Survey of Corrosion Cost in Japan

Committee on Cost of Corrosion in Japan

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Abstract

The first report on the cost of corrosion in Japan had been published at 1977. The report estimated that the corrosion loss in Japan which did not include indirect loss was 1-2 percent of Gross National Product (GNP) at that time. Since then, almost two decades have passed and the industrial structure has drastically changed. Corresponding to this situation, the Committee on the Cost of Corrosion in Japan was organized at 1999 jointly by the Japan Society of Corrosion Engineering (JSCE) and the Japan Association of Corrosion Control (JACC). The project was funded by the National Research Institute for Metals (NRIM) as part of the Ultra-Steels (STX-21) Project. Cost of corrosion in 1997 was estimated by the Uhlig method and the Hoar method. The estimated cost was compared with the past data which was estimated in 1974 by the same methods of the Uhlig and the Hoar method. In addition to the above estimation, a preliminary analysis by the Input/Output method was performed to estimate the total cost of corrosion including the direct and indirect costs. The overall costs estimated by the Uhlig and Hoar methods for 1997 were 3,938 billion yen and 5,258 billion yen, respectively, which were equivalent to 0.77% and 1.02% of the GNP of Japan. The total cost including the direct and indirect costs, which were estimated preliminary by the Input/Output analysis, is likely to be more than 2 times larger than the direct cost estimated by the Uhlig method.

KEYWORDS: cost of corrosion, Uhlig method, Hoar method, ratio to GNP.

1. Introduction

In FY 1997, the National Research Institute for Metals of the Science and Technology Agency (currently the National Institute for Materials Research of the Ministry of Education, Culture, Sports, Science and Technology) began a ten-year project to study ultra steel materials. The first five-year phase will end in FY2001, and the second five-year phase will commence in FY2002. This ultra steels research project aims to achieve revolutionary advancements in traditional materials performance for sustaining the industrial and social growth under restricted environmental and resource conditions. Research project is currently underway to develop the higher strength steels having more than twice the strength, and weather-resistant steels and stainless steels that have more than twice the corrosion resistance compared with conventional steels. In order to understand the social and industrial needs for ultra steels in Japan, it is required to conduct quantitative survey and analyses on the corrosion cost of metallic materials.

With the increased global concern in corrosion loss in the 1970s, committees surveying corrosion loss were established in various countries and also the committee on the cost of corrosion in Japan was established in 1976-77, with conjunction of the Japan Society of Corrosion Engineering and the Japan Association of Corrosion Control. Various committees had estimated corrosion loss using the Uhlig method which looks at the production aspect of corrosion, as well as the Hoar method which summarizes corrosion loss in the various industrial sectors[1].

In some countries where corrosion loss has been surveyed, economic loss[2] may reach 3-4% of GNP (Gross National Product). In Japan, where surveys had only limited to the direct loss, corrosion loss was estimated to be a whopping 1.8% of GNP. These surveys helped instill an awareness of the need for enlightenment to research and develop corrosion prevention techniques and technologies not only to help the national economy, but also to save resources and energy.

It has already been 25 years since the first survey was taken in 1976. During that time, Japan's economic development and industrial structure have undergone immense changes. What's more, the importance of corrosion prevention will become increasingly evident in the 21st century, which is shaping up to be the environment century. Therefore, the Japan Society of Corrosion Engineering and Japan Association of Corrosion Control established the Committee on Corrosion Loss, which surveyed corrosion losses by considering the economic trends that had occurred over a period of 22 years or so. However, in order to more accurately reflect the intent of the committee referring to the opinions of committee members to evaluate cost reductions gained through corrosion prevention technologies, the name of the Committee was officially changed to the Committee on the Cost of Corrosion in Japan.

The survey report[3] describes various survey methods and trends in other countries. It also lists the results of estimating corrosion costs in Japan using ;

1) The Uhlig method which makes estimates based on corrosion prevention methods.
2) The Hoar method which makes estimates in various industrial sectors.

3) The In/Out method which uses an Input-Output Matrix to make a preliminary estimate.

Detailed information on the survey and strategic proposals for corrosion-prevention technologies are given in the final report[3]. This paper summarizes the main result of the final report and provides an overview of the information given in the report.

2. Methods for Surveying Corrosion Costs

2.1 Types and characteristics of survey methods

Although a definitive method to survey corrosion costs has not been established, there are several methods that were widely used, including the Uhlig method[4], which calculates corrosion-related costs based on corrosion prevention methods; the Hoar method[5], which looks at the cumulative costs of direct losses arising from corrosion in each industrial sector and the costs of associated countermeasures; and the In/Out method based on the input-output matrix[6], which was used at BCL (Battelle Columbus Lab)/NBS (National Bureau of Standards which is now the National Institute of Science and Technology). Simple explanations of these three methods will be given in the following sections.

2.1.1 The Uhlig method

The Uhlig method makes simple calculations of direct corrosion costs from the production aspect. The previous survey[1] looked at the following six items: surface coating, surface processing (plating, etc.), corrosion resistant materials, inhibitors, cathodic protection, and corrosion research. The corrosion costs for each of these items were calculated properly, but it should be pointed out that the estimated cost largely depends on the cost of coating which occupies more than 60% in the total corrosion cost.

2.1.2 The Hoar method

The Hoar method examines each industrial sector in detail and calculates the cumulative total of direct losses and corrosion prevention costs. In Japan, questionnaire were sent to the major industries concerned, including energy, transportation, construction, chemicals, metals, and machinery industry. When necessary, visiting to the factories for inquiry was performed to obtain more detailed information and to improve the accuracy of the survey. However, detailed surveys were sometimes difficult and deficit occurred in the data collection in the survey, so that the estimated loss may be lower than the estimated value by the Uhlig method.

2.1.3 In/Out method

Industrial input-output analysis in the national economy can be summarized in one chart which lists monetary transactions for each industry. The In/Out analysis in Japan has 40-year old long history, during which the analysis is made every 5 years for detailed and performs for about 400 sectors. Although it treats monetary flow and not materials flow, the transaction of goods is captured thoroughly, and so, in recent years, has been used widely and applied ,for example, to estimate the amount of CO_2 production of industrial sectors for calculation of LCA.

In the In/Out method of BCL/NBS, the corrosion costs are estimated by calculating the GDP (Gross Domestic Product) for the following three "Worlds" for estimating corrosion loss:

World I: world where there is actual corrosion
World II: virtual world where corrosion does not exist
World III: world where corrosion is ideally suppressed

From the differences among the GDP of each "World", the actual corrosion costs and the avoidable corrosion costs are derived, as follows:

GDP (World II) - GDP (World I) = corrosion costs
GDP (World III) - GDP (World I) = avoidable corrosion costs

This method allows the total of direct and indirect costs to be calculated, and produces higher values than those estimated by both the Uhlig and Hoar methods. NBS estimates that the uncertainty of this method is 30%. In the present report, preliminary investigations of the method for estimating (direct + indirect) costs were made by deriving changes in GDP by inserting the direct costs calculated by the Uhlig method into the input-output matrix.

3. Changes in Industrial Structure in Japan

Fig. 1 shows the GNP of each year from 1955 (the start of the high growth period) to calendar year 1990 (based on net prices) and growth rate. Fig. 1 indicates years for estimating corrosion cost of this and the previous report and important issues related to corrosion prevention technology.

After the Second World War, the Japanese economy has passed through various phases, which can be roughly divided into three stages; the period of restoration (1945-55), the period of high growth (1955-72), and the period of relatively slow growth from 1973 to the present. In addition, the bursting of the bubble economy in the early 1990s has forced to lower the growth rate after 1990s at roughly 1% per year. However, the information technology revolution that has started in the US is expected to bring new growth to Japanese economy starting around 2000.

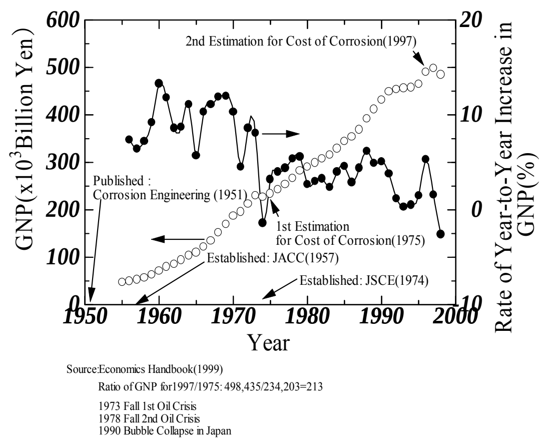

Fig. 1. GNP (Gross Domestic Product) and its growth rate.

The 97th committee of the Japan Society for the Promotion of Science, which had been established before the war, launched a journal, at the beginning of the period of high growth, named Data on Corrosion-Prevention Technology (later renamed Corrosion Prevention Technology). At around the same time, the Japan Association of Corrosion Control was established.

As we can see in Fig. 1, from 1955 to 1973, the year of the first oil crisis, the Japanese economy grew at a very high rate of 10% per year. During this time, the amount of production of the basic materials (raw steel, pulp, cement, etc.) increased rapidly by year and year as shown in Fig. 2, but after 1973, the amount of production have shown a

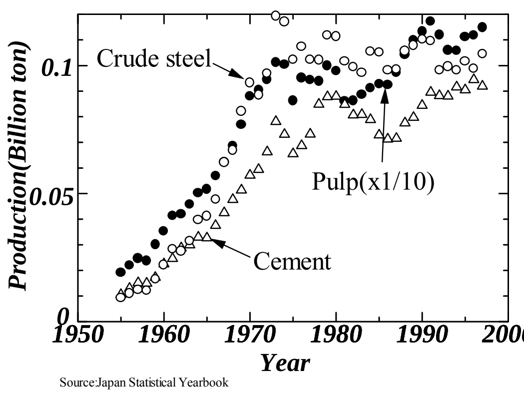

Fig. 2. Changes in the production of basic materials for industry

relatively constant and steady level.

The increase in production was achieved with the construction of new and better facilities, but with the expansion of production facilities came various troubles associated with corrosion. Interest in corrosion was bound to occur when the period of high growth was entered. At the end of this period, focus was turned toward maintenance and management of aged equipment and facilities, and the main themes became corrosion-control technologies, materials evaluation, and development of highly corrosion-resistant materials and coatings. At the start of the period of low growth, the Japan Society of Corrosion Engineering (JSCE) was established by a group of people with an interest in corrosion prevention. It was one of the reasons why the 5th International Conference on Corrosion was held in Japan in 1973. The first survey on corrosion costs was conducted in 1976, soon after the establishment of JSCE.

The expansion of raw materials industries, which had a period of high growth until the 1980s, has provided the basic condition to the development of the automobile industry since the 1980s. In other words, in the 1980s the growth leader changed from the materials industry to the automobile industry, and expansion continued until 1990. Unfortunately, this expansion caused severe trade friction with the

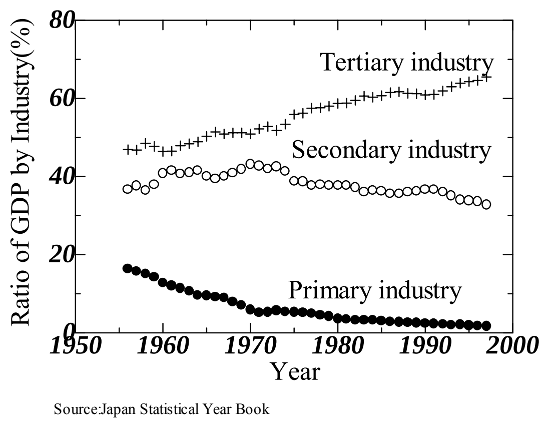

Fig. 3. Ratios of industrial components of GDP

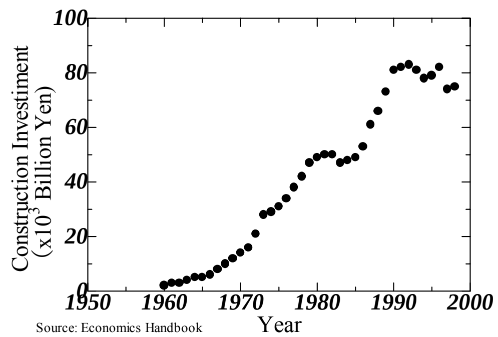

Fig. 4. Changes in construction investment.

Table 1. Corrosion costs estimated by the Uhlig method

Method of corrosion prevention	1997		1975		Ratio of 1997/1975
	Corrosion cost (billion yen)	Proportion (%)	Corrosion cost (billion yen)	Proportion (%)	
Organic coating	2299.46	58.4	1595.48	62.5	1.441
Surface processing of metal	1013.52	25.7	647.62	25.4	1.565
Corrosion-resistant materials	443.24	11.3	238.82	9.4	1.856
Rust preventive oil	63.68	1.6	15.65	0.6	4.069
Inhibitor	44.90	1.1	16.10	0.6	2.789
Cathodic protection	21.68	0.6	15.75	0.6	1.376
R & D in Corrosion	41.65	1.1	21.51	0.8	1.936
Corrosion investigation	9.56	0.2	-	0.0	-
Total	3937.69	100.0	2550.93	100.0	1.544

United States and Western Europe, and production began to shift from domestic production to oversea production.

Before the automobile industry is a leading sector, the expansion in the production of television sets, which rapidly became commonplace in Japanese households, became the driving force for the growth of Japan's electrical appliance industry. Beginning in the 1990s, the prominence of this industry, along with the automobile industry, as a growth leader has led to a remarkable expansion of the production in semiconductor electronics, personal computers, and portable telephones.

Beginning in the latter half of the 1980s, environmental problems became a matter of extremely important issue, and corrosion control technology was also focused by emphasizing environmental protection. In response to the changing of concerns, the journal of "Boshoku Gijutsu (Corrosion Engineering) " changed its name to "Zairyo-to-Kankyo (Materials and Environment)" in 1991, and continues to grow. At the same time, cost reductions, guaranteeing of safety and reliability, life predictions and life extension, etc., became important issues for corrosion prevention technology.

Changes and expansion of the fields of application of corrosion prevention technology have a close relation with the changes in industrial structure outlined above. Since the late 1980s, the growth of non-production industries has outpaced that of production industries, so that by 1996 investment in equipment by non-production industries was nearly double that of production industries, and the economic structure came to emphasize non-production industries. This trend is clearly seen in Fig. 3, which shows trends in the make-up of the GDP.

In addition, the electrical appliance industry, which has been the most active industrial sector for equipment investment in recent years, has been the industry leader since the 1990s. The fields of corrosion technology application had been concentrated in coastal industrial complexes during the period of high growth, but since the late 1980s it has been shifting toward inland automobile and electrical appliance production plants.

As we can see in Fig. 4, investment to the construction of infrastructure has risen consistently since the 1960s, and is growing at a faster rate than the GDP. A comparison of the amount of investment made in this construction in 1976 and 1996 shows a ratio of 82680/34197 = 2.42, which is larger than the GDP growth during the same period (490153/243542 = 2.01). Since the main themes associated with the infrastructure construction with this investment are maintenance/management and life extension, corrosion control technology should play a major developmental role in these fields.

4. Survey Results Using the Uhlig Method

Table 1 shows the results of the Uhlig method from the present survey in combination with the previous results. Figure 5 shows graphs of the costs. Total cost was 3.9 trillion yen, which is of 1.54 times higher than the previous result of 2.6 trillion yen. Since the growth rate of the GNP during this time increased by nearly 3 times, we can see that in comparison, the proportional increase in corrosion costs calculated by the Uhlig method is relatively small.

On a cost-by-cost basis, we can see that the

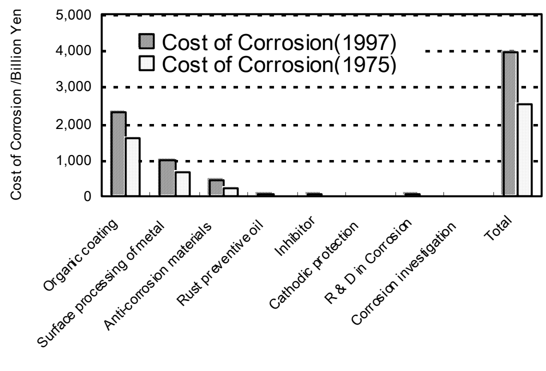

Fig. 5. Corrosion costs estimated by the Uhlig method.

increases were higher for corrosion resistant materials, rust preventive oils and inhibitors, which are frequently used in corrosion prevention. The increase in expenses was particularly high for rust-preventing oils, but this might be caused by differences in how the calculation standards were used. On the other hand, growth rates for organic coating and cathodic protection costs were relatively low, but this is because the unit price of each type of industrial product has, unlike economic parameters such as GDP, shown a very small growth rate in the past 22 years.

As we can see in Fig. 6, organic coating accounts for the large portion of corrosion costs, more than half. In the previous report it had stood at 62.5%, and in the present report it was not significantly changed, at 58.4%.

4.1 Costs for organic coating

In the Uhlig calculations, organic coating costs, which account for the largest share, were 1.44 times higher than in the previous report, but the breakdown is much different. The results are shown in Fig. 6. Here, in order to facilitate the comparison with the previous results, we assumed the same proportion of fabrication costs. In other words, fabrication costs were calculated at 10 times for marine transportation, and 5 times for the other industries.

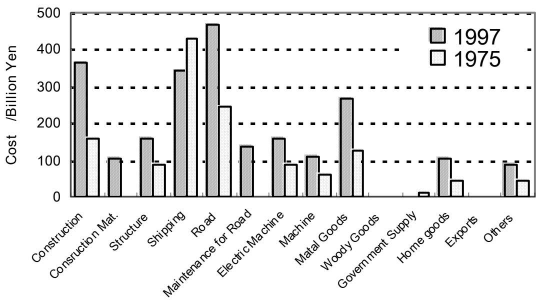

Fig. 6. Breakdown of coating costs and a comparison with the previous survey

As we can see in Fig. 6, the growth rates for construction, roads, and metal products were all around 2 times higher than in the previous report. In contrast, the highest rate of costs in the previous report, i.e., for marine transportation, declined. As will be mentioned later in the section of the Hoar method in the transportation field, this was the effect of continuing cost reductions, including overseas production. At the same time, a comparison with organic coating costs related to roads and vehicles, including repairs, which had increased significantly shows that during the 22-year period, logistics inside Japan shifted from marine (ship-based) to land (truck- and rail-based) transportation.

From the technical side, organic coating during this 22-year period shifted from oil-based resins to synthetic resins, and the use of fluorine-containing resin coating materials was hailed as a way to enhance durability. Furthermore, due to the environmental issues in recent years, advancements have been made in the use of water-based, powder and non-solvent coating materials.

Table 2. Metal surface processing cost.

Surface processing cost (billion yen)	1975	1997
Surface processing cost of steel materials	175.8	358.8
Surface processing cost in small- and medium-sized plating companies	399.0	462.5
Surface processing cost of aluminum	72.8	192.3
Total	647.6	1013.5

4.2 Surface processing of metals and the use of corrosion resistant materials

Metal surface processing costs were 1.6 times higher than in the previous report. However, the breakdown of these costs, which is shown in Table 2, changed significantly. For example, the surface processing of steel materials cost about 176 billion yen in 1975, but by 1997 it had more than doubled, to 360 billion yen.

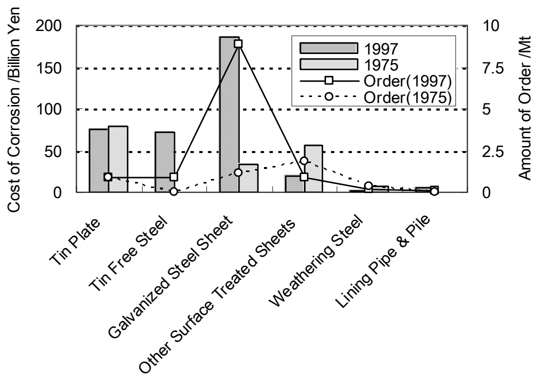

Fig. 7. Breakdown of metal surface processing costs and a comparison with the previous survey.

Figure 7 gives more details and shows changes in sales orders received. Galvanized steel sheets accounted for a significant increase in corrosion costs, rising from 34 billion yen to 180 billion yen, a rise of more than 5 times, while orders rose 9-fold, from 1 million tons to 9 million tons. The biggest reason for this is believed to be the use of galvanized steel sheet in automobile bodies.

Table 3． Comparison of corrosion resistant materials examined in the present and previous surveys

Anti-corrosion materials	1975		1997	
	Ordered amount (1,000 ton)	Corrosion cost (billion yen)	Ordered amount (1,000 ton)	Corrosion cost (billion yen)
Ferritic stainless steel	150	39.1	583	81.6
Austenitic stainless steel	497	193.7	1500	300.0
Titanium alloy	2	6.0	4.4	13.1
Copper alloy	-	0	53	48.5
Total	-	238.8	-	443.2

Another major reason may have been an increase in the use of galvanized steel sheet for building materials etc.

On the other hand, the reason why the growth of corrosion costs was relatively low compared with the increase in sales orders may have been due to declines in production costs.

In addition, tin-free steels (TFS), which were included in the miscellaneous surface processing in the previous survey, have about the same corrosion costs as tinplate. The reasons might be the increase of the ratio in beverage can use over food can use, and technological advancements such as the development of lamination techniques using organic resins.

Furthermore, in the present survey the amount of imports is included in the cumulative calculations, but they account for only 4% of each of tinplate and galvanized steel sheet. This figure is essentially an import amount as raw material, and it was not possible to include values for imported electrical appliances and food cans in the cumulative totals. Today, when the amount of imports is increasing, there is a possibility that the value could rise to the point where it could no longer be ignored, but it would be very difficult to deal with that kind of situation.

It is difficult to accurately calculate corrosion costs for small- and medium-sized plating companies, so they were set at 60% of the sales of these companies. As a result, corrosion costs were a little less than 1.2 times higher than in the previous survey. However, since sales from small- and medium sized plating companies were not included in the present survey, we believe the actual costs are a little higher.

Aluminum surface processing costs were calculated based on construction aluminum materials that is used in metal window shutters, doors and external coating materials. Other than that, the use of aluminum in cars grew more than 10-fold from 15 kilo tons in 1975 to 210 kilo tons in 1997. But it is believed that the purpose of this was to reduce the weight of the cars and not to improve corrosion resistance, so it was not included here. As a result, surface processing for aluminum alloys, at 192 billion yen, had increased nearly 3-fold from the previous report. Because there was not such a large increase in sales, the remarkable increase in corrosion costs might be attribute to cost increases due to an advance of surface processing technique.

Corrosion costs resulting from the use of corrosion resistant materials increased 1.8 times over the totals in the previous report. The breakdown is shown in Table 3. Seen individually, sales orders for both austenitic and ferritic stainless steels increased 3-fold. However, the price difference between these stainless steels and mild steels declined to about half. Therefore, the increase in sales orders was not strongly affected to the increase in corrosion costs.

Sales orders for titanium increased by about 2-fold. The titanium price was about half of that in the previous report. The proportion used for corrosion prevention measures were assumed to be 50% in the previous report. In more recent years nearly 100% of industrial titanium is used for corrosion prevention purpose resulting that corrosion costs nearly doubled in this report. Copper alloys were not included in the previous report, but in the present report they represent about 50 billion yen of corrosion costs.

4.3 Use of inhibitors

Corrosion cost using inhibitors has increased by about 2.8 times. A detailed overview is given in Table 4. Here we can see that boiler water treatment increased 1.6-fold over the previous estimation, which is believed to be due to changes from the central and integrated facilities into smaller, scattered ones with better efficiency. In addition, corrosion costs increased more than 5-fold over the previous estimation in the use of cooling water treatment. During this 22-year period, there was a shift away from heavy chemical industries at sea coast toward inland factories and increase of air conditioning for buildings, greatly increasing the use of cooling water. Furthermore, while the amount of water used for this purpose increased, technological advancements were made in the recycling of water, rather than using fresh water, so that the amount of fresh water supplied to industry has actually been decreasing.

Table 4. Comparison of the use of inhibitors

Treatment cost of inhibitor (billion yen)	1975	1997
Boiler water treatment	12.04	19.7
Cooling water treatment	3.76	22.6
Treatment on the process side	0.3	1.1
Anti-rust for water supply	0	1.5
Total	16.1	44.9

Water treatment on the process side is mainly used in oil refining industry, which also showed a strong growth. This was due to the technological improvement and integrated processing of inhibitors. At the same time, inhibitors were used for water supply, so corrosion costs in this field also increased.

4.4 Other types of corrosion costs

The Uhlig method is used to calculate corrosion costs of other items including those associated with rust preventive oils, cathodic protection, research and development in corrosion, and corrosion investigation and inspection. Compared with the increase in GNP and construction facilities, growth of cathodic protection has been relatively low, i.e. 1.4-fold over the previous estimation. This might be a result of the development of economical cathodic protection systems.

The costs for rust preventive oil could not be calculated very accurately due to inaccuracy of the statistical data. As for the costs of corrosion research and development, the number of researchers increased during this period with increase in the cost per researcher, so this accounted for a larger proportion of the total increase. In addition, the corrosion investigation and inspection costs were not counted in the previous report, so they were estimated from the amount of sales of the investigation and research companies by multiplying the proportion of corrosion prevention costs. However, there were many discrepancies, and it is believed that the actual amounts are much higher.

The rise in the proportion of R & D costs in corrosion, investigation and inspection, etc., can be attributed to a growing awareness of corrosion problems and the fact that numerous facilities, infrastructure, etc., that were built during the high growth period, have been aging and deteriorating due to corrosion. Therefore, we predict that corrosion costs related to these issues will increase in the future.

Table 5. Corrosion cost estimated by the Hoar method.

Sector	Corrosion cost (billion yen)		Ratio of 1997/1975
	1997	1975	
Energy	456.8	59.8	7.64
Transportation	544.7	194.5	2.80
Chemicals	1070.0	154.3	6.93
Machinery	1561.5	427.8	3.65
Metals	27.6	26.5	1.04
Construction	1597.6	175.2	9.12
Total	5258.2	1038.1	5.07
Ratio to GNP (Hoar method)	1.02%	0.70%	1.46
Comparison (Uhlig method)	3937.7	2550.9	1.54
Ratio to GNP (Uhlig method)	0.77%	1.72%	

5. Survey Results Using the Hoar Method

The survey using the Hoar method focused on the same six sectors as in the previous report, i.e., energy, transportation, chemicals, metals, machinery and construction industry. The following sections describe in detail the corrosion costs estimated by the Hoar method for each sector. The results derived here were tabulated and are compared with the previous results in Table 5. The total for all sectors was 5,258 billion yen, a significant increase over the 1,381 billion yen from the previous report.

Though the ratio to GNP in the present Uhlig method is lower than that of previous survey, the result estimated by the Hoar method shows a increasing ratio to GNP. In addition, the previous survey showed more discrepancies in the Hoar method than in the Uhlig method and estimates for corrosion costs were low, but just the opposite occurred in the present survey. The biggest reason for this was that there was much more thorough investigation in the present Hoar survey. However, another factor was that the Uhlig method focuses only on initial costs, while the Hoar method also includes maintenance costs. This suggests that given the economic changes that occurred during the 22-year (1975-97) period, maintenance costs have been consumed much more than initial costs.

5.1 Corrosion costs in the energy sector

As with the previous report[1)], written questionnaire surveys were conducted for three fields in the energy sector: water service, gas and electric power industry. The surveys were designed in such a way as to enable comparisons with the previous report and evaluate subsequent changes. Because the water service involved numerous local public water service, questionnaire survey to administer would be difficult, so we made our calculations based on data analyses of statistical yearbooks for water facilities.

5.1.1 Water service systems

By the end of 1997, water services in Japan were fulfilled at 96.1%, so it has changed from facility expansion to maintenance and management. However, water service systems that had been built during the high growth period in the 1950s and early 60s have been noticeably deteriorating, and it has become a technical issue to make the upgrading of aging facilities more efficient.

Water service facilities are classified as shown in Table 6. Calculations were made for pipes, because this category has been most affected by corrosion and it accounts for nearly 70% of the assets of all water systems.

In addition to normal aging, metal pipes used in water systems have undergone deterioration of inner and outer coatings and corrosion by water and soil, causing various problems. Therefore, as a preventive measures it was recommended throughout Japan that damaged pipes be replaced with new pipes. As Table 7 shows, 27.2% of all metal pipes were replaced due to corrosion. Therefore, we assumed that 30% of all replacements in Japan would be for this reason. In other words, from the water systems data listed in the 1997 Water Supply Statistics published by the Japan Water Works Association, we derived the total length of pipes replaced, then using the following equation we calculated that the cost to replace water pipes due to corrosion was nearly 200 billion yen.

Total pipe length × unit price for replacing pipes × proportion of pipes replaced due to corrosion = 8,752,665m × 75,315 yen/m × 0.3 = 197,762,089,543 yen

5.1.2 Gas

Corrosion-related costs in the gas industry were derived from the results of questionnaire survey that was sent to five of the major gas companies in Japan. The survey sought information about the companies' piping facilities and production storage facilities, and divided costs into expenses for construction, and expenses for maintenance and management in FY1997.

Table 6. Classification of water facilities

Water facilities	Intake facilities	Intake tower, Intake dam, Sand-settling basin, Conducting pipe
	Purification facilities	Sedimentation basin, Filter basin, Clean water reservoir
	Supply facilities	Distribution reservoir, Distributing tower, Conveying pipe, Distributing pipe, Feed pipe

Items related to corrosion costs were (a) cost increases due to the use of corrosion resistant materials, (b) cost increases due to the use of coated or covered pipes, (c) coating and lining work, (d) plating and metallic coating work, (e) corrosion prevention chemicals(inhibitors, rust-preventing oils, etc.), (f) cathodic protection, and (g) others.

Responses were received from four of the five companies.

(i) Costs for corrosion prevention work during the construction of new facilities

According to the capital investment figures for 1997 listed in the Handbook of the Gas Industry published by the Japan Gas Association, the total amount of equipment investment made by gas companies nationwide was 445.1 billion yen, of which the four companies accounted for 280 billion yen, or 63%. In addition, there was a nationwide total of 334.79 billion yen spent for laying pipes, and 81.25 billion yen spent for production storage facilities.

According to the responses of the four companies regarding corrosion prevention costs for construction and for piping facilities, total expenses of 6.54 billion yen included 5.08 billion yen for coating and covering pipes, 210 million yen for

Table 7. Total length of pipes replaced (1997 Water Supply Statistics, Japan Water Works Association).

Type of pipe	Conducting/conveying pipes		Distribution pipes	Total	
	Water works	Supply	Water works		
Cast iron	18,137 m	3,586 m	1,149,698 m	1,171,421 m	14.7 %
Ductile iron	32,932 m	2,375 m	735,286 m	770,593 m	9.6 %
Steel	11,220 m	1,210 m	220,554 m	232,984 m	2.9 %
Asbestos cement	103,679 m	0 m	3,723,932 m	3,827,611 m	47.9 %
Hard vinyl chloride	19,157 m	0 m	1,798,719 m	1,817,876 m	22.8 %
Concrete	3,163 m	632 m	3,458 m	7,253 m	0.1 %
Polyethylene	668 m	0 m	63,046 m	63,714 m	0.8 %
Stainless steel	0 m	0 m	395 m	395 m	0.0 %
Other	4,597 m	0 m	91,907 m	96,504 m	1.2 %
Total	193,558 m	7,803 m	7,786,995 m	7,988,351 m	100.0 %

coating and lining pipes, and 1.25 billion yen for cathodic protection and prevention of stray current corrosion. Since the Handbook of the Gas Industry considered this to be about 63% of the national total, we estimated the total cost of corrosion preventing work in the gas industry in Japan to be 10.38 billion yen, equal to about 3.1% of the 334.79 billion yen price tag for construction.

In contrast, the total amount spent by the four companies for corrosion prevention measures for production storage facilities was 480 million yen, which included 180 million yen for coating and lining storage facilities. Using the same figure of 63% as before, we estimated national corrosion costs to be 760 billion yen. This is equal to about 0.9% of the 81.25 billion yen spent on production storage facilities nationwide.

From these results, we concluded that the total amount of construction expenses for pipe laying and storage facilities related to corrosion prevention measures was 11.14 billion yen.

(ii) Corrosion prevention costs for existing facilities

According to the responses of the four companies, the total amount of money spent per year for maintenance was 43.2 billion yen, of which 650 million yen was earmarked for corrosion prevention measures. The total spent for corrosion prevention measures on the maintenance / management side was 1.41 billion yen in production storage facilities.

According to personal interviews, about 70% of the corrosion-related expenses for piping facilities was directly related to preventive maintenance, while the remaining 1.07 billion yen was used for cathodic protection and prevention of stray current corrosion, etc. According to the Handbook of the Gas Industry, the total length of piping lines owned by the four companies was 55.3% of the national total, so we estimated that the total amount spent nationwide for these facilities was 11.75 billion yen.

The total costs to the four companies for corrosion preventing work for storage facilities was 960 million yen for coating and lining, and 110 million yen for plating and metallic coatings. Since the production capacity of the four companies was 85.9% of the nationwide total, we estimated that the total national cost for the facilities was 1.64 billion yen.

Given the above results, we concluded that the total amount spent for corrosion prevention

Table 8. Proportion of corrosion prevention cost calculated from the survey data.

	To construction Costs	To maintenance/management costs
Thermal power generation	1.1-9.8% Average 5.9%	3.1-12.3% Average 10.3%
Nuclear power generation	1.7-9.8% Average 7.6%	5.0-15.4% Average 11.9%
Hydroelectric power Generation	0.52-1.33% Average 0.89%	0.8-4.6% Average 3.1%

Table 9. Corrosion prevention cost of electric power generation (billion yen).

	Previous survey		Present survey	
	Corrosion prevention costs in construction	Corrosion prevention costs in maintenance /management	Corrosion prevention costs in construction	Corrosion prevention costs in maintenance /management
Thermal	21.40	6.90	58.5 [2.7]	52.4 [7.6]
Nuclear	5.00 *	0.35 *	46.0 [-]	31.5 [-]
Hydroelectric	1.50	1.20	7.8 [5.2]	16.8 [14.0]
Subtotal	27.90	8.60	112.3 [4.0]	100.7 [12.0]
Total	36.5		213.0 [5.8]	

Figures in [ ] show multiples of the present survey to the previous one.
*Calculated as same proportion of corrosion prevention costs as thermal power generators.

Table 10. Comparison to the previous survey for the percentage of corrosion prevention costs in construction and maintenance/management costs.

	Previous survey		Present survey	
	In construction costs (%)	In maintenance /management costs (%)	In construction costs (%)	In maintenance /management costs (%)
Thermal	4.0	10.0	5.9 [1.5]	10.3 [1.0]
Nuclear	4.0 *	10.0 *	7.6 [-]	11.9 [-]
Hydroelectric	0.60	2.0	0.89 [1.5]	3.1 [1.6]

Figures in [ ] show multiples of the present survey to the previous one.
*: Calculated as same proportion of anti-corrosion costs as thermal power generators.

measures in the maintenance and management of gas storage facilities was 13.39 billion yen.

(iii) Corrosion prevention costs in the gas industry

Given the above results, the total annual amount of corrosion-related expenses in the gas industry was estimated to be 24.5 billion yen in FY1997. Of this amount, 13.4 billion yen, more than half was used for maintenance and management, a huge increase from the 1974 figure of 550 million yen. In addition, the amount of corrosion prevention costs in construction was 11.1 billion yen, an increase of about 1.3-fold from the 8.72 billion yen in the 1974 survey, but was much smaller than the GDP rate of increase (3.6 times) during the same period. This may be due to the greater amount of maintenance put into permanent structures at the present time.

5.1.3 Electric power

Questionnaires of corrosion costs in the field of electric power industry were given to 12 companies engaged in the production of hydroelectric, nuclear and thermal power (hereafter, power generation sector) and to 41 departments in the power transmission sector. Responses came from 39 departments and all 12 electric power companies.

(i) Corrosion costs of electric power generators

The surveys of the electric power generation sector concerned a typical thermal, nuclear, or hydroelectric plant of the respective companies. Responses were given for the following items:

a. Total construction costs and the amount of that expense that is earmarked for corrosion costs (coating and lining, use of corrosion resistant materials, production of corrosion prevention equipment, chemical cleaners, other measures)

b. Total annual maintenance and management costs and the amount of those expenses that is earmarked for corrosion costs (repairs by coating and lining, water treatment, chemical cleaners, operation and repair of cathodic protection equipment, replacement of pipes and equipment, other measures)

Calculations were first made from the survey data to find out the proportion of construction costs of new facilities, and annual maintenance/management costs of existing facilities, could be attributed to corrosion costs in 1997. The results are shown in Table 8.

Corrosion costs associated with the construction of new plants were calculated as follows: We estimated the total annual construction costs of each electric power generating facility by multiplying the new production capacity in FY 1997 listed in the Electric Power Industry Handbook of the Japan Electric Association by the average construction cost per unit output derived from a survey. This was then multiplied by the proportion of corrosion costs to total construction costs at the time of construction. It should be noted that it takes several years to build an electric power plant, and the amount of new construction varies widely from year to year, so the figure we used for 1997 was averaged from the six fiscal years from 1993 to 1998, inclusive.

The corrosion costs associated with existing facilities were calculated in a similar way. By multiplying capacity of existing facilities in FY 1997 listed in the Electric Power Industry Handbook of the Japan Electric Association by the average maintenance/management cost per unit output derived from a survey, we estimated the total annual maintenance/management costs of each electric power generating facility. This was then multiplied by the proportion of corrosion costs to total maintenance/management costs.

The results are shown in Table 9. Here we can see that the total in 1997 was 213 billion yen. For comparison, Table 9 also lists the results of the previous survey (FY1974).

(ii) Corrosion costs for transmission equipment

In the surveys of transmission equipment, responses were received regarding the following items related to transmission facilities of each power company in 1997.

a. Total length of new transmission lines and associated installation costs, number of new towers and associated construction costs, and the proportion of corrosion costs to installation and construction costs

b. Total length of replaced transmission lines and associated costs, repair costs (coating steel towers, replacing metal parts, etc.), and miscellaneous corrosion costs.

The survey results showed that in 1997, corrosion prevention measures accounted for 15.9 billion yen of new construction costs and 5.6 billion yen of maintenance/management costs of existing facilities; thus the total corrosion costs in the transmission subsector were assessed at 21.5 billion yen.

(iii) Corrosion costs in the electric power sector

The above corrosion costs in the electric power sector in FY 1997 included 213 billion yen in the generation subsector and 21.5 billion yen in the transmission subsector, for a total of 234.5 billion yen.

It should be noted that corrosion costs in the electric power generating subsector were 5.8 times higher than 36.5 billion yen in the previous survey. One reason for this increase is that, as shown in Table 10, the percentage of corrosion costs in construction costs for new facilities, and maintenance/management costs of existing facilities, increased only slightly from the previous survey, but there were increases in construction costs per unit of output and in maintenance/management costs. The increase in construction costs per unit of output entailed increases for environmental equipment, etc., but the increases in maintenance/management costs per unit of output probably could be tied to increased costs associated with plant aging.

5.1.4 Corrosion prevention costs in the energy sector

In FY1997, corrosion prevention costs in the energy sector in Japan were estimated to be 456.8 billion yen. These costs were 7.6 times higher than the 59.8 billion yen spent in 1974, and much higher than the 3.6-fold increase in GDP during this time. The energy sector is a facilities-based industry, so we can assume that the industry is working hard to provide and manage a stable supply of energy.

5.2 Corrosion costs in the transportation sector

The scope of the survey in the transportation field involved companies associated with producing rail cars, ships, and motor vehicles. These companies have formed an industrial association, which assisted us greatly in our costs-at-production survey. In addition, main users and user groups helped us with assessing repair costs. Information from motor vehicle manufacturers was obtained through interviews with individual makers.

5.2.1 Corrosion costs associated with rail cars

Since the time of the previous survey[1)], the railroad sector has been undergoing major changes. The number of Shinkansen ("Bullet Train") lines has been rapidly increasing, and nearly all of the cars are now made out of aluminum alloys. At the same time, the overwhelming majority of commuter cars and suburban-type trains, even in the JR system, are stainless steels. Including the aluminum alloy cars from the private lines the number of cars being produced from carbon steels is declining dramatically. It should be noted that land transportation is shifting from railways to motor vehicles, and the number of freight cars (trains) is decreasing, with most of the remaining ones being either container or tanker cars.

The results of these surveys are shown in Table 11. The cost reduction ratio was shown as the ratio of 1997/1974 in the lowest line. The diversification of transportation, especially the decreasing dependence on railways for freight transport, has had an effect, and we can clearly see a decrease in the production and retention of locomotives and freight cars, while the per car corrosion costs are soaring. This corresponds with the rapid increase in stainless steel and aluminum alloy cars. Relatively speaking, the cost of corrosion prevention measures per car at the time of repair is decreasing dramatically. The use of corrosion resistant materials by railways is an excellent example of how life-cycle costs have been reduced.

5.2.2 Corrosion costs for ships

The most noticeable recent trend in the Japanese commercial shipping fleet is the decrease in the number of vessels registered as Japanese ships, and an increase in foreign-registered “flag of

Table 11. Corrosion costs in production/repair of rail cars in 1997.

Type of car	Number of cars		Production cost (billion yen)		Ratio of corrosion prevention cost to car (%)		Corrosion cost (billion yen)	
	New cars	Existing cars	Production cost	Repair cost	At production	At repair	At production	At repair
Locomotive	4	1,996	1.8	19.6	-	-	-	0.98
Passenger car	1,425	50,902	141.6	135.0	3-19	3.3-10	8.66	7.94
Freight car	692	14,741	12.0	4.9	5	3	0.6	0.15
Total	2,125	67,639	155.4	159.5			9.26	9.07
Cost ratio of 1997/1974	0.47	0.34	1.47	0.90			4.03	0.52

Table 12. Corrosion prevention costs at production of motor vehicles evaluated from anti-corrosion materials (1997).

Material for corrosion prevention	Amount shipped (Thousand tons)	Value of shipment (billion yen) (* Difference in price with general steels)
Galvanized steel sheet	3618.8	72.4 *
Stainless steel	93.4	18.7 *
Paint	314.2	137.7
Total		227.8

convenience” ones. Thus, it was very hard to precisely define a "Japanese" ship. If only Japanese-registered ships were included, it would be too detached from actual conditions, so this survey also included “flag of convenience” ships.

(1) Corrosion costs for new ships

Corrosion costs for new ships were calculated with the assistance of the Shipbuilders' Association of Japan. 1) A survey was conducted to find the proportion (coefficient) of corrosion prevention measures of total costs to build each type of new ship built by member companies. 2) For each type of ship, the resulting coefficients for building were multiplied by the corrosion costs. 3) As a result of the surveys, we concluded that the percentage was around 6.2%. Cumulative tabulations resulted in a total of 43.153 billion yen in corrosion costs for new ships. These costs include coating, corrosion resistant materials, cathodic protection, plating, etc. (including workers' wages).

(2) Maintenance costs of ships in service

Maintenance costs of ships in service were derived with the assistance of the Japanese Shipowners' Association. The association obtained data from member companies on the costs of ship repairs, parts, etc., then used this as a basis for selecting items related to corrosion and prevention to calculate corrosion costs for ships in service. The survey period was from 1 April 1997 to 31 March 1998. While the survey targeted Japanese-registered ships (both for domestic and international use), costs related to foreign-registered “flag of convenience” vessels were calculated as corrosion cost coefficients converted from the ton ratio. These coefficients, which are the percentage of corrosion costs in docking costs, was 75% for ships, 55% for engines, and 50% for minor repairs. Corrosion costs for ship supplies included paint, roping, and chemicals (corrosion prevention chemicals, etc.) Most of the docking costs of the ships were for coating (surface processing of steel materials, coating, paints, etc.) and costs for replacing corroded steel members, parts, etc.

The total aggregate tonnage of ships for international use was 12,539,529 tons, which required 6.71 billion yen annually in corrosion costs. In contrast the tonnage of ships used in domestic lines was only 775,015 tons, and 3.79 billion yen was spent annually in corrosion costs. The costs for “flag of convenience” ships were evaluated to be 4 times higher than those for domestic ships, giving us a total of 26.85 billion yen. Total corrosion costs for all ships in service were about 37.35 billion yen.

5.2.3 Motor vehicles

According to statistics from the Japan Automobile Manufacturers Association, Inc. and other organizations, the total number of four-wheeled motor vehicles produced in Japan in FY1997 was 10,975,000. Of this total, 4,553,000 vehicles were exported. The total number of vehicles was used in the production costs. The total number of registered four-wheeled motor vehicles in Japan was 70,551,000.

(1) Corrosion costs at production

Based on publicly released statistics of materials shipped to the automobile industry, we attempted to evaluate costs strictly from a materials point of view. The results are shown in Table 12. The corrosion price difference with carbon steel materials was 20,000 yen/ton for zinc-plated steel sheets and 200,000 yen/ton for stainless steel. The statistics on local- and usage-categorized ordering of common steel published by the Japan Iron and Steel Federation were used to determine the amount of zinc-plated steel sheets consumed in the automobile industry, while statistics of the Japan Stainless Steel Association were used for stainless steel and statistics of the Ministry of International Trade and Industry were used for the monetary value of coating materials shipped. In terms of raw materials alone, corrosion costs amounted to roughly 19,500 yen per vehicle.

For Japanese passenger cars of the 1500-2000 cc class, we received information from car makers regarding the per vehicle corrosion costs. The figure was 19,000 yen per vehicle for bodies, plus 6,500 yen per vehicle for parts, making a grand total of 25,500 yen per vehicle. Compared with the 19,500 yen/vehicle figure for raw materials alone, it is somewhat expensive, but the difference is not excessive. Coating has become increasingly automated in the industry, and costs for wages, etc., in this area have declined dramatically. Assuming an average price of 1.4 million yen per new car, the corrosion-related costs at production accounted for 1.8% of the total price. Multiplying total corrosion costs at production of 25,500 yen/vehicle by total number of vehicles produced of 10,975,000 gives us a total of 279.9 billion yen in production-related corrosion costs per year.

(2) Maintenance-related corrosion costs

Compared with production-related evaluations, corrosion costs for automobile owners depended widely on use conditions, and it was difficult to take organizational surveys of users. Maintenance-related corrosion costs have been regularly reported by the Japan Automobile Service Promotion Association in their "Survey of

Automobile Inspection Fees", which we referred to for users' corrosion costs. In the evaluation of users' corrosion costs at the national level, we multiplied the chassis coating cost of 4,700 yen/vehicle by 70,551,000 registered vehicles, and then multiplied it by 1/2 to get an annual figure of 165.8 billion yen.

5.2.4 Discussion about the transportation sector

Table 13 shows the annual corrosion costs for ships, railway cars, and motor vehicles for FY 1997.

Maintenance-related corrosion costs for railway cars were lower than they had been in 1974. This is largely due to an increasing number of cars which were made either of stainless steel or aluminum alloys, and coating costs came down. The use of corrosion resistant materials in railway cars helped to reduce lifecycle costs.

In FY 1997, the proportion of corrosion cost for new ships, 6.2%, was lower than the value of 9.0% for 1974. Despite the fact that during this period tankers with double-hull structures became common and the area needing coating increased by 50%, corrosion costs declined as a proportion of total building costs. This reason appears to have been greater efficiency and rationalization in coating methods (for example, greater use of advanced equipment, greater efficiency of work done by specialized workshops, more work subcontracted, automation, etc.) which account for most of the corrosion prevention costs.

Regarding ships in service, we should note that since “flags of convenience” ships were included, corrosion costs increased only 9% from 1974, despite the fact that laden weight of 103 million tons was 160% higher than in 1974. Costs were kept down through such measures as transferring docking places from domestic ports to ports overseas where labor was cheaper.

In FY 1997, the corrosion costs of automobiles at production, which were estimated to be 279.9 billion yen, were markedly higher than the 1974 figure of 97.5 billion yen. This was due to the increase in production (from 6.5 million vehicles to the 11 million level) and expensive measures that were taken for each vehicle. Furthermore, the present report was more exacting than the previous one. The increase in corrosion costs of automobiles at production should have led to a reduction in maintenance costs for users, but since this information was not included in the previous survey, we could not make a comparison.

Table 13. Annual corrosion cost in the transportation sector of Japan in 1997 (billion yen/year)

	Production	Maintenance	Total
Rail cars	9.3	9.1	18.4
Ships	43.2	37.4	80.6
Motor vehicles	279.9	165.8	445.7
Total			544.7

5.3 Corrosion costs in the chemical industry sector

5.3.1 Introduction

Corrosion costs in the chemical industry sector were examined for not only the subsectors that were included in the 1977 Survey[1] of oil refining; petroleum and coal products; soda production; chemical fertilizers and inorganic chemicals; organic chemicals and chemical fibers; plastics production; and rubber production, but they were also examined for the subsectors of pulp and paper production; fine chemicals; ceramic products; and the food industry. Thus, a total of nine subsectors were also examined. Following the format for the corrosion cost survey[7] conducted on the chemical industries in the Chugoku and Shikoku regions by the Chugoku and Shikoku branches of the Japan Society of Corrosion Engineering, we sent the questionnaires to 29 companies in these fields, and received responses from 21 of them.

5.3.2 Survey method

5.3.2.1 Definition of terms

1) Total maintenance cost: A constant repair cost and new investment cost added to the routine maintenance cost.

2) Ratio of corrosion cost to total maintenance cost: The proportion of corrosion costs to total maintenance cost. This includes costs for inspecting equipment and inspection of facilities, removing insulating materials, coating, scaffolding, etc.

3) Ratio of corrosion prevention costs to maintenance cost: The percentage of corrosion costs multiplied by the total maintenance cost.

4) Corrosion prevention costs except for maintenance costs: Costs for operating expenses such as cathodic protection, corrosion inhibitors, rust-prevention oils, etc., and new facility investments for corrosion prevention measures except for total maintenance cost.

5) Ratio of corrosion costs to new facility investment: Adding coating costs in the case that all new facility is made of ordinary steel to increment cost of corrosion resistant materials, corrosion allowance and coating costs.

6) Direct corrosion costs: Sum total of 3), 4) and 5).

7) Indirect corrosion costs: Losses due to reduced productivity, defects in finished and unfinished goods, loss effects to other departments, wages for repairmen (excluding corresponding cost to residents, reimbursements, etc.)

5.3.2.2. Survey

The survey period was FY 1997. The survey method, which referred to the previous survey[1], involved direct surveys and tabulations (Hoar method) of corrosion cost data of plant equipment users. Corrosion costs were calculated as the ratio of direct corrosion costs to sales for each industry derived from the survey tabulations and were set at the same rate nationwide. This ratio was multiplied by the shipping price of goods in Japan on an industry-by-industry basis.

5.3.3 Survey results

5.3.3.1 Tabulations of questionnaire surveys

1) Revenues from sales: The total sales of all surveyed companies amounted to 6.511 trillion yen, which was about 10% of the 66.7272 trillion yen of all goods in chemical industry sector in Japan as recorded in the MITI's Industrial Statistics Tables.

2) Investment in new equipment: Total investment in new equipment of the surveyed companies was 380 billion yen, or 5.8% of sales

3) Ratio of corrosion prevention costs to new equipment investment: Total corrosion prevention costs accounted for 38 billion yen, or 10%, of the new equipment investments, and 0.6% of the sales of the surveyed companies.

4) Maintenance cost: Total maintenance cost of the surveyed companies were 184.6 billion yen, or 2.8% of sales.

5) Ratio of corrosion prevention costs to maintenance costs: Total corrosion losses of the surveyed companies amounted to 57.8 billion yen, 31.3% of total maintenance costs. This figure also represents 0.9% of sales.

6) Corrosion prevention costs not excluding maintenance costs: Total corrosion prevention costs that are not related to maintenance costs (such as cathodic protection, corrosion inhibitor, rust-prevention oil, etc.) amounted to 3.5 billion yen, or about 6% of the 57.8 billion yen in corrosion losses that are included in the maintenance costs.

7) Direct corrosion costs: These costs were considered to be the sum of 3) + 5) + 6) obtained from the results of the present survey. They were derived on an industry-by-industry basis. Direct costs amounted to 99.1 billion yen, accounting for 56% of total maintenance costs, or 1.52% of sales.

8) National total shipment value in chemical industry and direct corrosion costs: The present survey found that the direct corrosion costs were 1.07 trillion yen, accounting for an estimated 1.6% of the value of chemical shipments.

5.3.3.2 Indirect corrosion costs

Questions were asked about individual examples regarding the ratio of direct corrosion costs (repair costs + corrosion prevention costs) to indirect costs (losses due to decreased productivity + losses due to defective finished and unfinished goods + losses from effects from other departments + wages spent for restoration (not installation)). Responses were received for 15 cases. There was a great discrepancy in ratios, which ranged from 0.01 to 100 times The average was 19 times.

5.3.3.3 Proportion of avoidable corrosion costs

Respondents were asked about what proportion of corrosion costs they could reduce by using currently available technology. Answers varied widely, from 0.2% to 80%, with an average of 25%.

5.3.3.4 Issues associated with corrosion control technology

Technical topics that will be of special interest in the future will include the training of specialists, technology transfer, creation of a database to respond to selection of materials and failures, preventive maintenance management systems (LCC, LCA, RCM, RBI, etc.), evaluating the remaining life estimetion, etc. Respondents also mentioned 29 technical topics that were not among the choices we gave. These included long-term continuous operation of plants, techniques for evaluating corrosion-induced deterioration of organic and inorganic materials and various types of metals, and estimation of remaining life estimation.

5.3.4 Results and discussion

5.3.4.1 Comparison of present and previous surveys

As we can see in Table 14, total sales of the chemical industry were 19.4 trillion yen in 1974, but were 66.7 trillion yen in 1997. Sales from the entire chemical industry in 1997 had grown 3.4-fold since the 1974 survey, but corrosion prevention costs for new and existing facilities during this 23-year period rose 4- and 10-fold, respectively. As a proportion of sales, corrosion prevention costs had risen 1.2 times for new facilities, and 2.9-fold for existing ones. However, since there were differences in survey methodologies between the two surveys, we could not make a precise comparison; nonetheless, we could conclude that corrosion prevention expenses for both new and existing facilities grew faster than sales.

While there are several possible reasons for this, the greatest factor may have been that wages accounted for more than half of repair work, and

Table 14. Comparison of corrosion costs in the chemical industry sector in 1974 and 1997 (billion yen).

	Total sales	Corrosion costs to new equipment	Ratio to sales (%)	Corrosion costs to existing equipment	Ratio to sales (%)	Total corrosion costs	Ratio to sales (%)
Survey in 1974	19400.0	95.0	0.49	59.3	0.31	154.3	0.80
Survey in 1997	66727.2	388.4	0.58	591.8	0.89	1070.8	1.60
1997/1974	3.4	4.0	1.2	10.0	2.9	6.9	2.0

Note: The total sales in 1974 is the sum of sales of "all chemical industries" (7.2 trillion yen) shown in the previous report and the sales of oil refineries (12.2 trillion yen) in 1974.

were twice as high in 1997 as they were in 1974. At the same time, plants have been deteriorating since 1974, presumably resulting in an increase in corrosion prevention costs.

5.3.4.2 Corrosion costs in chemical industrial subsectors

Fig. 8 shows the proportion of corrosion costs to new facilities investment and maintenance costs in various chemical industry subsectors.

Corrosion costs accounted for about 12% of new facility investment, but they consumed 31% of maintenance costs. Corrosion costs were particularly high in the soda industry and fertilizer/inorganic chemical subsector, and low in the oil refining and food industries.

Because the soda industry uses salt water and caustic soda in electrolysis vessels, we can expect corrosion costs to be high. This also true for the fertilizer industry, which handles inorganic acids such as phosphoric acid, and other inorganic industries that handle such substances as sulfuric and nitric acids.

In oil refining, corrosion prevention costs accounted for more than 30% of maintenance costs, but the 2% proportion of maintenance costs to sales was lower than in other industries, and corrosion costs were less than 1% of sales of oil refineries. The same kind of trend was found in the food industry. The following is a detailed report of corrosion costs in the oil refining and food industries.

5.3.4.3 Oil refining industry

National totals for corrosion costs in the oil refining industry increased from 2.4-fold from 1974 to 1997, going from 23.3 billion yen/year to 56.3 billion yen/year, respectively.

Insurance company indices[8)] for oil refinery equipment costs showed a 2-fold increase in the cost of equipment acquisition from 1974 to 1997, while wages increased 2- or even 3-fold. Therefore, we can conclude that the large increase in maintenance costs was strongly related to increases in these other costs.

On the other hand, the total volume of refined petroleum production was 250 billion litters in 1974, but in 1997 it was slightly less, at 230 billion litters. During the same time, the value of shipments declined significantly, falling from 12.2 trillion yen to 8.4 trillion yen. As a proportion of maintenance costs, corrosion costs accounted for about 35% (20.1% in oil tanks, 36.2% at refineries) in 1974, versus 32% in 1997.

In the above case of oil refining, the large increase in corrosion costs despite the decline in production over the 23-year period can be attributed in large part to increases in wages.

5.3.4.4 Food industry

Corrosion costs in the food processing industry can be characterized as follows:

1) The total value of shipments nationwide was a high 11.2 trillion yen, of which 17% was accounted for by the groups which we surveyed.
2) Corrosion costs for new equipment were quite high due to the need to maintain sanitary conditions in food production.
3) However, the proportion of maintenances to total sales was only 0.71%, the lowest of all groups we surveyed.
4) At the same time, the proportion of corrosion costs in maintenance costs was also the lowest, at 17.2%.
5) Therefore, the ratio of corrosion costs to sales was 0.13% if we don't include corrosion costs for new equipment, and 0.67% if they are included, making this by far the lowest group for these costs.
6) However, since the national total of shipped value was high, we cannot overlook the fact that the absolute value of corrosion losses was a rather high 75.1 billion yen.

Corrosivity of food and food processing is not always lower than in other industries. This is because many foods often contain salt or chlorides. They are also many instances of the use of organic acids, as well as the use of oxidizing chlorides as disinfectants. Moreover, the cycle of disinfecting often involves heating at high temperatures. Despite

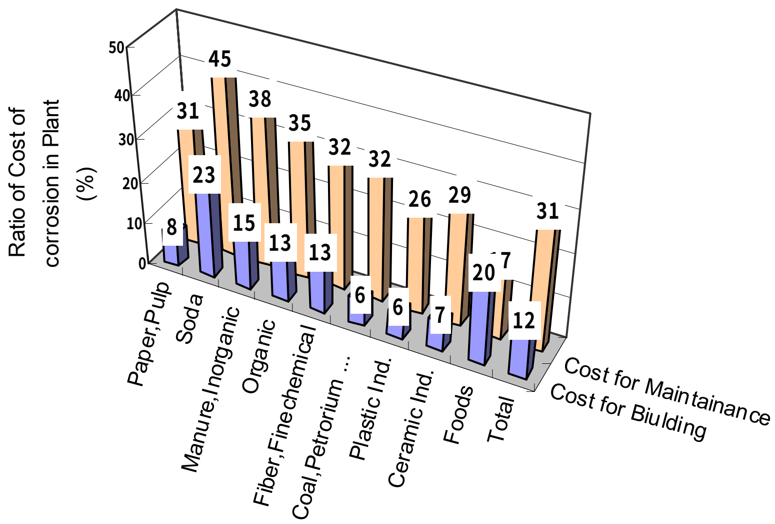

Fig. 8. The proportion (%) of corrosion costs in new facilities investment and maintenance costs.

all these factors, however, it appears that corrosion costs in the food industry are somewhat lower than in other industries for the following reasons:

1) The goods handled by plants are designed to go into people's mouths, so corrosion allowances are very strict. Moreover, highly corrosion-resistant stainless steel pots and pans are mainly used, usually in a relatively safe environment, so that there are a very small number of corrosion incidents.

2) Strict sanitary conditions are required during the production process, so plants are frequently cleaned, so crevice corrosion, etc., that is frequently found in other industries is prevented here.

5.3.4.5 Reducing corrosion

The percentage of corrosion reduction was based on subjective numbers given by respondents and was obtained without a quantitative reference. Therefore, there was a great discrepancy in figures, ranging from 0 to 80%. However, most of the responses ranged between 20 and 30%, with a weighted mean value of 22%.

5.3.5 Conclusions

We examined corrosion costs using 1997 data on the chemical industry (Research and Statistics Department, Minister's Secretariat of the MITI: "Preliminary Report on Industrial Statistics for 1996") and our own surveys of 21 companies in 9 sectors. As a result, of the 66.7 trillion yen in total sales in these industries (19.4 trillion yen in 1974), 1.4 trillion yen (150 billion yen in 1974) involved corrosion costs, and corrosion costs accounted for 1.56% of the value of shipped goods (0.8% in 1974). At the same time, corrosion losses for existing facilities, about 58 billion yen (12-15 billion yen in 1974), accounted for 31% (20-26% in 1974; 20.1% in oil refining and 25.8% for other chemicals) of the 180 billion yen in maintenance costs for existing facilities (which were 60 billion yen in 1974).

Industrial development in the surveyed fields expanded over the 23-year time frame, as did the scope of the survey, which led us to consider more factors such as increment of corrosion cost and cost reductions through technical advancements. However, at the present time we cannot characterize these factors.

Nonetheless, at the time of the previous report, there were several themes regarding corrosion cost reduction, and there was high demand for technological development. As a result, various technologies were developed in the ensuing 22 years. On the other hands, Japan makes a contribution to develop the world economy, and has given top priority to reducing labor and investment costs for maintenance of plant facilities to the minimum level. It has been difficult to apply the technology and information for cost reductions acquired during this time to specifically emphasize production and reduce operating costs. Given these conditions, we make the following proposals to reduce corrosion costs based on the present corrosion cost surveys in the chemical industry through discussions by the subcommittee members.

(1) Technical aspects

In order to develop elemental technologies for corrosion cost reductions, it will be necessary to formulate a Technology Road Map for each of the 9 sectors of the chemical industry.

(2) Framework aspects in the social system

- The establishment of a community for corrosion prevention specialists from various academic societies to come together and exchange information (NACE-type organization, and the convening of an autumn symposium of the Japan Society of Corrosion Engineering)
- Proposal of standards and common rules (creating a database of information on corrosion prevention technology)
- Establishing a certification system for qualifications (as a unified base).

5.4 Corrosion costs in the metals industry sector

The metals sector was divided into smelters of steels (including stainless and special steels), aluminum, and titanium; manufacturers of semiconductors (including wafers) made of single and poly-crystals of silicon, and various types of surface finishing and plating. Questionnaires were given to many typical production plants based on the previous survey, and these were confirmed with on site interviews, etc. The base year for the present survey was calendar year 1997. Corrosion costs in each sector were calculated by totaling the costs in each manufacturer's survey, totaling either the production volume or production capacity at each plant, and totaling the domestic production capacity or production volume. In the present surveys, zinc and copper refiners, which were included in the previous survey, were excluded here, while silicon crystal production, which has grown dramatically, was included in the present corrosion cost survey, as were plating companies, which are usually small. Furthermore, since the 1974 survey, these raw materials companies have seen major changes in production and business conditions, so the present survey also included production transitions from 1974 to recent times.

The following items were included in questionnaires on corrosion costs:

1) Survey year and production volume or capacity during that year (production volume and facility capacity did not have to be listed if there was some sort of obstacle to production.

2) The initial corrosion costs during construction of a new facility were divided by the number of years of usable life to give the annual corrosion cost.

3) Facility maintenance costs in the survey year

These costs were divided into coating, lining, metal covering, cathodic protection, corrosion inhibitors, and corrosion-resistant materials, and tabulated.

4) Cost of replacing parts

The sum total of corrosion costs (2) + 3) + 4)) for surveyed sites multiplied by GDP or facility capacity was divided by the annual production of surveyed plants or the sum of facility capacity to derive corrosion costs for each subsector.

Table 15 Details of corrosion costs of the surveyed steel mills

Surveyed items	Corrosion costs (billion yen)			
	Equipment	Equipment maintenance	Parts replaced	Total
Steel mill A	0.37	0.32	0.49	1.18
Steel mill B	0.20	0.57	0.52	1.29
Total	0.57	0.89	1.01	2.47

5.4.1 Steel subsector

Total steel facility capacity, which includes domestic production of raw steel, and the capacity of converters and electric furnaces since the 1974 survey, has been declining since reaching its peak in the latter half of the 1970s. According to Preliminary Report on Iron and Steel products Statistics, the steel facility capacity in the 1997 survey year was 149,775,000 tons, while 104,545,000 tons of raw steel were produced.

The sum total of production capacity of two steel mills that were given the written survey was estimated to be 21,500,000 tons, accounting for 14.35% of the national total, and the sum of the corrosion costs was 2.47 billion yen. The survey items, which included corrosion prevention costs for iron and steel equipment, maintenance costs for same, and cost of replacing parts, which were all part of corrosion costs, are shown in Table 15.

Table 16 Details and items of corrosion costs of the surveyed aluminum alloy mills

Surveyed items	Corrosion costs (million yen)			
	Equipment	Equipment maintenance	Parts replaced	Total
Alloy mill A	-	4.91	0	4.91
Alloy mill B	-	20.1	194.2	214.3
Alloy mill C	-	7.0	41.2	48.2
Total	-	32.01	235.4	267.4

Table 17 Corrosion costs of the surveyed aluminum recycling mills

Surveyed items	Corrosion costs (million yen)			
	Equip-ment	Equipment maintenance	Parts replaced	Total
Recycling mill A	-	4.0	3.0	7.0
Recycling mill B	-	10.8	-	10.8
Recycling mill C	-			0
Total	-	14.8	3.0	17.8

The results of the above survey were used to convert the corrosion costs of the surveyed sites into a national total, which was 17.26 billion yen/year. In contrast, the average price of steels, including stainless and special steels, was 67,000 yen/ton, and domestic sales of steel materials that were derived from raw steel production, were roughly estimated to be 7.45 trillion yen. Therefore, the proportion of corrosion costs to total steel sales was 0.246%. In the previous survey, steels were divided into smelted steel and stainless/special steels, with corrosion costs of 20.4 billion yen and 1.81 billion yen/year, respectively, accounting for 0.26% and 0.27% of sales figures, respectively. In the 22 years from the previous survey until the present one, total corrosion costs were reduced 25% but there was no large difference in the proportion of these costs to total sales, which declined slightly.

While the production of steel products had been in decline for the past 22 years, the production of corrosion-resistant plated steels (tinplate, tin-free steel, zinc-plated sheets, other plated sheets) and stainless steels were both double the 1974 figures, indicating that the supply of corrosion-resistant materials was growing for other industries in the steel sector.

5.4.2 Aluminum subsector

Regarding the aluminum sector, we sent written surveys to plants that were engaged in the production of either 1) smelted aluminum, 2) aluminum alloys, or 3) recycled aluminum ingots. The production structure of the aluminum sector was considerably different from what it had been in the previous survey. Therefore, in order to understand these changes, we investigated the transition using statistics on new domestic metal production, domestic production of recycled metal, and demand for domestic aluminum products that we obtained from the Japan Aluminum Association.

(i) Smelting mills

Aluminum smelting in Japan peaked at about 1 million tons in the 1970s, but all companies started falling on hard times in the 1980s, and by 1999 production had fallen to a mere 10,000 tons. Presently the only smelting mill in Japan is the Kambara plant of Nippon Light Metal Co., Ltd. A written survey was sent to the plant, but we were told that the corrosion prevention costs were not used for facility maintenance.

(ii) Alloy mills

Three alloy mills were asked the same questions about smelting, casting, hot rolling、cold rolling, heat treatment, incidental equipment, etc. The total cold rolling capacity of the surveyed mills was 916,000 tons, with 1997 production of 805,000 tons (this includes 1999 figures from one plant).

Table 16 shows the results of the surveys. At all mills, corrosion costs were not classified as key components of maintenance costs, so the calculations are probably not very accurate. In addition, corrosion prevention costs at the time of new construction had some problems because there were many facilities and they took several years to build, so we were able only to get a rough estimate.

We also made a rough estimate of corrosion costs in the field of aluminum rolling. In 1997, domestic production of rolled aluminum products amounted to 2,545,000 tons. Since production at the surveyed mills was 805,000 tons and corrosion costs were 260 million yen, we estimated the corrosion costs of the entire rolling subsector to be 840 million yen/year. Pro-rating this figure to the 1997 rolled aluminum production of 3,956,000 tons gives us 1.31 billion/year industry-wide in corrosion costs.

(iii) Recycling mills

Three mills that produce recycled aluminum ingots were surveyed. Each of these mills was asked about smelting, casting, incidental equipment, and miscellaneous items. These items were further divided into equipment operating costs, equipment maintenance costs, and costs for replacing parts. The survey results are shown in Table 17. At all three mills, corrosion costs were not classified as key components of maintenance costs, so, as with the alloy mills (mainly rolling), the calculations are probably not very accurate.

In 1997, domestic production of recycled aluminum metal was 958,000 tons. Since production at the three surveyed mills was 89,000 tons and corrosion costs there were 17.8 million yen, the corrosion costs for the entire recycled aluminum ingot industry were pro-rated to be 190 million yen.

In the present survey, the total corrosion costs in the aluminum sector were calculated to be 1.5 billion yen/year. In the previous survey, they were

Table 18. Corrosion costs of surveyed facilities for producing titanium.

	Corrosion costs for surveyed facilities (million yen)				Corrosion costs (million yen)
	Equipment	Equipment maintenance	Parts replaced	Total	
A				248.0	677.04
B			3.85	3.85	15.21
C		0.39		0.39	1.61
D	0.36		0.58	0.94	2.12
E	0.08	0.05	0.03	0.16	0.70

A: Producing and smelting sponge titanium (36.6%); B: Forging (25.3%); C: Hot rolling (24.0%); D: Cold rolling (44.4%); E: Producing welded pipes (22.5%). Figures in parentheses show the domestic shares of the surveyed facilities.

reported as being 1.79 billion yen/year, but as was previously mentioned, the industrial structure during the ensuing years had undergone dramatic changes, so we could not make any comparisons.

5.4.3 Titanium subsector

For the titanium subsector, we surveyed all processes, from upstream processes such as the production and smelting of sponge titanium, to subsequent downstream processes such as forging, hot rolling, cold rolling, and the equipment for producing welded pipes. Seamless pipes were not included in the survey.

According to the Japan Titanium Society, domestic output of sponge titanium in 1997 was about 24,500 tons, and output of extensible materials was about 13,300 tons. About half of sponge titanium was exported. Table 18 shows the survey results and the domestic share of the surveyed mills.

The previous survey looked only at facilities that were involved in the production and smelting (upstream processes) of sponge titanium, and considered downstream processes to be shared facilities with other subsectors, so these processes were excluded. The present survey raised accuracy levels by also surveying forging, hot rolling, cold rolling, and the equipment for producing welded pipes. However, we determined that as a result, the corrosion costs for the downstream processes were much smaller than those for the upstream processes.

Table 19. Corrosion costs of the surveyed facilities for producing silicon

Surveyed items	Corrosion costs (million yen)			
	Equipment	Equipment maintenance	Parts replaced	Total
Poly crystal silicon	540	20	90	660
Single crystal silicon	530	10	6	550

The volume of titanium production (with shipments of extensible materials as a base) in the

Table 20. Corrosion costs of plating equipment.

Type of plating	Corrosion costs of surveyed equipment(thousand yen)				Domestic corrosion costs	
	Equipment	Equipment maintenance	Parts replaced	Total	Number of companies	Gross total (billion yen)
Pre-treatment	100	1,000		1,100	2,482	2.73
Zinc plating	53	1,350	1,086	2,489	1,086	2.70
Copper plating	400	1,200		1,600	871	1.39
Nickel plating	50	100		150	1,518	0.22
Chromium plating	50	100		150	1,052	0.15
Hard chromium	25			25	344	0.09
Solder	No measures	1,000		1,000	186	0.18
Non-electrolytic nickel	1,000			1,000	297	0.29
Precious metal	No measures	500		500	1,169	0.54
Post-treatment	No measures	100		100	2,482	0.24
Electrolytic coating	1,000	500		1,500	89	0.13
Liquid waste treatment		4,000	12,000	16,000	11	0.17
Boiler			1,500	1,500	500*	0.75
Building				3,098	2,482	7.69

*Estimated　　Gross total / 6.5 = 26.2

Table 21. Total corrosion costs in the metals sector.

Type of metal subsector	Corrosion costs (billion yen/year)		Ratio of corrosion costs to sales (%)	
	1997	1974	1997	1974
Steel Stainless	* 17.26	20.40 1.81	0.246	0.26 0.27
Aluminum refining Aluminum processing	** 0.19 0.84	1.79		0.34
Copper		1.80		0.56
Zinc		0.30		
Titanium	0.69	0.40	2.10	1.28
Polycrystal silicon	2.23		10.48	
Single-crystal silicon	3.76		0.506	
Plating	2.62		0.340	
Total	27.59	26.50		

* Includes stainless steels and special steels.　** Recycled ingot

1997 survey was about 5 times higher than in the 1974 survey. During the same period, corrosion costs increased about 1.8-fold, going from about 400 million yen/year to 690 million yen/year. The average selling price of the product was 2.5 million yen/tons total sales of titanium were calculated as 33.25 billion yen. Corrosion costs in titanium production amounted to 2.1% of sales, a large increase over the 1.28% of the previous survey.

5.4.4 Silicon subsector

At the time of the previous survey, semiconductor materials such as silicon wafers were only produced in very small quantities, so their corrosion costs were not examined. However, there has been explosive growth in single- and polycrystalline silicon since then. In the 1997 survey period, 5.378 tons of poly-crystal, and 4,248 tons of single crystal of silicon were produced (from the Silicon Statistics of the Japan Society of Newer Metals). These figures are 20 times and 50 times higher than the respective 1974 figures. Against this backdrop, we decided to survey corrosion costs for production equipment for high purity poly- and single-crystal silicon (including wafers) that is being made for the electronics industry. Here, corrosion costs were calculated in the same way as for other metals subsectors, and questionnaires were divided into corrosion prevention costs for equipment operating costs, equipment maintenance costs, and costs of replacing parts. Table 19 shows the results.

The total capacity of surveyed multi-crystal production plants was 1,600 tons, only slightly higher than their actual 1997 production of 1,594 tons. Total production at the surveyed sites was about 29.64% of the national total, so using this ratio the corrosion costs were calculated to be 2.23 billion yen/year. Furthermore, setting the selling price of poly-crystal silicon at 4,000 yen/kg, we found that corrosion costs amounted to 10.48% of the 21.51 billion yen in sales. Due to the demand for high-purity products and use of corrosive materials, the production equipment for poly-crystal silicon requires a higher outlay for corrosion measures than do other subsectors.

Because there are great fluctuations in the production capacity for single-crystal silicon, corrosion costs were calculated using production volume. The total 1997 production of 630 tons at the surveyed plants accounted for 14.83% of total production in Japan. Thus using this ratio, total corrosion costs in this subsector were calculated to be 3.76 billion yen/year.

Sales of silicon wafers were estimated as follows by considering the import/export ratio: The wafer market in 1997 was reported to be 784.1 billion yen. Imports met an estimated 23% of domestic demand (according to statistics of the Japan Society of Newer Metals, with 19% in 1995 and 21% in 1996). In contrast, 37% of the single-crystal silicon products made in Japan in 1997 were exported, bringing in a reported US$ 1,154,420,000. Subtracting imports from the wafer market and assuming 120 yen per US dollar, total domestic sales were estimated to be 742.3 billion yen, with corrosion costs associated with single-crystal silicon production estimated to be 0.506% of that.

The above corrosion costs for silicon-related production equipment were mostly spent during initial facility construction, as shown in Table 25.

5.4.5 Plating industry subsector

Not counting large-scale plating facilities such as at steel mills, there were 2,484 plating companies in Japan in 1997 (National Plating Company Overview), all of which were small- or medium-scale. Total 1997 sales of these companies was reported to be 770.7 billion yen, with a per-company average of 310 million yen.

Because corrosion prevention measures for plating equipment differed depending on the type of plating, and there were many companies and large differences in production scale, it was difficult to calculate corrosion costs with any degree of accuracy. In the present survey, we looked at national statistics on the number of plating companies engaged in either treatment or processing and conducted personal interviews with relevant people from typical companies to derive corrosion costs. The production scale of surveyed companies was relatively large, with average sales in 1997 of 2 billion yen, about 6 times higher than the national average.

Table 20 shows the corrosion costs by type of operation based on our survey results and national statistics. The gross total of corrosion costs for all operations was 17.05 billion yen/year. Adjusting this to the 6.5-fold scale of the surveyed companies, we got a figure of 2.62 billion yen/year, accounting for 0.34% of total sales.

5.4.6 Conclusions about the metals industry sector

Corrosion costs associated with the metals sector surveyed in 1997, which included equipment used in the smelting, production, and processing of metals, production of single crystal and poly-crystal silicon, and the plating industry, are shown in Table 21. Statistics from 1974 are included for comparison. Total corrosion costs in this sector were roughly 27.6 billion yen/year, or 25 billion yen/year if the plating industry is excluded. The present survey also excluded zinc and copper. Comparing with the previous survey, we found that corrosion costs vis-a-vis sales for the relatively low-cost subsectors of steel and aluminum went down, but in relatively high-cost subsectors like silicon and titanium, they went up.

5.5 Corrosion costs in the machinery industry sector

5.5.1 Survey methods

Corrosion cost surveys in the machinery sector were conducted using questionnaires and interviews. Items regarding production for each surveyed company were based on the Machinery Statistics Yearbook of the Ministry of International Trade and Industry, and respondents gave answers on the proportions (%) of corrosion costs to the annual sales of each item. It should be noted that "corrosion costs" were divided into corrosion prevention costs (for corrosion prevention coating, surface processing by plating, etc., and/or cost of cathodic protection equipment) and the cost of corrosion-resistant materials (costs of replacing regular steels with stainless steels, copper alloys,

Table 22. Tabulated results of the corrosion cost survey.

	Production in 1997 (million yen)	Survey results		Committee's estimate	
		Corrosion prevention cost (%)	Cost of corrosion-resistant material (%)	Corrosion cost (%)	Corrosion cost (million yen)
01 Boilers and motors	1,490,077	1.0	0	1.0	14,901
02 Civil engineering and construction machinery, mining machinery, tractors and crushers, separators	1,542,228	1.0	0	1.0	15,422
03 Chemical machinery and storage tanks	399,970	0.5	0.1	0.6	2,400
04 Pulp and paper making machinery, plastic processing machinery	358,864			1.5	5,383
05 Machinery for printing, plate making, book-binding, paper processing	381,404			1.0	3,814
06 Pumps, compressors, fans and blowers	478,892			2.0	9,578
07 Oil hydraulic and pneumatic equipment	537,164			2.0	10,743
08 Materials handling machinery and industrial robots	1,183,834	1.0	1.0	2.0	23,677
09 Power transmission devices	386,077			1.5	5,791
10 Agricultural machinery	376,777			3.0	11,303
11 Machine tools for metals	1,017,129			1.5	15,257
12 Metal cutting machinery and casting equipment	389,113			1.0	3,891
13 Fiber machinery	281,668	2.0	1.0	3.0	8,450
14 Food product machinery, rapping and packing machinery	276,826	2.0	1.0	3.0	8,305
15 Woodworking machinery	82,901			1.0	829
16 Office machinery	919,196	10.0	2.0	12.0	110,303
17 Sewing machines, yarn hand-weaving machinery	139,816	5.0	0.5	5.5	7,690
18 Refrigerating machines and appliances	2,461,721	4.0	1.0	5.0	123,086
19 Vending machinery, automatic service machinery, washing machines for business use	274,875			5.0	13,743
20 Bearings	625,669	0.1	0.004	0.1	626
21 Steel construction and transmission line hardware	1,165,431	3.0 5.0	0	5.0	58,272
22 Springs	301,469			0.1	301
23 Molds	472,799	0	0	0.1	473
24 Tools for machines	418,326			0.2	837
25 Valves and pipe fittings	654,608			1.0	6,546

Table 22. Tabulated results of the corrosion cost survey (continued).

	Production in 1997 (million yen)	Survey results		Committee's estimate	
		Corrosion prevention cost (%)	Cost of corrosion-resistant material (%)	Corrosion cost (%)	Corrosion cost (million yen)
26 Pneumatic tools, machinist hand tools, Tools for machines for automobiles, saw blade, knives for machines, files	205,991			2.0	4,120
27 Equipment using gas, oil, or solar power	658,925	1.1	1.9	3.0	19,768
28 Electrical rotating machines	1,138,773	0.2 1.23	0.02 0.03	1.26	14,349
29 Electrical stationary machines	768,754	1.3 5.0	0 2.0	4.15	31,903
30 Switching and controlling equipment	1,739,661	3.0 5.0	0.5 2.0	5.3	92,202
31 Household appliances and equipment	1,580,502	2.0	1.0	3.0	47,415
32 Lamps, wiring devices and illumination equipment	1,117,956			1.0	11,180
33 Communication machines and equipment and wireless devices	4,312,027	0.5 2.0	0.2 2.0	3.0	129,361
34 Household electronic goods	2,241,572	5.0	5.0	10.0	224,157
35 Parts and accessories for communication and electronic devices	3,452,386	5.0 1.0	3.0 1.0	5.0	172,619
36 Electronic tubes, semiconductor devices and IC	6,388,094	1.0 3.0 0.5	1.0 1.0 0.18	2.3	146,926
37 Electronic devices	7,372,133	0.5 2.0	0.2 1.0	2.5	184,303
38 Electrical measuring instruments	796,486			1.5	11,947
39 Batteries	800,032			0.5	4,000
46 Measuring instruments	503,356			1.0	5,033
47 Optical instruments and apparatus	326,754			0.5	1,634
48 Watches and clocks	224,848			2.0	4,497
49 Weapons	459,320			1.0	4,593
50 Hunting rifles	6,954			1.0	70
Total	50,711,38			(3.08)	1,561,598

non-metallic materials, etc.). The questionnaire was given to 86 companies, especially to members of the Japan Machinery Federation, 11 of whom provided responses. Eighteen companies were also given additional surveys via e-mail or through on-site interviews.

As with the previous survey[1)], the objects of the present survey included a wide range of goods, including everything from industrial machinery to household appliances and electronic parts. In addition, it was very difficult to get an accurate estimation of corrosion costs for each type of good, so the answers might not cover all fields as thoroughly as they could have. Therefore, for products for which no response was given, we gave priority to those with the highest production value. Then, based on these results and on interviews with corrosion experts, we estimated values in our capacity as the Committee on Cost of Corrosion in Japan.

5.5.2 Tabulated results

Table 22 shows the tabulated results. Please note that the production value for each item is the 1997 figure taken from the Machinery Statistics Yearbook of the Ministry of International Trade and Industry.

Total corrosion costs increased significantly, from 433,120 million yen in the previous survey[1)] to 1,551,121 million yen. Production value also increased significantly, going from 17,104,000 million yen to 50,711,000 million yen during the same time period. Corrosion costs rose higher than production value, going from 2.5% to 3.06% of total production. However, the previous survey only looked at corrosion prevention costs and did not consider the cost of corrosion resistant materials, so it can be concluded that the actual proportion of corrosion costs did not change so much.

A comparison of general machinery products No. 01 through No. 27 shows that, with the exception of a very few items with very low production value, production value was either stagnant, or grew by up to 3-fold. Items with total production of more than 1 trillion yen all saw growth in production value of more than 2-fold, and there were three that saw more than 3-fold growth: No. 02 (civil engineering and construction machinery, mining machines, tractors and pulverizers, classifiers and selectors, 3.61-fold), No. 08 (transportation machinery and industrial robots, 3.23-fold), and No. 18 (refrigeration machinery and associated products, 3.42-fold). At the same time, the corrosion cost ratio tended to remain stable or even decline slightly.

Regarding products No. 28 through No. 38 (electric and electronic machinery), a comparison with the previous survey shows that there was exceptional growth in the production value of items related to electronic machinery, instruments and parts. Production value of No. 30 (switching devices) and No. 34 (electronic machinery and instruments for personal use), which were not independent in the previous survey, was 1.74 trillion yen and 2.24 trillion yen, respectively, and corrosion cost ratios were estimated to be 5.3% and 10.0%, accounting for much of the overall rise in corrosion cost ratios in the machinery sector.

Noticeably large production growth was also found in No. 33 (communications machinery and radio equipment), No. 35 (parts and accessories for communications and electronic equipment), No. 36 (electronic discharge tubes, semiconductor components and integrated circuitry) and No. 37 (electronic devices), whose values were 4.31 trillion yen, 3.45 trillion yen, 6.39 trillion yen, and 7.37 trillion yen, respectively. Compared with the previous survey, growth in these production values was 6.9-fold, 4.61-fold, 11.4-fold and 9.95-fold, respectively. Corrosion cost ratios of these items were (1997/1974 ratios) 3.0%/2.82%, 5.0%/1.0%, 2.3%/0.59%, and 2.5%/1.7%, respectively. These items were also one of the reason why the overall corrosion cost ratio increased in the machinery sector.

However, in the subsectors of electronic machinery, instruments, and parts, rational corrosion preventions are being advanced, much of the corrosion problem has been solved and cases of corrosion are declining. Therefore, rather than being considered actual increases in corrosion costs themselves, these tabulations should be considered as originating in changes (improvements) in the awareness of corrosion and corrosion cost specialists.

Looking at the comments of respondents regarding, for example, gold plating of electronic equipment connectors, we can find frequent cases in which the underlying idea is that because "connection points are protected from metal oxidation and electrical connectivity is maintained, these are considered to be corrosion costs." Such awareness of corrosion and corrosion costs apparently had not satisfactorily permeated the thinking of specialists in the previous survey, so our impression is that most of the increase in the present survey reflects this type of situation. Further, with this sort of thinking, if we can conduct a more accurate survey of costs then tabulated values for corrosion cost ratios in the next survey should show even higher values.

5.5.3 Future topics

As was touched upon in the previous survey report[1)], surveys that primarily use questionnaires tend to be plagued by major discrepancies in respondents' awareness of corrosion and corrosion costs, and there are limitations, and many problems remain for future investigation. We believe that the possibility of using survey methods that do not include questionnaires must be investigated in the future.

5.5.4 Concluding remarks

Questionnaires were given out to survey corrosion costs in the machinery sector. Below is a brief overview of our findings.

(1) The total amount of corrosion costs increased dramatically, from 433,120 million yen in 1974 to 1,561,598 million yen in 1997, as did production value, which significantly rose from 17,104,000 million yen to 50,711,000 million yen during the same period. This was accompanied by a rise in the ratio of corrosion costs to total production value from 2.5% to 3.08%.

(2) In the general machinery subsector, production value was either stagnant, or increased up to at most 3-fold. However, corrosion cost ratios stayed at the same level or declined slightly.

(3) In the subsector of electric and electronic machinery, there was noticeable growth in the production value of electronic machinery, instruments, and parts, and corrosion cost ratios also increased, making this one of the factors responsible for pushing up the corrosion cost ratio in the sector as a whole. Therefore, more than being considered actual increases in corrosion costs themselves, these tabulations should be considered as originating in changes (improvements) in specialists' awareness of corrosion and corrosion costs.

(4) Surveys that primarily use questionnaires tend to be plagued by major discrepancies in respondents' awareness of corrosion and corrosion costs, and there are limitations, and many problems remain for future investigation.

5.6 Corrosion cost in the construction industry sector

The previous corrosion cost survey of the construction industry divided it into three sectors, i.e., buildings, bridges, and ports and harbors.

The present survey looked at 5 sectors, i.e., general buildings, housing, roads and bridges, river structures, and ports and harbors.

5.6.1 General building and housing

Corrosion costs for general building and housing have been calculated by adding the 30 years' relevant annual costs by assuming the life of a house is 30 years when it is built. In this survey, however, the cost of a relevant year was calculated based on Fig. 9.

5.6.1.1 Methods to calculate corrosion costs in the construction sector

Calculation methods using data which have been published continuously as long as possible, were chosen since traceability is considered important.

(1) Assorted Construction Cost Matrix

The Assorted Construction Cost Matrix, $ACCM_{i,k}$ is defined as follows:

$ACCM_{i,k}$, where i = 1 to 9, and k = 1 to 3

i: 1. housing only (except wooden houses), 2. both housing and industrial use, 3. agriculture, forestry and fisheries, 4. mining and manufacturing, 5. public buildings, 6. commercial, 7. hospitality, 8. public service and education, 9. others

k: 1. year 1996, 2. year 1997, 3. year 1998

Data is from "Construction Statistical Yearbook" edited by Research and Information Division, Economic Affairs Bureau, Ministry of Construction, published by Construction Research Institute (Table 1: Summary Chart, Table 3: Estimated Construction Cost of Total Floor Space by Usage, Table 4: Estimated Construction Cost of Total Floor Space by Structure).

(2) Assorted Cost Breakdown Matrix

The Assorted Cost Breakdown Matrix, $ACBM_{i,j}$ is defined as follows:

$ACMB_{i,j}$, where i = 1 to 9, and j = 1 to 121

Corresponding use of i for ACCM and ACBM are defined as follows:

Use	Purpose	Structure
1. housing only	apartments and mansions	RC
2. both housing and industrial use	multi-purpose buildings	RC
3. public buildings	offices and government buildings	RC
4. public service and education	offices and government buildings	SRC
5. Commercial	shops and department stores	S
6. Hospitality	hotels and inns	SRC
7. Agriculture, forestry and fisheries	storehouses	S
8. Mining and manufacturing	factories	S
9. Others	offices and government buildings	RC

(S: steel frame, RC: reinforced concrete, SRC: steel framed reinforced concrete)

Construction item breakdown j is as follows:

1) Construction work (j = 1 to 22)

Breakdown of construction works is as follows.

1. temporary, 2. earthwork, 3. foundation work, 4. concrete, 5. molding, 6. reinforced concrete, 7. steel frame, 8. precast concrete, 9. waterproofing, 10. stone, 11. tile, 12. carpentry, 13. metal, 14. plastering, 15. wooden fittings, 16. metal fittings, 17. glass, 18. painting, 19. interior and exterior finish, 20. miscellaneous, 21. curtains and walls, 22. others.

2) Installing work (j = 23 to 121)

Installing work is broken down into electricity, sanitation, air condition, 118. elevators, 119. machines, 120. others, 121. exterior equipment.

(a) Electric work (j = 23 to 57)

Breakdown of electric works is as follows:

power receiving facilities, private power generation plants, electric condenser facilities, boards, light electric instruments, disaster prevention instruments, lighting, wiring and piping materials, wiring accessories, concrete materials, painting labor expenses, transportation expenses, miscellaneous expenses at the work site, others

(b) Sanitation work (j = 58 to 83)

Breakdown of sanitation works is as follows:

tanks, cannery, pumps, boilers, sanitary tools, fire extinguishing equipment, special fire extinguishing equipment, steel tubes, cast iron tubes, copper tubes, vinyl tube valves, meters, metallic materials, heat insulation, painting, gas fitting work, labor expenses, transportation expenses, miscellaneous expenses at the work site, others

(c) Air conditioning work (j = 84 to 117)

Breakdown of air conditioning works is as follows:

boilers, freezers, cooling tower, air conditioners, units, pumps, fans, cannery, ducts, piping materials, auto-controlling, ventilating openings, valves, meters, metallic materials, concrete, heat insulation, painting, labor expenses, transportation expenses, miscellaneous expenses at the work site, others

Data for cost breakdown is from "Construction Work Cost Analysis Information," edited by the Japan Association of General Contractors, published by Taisei Shuppan.

(3) Corrosion Cost Ratio Matrix

Corrosion Cost Ratio Matrix, $CCRM_j$, is defined as follows:

The ratio of the breakdown cost to be used for calculating corrosion costs is assumed as follows:

In terms of corrosion cost ratio, $CCRM_j$

In the breakdown cost j, the ratio is assumed to be the proportion of the difference between the price of the product with no corrosion resistance, and that of the product with some corrosion resistance the users actually choose, to the total construction cost. That is assumed to be 25% when the price of the product with corrosion resistance is twice as much if the product price is 50% of the total construction cost. In the case of coating work, it is the ratio between coating for rust prevention and that for design. In general, it is assumed that the users should pay an additional 5% for rust prevention from air corrosion, and 10% for that from water corrosion.

In the present survey, $CCRM_j$ is set equally regardless of the type of building. In the future, however, further research may allow it to be set differently depending upon building use

(4) Calculation of corrosion costs

Corrosion costs of year k (CC_k) are calculated using the following equitation:

$$CC_k = \Sigma(i = 1 \text{ to } 9)\ ACC_{i,k} \times \Sigma(j = 1 \text{ to } 121)\ ACBM_{i,j} \times CCRM_{i,j}$$

(5) Results and summary

Based on the above, Table 23 shows the figures for "Corrosion costs of buildings in Japan except wooden houses".

Overall, it was estimated that users have been paying 5% of the total construction expenses for corrosion prevention in Japan.

5.6.1.2 Methods to calculate corrosion costs in housing

Corrosion costs of houses (for individual and apartment houses, including modifications to condominiums, but not construction of new condominiums, which is included in general building section) was estimated based on the following two costs:

- Expenses calculated based on the relevant construction items of the year's new construction of houses

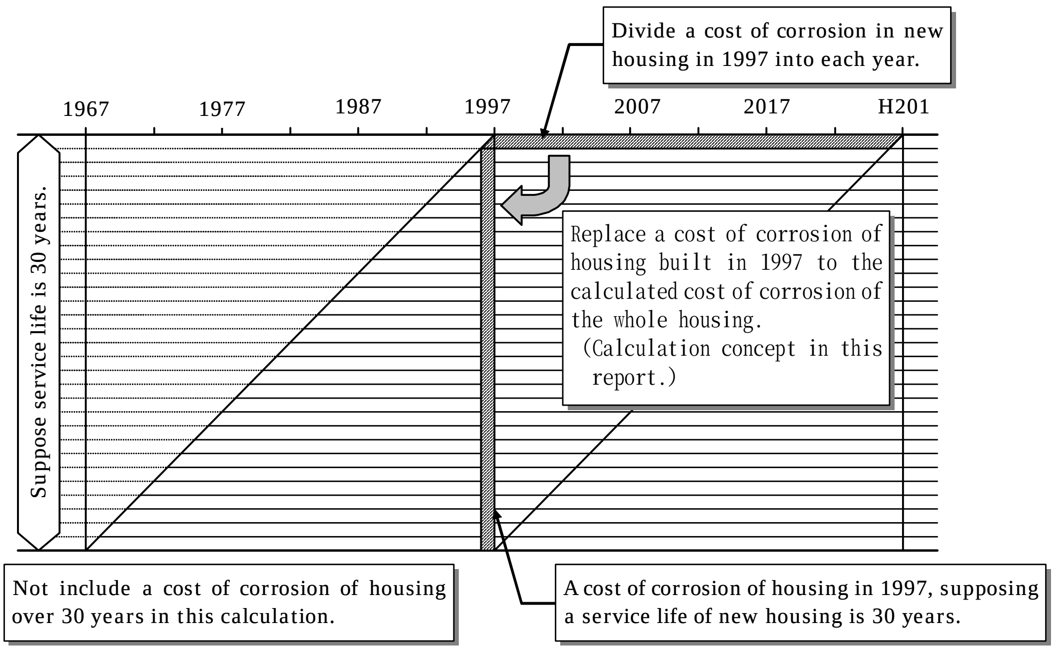

Fig. 9. Concept of estimating the annual corrosion costs for houses and general buildings

The actual content is described in Table 24. Metal parts of bathroom or kitchen equipment for daily use, steel frames (not included for corrosion) and piles (not used in standard cases) of concrete were not included.

- Expenses calculated based on the relevant construction items of the year's modifications of houses

The relevant number of houses was calculated according to the kinds of periodical reforms from the number of all houses (so called stock number of houses). Then from such expenses, the corrosion cost was calculated.

In this calculation, the life of both wooden and of steel frame houses is considered to be 30 years, and that of concrete houses to be 45 years. For corrosion cost calculations, we referred to the Report of Extension, Reform and Renovation of Houses by the Ministry of Construction and modification materials by Council of Condominium (iron coating was added to the estimates). As a result, the average corrosion cost for FY 1996, 1997, and 1998 was 207 billion yen.

Corrosion cost in each fiscal year were as follows:

Corrosion costs were approximately 226.7 billion yen in FY 1996, approximately 202 billion yen in FY 1997, and approximately 192.2 billion yen in FY 1998. The average of the 3 years, 207 billion yen, is equivalent to 6.2% of the monetary transactions of the construction industry related to housing in the industrial Input/Output analysis.

Table 23. Corrosion costs of buildings in Japan (excluding wooden houses).

(billion yen)	1996		1997		1998	
Type	Construction cost	Corrosion cost	Construction cost	Corrosion cost	Construction cost	Corrosion cost
Public service and education	4313.5	228.7	4107.6	217.7	3436.3	182.2
Hospitality	3550.9	173.2	3231.8	157.6	3197.6	155.9
Housing only	10486.9	390.4	9017.4	335.7	7560.3	281.5
Both housing and industrial use	2322.7	104.1	2122.3	95.1	1764.7	79.1
Public buildings	1071.1	48.9	1013.6	46.3	911.3	41.6
Commercial	3069.0	150.8	3099.9	152.3	2515.5	123.6
Agriculture, forestry, fisheries	327.8	15.4	290.4	13.6	295.8	13.9
Mining and manufacturing	2294.2	130.8	2413.3	137.6	1683.8	96.0
Others	103.2	4.7	99.6	4.5	55.9	2.6
Total	27539.3	1247.0	25395.9	1160.6	21421.2	976.3

Table 24. Basic concept used in calculating corrosion loss costs (in housing).

Parts for calculation	Time for calculation		Expense items in new construction	Expense items in modification	Notes
	When construct	When modify			
Structural frame	○		Materials and labor in surface treatment; steel for corrosion margin		Steel is mainly used.
Roof	○	○	Materials and labor in surface treatment	Materials and labor in surface treatment	Proportion of metal roofs must be checked.
Eaves	○	○	Materials and labor in surface treatment	Materials and labor in surface treatment	Proportion of metal materials must be checked.
Exterior walls	○	○	Materials and labor in surface treatment	Materials and labor in surface treatment	Proportion of metal walls must be checked.
Metal shutters	○		Price differences in steel and aluminum; materials and labor in surface treatment		Mainly aluminum is used. Glass is not included.
Pipes	○		Materials and labor in surface treatment; steel for corrosion margin; Price differences in steel and resin		Includes only main pipes.

5.6.2 Calculation of road-related corrosion costs

According to the previous survey of corrosion loss, corrosion costs in construction related to bridges were 34.71 billion yen including the cost of painting/coating guardrails, which was 3.94 billion yen. At that time, bridges in the construction industry included road and railway bridges. In the present survey, corrosion costs were calculated for road structures such as steel road bridges, guardrails (including guard cables), metal noise barriers (sound-proof walls), and concrete coating.

(1) Surveyed road and bridge facilities

Major road and bridge facilities for the corrosion cost survey included steel road bridges, traffic signs, guardrails, metallic noise barriers (sound-proof walls) that contained mainly steel materials. Recently, however, repair work to prevent corrosion from separation and stripping of concrete parts by salt damage, neutralization or alkali-aggregate reaction and others of reinforced concrete have been added. Such repair work does not always have a purpose of direct corrosion prevention. To maintain the durability and load-carrying capacity of concrete structures, however, it is always most important to prevent the corrosion of reinforcements. Therefore, all repair work for salt damage, neutralization, and alkali-aggregate reaction is included in corrosion costs here.

(2) Survey methods

Reference data upon which calculations of corrosion costs were made were based on published data. However, most of the published data were summarized data sent from each manufacturer to their respective supplier associations (such as manufacturer's association), but many of them are different from the data collected from consumers and thus cannot be used. Therefore, for some items, corrosion costs could be calculated only based upon personal interviews with supplier associations. The survey method for each item was as follows:

1) Steel road bridges

Corrosion costs of steel road bridges can be divided into weathering steel bridges which use weathering steel for corrosion prevention, and coated bridges. Hot dip galvanizing is another method of corrosion prevention for bridges, but is much less popular than the other two. Therefore, corrosion costs were calculated for weathering steel bridges and coated bridges here.

2) Guardrails and guard cables

There is no published information on how many guardrails and guard cables are in use. Therefore, the results of an on-site interview at the Steel Guard Fence Association were used to estimate the amount of average annual use.

3) Metallic noise barriers (sound-proof walls)

There is no published information on how many metal noise barriers (sound-proof walls) are in use. Therefore, the results of on-site interviews with manufacturers were used to estimate the amount of average annual use.

4) Concrete coating (corrosion prevention of reinforced concrete)

There is no published information on the actual usage of concrete lining. Therefore, the results of on-site interviews with builders were used to estimate the amount of average annual use

(3) Survey result (calculation of corrosion cost)

Corrosion cost for roads is as follows:

			billion yen / year
Steel road bridge			139.9
	(breakdown)	Coated bridge	138.2
		Weathering steel bridges	1.7
Guardrails and others			0.3
	(breakdown)	Hot dip galvanizing	0.02
		Coating	0.3
Metal noise barrier (sound-proof wall)			0.3
Concrete coating (prevention of corrosion of reinforcement)			36.9
Total road-related costs			177.4

5.6.3 Calculation of corrosion costs for river structures (flood control)

River structures are divided into river control facilities such as sluice gates, sluiceway, sluice pipe, lock gates, and weir and dam facilities. These structures have been coated to prevent corrosion, but recently, from considerations for reducing maintenance, management, and life cycle cost of structures, use of stainless steel as corrosion prevention material has been increasing.

River structures were not surveyed in the previous survey. This time, however, based on "Dams and Gates General Survey IV" (published by the Japan Association of Dam and Weir Equipment Engineering) total corrosion costs required to employ stainless steel at dams and gates since around 1955 amounted to 2.99 billion yen. This figure, however, does not include the corrosion costs of this survey year, and there are no other statistics concerning river control facilities. Therefore, corrosion costs other than those for corrosion prevention materials could not be identified.

Corrosion costs of river structures were calculated using the FY 1995 Analytical

Input/Output Analysis for construction, where the breakdown of construction sector and input items is shown in one matrix table. The Analytical Input/Output Analysis is an industrial Input/Output analysis that shows domestic monetary transactions between industries in one matrix table. For this table, corrosion cost survey items were chosen from input items in "water control" departments (river improvement, integrated river development, beach erosion control). Then corrosion cost (total of internal items: current consumption only) was calculated by multiplying the monetary amount of each item with the corrosion cost ratio that is set for each item. This value was then divided by internal ratio (0.545) to obtain a theoretical corrosion cost (current consumption plus gross value added). The results were as follows:

items	Ratio of corrosion cost (%)	Corrosion Cost(billion yen / year)
Coating	500	7.23
Steels	10-30	6.13
Nonferrous metals	10-20	0.37
Metal products and machines	3-20	13.82
Construction repair	30	2.93
Corrosion cost (total of internal departments)		30.48
Total of river structures (water control)		55.9

Note) (1) Coating expense were 5 times as much as "coating" transaction.
(2) Internal ratio = Total of internal items/gross domestic product = 0.545

Monetary amount of internal items in "water control" subsector: 1,660.62 billion yen

Gross domestic product in "water control" subsector: 3,048.18 billion yen.

5.6.4 Calculation of corrosion costs in ports and harbors

The corrosion costs in ports and harbors were 2.82 billion yen in the previous survey. At that time, steel structures (steel sheet pile, steel pipe pile, steel vessel, etc.) in port and harbor facilities were surveyed. Cathodic protection expenses calculated from work performance of 2 specialized builders, and 20% of the expenses as coating expenses were combined to obtain corrosion costs in port and harbor sector.

The present survey was based on "Port and Harbor Facilities" described in the 2nd article of the "Port and Harbor Law." This took into account not only expenses for cathodic protection, coating and covering, and corrosion allowance for steel structures of basic facilities such as revetments, quay walls and piers, but also expenses of coating and corrosion prevention materials for other port and harbor facilities.

As for cathodic protection expenses, total sales of cathodic protection (5.94 billion yen) in questionnaires collected from member companies of Cathodic Protection Association were considered to be direct construction expenses, and 1.2 times of this figure (7.13 billion yen) was regarded as corrosion cost.

As for expenses for coating/covering and corrosion allowance, expenses for corrosion preventing coating (1.13 billion yen) and corrosion allowance (0.79 billion yen) from some port and harbor management data were multiplied by the ratio (9) of expenses for cathodic protection(0.79 billion) collected from some port and harbor management data to that (7.13 billion yen) collected from the association. Each result was regarded as corrosion cost for relevant items at ports and harbors in Japan.

Corrosion prevention costs (5.02 billion yen) were obtained from data described in "Corrosion Prevention Handbook for Steel Pipe Pile, Steel Pipe Sheet Pile, Steel Sheet Pile" published by the Steel Pipe Pile Association. This figure, however, was not used for calculation and was regarded only as reference data because it was limited to new construction as factory shipment products.

For coating and corrosion resistant materials, input items related to corrosion cost (those which may not overlap the above expenses of electric protection and coating corrosion prevention) were obtained from port, harbor, and fisheries sector in "Input/Output Analysis for Construction FY 1995." Then, they were multiplied by each corrosion cost coefficient set for monetary amount of the relevant items in terms, and the combined result was considered to be corrosion cost.

Corrosion costs for the port and harbor sector were as follows:

Cathodic protection costs	7.1 billion yen
Coating corrosion prevention costs	10.2 billion yen
Corrosion allowance	0.4 billion yen
Coating and corrosion resistant materials costs	11.6 billion yen
Total	29.3 billion yen

Table 25. Results of a corrosion cost survey in the construction sector.

Investigation scope		Corrosion cost (billion yen)
(1) General buildings		1128.0
(2) Houses	-1- Apartment (Initial cost)	207.0
	-2-Apartment (Maintenance cost)	
	-3- Individual house	
(3) Roads and bridges		177.4
(4) River structures (water control)		55.9
(5) Ports and harbors		29.3
Total		1597.6

5.6.5 Summary

Table 25 shows a summary of corrosion costs estimated on general building, housing, roads and bridges, river structures, and ports and harbors in construction industry.

6. Calculation of Corrosion Costs by the In/Out Method

Consumer goods which we need in daily life and capital goods which companies invest in to expand their facilities are made by various industries such as agriculture, forestry, fisheries, manufacturing, and service sectors. Such industries are connected with each other through the inputting raw materials, fuels, or services in each production process. Thus, all the economic activities have a very close mutual dependence between industries, companies and households or government, and are affecting each other. The Input/Output Matrix describes such economic transactions during some designated period (usually for a year) in a table format. The basic structure of the Input/Output

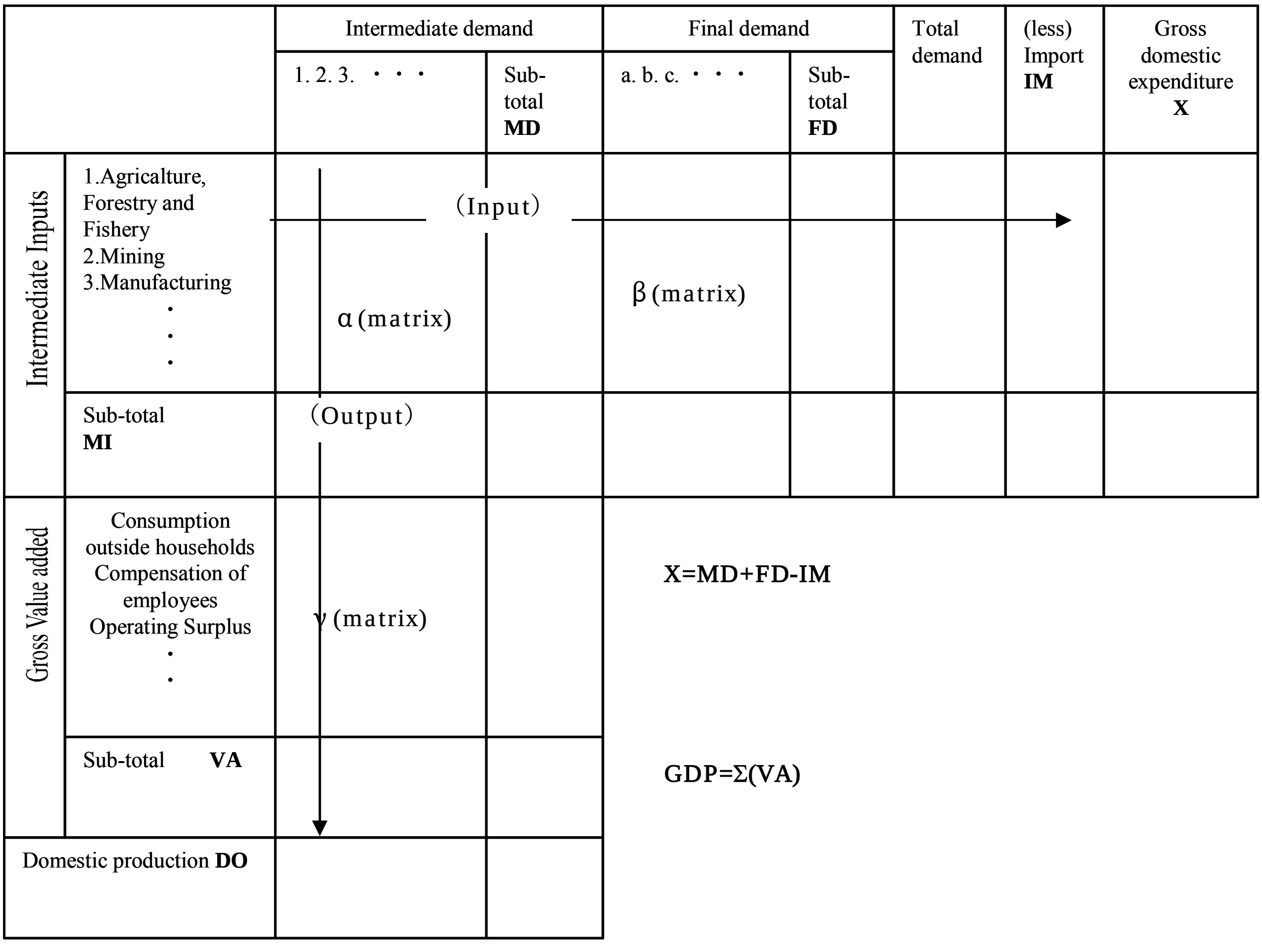

Fig. 10. An example of the Industry Input/Output Matrix

Table 26. Results obtained from the In/Out and Uhlig methods (million yen).

	Results of In/Out method	Direct cost	Results of Uhlig method
Total	9,694,716	2,418,500	3,976,900
Ratio to GNP	1.88%	0.47%	0.77%

Matrix is shown in Fig. 10.

Omitting the detailed explanation of the Input/Output Matrix here, we would like to describe how it was used to calculate a cost of corrosion. First, as shown in Fig. 10, we defined the result of dividing matrix α by vector ***X*** as coefficient matrix ***A***. However, we didn't analyze very closely, we only pick up the gross domestic capital formation part from matrix β and made it into a matrix form. Similarly, we divided it by vector ***X*** and made coefficient matrix ***B.*** From this, the following matrix equitation could be obtained:

X = FD + X×A + X×B (1),

where matrix ***A*** represents the amount of intermediate input from each industry sector to the other, and matrix ***B*** represents the amount of capital formation. In the Input/Output Matrix, changing matrix ***A*** or ***B*** and calculating the inverse matrix may make it possible to analyze how the changes of each sector influence the others, and finally how they influence the entire domestic industry, or GDP.

Now, let's assume that there is an ideal world where corrosion does not exist. Since there is no need to replace corroded parts or to use special materials for corrosion prevention, the expenses for these purposes can be reduced. In addition, service life of equipment and property will lengthen because there is no corrosion. As a result, annual capital investment can be reduced. Each matrix considering these assumption is defined as ***A'***, or ***B'***, respectively. Then substituting them for ***A*** and ***B*** in Equitation 1, the following equation is obtained:

X = FD + X×A' + X×B' + SS (2),

where, ***SS*** is the amount of money saved in the world without corrosion and its sum total is equal to the corrosion cost based on In/Out method.

Table 27. Comparison in the results of the corrosion cost survey.

	1997 (billion yen)	1974 (billion yen)	Ratio of 1997/1974
GNP (standard of 1990)	514343	148170	3.47
Corrosion cost (Uhlig method)	3937.69	2550.93	1.54
%GNP (standard of 1990)	0.77	1.72	0.45
Corrosion cost (Hoar method)	5258.2	1038.1	5.07
%GNP (standard of 1990)	1.02	0.70	1.46
Corrosion cost (In/Out method)	9694.72		
%GNP (standard of 1990)	1.88		

In a preliminary study for the present survey, we investigated how changes of each factor would affect calculation results of the corrosion costs using a breakdown table with 32 items for the Input/Output Matrix in 1995. Table 26 shows the result of applying the estimated results of the Uhlig method to In/Out method. In the Uhlig method, the corrosion cost amounts to 3.9 trillion yen, which includes fabrication costs of organic coatings. After the fabrication costs were deducted, the calculations showed expenses of 2.4 trillion yen as the direct costs for corrosion. Putting it to matrix ***A*** and calculating corrosion costs including the spreading effect resulted in a calculated corrosion cost of 9.7 trillion yen. This amount is twice as much as that based on the Uhlig method.

7. Summary of Corrosion Cost Results and Scenarios for its Reduction

7.1 Summary of corrosion cost survey

Table 27 shows the results of corrosion cost estimates based on both the Uhlig and Hoar methods, and the result of a preliminary study based on the In/Out method compared to GNP. The corrosion costs in 1997 based on the Uhlig method were approximately 3.9 trillion yen, accounting for 0.77% of GNP. On the other hand, unlike the 1974 survey, the corrosion cost estimation based on the Hoar method, which was higher than the estimates based on the Uhlig method, was approximately 5.3 trillion yen, which accounted for 1.02% of GNP. In addition, the results of the preliminary study of corrosion costs based on the In/Out method (direct + indirect) using the estimates based on the Uhlig method was higher than the others, at 9.7 trillion yen, and accounted for 1.88% of GNP. If a survey based on the In/Out method is conducted much more strictly, the estimated (direct + indirect) corrosion cost could be higher than the values estimated in this survey, possibly accounting for as much as 3 to 4% of GNP.

7.2 Scenario for the reduction of corrosion costs

7.2.1 Development of technology in corrosion and corrosion prevention into technology for public infrastructure

As has been described earlier, the industrial structure in Japan has changed quite drastically over the past 22 years. The proportion of secondary industries has been decreasing yearly, while that of tertiary industries has been increasing. Electronics and information industries have been particularly flourishing, and factories that were once built in coastal industrial zones are now being relocated along highways or near airports where there is well-developed transportation infrastructure. In the 21st century, it is expected that the maintenance of highways will become more important than the construction of them. Seeing that the corrosion cost survey in USA focused on transportation and communication, it is anticipated that in the next decade, the development of corrosion and corrosion prevention technologies related to the maintenance and management in these areas will become important.

7.2.2 Role of corrosion and corrosion prevention technology in a recycling-oriented society

Since the new century will likely be the environment conscious century, the most important issue for engineering technology will be to maintain and expand a highly industrialized society under very restricted conditions of natural resources and energy. In the reuse, recycling or reduction of the use of natural resources, corrosion and corrosion prevention technology must play a direct role. Steel products are used in a wide variety of areas. Materials showing promise as eco-steel products include steel sheets with high corrosion resistance for longer life in automobiles, household electric appliances, and the electricity sector; corrosion resistant pipes for garbage incinerators in the power and energy sectors; steel sheets with high corrosion resistance for longer life, and weathering steel for longer lived steel bridges in the civil engineering and construction sectors. The key word for all the above is “longer life span.” To develop such steel will require further research in corrosion science and corrosion prevention engineering, such as appropriate alloy design, establishing methods for evaluating life cycles, etc.

7.2.3 Strategy to minimize corrosion costs

The Committee on Cost of Corrosion in Japan has often discussed how the quantitative evaluation of corrosion costs could be reflected in the reduction of corrosion costs, how the accuracy of current corrosion costs could be evaluated, and how the minimization of corrosion costs could be achieved.

The most important subject is the scenario for minimizing corrosion costs. This purpose, however, requires an examination of the corrosion costs for each process, system, equipment and apparatus, and machinery, and whether these costs are accurate or not. Through interdisciplinary discussions, experts in each sector realized that they had known the qualitative accuracy of corrosion costs but not the quantitative accuracy. Thus, appropriate indexes for quantitative analyses must be developed.

7.2.4 Enlightenment and instruction on corrosion and corrosion prevention, and establishment of a qualification system

As is emphasized in the Hoar method, enlightenment and dissemination of information on corrosion is the most effective means to prevent corrosion. Compared to 20 years ago, more training courses or seminars by the expert’s associations are being held. This has been helping to improve the technological level and to lower the corrosion cost to some extent, which is shown in the analysis of this report.

The main purpose up to now has been to solve technical problems in heavy chemical industries, and it has been enough to provide education for engineers in relatively small and restricted areas. Now, however, the applicable areas of corrosion and corrosion prevention have been expanded to maintenance and management areas of infrastructure that is a major foundation of society. In addition, at atomic power plants where safety is of the utmost importance, technologies for improving life spans, maintenance and management are being given the highest priority. This includes the dissemination and enlightenment of corrosion and corrosion prevention technology in these areas.

Since 1961 when it opened its doors, until 1999, more than 10,000 students have graduated from Corrosion Engineering School established by Japan Association of Corrosion Control. Graduates are qualified as corrosion control managers, whose tasks include working to raise the public awareness to the importance of corrosion work.

7.2.5 Activities and roles of the Corrosion and Corrosion Prevention Center in the information age

The 1975 report included a proposal to establish the Corrosion and Corrosion Prevention Center as a public organization, but this has not been accomplished yet. It was only in 1995 when the Corrosion Center started its activities in the Japan Society of Corrosion Engineering. Some of the proposals have been gradually taking shape.

A lot of inquiries on corrosion issues or requests for corrosion tests come to the research and testing institutions of local governments, but few of them have enough staff with special knowledge. In the information age, we can relatively easily get information on corrosion and corrosion prevention through the internet. Actual utilization of this information, however, requires experts in many cases. This problem will be partly solved if the networking of that small number of experts is successful. It is desirable to create a network of experts and to utilize the Corrosion

Center as the core center.

7.2.6 Organizing experts on corrosion and corrosion prevention, and exploitation of their knowledge

The relationship between the corrosion science and corrosion engineering is sometimes compared to the relationship between basic medical science and clinical medicine. To solve the actual problems of corrosion, we must have clinical experiences in wide range of actual practices. It is also very important to have profound experiences for problem solving. Unfortunately, many veteran experts with such experiences are now retiring or otherwise leaving their jobs, resulting in a lack of skilled technicians. Many efforts such as building a database to utilize knowledge based upon experiences have been made, though they are not enough to solve the problems. It would be best to organize corrosion and corrosion engineering experts who have a wide variety of experiences and utilize their knowledge in order to reduce the costs to the public.

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Chairman; *T. Shibata(Osaka Univ.),*
Organizing Committee Members; *M. Hirano(The Japan Machinery Federation), T. Tanaka(The Japan Iron and Steel Federation), S. Uchino(The Shipbuilder's Association of Japan), G. Nakao(Japan Paint Manufacturers Association), K. Takahashi(Japan Paint Manufacturers Association), T. Nomasa(Japan Association of Corrosion Control), T. Shibata(Japan Society of Corrosion Engineering),*
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The symbol of " * " indicates the chairman of SC. Affiliation at the end of March, 2001 was shown

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