Abstract

As of April 2006, Osaka City manages 763 bridges, having a combined area of approximately 720,000 m². Most of these bridges were built intensively at the beginning of the Showa era (period of the first urban planning program), when the urban infrastructure was improved drastically, and also during the period of high economic growth (when the world exposition was held). It is expected these aging bridges will simultaneously require intensive repair and renewal work in the near future. To maintain the service standard for users within a limited budget, it is necessary to equalize renewal times and minimize the cost of repair and renewal work. Therefore, it is essential to develop a comprehensive bridge management system to establish an optimal maintenance and management plan based on prediction of bridge deterioration and minimization of life cycle cost.

This paper introduces a study on our city's bridge management system.

1 CURRENT SITUATION OF BRIDGES IN OSAKA CITY

1.1 The number of managed bridges and their characteristics

As of April 2006, there are 880 road bridges in Osaka City. Among them, 763 bridges are managed as certified roads by Osaka City. The total length is 47.6 km with area of 723,000 m². (See Table 1, Current situation of bridges.) One of the characteristics of bridges in Osaka is that there are many steel bridges. Approximately 90% of the whole bridge areas are steels. One of the reasons for this is a limited girder height of bridges in Osaka due to overhead crossing of bridges that are laterally crossing the river or located in urban areas. Another reason is a measure being taken to alleviate dead load against constructions on the soft grounds and underground facilities such as subways. Another characteristics of bridges in Osaka are as follows. There are many large-scale and long bridges because they are located at the mouth of vast river like Yodo-river and Yamato-river. There are also many viaducts (amount of 82) across the roads and railways which are crowded in the city. (It seems that the underpasses (amount of 71) are chosen in consideration for environment and esthetics although they are more expensive than the viaducts.)
1.2 **Trends of the number of Bridges Managed by Osaka City and bridge areas**

The Figure 1 shows the trends of the number of bridges managed by Osaka City and bridge area. When the city was municipalized in 1889, there were 196 bridges. During the first city expansion period in 1897, there were 395 bridges. After that, from the end of the Meiji era to the Taisho era, there were 400 to 500 bridges. During the second city expansion period in 1925 (Taisho 14), the number of bridges increased rapidly to 1629. Then the number decreased to 1200 or so due to reclamation of waterways. However, it increased again to 1470 bridges because of the third city expansion period in 1955. After the world war, Japanese economy entered the high growth period, and waterways were reclaimed because of improvements of the sewage system in Osaka City. Consequently, the number of bridges decreased to less than 800. Around the same time, Japan started constructing elevated bridges and large scale bridges. Along with it, the number of bridges decreased, however, the average bridge length and bridge area have increased up to the present date.

1.3 **Year of bridge construction and bridge’s age**

The Figure 2 shows years of construction and ages of bridges managed by Osaka City. According to this figure, there are two peaks for construction years: one in prewar times and another in postwar times. In particular, the number of bridges built is the highest in 1970 (Showa 45) when the Japan World Exposition was held. An average bridge’s age is approximately 40.

The oldest existing bridge in Osaka is the Honmachi Bridge built in 1913 (Taisho 2). The bridge has been used for transportation for 94 years. (See Figs 3, 4) However, there is no urgent need for reconstruction at this point so that it is possible that the bridge will be used for over 100 years. Factors for this longevity are daily maintenance and a large-scale repair implemented in 1983 (Showa 58). Replacement of damaged members and reinforcement of RC slabs have been conducted for other aging bridges also. A proper management after some years is probably a factor that lengthens a life of a bridge.

1.4 **Distribution of managed bridges’ ages**

The Table 2 shows the number of bridges in Osaka by date. Bridges built during the first urban planning project, which is the first construction peak, account for approximately 10% of all bridges. When combining these bridges and bridges built before the first urban planning project, approximately 13% of all bridges are 70 years old or older as of today. These bridges will be 100 years old or so in 30 years. Additionally, bridges that will be 70 years old or older in 30 years from today will account for approximately 32% of all the bridges. The bridges built during the Japan world Exposition year, which is the second construction peak, will be also as old as 68 years old in 30 years. As a result, in the future we will face a situation where a wave of aging bridges will surge one after another. In preparation for such a situation, an urgent issue in addressing aging bridges is
development of a maintenance and management system to minimize life cycle cost through life extension (lengthening of life cycle) and a lower cost for maintenance and repair.

2 BRIDGE PROJECT IN OSAKA CITY

2.1 Current situation and budget of bridge project

We will show a trend of the budget situation and scale of each bridge project of Osaka City. Bridge projects in Osaka City can be divided into the following four groups.

1. New construction: New construction or reconstruction of bridges
2. Improvement: Widening, changing stairs to slopes, surrounding improvement
3. Quakeproof: Pier reinforcement, prevention for bridge fall, series of girder
4. Repair: Regular repair, repair and reinforcement measures, steel bridge recoating

The Figure 5 shows a trend of project cost in 10 years. A project cost for 2003 was approximately five billion yen, with a breakdown of 1.9 billion yen for new construction, 1.3 billion yen for improvement and quakeproof work, and 1.8 billion yen for repair work. Although necessity for repair and reinforcement is increasing, a budget for such work is decreasing, allowing only minimum level of maintenance work.

Next, the Table 3 shows bridges that were reconstructed during the last 20 years and reasons for such reconstruction. Traditionally, main reasons for reconstruction of bridges are to raise bridge girders and/or to expand span length along with river improvements, and to expand width along with road improvements. There have been few cases where bridges have to be reconstructed due to structural malfunction. There are five cases of reconstruction due to aging in 20 years. Such reconstruction takes place at a rate of one bridge in four years.

3 BMS (Bridge Management System)

3.1 Necessity of BMS (Bridge Management System)

Aging of bridges managed by Osaka City is advancing. A traffic control due to deficiency of trafficability of old bridges and a sudden increase in traffic restriction due to reconstruction and/or reinforcement of bridges can seriously influence social and economic activities. Therefore, in order to avoid such situations and to maintain proper municipal services for the citizens into the future, it is necessary to try to prolong lives of old bridges and to promote leveling of facility renewal. Additionally, concentration of reconstruction must be avoided since public investment will be restrained according to a prediction of a social condition in the future. It is imperative that reconstruction should take place in order from bridges with a low level of soundness and load bearing capacity among old bridges. Also, adequate maintenance and reinforcement must be taken to
promote measures to prolong lives of existing bridges. Besides these points, it is necessary to develop a maintenance and repair plan based on consideration for the following characteristics of bridges managed by Osaka City. Such characteristics can be roughly divided into three groups.

i) Approximately 90 of all managed bridges are steel bridges

ii) In urban areas, there are large-scale, elevated bridges that can seriously impact economic activities.

iii) There are two main construction periods: in the beginning of the Showa era and during the high economic growth period. Times for reconstruction, reinforcement and repair will be concentrated.

3.2 Future approaches of BMS

The maintenance works of bridges need the skills of inspection and diagnosis and the decision of the management plan and the update of the database and so on. We arranged the bridge management cycle shown as the figure 4 in 2006 to carry them out smoothly as a cycle. Mainly on the bridge database, this management cycle consists of the inspection and diagnosis system of bridges and the evaluation of maintenance level and the decision of the management plan and the executions of repair and reinforcement and the inspection and update of the database after executions.

In addition, the bridge maintenance support system established in 2005 is recognized to be as a support tool for decision of the management plan. In future, based on the bridge management cycle such as the above, it will be necessary for us to decide the management plan in consideration of characteristics of each bridge.

4 CONCLUSION

It used to be that a great emphasis was placed on bridge construction itself and technical investigation of newly constructed bridges. However, today, examination of measures to safely preserve existing bridges for a long time is required. A traditional way of bridge maintenance and management needs to undergo a drastic reform. As the bridge administrators, we must autonomously coordinate a series of process to gain citizens’ consensus and establish a bridge maintenance and management system to draw results that are quantitatively easy-to-understand.
Table 1. Current situation of bridges
As of April 1, 2006

<table>
<thead>
<tr>
<th></th>
<th>Number of bridges (unit: bridge)</th>
<th>Total bridge length (unit: m)</th>
<th>Total bridge area (unit: m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel bridge</td>
<td>508</td>
<td>41,351</td>
<td>640,820</td>
</tr>
<tr>
<td>Concrete bridge</td>
<td>250</td>
<td>5,692</td>
<td>81,076</td>
</tr>
<tr>
<td>Stone bridge</td>
<td>4</td>
<td>11</td>
<td>23</td>
</tr>
<tr>
<td>Wooden bridge</td>
<td>1</td>
<td>614</td>
<td>1117</td>
</tr>
<tr>
<td>Sub total</td>
<td>763</td>
<td>47,668</td>
<td>723,036</td>
</tr>
<tr>
<td>Management of Osaka City (Certified roads)</td>
<td>68</td>
<td>7,856</td>
<td>142,441</td>
</tr>
<tr>
<td>Management of Osaka Prefecture or adjacent local governments</td>
<td>20</td>
<td>1,131</td>
<td>13,972</td>
</tr>
<tr>
<td>Management of the nation</td>
<td>29</td>
<td>7,867</td>
<td>235,877</td>
</tr>
<tr>
<td>Total</td>
<td>880</td>
<td>64,522</td>
<td>1,115,326</td>
</tr>
</tbody>
</table>

Figure 1. Trends of the number of bridges and bridge area
Figure 2. Relationship among bridge’s age, the number, and bridge area

Figure 3. Side of Honmachi Bridge

Figure 4. Bridge face of Honmachi Bridge
Table 2. List of the numbers of bridges in Osaka by date (road bridges)

<table>
<thead>
<tr>
<th>Date</th>
<th>Years used</th>
<th>Number of bridges</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>1912 - 1925</td>
<td>95-82</td>
<td>17</td>
<td>Improvement through city electric project</td>
</tr>
<tr>
<td>1926 - 1930</td>
<td>81-77</td>
<td>25</td>
<td>First urban planning project</td>
</tr>
<tr>
<td>1931 - 1935</td>
<td>76-72</td>
<td>54</td>
<td>First urban planning project</td>
</tr>
<tr>
<td>1936 - 1940</td>
<td>71-67</td>
<td>20</td>
<td>First urban planning project</td>
</tr>
<tr>
<td>1941 - 1945</td>
<td>66-62</td>
<td>2</td>
<td>Wartime and postwar recovery</td>
</tr>
<tr>
<td>1946 - 1950</td>
<td>61-57</td>
<td>2</td>
<td>Wartime and postwar recovery</td>
</tr>
<tr>
<td>1951 - 1955</td>
<td>56-52</td>
<td>26</td>
<td>High water prevention project</td>
</tr>
<tr>
<td>1956 - 1960</td>
<td>51-47</td>
<td>29</td>
<td>1964, Tokyo Olympic</td>
</tr>
<tr>
<td>1961 - 1965</td>
<td>46-42</td>
<td>68</td>
<td>1964, Tokyo Olympic</td>
</tr>
<tr>
<td>1981 - 1985</td>
<td>26-22</td>
<td>90</td>
<td>1990, Osaka Flower Expo</td>
</tr>
<tr>
<td>1986 - 1990</td>
<td>21-17</td>
<td>76</td>
<td>1990, Osaka Flower Expo</td>
</tr>
<tr>
<td>1991 - 1995</td>
<td>16-12</td>
<td>37</td>
<td>1995, Kobe earthquake</td>
</tr>
<tr>
<td>1996 - 2000</td>
<td>11-7</td>
<td>16</td>
<td>1995, Kobe earthquake</td>
</tr>
<tr>
<td>2001 -</td>
<td>6-</td>
<td>3</td>
<td>1995, Kobe earthquake</td>
</tr>
</tbody>
</table>

Total  763  100.0%
Figure 5. Trend of bridge project cost

Table 3. List of reconstruction in the last 20 years in Osaka City

<table>
<thead>
<tr>
<th>Bridge name</th>
<th>Style</th>
<th>Year of construction</th>
<th>Major reason for reconstruction</th>
<th>Year of reconstruction completed</th>
<th>Years in service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iwamatsubashi</td>
<td>Plate girder</td>
<td>1922</td>
<td>Road improvement</td>
<td>1997</td>
<td>75</td>
</tr>
<tr>
<td>Onkishimabashi</td>
<td>Plate girder</td>
<td>1926</td>
<td>Highway project</td>
<td>1998</td>
<td>72</td>
</tr>
<tr>
<td>Hanatenobashi</td>
<td>Plate girder</td>
<td>1930</td>
<td>Road improvement</td>
<td>2001</td>
<td>71</td>
</tr>
<tr>
<td>Imabashi</td>
<td>Plate girder</td>
<td>1924</td>
<td>Aging</td>
<td>1994</td>
<td>70</td>
</tr>
<tr>
<td>Takatsuharabashi</td>
<td>Plate girder</td>
<td>1927</td>
<td>Subway</td>
<td>1997</td>
<td>70</td>
</tr>
<tr>
<td>Kamiyamatobashi</td>
<td>Plate girder</td>
<td>1925</td>
<td>Aging</td>
<td>1994</td>
<td>69</td>
</tr>
<tr>
<td>Kasugadebashi</td>
<td>Plate girder</td>
<td>1935</td>
<td>Aging</td>
<td>2005</td>
<td>70</td>
</tr>
<tr>
<td>Ukishimabashi</td>
<td>Plate girder</td>
<td>1925</td>
<td>Aging</td>
<td>1990</td>
<td>65</td>
</tr>
<tr>
<td>Hakurakubashi</td>
<td>Plate girder</td>
<td>1940</td>
<td>Road improvement</td>
<td>2005</td>
<td>65</td>
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<tr>
<td>Gokurakubashi</td>
<td>Plate girder</td>
<td>1932</td>
<td>River improvement</td>
<td>1992</td>
<td>60</td>
</tr>
<tr>
<td>Naniwabashi</td>
<td>Arch</td>
<td>1915</td>
<td>Subway</td>
<td>1975</td>
<td>60</td>
</tr>
<tr>
<td>Taishobashi</td>
<td>Arch</td>
<td>1915</td>
<td>Road improvement</td>
<td>1974</td>
<td>59</td>
</tr>
<tr>
<td>Bridge name</td>
<td>Style</td>
<td>Year of construction</td>
<td>Major reason for reconstruction</td>
<td>Year of reconstruction completed</td>
<td>Years in service</td>
</tr>
<tr>
<td>------------------</td>
<td>----------</td>
<td>----------------------</td>
<td>---------------------------------</td>
<td>----------------------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>13 Shimoyamatobashi</td>
<td>Plate girder</td>
<td>1928</td>
<td>Landscaping</td>
<td>1987</td>
<td>59</td>
</tr>
<tr>
<td>14 Nishifukubashi</td>
<td>Plate girder</td>
<td>1936</td>
<td>Aging</td>
<td>1995</td>
<td>59</td>
</tr>
<tr>
<td>15 Meijibashi</td>
<td>Plate girder</td>
<td>1930</td>
<td>Road improvement</td>
<td>1988</td>
<td>58</td>
</tr>
<tr>
<td>16 Emonbashi</td>
<td>Plate girder</td>
<td>1929</td>
<td>River improvement</td>
<td>1984</td>
<td>55</td>
</tr>
<tr>
<td>17 Nakamotobashi</td>
<td>Plate girder</td>
<td>1927</td>
<td>Road improvement</td>
<td>1982</td>
<td>55</td>
</tr>
<tr>
<td>18 Furudutsumibashi</td>
<td>Plate girder</td>
<td>1939</td>
<td>River improvement</td>
<td>1992</td>
<td>53</td>
</tr>
<tr>
<td>19 Sigitabashi</td>
<td>Plate girder</td>
<td>1934</td>
<td>River improvement</td>
<td>1986</td>
<td>52</td>
</tr>
<tr>
<td>20 Kozaibashi</td>
<td>Plate girder</td>
<td>1919</td>
<td>Road improvement</td>
<td>1970</td>
<td>51</td>
</tr>
<tr>
<td>21 Nakatsurikubashi</td>
<td>Truss</td>
<td>1929</td>
<td>Road improvement</td>
<td>1980</td>
<td>51</td>
</tr>
<tr>
<td>22 Watayabashi</td>
<td>Plate girder</td>
<td>1922</td>
<td>Road improvement</td>
<td>1972</td>
<td>50</td>
</tr>
<tr>
<td>23 Sendannokibashi</td>
<td>Plate girder</td>
<td>1935</td>
<td>Landscaping</td>
<td>1985</td>
<td>50</td>
</tr>
<tr>
<td>24 Nakasumirebashi</td>
<td>Plate girder</td>
<td>1956</td>
<td>River improvement</td>
<td>1996</td>
<td>40</td>
</tr>
<tr>
<td>25 Minamiimafukubashi</td>
<td>Plate girder</td>
<td>1964</td>
<td>River improvement</td>
<td>1999</td>
<td>35</td>
</tr>
<tr>
<td>26 Imafukukitabashi</td>
<td>Plate girder</td>
<td>1968</td>
<td>River improvement</td>
<td>2003</td>
<td>35</td>
</tr>
<tr>
<td>27 Shinmorikobashi</td>
<td>Plate girder</td>
<td>1975</td>
<td>River improvement</td>
<td>1995</td>
<td>20</td>
</tr>
</tbody>
</table>
Figure 6. The bridge management cycle