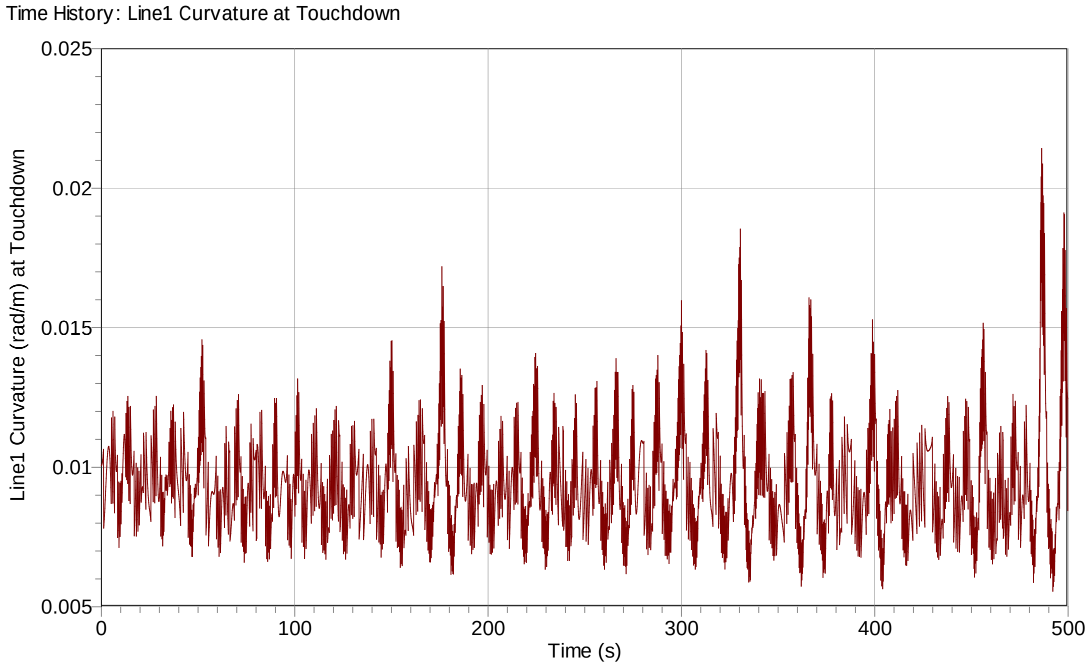

Fig. 3.3-12 Time history of the curvature at TDP.
(W.D: 200m; W.P: 12.0 sec)

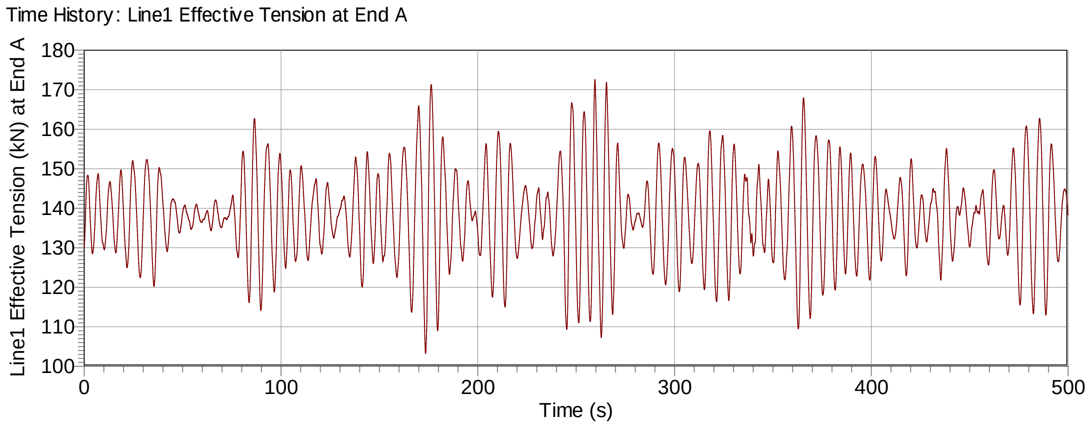

Fig. 3.3-13 Time history of the tension at CP.
(W.D: 500m; W.P: 6.0 sec)

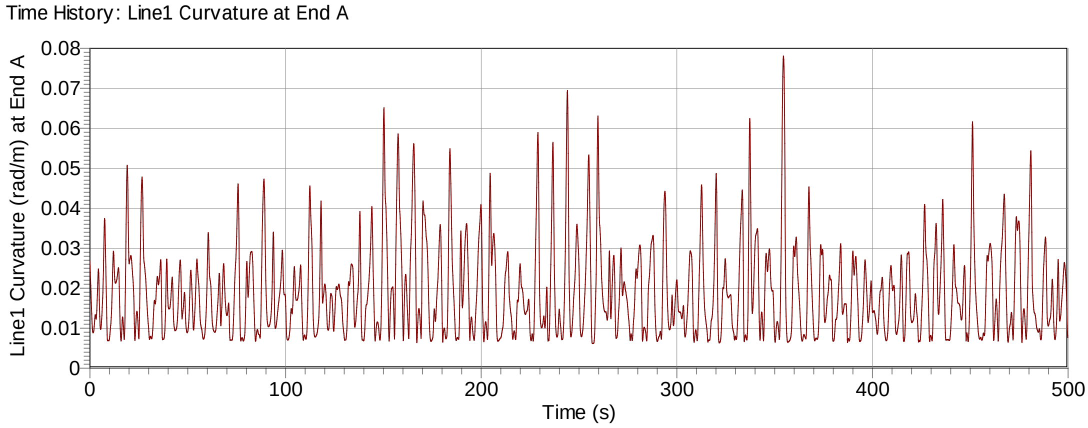

Fig. 3.3-14 Time history of the curvature at CP.
(W.D: 500m; W.P: 6.0 sec)

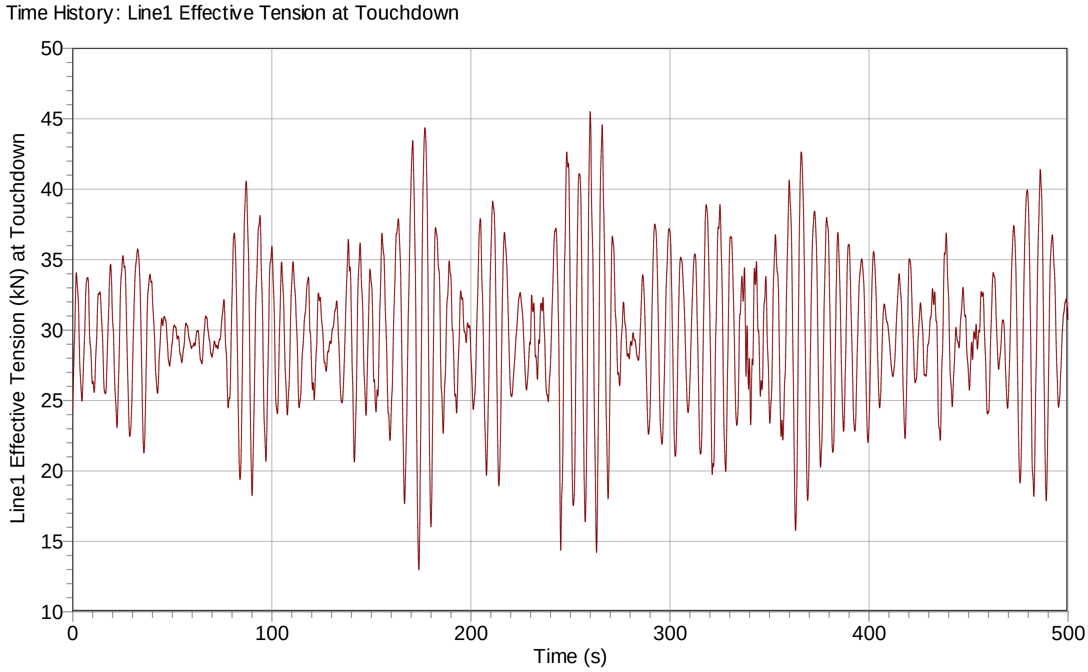

Fig. 3.3-15 Time history of the tension at TDP
(W.D: 500m; W.P :6.0 sec)

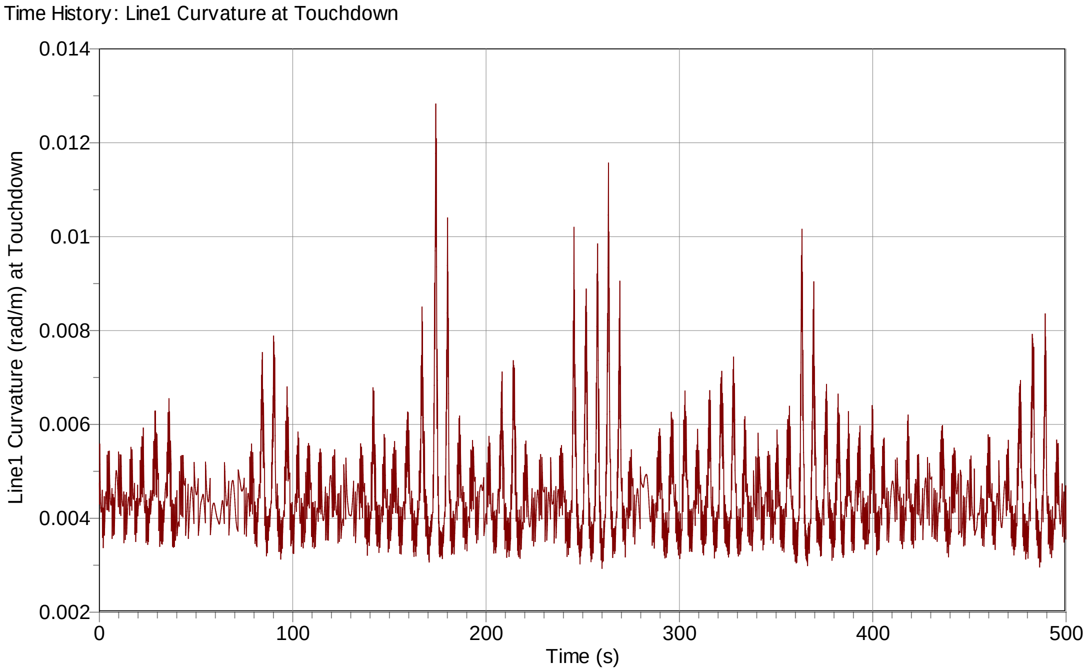

Fig. 3.3-16 Time history of the curvature at TDP.
(W.D:500m, W.P:6.0 sec)

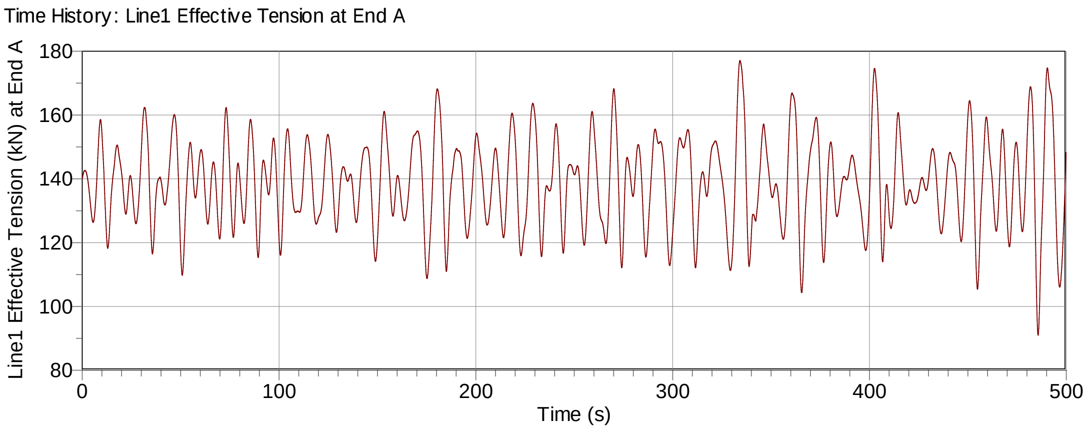

Fig 3.3-17 Time History of Tension at TDP
(W.D:500m, W.P:12.0 sec)

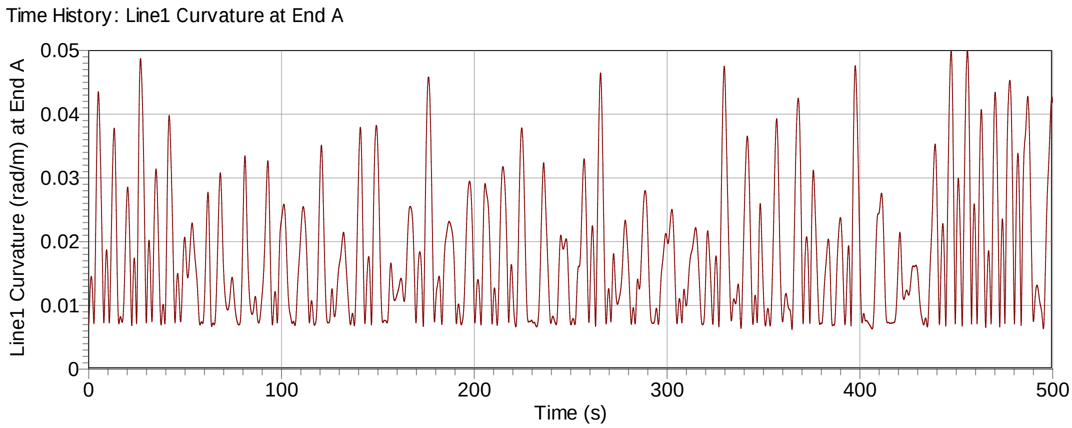

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Fig. 3.3-18 Time history of the curvature at TDP.
(W.D:500m; W.P:12.0 sec)

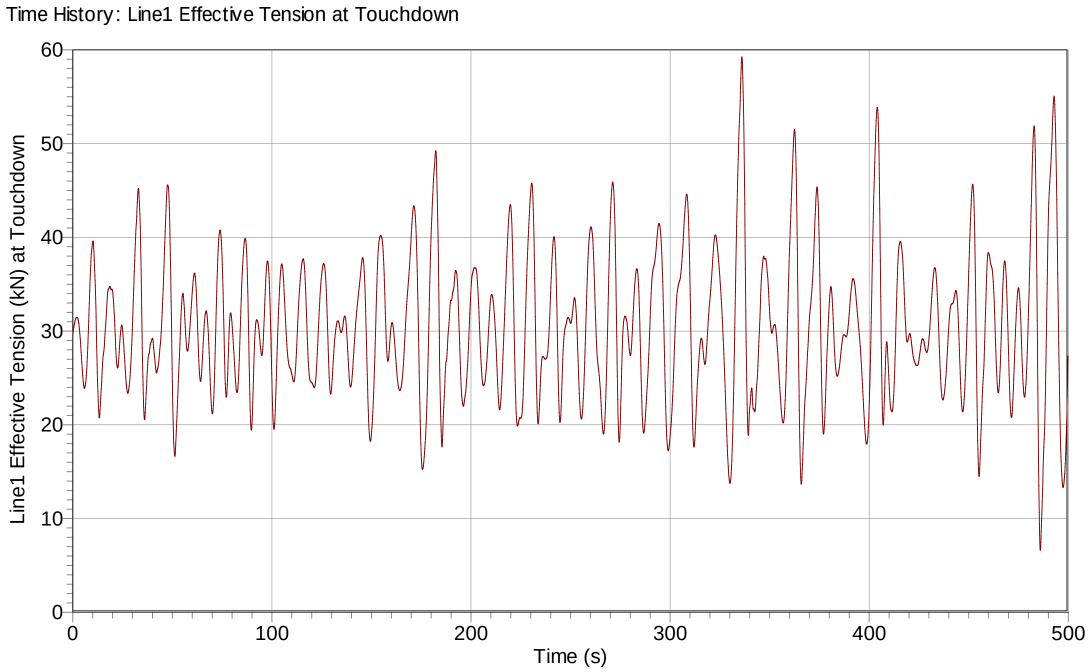


Fig.3.3-19 Time history of the tension at TDP.
(W.D: 500m; W.P: 12.0 sec)

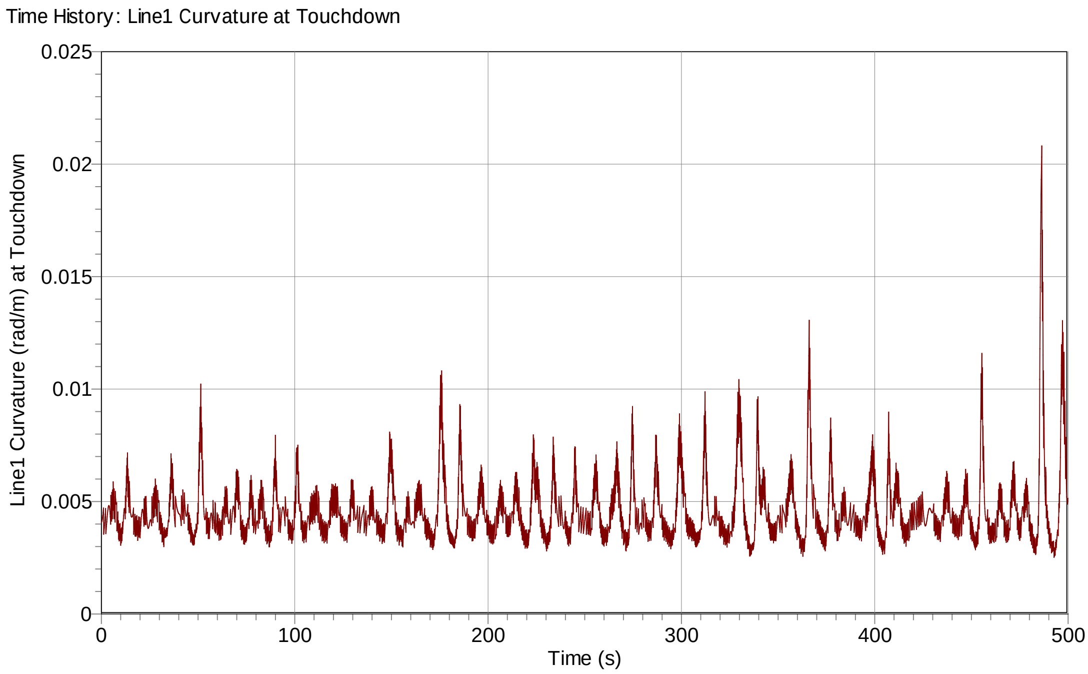


Fig. 3.3-20 Time history of the curvature at TDP.
(W.D: 500m; W.P: 12.0 sec)

3.3.4 Fatigue analysis for flexible riser pipe

1) Assumption

- Water depth: 500m
- Flexible riser pipe configuration: Free hanging
- Specified fatigue stress: Curvature change of pipe at CP
- Wave spectrum: Bretschneider
- Response amplitude operator: Same as dynamic analysis
- Connecting point of riser top: Same as dynamic analysis
- Surface current: 0.75 m/sec (declines by 1/7-th power law)
- Applied software: OrcaFlex Dynamics(Ver. 9.4)
- Wave scatter diagram: See Table 3.3-10

Table 3.3-10 Wave scatter diagram (offshore Miyazaki)

Wave height (m) \ Wave Period (sec)	0～5.0	5.0～8.0	8.0～11.0	11.0～14.0	14.0～17.0	17.0～
2.0～3.0	0 %	3.02%	5.91%	1.29%	0.14%	0 %
1.5～2.0	0.02	6.40	3.64	0.91	0.06	0
1.0～1.5	0.63	15.05	7.50	1.13	0.02	0
0.5～1.0	5.20	31.04	11.33	0.45	0	0
0.0～0.5	0.55	4.26	1.45	0	0	0

※The waves more than 3 m in height are not listed in the table.

・ Fatigue property of the flexible riser pipe

Bending fatigue property (SN-curve) of the flexible riser pipe was derived from the in-house data (OTC6876) of Furukawa Electric Co. Ltd. as follows.

$$\mathrm{Log}(N) = A - B \cdot \mathrm{Log}(\delta k)$$

where N : damaged number

δk : curvature change (1/m)

A : Coefficient from SN curve (4.0)

B : Coefficient from SN curve (1.912)

2) Procedure

Fatigue analysis was carried out by the flow as shown in Fig. 3.3-21.

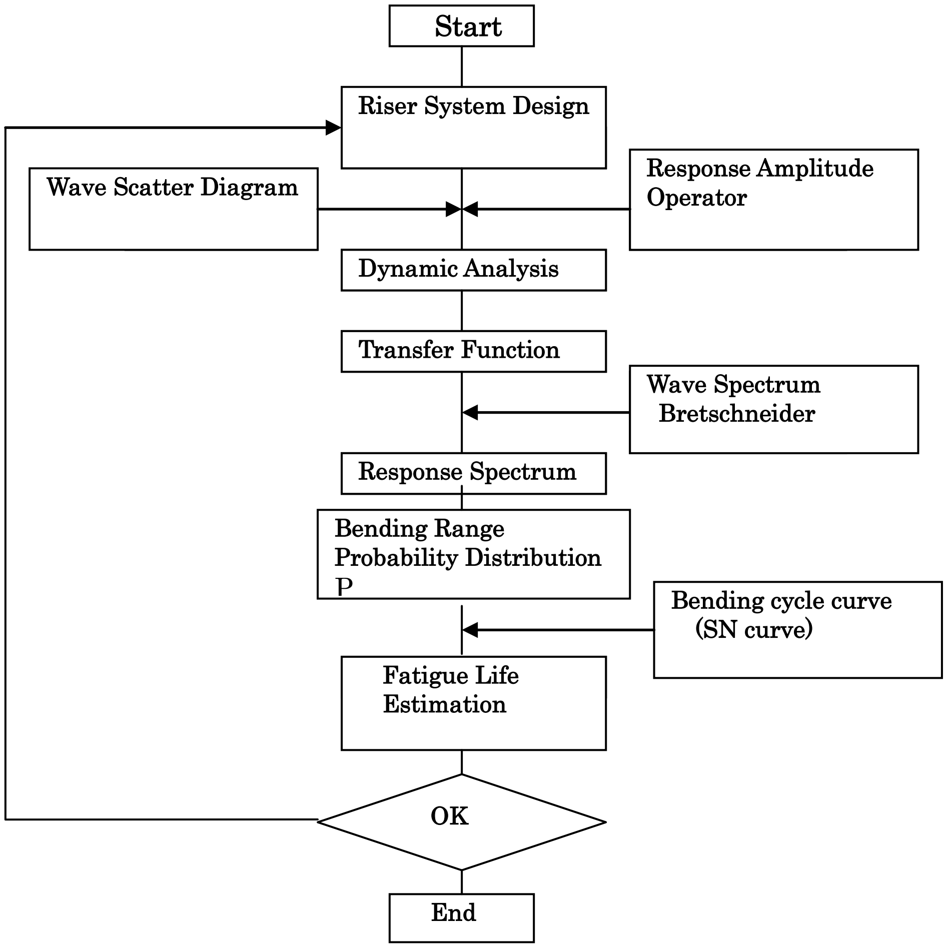


Fig. 3.3-21 Flow diagram of the fatigue analysis.

3) Results

The results of the fatigue analysis are shown in Table 3.3-11. The estimated damaged number was 0.04137 in one year. The fatigue life is estimated from the damaged number $1/\Sigma(n/N)$ of the pipe and the operation rate (*k*) which considered the loss time caused by pick up and lay down work of the riser pipe. When *k* is estimated as 2/3, the fatigue life (*P*) is calculated as follows.

$$P = [1/\Sigma(n/N))]\times 1/k = 1 / 0.0413 \times 3/2 = 36.2 \text{ year}$$

If a bend stiffener is mounted at the riser top for the protection of excessive bending stress, it will reduce fatigue on the riser pipe thus extending the lifetime of the pipe.

Table 3.3-11 Estimated fatigue life

Curvature change (1/m)		Number of occurrences in one year (n)	Breakage number (N)	Damaged number in one year (n/N)
Min	Max			
0.000	0.004	2.07E+06	1.45E+09	0.00143
0.004	0.008	1.55E+06	1.77E+08	0.00876
0.008	0.012	6.20E+05	6.67E+07	0.00930
0.012	0.016	2.66E+05	3.50E+07	0.00760
0.016	0.020	1.21E+05	2.17E+07	0.00558
0.020	0.024	5.67E+04	1.48E+07	0.00383
0.024	0.028	2.63E+04	1.07E+07	0.00246
0.028	0.032	1.14E+04	8.16E+06	0.00140
0.032	0.036	4.50E+03	6.42E+06	0.00070
0.036	0.040	1.60E+03	5.19E+06	0.00031
0.040	∞	6.80E+02	4.71E+06	0.00000
$\Sigma(n/N)$				0.04137

3.3.5 Concept of flexible riser pipe pick-up system

1) Submerged Loading System (SLS) description

The entire system is shown in the following Fig.3.3-1 and Table 3.3-7

- The pickup wire, messenger line and pickup float are used for the riser pick-up.
- Each wire is wound up to the DPS-controlled vessel so that the flexible riser pipe is collected and connected.
- The bend stiffener for the bend buffer is installed at the top part of the flexible riser pipe.
- The configuration of the flexible riser pipe is assumed to be free cantenary.
- The pipe protector is installed around the touch down point (TDP) of the pipe that moves on the seabed with the excursion of the DPS-controlled vessel.
- The pipe protector aims at the wear-out prevention on the outer sheath of the flexible riser pipe.
- The anchor is installed from the touch down point of the flexible riser pipe to the wellhead equipment.
- The anchor counterbalances the tension of the flexible riser pipe and

protects the wellhead equipment.

- The bend restrictor is installed at the joint to the wellhead equipment for the purpose that the extreme bending is corrected.
- The umbilical cable is bundled as an annex in the flexible riser pipe.
- The umbilical cable is used to control the wellhead equipment and monitor the downhole data.
- Moreover, the loading inside of CO_2 is used to charge with battery in the monitor buoy.
- The positioning of the DPS-controlled vessel and the seafloor-lying flexible riser pipe is conducted by setting up a transponder on seabed.

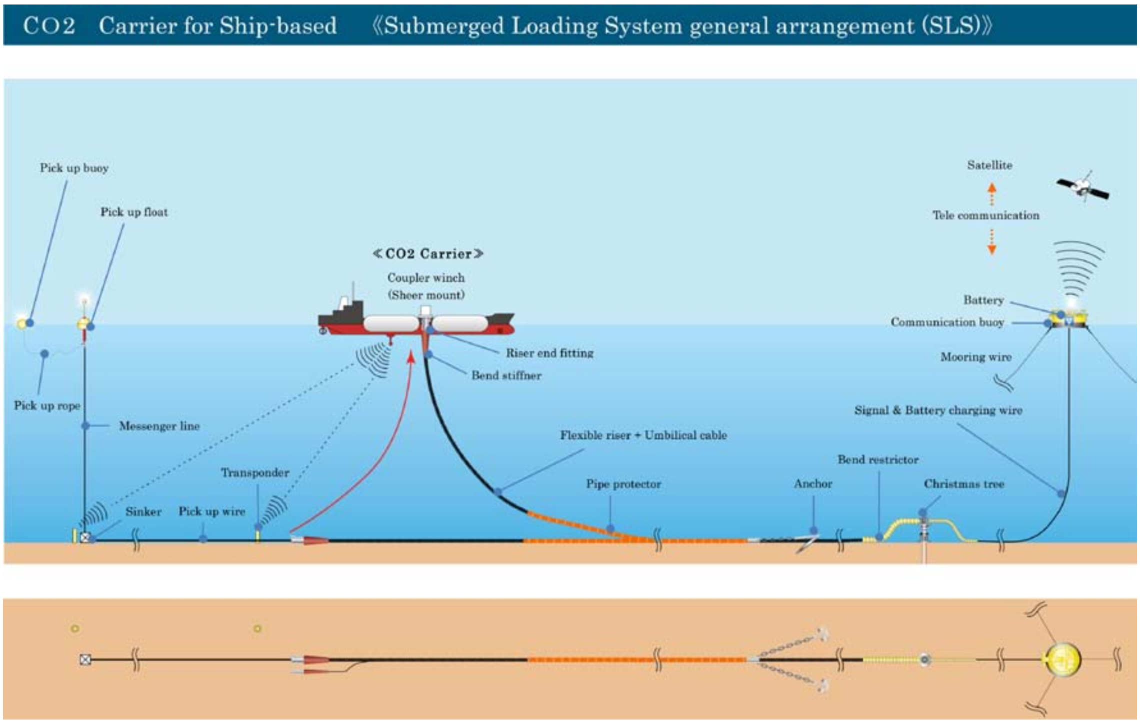
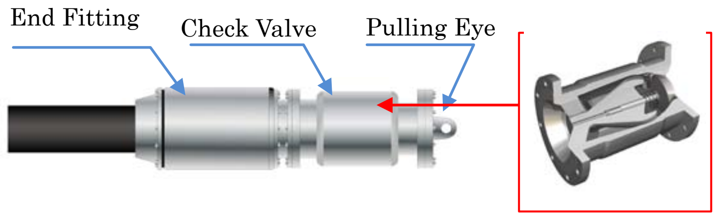
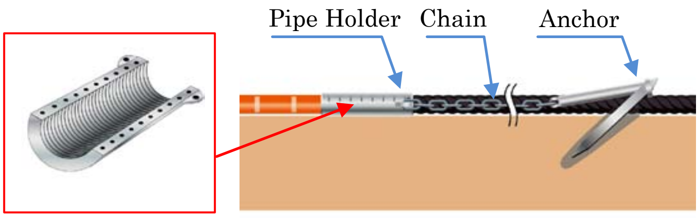
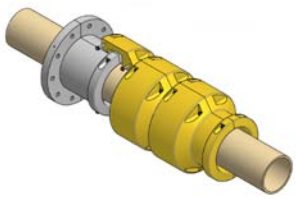
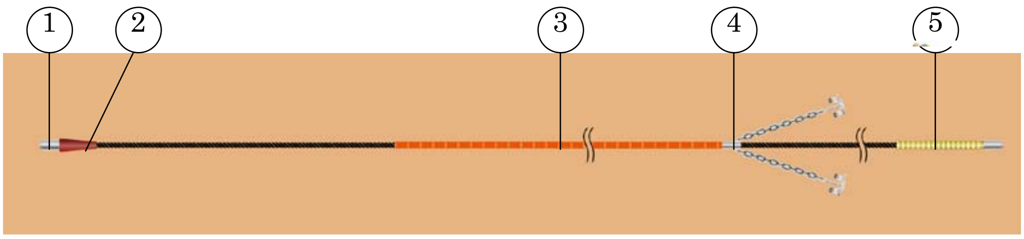


Fig. 3.3-22 General arrangement of the submerged loading system.

Table 3.3-12. Flexible riser pipe (components).

No.	Name	Description
1	End Fitting (EF)	
2	Bend stiffener (BS)	
3	Pipe Protector (PP)	
4	Anchor System	
5	Bend Restrictor (BR)	

Parts Arrangement



3.4 Pickup buoy systems

3.4.1 Socket buoy systems

Figure 3.4-1 shows a socket buoy used to moor a ship offshore. Although this method is efficient in shallow seas with calm wave conditions, it has the following disadvantages:

- difficulties in ship handling when approaching and connecting to the buoy in rough seas;
- structurally-complex buoy attachment;
- possible damage to the buoy in the event of a collision with the ship; and
- the flow line pipe connected to the socket buoy, always has to stay at the sea surface even in bad weather and rough seas.

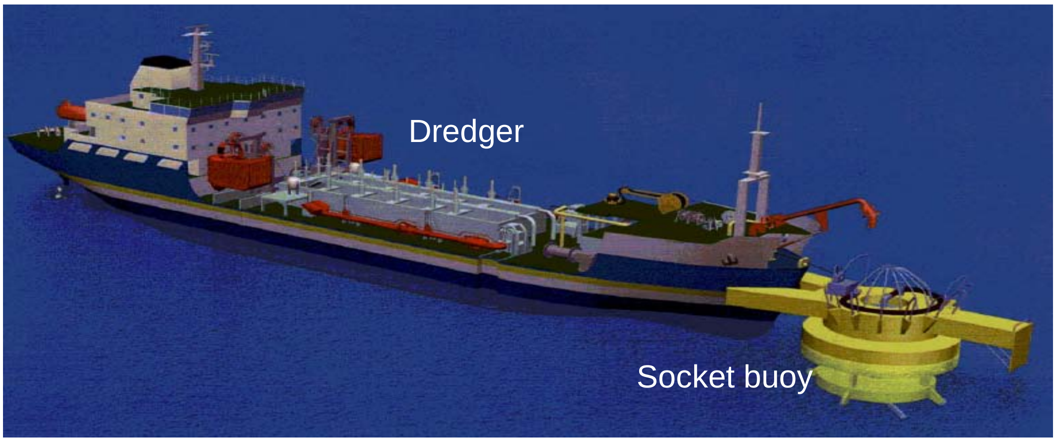


Fig. 3.4-1 Conceptual drawing of a floating socket buoy: connected to a dredger.

3.4.2 Pickup buoy systems

This method is much simpler than the socket buoy system. The flexible riser pipe, used as a riser flow line to carry oil or gas from the seafloor wellhead, will remain on the seabed and be connected to the CO_2 carrier ship when it approaches the ocean site. The entire pickup buoy system is shown in Fig. 3.4-2.

This system has the following advantages over the socket buoy:

- requires no buoy structure for ship mooring;
- being easy in ship handling compared with the socket buoy; and
- the flexible riser pipe can stay on the seabed in the rough seas.

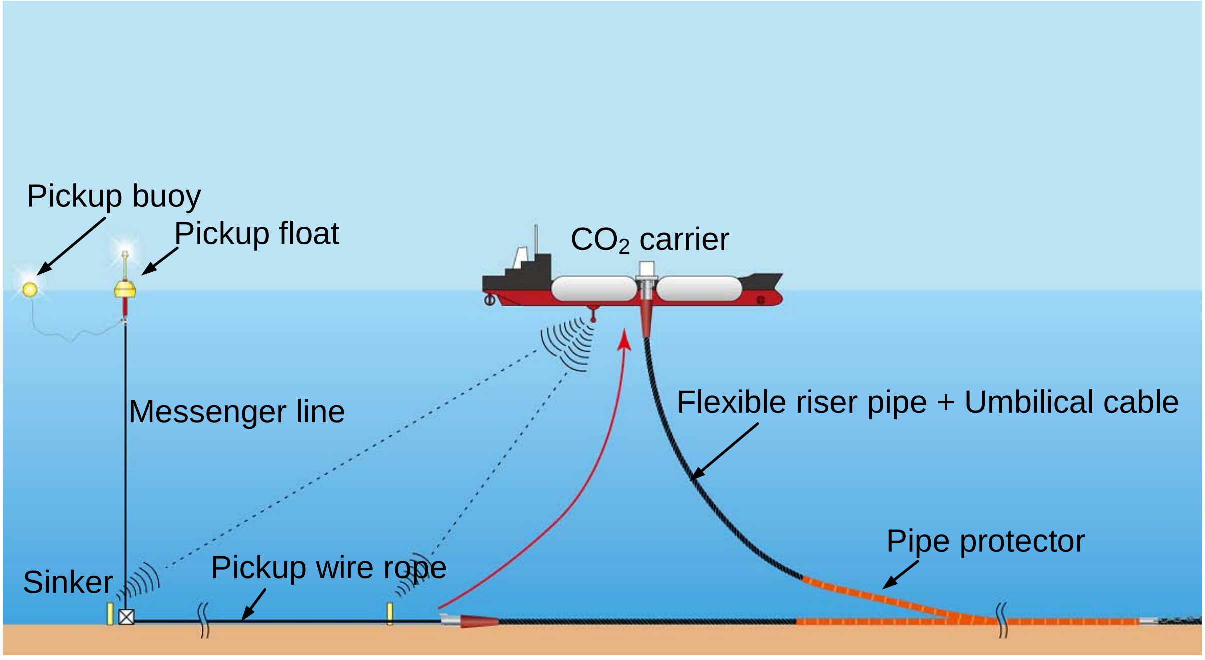


Fig. 3.4-2 Schematic drawing showing the procedure of connecting the flexible riser pipe to the CO_2 carrier

3.4.3 Flexible riser pipe pickup operation

1) Conditions of the flexible riser pipe pickup operation

The design conditions for the flexible riser pipe pickup operation are listed in Table 3.4-1 and can be summarized as follows:

- the buoy pickup operation can be carried out in conditions with the significant wave height ($H_{1/3}$) less than 2.5 - 3.0 m according to the interview survey to ship navigation operators,
- the pickup buoy and float must be stable in heavy weather conditions and have no kinetic influence on the flexible pipe on the seabed,
- the specification of the pickup wire rope is defined based on the operating conditions listed in Table 3.4-1,
- the specifications of the messenger line, sinker, and pickup float are defined based on the storm conditions listed in Table 3.4-1.

Table 3.4-1. Design conditions of the flexible riser pipe pickup operation.

Design criteria	Pickup operation	Storm condition
Sea water depth	500 m	
Significant wave height ($H_{1/3}$)	3 m	12 m
Significant wave period	17 sec	15 sec
Wind speed（10 min. mean)	15 m/sec	50 m/sec
Tidal current（at 100 m depth)	1.5 knot	1.5 knot
Safety factor of lifting appliance	6	
Flexible riser pipe weight in water	20 kg/m	

2) Pickup wire rope

The design requirements of the pickup wire rope are shown in Table 3.4-2.

Table 3.4-2. Design requirements of the pickup wire rope.

Load	127 kN (= 500 x 1.1 x 20 +2 = 13 t = 127 kN)	Flexible pipe end fitting: 2 tons
Wire rope	φ32 IWRC 6xP-WS(31) Galv.	
Breaking load	792 kN	Safety factor: 6.2
Specific weight	4.76 kg/m (in air) 4.14 kg/m (in sea water)	
Wire rope length	750 m	Sea water depth x 1.5

3) Messenger line

The messenger line needs to have enough mechanical strength to draw the sinker and the pickup wire rope up to the CO_2 carrier (see Fig. 3.4-2). The design requirements of the messenger line are shown in Table 3.4-3.

Table 3.4-3. Requirements for messenger line.

Load	32.3 kN (= 500 x 1.1 x 4.14 +1 = 3.3 t = 32.3 kN)	sinker: 1 ton
Wire rope selected	φ18 IWRC 6xP-WS(31) Galv.	
Breaking load	251 kN	Safety factor: 7.8
Specific weight	1.51 kg/m (in air) 1.31 kg/m (in sea water)	
Wire length	550 m	Sea water depth x 1.1

4) Pickup float

The pickup float needs 7 kN buoyancy to sustain the messenger weight in water. The design requirement of the pickup float is shown in Table 3.4-4. The pickup float and the pickup buoy connection is schematically shown in Fig. 3.4-3.

Table 3.4-4. Example of the coupling valve connecting a pipe to a dredger for a landfill operation: a pipe diameter is 800 mm in this picture.

Required buoyancy	abt. 7 kN (= 500m x 1.1 x 1.31kg/m x 9.8)
Sinker weight	1 ton
On-board equipment	Buoy light, Rader reflector

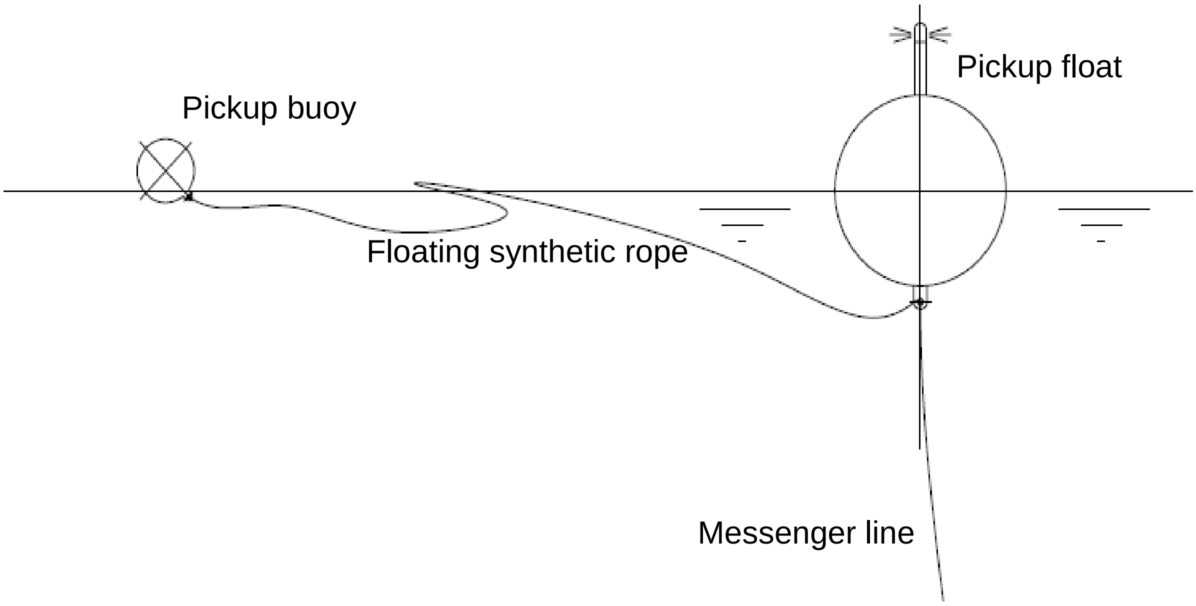


Fig. 3.4-3 Schematic of the pickup float and the pickup buoy connection.

5) Shipboard equipment for the flexible riser pipe pickup operation

The CO_2 carrier needs to be equipped with the following items for the riser pickup operation;

- a coupling valve to connect the flexible riser pipe to the ship;
- a crane to hoist the float onto the ship;
- winches to roll up the messenger line and the pickup wire rope; and
- an A-Frame for deployment and recovery of the float and pickup wire.

Figure 3.4-4 shows an example of the coupling valve connecting a pipe to a dredger for a landfill operation. The equipment layout on board the ship for the riser pickup operation is shown schematically in Fig. 3.4-5.

Fig. 3.4-4 Coupling valve connecting a pipe to a ship for a landfill operation: a pipe diameter is 800 mm

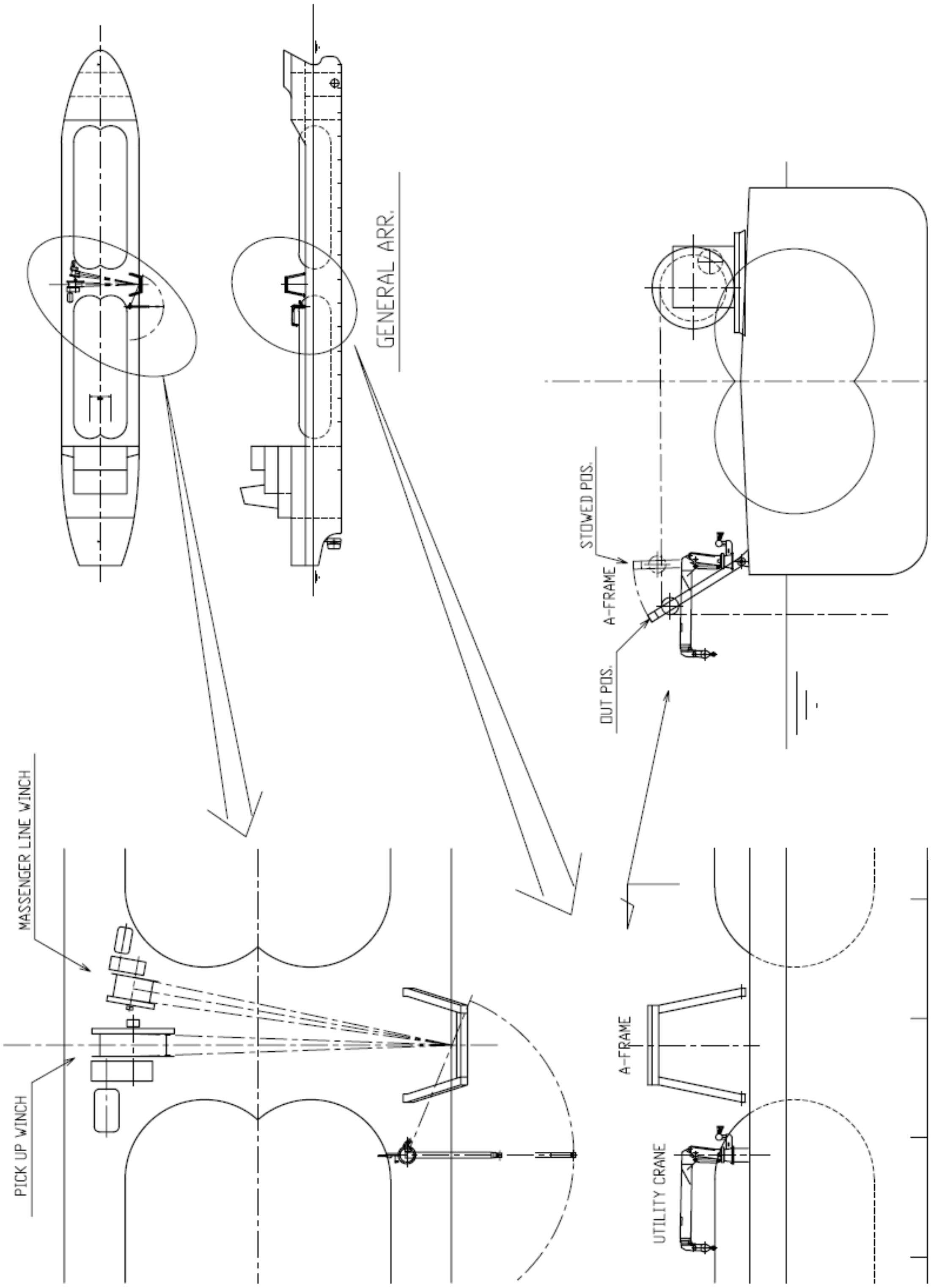


Fig. 3.4-5 Equipment layouts on the shipboard for the riser pickup

6) Communication buoy systems

For monitoring purpose of the storage operation, the real-time measurement data of the downhole pressure and temperature of the injection wells may be required by the regulator. A stand-alone communication buoy system for transmitting the relevant data via satellites is studied. It could be dependent on the details of wellhead equipment or necessary monitoring items in the storage reservoir, which are out of scope of the study. Hence, the study is the preliminary one and the results are described as Attachment D.

3.4.4 Mooring design of the pickup float

1) Design basis

Components of the pickup buoy systems are shown in Fig. 3.4-6. The pickup buoy is picked up followed by the pickup float connecting to the flexible pipe through the messenger line and the pickup wire rope.

A sinker is placed on the seabed and connecting to the messenger line and the pickup wire rope as shown in Fig. 3.4-6. The pickup float motion caused by waves does not directly affect the flexible riser pipe by these lines, thus stabilize the flexible riser pipe.

A light is attached to the pickup float for the CO_2 carrier safety approach.

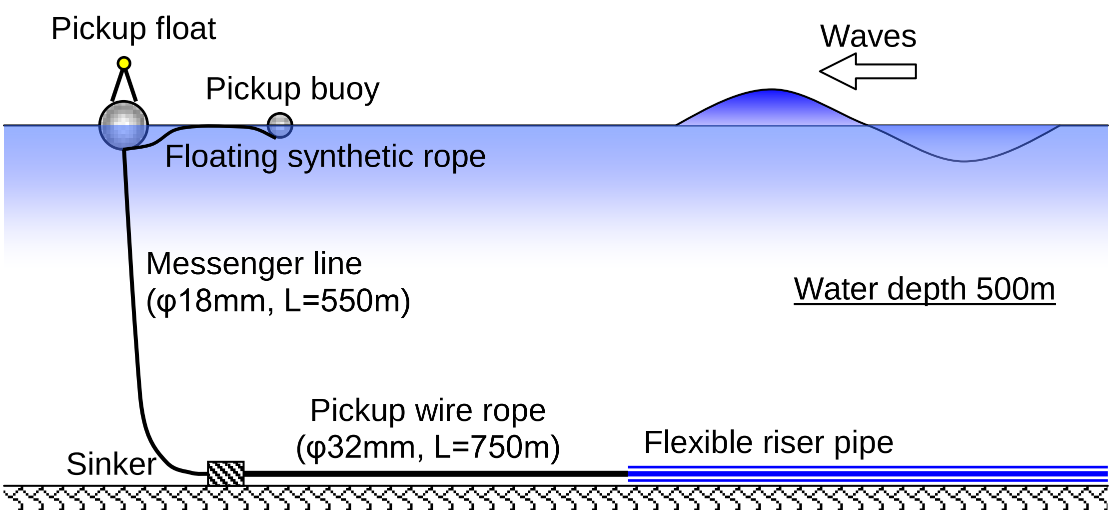


Fig. 3.4-6 Components of the pickup buoy systems.

2) Structure of the pickup float

The structure of the pickup float is schematically shown in Fig. 3.4-7. The pickup float is made of fiber-reinforced plastic (FRP) filled with urethane foam. A heavy bob is placed at the inside bottom to avoid the float upside down by the wave motion. Two types of pickup float with different diameter, shown in Table 3.4-5, are comparatively designed.

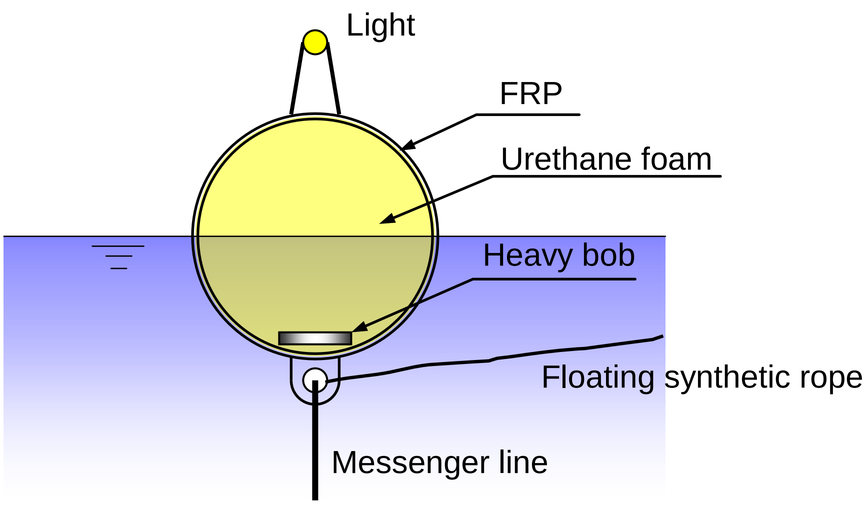


Fig. 3.4-7 Schematic of the pickup float structure.

Table 3.4-5. Dimensional data of the pickup float for structural design.

Pickup float item		Case A	Case B	Remarks
Diameter	m	2.80	1.80	
Surface area	m^2	24.63	10.18	
Cubic volume	m^3	11.49	3.05	
Displacement	ton	5.89	1.56	Hemisphere submerged
Water-plane area	m^2	6.16	2.54	
FRP weight	ton	0.74	0.31	Board thickness:20mm Specific weight:1.5
Bloating agent weight	ton	0.57	0.15	Urethane foam Specific weight:0.05
Messenger line weight	ton	0.66	0.66	Unit weight:1.31kg/m
Heavy bob weight	ton	3.92	0.45	

3) Design wave conditions

Design waves are set in two conditions; a) marginal operating condition and b) 100-year storm wave condition. The design conditions are listed in Table 3.4-6.

Table 3.4-6. Design conditions of the pickup float mooring.

Water depth	500m	
Waves	Marginal operating condition	Significant wave height $H_{1/3}$=3.0m
		Significant wave period $T_{1/3}$=17.0s
	100-year storm	Significant wave height $H_{1/3}$=12.0m
		Significant wave period $T_{1/3}$=15.0s

4) Computational technique

Hydrodynamic forces are calculated by the three dimensional singularity distribution method based on the potential theory, i.e., the added mass, the damping, and the wave exciting forces acting on the pickup float. The mooring properties of the float-messenger line and the sinker-connected lines are calculated by the catenary theory, and these properties are modeled as the nonlinear restoring forces. The float motion and the tensions of the line and rope are numerically calculated by solving the equations of motion in the time domain.

The finite element modeling (FEM) for the structural analysis of the pickup float is schematically shown in Fig. 3.4-8.

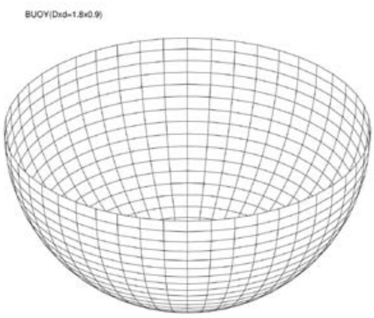


Fig. 3.4-8 Schematic of the pickup float FEM analysis.

5) Computational results

Computational results of the pickup float mooring analyses for the float diameters 2.80m and 1.80m in the case of the marginal operating condition and the 100-year storm wave condition are shown in Fig. 3.4-9 to Fig. 3.4-12, respectively.

The calculated maximum tension of the messenger line (φ18mm) in the case of the float diameter 2.8m and the 100-year storm wave condition is more than 46kN (see Tension in Fig. 3.4-10). This value does not satisfy 42kN which is the value of the breaking strength of φ18mm wire (251kN) under the design safety factor 6, albeit the maximum tension of φ18mm messenger line of the 1.8m diameter float satisfies 42kN in both wave conditions.

ϕ=2.8m, $T_{1/3}$=17.0(s), $H_{1/3}$=3.0(m)

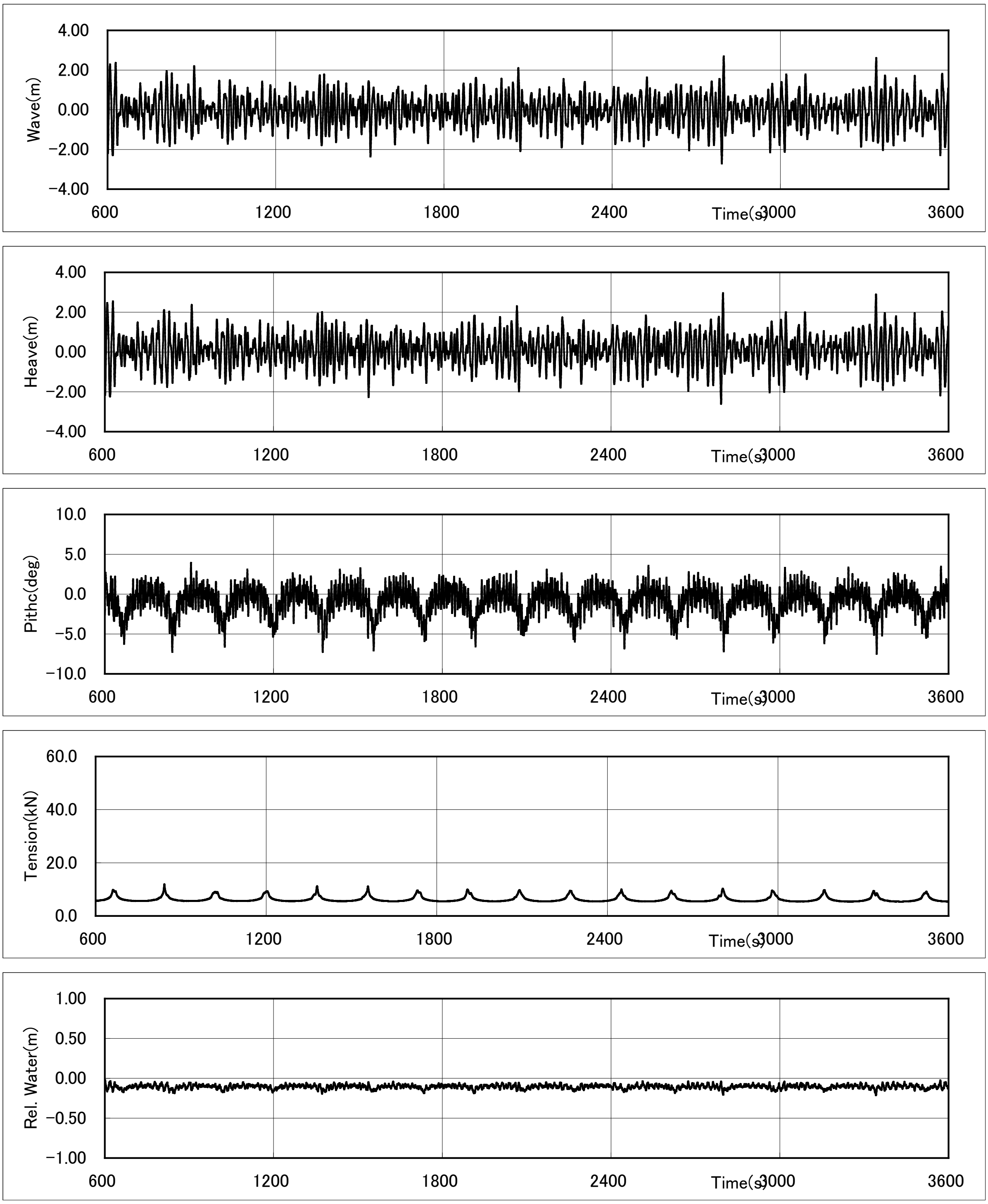


Fig. 3.4-9 Computational results of the pickup float mooring analysis in the time period starting from 600 to 3,600 seconds in the case of the pickup float diameter 2.80m and the marginal operating wave condition (the significant wave height $H_{1/3}$=3.0m and the significant wave period $T_{1/3}$=17.0sec.); from above, wave(m), heave(m), pitch(deg), tension(kN), and relative water(m, surface wave motion relative to the float hemisphere water level).

ϕ=2.8m, $T_{1/3}$=15.0(s), $H_{1/3}$=12.0(m)

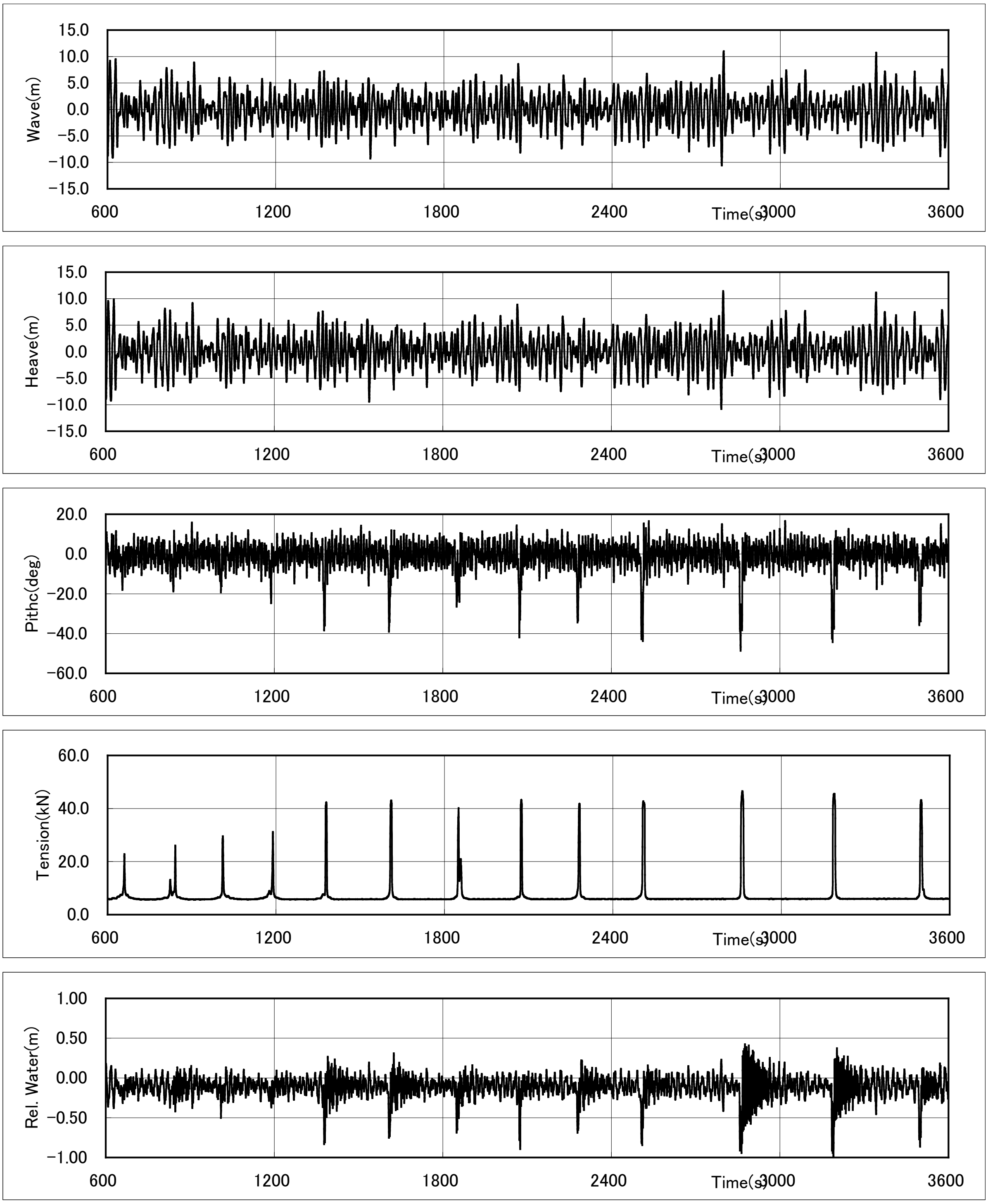


Fig. 3.4-10 Computational results of the pickup float mooring analysis in the time period starting from 600 to 3,600 seconds in the case of the pickup float diameter 2.80 m and the 100-year storm wave condition (the significant wave height $H_{1/3}$=12.0m and the significant wave period $T_{1/3}$=15.0sec.); from above, wave(m), heave(m), pitch(deg), tension(kN), and relative water(m, surface wave motion relative to the float hemisphere water level).

ϕ=1.8m, $T_{1/3}$=17.0(s), $H_{1/3}$=3.0(m)

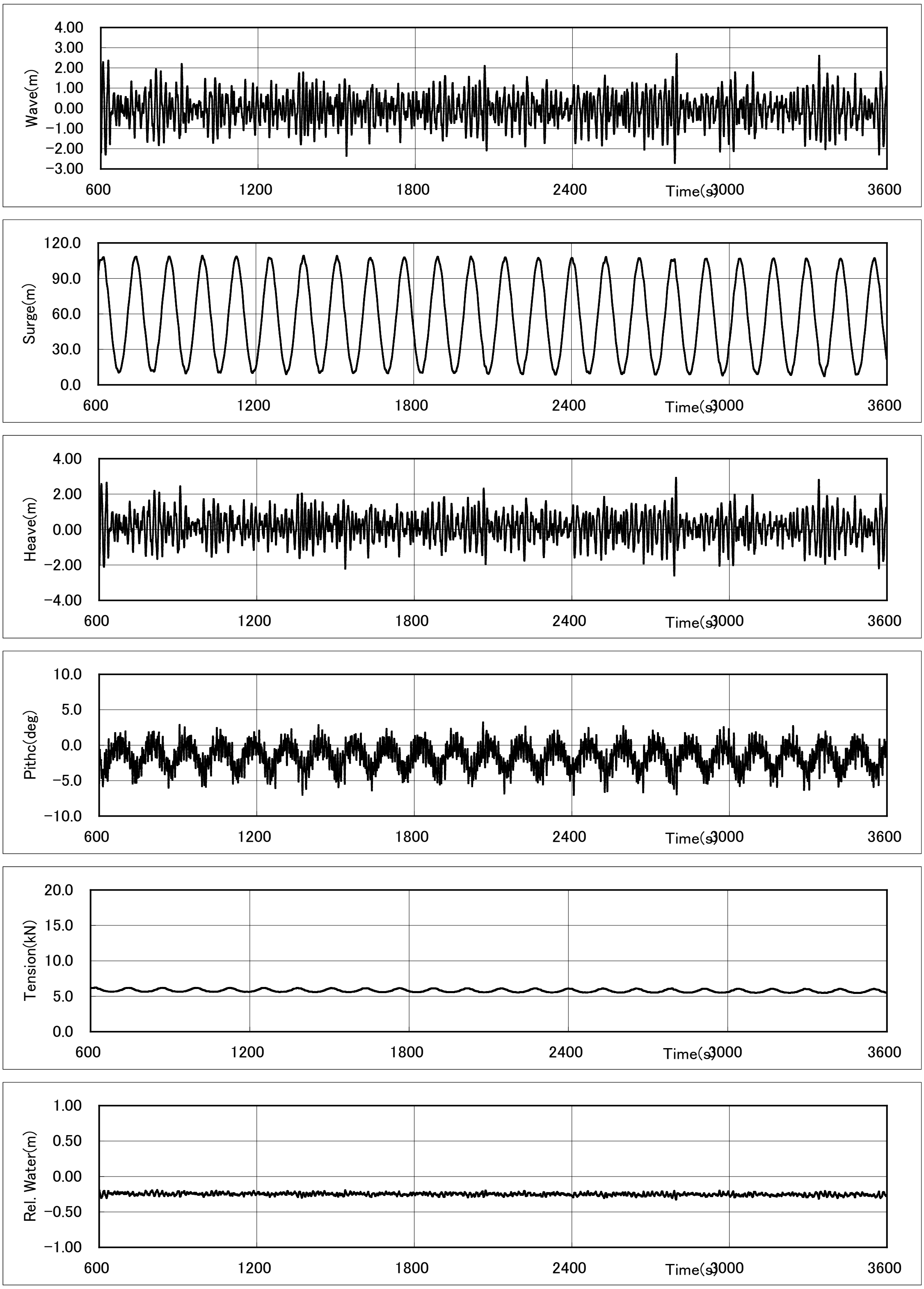


Fig. 3.4-11 Computational results of the pickup float mooring analysis in the time period starting from 600 to 3,600 seconds in the case of the pickup float diameter 1.80m and the marginal operating wave condition (the significant wave height $H_{1/3}$=3.0m and the significant wave period $T_{1/3}$=17.0sec.); from above, wave(m), surge(m), heave(m), pitch(deg), tension(kN), and relative water(m, surface wave motion relative to the float hemisphere water level).

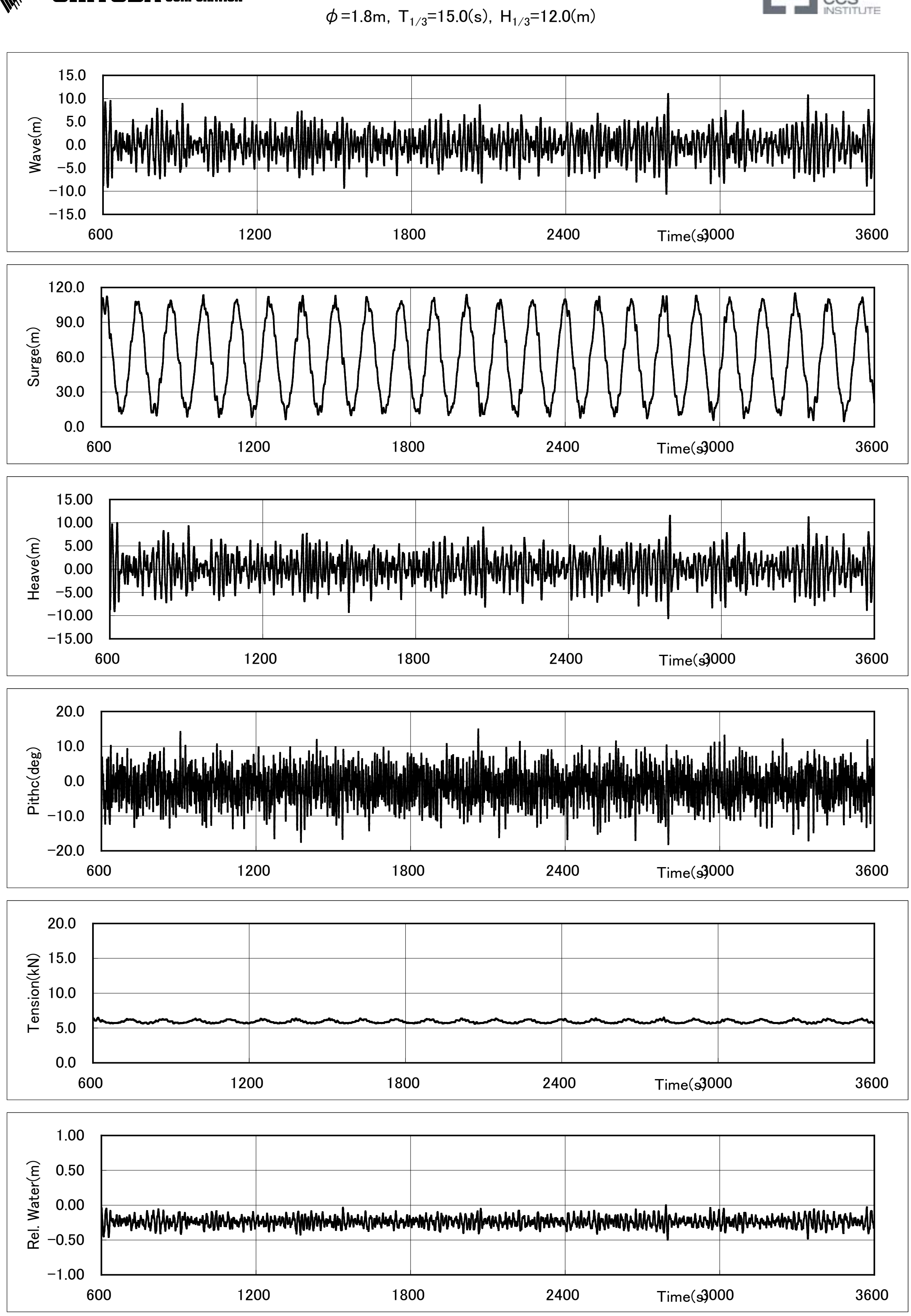
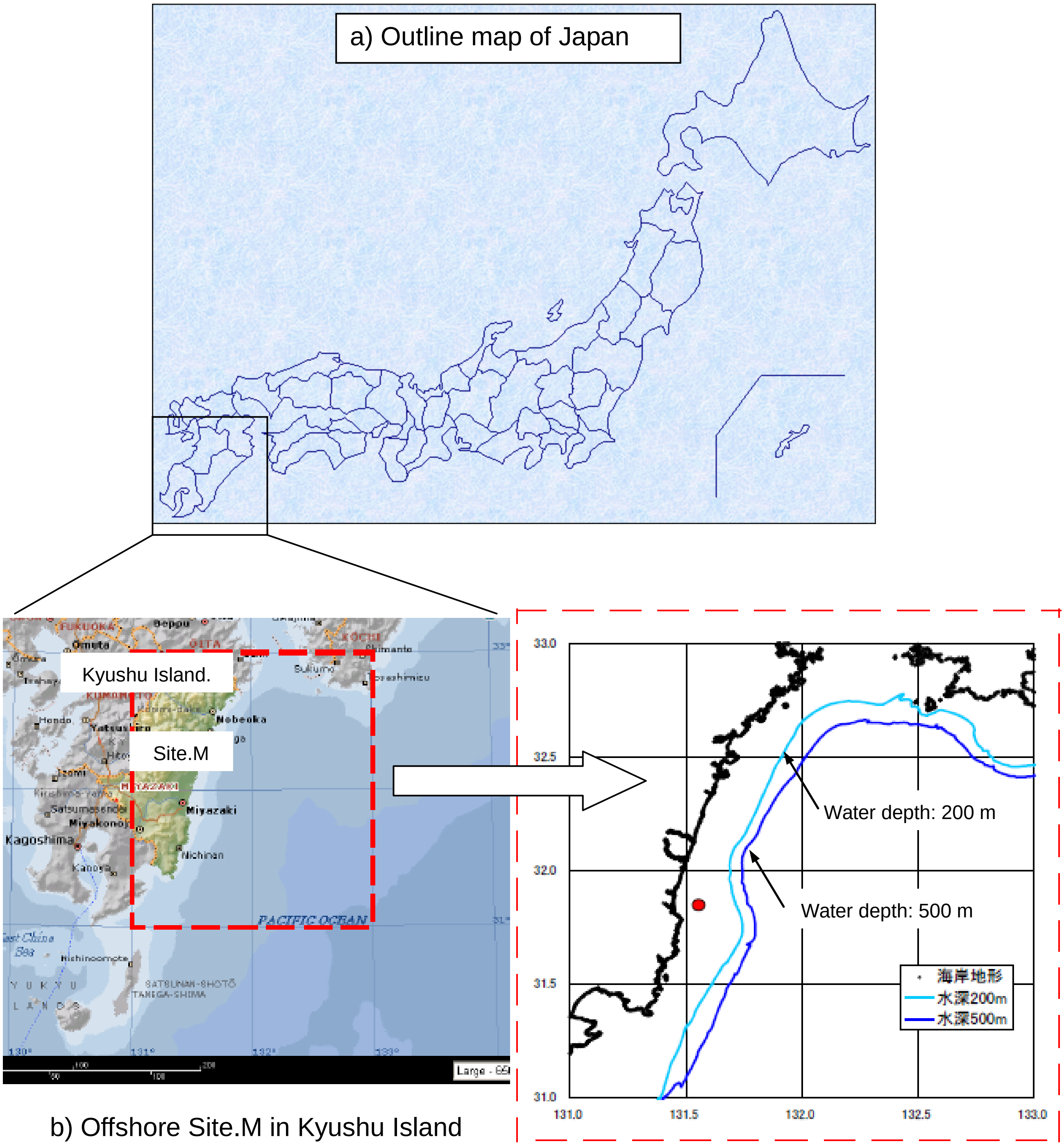


Fig. 3.4-12 Computational results of the pickup float mooring analysis in the time period starting from 600 to 3,600 seconds in the case of the pickup float diameter 1.80m and the 100-year storm wave condition (the significant wave height $H_{1/3}$=12.0m and the significant wave period $T_{1/3}$=15.0sec.); from above, wave(m), surge(m), heave(m), pitch(deg), tension(kN), and relative water(m, surface wave motion relative to the float hemisphere water level).

3.5 Offshore operation

3.5.1 Sea conditions

Offshore Site.M was selected to collect the oceanographic data in this study. Refer to Figs. 3.5.1-1 to 3.5.1-4 for the oceanographic conditions.

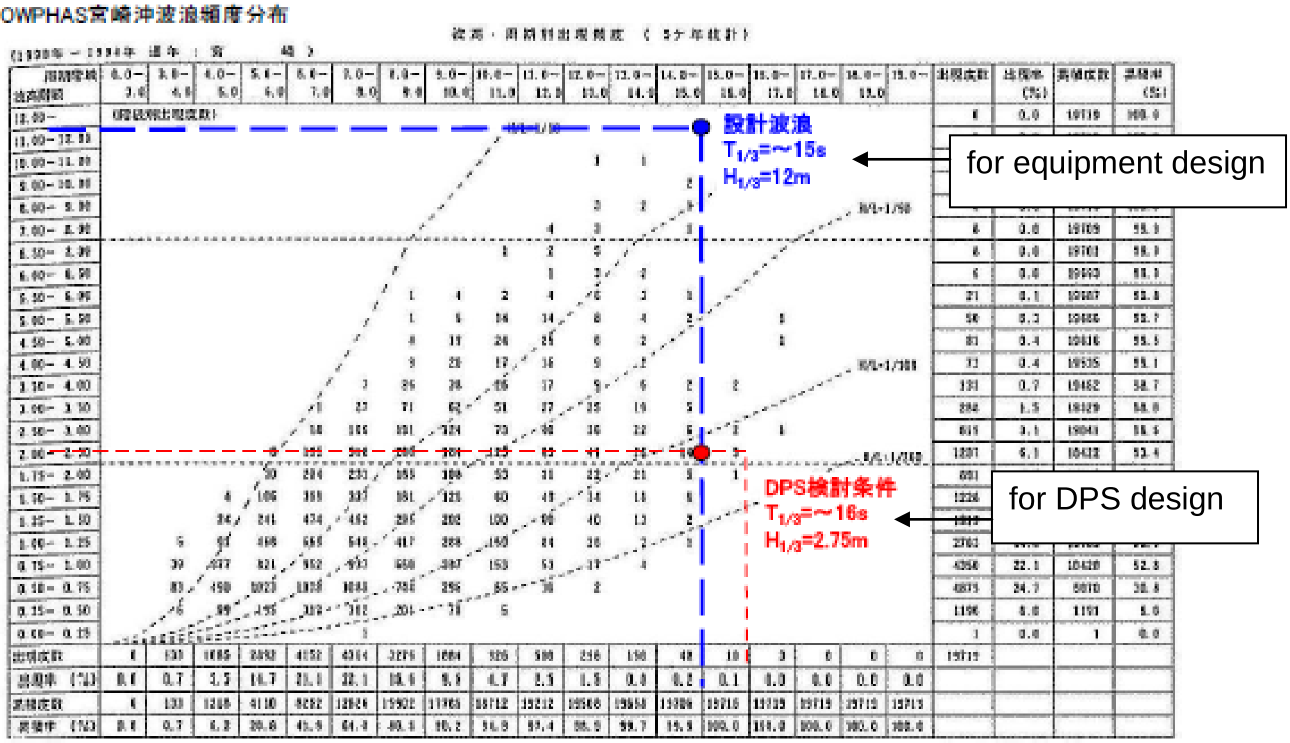


b) Offshore Site.M in Kyushu Island

c) Water depth

<u>Fig. 3.5.1-1 Location of selected site for the oceanographic data.</u>

NOWPHAS宮崎沖波浪頻度分布



(秋季波浪頻度)

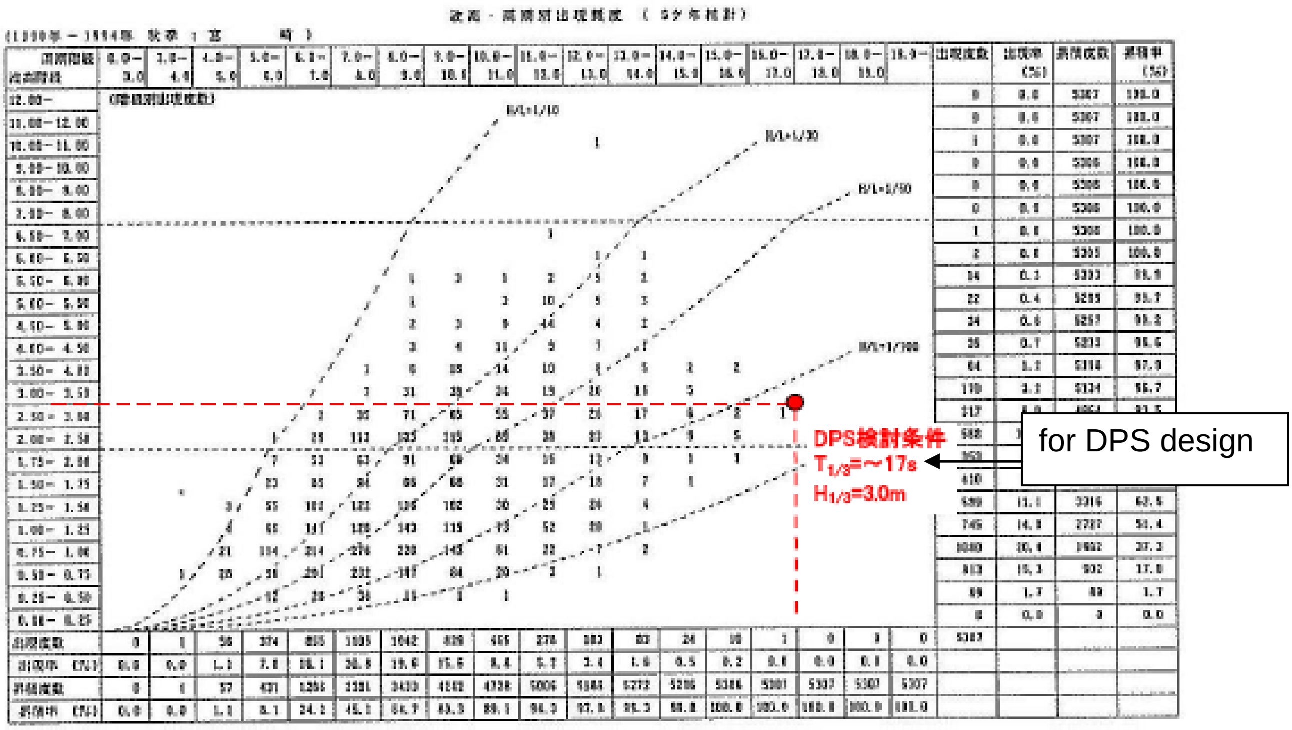


Fig. 3.5.1-2 Frequency of distribution of wave height and wave period in offshore site.M: all year (above) and fall season (below), data from National Ocean Wave Information Network for Ports and Harbors (NOWPHAS).

DISPLAY AREA
e08

WIND SPEED − WIND DIRECTION
HIND DATA
Annual

MEAN OF WIND SPEED 13.39 (KT)

	345−	015−	045−	075−	105−	135−	165−	195−	225−	255−	285−	315−	TOTAL	
70−	0	0	0	0	0	0	0	0	0	0	0	0	0	
60−	0	0	0	0	0	0	0	0	0	0	0	0	0	100.0%
50−	0	0	0	1	0	0	1	0	0	0	0	0	2	100.0%
40−	0	2	11	7	11	4	6	6	4	0	12	3	66	100.0%
30−	18	26	65	83	31	26	24	23	27	12	137	97	569	99.8%
20−	383	175	392	387	220	160	152	239	329	198	648	1040	4323	97.8%
10−	1677	1187	1370	1341	840	543	580	808	1129	1060	1300	2143	13978	83.0%
0−	1118	1114	1004	893	772	643	655	687	754	824	849	965	10278	35.2%
TOTAL	3196	2504	2842	2712	1874	1376	1418	1763	2243	2094	2946	4248	29216	
MAX1	38.5	49.8	46.7	58.8	47.3	48.2	53.7	47.1	47.3	36.4	44.9	43.4		
MAX2	0	17	64	97	122	140	172	213	235	257	301	316		

30.9 m/s
60.0 knot
平均風速の最大値
設計風速:U10=50m/s
15m/s

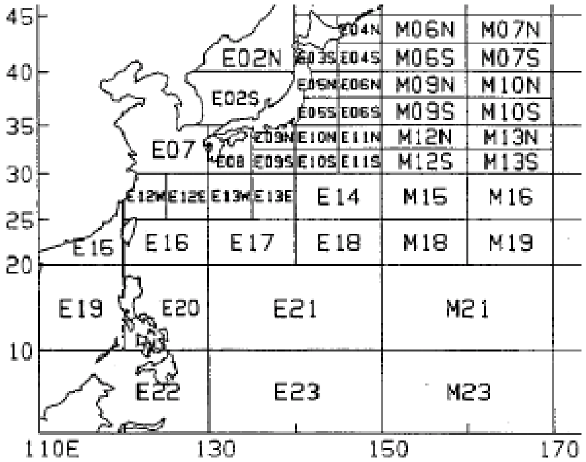


Fig. 3.5.1-3 Frequency of distribution of wind speed and wind direction in offshore site.M: the location is labelled E08 and the design wind speed is U10 = 50 m/sec.

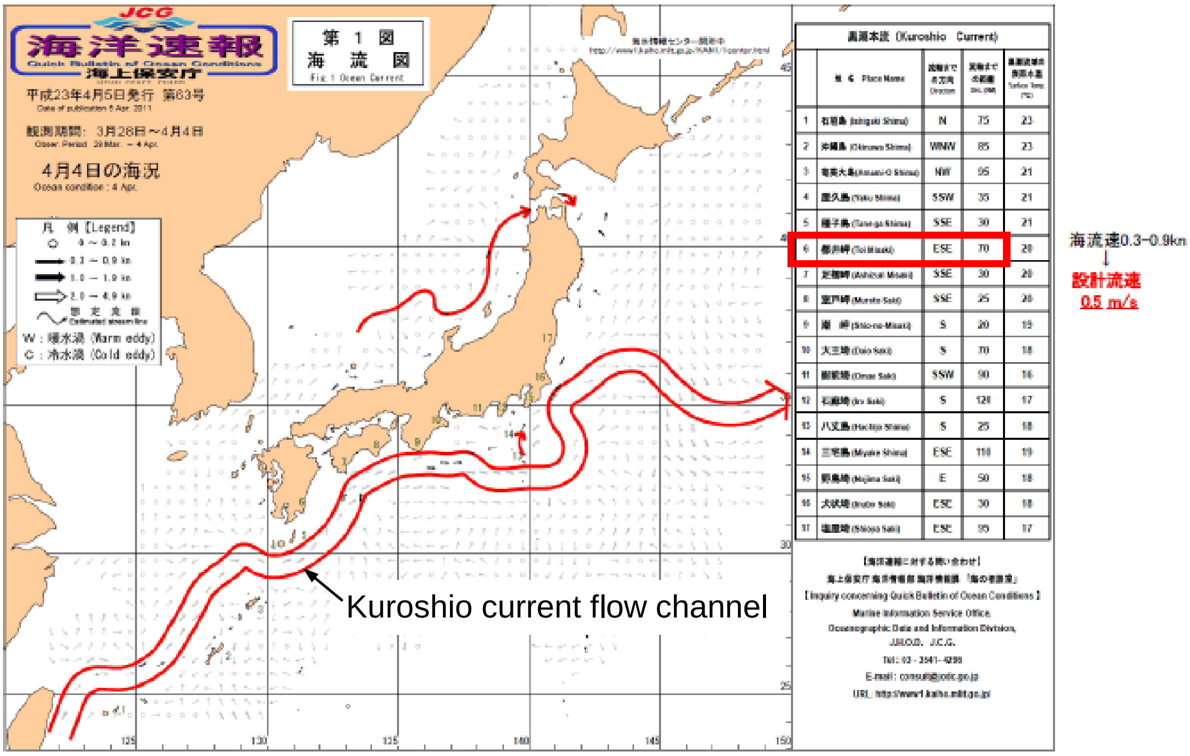


Fig. 3.5.1-4 Kuroshio current flow channel observed in the period of March 28 - April 4 in 2011: the design current speed of offshore site.M is estimated 0.5 m/sec.

3.5.2 Limiting sea condition for offshore operation

1) The response amplitude operator (RAO) of the CO_2 carrier vessel in moderate waves was calculated based on 3-Dimensional Singularity Distribution Method (3DSDM) with a computational grid representing a hull shape of the proposed vessel. The result of the interview survey with captains of research vessels showed that for offshore operations a vessel's pitch motion and service deck wetness are dominant factors which define a vessel's operational availability. Therefore, the RAO of pitch and relative wave elevation is shown as Figs. 3.5.2-1 and 3.5.2-2. In Fig. 3.5.2-1, the vertical axis shows a normalized value X5a/ζa, where X5a stands for the amplitude of pitch motion angle and ζa is the incident wave amplitude. The horizontal axis shows the wave period, T. The RAO of relative wave elevation at the midship is shown in Fig. 3.5.2-2; the pick-up buoy operation is planned to be carried out at the midship. The vertical axis shows a non-dimensional value Zr/ζa, where Zr stands for the amplitude of relative wave elevation and ζa is the incident wave amplitude. The definition of incident wave angle is shown in Fig. 3.5.2-4.

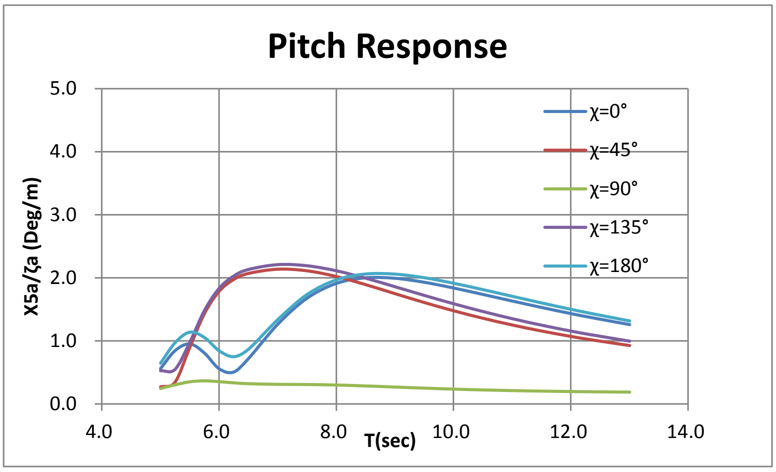


Fig. 3.5.2-1 RAO of Pitch

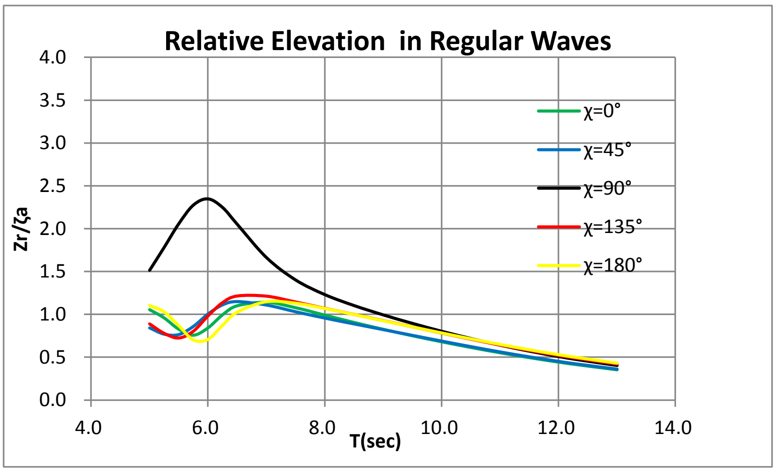


Fig. 3.5.2-2 RAO of Relative wave elevation at mid-ship

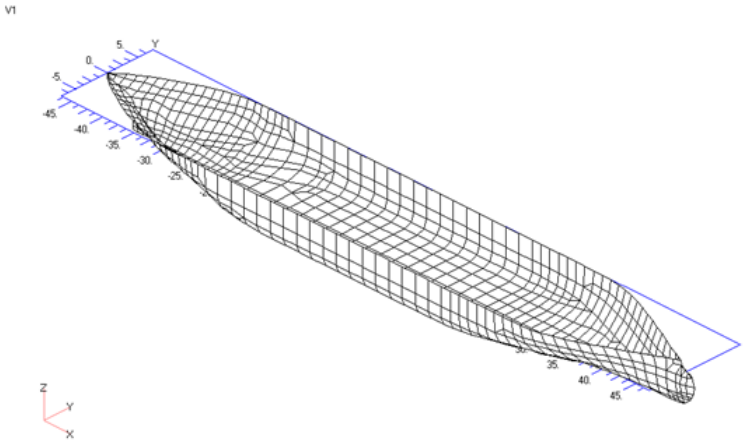


Fig. 3.5.2-3 Computational grid of hull

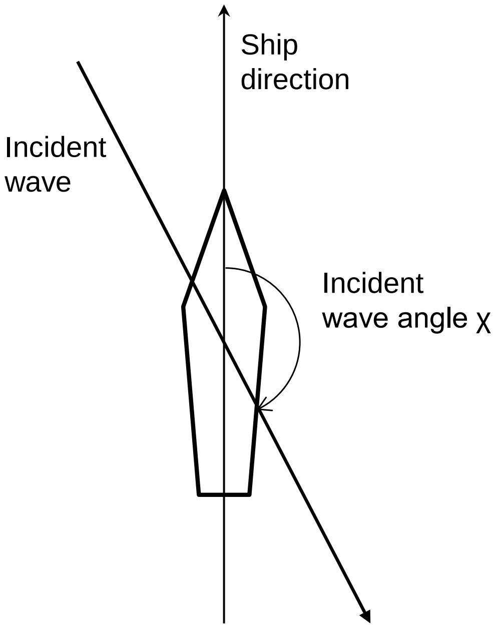


Fig. 3.5.2-4 Definition of incident wave angle

2) The hull motions (1/10 maximum expected response value of pitch) and the relative wave elevation (1/10 maximum expected response value of relative wave elevation) in unidirectional irregular waves and in multidirectional irregular waves (significant wave height: Hv=1.0m) were calculated by a conventional method based on the sea-keeping theorem using the RAOs, the wave spectrum (ISSC type) and the directional wave spectrum ($\cos^2\theta$ type). The calculated results are shown in Figs. 3.5.2-5 to 3.5.2-8. The vertical axis of these graphs means the 1/10 maximum expected response value and the horizontal axis means the significant wave period, where the notation of long crested irregular waves means unidirectional irregular waves and the notation of short crested irregular waves means multidirectional irregular waves.

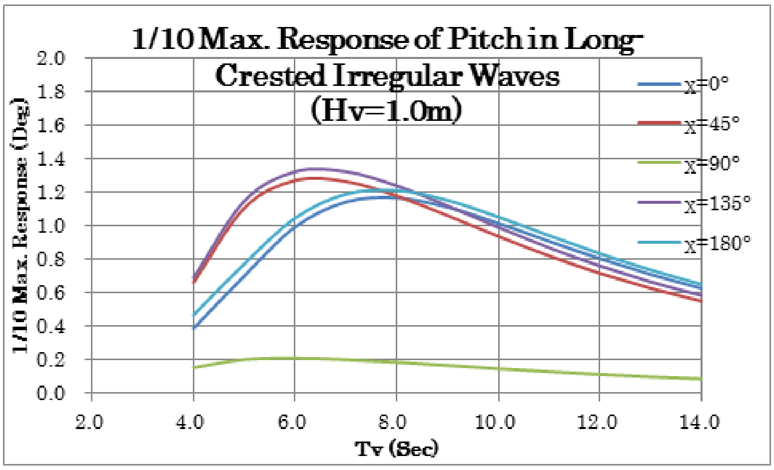


Fig. 3.5.2-5 1/10 maximum expected response value of Pitch (Long crested irregular waves)

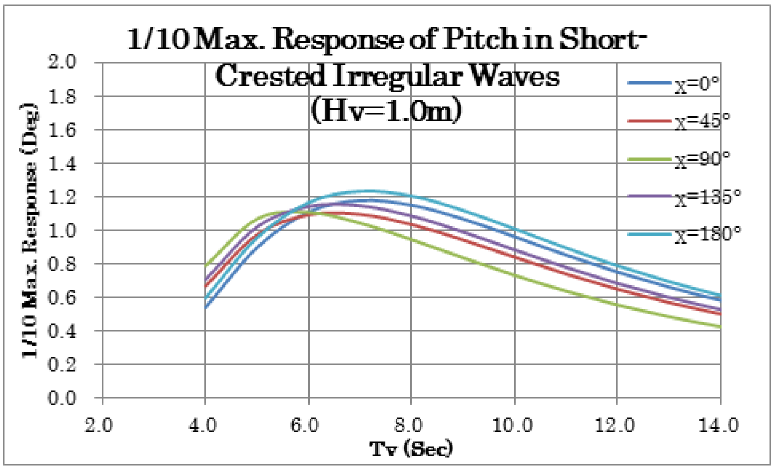


Fig. 3.5.2-6 1/10 maximum expected response value of Pitch (Short crested irregular waves)

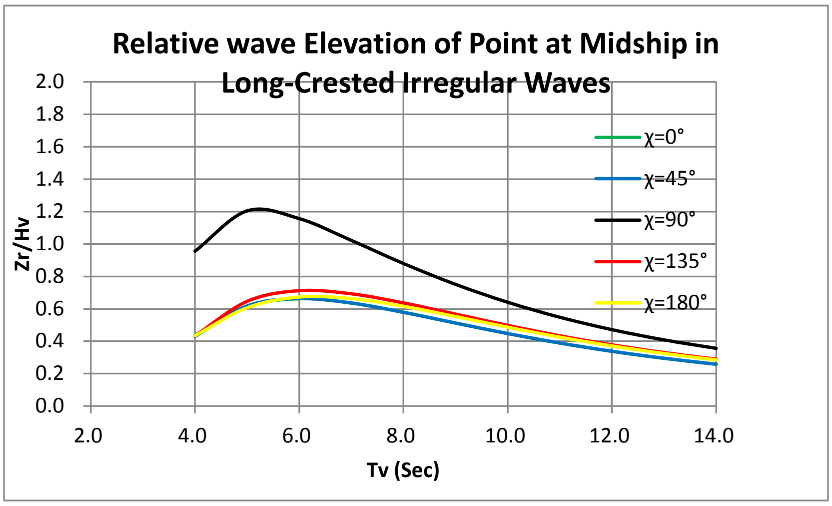


Fig. 3.5.2-7 1/10 maximum expected response value of Relative wave elevation (Long crested irregular waves)

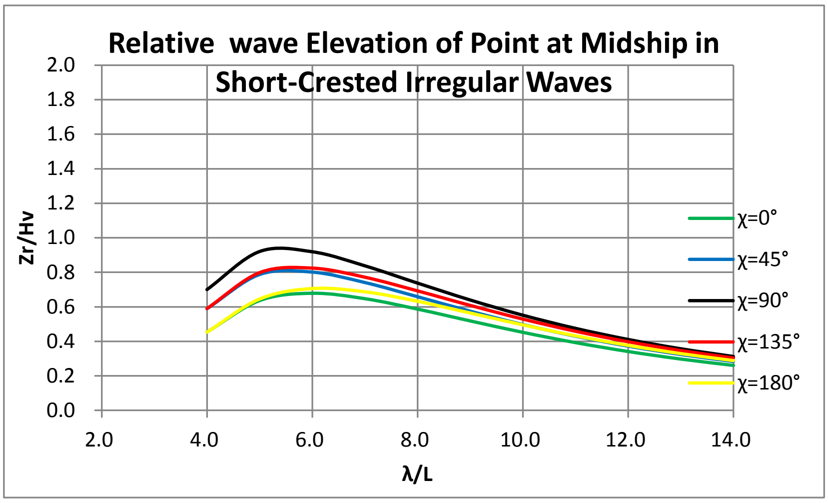


Fig. 3.5.2-8 1/10 maximum expected response value of Relative wave elevation (Short crested irregular waves)

3) Under the assumption that the operational availability of the proposed CO_2 carrier vessel is constrained by the pitch motion and the service deck wetness, the allowable upper limit values of the significant wave height were calculated by a conventional method based on the sea keeping theorem using the 1/10 maximum expected response value of pitch motion and the relative wave

elevation shown in the previous section. The threshold value of operation availability was set at the pitch of 3.0 degrees and the relative wave elevation at the freeboard to the service deck, based on the result of the interview survey with captains of research vessels. The calculated results are shown in Table 3.5.2-1, where Tv means the significant wave period, χ means the incident wave angle and Hv means the significant wave height.

Table 3.5.2-1 allowable upper limit value of significant wave height with Pitch (Long crested irregular waves)

Tv(sec) \ χ(deg.)	0	45	90	135	180
4	7.69	4.52	19.23	4.33	6.38
5	4.27	2.7	14.71	2.61	3.88
6	3.02	2.36	14.22	2.27	2.86
7	2.63	2.38	13.04	2.27	2.52
8	2.56	2.54	16.04	2.42	2.48
9	2.7	2.83	17.75	2.68	2.61
10	2.94	3.2	20	3.02	2.86
11	3.3	3.65	22.73	3.45	3.18
12	3.73	4.18	25.86	3.94	3.59
13	4.22	4.78	29.7	4.5	4.07
14	4.78	5.43	33.63	5.12	4.6
				unit:	m

Table 3.5.2-2 allowable upper limit value of significant wave height with Pitch (Short crested irregular waves)

Tv(sec) \ χ(deg.)	0	45	90	135	180
4	5.56	4.5	3.81	4.25	5.03
5	3.34	3.08	2.8	2.94	3.14
6	2.7	2.75	2.7	2.63	2.59
7	2.54	2.75	2.88	2.61	2.44
8	2.61	2.91	3.18	2.78	2.5
9	2.8	3.18	3.59	3.03	2.68
10	3.12	3.58	4.1	3.4	2.97
11	3.52	4.06	4.71	3.86	3.36
12	4	4.63	5.42	4.39	3.81
13	4.54	5.27	6.2	5.01	4.33
14	5.15	5.99	7.08	5.68	4.91
				unit:	m

Table 3.5.2-3 allowable upper limit value of significant wave height with relative wave elevation (freeboard = 1.3m) (Long crested irregular waves)

Tv(sec)	χ=0°	χ=45°	χ=90°	χ=135°	χ=180°
4	2.96	3.02	1.36	3.00	2.99
5	2.12	2.10	1.08	2.01	2.14
6	1.96	1.96	1.12	1.83	1.93
7	2.04	2.05	1.27	1.88	1.96
8	2.25	2.25	1.48	2.04	2.11
9	2.54	2.54	1.73	2.29	2.35
10	2.91	2.91	2.03	2.61	2.67
11	3.34	3.34	2.37	3.00	3.06
12	3.85	3.84	2.76	3.44	3.50
13	4.41	4.41	3.18	3.94	4.01
14	5.04	5.03	3.65	4.49	4.57
				unit:	m

Table 3.5.2-4 allowable upper limit value of significant wave height with relative wave elevation (freeboard = 1.3m) (Long crested irregular waves)

Tv(sec)	χ=0°	χ=45°	χ=90°	χ=135°	χ=180°
4	2.86	2.21	1.86	2.20	2.87
5	2.04	1.65	1.41	1.63	2.01
6	1.92	1.62	1.41	1.58	1.84
7	2.01	1.76	1.55	1.68	1.89
8	2.22	1.97	1.76	1.88	2.06
9	2.51	2.26	2.03	2.14	2.30
10	2.88	2.61	2.36	2.46	2.62
11	3.31	3.02	2.74	2.84	3.01
12	3.81	3.49	3.16	3.27	3.45
13	4.37	4.01	3.64	3.75	3.95
14	4.99	4.59	4.17	4.29	4.51
				unit:	m

3.5.3 Offshore operation availability of CO_2 carrier against sea conditions in the supposed site location

1) Estimation method

Based on the collection of sea condition data in the supposed site location (see 3.5.1) and the estimation of the limiting sea condition for offshore operation (see 3.5.2), the estimation and the evaluation for the offshore operational availability of the proposed CO_2 carrier vessel against the sea conditions in offshore site M were carried out. The flow diagram for the estimation for the offshore operational availability of CO_2 carrier is shown in Fig. 3.5.3-1.

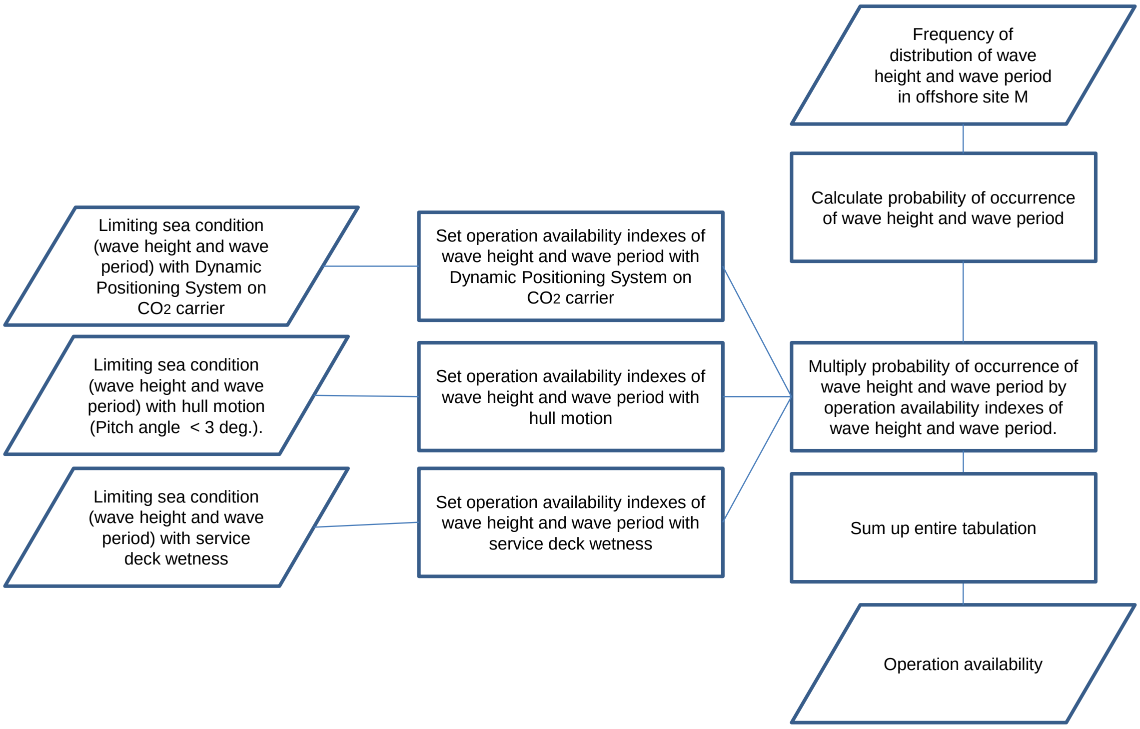


Fig. 3.5.3-1 Flow diagram for estimation with offshore operation availability

Here, “operation availability indexes” is a figure of 1 or 0. “Operation availability index = 1” means that the operation is available. On the contrary, “operation availability index = 0” means that the operation is not available.

2) Estimation results

As discussed in the previous sections, the pitch motion of the vessel and the service deck wetness for offshore operations are dominant factors to define vessels operational availability. Among them, the event of service deck wetness relies heavily on freeboard of service deck. Therefore, the operational availability of the proposed CO_2 carrier vessel was systematically-calculated based on parametrically-changed freeboard of service deck (1.3m, 2.0m, 2.3m and 2.5m). The estimation results are shown below.

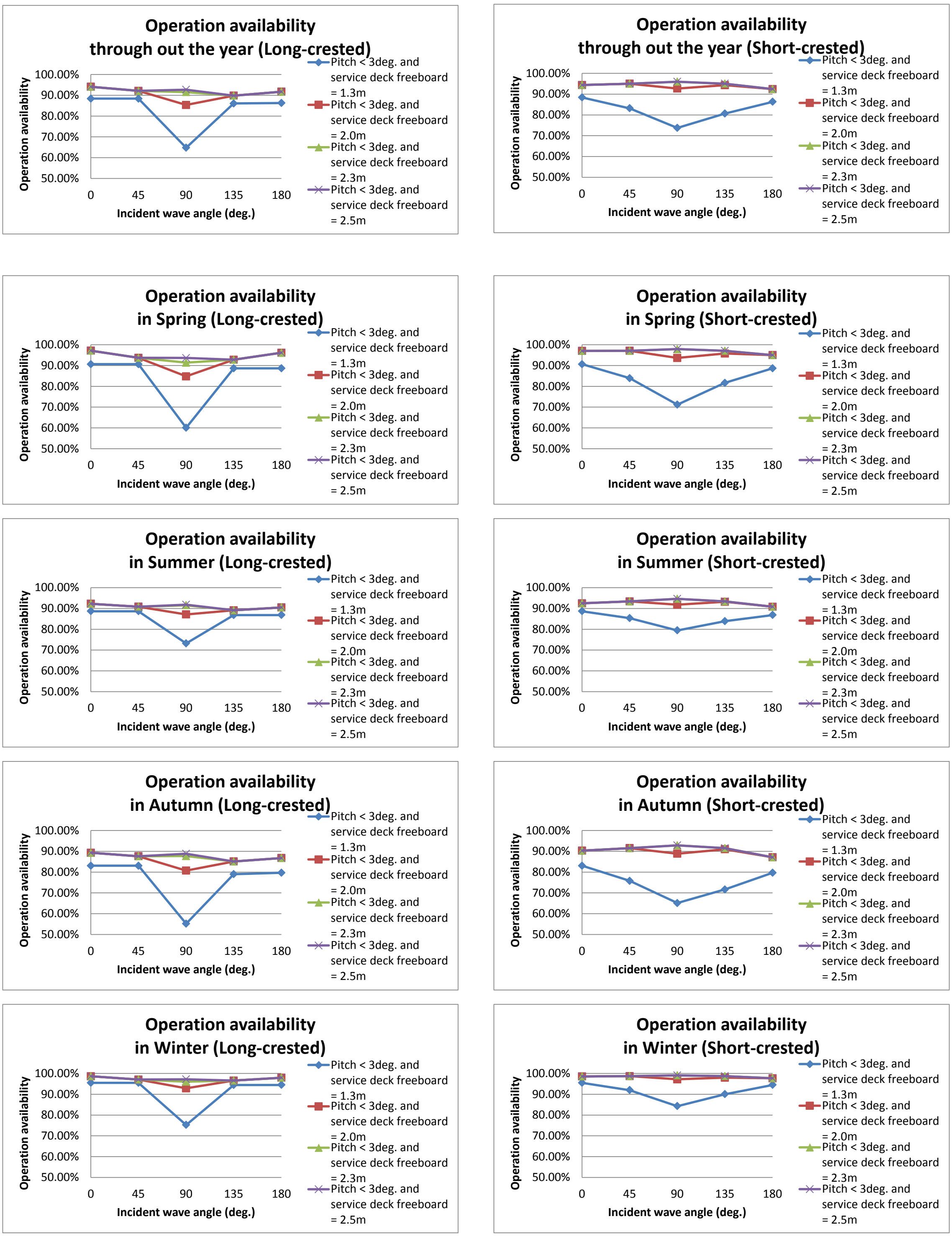


Fig. 3.5.3-2 Estimation results of operation availability (full year and four seasons)

These results show that the operational availability of the proposed CO_2 carrier vessel reaches a target value of nearly 90% for both full year and four seasons in the case that freeboard of service deck for offshore buoy picking-up operations set greater than 2.3 m as a service platform.

3) Conclusions

The results of the estimation with the operational availability of the proposed CO_2 carrier vessel lead to the suggestion that the operational availability reaches a target value of nearly 90% by higher freeboard of a service platform for offshore buoy picking-up operations.

4. Regulations on ship-based CCS

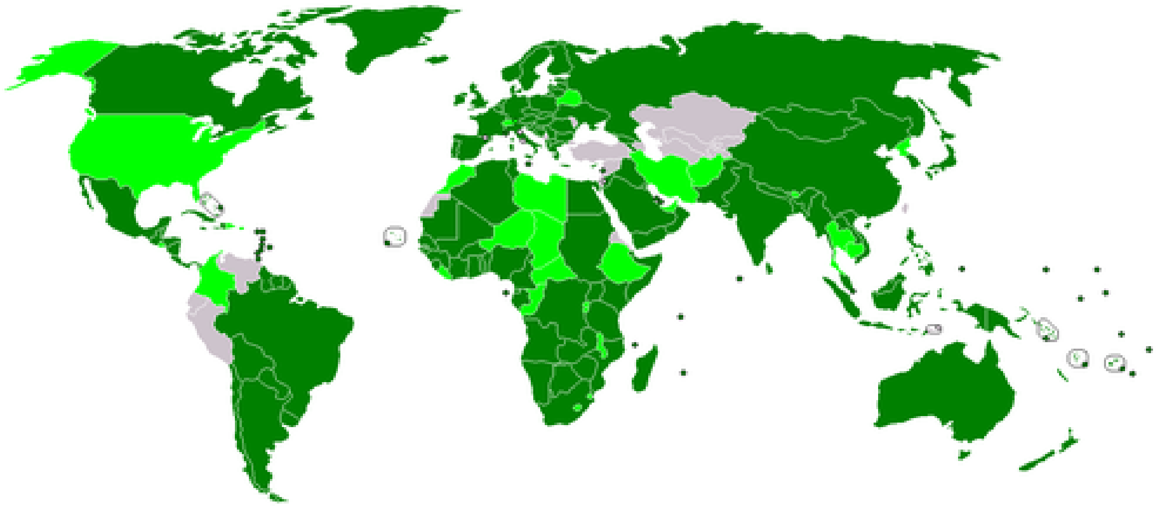
4.1 International regulatory framework

For applying CCS technology, not limited to the shuttle ship method, where CO_2 is stored in sub-seabed geological formations, the United Nations Convention on the Law of the Sea and the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972 and the 1996 Protocol thereto are considered relevant international laws.

4.1.1 United Nations Convention on the Law of the Sea

1) Overview[1]

The main text of the United Nations Convention on the Law of the Sea (UNCLOS) comprises 17 parts and 320 articles in total and nine annexes. This treaty was adopted in 1982 after negotiations lasting over 10 years, and came into force 12 years later in November 1994. As of November 2010, 161 nations and areas concluded the treaty (Fig. 4.1-1).



ratified signed, but not yet ratified did not sign

Fig. 4.1-1 Parties to UNCLOS (November 2010)

UNCLOS was established by reviewing and merging existing laws of the sea such as the four 1958 Geneva Conventions on the Law of the Sea.[2]

[1] The documents available at the Ministry of Foreign Affairs of Japan can be found at: http://www.mofa.go.jp/mofaj/gaiko/kaiyo/pdfs/jyouyaku_j.pdf

[2] The four conventions adopted in 1958, in Geneva, Switzerland: "Convention on the Territorial Sea and the Contiguous Zone," "Convention on the High Seas," "Convention on Fishing and Conservation of the Living Resources of the High Seas," and "Convention on the Continental Shelf."

First, a new maritime zone called the exclusive economic zone (EEZ) was defined, and the distance of the "Territorial Sea," which was not prescribed in the four 1958 Geneva Conventions on the Law of the Sea, was set to no more than 12 nautical miles.[3]

Although the area of "Continental Shelf" was defined in the four 1958 Geneva Convention on the Law of the Sea as the submarine area to a depth of 200 meters or as submarine areas that have the potential to be developed, UNCLOS defines the area as basically being up to 200 nautical miles from the baseline of the territorial sea (this can be extended under certain conditions if the continental shelf exceeds 200 nautical miles). Also, a new regime was established whereby the seabed and under the seabed beyond the continental shelf are defined as "Deep Seabed" and whereby these resources are managed internationally as "the common heritage of mankind."(Fig. 4.1-2)

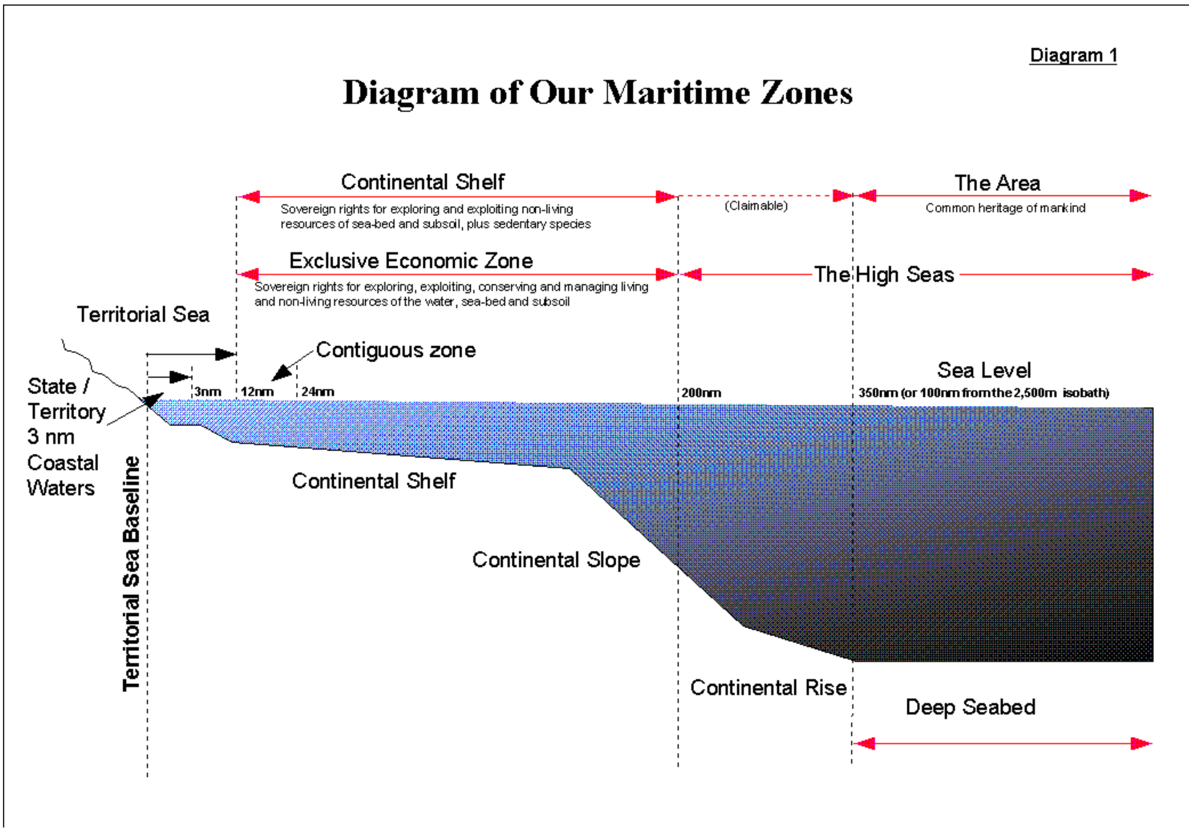


Fig. 4.1-2 Diagram of maritime zones

Adapted from
http://www.environment.gov.au/coasts/oceans-policy/publications/images/maritime-zones.gif

[3] One nautical mile equals 1,852 meters.

Additionally, UNCLOS includes detailed provisions relating to the settlement of disputes that in principle require compulsory jurisdiction procedures, as well as prescribing the establishment of an International Tribunal for the Law of the Sea (ITLOS). The rights of nations except nations are classified as shown in Table 4.1-1.

Table 4.1-1. Rights of nations except coastal nations according to the maritime zone.

Rights of states other than coastal states	Territorial Sea	EEZ	The High Seas
Right of innocent passage	Yes	-	-
Freedom of navigation	No	Yes*	Yes
Freedom of overflight	No	Yes*	Yes
Freedom to lay submarine cables and pipelines	No	Yes*	Yes
Freedom of fishing	No	No	Yes
Freedom of scientific research	No	No	Yes
Freedom to construct artificial islands and other installations	No	No	Yes

*These freedoms shall be exercised with due regard for the rights and duties of the coastal state.

2) Relation to CCS[4]

Article 192 of UNCLOS prescribes that coastal nations have the obligation to protect and preserve the marine environment. Coastal nations are required to establish domestic laws and regulations that comply with international rules and standards and make efforts to prevent, reduce, and control pollution of the marine environment by taking necessary measures. In addition, Article 194 states that coastal nations shall use necessary and practicable means to "prevent, reduce and control pollution of the marine environment from any source."

UNCLOS defines "marine pollution" as follows:

"Marine pollution" means:

"the introduction by man, directly or indirectly, of substances or energy into the

[4] The documents available at the Ministry of Foreign Affairs of Japan can be found at: http://www.mofa.go.jp/mofaj/gaiko/kaiyo/pdfs/jyouyaku_j.pdf

marine environment, including estuaries, which results or is likely to result in such deleterious effects as harm to living resources and marine life, hazards to human health, hindrance to marine activities, including fishing and other legitimate uses of the sea, impairment of quality for use of sea water, and reduction of amenities."

UNCLOS also classifies marine pollution into the following five categories based on the cause of pollution, authorizes coastal nations to prevent, reduce, and control pollution according to the type of pollution using their domestic laws and regulations, and requires that such laws and regulations comply with international standards.

[Five types of pollution cause]

i. Pollution from land-based sources (Article 207)
ii. Pollution from seabed activities and activities in the deep seabed (Articles 208 and 209)
iii. Pollution by dumping (Article 210)
iv. Pollution from vessels (Article 211, Articles 217 through 221)
v. Pollution from or through the atmosphere (Article 212)

According to University College London,[5] there is no final consensus regarding whether the definition of marine pollution in UNCLOS would apply to CCS activities. Moreover, although UNCLOS applies to the seabed and its subsoil, there remains uncertainty as to whether its provisions would apply to formations deeper than the subsoil where CCS activities are undertaken.

Concerning development activities in the EEZ, Article 56 of UNCLOS prescribes that "the coastal state has sovereign rights for the purpose of exploring and exploiting, conserving and managing the natural resources of the waters adjacent to the seabed and of the seabed and its subsoil."

Article 56 Rights, jurisdiction, and duties of the coastal state in the exclusive economic zone

1. In the exclusive economic zone, the coastal state has:

(a) sovereign rights for the purpose of exploring and exploiting, conserving and managing the natural resources, whether living or non-living, of the waters adjacent to the seabed and of the seabed and its subsoil, and with regard to other activities for the economic exploitation and exploration of the zone, such as the

[5] http://www.ucl.ac.uk/cclp/ccsunclos.php

production of energy from the water, currents and winds;
(b) jurisdiction as provided for in the relevant provisions of this Convention with regard to:
(i) the establishment and use of artificial islands, installations and structures;
(ii) marine scientific research;
(iii) the protection and preservation of the marine environment;
(c) other rights and duties provided for in this Convention.
2. In exercising its rights and performing its duties under this Convention in the exclusive economic zone, the coastal state shall have due regard to the rights and duties of other states and shall act in a manner compatible with the provisions of this Convention.
3. The rights set out in this article with respect to the seabed and subsoil shall be exercised in accordance with Part VI.

However, Item 7 of Article 60 prescribes that "artificial islands, installations and structures and the safety zones around them may not be established where interference may be caused to the use of recognized sea lanes essential to international navigation." This may need to be taken into consideration if CCS injection facilities are installed at sea.

4.1.2 London Protocol

1) Overview

The "Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter 1972", the "London Convention" for short, is the conventions to protect the marine environment from human activities and has been in force since 1975. Its objective is to promote the effective control of all sources of marine pollution and to take all practicable steps to prevent pollution of the sea by dumping of wastes and other matter. As at 5 July 2011, 87 States are Parties to this Convention.

In 1996, the "London Protocol" was agreed to further modernize the Convention and, eventually, replace it. Under the Protocol all dumping is prohibited, except for possibly acceptable wastes on the so-called "reverse list" (Annex I). The Protocol entered into force on 24 March 2006 and there are, as at 5 July 2011, 40 Parties to the Protocol (Fig. 4.1-3). Its objective is to “protect and preserve the marine environment from all sources of pollution and take effective measures, according to their scientific, technical and economic capabilities, to prevent, reduce and where practicable eliminate pollution caused by dumping or incineration at sea of wastes or other matter.” (Article 2)

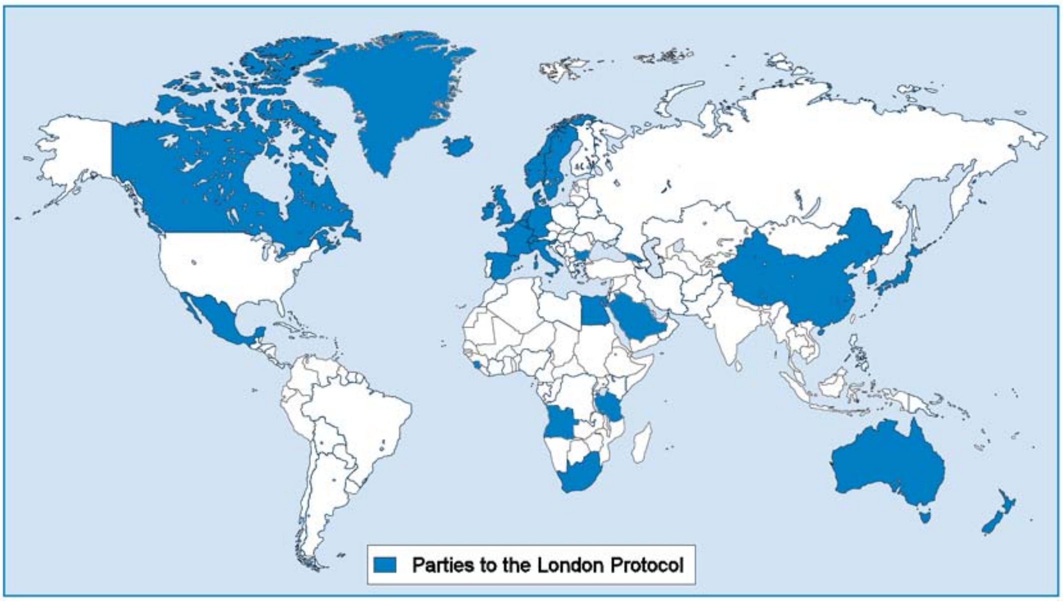


Fig. 4.1-3 Parties to the 1996 London Protocol (40 countries as of July 2011)

The Protocol prohibits dumping of land wastes at sea in principle except certain waste items listed in its Annex I as follows:

1 Dredged material;
2 Sewage sludge;
3 Fish waste, or material resulting from industrial fish processing operations;
4 Vessels and platforms or other man-made structures at sea;
5 Inert, inorganic geological material;
6 Organic material of natural origin;
7 Bulky items primarily comprising iron, steel, concrete and similarly unharmful materials for which the concern is physical impact, and limited to those circumstances where such wastes are generated at locations, such as small islands with isolated communities, having no practicable access to disposal options other than dumping; and
8 Carbon dioxide streams from carbon dioxide capture processes for sequestration (See Fig.4.1-4)

The dumping of waste items listed in Annex1 requires a permit, which must be issued in accordance with the provisions of Annex II as follows:

1 Waste prevention audit;
2 Consideration of waste management options;
3 Identification of chemical, physical and biological properties;
4 Consistency with action list;
5 Dump-site selection;
6 Assessment of potential effects;
7 Monitoring; and
8 Permit and permit conditions.
(see Fig.4.1-5)

Besides these annexes, "Generic Waste Assessment Guidelines" and "Specific Waste Assessment Guidelines" complement these annexes (see Fig.4.1-4).

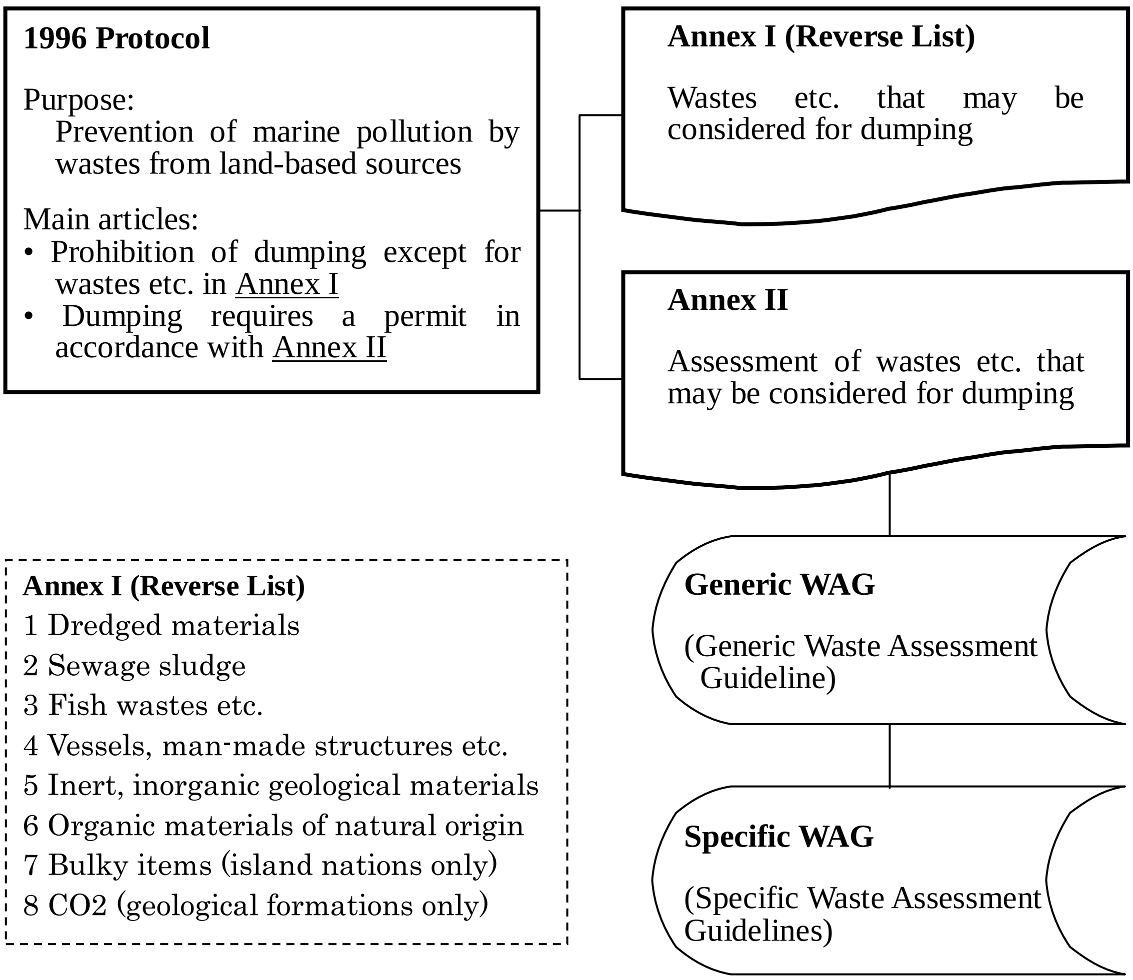


Fig. 4.1-4 Structure of the 1996 London Protocol

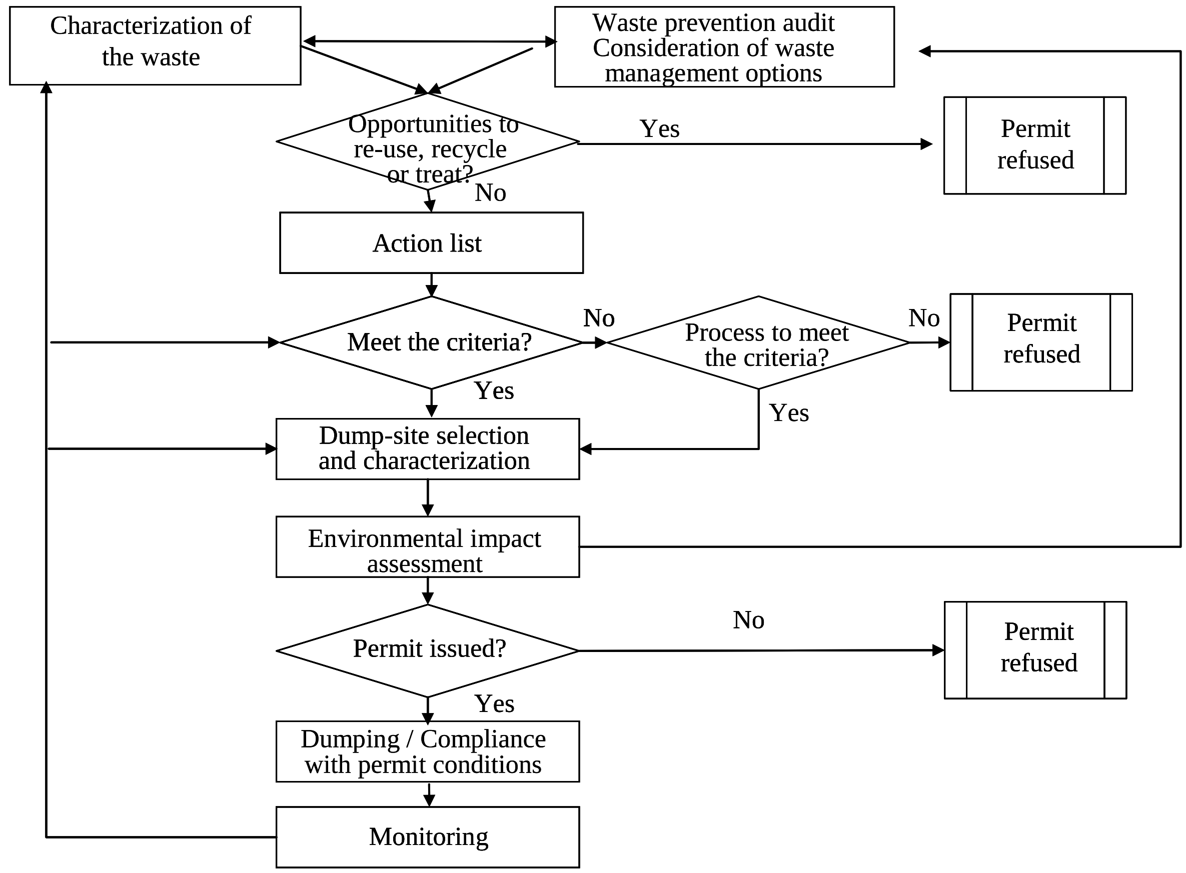


Fig. 4.1-5 Flowchart of environmental impact assessment and permit approval procedures in Annex II of the 1996 London Protocol

2) Relation to CCS

The 1996 London Protocol added CO_2 streams stored in sub-seabed geological formations to the list of exceptional waste items at the 28th Consultative Meeting of Contracting Parties to the Convention and the First Meeting of Contracting Parties to the 1996 Protocol in November 2006 (LC28/LP1), which as a result made it an international treaty significantly connected with CCS technology.

Whether to incorporate carbon dioxide storage in sub-seabed geological formations into the 1996 London Protocol was reviewed through the historical background described in Table 4.1-2. As a result, after Annex I was amended in November 2006 and CO_2 streams stored in sub-seabed geological formations were added to the exclusive list of items under the following conditions.

.1 Disposal is into a sub-seabed geological formation;

.2 They consist overwhelmingly of carbon dioxide. They may contain incidental associated substances derived from the source material and the capture and sequestration processes used; and

.3 No wastes or other matter are added for the purpose of disposing of those wastes or other matter.

Table 4.1-2 Background to the review of the London Convention relating to CO_2 storage in sub-seabed geological formations

August 1996	Adoption of the London Protocol 1996 (LP)
March 2006	The LP entered into force, enabling amendment by the contracting parties to the LP alone
April 2006	Proposal for amendments to Annex I of the LP by Australia, France, Norway, and UK
November 2006	Adoption of the amendments to the Annex I of the LP
February 2007	Amendments entered into force
November 2007	CO_2-WAG accepted in principle (more issues to be covered)

As for CO_2 storage in sub-seabed geological formations discussed as stated above, another issue of whether to allow the transboundary movement of CO_2 for underground sequestration was discussed. Article 6 of the 1996 London Protocol prohibits the export of wastes.

Transboundary movement was discussed by dividing the issue into the following three cases.

(1) Export: exporting CO_2 to other countries by pipelines and other means.

(2) Intentional migration: transboundary movement under formations that was expected prior to injection.

(3) Unintentional migration: transboundary movement under formations that was unexpected prior to injection.

As the conclusion to the discussion, the article was amended in 2009, which resulted in export of CO_2 being enabled for underground sequestration as an exceptional case. Also, the amended article made it allowable to export CO_2 from a contracting party to the 1996 Protocol to a non-contracting party under an agreement or arrangement among the countries concerned. However, it only prescribes "the provisions relating to the issuance of permits and permit conditions to ensure that the agreement or arrangement does not derogate from the obligations of the Contracting

Parties under the London Protocol," and no further provision has yet been made.

There was an agreement that if the contracting parties ratified this amendment, it would enter into force 60 days after two-thirds of the contracting parties had deposited an instrument of acceptance of the amendment with the IMO (International Maritime Organization). However, as of May 2011, it has not yet come into force.

4.2 Domestic regulatory framework

4.2.1 List of related laws and regulations

Domestic laws and regulations applicable to the Preliminary Feasibility Study on CO_2 Carriers for Ship-based CCS (hereinafter referred to as the "Project") are listed in the following tables.

Table 4.2-1 Laws and regulations to be observed

	Name of applicable law or regulation	Operations		
		CO_2 refilling (in ports and harbors)	During CO_2 transportation	During injection (including site works)
Laws and regulations to be observed	* Marine Pollution Prevention Law	Permit approval on the whole		
		CO_2 concentration standards		Reporting on installations of marine facilities Dumping CO_2 into seabed
	* High Pressure Gas Safety Act	Tanks, conduit pipes, refilling facilities		CO_2 injection facilities, riser pipes, etc.
	* Ship Safety Act		Rules on hazardous materials transportation by ship and storage (containers and transportation methods)	
	* Industrial Safety and Health Act	Loading onto ships		

Table 4.2-2 Laws and regulations to be studied after site determination

<table>
<tr><th rowspan="2"></th><th rowspan="2">Name of applicable law or regulation</th><th colspan="3">Operations</th></tr>
<tr><th>CO_2 refilling (in ports and harbors)</th><th>During CO_2 transportation</th><th>During injection (including site works)</th></tr>
<tr><td rowspan="8">Laws and regulations to be studied after the site determination</td><td>* Ports and Harbors Act</td><td colspan="3">Applicable to operations in ports and harbors (especially when a vessel is used)</td></tr>
<tr><td>* Act on Port Regulations</td><td colspan="3">Applicable to operations in specified ports, etc.</td></tr>
<tr><td>* Coast Act</td><td colspan="3">Applicable to operations in coast preservation areas</td></tr>
<tr><td>* Maritime Traffic Safety Act</td><td></td><td colspan="2">Applicable to operations in designated marine lines and neighboring areas</td></tr>
<tr><td>* Act on Development of Fishing Ports and Grounds</td><td colspan="3">Applicable to operations in fishing port areas</td></tr>
<tr><td>* Act on the Protection of Fishery Resources</td><td colspan="3">Applicable to operations that will result in a change in the flow or water level of the waterway or river</td></tr>
<tr><td>* Marine Resources Development Promotion Act</td><td colspan="3">Applicable to operations in development areas</td></tr>
<tr><td>* Fishery Act</td><td colspan="3">Applicable to operations on water surfaces where a fishing right is set</td></tr>
</table>

We examined each law and regulation based on the documents discussed at Carbon Dioxide Capture and Storage (CCS) Study Group meetings during 2008 and 2009 set up under the Ministry of Economy, Trade and Industry,[6] and the "Guideline for Safe CCS Demonstration Projects" (August 2009), which was prepared by the Study Group.[7]

We also had hearings with Japan CCS Co. Ltd. (JCCS), which engages in surveys on CCS, and the Japan Oil, Gas and Metals National Corporation (JOGMEC), which

[6] http://www.meti.go.jp/english/press/data/pdf/090807_02PDF.pdf
[7] http://www.meti.go.jp/press/20090807003/20090807003-3.pdf

engages in surveys of oceans. As a result of the hearings, we have decided to cover the laws and regulations currently in force in the Project.

The operations to be considered under this Project are subdivided into the following three sections, namely 1) loading CO_2 into ships in a port or harbor, 2) transporting CO_2 to a site from a port or harbor, and 3) injecting CO_2 into the site. The above table lists laws and regulations applicable to any of the parts of the operations.

4.2.2 Overview of applicable laws and regulations

Individual laws and regulations are studied in detail in Section 4.2.3. An overview of these laws and regulations is organized as follows:

1) Overview of laws and regulations to be observed

The laws and regulations referred to throughout this report are the Law for the Prevention of Marine Pollution and Maritime Disasters (hereinafter referred to as the "Marine Pollution Prevention Law"). In accordance with the London Protocol concluded in 2006 that allows CO_2 stream storage in sub-seabed geological formations for CCS purposes, the Marine Pollution Prevention Law was amended in 2007, followed by the enforcement of the relevant cabinet order, ministerial ordinance, and notices on CCS in the same year.

The High Pressure Gas Safety Act is applicable to the storage, refilling, and injection of CO_2 streams or liquid CO_2. Since the law regards refilling such CO_2 as the production of highly pressurized gas, operations in ports and harbors are subject to the law. Concerning shuttle ships for transporting CO_2, equipment required for injecting CO_2 into wells is also regarded as subject to the High Pressure Gas Safety Act. The riser pipes used to feed CO_2 from the containers of a shuttle ship into a well are also required to comply with the provisions of this law. In this connection, the CO_2 stream containers of a shuttle ship are subject to the Ship Safety Act.

CO_2 ship transportation is stipulated in the Ship Safety Act. CO_2 refilling containers are not subject to the aforementioned High Pressure Gas Safety Act, but are subject to the Ship Safety Act, and methods for installing such containers are also stipulated.

2) Overview of laws and regulations to be studied after an injection site is determined

This section outlines the laws and regulations to be studied after an injection site and a port and harbor where CO_2 is to be refilled are determined.

Engineering works and operations at CO_2 injection sites and refilling areas stipulated in any of the following laws are subject to the corresponding Ports and Harbors Act, Act on Port Regulations, Coast Act, Maritime Traffic Safety Act, Act on

Development of Fishing Ports and Grounds, Act on the Protection of Fishery Resources, Marine Resources Development Promotion Act, and/or Fishery Act.

CO_2 refilling is assumed to be conducted in ports and harbors stipulated in the Coast Act. Even though CO_2 injection is not covered by the abovementioned laws, the CO_2 injection site may be subject to the fishery rights stipulated in the prefectural regulations concerned. Therefore, studying prefectural regulations, if any, is also required when determining such sites.

If any of the abovementioned laws outlined in a foregoing section or this section requires the submission of a report to the prefecture governor concerned, the prefecture concerned must be identified after such site is determined. The head office of such business operator, the location of the port where CO_2 is refilled, and the prefecture nearest to such site can be identified after consultation with the minister or administrative organ that has enacted such laws or regulations.

3) Other laws and regulations

An injection facility may be subject to the Radio Act, depending on the specifications of the telecommunication buoy, etc.

Although it is not covered by this Project, a permit to dig a well necessary for CO_2 injection and the related well specifications are subject to compliance with the Mining Act and Mining Safety Act or application mutatis mutandis of these laws. Furthermore, operations specific to CCS that are covered by no law may be undertaken, besides digging a well for injection, and a study on the application mutatis mutandis of the Mining Act or the Mining Safety Act would be necessary.

Concerning experiments on underground CO_2 sequestration conducted during 2002 through 2008 in Nagaoka City, etc. of Niigata Prefecture, the facilities related to CO_2 injection had permits in accordance with the Mining Safety Act. However, according to our hearing with JCCS, the Ministry of Economy, Trade and Industry indicated its opinion that such CO_2 injection be subject to the High Pressure Gas Safety Act.

In the case that an injection site or CO_2 refilling site is located in an area stipulated in the National Land Use Planning Act, City Planning Act, Natural Parks Act, and/or Nature Conservation Act, the site is subject to the corresponding laws.

In the case that in this Project, materials other than CO_2 including earth and sand discharged during civil engineering works are discarded, such operations are subject to the Waste Management and Public Cleansing Act.

4.2.3 Overview of specific laws and regulations

1) Marine Pollution Prevention Law

(1) Overview

Japan guarantees the 1996 London Protocol (officially called the 1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972) discussed below domestically by the Law relating to the Prevention of Marine Pollution and Maritime Disasters (hereinafter referred to as the "Marine Pollution Prevention Law"). Aiming to ratify the protocol by 2007, Japan amended the Marine Pollution Prevention Law to domestically guarantee the amendments to Annex 1 of the 2006 Protocol.

(2) Relation to CCS

As stated above, after Annex 1 of the 1996 London Protocol was amended, which provided a framework for regulating CO_2 storage in sub-seabed geological formations, the domestic system was reviewed to incorporate the amendment. In other words, the Japanese government promoted preparations to cope with the amendment by amending the Marine Pollution Prevention Law that domestically guarantees the Protocol (see Table 4.2-3).

Table 4.2-3. Steps to amend the Marine Pollution Prevention Law for CO_2 storage in sub-seabed geological formations

9.4.2006	Consultation between the minister of the environment and the Central Environmental Council on "Utilization of CO_2 storage in sub-seabed geological formations as a countermeasure against global warming and prevention of its impact on the marine environment"
9.25.2006	Expert committee on CO_2 storage in sub-seabed geological formations 1st meeting
10.12.2006	2nd meeting
11.20.2006	3rd meeting
12.26.2006	4th meeting
12.28.2006	Public comment period ~ 1.27.2007
2.8.2007	Expert committee on CO_2 storage in sub-seabed geological formations 5th meeting
3.9.2007	Cabinet approval of the bill to amend the Marine Pollution Prevention Law
5.8.2007	Passage of the bill in the House of Representatives
5.23.2007	Passage of the bill in the House of Councilors
5.30.2007	Publication of the amended law

The framework of the amended Marine Pollution Prevention Law that regulates CO_2 storage in sub-seabed geological formations is summarized below. This framework

follows the concept of the 1996 London Protocol (see Fig. 4.2-1).
- The dumping of wastes and other matter under the seabed is prohibited in principle, exempting CO_2 storage in sub-seabed geological formations.
- A permit from the minister of the environment is required in order to store CO_2 in sub-seabed geological formations.
- Applicants are obligated to assess the environmental impact and develop an environmental monitoring plan when a permit is applied for.

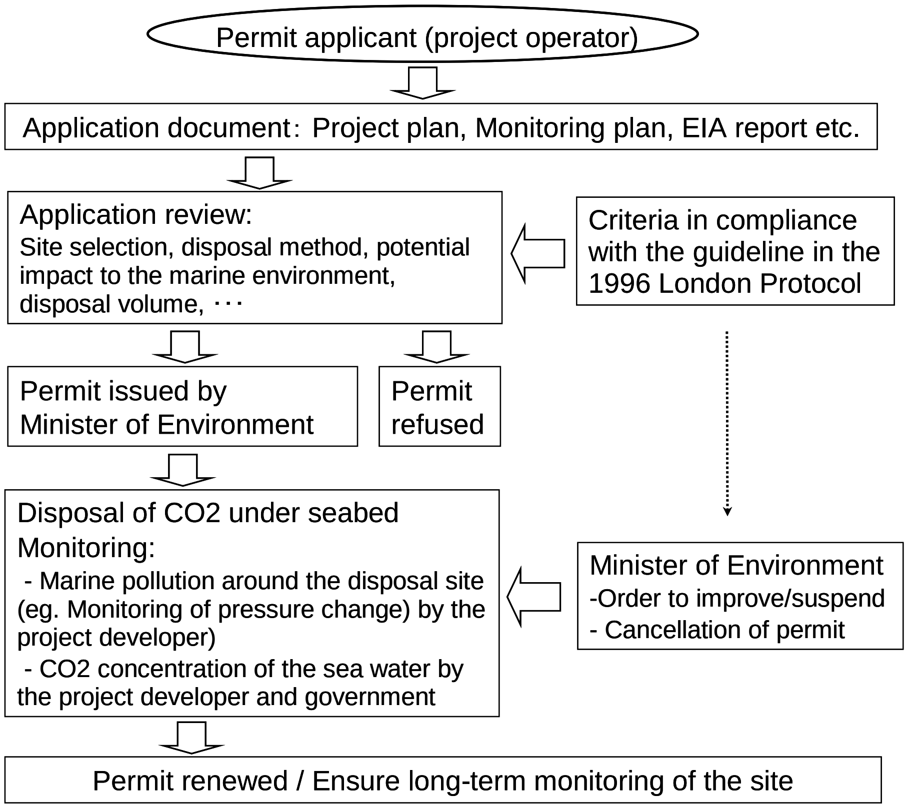


Fig. 4.2-1 Framework for CCS regulations according to the Marine Pollution Prevention Law

In 2007, when the amended law was enacted, detailed provisions for the Cabinet Order, Ordinance, and Notification were established and issued (see Fig.4.2-2), and these comply with the "Waste Assessment Guidelines for Carbon Dioxide Storage in Sub-seabed Geological Formations" (CO_2-WAG), which complements the 1996 London Protocol.

(3) Guideline for applicants to obtain the disposal permission

A MOE's document entitled "Guideline for applicants to obtain permission for CO_2

stream disposal" was issued in January 2008**.** In this section, the legal status of this document is examined.

The "Guideline for applicants to obtain permission for CO_2 stream disposal (January 2008)" developed by the Ministry of the Environment falls within the following system of the Marine Pollution Prevention Law, and is regarded as "commentaries to the Notification." The guideline, in a precise sense, has no legal binding force since it was not announced by an official gazette. However, as officials in charge will refer the guideline when reviewing application forms, applicants should take it into great consideration when preparing the application form.

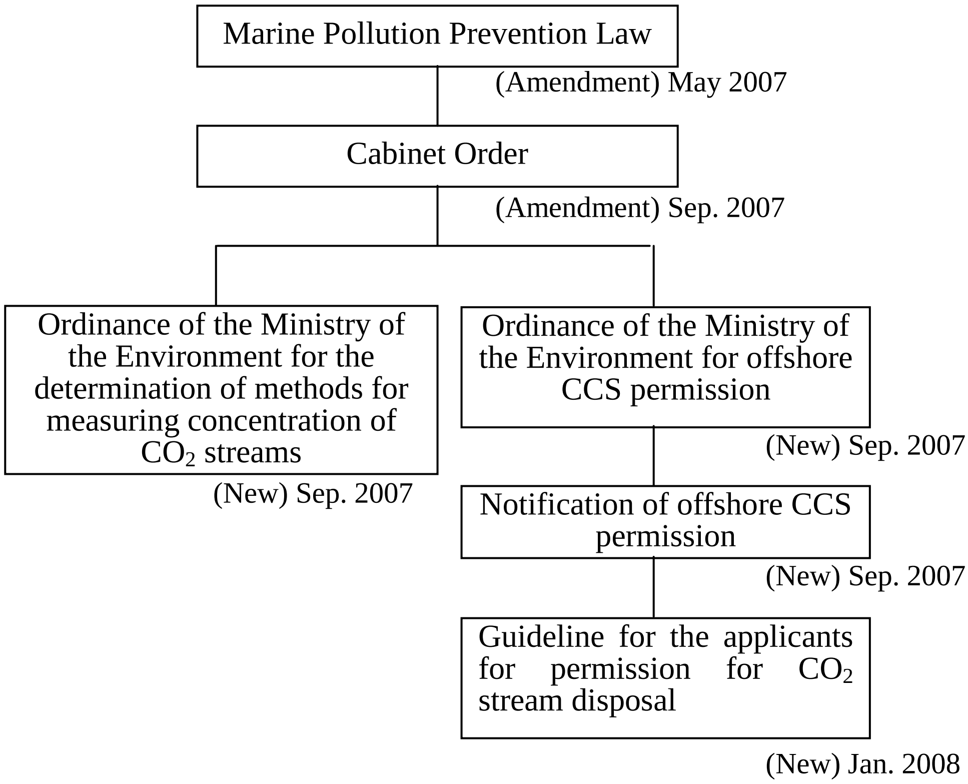


Fig. 4.2-2 Regulatory system for CO_2 storage in sub-seabed geological formations by the Marine Pollution Prevention Law

2) High Pressure Gas Safety Act

(1) Overview

The purpose of the High Pressure Gas Safety Act is to regulate the production, storage, sale, transportation, and other matters related to the handling of high-pressure gases, their consumption as well as the manufacture and handling of their containers and to encourage voluntary activities by private businesses and the High Pressure Gas Safety Institute of Japan for the safety of high-pressure gases with the aim of securing public safety by preventing accidents and disasters caused by high-pressure gases (Article 1). The High Pressure Gas Safety Act is in a complex framework that encompasses the High Pressure Gas Safety Act Cabinet Order and the corresponding Ordinance of METI, in addition to a number of notifications.

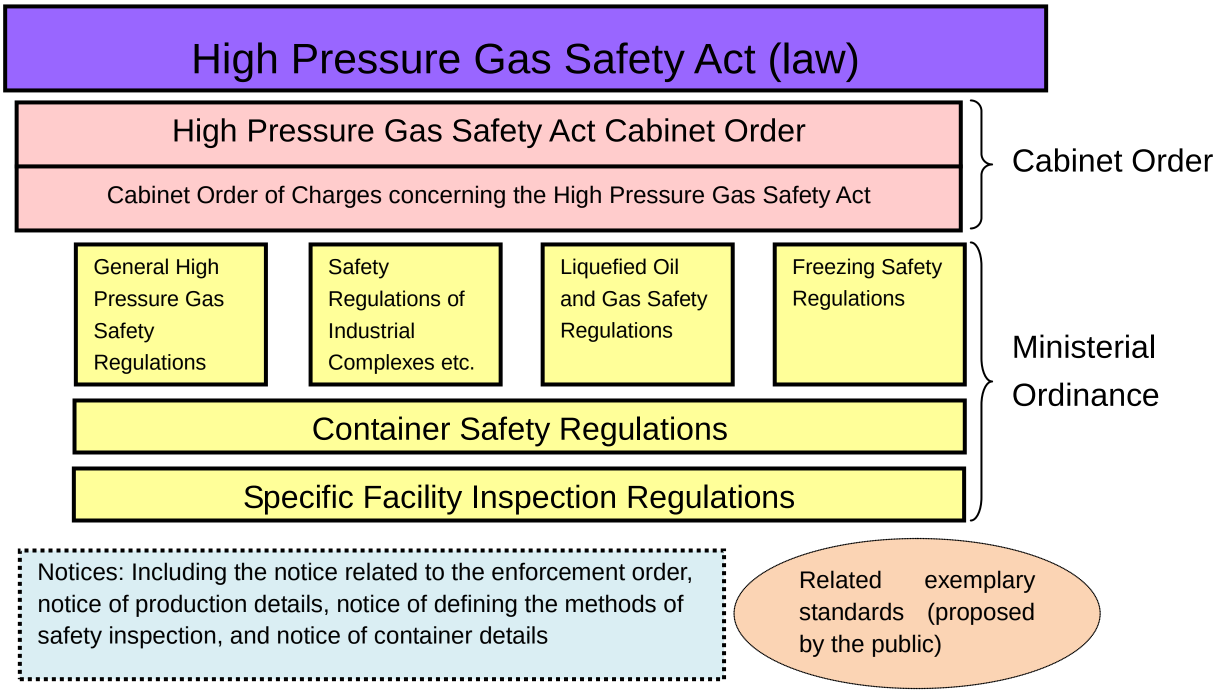


Fig. 4.2-3 Framework of the High Pressure Gas Safety Act[8]

(2) Relation to CCS

Article 2 of the High Pressure Gas Safety Act stipulates that liquid CO_2 (CO_2 stream) is subject to the act.

Article 5 also regards refilling containers with high-pressure gas as "producing high-pressure gas." Accordingly, the facilities for refilling containers with CO_2 are subject to the High Pressure Gas Safety Act. Further, because changing the pressure of high-pressure gas is also regarded as "producing high-pressure gas," such injection facilities are also subject to the High Pressure Gas Safety Act.

The containers installed in shuttle ships are subject to the Ship Safety Act. However, facilities for transporting CO_2 streams in a port or harbor, onboard facilities used during injection, and riser pipes used when a shuttle ship injects CO_2 streams into wells are subject to the High Pressure Gas Safety Act.

(3) Points of compliance during CO_2 refilling

-Permit approval

Article 5 of the High Pressure Gas Safety Act stipulates that any person who intends to produce 300 cubic meters of CO_2 or more (when converted into zero Pa

[8] http://www.meti.go.jp/committee/materials2/downloadfiles/g80730a05j.pdf

state at 0 deg.C) shall apply for a permit for a Class 1 producer from the prefectural governor concerned. Likewise, any person who intends to produce less than 300 cubic meters of CO_2 shall, as a Class 2 producer, submit a report to the prefectural governor.[9] Because refilling containers with CO_2 is regarded as CO_2 production, production permit approval and reporting are required.

Articles 15 and 16 of the same act stipulate permission for high-pressure gas storage. According to these articles, any person intending to install a tank of 3,000 cubic meters or greater capacity in a port or harbor to store CO_2 temporarily is required to obtain a permit for a Class 1 storage place. Likewise, any person intending to install a tank of not less than 300 cubic meters and not more than 3,000 cubic meters is required to obtain a permit for a Class 2 storage place from the prefectural governor.

-Technical standards

To obtain permit approval for CO_2 production, the technical standards stipulated in Article 8 of the High Pressure Gas Safety Act shall be satisfied. Such specific standards are stipulated in the METI Ordinance of the same act. Although the standards cover 47 items in total, this section refers to only those that require attention for this Project. In this connection, the laws and regulations on filling stated below are applicable to cases where temporary storage is needed in a port or harbor but is not applicable to the refilling of tanks installed in shuttle ships (refilling tanks installed in shuttle ships is regulated by the Ship Safety Act).

Facilities (riser pipes, onboard pumps, etc.) used when a shuttle ship injects CO_2 into a well are also required to satisfy the METI Ordinance of the same act.

3) Industrial Safety and Health Act

(1) Overview

The purpose of the Industrial Safety and Health Act is to secure, in conjunction with the Labor Standards Act, the safety and health of workers in the workplace, as well as to facilitate the establishment of a comfortable working environment, by promoting comprehensive and systematic countermeasures concerning the prevention of industrial accidents, such as taking measures for establishing standards for hazard prevention, clarifying safety and health management responsibility, and promoting voluntary activities with a view to preventing industrial accidents.

[9] Article 3 of the High Pressure Gas Safety Act Cabinet Order specifies that a production permit is required when producing 300 cubic meters of CO_2 or more per day.

(2) Relation to CCS

Any person intending to conduct operations that are specified in the Industrial Safety and Health Act or the Industrial Safety and Health Act Cabinet Order shall conduct the operations with a working system that complies with these laws. In relation to this Project, major operations that accompany refilling CO_2 in shuttle ships include loading and/or unloading cargos to/from ships, using a crane, etc.

4) Laws and regulations to be studied after an injection site is determined

(1) Ports and Harbors Act

Article 37 of the Ports and Harbors Act stipulates that any person intending to occupy waters or an unused public site in a port or harbor area shall obtain a permit from the port administrator.

The Ports and Harbors Act deals with important ports and harbors, specified important ports and harbors, and regional ports and harbors. Article 2-2 of the act refers to important ports and harbors that are bases of international marine transport networks or domestic marine transport networks and that have a significant relationship with other countries. Specified important ports and harbors refer, among important ports and harbors, to ports and harbors especially important for international marine transport networks, which are designated by cabinet order. Regional ports and harbors refer to those other than important ports and harbors.

For this Project, ports and harbors are likely to be used as places where shuttle ships refill containers with CO_2.

(2) Act on Port Regulations

The Act on Port Regulations stipulates that any person intending to conduct engineering works or operations in a specified port or near the border of a specified port shall obtain a permit from the captain of the port. Such specified ports have been defined by ministerial ordinance.

(3) Coast Act

Any person intending to build or refurbish a facility in a water surface or a site other than a public coast in a coast preservation area shall obtain a permit from the coast authority.

(4) Maritime Traffic Safety Act

The Maritime Traffic Safety Act has been enacted to ensure safe maritime traffic in congested sea areas by providing a special traffic method and implementing rules to prevent such risk. Any person intending to conduct engineering works or operations in waters designated by cabinet order in Tokyo Bay, Ise Bay, or Seto Inland Sea shall obtain a permit from the director general of the Japan Coast Guard.

(5) Act on Development of Fishing Ports and Grounds

Any person intending to conduct operations, such as building a structure, in water or in an unused public site in the area of a fishing port shall obtain a permit from the fishing port administrator.

(6) Act on the Protection of Fishery Resources

Any person intending to conduct engineering works in a protected water surface that is likely to result in a change in the waterway or river flow or water level shall obtain a permit from the prefectural governor or the Minister of Agriculture, Forestry and Fisheries, who controls the protected water surface.

(7) Marine Resources Development Promotion Act

Any person intending to engage in an activity in a development area that is likely to disturb the performance of a development plan shall submit a notification to the prefectural governor.

(8) Fishery Act

The "fishery right," which is an exclusive right, has been granted to fishery cooperative~~s~~ in injection sites to protect the business for livelihood of the fishery operators, and negotiations including those on compensation are necessary. If a fishery operator has a fishery right in an injection site, negotiations including those on compensation for such an operator are necessary.

The table below lists the laws and regulations stated in Sub-sections (1) through (8) above. Any person intending to engage in engineering works or operations in an area covered by any of these laws and regulations shall apply to the competent authority for permit approval.

Since we have experienced difficulty in negotiating with local fishermen for decades in Japan, the Fishery Act is examined in detail in the next section.

Table 4.2-4 Laws and regulations to be studied after an injection site is determined

Laws and regulations	Areas covered	Person authorized to permit
* Ports and Harbors Act	Port and harbor areas	Port administrator
* Act on Port Regulations	Special ports	Captain of the port
* Coast Act	Coast conservation areas	Coast authority
* Maritime Traffic Safety Act	Tokyo Bay, Ise Bay, Seto Inland Sea	Director general of the Japan Coast Guard
* Act on Development of Fishing Ports and Grounds	Fishing ports	Fishing port administrator
* Act on the Protection of Fishery Resources	Protected water surfaces	Prefectural governor or Minister of Agriculture , Forestry and Fisheries
* Marine Resources Development Promotion Act	Development areas	Prefectural governor
* Fishery Act	Water surfaces with a fishing right	Fishery cooperative (as a counterpart of the negotiation)

5) Fishery Act

"In Japan, is there any registration system of the historically inherited fisherhermen's right to specific sea areas?" is one of the frequently-asked questions. In this section, a legal analysis on this question is provided.

In Japan, as large-scale CO_2 sources are concentrated in coastal areas, it is rational to determine a CO_2 storage point in a seaside area rather than in an inland area. However, commercial fishing operations have been widely conducted in the seacoast areas of Japan. Thus, coordinating with fishery operators if CCS is implemented in coastal sea areas is a major problem.

(1) Legal system on fishery in Japan

Fishery in Japan is categorized into 6 groups: fishery with fishery right, designated fishery, fishery with approval, fishery with notification, fishery with governor’s permit, and free (non-regulated) fishery. Each group is regulated separately as follows.

The “fishery right,” which is an exclusive right, has been granted to fishery cooperatives to protect the business for livelihood of the fishery operators.

Designated fishery, which includes offshore trawl fishery and pelagic tuna and bonito fishery, requires permit from the minister of agriculture, forestry and fisheries.

Fishery with approval, which includes snow crab fishery and Atlantic longline fishery, requires approval from the minister of agriculture, forestry and fisheries.

Fishery with notification, which includes drift net fishery for swordfish and coastal tuna longline fishery, requires notification to the minister of agriculture, forestry and fisheries.

Fishery with governor’s permit, which includes small-scale round haul net fishery and small-scale trawl fishery, requires permit from the local governor.

The following section explains fishery right.

(2) Fishery right

(a) What is the fishery right?

The fishery right is the right to fish on the surface of the water, and is set by governors on the basis of the Fisheries Act. According to Article 23 of the Fisheries Act, "The fishery right is considered as a real right and the provisions for land shall apply mutatis mutandis," and a claim right or real right is granted to the owner of fishery rights. Thus, in fishing operations based on the fishery right, the exclusive right of utilization in certain sea areas shall be protected.

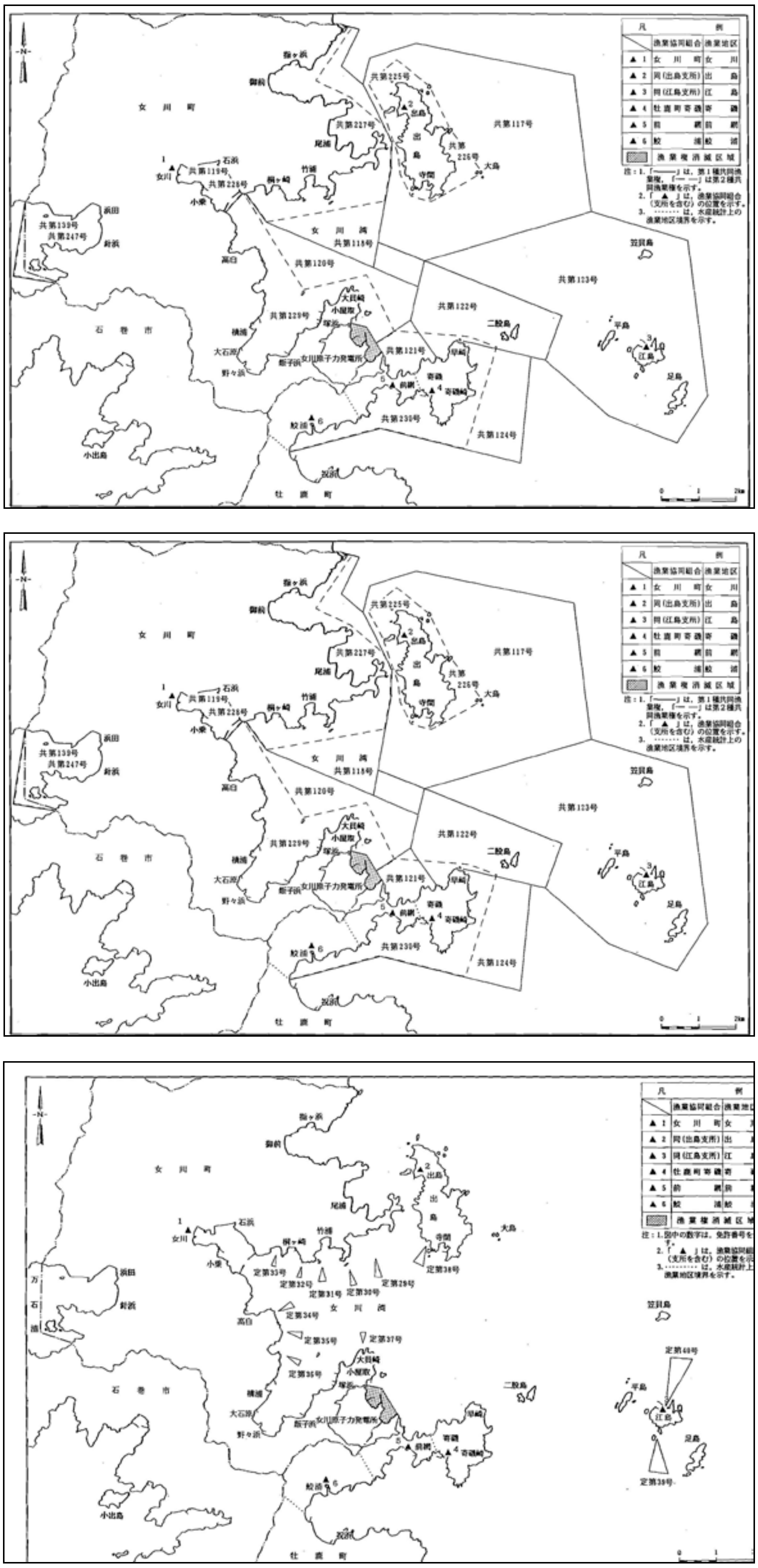
The fishery rights include "stationary fishery right," "demarcated fishery right," and "common fishery right" (Table 4.2-5).

Table 4.2-5 Types and description of fishery rights

Type of Fishery Right	Description of Right	Right Subjects
Stationary Fishery Right (Fisheries Act, Article 6, Section 3)	Right to fish by fixing fishing gear	Individual fishery operators
Demarcated Fishery Right (Fisheries Act, Article 6, Section 4)	Right to farm in a certain zone (typically, fish culturing of laver, oysters, pearls, etc.)	Individual fishery operators
Common Fishery Right (Fishers Act, Article 6, Section 5)	Right to fish cooperatively in a certain surface of water (Shellfish, lobster, seaweed are typical fishing targets.)	Fishery cooperatives or the Federation of Fisheries Cooperative Associations

(b) Status of setting of fishery rights

Fishery rights have been set in most of the domestic seacoast areas in Japan (Fig. 4.2-4). For this reason, it is highly likely that negotiations with fishery operators or fishery cooperative associations will be needed when the CCS project is implemented on the coast. It is expected that the negotiations will include coordination of a survey period for geological formations and fishing seasons, adjustment of the position of injection wells or survey wells, etc.



<u>Fig. 4.2-4 Examples of fishery rights set in Japanese coastal zones</u>

(Upper figure: common fishery; Middle figure: demarcated fishery; Lower figure: stationary fishery)
(Source: *Onagawa Nuclear Power Plant Modified Environmental Impact Study Report*)

(3) Possibility of compensation for fishing operations

In Japan, if construction of public projects such as reclamation and landfill requires restriction on the fishery activity, compensation is paid to fishery operators. The compensation includes compensation for abolition of fishing, that for suspension of fishing, that for reduction of management scale of fishing, and others.

Unlike the projects described above, the CCS project does not occupy the surface of the water permanently. Thus, it seems unlikely that the CCS project will involve extinguishment of fishery rights. However, it is highly likely that the need for compensation will arise for suspension of fishing operations involved in a survey such as seismic exploration of the geological formation under the seabed, building of an offshore pipeline, and drilling of an exploration well, or restrictions on fishing due to the existence of the offshore pipeline built, or facilities such as platforms to be used in injection.

6) Mining Law and Mine Safety Act

(1) Overview[10]

The Mining Act of Japan was issued as Act No. 289 of December 20, 1950, came into force in January 31, 1951, and has been amended several times since it was enforced. This law provides a variety of systems based on the following concepts.

(a) "Mining right," independent of land ownership, shall be acknowledged as the title for mining and acquisition, and shall be endowed by acts of government.
(b) No particular qualifications or requirements shall be required in order to acquire mining rights. Based on the principle of "first-to-file," equal opportunities to participate in mining shall be provided for anyone, as long as one is a citizen or corporate body of Japan.
(c) Enforcing the mining right is entrusted to the ingenuity and responsibility of the mining right holder. However, due to the peculiarity of mining, the nation shall supervise to the necessary degree and impose obligations on the mining right holder.
(d) In an effort to coordinate interests among the mining industry, the public, and other industries, the nation shall be actively involved in enforcing the mining right. In addition, damage to outside parties that may be caused by mining activities shall be justly compensated.

[10] Adapted from "Mining Law" in JOGMEC's "Dictionary of Oil and Natural Gas Terms" (http://oilgas-info.jogmec.go.jp/dicsearch.pl).

(2) Relation to CCS

There are no provisions in the Mining Act that mention CCS explicitly. However, enhanced oil recovery (EOR), which has made some achievements in Japan, is considered to have been undertaken within the scheme of the Mining Act.

CO_2 EOR is a recovery technique for increasing the recovery rate of crude oil by injecting CO_2 into an oil field, and it has been commercialized mainly in the United States. It can be expected that EOR with CO_2 recovered from the origin of emissions may be environmentally effective in terms of reducing CO_2 emissions, as CO_2 is sequestrated in underground oil fields.

In Japan, the "EOR demonstration project in Kubiki oil field, Niigata Prefecture" (Japan National Oil Corporation and Teikoku Oil Co., Ltd., for six years from FY 1988) and "EOR demonstration project in Sarukawa oil field, Akita Prefecture" (Japan National Oil Corporation and Japan Petroleum Exploration Co., Ltd., for seven and a half years from FY 1993) were implemented as EOR projects with CO_2, within the legal framework for the petroleum or mining industry. If CO_2 EOR is undertaken, the current domestic law also requires the submission of an application to the relevant ministries and the local government for each process relating to CO_2 underground injection (e.g., drilling of an injection well, installation of injection facilities, injection operations, etc.), within a framework such as the Mining Act and Mine Safety Act.

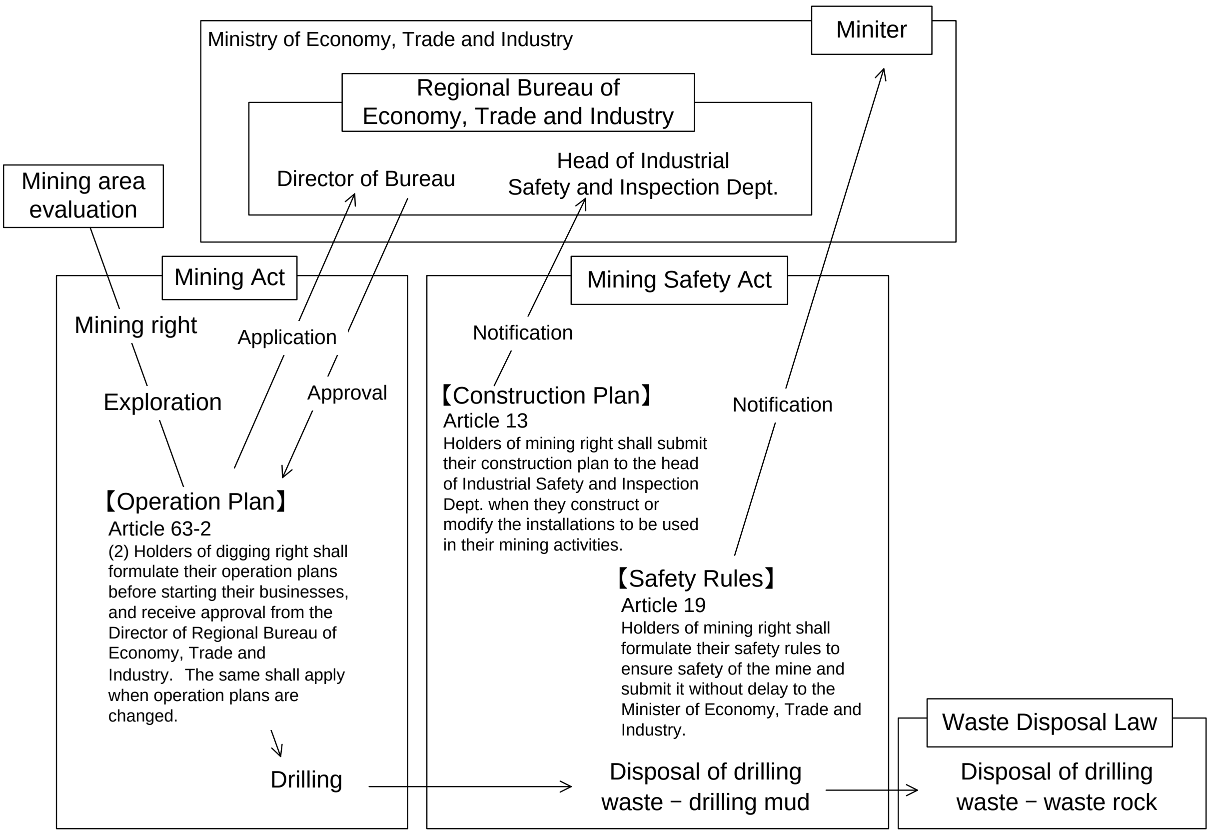


Fig. 4.2-5 Schematic diagram of the legal procedures for the CO_2 EOR project

(3) Operator's liability issues

The long-term strict liability under the laws such as the Mining Act, the Water Polution Control Law, and so on is a typical liability issue in CCS. The treatment of this issue in the domestic laws are summarized in this section.

[Monitoring duration]

As of today, the Marine Pollution Prevention Law is the only law in Japan that explicitly prescribes rules for CO_2 storage under the seabed. The Marine Pollution Prevention Law defines "dumping under the seabed" as "dumping matter under the seabed *(including stored matter)"* (Article 3-7.2), and prescribes that one should apply for a "dumping permit" every five years and continue monitoring as long as the dumping under the seabed is continued. Although future studies may provide the period of environmental monitoring for which the operator should continue, the current framework implies the permanent need for environmental monitoring after the operator has stored CO_2.

[Liability]

According to the provisions relating to Damages in Tort of the Civil Code, a person who has intentionally or negligently infringed any right of others, or a legally protected interest of others, shall be liable to compensate any damages resulting in consequence (Article 709). In other words, the fault liability principle is the basic rule in general terms. Thus, the principle under the interpretation of Article 709 of the Civil Code is that the victim is liable to prove the fact corresponding to the negligence of the perpetrator when demanding compensation for damages in tort.

In contrast, a no-fault liability system is a system whereby liability is imposed with or without negligence if a business has caused air/water pollution to damage human health. In an effort to increase the responsibility of businesses and facilitate bailout for victims, this was introduced to the Air Pollution Prevention Law (1968) and the Water Pollution Prevention Law (1970) as an exception to the negligence liability principle of the Civil Code, when those laws were amended in 1972.

In order to demand compensation for damages in accordance with the provisions of the Civil Code, the victim must prove the occurrence of damage, causality of the act and subsequent result, illegality, and intentional or negligent act of the perpetrator. However, it became unnecessary to prove intentional or negligence acts among those above in certain fields such as air pollution.

Example cases of no-fault liability are found in the Mining Act applied at the *Itai-Itai* (ouch-ouch) disease trial, liability for damage caused by space objects, liability for nuclear damage, civil liability for oil pollution damage, etc.

In the case of damage caused by CO_2 leakage occurring during CCS activities, no-fault liability might be imposed. However, this issue has not even been discussed as yet.

(4) Amendment of the Mining Act

The bill to amend the Mining Act was approved by the Cabinet on March 11, 2011 and passed the House of Representatives on April 5. The bill revises the existing "first-to-file" principle. Instead, it requires financial and technical capabilities of applicants to conduct reasonable development of mining in an appropriate manner. This is the same as one of the requirements for CO_2 storage, regulated by the Marine Pollution Prevention Law.

4.2.4 Difference between the Waste Assessment Guidance in the London Protocol and MOE's regulation

The difference between the Waste Assessment Guidance in the London Protocol and MOE's regulation in Japan includes monitoring frequency, purity of the CO_2 stream, consultation with stakeholders, and so on.

Regarding CO_2 storage in sub-seabed geological formations, the Marine Pollution Prevention Law adopts most of the contents in the 1996 London Protocol with little change; it can therefore be said that it is the same in many parts.

The differences between these two are as follows:

1) CO_2 storage by facilities connected to land

[The 1996 London Protocol]

In principle, the Protocol regulates dumping of land wastes at sea (including in seabed) from vessels, aircrafts, or platforms. Therefore, activities storing CO_2 under the seabed by facilities connected to land are exempt. CO_2 injection using extended reach drilling (ERD) or subsea injection system with subsea pipelines (*eg.* Snohvit project in Norway) are also exempt.

[Marine Pollution Prevention Law]

Under the Marine Pollution Prevention Law, CO_2 storage under the seabed even by the above method is regarded as dumping of CO_2 at sea (under the seabed), and is subject to control.

2) Approaches for Risk Assessment

[The 1996 London Protocol]

The "Specific Guidelines for the Assessment of Carbon Dioxide Streams for Disposal into Sub-seabed Geological Formations," which is under the system of the 1996 London Protocol, states that "for the disposal of carbon dioxide streams into sub-seabed geological formations, the assessment should address risks posed by a leak from the carbon dioxide stream sequestration process." In general, "risk" is defined as the result of multiplying a hazard from an event by the probability of an event occurring. Therefore, it can be considered that the leakage probability is also within the scope of consideration in the 1996 London Protocol.

[Marine Pollution Prevention Law]

The "assessment of potential marine environmental impact," which is within the scope of the assessment of marine environmental impact in accordance with the Marine Pollution Prevention Law, shall be conducted based on a deterministic method, by evaluating possible impacts on the marine environment caused by CO_2 leakage into the sea under certain assumptions.

3) CO_2 purity

[The 1996 London Protocol]

According to Article 4 of Annex 1 of the 1996 London Protocol, the conditions for CO_2 streams to be disposed of into sub-seabed geological formations are as follows:

4 Carbon dioxide streams referred to in Paragraph 1.8 may only be considered for dumping, if: .1 disposal is into a sub-seabed geological formation; and .2 they consist overwhelmingly of carbon dioxide. They may contain incidental associated substances derived from the source material and the capture and sequestration processes used; and .3 no wastes or other matter are added for the purpose of disposing of those wastes or other matter.

In summary, it only describes the CO_2 to be disposed of as "overwhelmingly" pure CO_2, and no definite values are shown.

[Marine Pollution Prevention Law]

In the Marine Pollution Prevention Law Cabinet Order, conditions for a CO_2 stream to be disposed of into a sub-seabed geological formation are described as follows:

1. The standards concerning the sea areas of sub-seabed disposal of wastes that arise from mineral exploitation (Article 11.4). After appropriate measures have been taken in accordance with the regulations in the Mineral Safety Act for the prevention of mine pollution.

2. Purity standards for CO_2 that can be stored under the seabed (Article 11.5)

(1) Only the CO_2 captured from chemical reactions between amine solvents and CO_2 is to be considered in order to separate CO_2 from other substances.

(2) CO_2 purity is to be more than 99% by volume percentage or more than 98% for the CO_2 captured from the hydrogen production process at a petroleum refinery.

(3) No wastes or other matter are to be added.

4.3 HSE

4.3.1 Ideas of HSE for the Project

Most companies in the oil development industry refer to the "Guidelines for the Development and Application of Health, Safety and Environmental Management Systems" (No. 210) prepared by the OGP (Internal Association of Oil & Gas Producers) as guidelines for their HSE (health, safety and environment) management systems.

Meanwhile, most companies refer to the OHSAS 18001 (Occupational Health and Safety Assessment Series), a set of international certification standards, in studying their HSE management systems in general industries. In Japan, many companies have studied their HSE management system in reference to the "Guidelines on Occupational Safety and Health Management System (OSHMS Guidelines)" published by the Ministry of Labour (the present Ministry of Health, Labour and Welfare) in 1999.

We need to bridge the HSE policies of participating corporations and organizations and to examine the HSE policies of this Project in studying an HSE management system and policy for this Project. Specifically, the following process will be necessary. That is, it will be necessary to 1) check the HSE policies of corporations and organizations participating in this Project; 2) formulate an HSE policy by bridging the HSE policies of the participating corporations and organizations; and 3) comply with the HSE policy after the Project is launched.

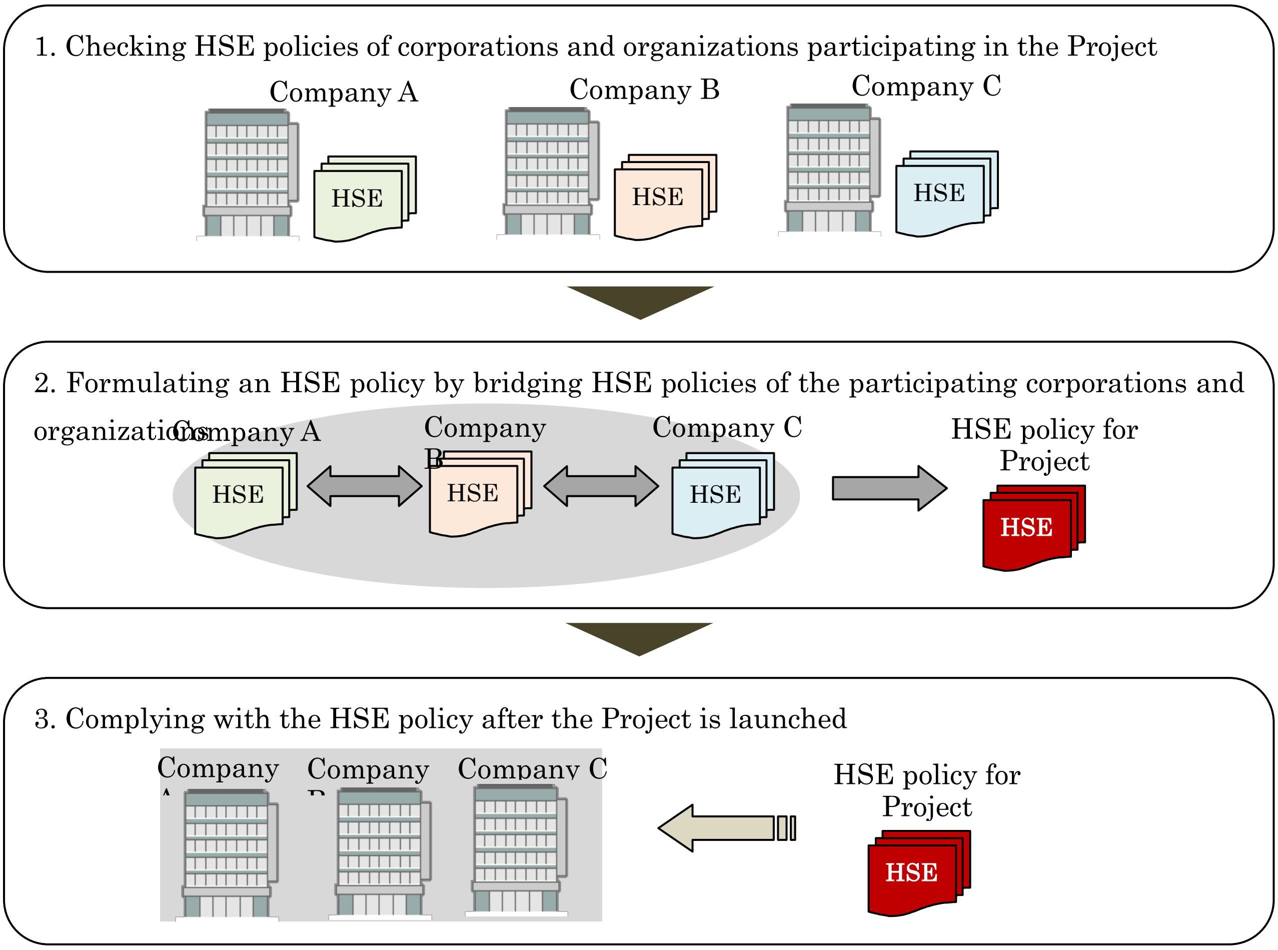


Fig. 4.3- 1 Flow of bridging HSE

In other words, we will study optimal HSE standards, which are necessary for implementing the Project, by bridging the HSE policies of participating corporations and organizations rather than formulating an HSE for the Project.

4.3.2 Specific HSE Policies

The HSE policies stated below have been adopted by the following two companies in the oil development industry. They have a record of achievement in CCS projects.

INPEX CORPORATION (INPEX) offered a gas field for a demonstrative experiment on CO_2 underground storage, which was conducted by the Research Institute of Innovative Technology for the Earth (RITE), and extended cooperation for the experiment of injecting CO_2, drilling an observation well, and building and operating an injection plant. INPEX has also participated in JCCS to conduct a feasibility study on a CCS project in Japan.

Japan Oil, Gas and Metals National Corporation (JOGMEC), an independent administrative institution, has continued engaging in research and development in CCS EOR (enhanced oil recovery). Specifically, JOGMEC has been conducting research on CCS projects for oil and natural gas developers, studying the commercialization of CO_2 EOR at oil fields in Southeast Asia and Mexico, and offering technological support to CCS-related projects run by Japanese organizations (e.g., a CCS/EOR project in China).

Cases of projects conducted by JOGMEC will become "HSE examination standards" that JOGMEC will request from bodies implementing a project if JOGMEC invests and/or finances the project. Meanwhile, cases of projects conducted by INPEX CORPORATION will become guidelines for HSE management systems defined by the group.

JOGMEC's HSE Examination Items[11]

1. General Efforts towards HSE

1.1 Systems, etc. for HSE

1.1.1 HSE Management System

1.1.2 Environmental Impact Assessment (EIA) Report, etc.

1.1.3 Monitoring System

1.2 Legal Compliance

2. HSE Standards, etc.

2.1 Pollution Control Measures

2.1.1 Air

2.1.2 Water Quality

2.1.3 Wastes

2.1.4 Soil Contamination

2.1.5 Noise and Vibration

2.1.6 Bad Odors (on land alone)

2.2. Natural Environment

2.2.1 Protection Areas

2.2.2 Ecosystems

2.2.3 Hydrometeors

2.2.4 Topography and Geology (on land alone)

2.3 Social Circumstances

2.3.1 Relocation of Residents (on land alone)

2.3.2 Life and Livelihood

2.3.3 Cultural Heritages

[11] http://www.jogmec.go.jp/about_jogmec/informationopen/active_report/docs/sekiyu_07.pdf

2.3.4 Scenery
2.3.5 Minorities and Indigenous People
2.3.6 Neighboring Projects (development projects alone)
2.4 Health Effects
2.4.1 Hazardous Materials
2.4.2 Radioactive Materials
2.4.3 Working Noise
2.4.4 Health Control
2.5 Safety
2.5.1 Design Policy
2.5.2 Safety Design
2.5.3 Risk Analysis
2.5.4 Measures to Control Accidents and Emergency Cases
2.5.5 Work Safety and Maintenance
2.5.6 Education and Training
2.6 Other
2.6.1 Discarding Facilities
2.6.2 Use of the Project Site
2.6.3 Measures to Deter Terrorism and Crime

INPEX List of Corporate HSE Management System Procedures[12]

1 Document and Record Control
2 Contractors' HSE Management
3 Risk Assessment
4 HSE Plan Development
5 HSE Objectives and Programs
6 Emergency Response
7 Incident Reporting and Investigation
8 HSE Performance Data
9 Competence and Training
10 HSE Audit
11 Environmental and Social Impact Assessment
12 Personnel Security
13 Personnel Health
14 HSE Corrective and Preventive Actions
15 Corporate HSE Management System Vocabulary
16 Legal and Other Requirements
17 Internal Communication
18 External Communication
19 Asset Integrity
20 Transport Safety Management
21 Personal Protective Equipment
22 Management Review
23 Operational Organization HSE Committee

4.4 Other International Rules, etc.

4.4.1 Rules to be observed

As described above, the operations under this Project are subdivided into the following three sections, namely 1) loading CO_2 into ships in a port or harbor, 2) transporting CO_2 into ships in a port or harbor, and 3) injecting CO_2 in the site. For a shuttle ship to be used in 2) transporting CO_2 into ships in a port or harbor, and 3) injecting CO_2 in the site, there are the international rules or regulations to be noted, in addition to the laws and regulations (mainly, the Ship Safety Act).

[12] http://www.inpex.co.jp/english/csr/system.html

As summarized in Table 4.4-1, under the Ship Safety Act, which is a domestic regulation, rules to enable a shuttle ship to travel safely as a vessel have been defined.

The IGC code (International Gas Carrier Code), which is an international convention, stipulates the structure or equipment of a ship for carrying liquefied gas and has been established by the IMO (International Maritime Organization).

In the Rules and Regulations for the Construction and Classification of Ships of NK (Nippon Kaiji Kyokai), provisions unique to the Classification Society are provided, in addition to those of the IGC Code.

For a shuttle ship used to transport liquefied CO_2, the IGC Code has set out provisions on liquid CO_2, which have a lower request level than other inflammable cargo. However, we will basically comply with provisions similar to those for other liquefied gas, and design a shuttle ship.

Table 4.4-1 Laws and regulations/international rules to be observed by shuttle ships

Name	Overview
Ship Safety Act (Ministry of Land, Infrastructure, Transport and Tourism)	It has been provided to ensure that vessels can travel safely.
IGC Code (IMO)	International convention that defines special cases of ships carrying liquefied gas.
Rules and Regulations for the Construction and Classification of Ships (NK)	They include regulations unique to the Classification Society, in addition to the IGC Code.

4.4.2 IGC Code

As the number of vessels that carried LPG or LNG had increased since the 1960s, the need arose to improve international conventions concerning safety measures for liquefied gas carriers. Although the Rules and Regulations for the Construction and Classification of Ships (IMCO Gas Code) were adopted in 1975, their binding power in terms of international conventions was weak. Subsequently, in 1983, IMO made the IGC Code compulsory, which then became an international convention governing liquefied gas carriers including LPG and LNG carriers.

4.4.3 Rules and Regulations for the Construction and Classification of Ships

In some cases, apart from international rules or conventions, the Classification Society of each country has established rules or regulations governing hull construction to ensure safe navigation. In Japan, there are Rules and Regulations for the Construction and Classification of Ships established by NK. Under the Rules and Regulations for the Construction and Classification of Ships, provisions unique to the Classification Society have been established, in addition to the IGC Code.

If a foreign vessel navigates into Japanese territorial waters, it must abide by the regulations of the convention, such as the IGC Code and meet the special requirements of its home country.

4.4.4 Coastal Ships and Ocean-Going Ships

In this Project, it is assumed that work will be performed in Japanese territorial waters, hence it is assumed that shuttle ships will be operated as coastal ships. In such cases, in which CO_2 is carried to sites overseas, the shuttle ships involved must abide by provisions as vessels involved in international voyages. In the case of the shuttle ships studied in this Project, the hull construction complied with the provisions on freeboard, etc., in accordance with the International Convention on Load Lines.

In view of the future potential for overseas voyages, we can also register the shuttle ship as a vessel involved in international voyage. However, if a ship is registered in any country other than Japan, it must be built based on a design that conforms to the laws and regulations or rules in that country.

Accordingly, in cases where a ship of foreign registry participates in this Project, it must respectively abide by the regulations established by the Government of Japan.

5. Shuttle-type operation of CO_2 transportation by ship

5.1 Applicability of the proposed system

In this section, possible applications of the proposed CO_2 carrier ship are presented from the viewpoint of strategic CCS deployment, particularly in East Asia region around Japan, including:

- the storage hub concept of CCS scheme using CO_2 carrier ships is characterized as the transportation from multiple sources to a large scale storage complex and provides various CO_2 emitters the opportunity to make access to the storage complex site,
- in using CO_2 carrier ships, the unit approach adopted in this study can be extended to the CCS deployment strategy, and
- advantageous feature of the proposed CO_2 carrier ship in identifying the sub-seabed geological formations for CO_2 storage is its applicability to the wider range of sea depth where the injection wells are located.

5.1.1 Storage hub

In the “source to sink” matching considerations, the original proposal of ship-based CCS (Ozaki and Ohsumi, 2010) put focus on the concept of "storage site complex", which is identified as a promising storage district in a large sedimentary basin with or without the confirmed hydrocarbon resources. The location of the storage site complex would be a "hub" connected by ships to various CO_2 sources varying with the plant size of capturing CO_2. From a viewpoint of the industrial CCS strategy, the storage hub serves a depository of CO_2 in the area where the capture plants are located within a distance of CO_2 ship transportation.

The "storage hub" might be effectively managed and operated by a single corporate body not only in identifying the storage sites, obtaining the storage permits, monitoring in the pre- and post-closure phases, and transferring the long-term liability to the state, but also in negotiating with locals. Hence, in Japan, if Japan CCS Company Limited is expected to be a future operator of CO_2 storage in the area, it is requested that the company's effort should cover the use of CO_2 ship as an alternative of the pipeline transportation.

By the proposed CO_2 carrier vessel equipped with the on-board CO_2 injection facility, the storage site complex area can be spatially extended to deep-sea side beyond the edge of the continental shelf, since we showed that the operation of offshore CO_2 injection is able to be conducted in the water depths of 500 m. That could result in larger storage potential capacity of the complex, favouring the responsible and reliable operation for longer duration of time and/or the acceptance of larger annual amount of CO_2 from the emission sources.

5.1.2 Strategy of unit size siting (matching)

The proposed CO_2 carrier vessel can be used to connect a CO_2 sink and a CO_2 source as one unit in a time and space manner. Whereas the storage operation of CO_2 consists of identifying the promising site by seismic probe, test drilling with the injectivity check of the well, and the CO_2 injection, the time sequence of the constituent operations can be treated as a unit for a given CCS scheme. In offshore storage concepts with low certainty of the injectivity of the wells, the key phase to form one "sink-source" unit of a CCS implementation is the decision of initial investment for deploying the test drilling ship. When we fix the CO_2 source size at one million tons per year, the best project strategy is that the mission of a series of drilling ship operations is defined as to drill a well capable to accept one million tons of CO_2 injection per year.

For example, if supposed that a large number of the candidate storage sites with small storage capacity are identified within an accessible distance, the best operation for a drill ship mobilization is to prioritize the promising site for test drilling.

5.1.3 Dense phase CO_2 storage in deep-sea shallow formations

As the "aquifer storage" in Sleipner has been achieved by the CO_2 injection into the geological formations at the condition where CO_2 is not gaseous but in dense phase, i.e. liquid or supercritical state, it is usually assumed that CO_2 cannot effectively be stored at depths above 700 m as described in the IPCC report (2005). However, based on the modelling of the geothermal gradient in the Utsira formation in the North Sea, Lindeberg *et al.* (2008) revealed that CO_2 can be stored in dense phase up to a depth of approximately 500 m below mean sea level (MSL). In this study, we also revealed that liquid phase injection into the reservoir would have no inconvenience in the actual operation as shown in Attachment B.

In the Japanese context of the research on the underground storage of CO_2, identifying the offshore storage site in the sea area with depths of greater than 200 m is neglected. The proposed CO_2 carrier ship equipped with onboard injection facilities provides CCS community in Japan of the opportunity to seek such storage sites.

References
Lindeberg, E., Vuillaume, J-F., and Ghaderi, A: Determination of the CO_2 storage capacity of the Utsira formation. Energy Procedia 1 (2009) 2777-2784.

IPCC, 2005: IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of IPCC [Metz, B, O. Davison, H. C. de Coninck, M. Loos, and L.A. Meyer (eds.)]. Cambridge University Press, United Kingdom and New York, USA, 442pp.

5.2 Economic analysis of the proposed transport system

The economic analysis of the proposed CO_2 transportation system is evaluated using following indicators.

- Capital cost: construction cost of whole plants and facilities
- Injection cost: Annual cost and cost per kg-CO_2

These costs are indicated using the Japanese yen and Australian dollar.
Exchange rate of Japanese yen to Australian dollar is 86.65yen/AUD, based on TTM rate of 29, July, 2011 Bank of Tokyo-Mitsubishi UFJ.

5.2.1 Basis of economic analysis

Evaluations are using the following basis;

1) Scope of proposed CO_2 transportation system
   (1) Onshore plant: loading section (CO_2 tank, CO_2 loading pump, loading arm and related equipments)
   (2) CO_2 shuttle tanker including on-board CO_2 injection pump, sea water pump, CO_2 heater, Injection control system and riser winch.
   (3) Offshore facilities: CO_2 injection riser and buoy.

   The followings are out of scope.
   - CO_2 capture facilities
   - CO_2 gathering pipelines
   - CO_2 compression and liquefier facility (the information of the facility is reported

as references)

- CO_2 Loading berth
- CO_2 wellhead equipment
- Pipelines between wellhead equipment and injection well
- CO_2 injection wells

2) Injection capacity of proposed CO_2 transportation system
   (1) Nominal injection capacity: 1,000,000 tons/year
   (2) Operation factor: 350 days/year
   (3) Transport capacity of CO_2 shuttle tanker: 2,858 tons/shuttle
   (4) Net injection capacity: Capacity calculated by next formula
   Net injection capacity= Injection capacity - Discharged CO_2
   Note: Discharged CO_2 is calculated from electricity and fuel oil consumption of onshore facilities and CO_2 shuttle tanker base on CO_2 discharged index of Japanese Ministry of Environment.
   - Electricity: 0.561 kg-CO_2/kWh
   - Fuel oil: 2.71 kg-CO_2/kL-oil

3) System life
   30 years after the start of injection.
   Each plants and facilities life is as follows;
   - Onshore plant: over 30 years
   - CO_2 shuttle tanker: 15 years, CO_2 shuttle tanker will be changed to new tankers 15 years after the start of injection.
   - Offshore facilities: 30 years

4) Standby period for CO_2 shuttle tanker
   For breakdowns/out-of-service: 25% of the period number, considering for the maintenance period (3 weeks/2 years) of tanker.

5.2.2 Case study of economic analysis

The economic analysis of the proposed CO_2 transportation system is evaluated by the following two cases.

1) Case-1: 200 km distance and 2 (two) tankers operation case
   (a) Distance from onshore base to Injection point: 200 km
   number of CO_2 shuttle tanker in operation: 2 (two)

(c) Loading: quarter day
(b) Shuttle: 3 quarters day
(d) Injection: 1 day
(e) Total 2 days

2) Case-2: 400 – 800 km distance and 4 (four) tankers operation
(a) Distance from onshore base to Injection point: 400 – 800 km
number of CO_2 shuttle tanker in operation: 4 (four)
(b) Loading: quarter day
(c) Shuttle: 2 and 3quaters day
(c) (d) Injection: 1 day
(e) Total 4 days

5.2.3 Method for evaluating injection cost

Structure and components of injection cost is defined as follows;

Injection cost
- Capital relate cost (interest, depreciation)
- Management cost (maintenance, Insurance, property Tax, satellite communication, administration)
- Operating cost (operators' wages, utilities)

Fig. 5.2-1 Structure of injection cost

1) Capital related cost
(1) Interest cost: Payment of interest for capital cost
(a) The amount of Loam: capital cost (S)
(b) Payment schedule: n years (n=10)
(c) Interest rate: γ (γ = 1.50 % Japanese long term prime rate on July, 2011)
(d) Interest cost per year (R) is indicated next formula
$R = \gamma \times S \times (1.0 + \gamma)^n / [(1.0+\gamma)^n - 1.0] - S / n$
@ n = 10 years, γ = 1.50 % R = S x 0.843 %
In case of Facility Life = 30years
- First 10 years: R = S x 0.843 %, 11 – 30 years: R = 0
- Average in system life: R = S x 0.281 %
In case of Facility Life = 15 years
- First 10 years and 16-25 years: R = S x 0.843 %
- 11-15 year and 26-30 years: R = 0

- Average in system life: R = S x 0.562 %

(2) Depreciation cost:

(a) Depreciation period: 10 year

(b) Salvage value: 10 % or 0 %

(c) Depreciation cost =

(Capital cost – salvage value) / Depreciation period

In case of salvage value = 10 %

- First 10 years and 16-25 years: S x 9 %, 11- 30 years: 0
- Average in system life: S x 3 %

In case of salvage value = 0

- First 10 years and 16-25 years: S x 10 %, 11- 30 years: 0
- Average in system life: S x 3.33 %

(3) Working capital: Not taking into account.

2) Injection management cost

(1) Maintenance cost: 3.0 % of Capital for all facilities except injection riser based on Japanese general chemical plants, and 1.0% for injection riser

(2) Insurance premium: 0.35 % of Capital based on Japanese general chemical plants

(3) Property Tax : 1.4% of Capital based on Japanese general chemical plants

(4) Satellite communication cost: Charge of the Inmelsat

(5) Administration cost (Including welfare cost of operators and management and control center cost):

- Loading plants: 150% of operators' wages
- Shuttle CO_2 Tanker: 100% of operators' wages
- Injection: 100% of operators' wages

3) Operating Cost

(1) Operators' wages

- Operators for onshore Plants: ¥8,000,000/year based on Japanese operators' average wages
- Crew for CO_2 shuttle tanker: ¥9,000,000/year Based on Japanese crews' average wages considering the captain
- Crew for CO_2 Injection: ¥8,000,000/year same as operators' wages for onshore plants

(2) Utilities cost

(a) Electric power of onshore plants: ¥10/kWh based on Japanese general chemical plants

(b) Cooling water of onshore plants: ¥8.0/ton based on Japanese general chemical plants

(c) Treatment cost of waste water from onshore plants: ¥80/ton based on Japanese general chemical plants

(d) Fuel oil cost of CO_2 shuttle tanker engine: ¥63,540/kL based on Japanese market average price from Aug., 2010 to July, 2011

5.2.4 Capital cost

1) Construction cost of Individual facility

(1) Onshore CO_2 Loading facilities: 4,300 Million Yen

(2) CO_2 shuttle tanker

Table 5.2-1. Capital cost of CO_2 shuttle tanker

	Main body & tanks	pump, HE & control system	Pick-UP Winch	Subtotal
Estimated cost (Million yen)	2,200	300	108	2,608

(3) CO_2 injection riser: 900 Million yen (Wellhead depth of water: 500m)

2) Total system capital cost

(1) Case-1: 200 km distance and 2 (two) tankers operation case

Table 5.2-2. Capital cost of case-1

	Loading plant	shuttle tanker	Injection riser	Subtotal
Number	1	2.5	1	1
Estimated cost (Million yen)	4,300	6,520	900	11,720
(Million AU$)	49.6	75.2	10.4	135.2

(2) Case-2: 400 – 800 km distance and 4 (four) tankers operation

Table 5.2-3. Case-2

	Loading facilities	shuttle tanker	Injection riser	Subtotal
Number	1	5	1	1
Estimated cost (Million yen)	4,300	13,040	900	18,240
(Million AU$)	49.6	150.5	10.4	210.5

3) Capital cost payment schedule

(1) Case-1: 200 km distance and 2 (two) tankers operation case
- Total payment: 18,240 Million yen (210.5 AU$)
- Initial (before start of injection): 11,720 million yen (135.2 AU$)
- 15 years after start injection: 6,520 million yen (75.2 AU$)

(2) Case-2: 400 – 800 km distance and 4 (four) tankers operation
- Total payment: 31,280 Million yen (361.0 AU$)
- Initial (before start of injection): 18,240 million yen (210.5 AU$)
- 15 years after start injection: 13,040 million yen (130.5 AU$)

5.2.5 Injection cost

1) Number of operators and crew:
   (1) Operation of onshore plants:
   Number of operators: 2.0 (0.5 operators/team x 4 teams)
   (2) Crew of CO_2 shuttle tanker :
   Number of Crew : 6.0/Shuttle tanker (3 crews/team x 2 teams)
   (3) Crew of CO_2 Injection :
   Number of Crew : 6.0/Shuttle tanker (3 crews/team x 2 teams)

2) Utilities consumption
   (1) Onshore CO_2 Loading plants facilities:
   Elec. Power : 294,000 kWh/y
   (2) CO_2 shuttle tanker

Table 5.2-4. Summary of utilities consumption of tanker

Case	Items		Loading	Shuttle	Navigation Injection	Subtotal
Case-1	Injection time	h	8 h	8 h x 2	24 h	48 h
	Elec./Injection	kWh/I	-	7,568	46,174	53,742
	F.O./Injection	kg/I	-	1,762	9,751	11,513
	F.O./year	kL/y	-	717	3,969	4,686
Case-2	Injection time	h	8 h	32 h x 2	24 h	96 h
	Elec./Injection	kWh/I	-	15,136	46,174	61,310
	F.O./Injection	kg/I	-	3,524	9,751	13,275
	F.O./year	kL/y	-	1,434	3,969	5,403

Note: F.O. fuel oil

3) CO_2 discharge

Table 5.2-5. Summary of CO_2 discharge (Unit: tons/year)

	Loading	Shuttle	Navigation Injection	Subtotal	Gross Injection	Net Injection
Case-1	165	1,943	10,755	12,698	1,000,000	987,302
Case-2	165	3,886	10,755	14,641	1,000,000	985,359

4) Injection cost

Net injection costs are indicated as follows (detail calculations are indicated to table 5.2-6 to table 5,2-9 respectively

(1) Case-1: first 10 years 2.460 yen/year (0.0284AU$) - Table 5.2-6
average in system life 1.898 yen/year (0.0219AU$) - Table 5.2-7

(2) Case-2: first 10 years 3.874 yen/year (0.0447AU$) - Table 5.2-8
average in system life 3.097 yen/year (0.0357AU$) - Table 5.2-9

Transition of CO_2 injection cost is illustrated in Fig 5.2-1, Fig 5.2-2.

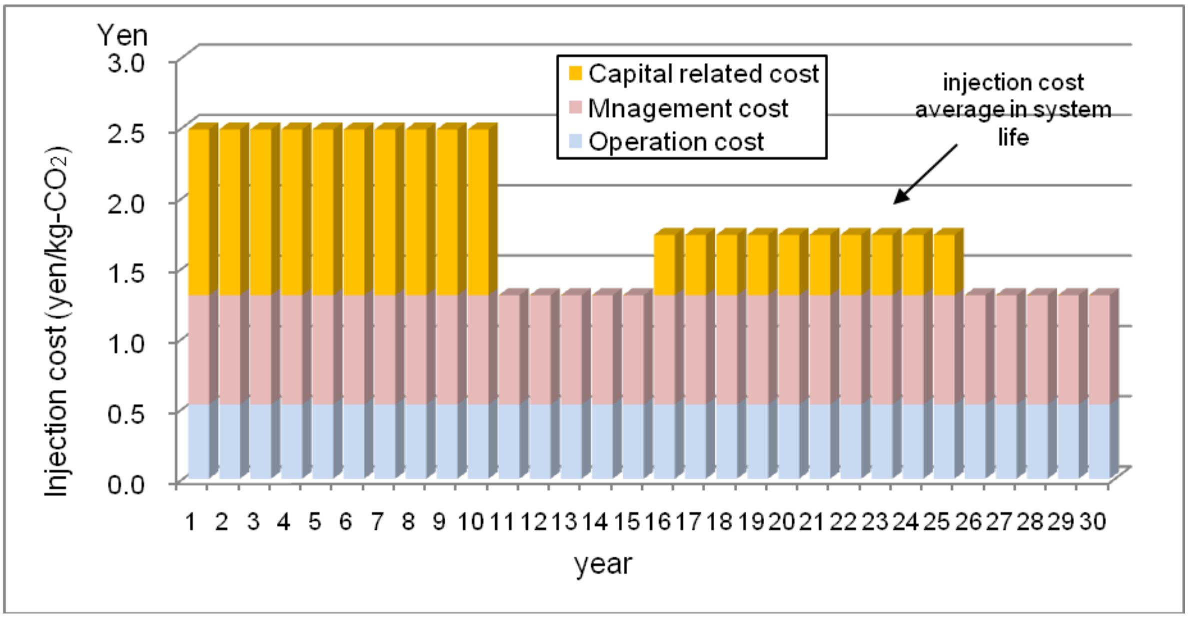


Fig. 5.2-1 Case-1 Transition of CO_2 injection cost

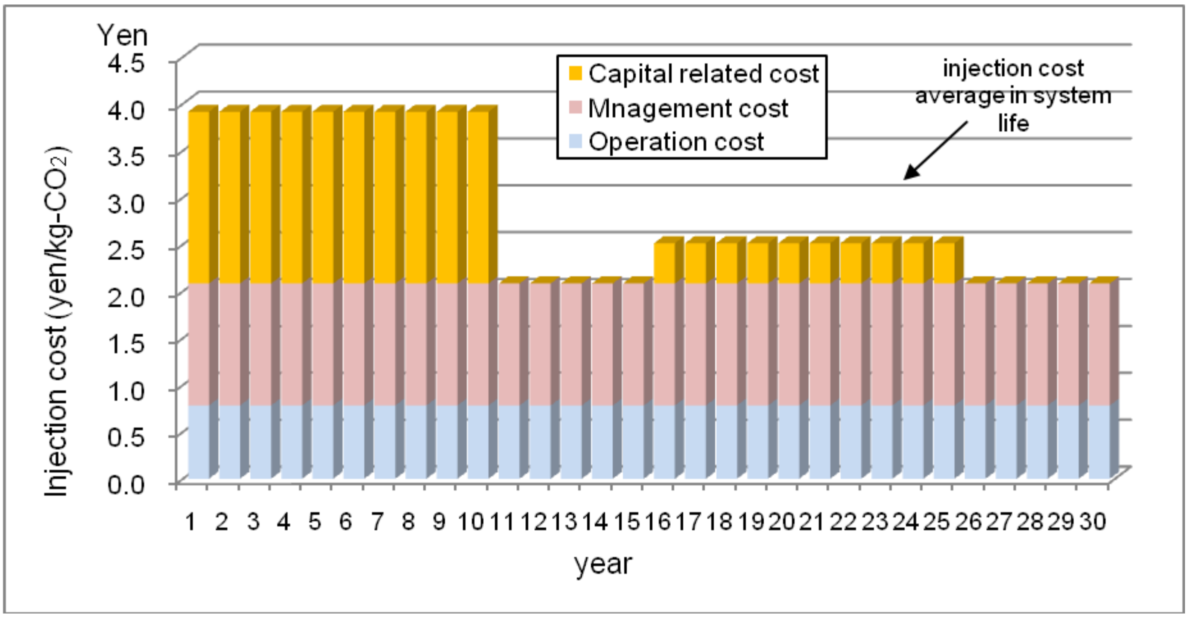


Fig. 5.2-2 Case-2 Transition of CO_2 injection cost

Operation cost of the CO_2 compression and liquefier facility is indicated to attached table as references.

Table 5.2-6 Case-1 : 200 km distance and 2 (two) tankers operation case First 10 years

Items		Unit	Loading	Shuttle	Injection	Total
System capacity		tons/year	1,000,000	1,000,000	1,000,000	1,000,000
Operating factor		days/year	350	350	350	350
System life		years	30	15	30	30
Number of Facilities		set	1	2.5	1	1
Capital cost		Mill. yen	4,300	6,520	900	11,720
		Mill. AU$	49.6	75.2	10.4	135.2
Utilities consumption	Electric power	kWh/y	294,000	-	-	294,000
	Fuel	kL/year	-	717	3,969	4,686
Number of personnel		man	2	3 x4team	3 x4team	26
Injection capacity		tons/year	1,000,000	1,000,000	1,000,000	1,000,000
Discharged CO_2		tons/year	165	1,943	10,755	12,863
Net injection capacity		tons/year	999,835	998,057	989,245	987,137
Capital related cost	Interest	Mill. yen/year	36.25	54.96	7.59	98.80
	Depreciation	Mill. yen/year	387.00	586.80	90.0	1,063.80
	subtotal	Mill. yen/year	423.25	641.76	97.59	1,162.60
		¥/kg-CO_2	0.423	0.643	0.099	1.178
Injection management cost	Maintenance	Mill. yen/year	129.00	195.60	9.00	333.60
	Insurance	Mill. yen/year	15.05	22.82	3.15	41.02
	Property tax	Mill. yen/year	60.20	91.28	12.60	164.08
	Communication	Mill. yen/year	-	-	1.60	1.60
	Administration	Mill. yen/year	24.00	108.00	96.00	228.00
	subtotal	Mill. yen/year	228.25	417.70	122.35	768.30
		¥/kg-CO_2	0.228	0.419	0.124	0.778
Operation cost	Wages: loading	Mill. yen/year	16.00			16.00
	Tanker crew	Mill. yen/year	-	108.00		108.00
	Injection Crew	Mill. yen/year			96.00	96.00
	Electric power	Mill. yen/year	2.94	-	-	2.94
	Fuel	Mill. yen/year	-	45.56	252.19	297.75
	subtotal	Mill. yen/year	18.94	153.56	348.13	520.69
		¥/kg-CO_2	0.019	0.154	0.352	0.527
Injection cost total		Mill. yen/year	670.44	1,213.02	568.13	2,451.59
		¥/kg-CO_2	0.671	1.215	0.574	2.460
		AU$/kg-$CO_2$	0.0077	0.0140	0.0066	0.0284

Table 5.2-7. Case-1 : 200 km distance and 2 (two) tankers operation case average in system life (30 years)

Items		Unit	Loading	Shuttle	Injection	Total
System capacity		tons/year	1,000,000	1,000,000	1,000,000	1,000,000
Operating factor		days/year	350	350	350	350
System life		years	30	15	30	30
Number of Facilities		set	1	2.5	1	1
Capital cost		Mill. yen	4,300	6,520	900	11,720
		Mill. AU$	49.6	75.2	10.4	135.2
Utilities consumption	Electric power	kWh/y	294,000	-	-	294,000
	Fuel	kL/year	-	717	3,969	4,686
Number of personnel		man	2	3 x4team	3 x4team	26
Injection capacity		tons/year	1,000,000	1,000,000	1,000,000	1,000,000
Discharged CO_2		tons/year	165	1,943	10,755	12,863
Net injection capacity		tons/year	999,835	998,057	989,245	987,137
Capital related cost	Interest	Mill. yen/year	12.08	36.64	2.53	51.25
	Depreciation	Mill. yen/year	129.00	391.20	29.97	550.17
	subtotal	Mill. yen/year	141.08	427.84	32.50	601.42
		¥/kg-CO_2	0.141	0.429	0.033	0.609
Injection management cost	Maintenance	Mill. yen/year	129.00	195.60	9.00	333.60
	Insurance	Mill. yen/year	15.05	22.82	3.15	41.02
	Property tax	Mill. yen/year	60.20	91.28	12.60	164.08
	Communication	Mill. yen/year	-	-	1.60	1.60
	Administration	Mill. yen/year	24.00	108.00	96.00	228.00
	subtotal	Mill. yen/year	228.25	417.70	122.35	768.30
		¥/kg-CO_2	0.228	0.419	0.124	0.778
Operation cost	Wages: loading	Mill. yen/year	16.00			16.00
	Tanker crew	Mill. yen/year	-	108.00		108.00
	Injection Crew	Mill. yen/year			96.00	96.00
	Electric power	Mill. yen/year	2.94	-	-	2.94
	Fuel	Mill. yen/year	-	45.56	252.19	297.75
	subtotal	Mill. yen/year	18.94	153.56	348.13	520.69
		¥/kg-CO_2	0.019	0.154	0.352	0.527
Injection cost total		Mill. yen/year	388.27	999.10	503.04	1,890.41
		¥/kg-CO_2	0.388	1.001	0.509	1.898
		AU$/kg-$CO_2$	0.0045	0.0116	0.0059	0.0219

Table 5.2-8. Case-2 : 400 – 800 km distance and 4 (four) tankers operation First 10 years

Items		Unit	Loading	Shuttle	Injection	Total
System capacity		tons/year	1,000,000	1,000,000	1,000,000	1,000,000
Operating factor		days/year	350	350	350	350
System life		years	30	15	30	30
Number of Facilities		set	1	5.0	1	1
Capital cost		Mill. yen	4,300	13,040	900	18,240
		Mill. AU$	49.6	150.5	10.4	210.5
Utilities consumption	Electric power	kWh/y	294,000	-	-	294,000
	Fuel	kL/year	-	1,434	3,969	5,403
Number of personnel		man	2	3 x8team	3 x8team	50
Injection capacity		tons/year	1,000,000	1,000,000	1,000,000	1,000,000
Discharged CO_2		tons/year	165	1,943	10,755	12,863
Net injection capacity		tons/year	999,835	996,114	989,245	985,194
Capital related cost	Interest	Mill. yen/year	36.25	109.93	7.59	153.76
	Depreciation	Mill. yen/year	387.00	1,283.53	90.0	1,650.60
	subtotal	Mill. yen/year	423.25	641.76	97.59	1,804.36
		¥/kg-CO_2	0.423	1.289	0.099	1.831
Injection management cost	Maintenance	Mill. yen/year	129.00	391.20	9.00	529.20
	Insurance	Mill. yen/year	15.05	45.64	3.15	63.84
	Property tax	Mill. yen/year	60.20	182.56	12.60	255.36
	Communication	Mill. yen/year	-	-	1.60	1.60
	Administration	Mill. yen/year	24.00	216.00	192.00	432.00
	subtotal	Mill. yen/year	228.25	835.40	218.35	1,282.00
		¥/kg-CO_2	0.228	0.839	0.221	1.301
Operation cost	Wages: loading	Mill. yen/year	16.00			16.00
	Tanker crew	Mill. yen/year	-	216.00		216.00
	Injection Crew	Mill. yen/year			192.00	192.00
	Electric power	Mill. yen/year	2.94	-	-	2.94
	Fuel	Mill. yen/year	-	91.12	252.19	343.31
	subtotal	Mill. yen/year	18.94	307.12	444.19	770.25
		¥/kg-CO_2	0.019	0.308	0.449	0.782
Injection cost total		Mill. yen/year	670.44	2,426.04	760.13	3,856.61
		¥/kg-CO_2	0.671	2.436	0.768	3.874
		AU$/kg-$CO_2$	0.0077	0.0281	0.0089	0.0447

Table 5.2-9 Case-2 : 400 – 800 km distance and 4 (four) tankers operation
Average in system life (30 years)

Items		Unit	Loading	Shuttle	Injection	Total
System capacity		tons/year	1,000,000	1,000,000	1,000,000	1,000,000
Operating factor		days/year	350	350	350	350
System life		year	30	15	30	30
Number of Facilities		set	1	5.0	1	1
Capital cost		Mill. yen	4,300	13,040	900	18,240
		Mill. AU$	49.6	150.5	10.4	210.5
Utilities consumption	Electric power	kWh/y	294,000	-	-	294,000
	Fuel	kL/year	-	1,434	3,969	5,403
Number of personnel		man	2	3 x8team	3 x8team	50
Injection capacity		tons/year	1,000,000	1,000,000	1,000,000	1,000,000
Discharged CO_2		tons/year	165	1,943	10,755	12,863
Net injection capacity		tons/year	999,835	996,114	989,245	985,194
Capital related cost	Interest	Mill. yen/year	12.08	73.28	2.53	87.90
	Depreciation	Mill. yen/year	129.00	782.40	29.97	941.37
	subtotal	Mill. yen/year	141.08	855.68	32.50	1,029.27
		¥/kg-CO_2	0.141	0.859	0.033	1.045
Injection management cost	Maintenance	Mill. yen/year	129.00	391.20	9.00	529.20
	Insurance	Mill. yen/year	15.05	45.64	3.15	63.84
	Property tax	Mill. yen/year	60.20	182.56	12.60	255.36
	Communication	Mill. yen/year	-	-	1.60	1.60
	Administration	Mill. yen/year	24.00	216.00	192.00	432.00
	subtotal	Mill. yen/year	228.25	835.40	218.35	1,282.00
		¥/kg-CO_2	0.228	0.839	0.221	1.301
Operation cost	Wages: loading	Mill. yen/year	16.00			16.00
	Tanker crew	Mill. yen/year	-	216.00		216.00
	Injection Crew	Mill. yen/year			192.00	192.00
	Electric power	Mill. yen/year	2.94	-	-	2.94
	Fuel	Mill. yen/year	-	91.12	252.19	343.31
	subtotal	Mill. yen/year	18.94	307.12	444.19	770.25
		¥/kg-CO_2	0.019	0.308	0.449	0.782
Injection cost total		Mill. yen/year	388.27	1998.20	695.04	3,081.51
		¥/kg-CO_2	0.388	2.006	0.703	3.097
		AU$/kg-$CO_2$	0.0045	0.0232	0.0081	0.0357

Attachment Table: Operation cost of CO2 Compression & Liquefy facility

Items		Unit	Compress & Liq.
System capacity		tons/year	940,000
Operating factor		days/year	330
Facility Life		years	30
Capital cost		Mill. yen	3,800
		Mill. AU$	43.9
Utilities	Electric power	kWh/year	147,000,000
	Cooling water	tons/year	8,000,000
Waste water treatment		tons/year	18,900
Number of personnel		man	6
Injection capacity		tons/year	940,000
Discharged CO_2		tons/year	77,600
Net injection capacity		tons/year	862,400
Capital related cost	Interest	Mill. yen/year	10.68
	Depreciation	Mill. yen/year	114.00
	subtotal	Mill. yen/year	124.68
		¥/kg-CO_2	0.145
Injection management cost	Maintenance	Mill. yen/year	114.00
	Insurance	Mill. yen/year	13.30
	Property tax	Mill. yen/year	53.20
	Administration	Mill. yen/year	72.00
	subtotal	Mill. yen/year	252.50
		¥/kg-CO_2	0.293
Operation cost	Personnel	Mill. yen/year	48.00
	Electric power	Mill. yen/year	1,560.00
	Cooling water	Mill. yen/year	68.00
	Waste water	Mill. yen/year	1.69
	subtotal	Mill. yen/year	1,677.69
		¥/kg-CO_2	1.836
Injection cost total		Mill. yen/year	1,960.69
		¥/kg-CO_2	2.274
		AU$/kg-$CO_2$	0.0262

6. Conclusions

Ship-based CCS featuring a CO_2 shuttle ship equipped with injection facilities is proposed. CO_2 transportation by ship was given its role in the CCS chain as the alternative to pipeline when the distance across the sea is quite long, and therefore, large CO_2 carrier has been intended for the cost effectiveness in the sense of scale merit. However, if securing large-scale CO_2 sources or large-scale CO_2 sinks is uncertain, CO_2 shuttle transport by a number of small to medium sized ships is effective to suit the dispersive system. And in cases that require facilities for CO_2 buffer storage at both ends of shipping are difficult to build for technical, economical, or social reasons, frequent transport and direct injection to the well from ship can be a solution.

In this study, the technical and economical feasibilities of shuttle type CO_2 transport and offshore operation for CO_2 injection are demonstrated. The main components needed for the proposed system include liquefaction of CO_2, temporary storage at ports, offloading, shuttle ship with DPS and injection equipment~~s~~, and flexible riser pipe whose end is connected with the wellhead on the seafloor, and the pickup system. Among them, shuttle ship and flexible riser pipe with the pickup system were studied in detail. It was considered that novel technologies are avoided for each component though the total system is unprecedented.

And also in this study, the regulatory considerations on the ship-based CCS were discussed, especially when done within the Exclusive Economy Zone (EEZ) of Japan for example of applying to the country or region where the offshore oil and gas industries are inexperienced.

As a result, the feasibility of CO_2 shuttle ship equipped with injection facilities was clarified to a certain extent. More detailed studies shall be needed under the specified conditions for the system optimization.

ATTACHMENT

- **A.** DPS Simulation Study of CO_2 Tanker
- **B.**Tough2 simulation study
- **C.** Pipe flow simulation study
- **D.** Communication buoy systems
- **E.** Questions and answers for regulations on the ship-based CCS

Attachment A: DPS Simulation Study of CO_2 Tanker

1. Outline

To make an investigation on a capability of dynamic positioning system (DPS) for the proposed vessel (with LCO_2 cargo of 3000 tonnes in weight), a DPS simulation study was carried out under the combined disturbed conditions (wind, wave and current). Using marine and weather data base for offshore Site.M, a wind velocity of 15.0 m/s, a significant wave height of 3 m, a significant wave period of 9.0~17.0 s and a current speed of 1.46 knot were used for the DPS simulation calculation, under which a shipment efficiency can be maintained above 90%. Assuming a side thruster being installed at the bow and an azimuth propeller at stern, a required thruster capacity was calculated based on the above mentioned conditions. The calculation result indicated that required capacities were 1,150kW x 2 sets for side thruster and 3,000kW for azimuth propeller.

2. Preconditions for Study

(1) Major Items for Tanker

・length between perpendiculars	Lpp	89.60m
・ship's beam	(B_MID)	14.60m
・molded depth	(D_MID)	6.90m
・draft	(d_BL)	5.60m
・displacement	(△a)	6,000t
・Height of gravitational center	(KG)	5.00m
・transverse metacentric height	(KMT)	7.50m
・longitudinal metacentric height	(KML)	120.00m
・radius of gyration	(kxx/B)	0.320

(2) Water Depth and Thruster

・Water Depth 500.0m

・Bow Thruster Side Thruster of 1,150kW x 2sets
(as an initial value for calculation)

・Stern Thruster Azimuth Propeller of 3,000kW
(as an initial value for calculation)

3. Study Procedure

A flow chart of the simulation study is shown in Fig. A-3.1.

Firstly, wind drag force, wave drift force and Hydrodynamic manoeuvring need to be obtained by calculation or laboratory testing. Then, a thruster capacity can be calculated and examined by solving a manoeuvre motion equation in time series until it satisfies the condition of DPS requirement.

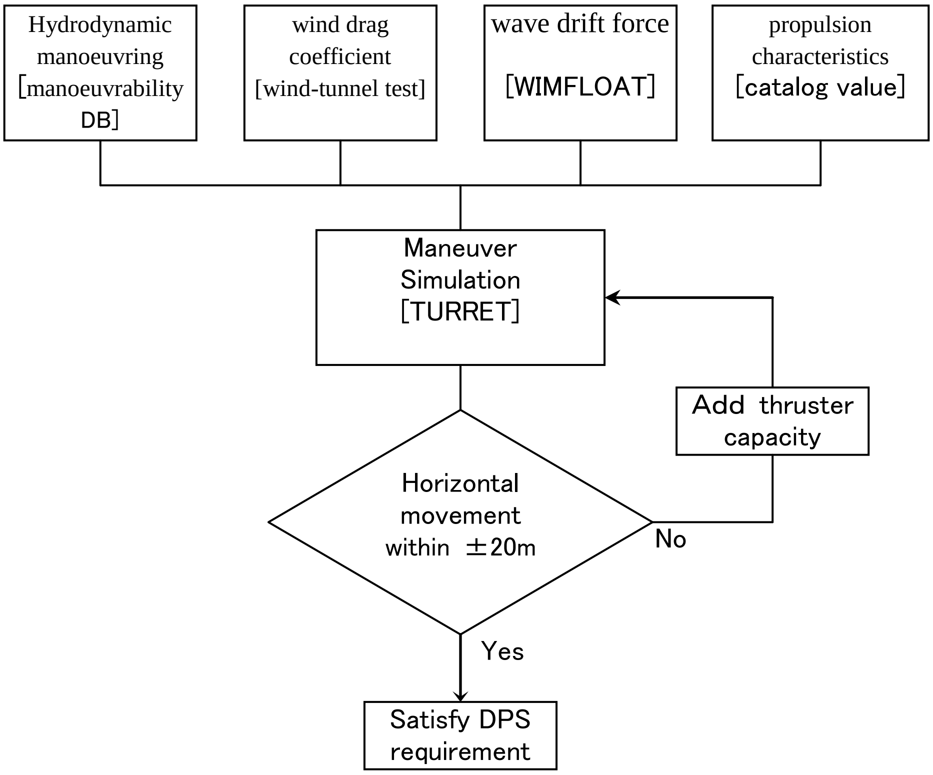
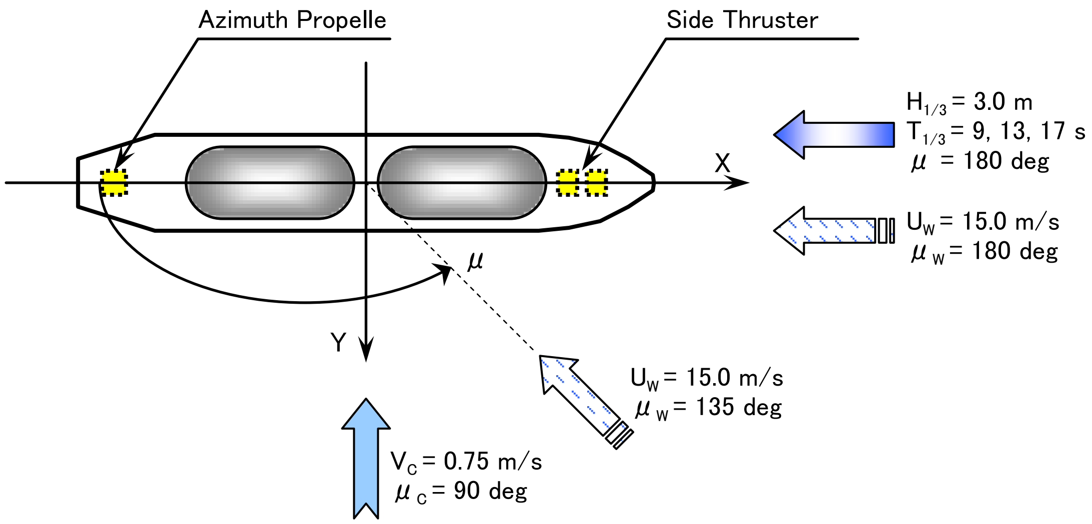


Fig. A-3.1 Flow Chart of Simulation Study

4. Other Conditions for the Study
   (1) Wind speed
   U_{10}=15.0m
   (2) Current
   V=1.46knot (=0.75m/s)
   (3) Location of Thrusters
   Side thrusters: in front and behind S.S.9
   Azimuth thruster: at A.P.
   (4) Combination of External forces



(5) Simulation Study Cases

	Wind velocity U_{10}(m/s)	Wind direction μ_C(deg)	Significant wave height $H_{1/3}$(m)	Significant wave period $T_{1/3}$(s)	Wave directionμ(deg)	Current speed V_C(m/s)	Current direction μ_C(deg)
Case01	15.0	135	3.0	9.0	180	0.75	90
Case02				13.0			
Case03				17.0			
Case04		180		9.0			
Case05				13.0			
Case06				17.0			

5. Study Results

A simulation study result of Case06 is shown in Figure A-5.1, as an example, which summarizes time series calculation results of turn angle of the ship, front-back movement, side to side movement, revolution and thrust force of propeller, etc. Presented in Fig. A-5.2 is a chart of ship movement at every100s for Case06. Table A-5.1 presents statistical results of simulation results for all study cases for the time interval between 300 s through 1000 s.

A statistical result of the simulation study indicates that an average ship turn angle is about 50°, the maximum front-back movement is 14. 2m and the maximum side-to-side movement is 12.5 m. This result satisfies the condition of allowable maximum horizontal movement of 20m, which is shown in Fig. A-3.1. The average thrust force of thrust propeller is 12.6t (about 1,300Kw).

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Table A-5.1. Statistical results of DPS Simulation Study（Time interval：300～1000s）

			Case01			Case02			Case03		
			Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.
PSI	Turn angle	(DEG)	50.0	31.8	66.0	50.3	30.6	70.0	50.3	32.8	66.6
R	Rate of turn	(DEG/S)	0.0	-1.4	1.8	0.0	-1.5	1.8	0.0	-1.4	1.6
U	Speed of front-back movement	(M/S)	0.6	0.1	0.9	0.6	0.1	0.8	0.6	0.2	0.8
V	Speed of side-to-side movement	(M/S)	0.5	0.0	0.8	0.5	-0.1	0.8	0.5	0.0	0.8
X	Front-back movement	(M)	0.7	-3.9	6.2	1.5	-3.3	8.6	1.3	-3.0	5.6
Y	Side-to-side movement	(M)	-0.8	-8.7	2.0	-1.1	-9.5	1.4	-0.8	-6.6	1.8
AZP1_THT	Rudder angle of azimuth propeller	(DEG)	-5.8	-164.1	145.5	-10.0	-164.1	163.8	-11.4	-153.7	136.2
AZP1_NP	Revolution of azimuth propeller	(RPS)	1.3	1.0	1.9	1.2	0.9	1.9	1.2	0.9	1.9
AZP1_TT	Thrust force of azimuth propeller	(TON)	12.6	8.0	30.4	11.7	6.7	30.1	11.2	6.5	30.4
AZP1_FN	Perpendicular force on azimuth propeller	(TON)	0.1	-18.4	20.6	-0.5	-19.9	20.5	-0.6	-18.4	19.9
NS.1	Revolution of side thruster	(RPS)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
NS.2	Revolution of side thruster	(RPS)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
TS1	Thrust force of side thruster	(TON)	0.1	-14.4	15.8	0.1	-16.7	16.6	-0.1	-14.6	16.0
TS2	Thrust force of side thruster	(TON)	0.2	-11.0	13.8	0.2	-13.1	16.2	-0.1	-12.3	13.3

			Case04			Case05			Case06		
			Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.
PSI	Turn angle	(DEG)	48.9	29.9	64.4	49.1	29.7	68.2	49.2	28.6	68.1
R	Rate of turn	(DEG/S)	0.0	-1.4	1.8	0.0	-1.4	1.7	0.0	-1.4	1.7
U	Speed of front-back movement	(M/S)	0.6	0.1	0.9	0.6	0.1	0.9	0.6	0.1	0.8
V	Speed of side-to-side	(M/S)	0.5	0.0	0.7	0.5	0.0	0.7	0.5	-0.1	0.8

	movement										
X	Front-back movement	(M)	4.7	-1.1	11.8	5.4	0.5	13.4	5.4	-1.5	**14.2**
Y	Side-to-side movement	(M)	-4.1	-10.2	-2.4	-4.4	**-12.5**	-2.7	-4.3	-11.7	-1.1
AZP1_THT	Rudder angle of azimuth propeller	(DEG)	-5.9	-170.9	141.1	-7.6	-165.1	155.3	-8.2	-168.0	162.8
AZP1_NP	Revolution of azimuth propeller	(RPS)	1.2	1.0	1.9	1.2	0.8	2.0	1.2	0.9	1.9
AZP1_TT	Thrust force of azimuth propeller	(TON)	**12.2**	7.0	30.4	**11.2**	5.1	31.0	**11.0**	5.3	30.5
AZP1_FN	Perpendicular force on azimuth propeller	(TON)	-0.9	-18.4	20.4	-1.3	-20.4	19.4	-1.5	-20.0	19.4
NS.1	Revolution of side thruster	(RPS)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
NS.2	Revolution of side thruster	(RPS)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
TS1	Thrust force of side thruster	(TON)	2.7	-12.1	16.2	2.8	-12.7	16.5	2.6	-16.1	**16.6**
TS2	サイドスラスタ推力	(TON)	2.7	-9.7	16.6	2.9	-7.6	16.5	2.7	-10.1	**16.6**

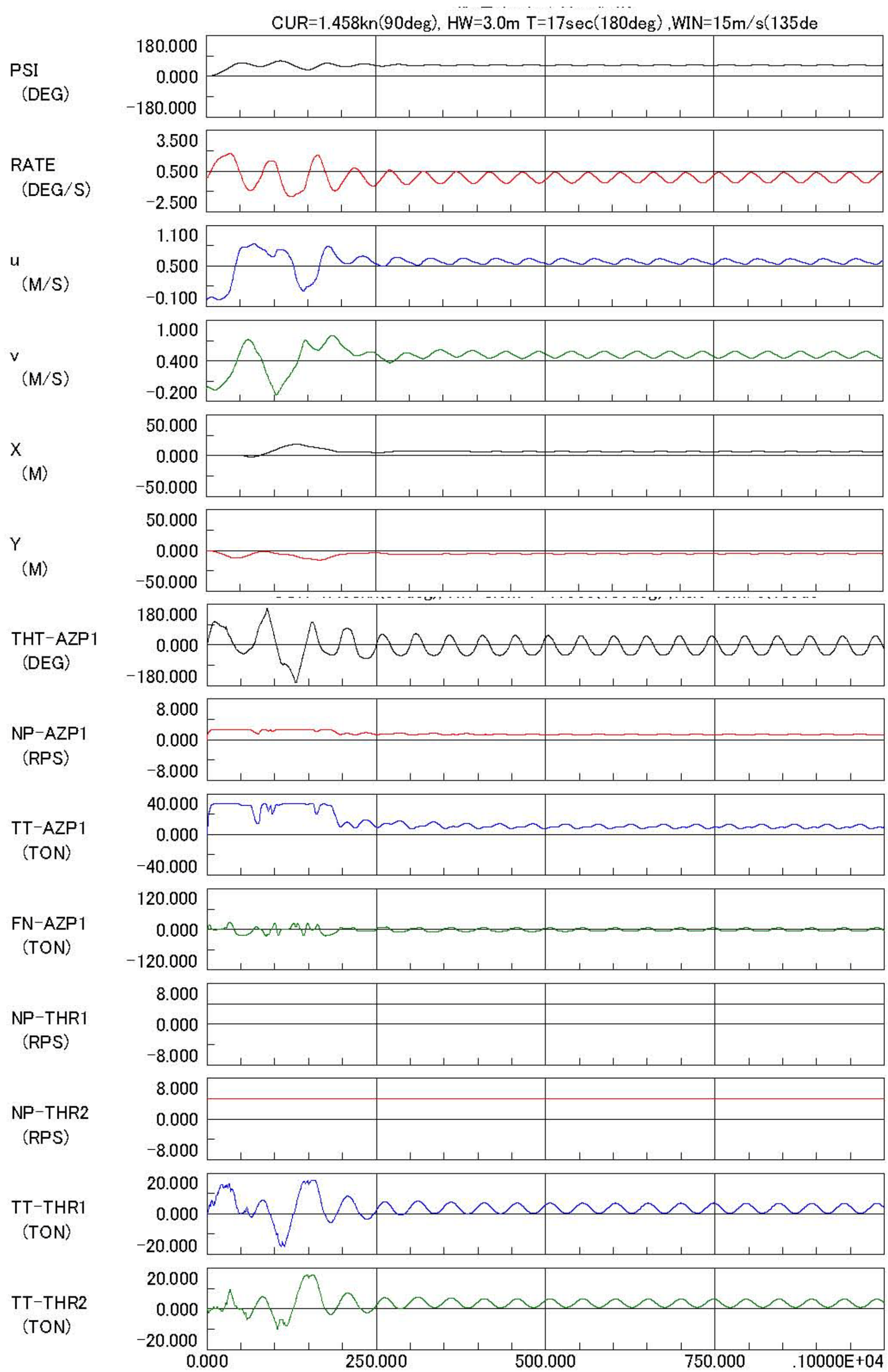

Fig. A-5.1 DPS simulation results in time series -Case06-

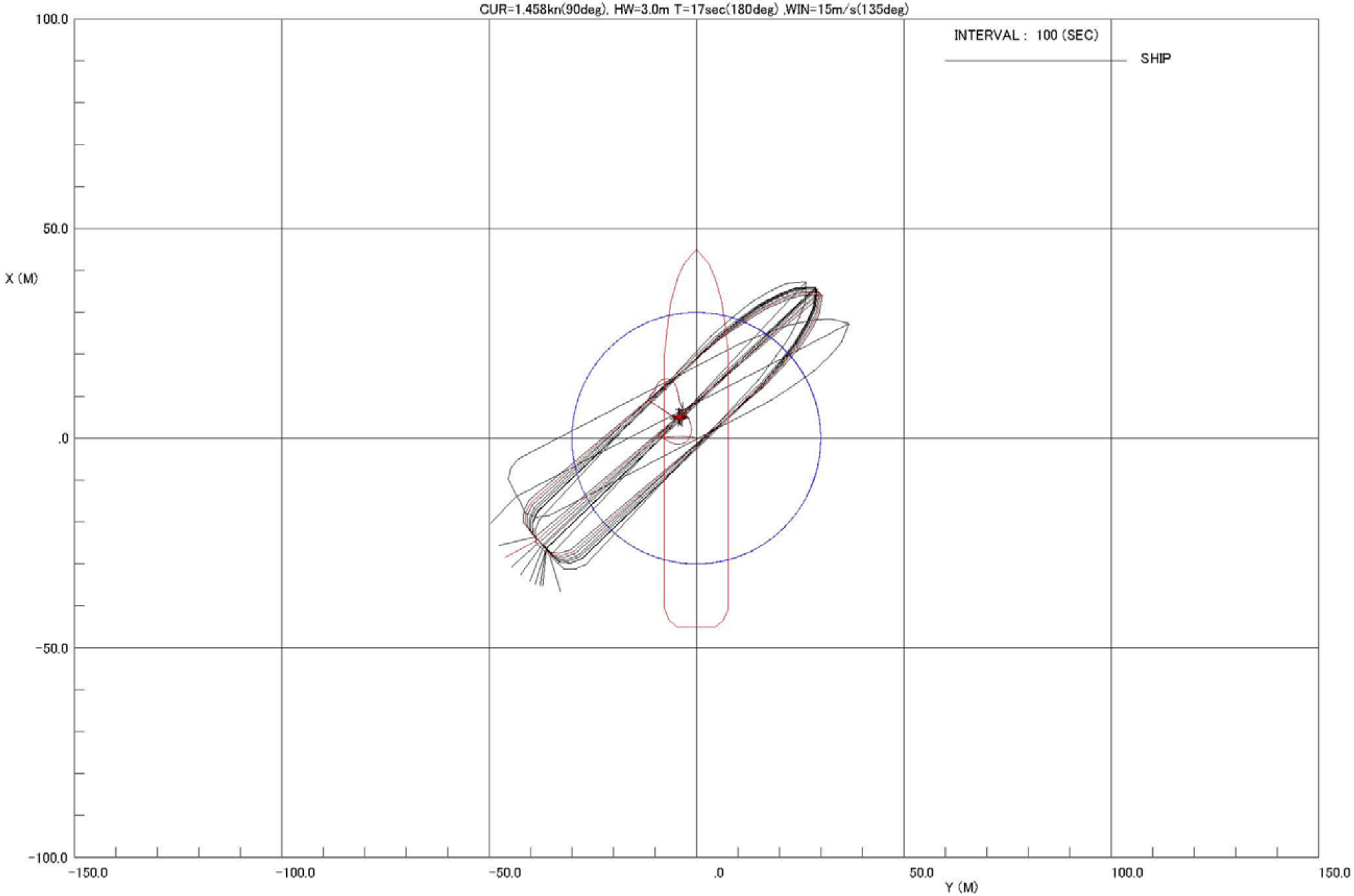

Fig. A-5.2 DPS simulation result of ship movement - Case 06

Attachment B: TOUGH2 simulation study

1. Objective

   In the CO_2 flowline of the proposed system of shuttle tanker transportation, the design heater capacity is set to elevate the CO_2 temperature only up to 5 ºC to avoid freezing the ambient waters, which can contribute some to energy saving. Under such conditions throughout the flowline, the CO_2 will probably be still in a liquid phase at the bottom of an injection well, while it will be in a super-critical condition in a reservoir after warmed up in the reservoir. This means that the reservoir pressure may increase much higher than the case of injecting CO_2 under super-critical condition, and may cause some negative effects on the integrity of seal formation overlaying the reservoir formations. Therefore, in order to investigate a reservoir pressure increase under CO_2 injection operation, a numerical model study was conducted by constructing a simplified reservoir model for both liquid CO_2 injection case and super-critical CO_2 injection case under the same injection rate condition.

2. Reservoir modeling and conditions

   1) Software for analysis

      - TOUGH2 [(1)]: multi-phase permeable flow analysis program based on finite volume method
      - ECO2N[(2)]: CO_2 phase behavior analysis program

   2) Numerical reservoir model

      - Reservoir Model (refer to Fig. B-1)
        - homogeneous reservoir model
        - a radial model with its origin at CO_2 injection point.
        - a radial model with no fluid flow in vertical direction.

      - Rock properties (refer to Table B-1)
        - The standard rock properties of reservoirs in Japan are used.

      - Physical property of CO_2

        The density and the viscosity coefficient of CO_2 are estimated as a function of pressure and temperature which satisfy the conditions for an equation of states of CO_2 by Span-Wagner [3]. The CO_2 solubility to the formation water is assumed to follow an extended Henry' Law [4]. Van Genuchten[5] model is adopted to establish the relative permeability curves and capillary pressure curve with treating the model as a two phase flow model between CO_2 and formation water. (refer to Fig.B-2)

- Initial reservoir condition (refer to Table B-2)
  - The pore space of the reservoir is filled with the formation water of 15% salinity.
  - The reservoir pressure is set at 16MPa, assuming that a sea depth is 500m and the reservoir depth is 1000m below the seabed.
  - The reservoir temperature is set at 35 deg.C, assuming that a seabed temperature is 5 deg.C and a thermal gradient below the seabed is 3 ºC/100m.

- Boundary conditions

  The reservoir is assumed to be an infinite reservoir. However, the analyses on the model calculation results were made only for the area within 100km from the CO_2 injection point, because it is confirmed by model calculations that the pressure disturbance caused by CO_2 injection does not propagate beyond such far area for all studied cases. A coefficient of heat conduction between the reservoir and both overlying and underlying formations is assumed to be the same of the reservoir.

- Case Setting (refer to Table B-3)

  The numerical model studies were conducted for the following 4 cases, i.e. two cases of CO_2 phase conditions (liquid and super-critical) and two cases of well injectivity.

Case 1	3000t CO_2/22h/10well	(3.8kg/s)	Liquid CO_2
Case 2	3000t CO_2/22h/10wel	(3.8kg/s)	Super-criticalCO_2
Case 3	3000t CO_2/22h/5well	(7.6kg/s)	Liquid CO_2
Case 4	3000t CO_2/22h/5well	(7.6kg/s)	Super-criticalCO_2

The injection operation is continued for 10 years, while a designed injection rate is reached within 4 hours after starting injection. In the analyses, the CO_2 temperature at the injection wellhead is set at 10 deg.C for liquid condition case, and 35 deg.C (same as the reservoir temperature) for super-critical condition cases.

The comparisons of the simulation results are made between Cases 1 and 2, and between Cases 3 and 4.

3. Results analysis

1) Pressure at injection point

Figure B-4 presents a behaviour of bottom-hole injection pressure and injection rate of all cases.

In all cases, it is predicted that a bottom-hole injection pressure increases to the maximum level within 4 hours after starting injection and, then, continues to increase quite gently till the end of CO_2 injection (after 10 years). The maximum injection pressure is about 19MPa for low rate cases, i.e. Case 1 and Case 2, while it is about 22MPa for high rate cases, i.e. Case 3 and Case 4. It is also predicted that the difference of the maximum injection pressures between Cases 1 and 2 (i.e. liquid vs. super-critical) and between Cases 3 and 4 (i.e. liquid vs. super-critical) are less than 0.1MPa and 0.2MPa, respectively.

After the completion of CO_2 injection, the bottom-hole injection pressure starts decreasing gradually and comes back to the initial reservoir pressure after about 240 years.

The present simulation study also proves that the capacity of an injection pump planned to be installed on a shuttle tanker is sufficient, as the pump has a design capability to increase the bottom-hole injection pressure up to 25MPa.

2) Pressure and temperature distribution in the reservoir

Presented in Figs.B-5 to B-9 are the changes of reservoir pressure, temperature and CO_2 properties in the radial direction at the different times after CO_2 injection. With regard to the behaviour of the reservoir pressure, the CO_2 saturation and the dissolved CO_2, only a little difference is observed between the liquid CO_2 injection case and the super-critical CO_2 injection case. However, regarding the reservoir temperature, it remains almost constant at the initial temperature of 35 deg.C for the super-critical CO_2 injection case. While, in the liquid CO_2 injection case, a low temperature area at about 10 deg.C expands with the progress of CO_2 injection. From the distribution of CO_2 density in the reservoir, it is observed that the CO_2 gradually changes from liquid phase to super-critical phase within its two phase region for liquid CO_2 injection case, while, in super-critical CO_2 injection case, it stays at initial condition of 850kg/m^3 in the reservoir.

Figures B-9 and B-10 show the difference in the reservoir temperatures between the liquid CO_2 injection case and the super-critical CO_2 injection case. These results indicate that, within CO_2 invaded area, the reservoir temperature for the super-critical CO_2 injection case is about 25 deg.C higher than the liquid CO_2 injection case regardless of the CO_2 injection rates.

In the same way, Figures B-11 and B-12 show a difference in reservoir pressures between the liquid CO_2 injection case and the super-critical CO_2 injection case. In the case of the super-critical CO_2 injection, the reservoir pressure in the area far beyond the CO_2 invaded area is higher than that of the liquid CO_2 injection case, and this pressure difference becomes at maximum at the location where the distance from injection point is as twice far from the CO_2 invasion front. The maximum pressure difference is less than 0.1MPa. To the contrary, within the area of CO_2 invasion, the reservoir pressure of the super-critical CO_2 injection case is lower than the liquid CO_2 injection case, indicating that the maximum pressure difference is less than 0.2MPa near the injection point.

The results of the study are summarized as follows: the pressure difference between two injection cases is quite small by less than 1% of the reservoir pressure in the CO_2 flooded area. This suggests that there are no significant risks on injecting CO_2 in the liquid phase. However, in the actual site investigation for a commercial CCS project, the prior careful evaluation on the rock properties of a reservoir and the associated seal formation is necessary based on the actual field data. Also, the similar numerical simulation model studies as presented here are recommended on the obtained data. It might be needless to say that the integrity of storage formations reservoir rock need to be investigated through the scheduled monitoring of the injection operation.

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Table B-1 Rock and hydraulic parameters.

Rock grain density	ρ_R = 2600 [kg/m^3]
Thermal conductivity	λ = 2.51 [W/m ºC]
Rock specific heat	C_R = 920 [J/kg ºC]
Permeability	k = 3×10^{-13} [m^2]
Porosity	φ = 0.3
Pore compressibility	C = 4.5×10^{-10} [1/Pa]
Storage reservoir thickness	H = 50 [m]
CO_2 injection temperature	T_{CO2} = 10[ºC] (liquid), T_{CO2} = 35[ºC] (super critical)
CO_2 injection time	t_{CO2} = 10[yr] (Rise time=4[h])
Relative permeability model (refer to Fig.2)	
Liquid : van Genuchten function $k_{rl} = \sqrt{S^*}\left\{1-\left(1-\left(S^*\right)^{1/\lambda}\right)^{\lambda}\right\}^2$	$S^* = (S_l - S_{lr})/(1-S_{lr})$ $S_{ls} = 0.3, \lambda = 0.457$
Gas : Corey curve $k_{rg} = \left(1-\hat{S}\right)^2\left(1-\hat{S}^2\right)$	$\hat{S} = (S_l - S_{lr})/(1-S_{lr})$ $S_{gr} = 0.05$
Capillary pressure model (refer to Fig.2)	
van Genuchten function $P_{cap} = -P_0\left(\left[S^*\right]^{-1/\lambda} - 1\right)^{1-\lambda}$	$S^* = (S_l - s_{lr})/(1-S_{lr})$ $S_{lr} = 0.0, \lambda = 0.457, P_0 = 19.61[kPa]$

Table B-2 Initial condition.

Pressure	16[MPa]
Temperature	35[ºC]
Salinity (mass ratio)	15[%]

Table B-3 Case conditions.

Case1	Q_{CO2}=3.8[kg/s], T_{CO2}=10[deg-C] (liquid)
Case2	Q_{CO2}=3.8[kg/s], T_{CO2}=35[deg-C] (super critical)
Case3	Q_{CO2}=7.6[kg/s], T_{CO2}=10[deg-C] (liquid)
Case4	Q_{CO2}=7.6[kg/s], T_{CO2}=35[deg-C] (super critical)

(Q_{CO2} and T_{CO2} are injection rate and temperature of CO_2, respectively)

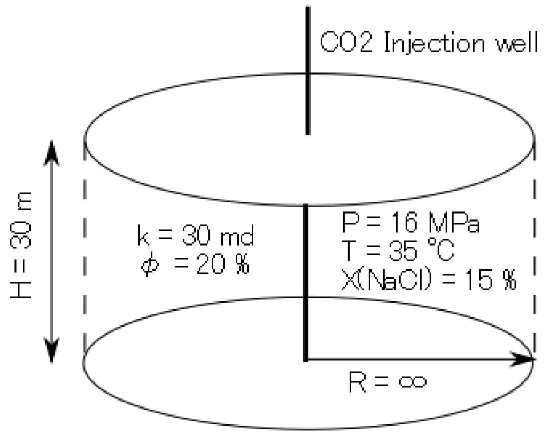

Fig. B-1 Schematic of the CO_2 injection model.

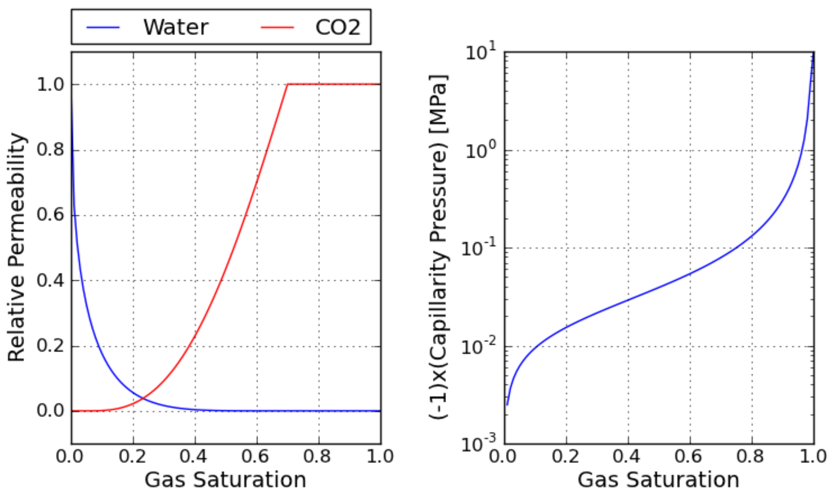

Fig. B-2 Two-phase model.

left: relative permeability model, right: capillarity pressure.

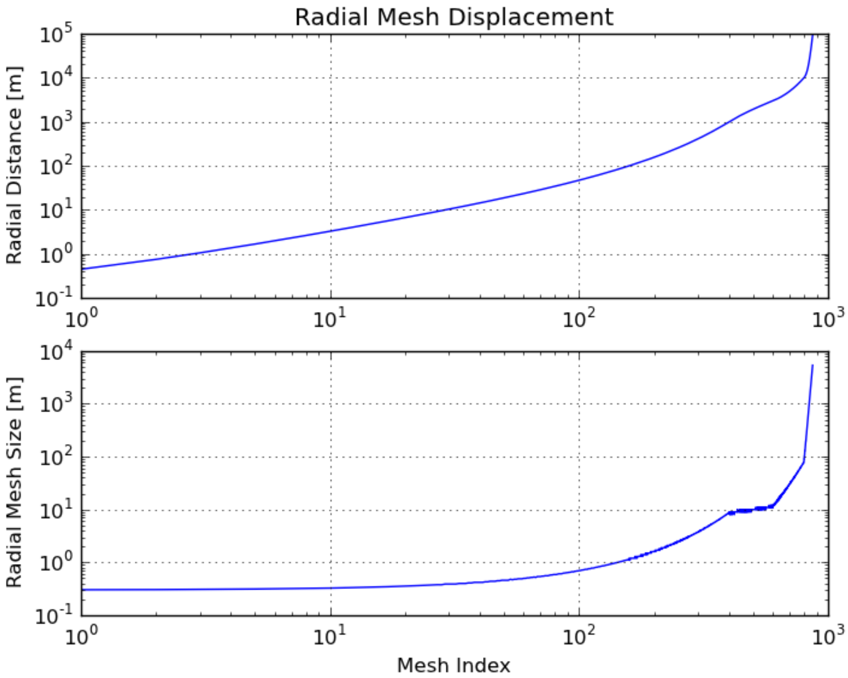

Fig. B-3 Radial mesh displacement.

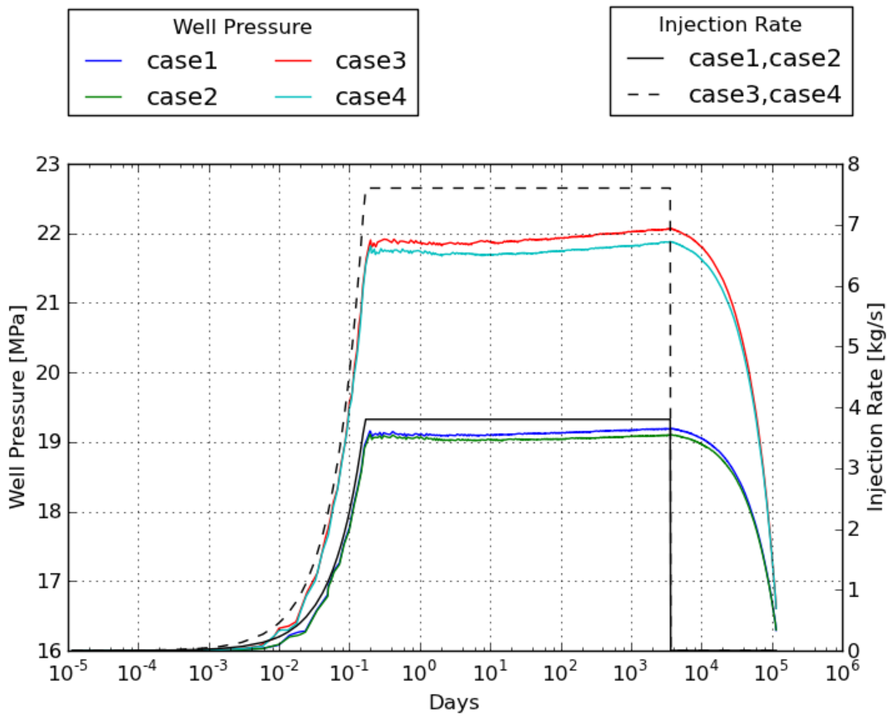

Fig. B-4 Time evolution of well pressures for all cases.

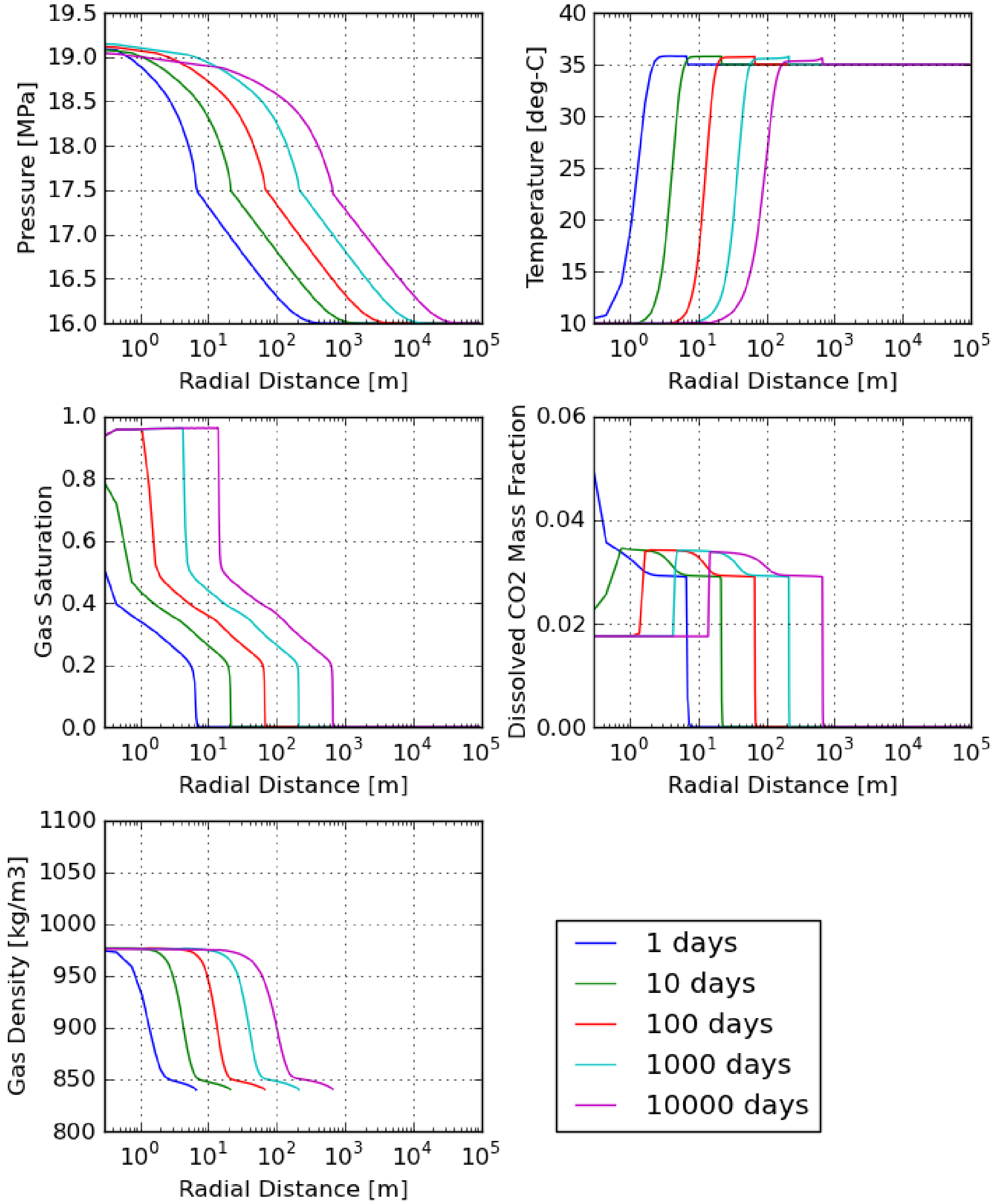

Fig. B-5 Radial profiles of thermal variables at different times. (Case1)

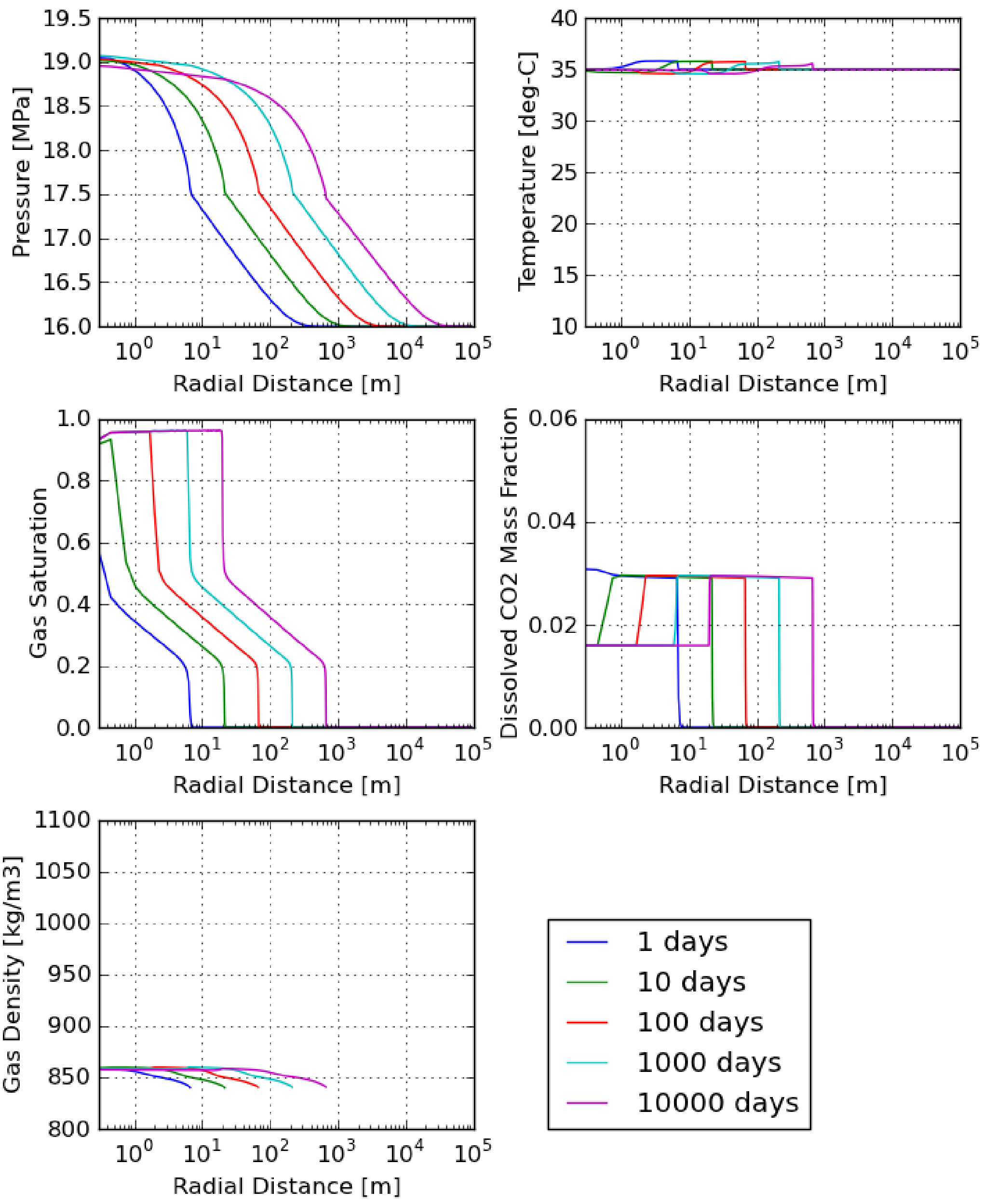

Fig. B-6 Radial profiles of thermal variables at different times. (Case2)

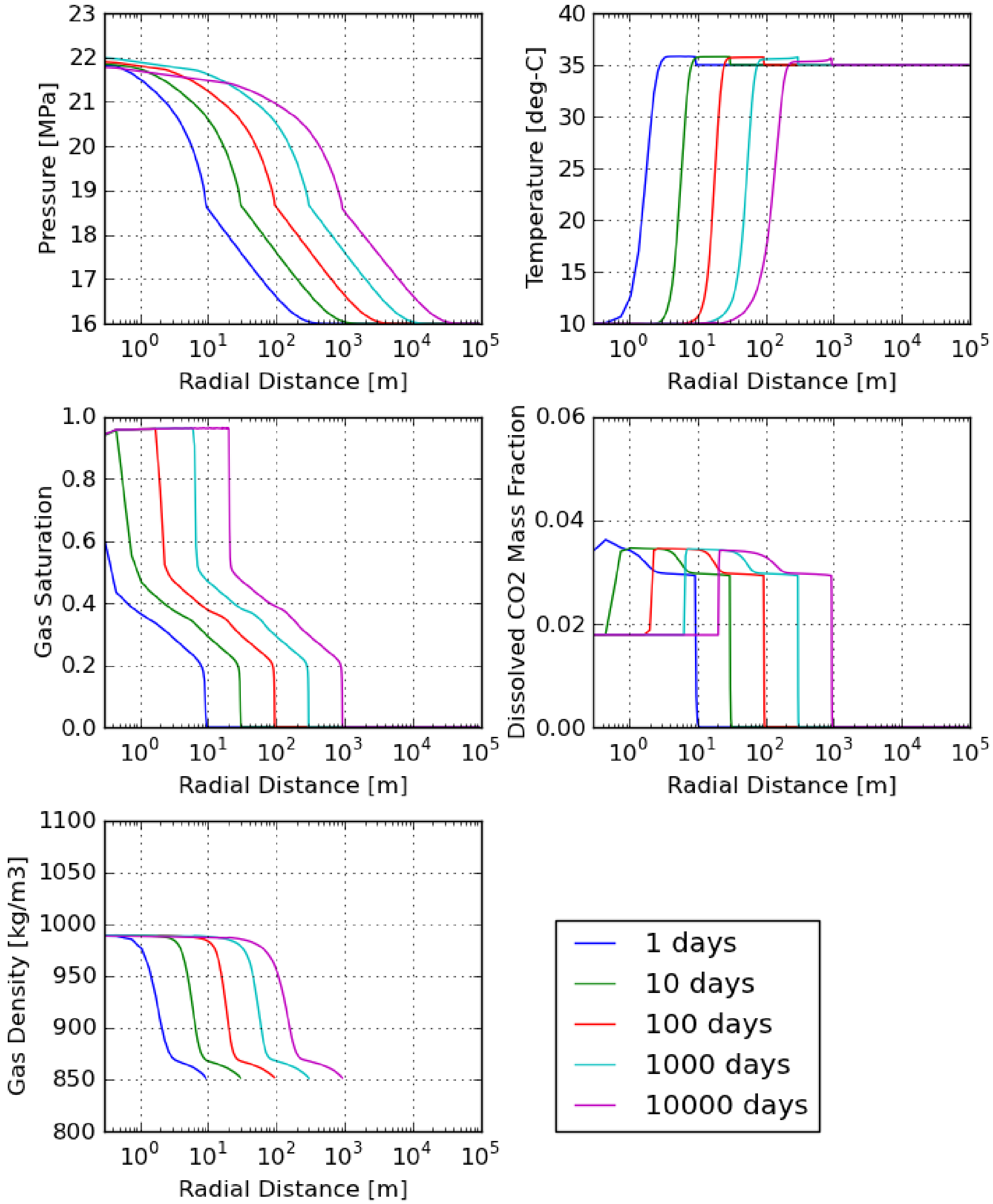

Fig. B-7 Radial profiles of thermal variables at different times. (Case3)

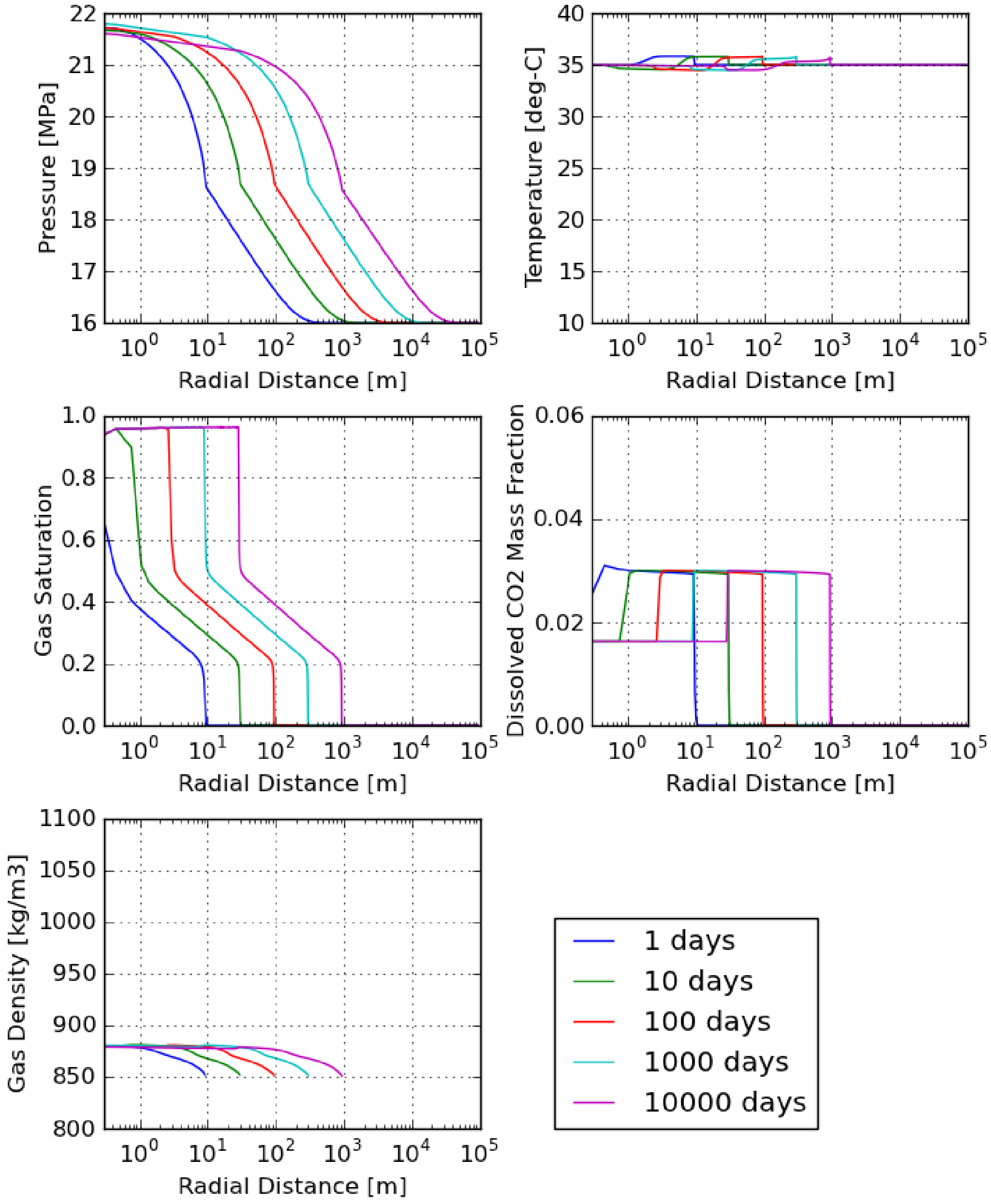

Fig. B-8 Radial profiles of thermal variables at different times. (Case4)

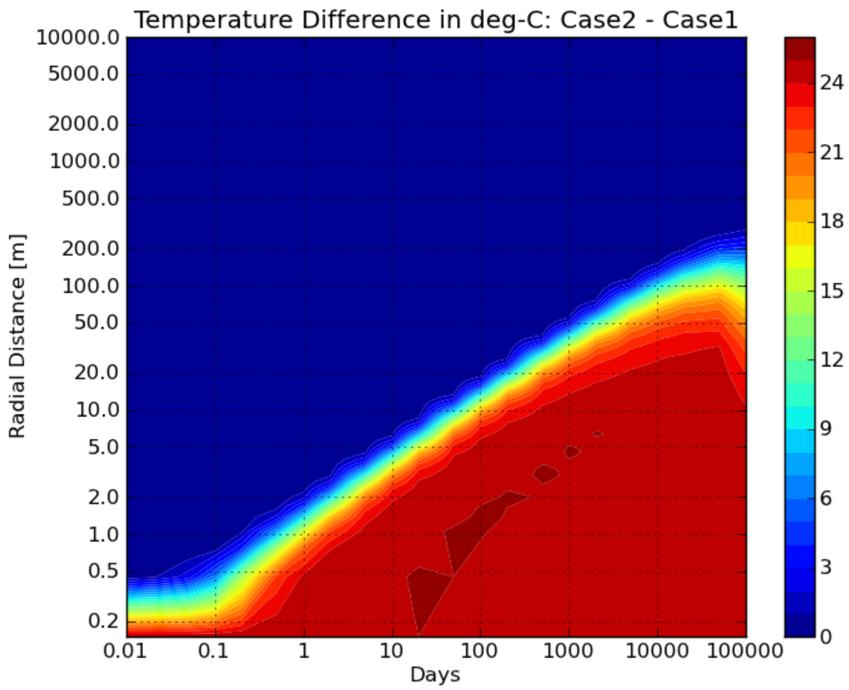

Fig. B-9 Radial-temporal profile of pressure difference between Case1 and Case2.

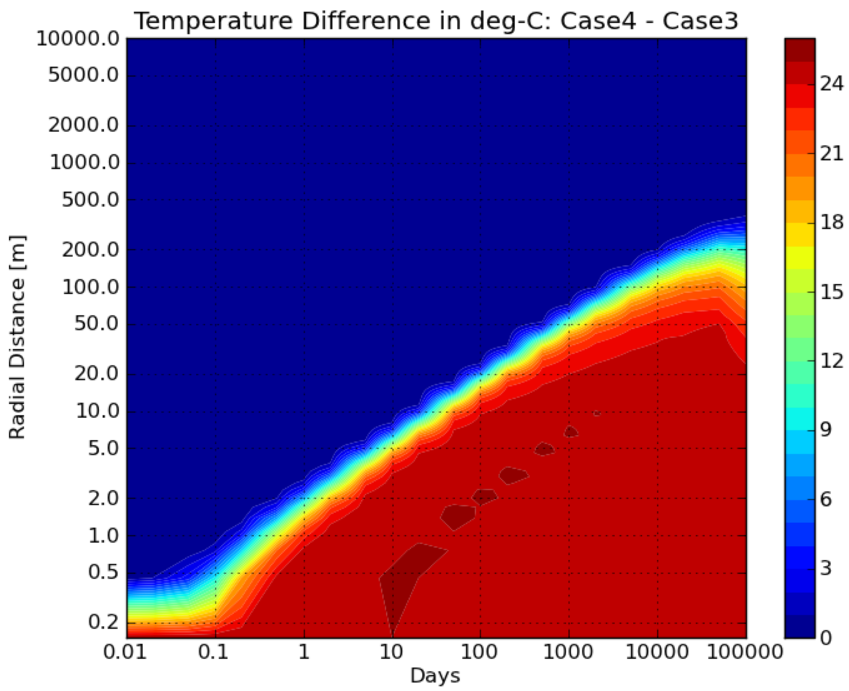

Fig. B-10 Radial-temporal profile of temperature difference between Case3 and Case4.

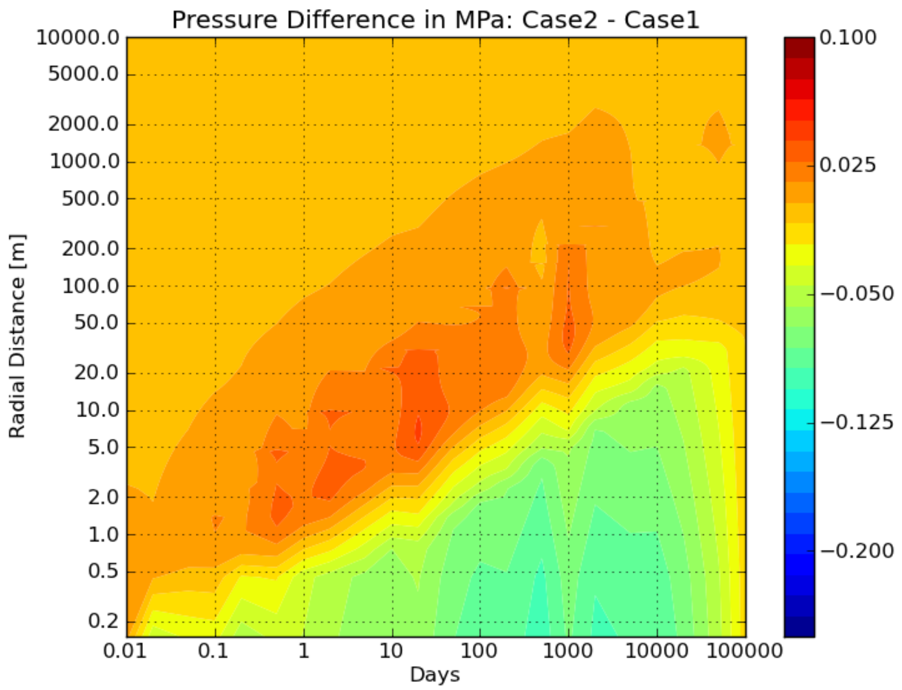

Fig. B-11 Radial-temporal profile of pressure difference between Case1 and Case2.

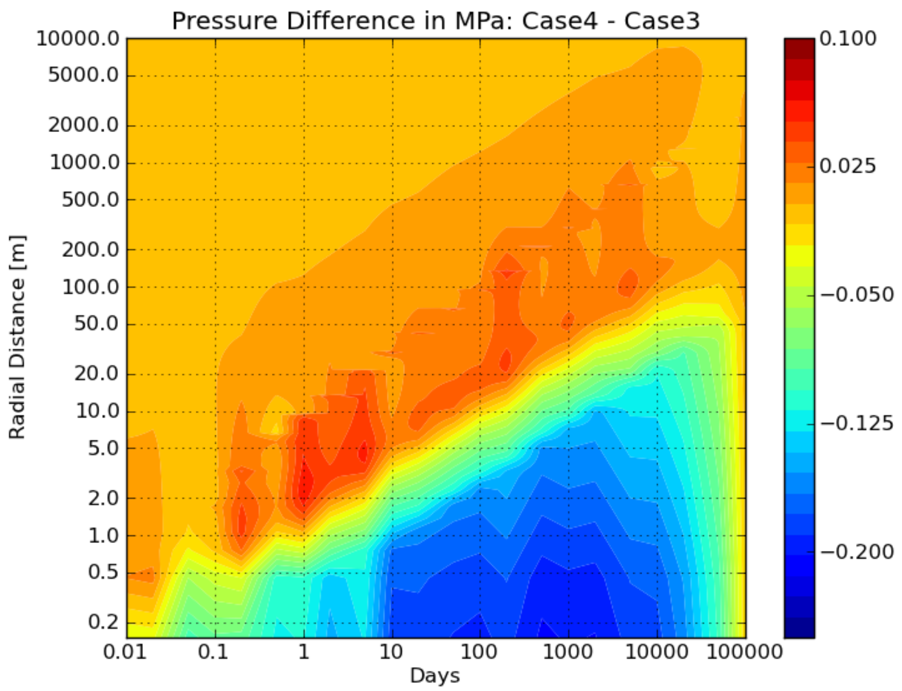

Fig. B-12 Radial-temporal profile of pressure difference between Case3 and Case4.

Attachment C: Pipe flow simulation study

1. Objective

The liquid CO_2 transported by the shuttle tanker will be delivered through the flexible riser pipe to the injection well, which are surrounded by the ambient seawater and the subsoil of the seafloor. The estimation of fluid properties in the flowline is important for the appropriate CO_2 storage.

In order to investigate the pressure and temperature profiles along the flexible riser pipe and the injection well, a numerical model study was conducted by constructing a simplified CO_2 flowline model.

2. Pipeline modeling and conditions

1) Software for analysis

- OLGA Ver. 6 : Dynamic multi-phase flow simulator developed by SPT Group

2) Numerical pipeline model

- Pipeline Schematic Model (refer to Fig. C-1)
  - Liquid CO_2 from cargo tanker will be transported through the pipeline A (flexible riser pipe ,refer to Fig.C-2) and the flowline B (injection well).
  - Each pipeline length : 1000 m
  - Depth of seawater : 500 m
  - Depth of soil/rock : 1000 m

- Temperature of seawater (refer to Table C-1)
  - Provided by Japanese Meteorological Agency

- Temperature of soil (refer to Table C-1)
  - Calculated by following equation

    $T_d = D_e*3/100+6.5$

    T_d : Temperature of soil D_e : depth from seabed

- Physical properties of CO_2

・Provided by OLGA's databank

- Pipeline conditions
  ・Pipeline A is divided into 5 parts according to temperature of seawater.
  ・Pipeline B : refer to case definition
  ・Pipeline condition and geometry : refer to Table C-2A /C-2B /C-2C
  ・Insulation : refer to Table C-2D

- Fluid conditions
  ・Riser inlet : refer to Table C-3A
  ・Injection inlet : refer to Table C-3B

- Boundary conditions
  ・Wellhead : 14.5 MPaA / 6.5 deg.C
  ・Well : 23.2 MPaA / 36.5 deg.C
  ・Heat transfer coefficient (refer to Table C-2C)

- Case definition (refer to Table C-4)
  The size and flow rate of pipeline B are changed as shown in the Table C-4.
  ・Case 1: Pipeline B has no branch to simplify the model.
  ・Case 2: Pipeline B branches 10 injection lines. It means the flow rate of pipeline B is 10% flow rate of pipeline A. Therefore the size of pipeline is changed to 3 inch according to the flow rate.
  ・Case 3 : Pipeline B branches 5 injection lines. It means the flow rate of pipeline B is 20% flow rate of pipeline A. The size of pipeline is changed to 3 inch according to the flow rate.

3. Results analysis

Pressure and Temperature at injection well

Case 1

Figure 3 shows temperature and pressure in the pipeline at steady state. Pressure increases by hydraulic head as the depth is deeper. And temperature also increases by environmental conditions of the seawater and soil.

At the injection well, temperature is 30.76 deg.C and pressure is 23.0 MPaA. Since critical point is 31.1 deg.C and 7.38 MPaA, the fluid condition at the injection well is very near to the super critical conditions.

Case 2

Figure 4 shows temperature and pressure in the pipeline at steady state.

At the injection well, temperature is 35.39 deg.C and pressure is 22.99 MPaA. Since critical point is 31.1 deg.C and 7.38 MPaA, the fluid condition at the injection well is the super critical conditions.

Case 3

Figure 5 shows temperature and pressure in the pipeline at steady state.

At the injection well, temperature is 34.77 deg.C and pressure is 22.65 MPaA. The fluid condition at the injection well is the super critical conditions.

Temperature of case 2 at injection well is higher than case 3 because the flow rate of case 2 is smaller as the same pipeline. On the other hand, pressure of case 3 at injection well is smaller than case 2 because the flow rate of case 3 is larger as the same pipeline.

Table C-1 Temperature of seawater and soil

Condition	Depth	Temperature
	m	deg.C
Seawater	0	24.5
Seawater	-50	21.5
Seawater	-100	18
Seawater	-200	14
Seawater	-400	8.5
Seawater	-500	6.5
Soil /Rock	-1500	36.5

Table C-2A Pipeline conditions of pipe A (Flexible riser pipe)

		Interlock Conduit	Inner Pipe	Pressure Armor	Tensile Armor	Buoyant Laver	Outer Sheath
ID	mm	157.6	163	176.4	184.4	193.4	295
Thickness	mm	2.7	6.7	4	4.5	50.8	7
OD	mm	163	176.4	184.4	193.4	295	309
Material	-	SUS304	HDPE	CS	CS	Micro balloon, Plastic tape	HDPE
Thermal Conductivity	W/m-K	16.3	0.22	83	83	0.17	0.22

Table C-2B Pipeline conditions of pipe B(Injection well)

Case		1	2	3
		Injection Line	Injection Line	Injection Line
ID	mm	157.6	73.9	73.9
Thickness	mm	7.6	7.6	7.6
OD	mm	172.8	89.1	89.1
Material	-	CS	CS	CS
Thermal Conductivity	W/m-K	83	83	83

Table C-2C Pipeline geometry and roughness

Pipe	Diameter	Roughness	Depth	h_{out}
	m	m	m	W/m2-C
Pipe A-1	0.158	1.0E-05	-50	2360
Pipe A-2	0.158	1.0E-05	-100	2360
Pipe A-3	0.158	1.0E-05	-200	2360
Pipe A-4	0.158	1.0E-05	-400	2360
Pipe A-5	0.158	1.0E-05	-500	2360
Pipe B-1	0.158	1.0E-05	-1000	1000

Table C-2D Physical properties of insulation material

Material	Density	Thermal Conductivity	Heat Capacity
	kg/m3	W/m-K	J/kg-C
HDPE	750	0.22	2300
CS	7850	83	500
Buoyant Laver	32	0.17	2000
SUS304	8000	16.3	500
Subsea soil	1750	2.6	1250

Table C-3A Fluid conditions at riser inlet

Pressure	MPaA	10
Temperature	deg.C	5
Flow rate	m3/day	3,000
Component	wt%	
CO2		100
Density	kg/m3	944
Vol Flow rate	m3/h	188
Mass Flow rate	kg/h	176,976

Table C-3B Fluid conditions at injection line

Case		1	2	3
Pressure	MPaA	calc.	calc.	calc.
Temperature	deg.C	calc.	calc.	calc.
Flow rate	m3/day	calc.	calc.	calc.
Component	wt%			
CO2		100	100	100
Density	kg/m3	calc.	calc.	calc.
Vol Flow rate	m3/h	calc.	calc.	calc.
Mass Flow rate	kg/h	176,976	17698	35395

Table C-4 Case definition of pipeline B

Case		1	2	3
		Injection Line	Injection Line	Injection Line
ID	mm	157.6	73.9	73.9
Thickness	mm	7.6	7.6	7.6
OD	mm	172.8	89.1	89.1
Flow rate	kg/h	176976	17698	35395

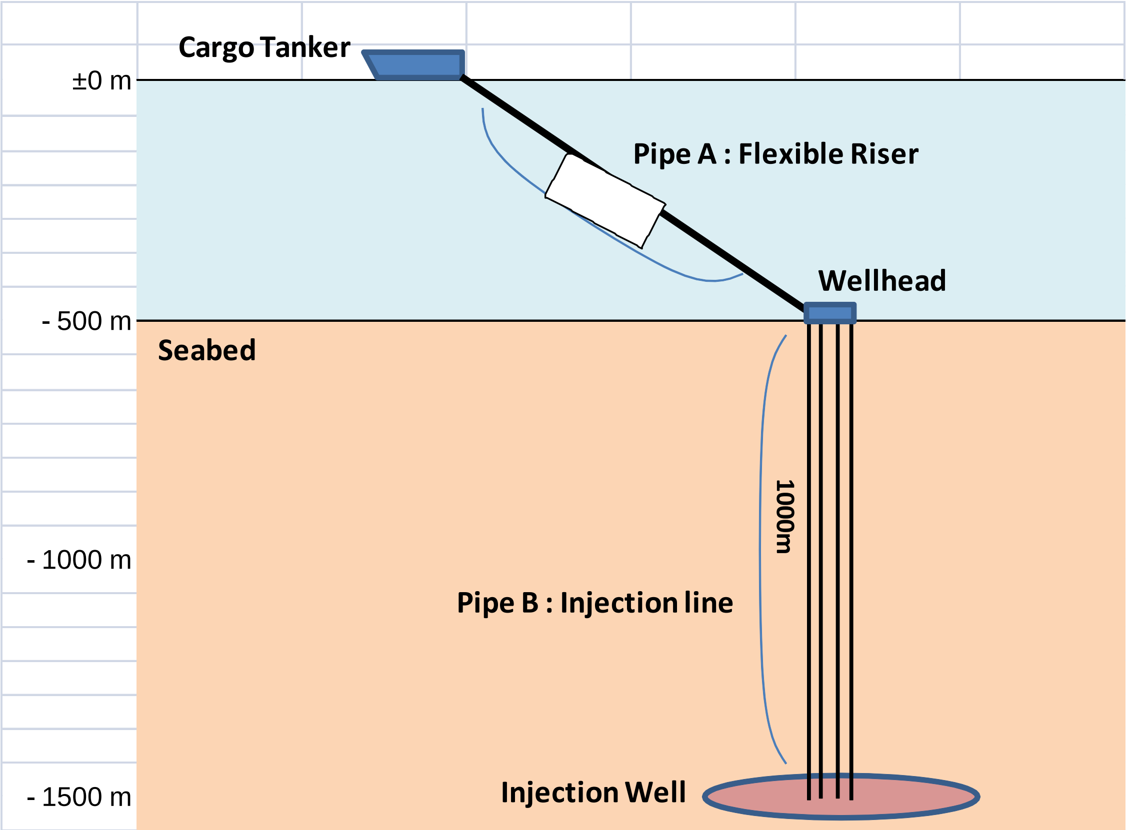

Fig. C-1 Schematic of the CO_2 injection model.

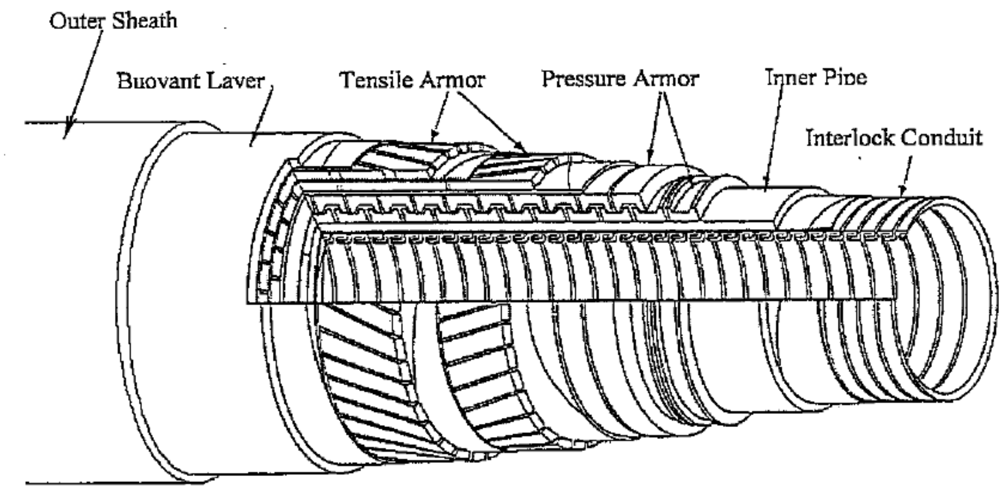

Fig. C-2 Construction of flexible riser

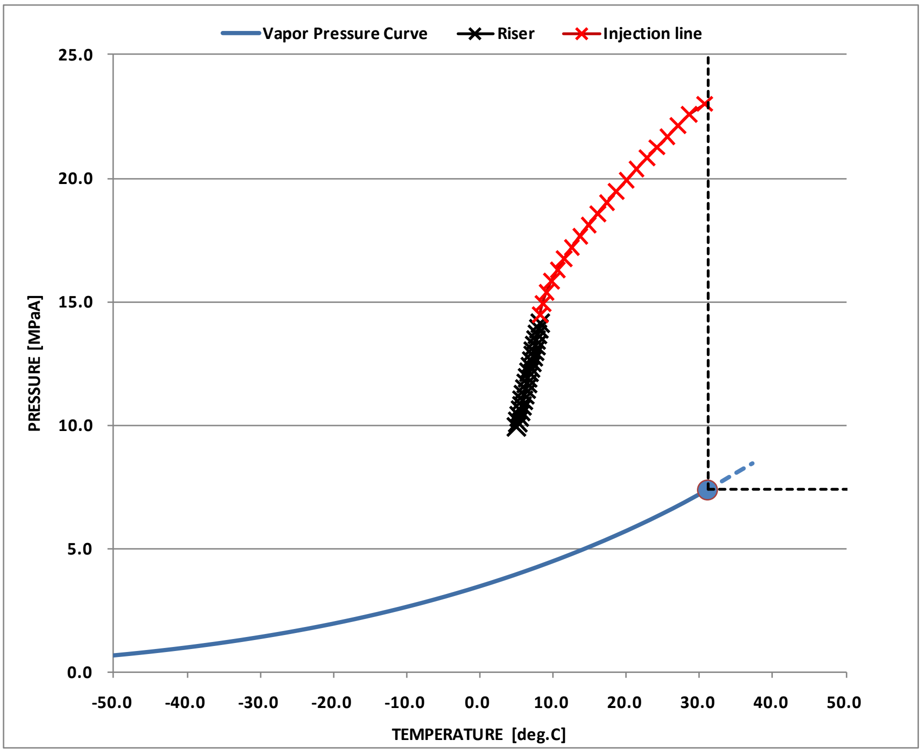

Fig.C-3 CO_2 temperature and pressure in the pipeline (Case1)

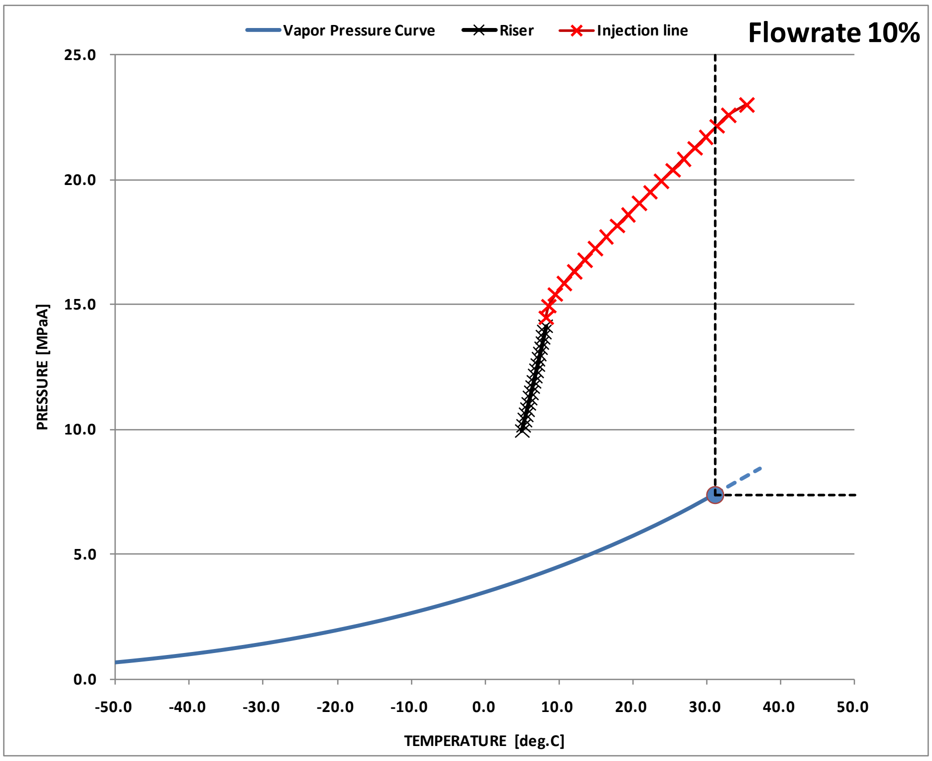

Fig.C-4 CO_2 temperature and pressure in the pipeline (Case2)

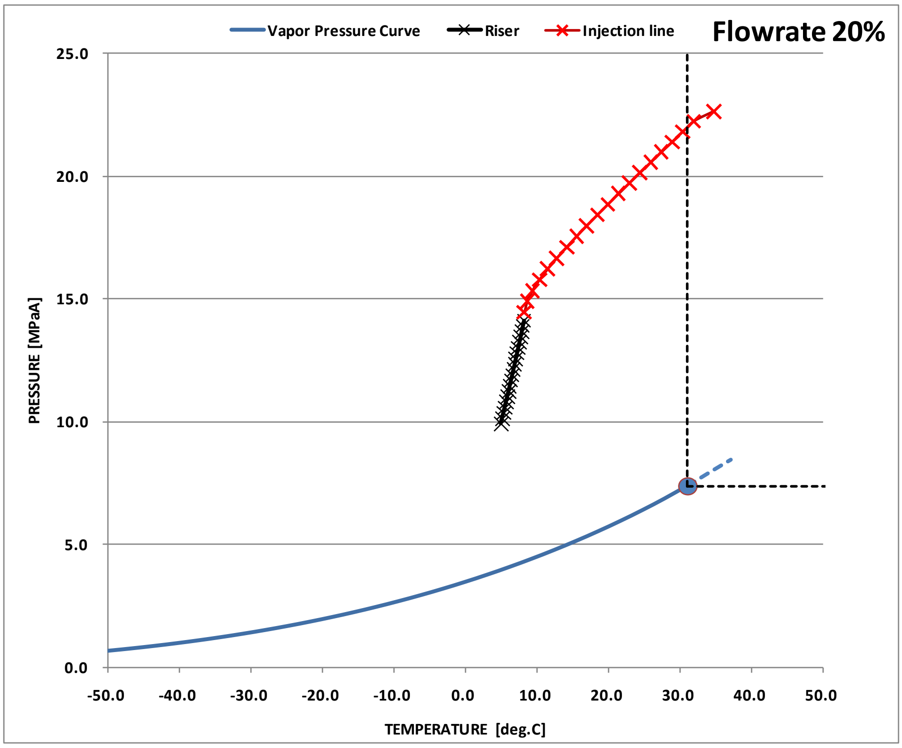

Fig.C-5 CO_2 temperature and pressure in the pipeline (Case3)

Attachment D: Communication buoy systems

The configuration of the offshore communication buoy system is schematically shown in Fig.D-1. The system obtains the information of the CO_2 storage wells and the atmospheric/oceanographic data of the offshore site. The design condition and the principal dimension of the buoy are shown in Tables 3.4-1 (refer to 3.4.3) and D-1, respectively. Equipped devices and sensors on the buoy for monitoring the site are listed in Table D-2.
In response to the request by the control station, the obtained information is transferred to the land-based control station via communication satellites.

Table D-1. Principal dimensions of the buoy and additional equipment.

Item	dimension
Outside diameter of the buoy hull	approx. 6.0 m
Height from the draft line to the upper deck	approx. 1.5 m
Height from the draft line to the antenna top	more than 8.0 m
Length of mooring line	approx. 650 m/line
Number of mooring line	3 sets (lines)
Electric power source	DC24V battery (to be charged by the CO_2 carrier during the operation)
Maintenance equipment	Ladders, platforms, steps, antenna, lights, buoy sign devices for navigation safety, etc.

Table D-2. Equipped devices and sensors on the buoy for monitoring the site.

Devices/sensors	Measurements
D-GPS and relating device	- GPS antenna - GPS receiver
CO_2 control data and control device	- CO_2 well/pipeline temperature - CO_2 well/pipeline pressure - CO_2 well/pipeline flow quantity
Observation sensors	- Wind direction - Wind velocity - Atmospheric temperature - Humidity - Atmospheric pressure - Rainfall
Buoy monitoring	- Motion sensor of the buoy - Shock sensor - Water temperature - Water detector (water leakage sensor) in buoy hull - Water tight doors open/close

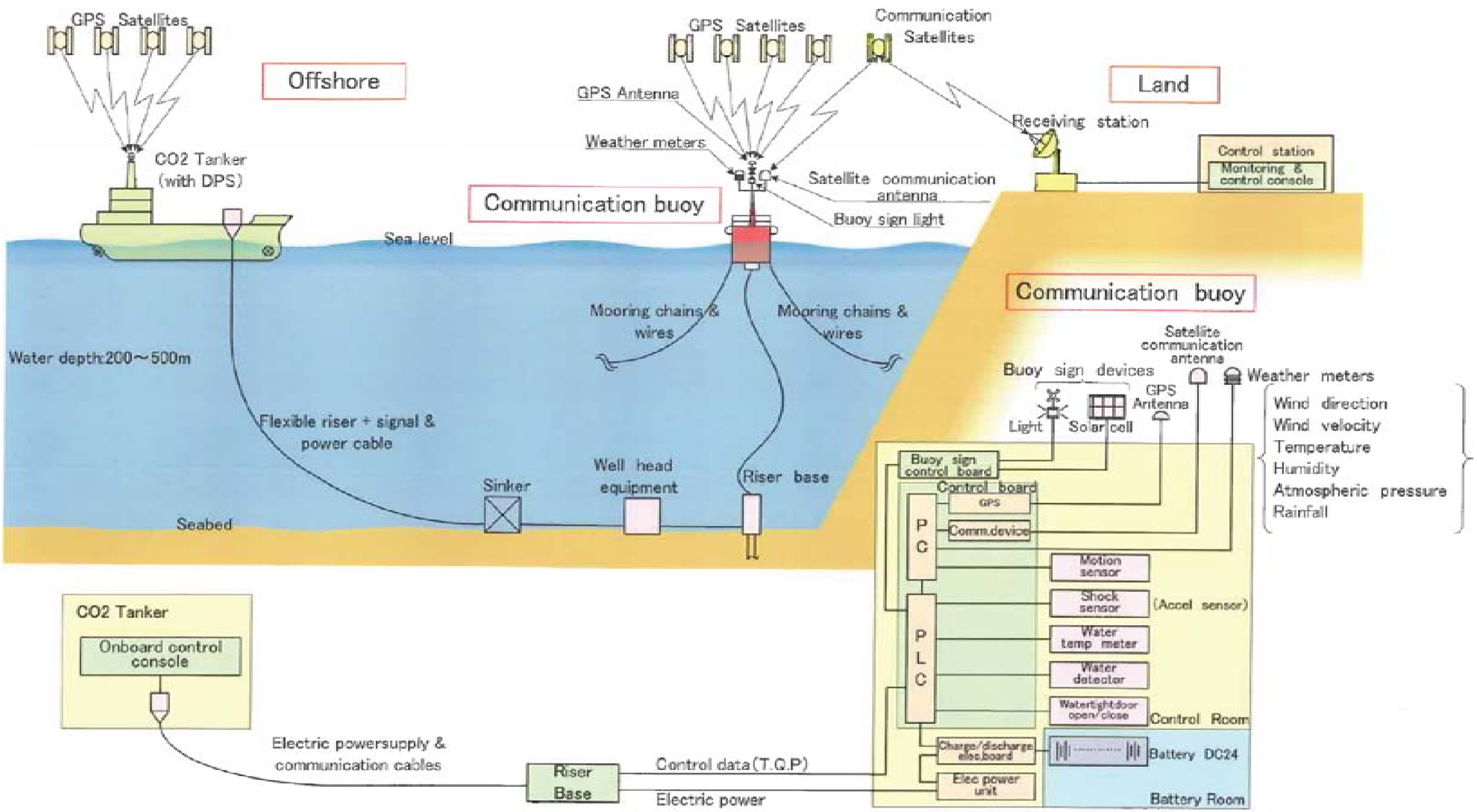

Fig.D-1 Configuration of the communication buoy systems.

Attachment E: Questions and answers for regulations on the ship-based CCS

In Chapter 4 on the regulatory consideration, the compilation and analyses on the codified fact on law and regulations on the ship-based CCS in domestic and international views were given. But a judicial actuality might be well understood in context of the supposed cases. This section addresses the particular cases, which might be encountered in the future employment of ship-based CCS in Japan in relation to the law and regulations. The questions listed are not necessarily implied that the selected cases are probable questions to be raised in the future in Japan.

Q1: Is a public hearing process expected for the future MOE 's approval of JCCS Company 's application for permission for CO_2 stream disposal ?

If a company undertakes CO_2 storage in sub-seabed geological formations, a permit request form and attached documents (including an environmental impact assessment report) should be submitted to the minister of the environment, and will be made available to the public for one month under the name of the minister of the environment, under the provisions of Article 10-6 of the Marine Pollution Prevention Law. Thus, anyone with an opinion from the environmental protection point of view can submit a written opinion to the minister of the environment by the final date of the period available for review.

Note that the currently planned large demonstration projects are supposed to be undertaken by Japan CCS Co., Ltd., commissioned by the Ministry of Economy, Trade and Industry. Therefore, either METI (the outsourcer) or JCCS (the outsourcee) should submit a permit request form and attached documents to the minister of the environment, and these documents will be made available to the public under the name of the minister of the environment.

On the other hand, there are no provisions, and therefore at least no obligations for METI, which is in the position of promoting CCS demonstration projects, to conduct a public hearing or public consultation. However, from a report in the media that METI previously explained to local communities at various times the conducting of preliminary studies (exploratory drilling, offshore seismic exploration), it is most likely that they will hold explanatory meetings to obtain agreement from local communities when a demonstration project is undertaken.

Q2: What will be the legal process if the Act for Assessment of Environmental Impacts is applied to CO_2 injection operations from ships into sub-seabed geological formations?

EIA relating to CO_2 storage in sub-seabed geological formations is undertaken based on Marine Pollution Prevention Law (see Fig.E-1). The EIA estimates how injected CO_2 leakage would impact the marine environment (the level of pH decrease, the degree of impact on organisms due to the increase in CO_2 partial pressure) and evaluates the quantity. This idea basically conforms to that for "CO_2 storage in coastal areas" that has been envisioned in Japan from the very beginning.

However, from a technical standpoint, sampling at offshore sites where the water is deep may make field studies to grasp the present condition of the biological environment more difficult, compared to those conducted in coastal areas where the water is shallow.

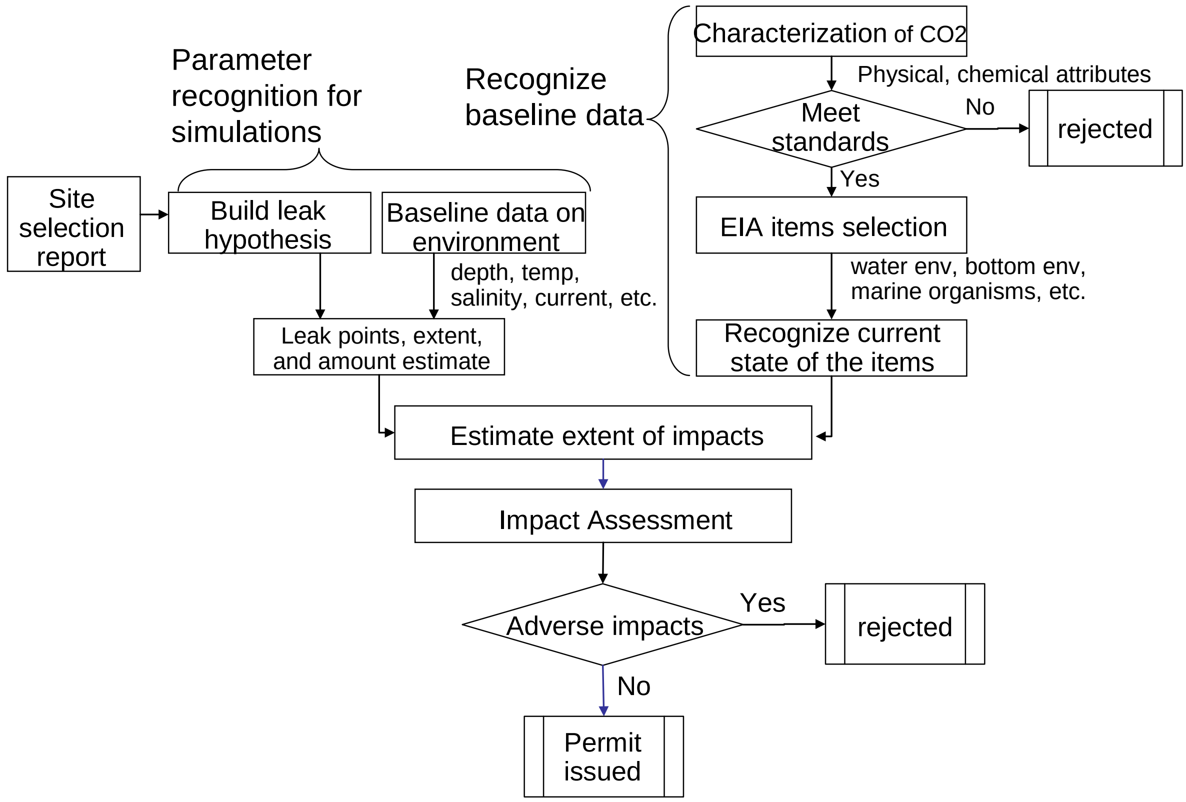

Fig.E-1 Flowchart of permit approval for CO_2 storage in sub-seabed geological formations according to the Marine Pollution Prevention Law.

Q3: How should the applicant to MOE for approval for CO_2 disposal operations take the document "On the Safety of CCS Demonstration Projects" issued by METI on August 2009 into account?

The objective of the document "On the Safety of CCS Demonstration Projects (August, 2009)" is described in the "Preface," which is as follows:

> "The standard desired to be followed from the safety and environmental viewpoints in implementing a CCS project" presented in this document only address the issues to be considered when implementing a CCS demonstration project, and is not a preliminary safety rule to be set up when putting CCS into practice in the future. The corporations executing the demonstration projects are expected to set up a more practical system (organization, internal regulations and procedures, etc.) to keep safety depending on the project-executed sites based on this standard.
>
> "CCS-related regulations including safety are being studied by the countries concerned and international organizations, and regulatory networks are also being developed and have recently started operating. Putting CCS into practice in the future, we shall need to conduct a study based on not only the knowledge gained through demonstration projects executed in Japan but also information obtained through CCS projects executed in other countries, the most advanced approach required to keep CCS projects safe, and the trend of regulations in other countries."

What can be understood from the statement above is that the standard described in this document is only applied to demonstration projects. Since currently planned large-scale demonstration projects are commissioned by METI, the ministry itself takes responsibility for implementing the projects. Therefore, this standard will surely be applied to large-scale CCS demonstration projects.

As an additional note, the document was made publicly available immediately after the "Guideline for applicants to obtain permission for CO_2 stream disposal (January 2008)" was released by the Ministry of the Environment, and its contents including environmental impacts are referred to in the "Guideline."

"On the Safety of CCS Demonstration Projects" issued by METI focuses on ensuring project safety. The framework for CCS regulations in the Marine Pollution Prevention Law under the jurisdiction of the Ministry of the Environment aims to prevent and reduce impacts on the marine environment, as well as obligating the submission of a "report on the selected sea area" as an attachment to the application form, which shows that the storage will be conducted safely from a geological standpoint. The assessment of marine environmental impact under the assumption of leakage from geological formations into seawater will also require geological assessment.

In other words, although there are no descriptions explicitly indicating mutual connections in either system, for METI, as the operator of planned large-scale demonstration projects, it may be reasonable to utilize the documents reviewed based on the "On the Safety of CCS Demonstration Projects" for the "report on the selected sea area" and "assessment of marine environmental impact" in accordance with the Marine Pollution Prevention Law.

A new guideline that will be revised from the "On the Safety of CCS Demonstration Projects" may be applied to CCS activities following large-scale demonstration projects, and its connection to the Marine Pollution Prevention Law is expected to be the same as above.

Q4: While the Strategic Energy Plan of Japan revised in June 2010 by METI refers to the CCS-ready requirement for future coal-fired plants, would its legal framework be a reformed "Electricity Business Act"?

The Strategic Energy Plan of Japan endorsed by the Cabinet in June 2010 mentions the time of introducing CCS and the CCS-ready concept.

> "While developing, demonstrating, and introducing highly efficient coal thermal power domestically, Japan is aiming for zero-emission coal-fired power generation for the future. In an effort to realize the above, Japan will accelerate CCS technology development for commercialization around 2020 as well as considering introducing the CCS-ready concept for new and additional coal-fired power plants to be planned in the future. In addition, Japan will consider introducing CCS technology for coal-fired power by 2030 in light of the commercialization."

(The Strategic Energy Plan of Japan endorsed by the Cabinet in June 2010)

On the other hand, while Japan obliges thermal power plants generating over 150,000 kilowatts to assess environmental impact in accordance with the Environmental Impact Assessment Act, the Ministry of the Environment revealed that the minister of the environment expressed his opinion regarding preparation documents for environmental impact assessment, and that he made requests to METI including the following:

> "Coal-fired power plants to be planned in the future should be capable of controlling carbon dioxide emissions to the maximum extent, utilizing the highest level of technologies that are adaptable at the time including integrated gasification combined cycle (IGCC) power generation and carbon dioxide capture and storage (CCS)."

http://www.env.go.jp/press/press.php?serial=11157

It can be said that the request by the Ministry of the Environment stated above (May 2009) was incorporated into the reference regarding CCS in the previously stated Strategic Energy Plan of Japan (June 2010).

Therefore, it is possible that thermal power plants to be built in the future may be required to take CCS into consideration by the review process according to the Environmental Impact Assessment Act, despite there being no obligations based on the Electric Utility Industry Law.

However, responding to the Great East Japan Earthquake of March 11, 2011 and the subsequent accident in Fukushima No. 1 nuclear power plant, Japanese prime minister Naoto Kan stated on May 11 that he would return to the drawing board on the Strategic Energy Plan. It is therefore important to pay close attention to how CCS is treated in a new Strategic Energy Plan.

Q5: What is the site selection report that the Marine Pollution Prevention Law requires of operators for permit application?

Under the Marine Pollution Prevention Law, limited items of waste can be considered for dumping into the sea. Operators need to conduct an EIA to obtain a permit from the minister of environment, on the basis that the waste should be disposed of in the given "disposal area." The disposal area was previously defined for each item and can be found at the following site.

http://www.env.go.jp/earth/kaiyo/ocean_disp/1hourei/pdf/kaiikizu.pdf

However, in the case of CO_2 disposal into a sub-seabed geological formation, the effectiveness of CO_2 storage depends highly on the characteristics of the target formation. Therefore, the law did not set the "disposal area" as other waste items, but established criteria for disposal site selection. In this scheme, operators need to conduct a geological survey and select an appropriate site based on their evaluation.

Based on this idea, Article 5 of the Ordinance of the MOE requires operators to submit a site selection report including:

(1) Characteristics of the sub-seabed geological formation
(2) Potential migration and leakage paths of CO_2 stored under the seabed
(3) Spatial extent of CO_2 stored within the sub-seabed geological formation, and estimated CO_2 storage capacity
(4) Characteristics of the marine environment of the storage site

The site selection criteria defined in Article 2 of the Ordinance of the MOE are as follows:

1. There is no record of significant movement in the geological formation.
2. The possibility of significant movement in the geological formation is low.
3. An appropriate geological structure to prevent CO_2 leakage is present.
4. It is possible to monitor CO_2 storage and the marine environment.
5. Mitigation measures can be taken in the area, in case of CO_2 leakage.
6. There is sufficient information on the existence and location of habitats

that need special protection.

The descriptions of 1 and 2 above are exactly the same as those in Article 6 of the Designated Radioactive Waste Final Disposal Act.