FLEXIBLE PROPERTIES OF ASPHALT CONCRETE BARRIERS AND APPLICATION TO THE DESIGN OF LANDFILLS

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ABSTRACT

In solid waste management, the use of a water impermeable barrier in landfills is essential in order to prevent leachates from contaminating the public water. There have, however, been reports of landfills constructed on soft ground which have had their water impermeable barriers damaged as a result of ground settlement in the course of filling waste.

In this paper, laboratory tests are conducted on the flexible properties of asphalt concrete to determine its suitability for use in landfill barriers.

The test results confirmed the high flexibility of asphalt concrete. Next the allowable settlement of the foundation bed is examined for the case when asphalt concrete is used in constructing a water impermeable barrier in landfills.

INTRODUCTION

As of now, there are approximately 25 landfills with asphalt concrete barriers that pre-date the issuance of the joint decree in 1998 of the Ministerial Ordinance on Determining Engineering Standards Pertaining to Final Disposal Sites for Municipal Solid Wastes and Final Disposal Sites for Industrial Solid Wastes. Since the issuance of the standards there have been approximately 10 landfill sites that have been designed with asphalt concrete barriers.

The requirements that asphalt concrete has to meet for use in landfills are:

① Specified water impermeability
② Adequate strength so as not to be broken by sharp shaped waste and other objects,
③ Flexibility so as to be able to follow the deformation of the foundation bed due to waste filling,
④ Chemical resistibility, and
⑤ Durability.

This paper focuses on flexibility and results of laboratory tests carried out on asphalt concrete are discussed. The design procedure for asphalt concrete in the construction of water impermeable barriers in landfills is then examined.

TEST ON FLEXIBLE PROPERTIES OF ASPHALT CONCRETE BARRIERS

Purpose of Testing

The Ministerial Ordinance stipulates three types of impermeable barriers: impermeable sheet, impermeable compacted-soil and asphalt concrete. The minimum thickness of asphalt barriers is specified to be more than 5 cm and its coefficient of impermeability less than 1×10^{-7}cm/sec.

Oshikata et al. (Oshikata et.al.,2001) assessed the flexible characteristics of asphalt concrete barriers as applied in landfills and confirmed the following:

- Even after deforming test pieces of asphalt concrete to values greater than 10 % of the diameter of the deformed range, not a single crack appeared and impermeability was fully maintained.
- Asphalt concrete fully met the flexibility requirement that is stipulated in Europe, namely that its deformability should be more than 10 % of the diameter of the deformed range.

Taking into consideration these results, this study pays special attention to the appearance of cracks on the surface of asphalt concrete when deformed for the purpose of establishing allowable deformation ranges which are then used to design asphalt concrete barriers and foundation bed in landfills.

Outline of Testing

Proportion of Asphalt:

A high-density asphalt concrete used in constructing water impermeable barriers in water facilities, is used in this test. The proportion of asphalt in the concrete is 8.5 %.

Test Device:

The permeability test device used in the investigation is developed, designed and manufactured by Taisei Rotec Corporation.

A disc-shaped asphalt concrete test piece is placed horizontally on the test device and fixed after waterproofing its edges as shown in Fig. 1. The test piece is then swollen by applying pressurized water underneath the test piece. A linear gauge is used to measure the vertical deformation at the center of the test piece.

Conditions of Test:

The test conditions are shown in Table 1.

Table 1 Condition of test

Item	Condition
Test Piece	Dense-graded Asphalt Concrete
Size of Test Piece(mm)	ϕ=620、t=50
Temperature of Test(℃)	+5, +15, +30
Deformation Rate (cm/min)	0.02

The rate of deformation plays a significant role in determining the flexibility of asphalt concrete. In actual landfills, the asphalt concrete barrier deforms as per the deformation of the foundation bed. It is normally expected that the deformation rate of the asphalt concrete barrier in the field is quite small because waste is filled evenly and slowly. Taking into account the difficulty in quantifying the details of the adjustment in the deformation because of manual operation of pressure valves of compressors, a deformation rate of 0.02 cm/min is applied, which represents a low value of deformation rates for manual operation.

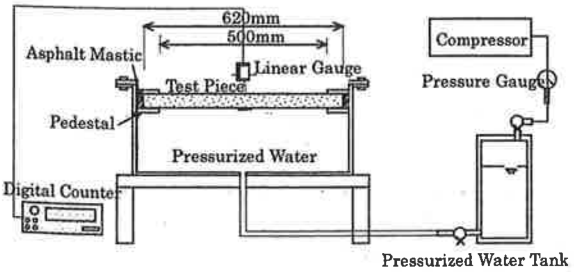

Fig. 1 Schematic diagram of test device

Along with deformation rate, temperature is a significant factor affecting the flexibility of asphalt concrete. Therefore, asphalt concrete is tested at three temperature settings, 5℃, 15℃ and 30℃. The lowest temperature of 5℃ supposes construction of landfills in cold regions and 30℃ supposes the temperature in filled wastes while 15℃ lies in between the two.

Sequence of Test:

① Fabrication of test piece

The asphalt concrete is placed in a mould (ϕ=620, t=50) after being mixed, and compacted fully by tamper to attain the specified density.

② Drawing a grid

After cooling the test piece to room temperature, grids at 5 cm intervals are inked on its surface, as shown in Fig. 2, in white color so as to facilitate the measurement of displacement of the surface.

③ Fixing test piece

The test piece is fixed to the test device and its edges are waterproofed by asphalt mastic.

④ Commencement of pressurized permeability test

The pressure valve is opened and deformation of the test piece is initiated. The pressure of the water in the pressurized water tank is adjusted from time to time in order to maintain the desired deformation rate of the test piece.

⑤ Observation of surface of test piece

The surface of the test piece is observed at all times to monitor the formation, if any, of cracks, and the displacement of the surface is recorded.

⑥ Removal of form

After the test piece is removed, any cracks on the reverse side are observed and recorded.

⑦ Change of condition

The above sequence is repeated for the three temperature settings.

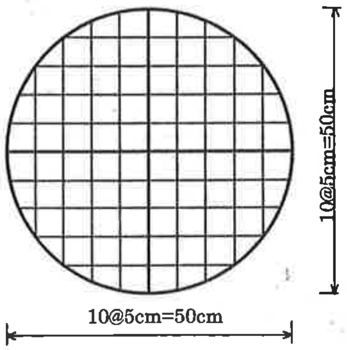

Fig. 2 Grid on test piece

Measurement:

In the test, the items measured and recorded are:

①Deformation at time of crack appearance

The time when a crack of width 0.25 mm appears, as measured by a crack gauge, is defined to be the time of crack appearance. (0.25 mm is the minimum confirmable width)

② Measurement of crack width and distance of inter-grid

The maximum crack width is measured. The distance between each point of the grid on the surface is measured at every 20 mm increments of the deformation.

③Deformation at the time of crack penetrating to the other surface

Water leakage in the center part of the test piece is considered to result from the penetration of cracks from one surface all the way to the other surface. The deformation at the time of a through crack is measured.

④Crack appearance on the back surface of the test piece.

Results of Test

Temperature in the Test Room:

The temperature in the test room is regularly monitored and is maintained within ±0.5℃ of the temperature of the test piece.

Deformation Rate:

The correlation between elapsed time and displacement are shown in Fig.3 for all three temperature settings.

The average loading rate from the start of the test to its completion is calculated and is 0.0215 cm/min for 5℃, 0.0201cm/min for 15℃ and 0.0203 cm/min for 30℃. The averaging loading rate in all three cases is approximately equal to 0.02 cm/min.

Deformation Volume and Crack Width:

The flexibility of asphalt concrete generally increases with temperature, and accordingly the expectation before the tests was that crack width would be smaller under the same deformation at higher temperatures.

In fact, as shown in Fig.4, the test piece underwent deformations up to 60 mm for all the three temperature settings as per expectations. However, for the temperature setting of 30℃ the crack width rapidly increased for deformations greater than 60 mm and its rate of increase (ratio of crack width to deformation) is the highest among the three temperature settings.

In the tests, the deformation is continued until the time that is required to confirm the water leakage from the central part of the test piece. The final deformation at the time of completion of the test was highest for 15℃.

The highest final deformation observed for 15℃ is presumed to arise from differences in the formation of cracks. Cracks for temperature settings of 5℃ and 15℃ are relatively dispersed, but for 30℃ cracks are not dispersed and the width of a crack around the center is much larger than those elsewhere.

The ratios of the final deformation to the diameter of the deformed range are 15.9 %、18.6% and 17.9% for the temperature settings of 5℃, 15℃ and 30℃ respectively. All three ratios exceed by significant amounts the value of the normal range of ground deformations in landfills, and moreover, impermeability is retained even for such large deformations. The test results confirm that asphalt concrete possesses the high deformability and impermeability required for use in the construction of landfill barriers.

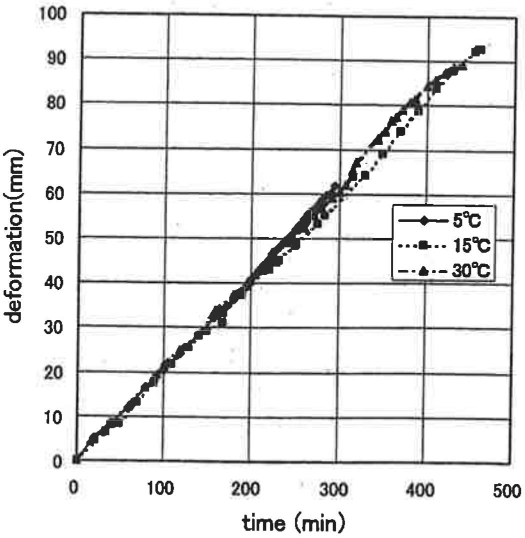

Fig. 3 Deformation with time

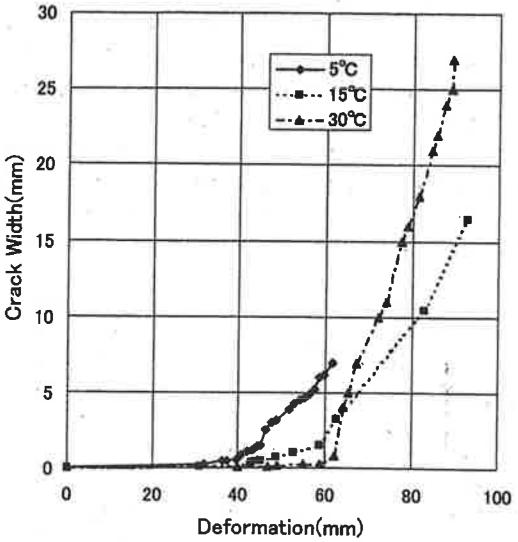

Fig.4 Relation between crack width and deformation

Strain and Deformation of Central Part:

Strains on the surface at the central part of the test piece are calculated based on the distances of inter-grid points during the test and before the test in the non-deformed test piece. The results are shown in Fig.5.

As seen in Fig.5, strains show large increases at deformations of around 40～60 mm for all three temperatures settings and the overall tendencies of the strain-deformation relationships are quite similar.

The similarity in behavior is due to a similar crack appearance and development, as the crack width increased significantly for all three temperature settings at deformations of around 40～60mm as described in section Deformation Volume and Crack Width.

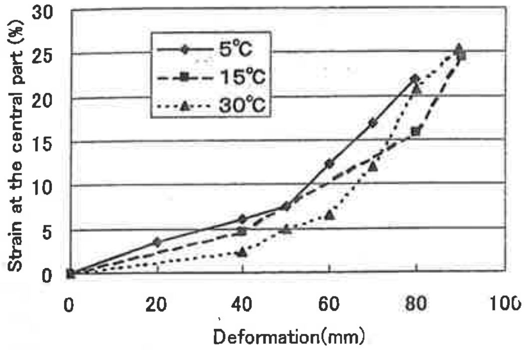

Fig.5 Strains at the center part versus deformation

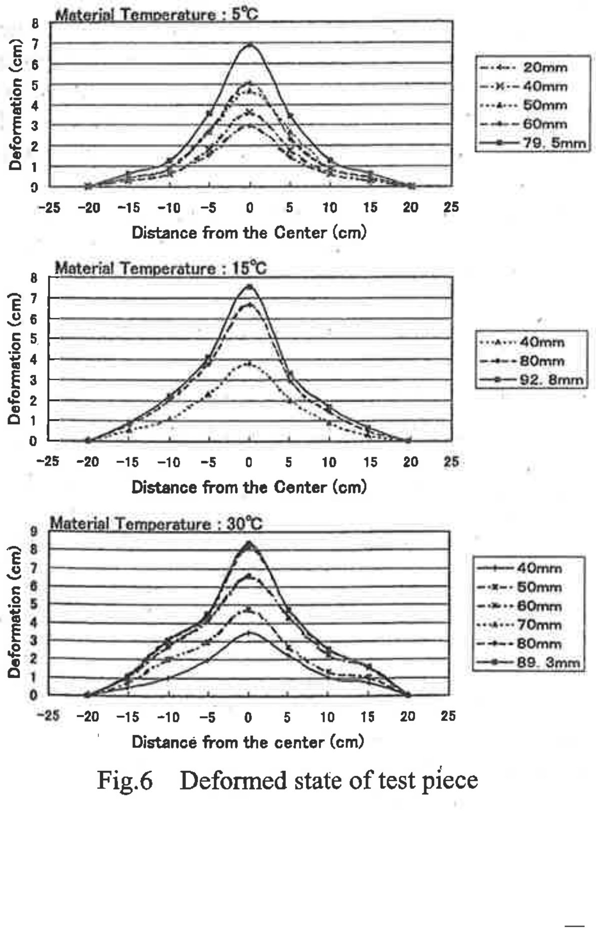

Fig.6 Deformed state of test piece

Taking this into account, it is considered that the strain-deformation relationship at the central part should be examined further by focusing in the deformation range of 0～40 mm.

Fig.5 indicates that at higher temperature there is tendency for the strain to reduce with deformation in the range of 0～40 mm. This is primarily due to differences in stiffness of the material under different temperatures.

Deformation State on the Surface of Test Piece:

Fig.6 shows the deformation of the surface of the test piece calculated at every 20 mm increments of deformation.

At the time of the test, only the distance of inter-grid on the surface of the test piece is measured. Then, supposing that each grid point is fixed horizontally, the deformation is calculated at other points.

Therefore, the calculated results are a little different from the actual values, however this is not considered to be a great deal as regards the investigation of deformation state on the surface. In all test cases the deformation at the central part is larger than at other parts because the edges of the test piece are fixed.

Conditions after Removal of Form:

Careful observations of crack appearance, if any, on the back side of the test piece, showed no cracks except around the fixed edges.

Examination of Result

In the test, an upward force is applied to the test piece from below so as to be able to observe the formation of cracks during deformation. In other words, this test is conducted without any base reaction force against the deformation. The test condition is similar to the case of an asphalt concrete barrier under back pressure, or the situation when voids are suddenly generated at the foundation bed of the asphalt concrete barrier.

However, asphalt concrete barriers actually settle and deform as per the deformation of the foundation bed caused by the load of the waste material. In the tests reported by Oshikata et al. (Oshikata et.al.,2001) a foundation bed was laid below the asphalt concrete barrier to more accurately represent actual conditions found in the field.

Comparing the results reported by Oshikata et al. (Oshikata et.al., 2001) with those from this tests, large differences can be found in the measured flexibility of asphalt concrete, especially after the appearance of cracks, as seen in Table.2.

The tests reported by Oshikata et al. (Oshikata et.al., 2001) were conducted with a reaction force at the base of the test piece, and therefore no cracks were found on the surface of the test pieces at the end of the tests for all temperature settings. On the other hand, in this test, which is conducted without any base reaction force, 0.25 mm wide cracks appeared at deformations of around 44.7 mm, which is about 65 % of the final deformation reported by Oshikata et al. (Oshikata et.al.,2001)

Table 2. Comparison between both results reported by Oshikata et al. (Oshikata et.al.,2001) and results of this test

Material Temperature		5℃	15℃	20℃	30℃	Remarks
Result of This Test	(A)	32.2mm	42.9mm		59.4mm	Cracks appeared, Water Leaked
	(B)	6.40%	8.60%		11.80%	
	(C)	79.5mm	92.8mm		89.3mm	
	(D)	15.90%	18.60%		17.90%	
Result of the test by Oshikata et al.	(C)	65mm		77mm	66mm	No crack appeared
	(D)	13.00%		15.40%	13.20%	

(A) : Deformation Volume of Crack Width of 0.25mm

(B) : Deflection Ratio of Crack Width of 0.25mm

(C) : The Final Deformation Volume

(D) : Deflection Ratio of the Final Deformation

(Deflection Ratio : Ratio of Deformation Volume to Diameter of Deformed Range)

Results of this test are clearly affected by the non-binding condition of the test piece, i.e. without a base reaction. The flexibility of asphalt concrete assessed under such non-binding conditions is a conservative estimate because cracks form more readily under such conditions than in binding conditions.

IMPLICATION OF TEST RESULTS TO DESIGN OF LANDFILLS

The test results confirm the high flexibility of asphalt concrete, but care should be taken in interpreting the results reported here.

In order to obtain a high impermeability it is necessary to fully compact the asphalt concrete used in the barrier. If the ground is soft (less than CBR=3), appropriate measures are required such as ground improvement by cement, lime or substitution by good quality material etc, or else that the proportion of the asphalt volume is increased. (Guideline for Pavement Design and Execution , Japan Road Association)

In addition, on grounds where there is still residual settlement, it is conceivable that steps will be formed due to uneven settlement at the boundaries with the structure or toe of slope. In such cases, appropriate measures must be taken to ensure the joint between asphalt concrete and other material as shown in Fig. 7.

Currently there is no standardized procedure for determining the appropriate way to treat foundation beds when applying asphalt concrete barrier to landfills. In order to address this issue, the formation of cracks on asphalt concrete deforming as per the deformation of the foundation bed is examined.

Limit Value on Deformation of Asphalt

The allowable deformation is herewith examined based on the formation of cracks in the asphalt concrete.

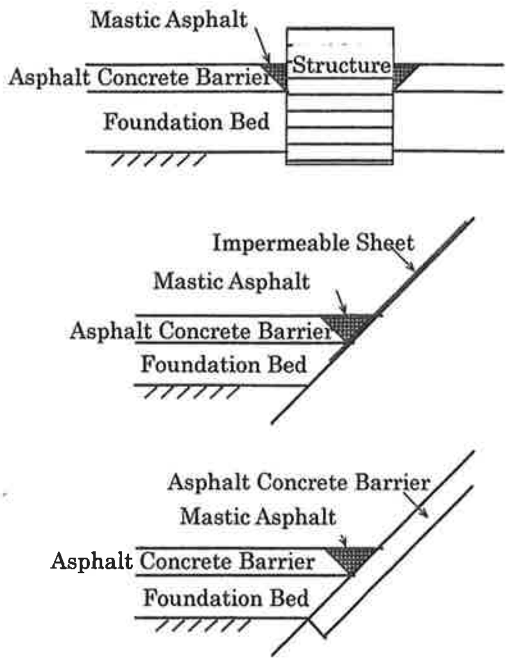

Fig.7 Structure of joint parts at the boundaries

The depth of crack assumes importance if the allowable deformation of asphalt concrete is stipulated by the state of crack appearance. However, the relation between crack width and depth has not been investigated in this study. Therefore the discussion in this paper is based on the assumption that a specified depth can not be secured at the time of crack appearance, or in other words, the asphalt concrete barrier does not maintain the thickness specified in the criteria. The deflection ratio, which is defined as the ratio of deformation volume to the diameter of deformed range, of 6 % obtained from the laboratory tests is taken as the allowable value.

Table.3 shows the deformation volumes at the central part at the time of appearance of 0.25 mm wide cracks and of water leakage from the central part.

Table 3 Deformation volume and deflection ratio

Material Temperature	5℃	15℃	30℃	Ave.
Deformation Volume at the Time of 0.25mm Wide Crack (mm)	32.16	42.87	59.04	44.69
Deflection Ratio at The time of 0.25mm Wide Crack (%)	6.43	8.57	11.81	7.15
Deformation at the Time of Water Leakage (mm)	79.5	92.8	89.3	87.2
Deflection at the Time of Water Leakage(%)	15.9	18.6	17.9	17.5
Crack Width at the Time of Water Leakage(mm)	17.4	14.5	27	19.6

The Japanese archipelago is long along the north-south axis, and the weather condition varies significantly from one end to the other. As temperature has a big influence on the characteristics of asphalt concrete, the weather conditions of each local region should be considered in the design of asphalt concrete barriers in landfills.

When the waste filling has progressed beyond a certain point, it is known that the temperature in the waste becomes stable at around 40℃. Here, supposing that the waste filling will be done during the winter periods in the relatively cold latitudes in the north of Japan as the worst condition, the characteristics of asphalt concrete at the temperature of 5℃ is used and therefore, the deflection ratio of 6.4 % is regarded as the limiting value.

Safety Factor and Allowable Value (Proposal)

Comparing conditions of laboratory tests with those in the field, it is generally accepted that quality of construction in the field shows a wider variation and that in general is less than those seen in laboratory tests.

In order to address the variability seen in the field and the differences between laboratory tests and actual conditions in the field, safety factors are generally applied to the results of laboratory tests. Factors of 2 to 3 are common in structural and foundation design.

However, in this examination, safety factors are not required for the following reasons:

① The deformation volume between the time of appearance of 0.25 mm wide cracks and water leakage is more than twice the deformation volume at the time of appearance of 0.25 mm wide cracks.

② Asphalt concrete barriers in the field follow the deformation of the foundation bed under the conditions of being sandwiched between the waste material and the ground (binding condition). However, the laboratory tests are conducted under non-binding conditions and cracks generate more easily than in the binding case.

③ In the results reported by Oshikata et al. (Oshikata et.al.,2001) from tests conducted under conditions more similar to that found in the field, there were no cracks and water leakage for deformations as high as 65 mm.

Therefore, no safety factors are used and the value from the laboratory tests is taken as the allowable value. The deflection ratio of 6 % obtained from the laboratory tests is taken as the allowable value.

Design Procedure (Proposal)

The Structure of the Asphalt Concrete Barrier:

A cross-section of an asphalt concrete barrier constructed on soft ground is shown in Fig.8.

The soil improvement layer shown in Fig.8 is designed to uniformly spread the load from the waste material as well as to support additional loads from above such as a sub-grade of road.

The layer of crusher-run stone, also, has similar roles to uniformly spread the load from above over the soil improvement and to level the rough surface caused by the soil improvement. Moreover, it often works as a drainage layer too.

For conditions such as those described in this example, the asphalt concrete barrier follows the deformation of the soil improvement, so it is necessary to examine the strength and thickness of the foundation improvement for such levels of settlement.

Example Calculation:

It is assumed that settlement of the foundation bed follows a circular arc pattern shown in Fig.9. The range, L, over which the settlement took place is 5 m. In this case, the allowable value of the settlement, D, is 30 cm corresponding to an allowable deflection ratio of 6 %. If on the other hand L is 1m or 3 m, the allowable settlement is 6 cm or 18 cm respectively.

Differential settlement sometimes takes place due to differences in the unit weights of the crushed stone and waste material near vending facilities as shown in Fig.10. Under this circumstance, the range, L, of the settlement is expected to be around 3 m and therefore the allowable settlement is 18 cm.

The strength and thickness of the foundation improvement needs to be examined for such levels of settlement.

One thing that has to be recognized in this

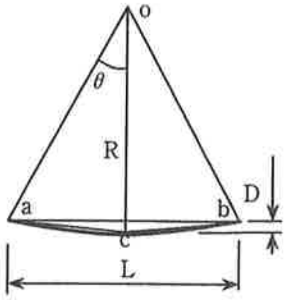

Fig. 9 Concept of Settlement

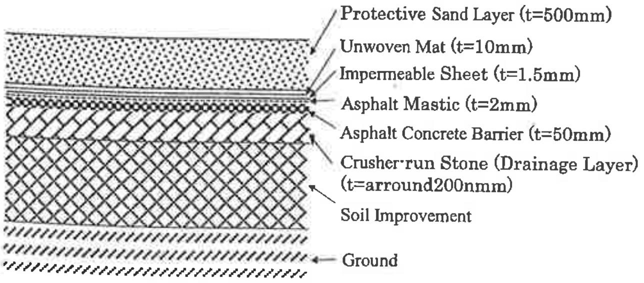

Fig.8 Structure of asphalt concrete barrier

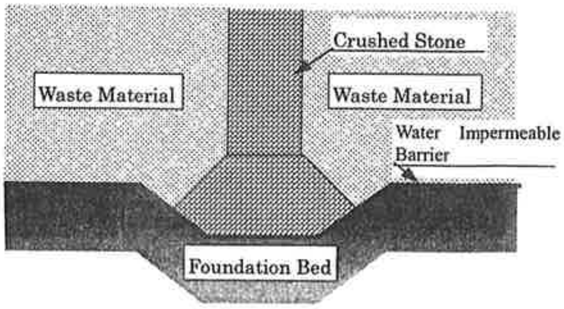

Fig.10 Vending facility of landfill gases

example is that the allowable settlement of the foundation bed is based on the premises that the asphalt concrete is fully compacted. Therefore the CBR of the foundation bed needs to be 3 or greater and if the CBR is less than 3, the foundation bed needs to be appropriately improved.

CONCLUSION

In this paper, the flexibility of asphalt concrete barriers is confirmed by laboratory tests. The test results are used to establish the allowable deformation of asphalt concrete barriers to 6 % which in turn serves to establish the allowable settlement of foundation beds.

An example computation using the above allowable value is illustrated for the case of settlement over a relatively small-sized area for which settlement could be considered to follow a circular pattern. However, larger ranged settlements are not expected to follow a circular arc pattern shown in Fig. 9 and this issue has to be addressed in the future.

Besides, it should be noticed again that the CBR of the foundation bed shall be 3 or more than 3 and when the CBR is less than 3, the foundation bed shall be appropriately improved when asphalt concrete barrier is used as a water impermeable barrier.

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