SEAL-O-SILO SYSTEM (METHOD FOR RESTORING AIRTIGHTNESS OF REINFORCED CONCRETE SILOS USED FOR STORAGE OF CEREALS)

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1. INTRODUCTION

This system, called Seal-O-Silo, was developed for the purpose of repairing the airtightness of reinforced concrete silos. Advantages of the Seal-O-Silo System are as follows.

High reliability

This method eliminates omissions caused by oversight in conventional methods. As materials and equipments used in this method are standarized, the complete and lasting airtightness can easily be realized.

Rapidity of repair

While repair work by conventional methods takes at least 30 days per silo, this method takes only 10 to 14 days.

High degree of safety

The degree of safety during repair work is extremly high since the silo interior requires little human labor due to the use of specially designed equipment.

2. THE NEED FOR IMPROVEMENT OF SILO AIRTIGHTNESS

2.1 STANDARDS FOR AIRTIGHTNESS IN JAPAN

Existing silos in Japan, used for imported food and feed cereals, are estimated to have the total capacity about four million tons. About 75% of these silos are made of reinforced concrete.

All imported cereals must be fumigated upon entry to Japan, under the Plant Quarantine Law. Fumigation is done in silos which can be sealed, so as to contain the fumigant (usually, methyl bromide). The Ministry of Agriculture and Forestry, which is in charge of administration of this law, inspects silos and authorizes their use for fumigation. Silos are required to show a loss, after 48 hours, of no more than 30% of the concentration of fumigant, introduced into the silo at 10 mg per cubic meter of volume (the silos which pass are designated as "Grade A" silos).

An expedient means of determining whether silos are satisfactorily airtight is to raise the internal pressure above normal and measure the drop in pressure over time. In practice, this is done by raising the pressure to more than 500 mmAq, and observing pressure after 20 minutes have passed from the time when the level of 500 mmAq has been attained. If pressure is 200 mmAq or more, the silo passes imspection.

2.2 CAUSES OF CRACKS

Reinforced concrete silos often develop cracks after having been used for a long period, and leak fumigant gas to the extent that they no longer pass inspection standards. The following are reasons for this deterioration of performance.

① Problems of design, such as failure to properly foresee pressure imparted to silo walls when the silo is filled and emptied.

② Problems arising during construction, such as poor or faulty positioning of R-bars or poor placement of concrete.

③ Changes in functioning of equipment used to fill and empty silos; changes in the equipment used. Both can impart pressures to silo walls in excess of those anticipated at the design stage.

④ Contraction of concrete due to drying. Over time, some of the water originally used to make concrete is lost.

⑤ Deterioration due to the influence of carbon dioxide; some stored grains will generate sufficient carbon dioxide as a product of respiration to promote neutralization of concrete.

⑥ Uneven sinking of silos, such as may occur when insufficient study was made prior to constructing a number of silos at one site.

⑦ Damage caused by earthquakes and other temporary phenomena.

2.3 DISTRIBUTION PATTERNS OF WALL CRACKS

Distribution pattern of actual silo wall cracks is shown in Fig.1.

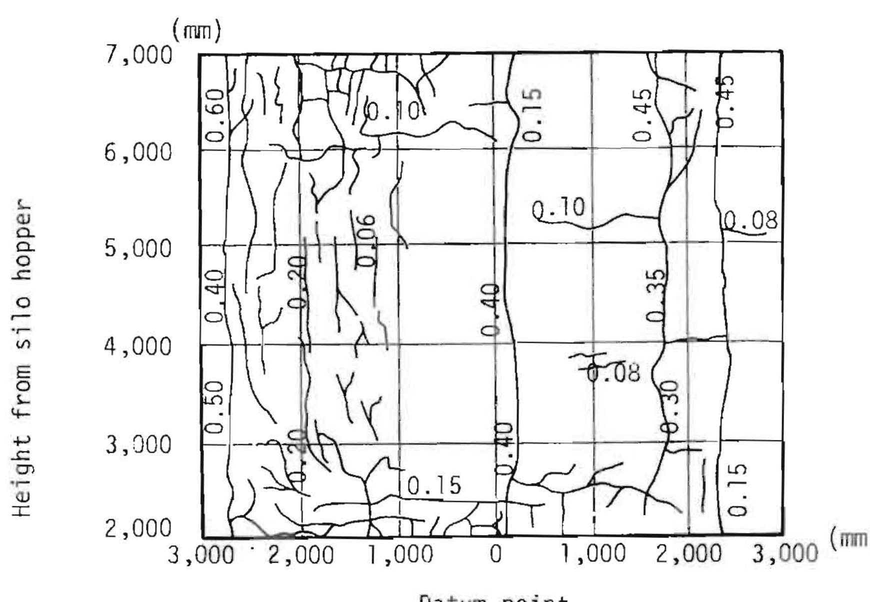
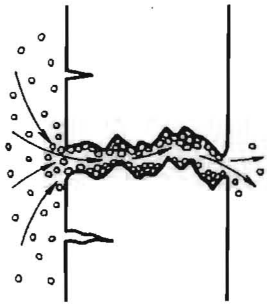


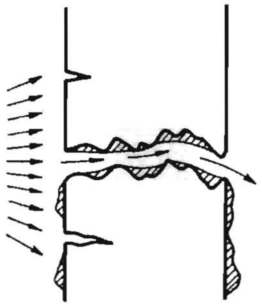
Fig.1. Distribution pattern of wall cracks on part of reinforced concrete silo which was constructed at 1967.
Exterior wall is 220mm at thickness.

3. THE SEAL-O-SILO SYSTEM

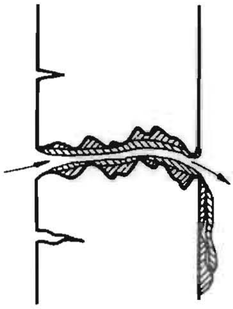
The principle of the Seal-O-Silos System is that particles of sealant will be forced into cracks and pinholes by the combination of a differential in atmospheric pressure (a higher pressure inside the silo) and micro-turbulence of the atmosphere as it moves through cracks and pinholes toward the low-pressure exterior. Sealing process of cracks in this system are as follows.



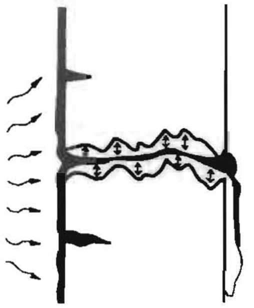
First air is introduced into a silo, to raise the atmospheric pressure inside the silo and enlarge the cracks in its wall. Air will begin to leak out of the cracks and pinholes. The sealant in fine powder form (Bintight-P) is sprayed into the interior atmosphere, and, borne by air currents, gradually enters cracks and pinholes. During this process, micro-turbulence are generated inside the cracks and the pinholes, causing the fine powder to be deposited in the cracks and the pinholes.



Next a liquid sealant (Bintight-L1) is sprayed. It enters cracks and pinholes and reacts with the powder sealant deposited there. With the combined effects of capillarity and air pressure, formation of a paste gradually forced deeper into the cracks and pinholes.



After the above procedure is repeated for several cycles (SOS cycles), the airtightness of the silo improves considerably. But in this state moisture is present in the cracks and pinholes so that as the silo dries and the moisture evaporates, the airtightness level will decrease. To counter this decrease, several cycles of the same procedure are repeated on the following day.



Cracks in the wall are always in a dynamic state due to the deposition and discharge of grains, the repeated drying and dampening of the silo and so on. To insure complete airtightness amid these dynamic changes, SOS System includes a finishing process in which a special sealant (Bintight-L2) is forced into the cracks and pinholes by the same procedure as above. After this procedure, sealant expanded and restoration completed.

Fig.2. The left side of wall is inside to silobin, in which the atmospheric pressure raised.

3.1 COMPARISON OF SEAL-O-SILO SYSTEM AND CONVENTIONAL METHOD

When cereals is stored after restoration, the silo which is repaired with Seal-O-Silo System hardly develops cracks again. But the silo which is repaired in conventional method sometimes develops cracks again. The prinsiple is shown as follows.

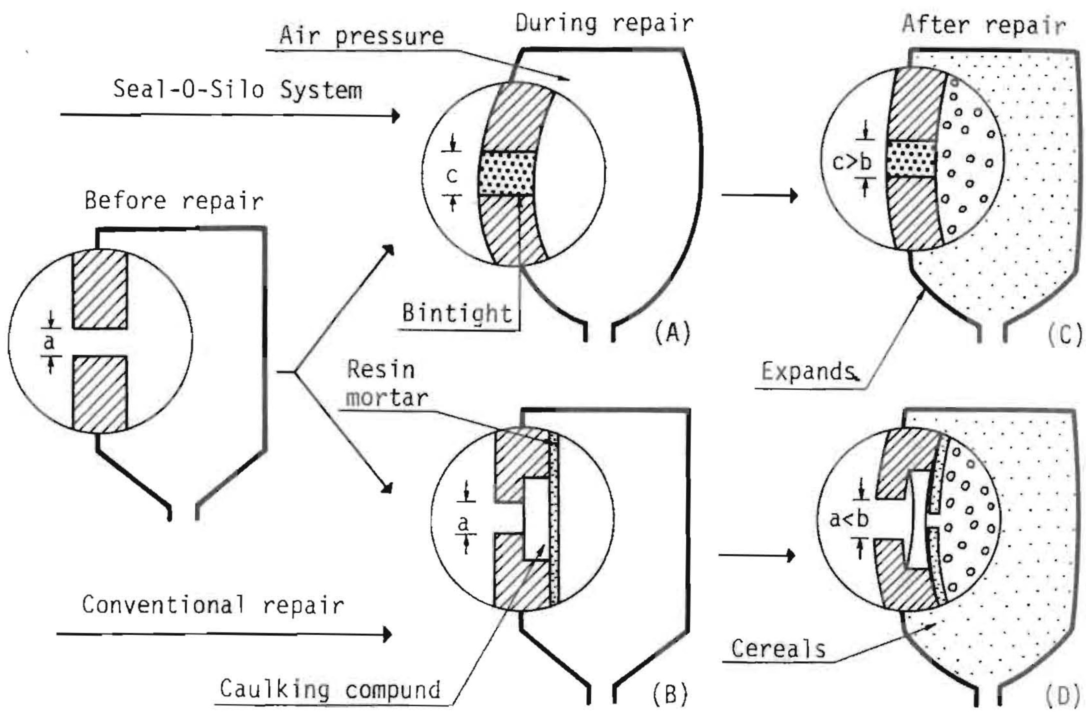


Fig.3. The dynamic changes of the silo wall and cracks.

(A) The repair work is carried out after raising the air pressure to expand the cracks. As a result, the crack width "c" is greater than the width "a" before repair.

(B) The silo interior is repaired at normal pressure by cutting cracks into a U-shape or a V-shape, filling the cut with caulking compound and coating over it with resin mortar. As a result, the crack width remains the same as the width "a".

(C) When cereals is stored after restoration, the silo wall expands by a small amount. But since the wall has been repaired by increasing the internal air pressure in such a way that the crack width "b" after the deposition of the grain will be smaller than the width "c" during repair, the crack can withstand this expansion.

(D) When the wall has been repaired at normal pressure, it cannot always withstand the expansion caused by cereals storage so that the caulking compound becomes stretched and the resin mortar sometimes re-opens. Also, the resin mortar can wear out or peel off after a long period of repeated deposition and discharge of cereals.

4. MATERIALS USED IN THE SEAL-O-SILO SYSTEM

4.1 GENERAL CHARACTERISTICS

Three kinds of materials, **Bintight**-P, Bintight L-1, and Bintight L-2, were developed for Seal-O-Silo System. General characteristics of each materials are as follows.

4.1.1 Characteristics of materials are shown in TABLE, Fig 4, Fig 5 and Fig 6

TABLE-1 Characteristics of Materials

B-P	Specific gravity	Powder characteristics: Ratio of surface area to weight (cm^2/g)	Powder characteristics: Particle size (μ)	Lubricant	Strength of compression (kg/cm^2) 1day	2days	Expandibility & Toxicity
	3.12	6,000 or more	10	Yes	469	744	Fig.3,TABLE.2
B-L1	Specific gravity	Coefficient of viscosity (cp)	Surface tension (dyne/cm)	Activity	pH	Color	Penetration & Toxicity
	1.0	1.0 or less	40.0 or less	Anionic	6	None	Fig.4,TABLE.2
B-L2	Specific gravity	Avr.particle size (μ)	Coefficient of viscosity (cp)	Solids	pH	Major ingredient	Penetration & Toxicity
	1.0	1.0 or less	10--100	20.0%	9	SBR	Fig.5,TABLE.2

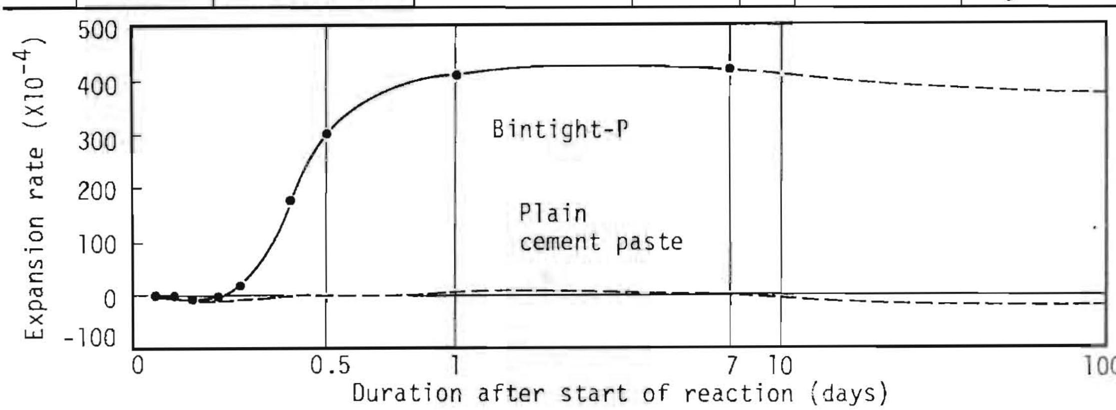


Fig. 4 Initial expansion of Bintight-P

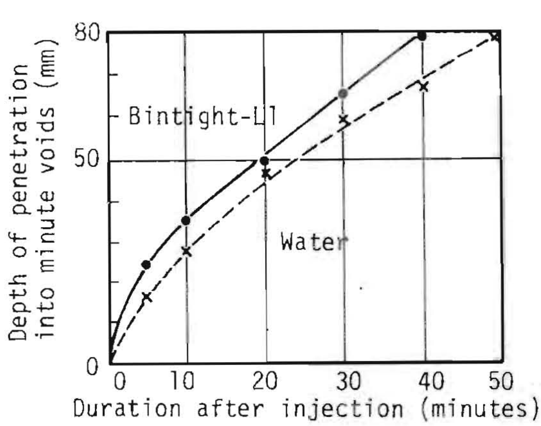


Fig. 5 Speed of penetration of Bintight-L1

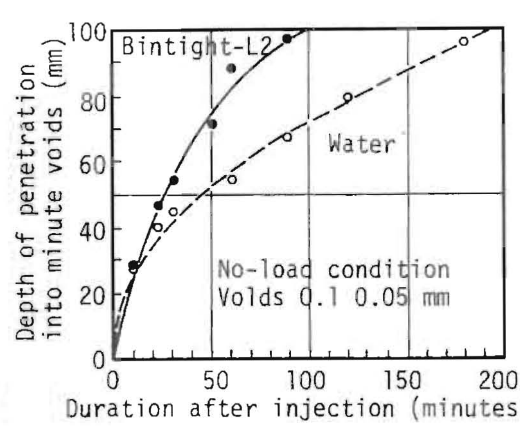


Fig. 6 Bintight-L2

4.1.2 Nontoxicity of materials

Nontoxicity of materials is shown in TABLE 2.

TABLE 2 Results of water quality test

	Water standard (Japan)	Bintight-P	Bintight-L1	Bintight-L2
Order	Not out of ordinary	None	None	None
Color	5 degrees or less	0	0	0
Turbidity	2 degrees or less	0	0	0
pH	5.8--8.6 ppm	8.6	5.8	6.0
Na^{++}	10 ppm	1.68	0.04	6.40
SO_4^{--}	200 ppm	5.4	5.4	2.0
NH_4-N	Not detected as same time	Not detected		
NH_2-N		Not detected		
NH_3-N	10 ppm	Not detected		
Free residual chlorime	0.1 or less ppm	1.5	2.0	---

4.2 RESTORATION OF AIRTIGHTNESS

As a silo is to be made more airtight by use of the Seal-O-Silo System the thickness of the silo wall, interior process pressure, number of SOS cycles, width of cracks, and other factors must be thoroughly studied.

4.2.1 Wall thickness, and interior process pressure

The relationship between the area of paste which will penetrate into cracks and the thickness of the wall and interior process pressure is shown in Fig. 7

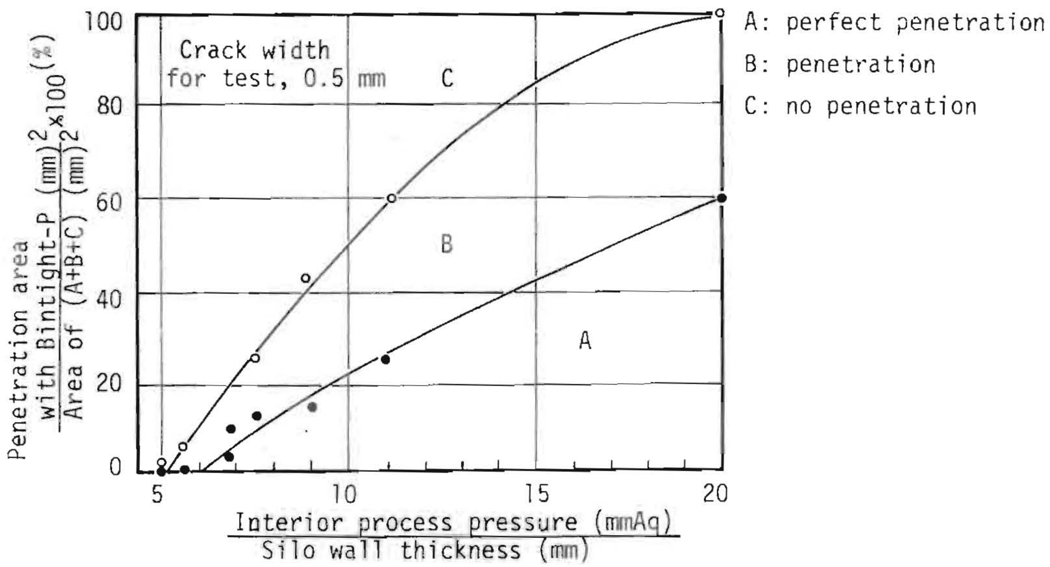


Fig. 7 Injection results of Bintight-P

4.2.2 Number of SOS cycles

The relationship between the airtightness of a silo and the number of SOS cycles is shown in Fig. 8

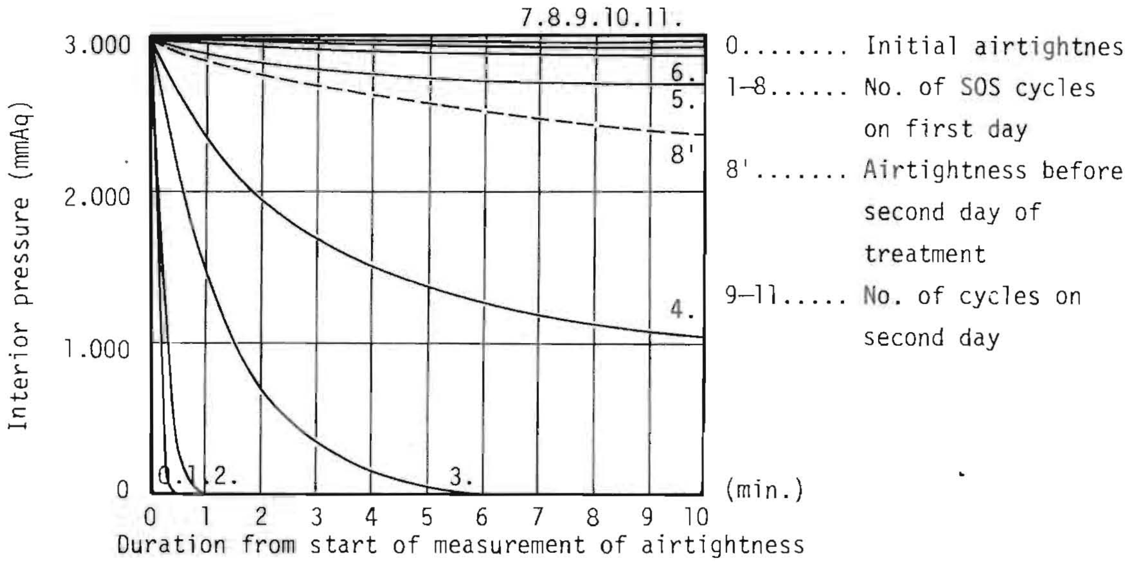


Fig. 8 Improvement of airtightness according to numbers of treatment cycle

4.2.3 Crack width (Kennedy, T.B., ASCE paper,1958)

When cracks or pinholes are to be filled with a powder, the narrower of crack the smaller must be diameter of the powder particles. When the ratio of crack width to particle diameter approaches unity, crack mouths will tend to become clogged. For particles to penetrate into a crack, it is necessary that the ratio is 3-5 or higher.

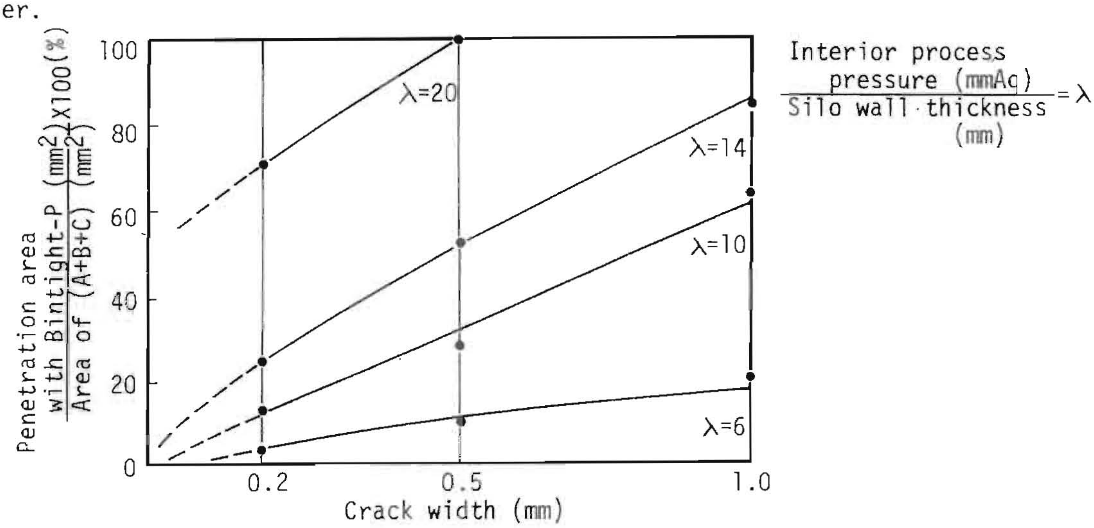


Fig. 9 Effects of crack width to injection effectiveness of Bintight-P

5. SEAL-O-SILO SYSTEM EQUIPMENTS

Seal-o-Silo System consists of the air supplying unit, the liquid controlling, suppling unit, and the movement controller of the top slab. These equipments are designed for easy assemble and simple ones. The diagram of Seal-o-Silo System is shown in Fig. 10, Fig. 11 and Fig. 12.

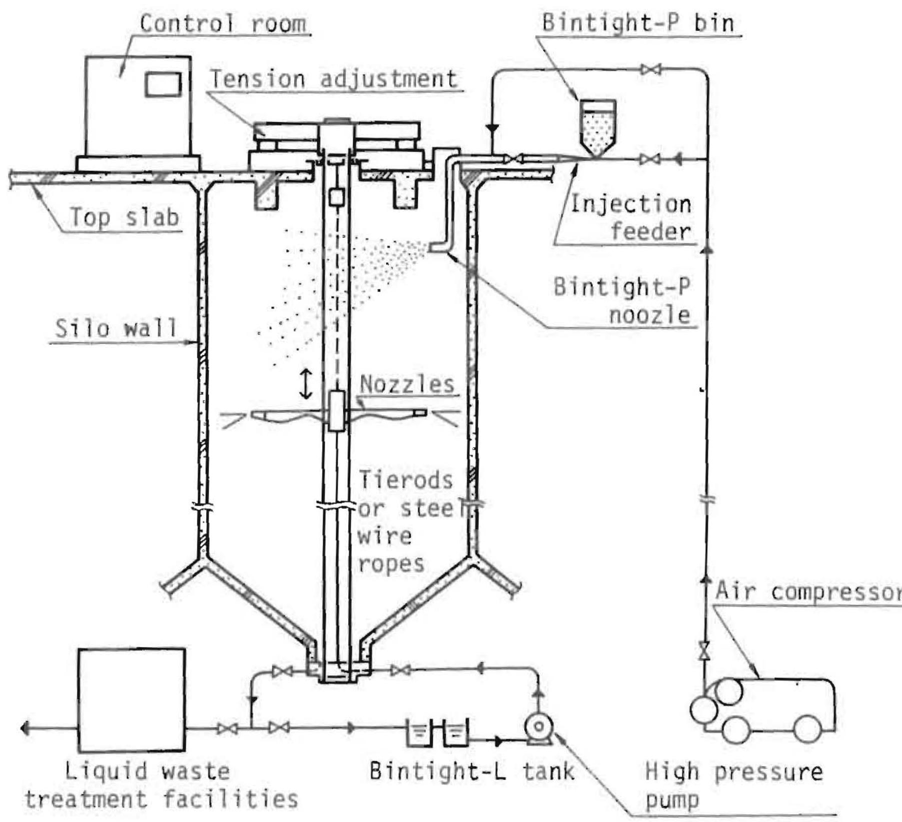


Fig.10 Diagram of SOS equipments

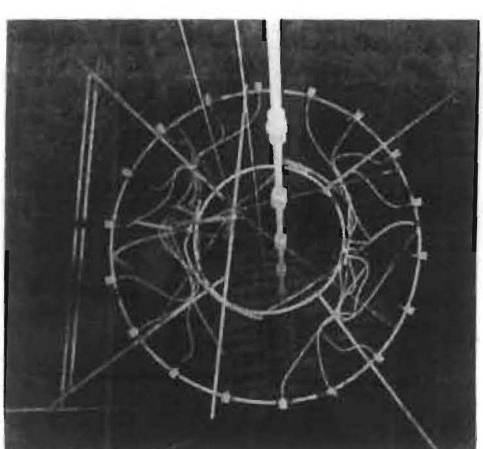


Fig. 11 Nozzles (interior of silo)

Fig. 12 Controllers on the top slab

6. A EXAMPLE REPAIR WORK

6.1 BASIC DATA ON THE IMPROVED SILO

Structure ; Reinforced concrete silo.

Use ; Storage of imported cereals.
(mostly soybeans, maize, rape)

Date constructed ; 1961-1967.

Constructor ; Shimizu C.C.(SCC), Mitsui C.C.(MCC). Toda C.C.(TCC)

Scale ; See Fig. 13. (*-Nonfumigant silo)

Date repair worked ; Dec. 1976-Dec. 1977.

Number of repaired work bins ; 40 bins.

6.2 RESULT & IMPROVEMENT OF AIRTIGHTNESS

Result and improvement of airtightness of silos are shown Fig. 14, Fig. 15. Airtightness level on longterm is shown in Fig. 16.

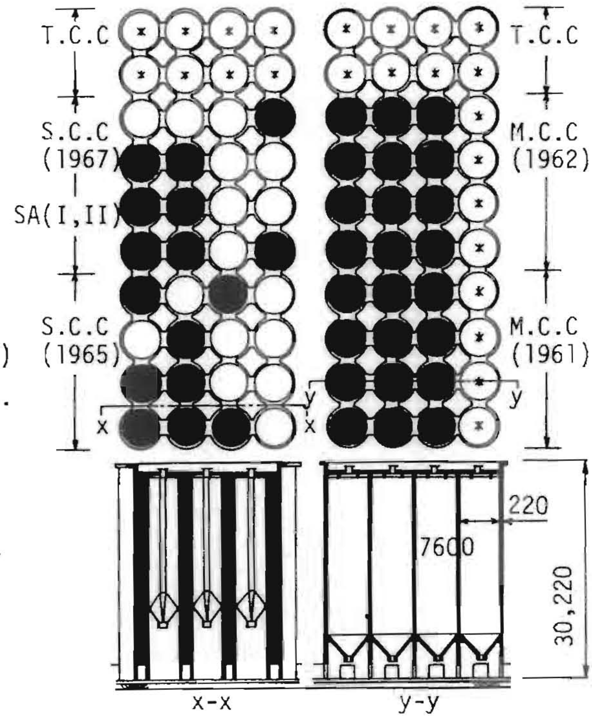


Fig. 13 Improved silos plan

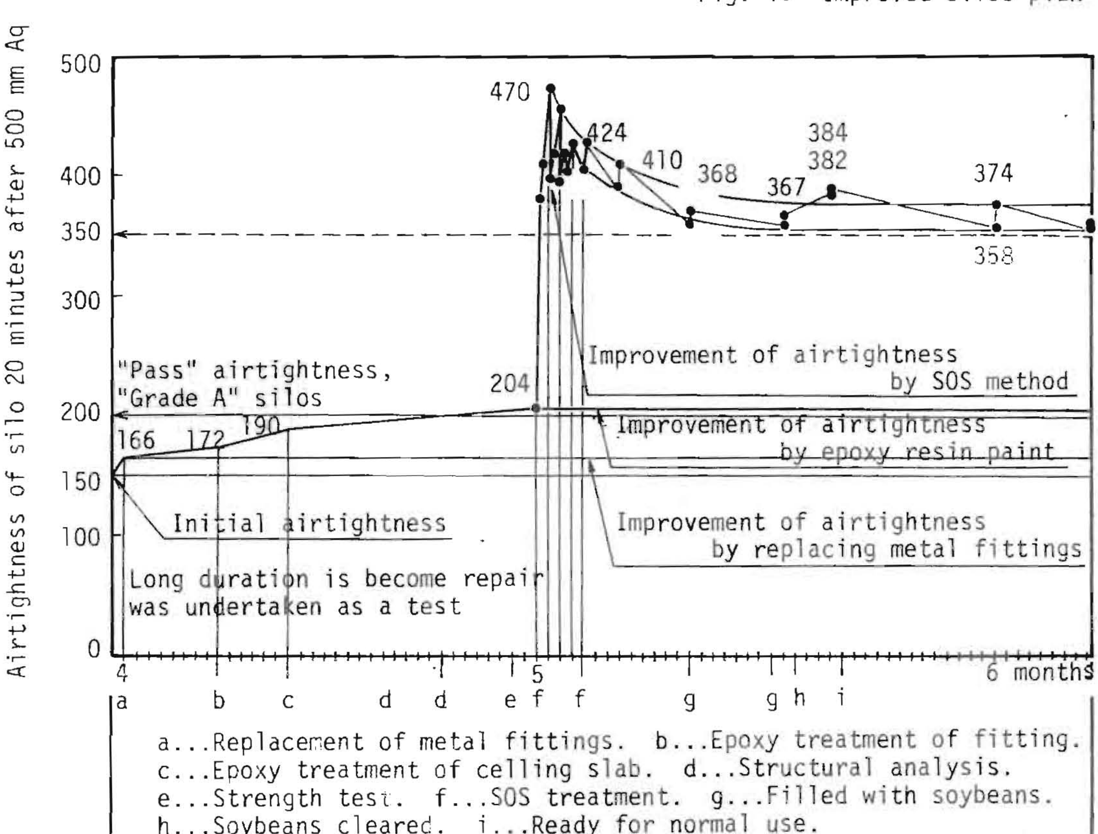


Fig. 14 Improvement of airtightness

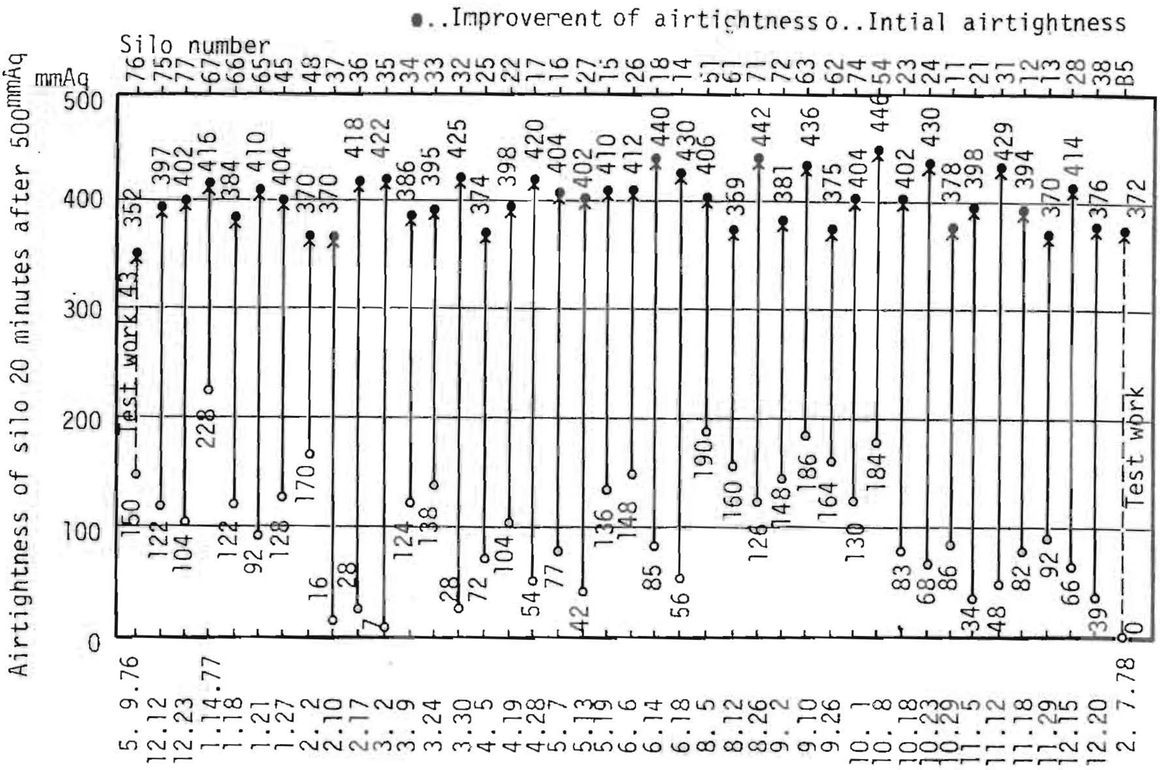


Fig. 15 Relationship between the level of initial airtightness and the level of improvementof airtightness.

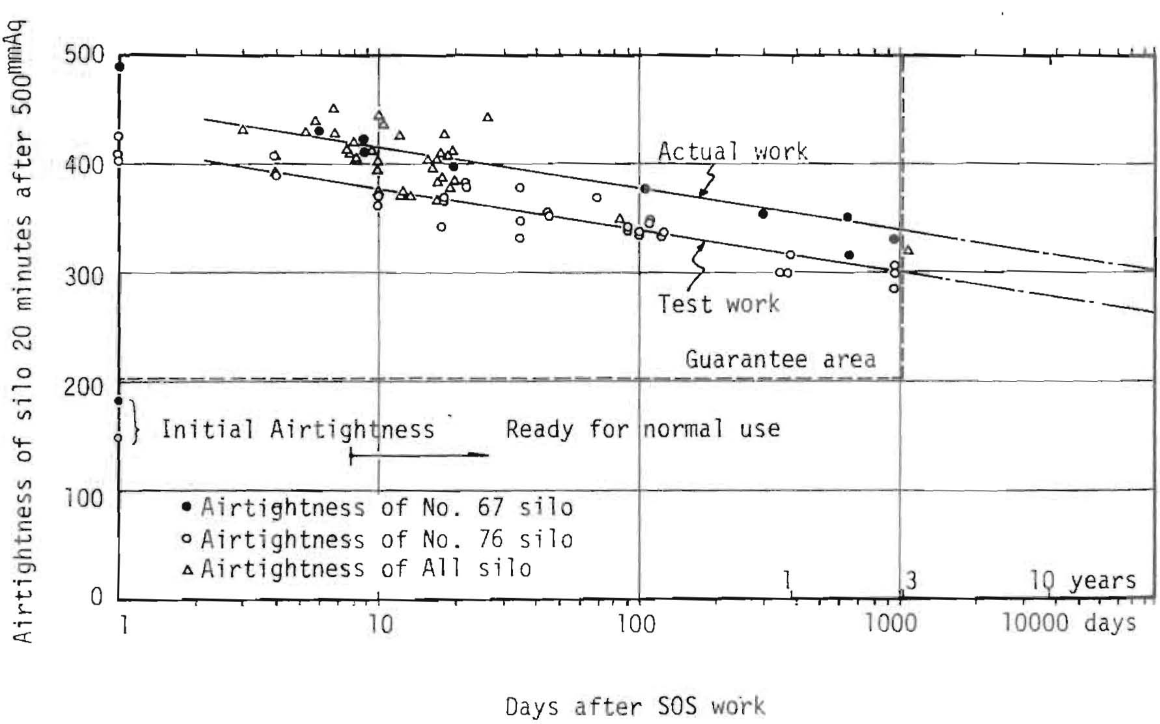


Fig. 16 Airtightness after repair work.

6.3 THE CONTENT OF IMPROVEMENT OF AIRTIGHTNESS

Airtightness of silo is improved by replacement of metal fittings, painting with epoxy resin, and SOS treatment.

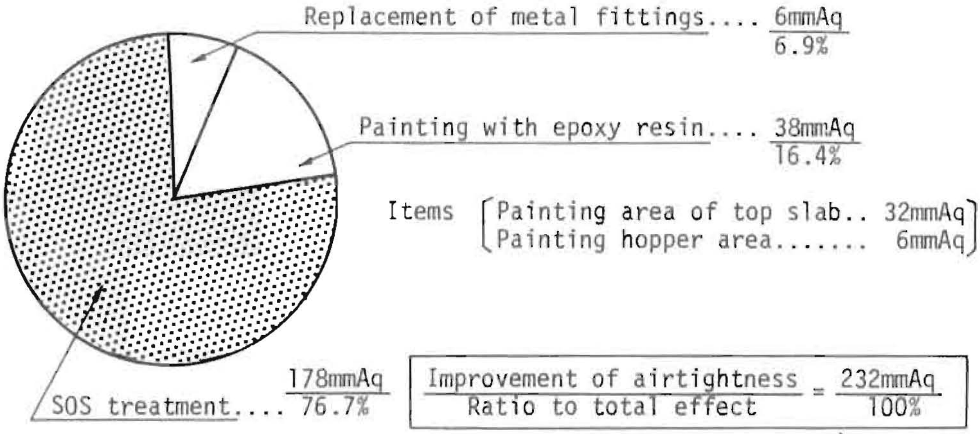


Fig. 17 The content of improvement of airtightness

6.4 CONFIRMATION THAT BINTIGHT-P HAD PENETRATED INTO CRACKS

During the Seal-O-Silo System, Bintight-P and Bintight-L1 had been applied in paste form to cracks, so as to penetrate toward the outside,(see Fig. 19) and after the completion of processing core borings were made in the silo wall to ascertain whether the compounds had fully penetrated the cracks. This was confirmed, verifying the value of the Seal-O-Silo System.

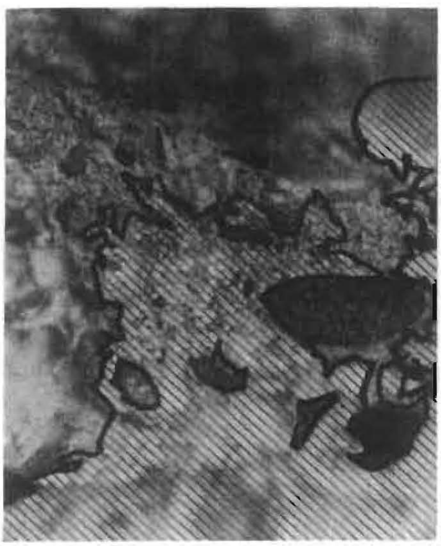


Fig. 18 Crack filled with Bintight-P, verified by a core boring.

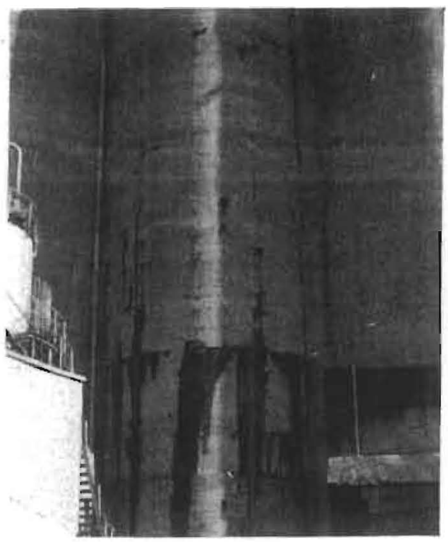


Fig. 19 Bintight-P penetrated through a crack of a silo wall.

7 CONCLUSION

The airtightness of grain silos is essential in the countries where fumigation for all imported cereals in silos is regulated.

The airtightness (gastightness) of storage silos is also important in the case of storing grains with gas for a long time.

Seal-o-Silo System, a system for improving airtightness of silos, can repair old silos in Japan. Their airtightness can well satisfy the Japanese standard.

Also, for the purpose of holding gastightness to high degree for a long time, this system is expected to be applicable.

In spite of further proceeding with researches and development of silo airtightness restoration, it is important to exchange internationally many informations about storage of grains.

We believe firmly that Seal-o-Silo System greatly contribute to food and feed problems.

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