MAINTENANCE OF ROAD BRIDGES IN JAPAN

Y. Morito
Ministry of Land, Infrastructure and Transport, Japan, morito-y2bz@mlit.go.jp
Y. Harada
Ministry of Land, Infrastructure and Transport, Japan, harada-y82ac@mlit.go.jp
S. Kashima
Japan Bridge Engineering Center, Japan, kashima@jbec.or.jp
S. Fukunaga
Japan Bridge Engineering Center, Japan, fukunaga@jbec.or.jp

ABSTRACT
Road bridges constructed during the period of rapid economic growth from 1955 to 1973 account for about 40% of all the bridges in Japan. Therefore, bridge aging will progress very rapidly. Damage to reinforced concrete slabs, fatigue cracks in steel bridges, and problems of chloride damage and ASR in concrete bridges have recently been reported. And seismic strengthening against large-scale earthquakes has become an urgent problem. To address these problems, the Ministry of Land, Infrastructure and Transport is developing a new bridge inspection system and bridge management data sheets. Under the inspection system, periodic inspections of bridges will be conducted once every five years, and the necessity of measures will be decided. The inspection results are recorded in bridge management sheets with such information as structural and environmental characteristics, and the history of repairs and strengthening of the bridges. The new inspection system and the management data sheets make proper bridge repair and extending the life expectancy of bridges possible. And it will be possible to equalize renewal periods for the bridges built during the period of rapid economic growth.

1. CURRENT STATUS OF ROAD BRIDGES IN JAPAN

As of April 2005, there were 148,223 bridges with span of 15 meters or more in length on roads in Japan, including those on expressways, national highways, prefectural roads and municipal roads. (See Table 1) Steel bridges and prestressed concrete (PC) bridges each account for approximately 40% of the total, and reinforced concrete (RC) bridges account for about 18%. The remainder consists primarily of combined steel and RC bridges, and steel and PC bridges. A very small number of stone and wooden bridges are in use.
By administrative classification, steel bridges account for about 47% or nearly half of the bridges on national highways. On prefectural roads, the percentage of PC and RC bridges is relatively high, while that of steel bridges is less than 40%. PC, RC and steel bridges each account for about one-third of the bridges on national expressways. The percentage of RC bridges on national expressways is higher than that of RC bridges among the bridges on national highways, where continuous hollow slab bridges are widely adopted on national

expressways.

Classified by structural form, girder bridges account for about 77% and floor slab bridges account for 17% of all bridges, followed by rigid frame, arch, and truss bridges in that order.

Table 1 – No. of bridge sites by type of bridge (no. of sites)

Classification	Steel bridges	RC bridges	PC bridges	Others	Total
National expressways	1,938	1,863	2,256	345	6,402
National highways	11,180	3,047	8,656	689	23,572
Prefectural roads	12,753	5,948	13,037	778	32,516
Municipal roads	31,712	15,120	35,257	3,644	85,733
Total	57,583	25,978	59,206	5,456	148,223

(As of April 1, 2005; excluding bridges shorter than 15m)

2. AGING OF JAPANESE BRIDGES

Figure 1 shows the number of bridges in service by year completed. We see shifts over time in the predominant type of bridges, from RC to steel bridges, and from steel to PC bridges, because of the progress of bridge technology. Although the number completed had increased rapidly since the middle of the1950s, it started to decrease in the mid-1970s, because of the oil crisis that occurred in the early 1970s and a subsequent restriction of public works. Bridges completed during the period of rapid economic growth from 1955 to 1973 account for about 40% of the cumulative total. Therefore, the number of the bridges over 50 years old will triple in 10 years, and be eight times greater in 20 years. We can see that the aging of Japanese bridges will progress very quickly.

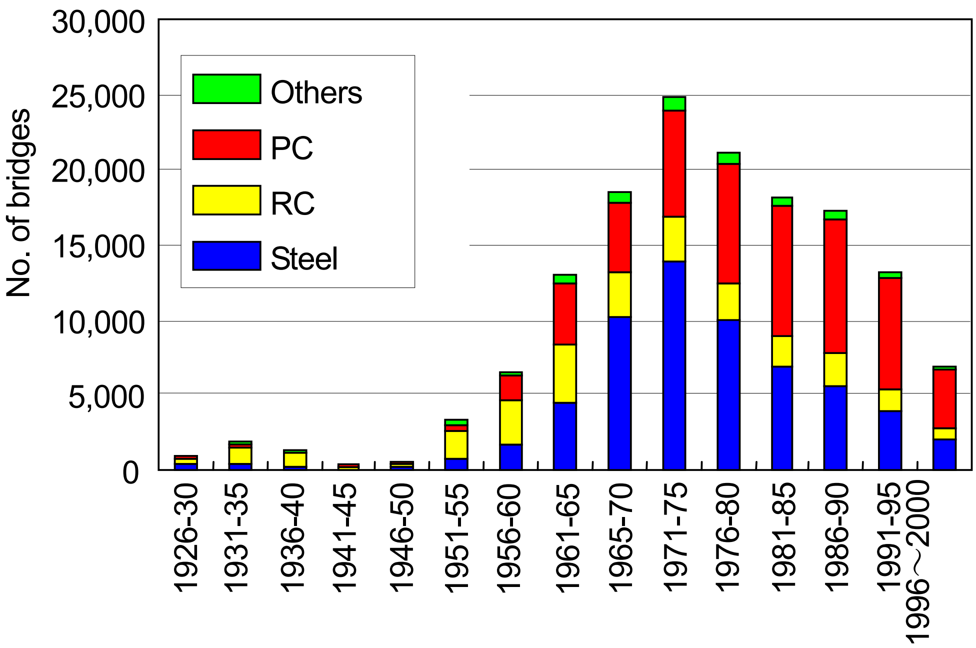


Figure 1 - No. of bridges by year completed (excluding those shorter than 15m) [1]

The life expectancy of bridges has been considered to be approximately 50 years, which is the period of depreciation of bridges as assets. In about 15 years, the number of bridges needing reconstruction will peak, and it is expected that the cost of reconstruction will be huge. Therefore, we will be faced with a lack of funds in the near future.

Comparing the current condition of Japanese bridges with that of U.S. bridges in the 1980s, which was referred to as “America in ruins,” we see that the current condition of Japanese bridges is becoming similar to that of U.S. bridges in the 1980s. Ten years from now, the aging of Japanese bridges will exceed that of U.S. bridges of that period. Therefore, it can be said that we have already entered a period necessitating large-scale bridge renewal.

3. DAMAGE TO ROAD BRIDGES AND RELATED ISSUES

3.1 Damage to road bridges

Table 2 shows how bridges are classified according to the necessity of countermeasures indicated in the Bridge Periodic Inspection Manual used by the Ministry of Land, Infrastructure and Transport.[2] The results of periodic inspections of bridges on national highways indicate few bridges categorized as Level E, a condition that would have a great impact on traffic. Therefore, few bridges have problems that must be dealt with immediately. But bridges in need of prompt repair account for about 4% of all the members inspected.

Table 2 - Classification of necessity of countermeasures for bridges according to periodic inspection manual

Necessity of measures classification	Description
A	Very little or no damage; no need for repair.
B	Repair may be necessary depending on condition.
S	Need for detailed investigation
C	Prompt repair or other remedial action required.
E	Emergency measures must be taken.
Total	

Recently, fatigue cracks in steel girders and steel-made piers, and damage to reinforced concrete slabs (RC slabs) have been reported. The problems of chloride damage and alkali-silica reaction (ASR) have developed in concrete bridges. Also damage to third parties has occurred because of dropping off and peeling off of concrete surfaces. And seismic strengthening against large-scale earthquakes has come to an urgent task in Japan. With aging of bridges in Japan being reported in this way, the reliability and safety of bridges is declining, and concern about maintenance and renewal of bridges has been aroused.

3.2 Major damage seen in road bridges

(1) Fatigue cracks in steel members

Fatigue cracks due to local stress concentration have been found in steel road bridges where traffic has been extremely heavy since the 1980s. Photo 1 shows cracks appearing along fillet welds between upper flanges and webs, between vertical stiffeners and upper flanges, and between webs and vertical stiffeners. The main areas where fatigue cracks occur are as follows:

- Connections of cross frames or cross beams and main girders, bearing support brackets on ends of girders, or welds of bearing's sole plates in plate girders;
- Connections of stiffening girders or chord members and cross beams, connections of stringers and cross beams, and connections at both ends of vertical members in arch or truss bridges;
- Weld lines just under the wheel loading portion of steel deck plates, for example, butt welding joints of U shaped ribs, the cross section of lateral and longitudinal ribs, and welds of vertical stiffeners and steel deck plates.

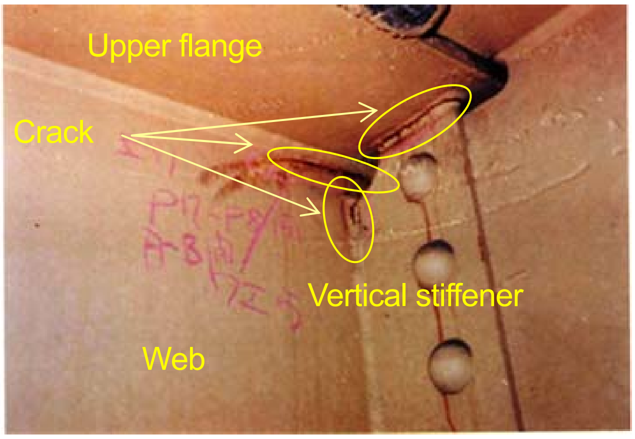


Photo 1 - Fatigue cracks on girder

Major causes of the fatigue cracks are considered to be increased traffic of large vehicles and the existence of vehicles with excessive weight. Another cause is insufficient consideration in both the design and manufacturing stages of the need for measures against road bridge fatigue. This is because it was thought that fatigue occurs only in railway bridges.

Recently, fatigue cracks have been found in the beam-to-column connections of steel piers. The high stress concentration occurred at the edges of flange plates in the beam-to-column connection of steel piers. And there are portions difficult to weld due to plate assembling in the beam-to-column connections. These portions turned out to be unwelded cavities. Fatigue cracks are thought to start at these points.

Fatigue damage to steel deck plates reported in Japan could possibly become a large problem in the near future.

Road traffic conditions will continue to be severe, and fatigue damage to the steel member will become an important problem in maintenance and management of road bridges.

(2) Damage of RC slabs

RC slabs are vulnerable to damage compared with the other main member of bridges because the effect of live load stress is very great. Cases of concrete dropping off became striking examples of this problem around 1965, when larger vehicles began appearing (See Photo 2). Damage to RC slabs has been a major maintenance problem for road bridges since then. RC slabs designed according to design specifications before 1968 have been severely damaged. The durability (resistance to fatigue) of these RC slabs is insufficient because they tend to be particularly thin, and the amount of distribution bars is very small.

Photo 2 - Dropping off of concrete of RC Slab

Experimental tests using wheel running machines have clearly indicated that damage to RC slabs is fatigue damage due to wheel loads. The deterioration mechanism in RC slabs is as follows. Originally, RC slab is nearly the same as isotropic slab. It has a very large load carrying capacity. However, cracks due to dry shrinkage change isotropic plate to anisotropic plate, and RC slab becomes lined beams in a transverse direction. As a concentrated load is placed on such beams, cracks in a longitudinal direction occur, and an RC slab becomes something like a collection of concrete cubes, and the two faces of the crack rub against each other. Also, seepage of water and flowing out of efflorescence widen the cracks significantly. Finally, a decline of punching shear capacity causes the RC slab to drop off.

Bonding steel plates beneath the slabs can repair early-stage damage to RC slabs, but the damage progresses, and large-scale measures with traffic control such as the thickness-increasing method over the upper slabs becomes necessary. Therefore, it is important that damage to RC slabs is detected and repaired at an early stage.

(3) Chloride damage of RC and PC bridges

Remarkable cracks with rust water have appeared on the surfaces of RC and PC bridges in various locations since the 1980's. The cause of such cracks is salt that enters the concrete from outside after it hardens and salt contained in the sea sand used in fine aggregate.

In coastal areas, especially along the Japan Sea, seasonal sea wind dominates in winter. Strong sea wind and waves bring salt particles onto concrete structures. The salt particles penetrate the concrete and cause corrosion of reinforcing bars and prestressing steel. Photo 3 shows the condition of a bridge located near the Japan Sea. The bridge had to be reconstructed because the girder was severely affected by chloride damage.

Photo 3 - Chloride damage of PC girder

Antifreeze agents also cause chloride damage. In winter, antifreeze agents containing calcium chloride have been sprinkled on the bridges. The calcium chloride flows out from expansion joints and damages the ends of girders and substructures.

Chloride damage due to sea sand has occurred mainly in western Japan. Because of bans against removing river sand and a lack of pit sand, sea sand began to be used during the period of rapid economic growth. Until the establishment of regulations on the total amount of salt in ready mixed concrete in 1986, sea sand had sometimes been used without sufficient washing.

Slight chloride damage caused by salt invading from the outside can be repaired by simple methods such as surface coating. However, large-scale methods such as desalination or bridge reconstruction are needed when the cumulative amount of invaded salt becomes large. Therefore, it is necessary to repair salt damage at an early stage.

(4) Damage due to alkali-silica reaction in concrete bridges

A large number of concrete structures were built during the period of rapid economic growth, and aggregate material for concrete replaced crushed stone from river gravel. Some crushed stone was reactive aggregate. This led to alkali-silica reaction (ASR) in concrete structures.

Photo 4 - Breaking of reinforcing bars by ASR

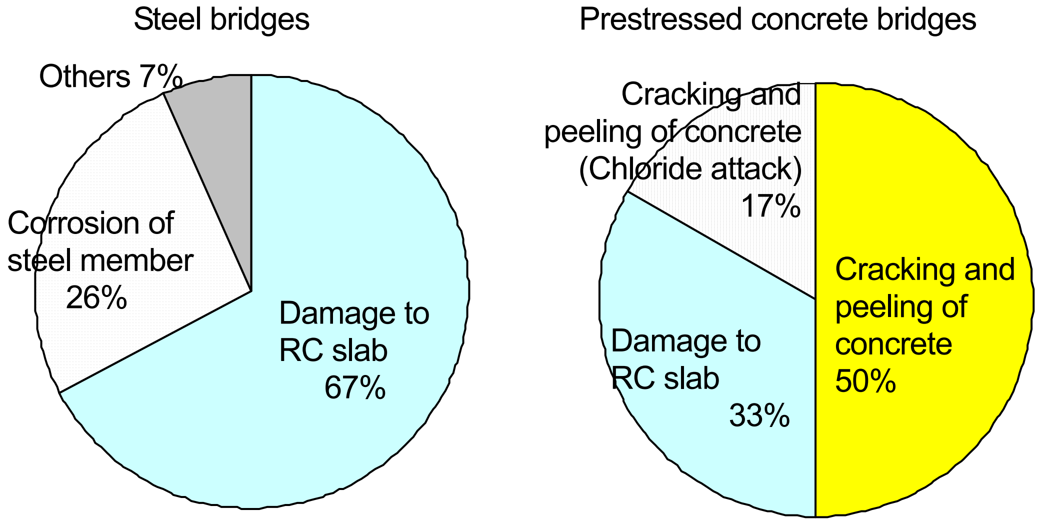
As the occurrence of cracks due to concrete expansion is the main problem in structures suffering ASR, measures to prevent water from penetrating concrete have been taken to delay the progress of the ASR. However, instances of reinforcing bars breaking due to ASR have recently been reported. This has not yet been reported in other countries. Photo 4 shows damaged reinforcing bars at some corners of the shear reinforcements and gas pressure weld points of longitudinal reinforcements. These were found in recent inspections. It is assumed that reinforcing bars were fractured due to expansion pressure caused by ASR. Therefore, repair methods to prevent ASR, detection methods to identify breaking points of reinforcing bars, and methods of repairing broken reinforcing bars must be developed.

3.3 Problem of seismic strengthening against large-scale earthquake

In Japan, devastating damages occurred to road bridges in the Niigata earthquake (M7.5) of 1964, the Miyagi-Oki Earthquake (M7.1) of 1978 and the Kobe earthquake (M7.3) of 1995. The seismic design method for road bridges in Japan has been revised each time after damage from these earthquakes. Design specifications were revised in 1980, and the design method for cut-off sections of main reinforcements in concrete piers was changed to eliminate damage that would influence bridge safety. The revised design methods were as follows: The anchored length of main reinforcements from the section where main reinforcement is unnecessary in design calculation was extended. The allowable concrete shear stress at cut-off sections of concrete piers was lowered. Hoop reinforcements were put in place about twice as close together as in the general section. In the Kobe earthquake, serious damage occurred to bridges with specifications older than the road bridge design specifications of 1980.
It has been predicted that a large-scale earthquake such as a Tokai earthquake, a Miyagi-Oki earthquake or an earthquake occurring directly below the Tokyo Metropolitan area will occur in the near future. Therefore, seismic strengthening of bridges is highly required for bridges with specifications older than those applied since 1980.

4. REASONS FOR BRIDGE RECONSTRUCTION

Figure 2 shows the reasons for reconstruction from 1986 to 1996 of bridges to repair superstructure damage. In the case of steel bridges, damaged RC slabs and corrosion of steel members accounted for a high percentage of the causes. With recent advances in painting and coating technology, it was thought that the need for bridge reconstruction due to steel corrosion had decreased. However, the number of bridges reconstructed due to damaged RC slabs has risen because of an increase in heavy vehicle traffic. Also, although it has not become a serious problem yet, fatigue damage in steel members is likely to become a reason for bridge reconstruction.
Cracking and peeling of concrete account for a high percentage of the reasons why PC bridges must be rebuilt. The causes of this are presumed to be carbonation, ASR or frost. Damage to RC slabs and deterioration due to chloride attack are other important reasons.
Therefore, damage to RC slabs and steel members due to fatigue caused by live loads, chloride and ASR has to be tackled to lengthen the life expectancy of bridges.



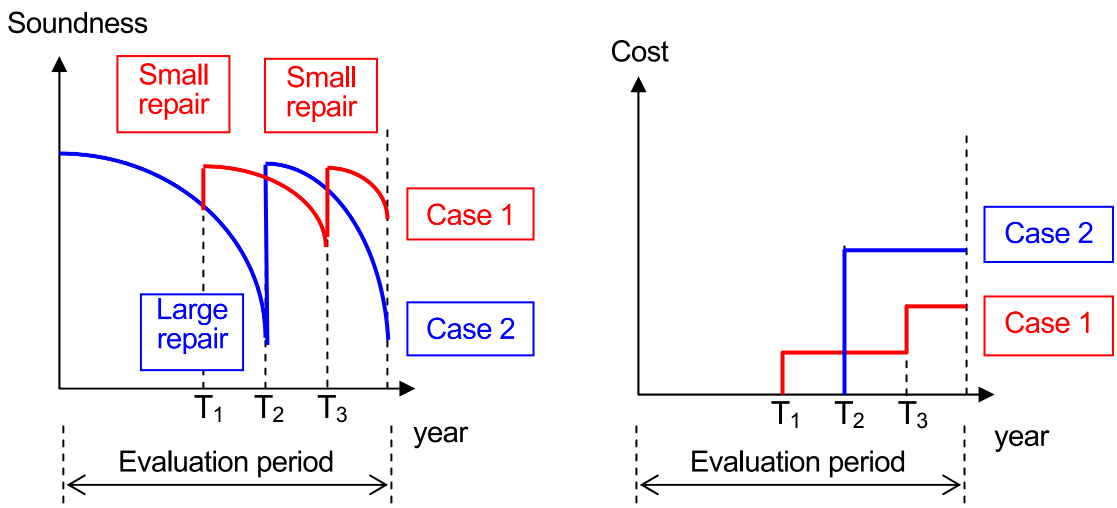
(National highways and prefectural roads, 1986-1996)

Figure 2 - Reasons for bridge reconstruction [3]

5. DEVELOPMENT OF NEW BRIDGE MANAGEMENT SYSTEM

5.1 New bridge inspection system established

In general, total costs are reduced by preventive measures in early stages rather than postponing them as much as possible. This is because deterioration of bridges accelerates year by year, as shown in Figure 3. Therefore, it is necessary to recognize signs of damage at an early stage and decide on the type and the time for measures to minimize life-cycle costs.



Case 1 : Preventive repair (minimizing life-cycle costs)
Case 2 : Repair at the repairable limit state

Figure 3 - Relationship between types of repair and cost

The results of past bridge inspections indicate that damage that adversely affects safe and smooth traffic usually arises 10 years or more after completion of repair work. However, it has been reported that some types of damage requiring repair arise four to seven years after previous repair. In addition, the period in which bridge inspection results can be fully relied on is thought to be limited because an environment that includes such factors as a high volume of large vehicle traffic is likely to change rapidly. Therefore, the Ministry of Land, Infrastructure and Transport has decided to conduct periodic inspections of bridges once every five years, starting in 2004. Prior to this, inspections were conducted once every 10 years. Table 3 provides an outline of the new system for periodic bridge inspections. [2]

Table 3 - Outline of periodic bridge inspection

Frequency	Once every 5 years
Object	All members
Scope	Grasp state and type of damage, evaluate degree of damage; determine necessity of countermeasures, and record
Method	Close-range visual inspection

(National highways (designated))

It is necessary to collect quantitative and objective information in inspections to grasp the soundness of bridges, to forecast subsequent deterioration, and to decide on the necessity of countermeasures and when they should be implemented. Therefore, the types and the degree of damage found in bridge inspections are recorded objectively and quantitatively by numeric information, figures, and photographs. The presumed causes of each type of damage are noted, and with the necessity of countermeasures such as emergency measures, repair, detailed investigation or maintenance is decided on. The diagnosis results are recorded in inspection data sheets for subsequent study of the scope and method of repair. The necessity of countermeasures is generally determined on the basis of judgments regarding the damage or deterioration of each structural member. Factors such as the importance of the members, the progress of the damage and environmental conditions are carefully considered. A diagnosis of the bridge’s overall condition is recorded, and all damage to all members of the bridge is evaluated.[2]

Development of technology for more efficient inspection work and effective recording methods is needed for more frequent inspections and to acquire more objective results. Therefore, we must aggressively develop and adopt various new technologies. One example would be using digital cameras to record the condition of structural surfaces.

5.2 Bridge management data sheets[4]

Bridge maintenance and management includes the repair or strengthening of bridges based on the results of various inspections, including periodic inspections. Efficient and effective maintenance and management requires making good use of the data obtained in inspections. The results of the various inspections, maintenance and strengthening has to be uniformly controlled and continuously accumulated to enable reference to the most recent data. The data on the main maintenance problems is managed and preserved, with their history in chronological order.

To arrange and save this data, the Ministry of Land, Infrastructure and Transport has prepared a Bridge Management Data Sheet for each bridge. These data sheets are equivalent to patients' medical records in hospitals. Bridge information is outlined. This includes a record of the latest inspection results, repair and strengthening history, and the state of seismic strengthening.

Bridge management data sheets are divided into those with individual records on each bridge, with important data such as inspection or repair results, and a section with compiled data on inspection or repair work. This section includes the data on the damage situation, inspections, repair history, and the state of seismic strengthening of each bridge. This information is used to grasp the soundness and history of bridges and to create a repair plan. The other type of data sheet has compiled data on the number of bridges requiring each necessity of measures classification, the percentage of bridges in sound condition, the rate of progress made in seismic strengthening, lists and outlines of bridges in need of prompt repair among all bridges administered by the National Highway Office. This data is used to grasp the overall situation of bridges and to decide the order of priority of repair and strengthening work on bridges administered by the National Highway Office.

6. CONCLUSION

This paper was written to introduce the current status of road bridges in Japan, bridge management undertaken by the Ministry of Land, Infrastructure and Transport, and to provide an outline of countermeasures for major damage to bridges, including fatigue, chloride attack, and ASR.

From the future, we intend to utilize the bridge inspection system and bridge management data sheets efficiently to be able to repair bridges appropriately according to the state of deterioration. Appropriate repair can extend the life expectancy of bridges, which is thought to be about 50 years. It should become possible to equalize renewal periods for many of the bridges that were built during the period of rapid economic growth, and to also reduce the total cost of bridge maintenance, repair and renewal. Future tasks include developing nondestructive test techniques and effective repair methods, and training inspectors to enable them to acquire a level of technical expertise.

REFERENCES

1. Nakatani, Tamakoshi, Hiromatsu : "Development of PC Road Bridges"; Civil Engineering Technology, Vol.57, No.10, 2002, Oct. (in Japanese)

2. Ministry of Land, Infrastructure and Transport : Bridges periodic inspection manual, 2004.March (in Japanese)

3. Nishikawa : "A concept of Minimized Maintenance Bridges"; Bridge and Foundation, 1997, Aug. (in Japanese)

4. Ministry of Land, Infrastructure and Transport : System of maintenance and management of bridges, and "Bridge management data sheet" preparation manual, 2004.March (in Japanese)