FULL-SCALE DEMONSTRATION OF EBS CONSTRUCTION TECHNOLOGY, (II) DESIGN, MANUFACTURING AND TRANSPORTATION OF PRE-FABRICATED EBS MODULE(PEM)

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Abstract

Pre-fabricated EBS module(PEM) has technical advantages as simplifying handling and emplacement procedure at repository drift tunnel of geological repository for high-level radioactive wastes. Carbon steel made PEM casing was designed and manufactured in full-scale. Assembling tests of PEM using simulated buffer material and overpack were conducted to evaluate technical feasibility of construction procedure and remote handling operability. While for heavy-load transportation and emplacement technique in repository drift tunnel, air-bearing system was tested using a full-scale test device of modified loading and simulated tunnel surface. Based on the tests results, applicability of air-bearing system for horizontal emplacement of PEM was discussed.

1 Introduction

In the geological disposal program of high-level radioactive waste in Japan, the waste is placed in the repository constructed underground at the depth more than 300 m below the surface. Long-term safety is ensured by multi-barrier system consisting natural and engineered barriers. The engineered barrier system(EBS) consists of a metal overpack, which contains vitrified waste and buffer material made of bentonite as shown in **Figure 1** (JNC, 2000). It is apparently important and essential issue that a reliable EBS should be constructed, transported and emplaced at the repository.

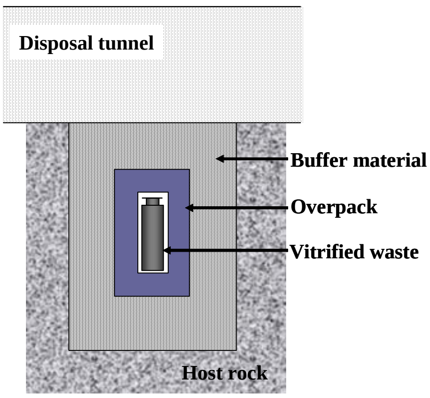
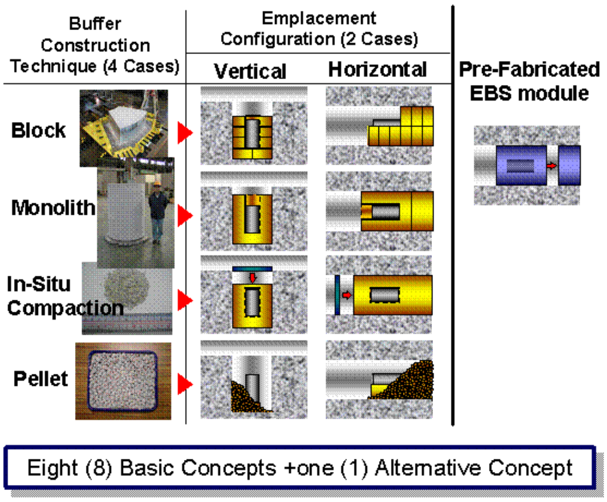


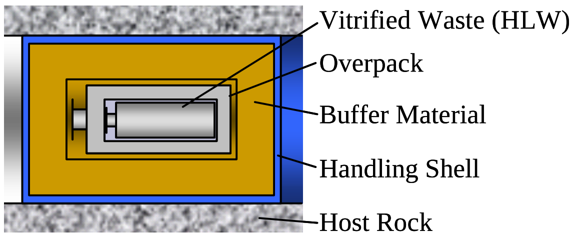
Figure 1: Engineered barrier system for geological disposal of high-level radioactive waste.

Radioactive Waste Management Funding and Research Center(RWMC) has been conducting development program for remote handling, transport and emplacement techniques for EBS since 2,000. In this program various repository concepts, which mainly depend on types of buffer material as shown in **Figure 2**, were collected and applicability of potential techniques for remote operation were surveyed and tested (Masuda et al., 2004a, Ueda et al., 2007).

In order to simplify the transportation and emplacement procedure of EBS under limited environmental condition at the repository, a concept of pre-fabricated EBS module (PEM) has technical advantages, while quality of EBS can be accomplished and maintained due to its well-controlled operation conducted at aboveground facility.



(1) Various emplacement concepts



(2) Concept of PEM

Figure 2: Repository concepts for different EBS emplacement techniques

In this work, full-scale manufacturing, assembling and transportation tests were conducted for the PEM concept in order to assure the technical feasibility of horizontal emplacement of EBS. Design requirements and design procedure of PEM casing were studied and presented. A carbon steel PEM casing was designed and manufactured in full-scale. By using modified buffer material blocks and overpack, assembling test was performed. While for the transportation technique for PEM, air-bearing device was selected to move a heavy load. The assembled devices in full-scale was tested its applicability to several different surface condition simulating a repository tunnel.

2 Design, Manufacturing and Assembling of PEM

2.1 Design of PEM Casing

Carbon steel casing with 2,220 mm in inner-diameter, 3,130 mm in inner-length was assumed to be applicable to the EBS specification shown in H12 Report (JNC, 2000). Through a numerical analysis, the thickness of the casing was settled in 20 mm as shown in 1.3.

2.1.1 Design Requirements

During the operation handling PEM at the underground tunnel, handling operability and maintaining of EBS quality are required to the casing. Also operation safety is important issue for it. From the view point of these operability, quality and safety, design requirements of PEM casing were extracted as shown in **Table 1**.

2.1.2 Design Procedure

Based on the design requirements shown in above, design procedure of the casing is summarized into as shown in **Figure 3**. In this procedure, material selection and countermeasures which need to fix a structure of the casing are principal steps. After choosing the countermeasures, basic structure of the casing are fixed from the view point of its manufacturability and economical issue. Based on the basic structure, more detailed structure is considered in consideration of the specification of EBS, which is placed inside of the casing. A numerical analysis is conducted on this detailed structure to ensure the structural integrity of the casing under the predicted maximum loading condition at the repository. Configuration of the casing is shown in **Figure 4**. It is full cover casing with connection flanges but no water tightness.

Table 1: Design requirements of PEM casing

Process	Items		Requirements
Material selection	Material selection		Availability & cost
Manufacturing	Manufacturing		Manufacturability
EBS emplacement	Transportation to aboveground facility		Manufacturing cost
	Set-up for assembling		Availability of EBS
	Buffer material emplacement		Assembling of EBS
	Overpack emplacement		Assembling of casing
	Buffer material emplacement		Handling capability
	Complete covering		Availability of inspection
	Transportation to inspection		Mechanical integrity
Inspection	Inspection		Remote handling operability
	Preparation to movement		Environmental condition
Transportation	Transportation to underground facility		Maintainability of EBS quality
	Transportation at drift tunnel		Gap filling capability
Emplacement	Emplacement		-
	Buck-filling		-

2.1.3 Mechanical Integrity

Before start a numerical analysis for structural integrity of the casing, loading condition was examined to fix the calculation condition. PEM will be transported through the drift tunnel, and placed on the floor. Due to intensified loading at a certain point of casing-drift floor interface, final emplacement position gives the maximum loading to the casing as shown in **Figure 5**.

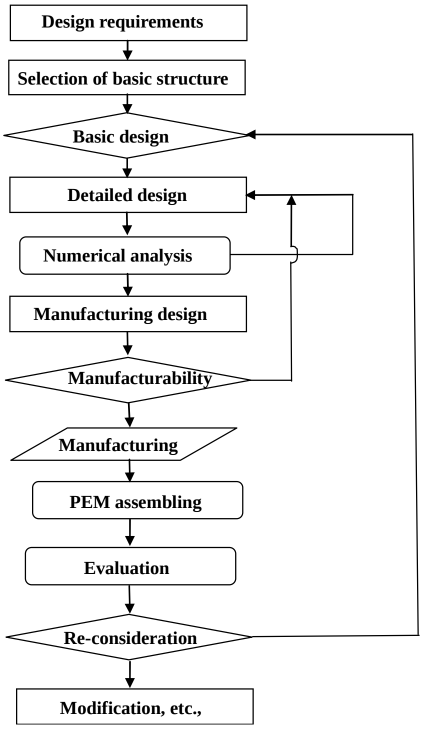


Figure 3: Design procedure of PEM casing

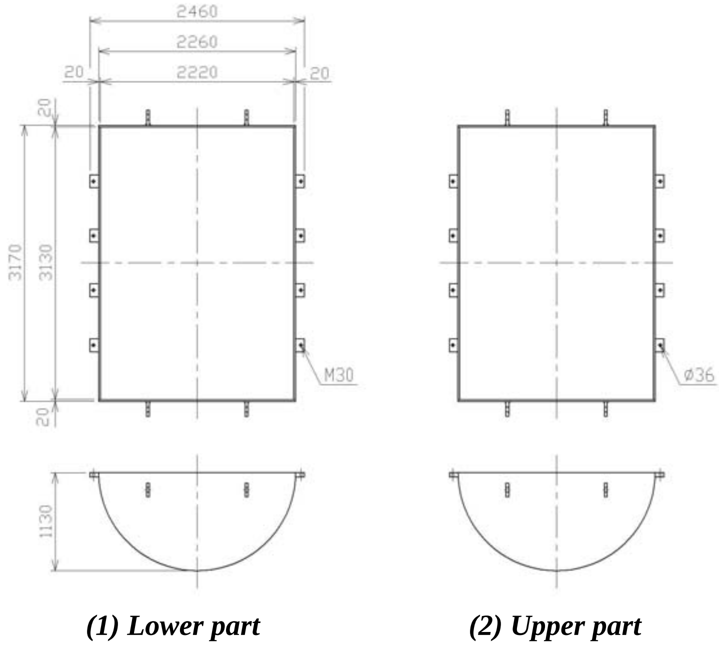


Figure 4: Configuration of PEM casing

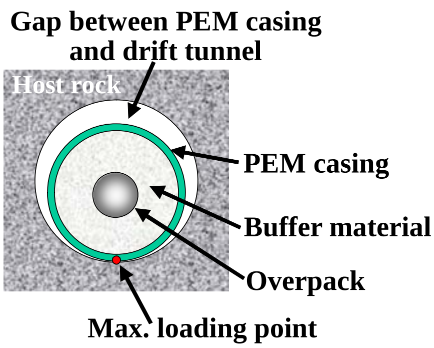
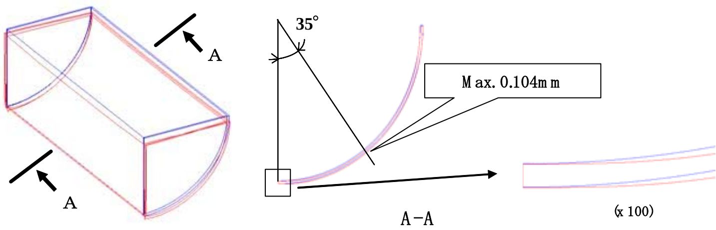


Figure 5: Loading condition of PEM casing at final emplacement position

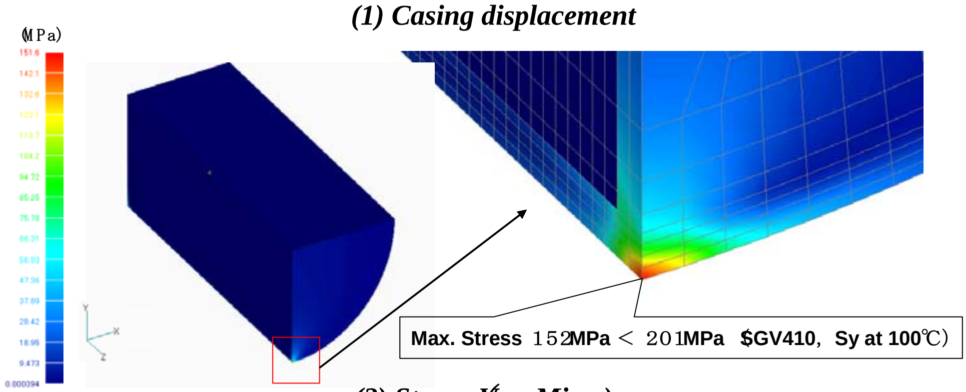
Displacement of the casing, maximum stress(Von Mises) and stress distribution were calculated by three dimensional stress analysis using a general-purpose finite element method code, ABAQUS 6.6. The maximum stress generated at the point was less than yield stress and tensile stress of the carbon steel(JIS Code 3118, SGV 410, carbon steel plates for pressure vessels for intermediate and moderate temperature service), while the maximum displacement was about 0.1 mm. From these results, it was confirmed that the casing with 20 mm in thickness maintain its mechanical integrity at the position of drift emplacement. Loading data and calculation result are shown in **Table 2** and **Figure 6**, respectively.

Table 2: Loading data of numerical analysis for PEM casing

Items	Weight(kg)
Overpack	6,060(vitrified waste: 500 kg & overpack: 5,560kg)
Buffer material	23,200(dry density: 1.9Mg/m^3, water content: 9%)
PEM casing	5,381(carbon steel: 7.81 Mg/m^3)



(1) Casing displacement



(2) Stress (Von Mises)

Figure 6: Calculation results of mechanical integrity of PEM casing

2.2 Manufacturing of PEM Casing

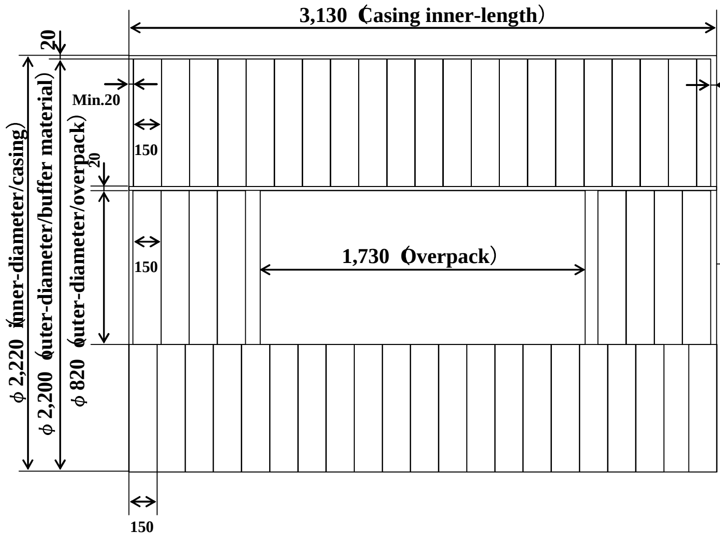
The casing was divided into three parts consisting of body, lid and flange. Through the process of cutting, bending, welding and assembling for carbon steel plate, it was completed as shown in **Figure 7**. It is 2,460 mm in outer-diameter, 3,170 mm in outer-length, and total weight of 5,381kg.

Figure 7: PEM casing, at final assembling and completed

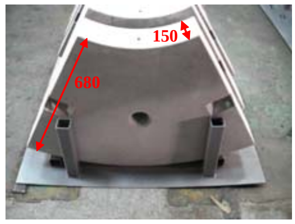
2.3 Assembling of PEM

2.3.1 Buffer Material Preparation

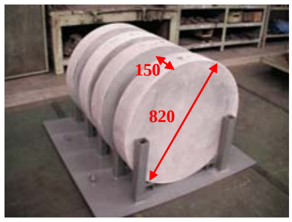
There are several ways to place EBS into the PEM casing. In this work the concept of block type bentonite was examined by using modified blocks made of mortal. A fan-shaped 1/6 section dividing block and a disc-shaped block were prepared as shown in **Figure 8**. 126 of fan-shaped block and 10 of disc-shaped block need to complete one unit of PEM, however in this work, a half of them were provided.



(1) Blocks dividing and overpack emplacement



(2) Fan-shaped 1/6 section dividing block



(3) Disc-shaped block

Figure 8: Configuration of EBS assembled in PEM casing

2.3.2 Overpack Preparation

Modified overpack with real scale of outside diameter and a half of the length, made of carbon steel, was prepared as shown in **Figure 8(1)**.

2.3.3 Full-Scale Assembling Test Results

At first, lower part of blocks and overpack were placed into lower part of PEM casing as shown in **Figure 9**. After that upper part of blocks were placed onto the already assembled lower part as shown in **Figure 10**. A special designed mechanical device, which made from metal frame and has an air cylinder, was prepared to hoist the blocks as shown in **Figure 11**. Complete assembling is shown in **Figure 12**.

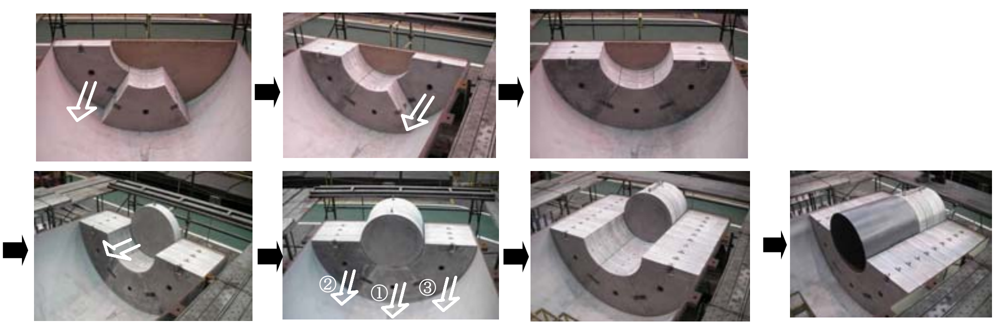


Figure 9: Block and overpack assemble for lower part of PEM casing

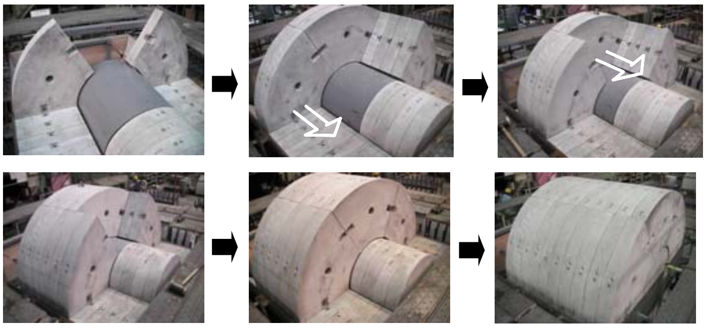


Figure 10: Block assemble for upper part of PEM casing

Figure 11: Hoisting device for blocks

Figure 12: Completed EBS assemble

3 Transportation of PEM

3.1 Air-Bearing System for Curved Surface

The feasibility of a horizontal emplacement system of PEM on the disposal tunnel was discussed, and a full-scale test of the transport system with air-bearing units was performed for the evaluation of its applicability to the drift tunnel (Iwata et al., 2007).

The air-bearing is a device that decreases the coefficient of friction to about 1/1000 by employing an air film, and enables the transport of heavy loads (JSME, 1995). The schematic structure of the air-bearing unit and mechanism of lift force generation is shown in **Figure 13.** The air- bearing systems are using in factories and they are mostly designed for use on smooth flat floors. Thus, its applicability to a curved floor of a drift tunnel in the repository must be confirmed. It is also necessary to clarify the range of its applicability to the varying degrees of surface roughness, the height difference at the joint of floor cover segments, and that of groundwater in the case of underground repository.

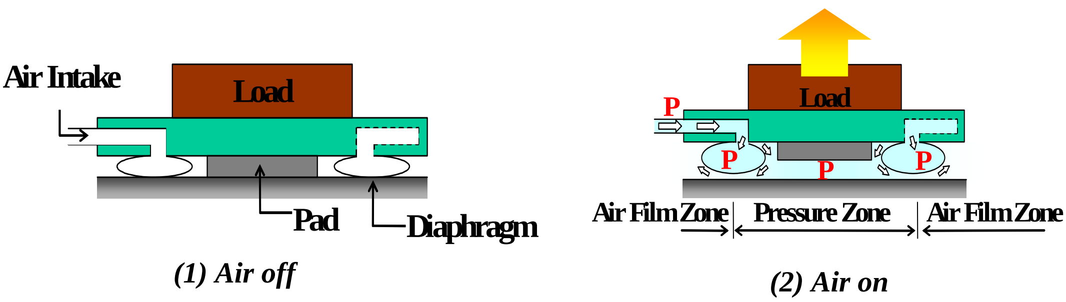


Figure 13: Mechanism of lift force generation by air-bearing unit

In order to design the air-bearing unit that is possibly applicable to such drift tunnel-like conditions, the performance of several commercially available air-bearing units was studied. From the view point of strength and flexibility, most likely the diaphragm form should be selected. Moreover, the load that is exerted on a single load air-bearing unit was calculated with consideration given to the number of load air-bearing units that may be installed and the mass of the pre-assembled waste package in order to select the appropriate air-bearing unit. The curvature of the diaphragm attachment plate was designed in consideration of the curvature of the drift tunnel and pre-assembled package casing.

Based on this design, an air-bearing unit altered for the curved floors was produced and the basic performance was examined. **Figure 14** is a photograph of the examination. The result confirmed the applicability of the air-bearing unit to transport on a curved surface, while the applicable range of air-bearing units on the curved floors was narrower than that on a flat surface.

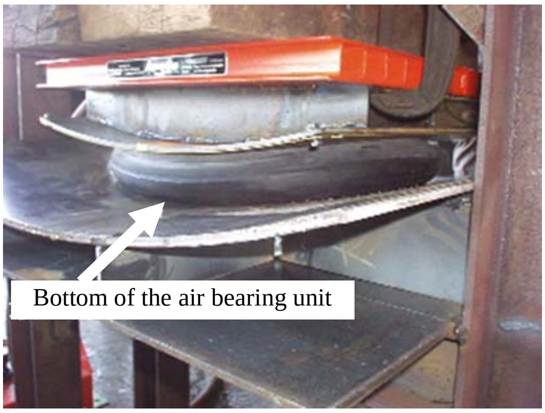


Figure 14: Air-bearing unit for the curved surface

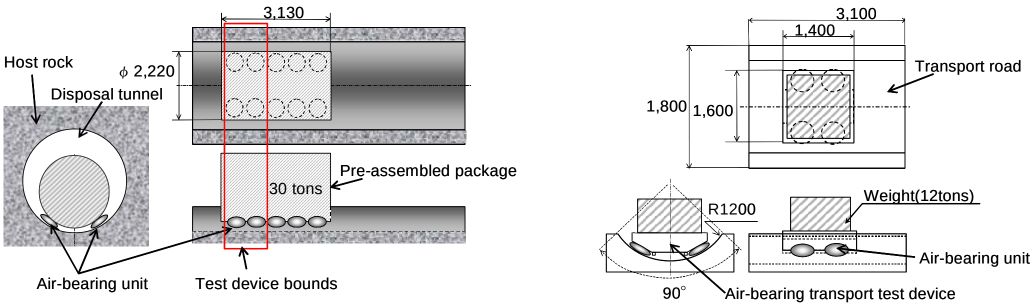
3.2 Heavy Load Transportation

3.2.1 Air-Bearing Device Preparation

It is anticipated that the actual transporting drift surface of the underground repository has a curved surface, roughness, and some puddles of underground water. The purposes of the full-scale test are (1) confirmation of applicability of above mentioned altered air-bearing units to a curved smooth surface, (2) clarification both of the applicable range on a curved rough surface which is expected to be on the actual transporting drift surface and of effectiveness of measures for such conditions, and (3) examination of the influence of water puddles on transportability.

A full-scale test device was designed and fabricated which is illustrated schematically in **Figure 15.** The curvature of the transport road surface and the load per air-bearing unit were set up with consciousness of the full-scale unit. On the other hand, the length of the air-bearing transport test device (1,400 mm) was 2/5 of the full-scale. With this length of air-bearing transport test device, the number of air-bearing units generally required at the minimum for confirming the performance of an air-bearing, in other words, the installation of 4 units (array of 2 x 2), may be assured. To simulate the load of the pre-assembled package, a 12-ton weight was placed on the transport test device. And then, the air-bearing system was started, and the transportability was examined by pulling that device with a human power.

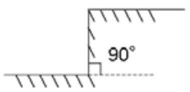
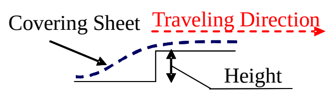
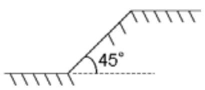
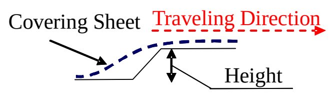
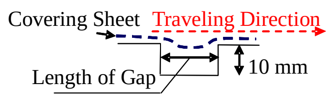
The roughness and unevenness of drift surface, for instance, the roughness of excavated rock surface and joint of segment, were modelled as the height differences and gaps. **Table 3** shows the test parameter, the height differences and gaps. In general, the tunnel surface with no surface treatment is expected to have height differences at least about 10 mm (RWMC,2001). Because of this limit of excavation accuracy, the target of height difference for this test is set at 10 mm.



(1) Full-scale unit *(2) Test device in 2/5-scale for length and weight*

Figure 15: Test device for heavy load transportation

Table 3: Forms of height differences and gaps[1]

	Edge Shape	Parameter	Range (mm)	Cross-section of height differences and gaps
Height difference	**90** 	**Height**	**1-3**	
	45 	**Height**	**1-7**	
Gap		**Length**	**10-50**	

It is expected that height difference and roughness can be buffered into gentle slopes by covering the floor of the tunnel with an appropriate sheet, and that the application range of the air-bearing will be expanded. The effects of covering sheets of several materials (Rubber, Polyethylene and Steel Plate) were examined.

3.2.2 Transportation Test Results

The results showed that the permissible difference in height without any covering sheets was 1 mm whether chamfered or not. Covering the floor with sheets enabled the air-bearing unit to run over a difference of 3 mm in height without chamfering and over one of 7 mm in height with 45° chamfering. The covering sheets enabled the air-bearing test device to run over a gap with a length of up to 40 mm. The applicability concerning groundwater and the actual tunnel surface simulated by mortar spraying as one of the tunnel surface treatment methods was similarly examined using the same test device (Masuda et al., 2004b).

These full-scale tests using the test device shown in **Figure15 (2)** suggested the applicability of the air-bearing system to the transporting system in the disposal tunnel. However, the result of the maximum height difference with the covering sheets which enabled the air-bearing unit to run over is

[1] The roughness and unevenness of drift surface, for instance the roughness of excavated rock surface and joint of segment, were modelled as the height differences and gaps.

7 mm and is less than the target height difference of 10 mm. Therefore, the results propose the importance of examining an appropriate covering sheet to optimize the performance of the air-bearing.

4 Discussion

4.1 Design, Manufacturing and Assembling of PEM

With regard to the design and manufacturing of PEM casing, the methods performed in this work were confirmed as they are sufficient to apply to a full-scale provision. Because of the appropriate procedure, the casing completed without any deformation and additional modification. The analysis method assuring mechanical integrity of the casing can be applied to a different type of casing.

Outlook observation of assembled upper and lower part blocks is shown in **Figure 16**. Because of a sliding generating at previously placed blocks, final alignment of the last (6th) block possessed some gaps as shown in **Figure 16**. This phenomenon is strongly depends on the number of block dividing and horizontality of the lower part block. For example, if a semi-circular shaped block is used to the upper part assembling, the gaps is no longer generated at the position shown in **Figure 13**, while precisely controlled horizontal assembling is required to the lower part blocks. Therefore, block dividing and assembling procedure still remain in further consideration.

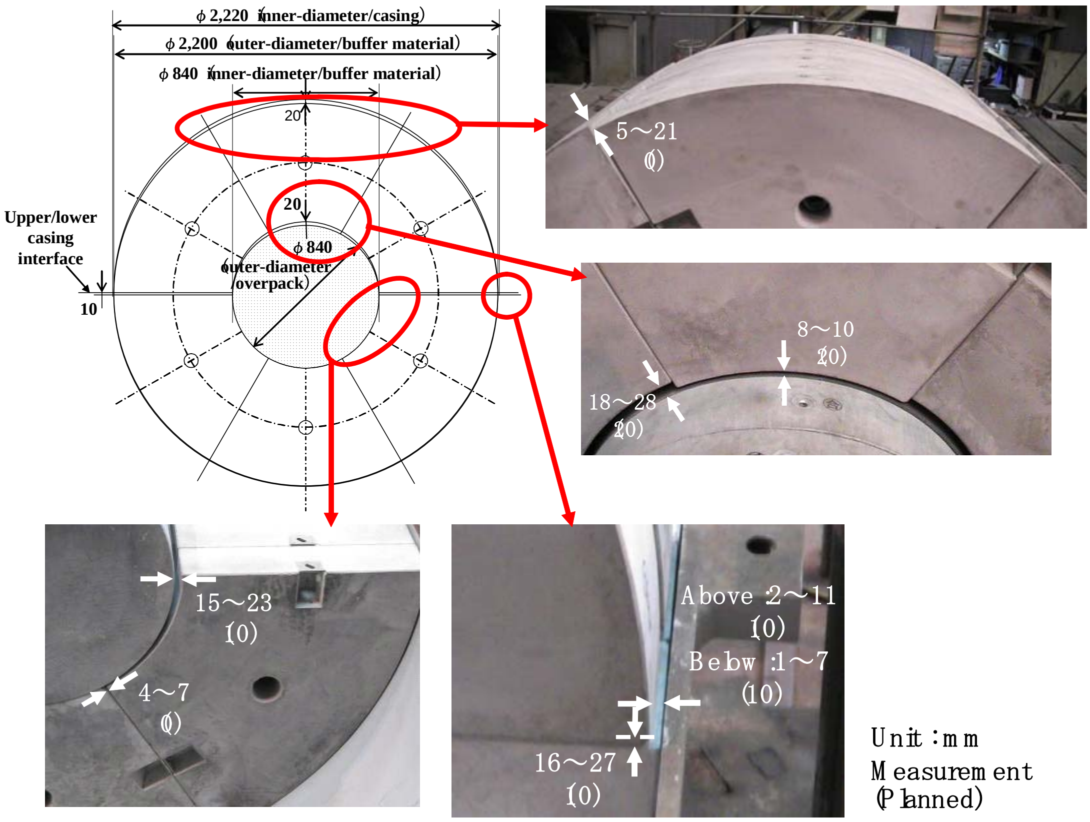


Figure 16: Observed gaps at the assembled upper and lower parts of blocks

Remote operability of PEM casing was reliable, especially for the final assembling of the upper part onto the lower part. Small guide pin attached on the casing flange was quite effective to fix the position between the upper and lower part casings during the hoisting process by crane.

Hoisting device for blocks managed overall movement of hoisting, placing and releasing the blocks for any dividing blocks at any direction. However precise positioning was hard to control. Hoisting mechanism including its technical principle is assessed as a further consideration.

4.2 Air-Bearing for Heavy Load Transportation

Also the applicability of the air-bearing transport system to the underground drift tunnel in a geological repository was investigated with several full-scale tests. Although a large number of actual results of the air-bearing transport system on a smooth flat surface have been obtained, little is known about their applicability on rough and curved surfaces. Full-scale tests showed that the tolerance to height differences and gaps was improved to endure practical use by the application of a covering material. This result showed the applicability of the air-bearing system as a transporting device to the drift tunnels of the geological repository which has surface roughness.

5 Conclusions

Full-scale manufacturing, assembling and transportation tests were performed on PEM concepts of geological repository for High-level radioactive waste. From the tests results, the following points were concluded.

(1) Design requirements and design procedure for PEM casing were extracted and identified. According to this procedure, carbon steel made casing was completed in full-scale without any mechanical deformation and additional modification. This shows that the design procedure can be used for some variations of PEM casing.

(2) Full-scale assembling of PEM was successfully conducted by using modified buffer material and overpack at horizontal position. Some gaps observed at assembled buffer material blocks suggested some technical implication for suitable block dividing and emplacement precision inside the PEM casing.

(3) Remote operability of PEM casing, especially for at the full assembling process, was successfully conducted due to a small guide pin attached on the casing flange. While, hoisting device for buffer material blocks was assessed that it need further improvement to manage more precise positioning at inside the PEM casing.

(4) Air-bearing unit was assessed that it possesses a sufficient applicability to the curved surface simulated a drift tunnel of repository by full-scale transportation tests. The test results showed the tolerance to height difference and gaps were improved to endure practical use by the application of a covering material.

Acknowledgement

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