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On Heavy Rainfall Disaster in Tokai District in September 2000

Kazuya INOUE, Motoyuki USHIYAMA, Taisuke ISHIGAKI, Keiichi TODA and Kensaku KURIYAMA*

* Graduate School of Engineering, Kyoto University

Synopsis

Heavy rainfall disaster occurred around Aichi prefecture including Nagoya City, central Japan from 11 to 12 September, 2000. This report describes this heavy rainfall disaster. Around Nagoya City, maximum 2 day, daily, and hourly precipitations were about 600 mm, 500 mm and 114 mm, respectively. They are the maximum records at Nagoya weather office since 1891. Due to this rainfall, 10 embankments collapsed and overtopping flow over embankment occurred in many places around Nagoya City. According to Fire and Disaster Management Agency, 10 people died, about 310 houses were destroyed and about 71,300 houses flooded. The figure of flooded houses is the largest during recent 10 years.

Keywords: Heavy rainfall disaster; Flood damage; Bank breach; Urban flood disaster; Tokai district

1. Introduction

Heavy rainfall occurred in Tokai district around Nagoya City on 11 and 12 September 2000. Caused by the typhoon 14th and stationary front, this heavy rainfall brought great damages to various areas in Tokai district. The DPRI organized an urgent investigation team to analyze this disaster. The present report outlines this disaster and describes its significant features based on the materials collected.

2. Outline of the disaster

2.1 The damage at each area

The Fire Defense Agency, Ministry of Home Affairs, summarized this disaster inflicted on the entire country as of 2 October 2000, as shown in **Table 1**. Aichi Prefecture was damaged to the extent that it composed 92 % of all the inundated houses in Japan. An embankment of about 100 m was destroyed in the Shinkawa river in the Nishi Ward of Nagoya City. Besides this, embankments were destroyed at ten places in Aichi Pref., and much flood damage occurred around Nagoya City and the northern part of the Chita Peninsula. Floods and debris flows occurred in the mountainous area of the upper reaches of the Yahagi river. Therefore, a lot of houses, roads, telephone lines, and lifelines were damaged, and the villages became isolated one after another.

The operation of the Tokaidou Shinkansen was suspended for about 24 hours from 11 September. 50,000 passengers had to stay in the train overnight. This suspension time was the longest since the Shinkansen began running in 1964. Since this caused a large social problem, the Ministry of Transport directed JR Central to improve the railway system so as to avoid such disasters in the future.

The National Disaster Act was put in force in the following 17 cities and towns: Nagoya City, Shikatsu Town, Toyoyama Town, Toyoake City, Nishibiwajima Town, Shinkawa Town, Handa City, Kariya City, Oobu City, Iwakura City, Mihama Town, Nishiharu Town, Kiyosu Town, Jimokuji Town, Ooharu Town, Higashiura Town in Aichi Pref., and Kamiyahagi Town in Gifu Pref.

2.2 Comparison with the past heavy rainfall disaster

In Aichi Pref., about 65,000 houses were inundated in this disaster. There were especially a lot of first floors which were inundated. This is one of the heaviest inundation damages after 1971. However, there were nine heavy rainfall disasters after 1971 in which the inundation of 50,000 houses or more was recorded in one prefecture. Most recent similar damage occurred in Saitama Pref. 18 years ago (September 1982) when the typhoon 18th and stationary front caused the inundation of 60,100 houses (Japan Meteorological Agency, 1999). The inundation damages of recent remarkable heavy rainfall disasters were rather smaller than these two disasters. In the case of the Kouchi heavy rainfall disaster in September 1998, eight people died or went missing, 141 houses were ruined or half-ruined, and 17,300 houses were inundated. In the case of the Hiroshima heavy rainfall disaster in June 1999, these factors were 32, 512, and 3,827, respectively.

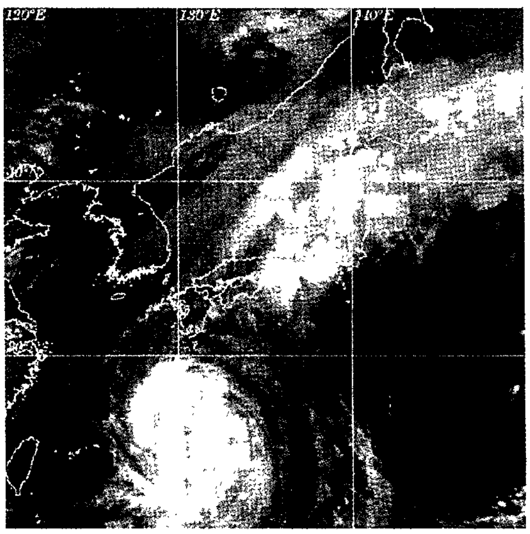

Fig.1 Infrared image of meteorological satellite (GMS) at 19:00 Sep.11, 2000
http://www.tkl.iis.u-tokyo.ac.jp/SatIAN/

Table 1 The damage in each prefecture

Prefecture	Death toll	Damage of buildings (buildings): Ruined and half-ruined	Inundated
Ibaraki	-	-	25
Tochigi	-	-	40
Gunma	-	-	38
Saitama	-	-	139
Kanagawa	-	-	47
Fukui	-	-	1
Yamanashi	-	9	650
Nagano	-	1	204
Gifu	1	28	483
Shizuoka	1	-	34
Aichi	7	239	65410
Mie	1	2	3089
Wakayama	-	31	1037
Osaka	-	-	12
Hyogo	-	-	16
Tokushima	-	1	31
Okinawa	-	1	35
All Japan	10	312	71291

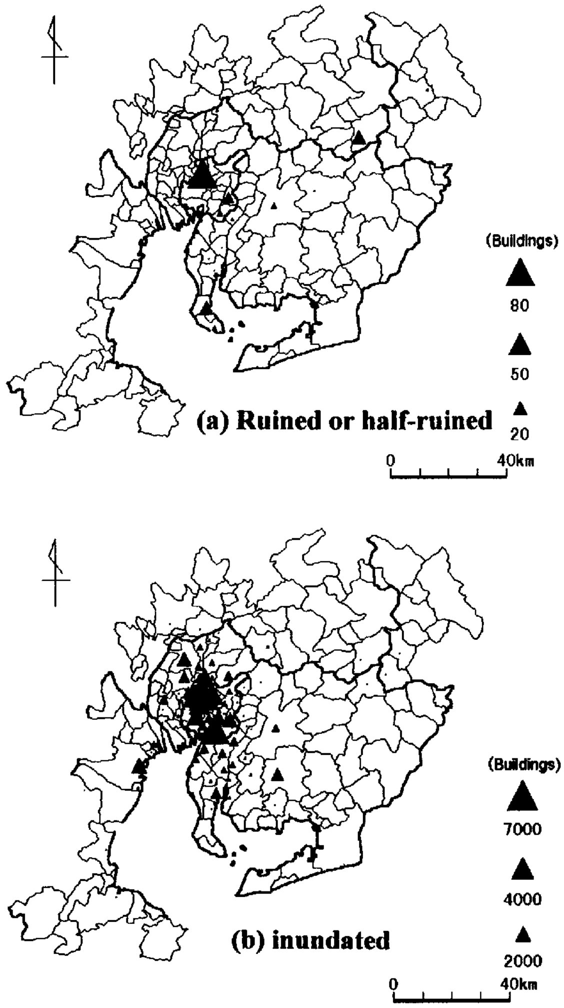

Fig.2 The damage in each municipality (Upper:The number of ruined or half-ruined houses, Lower:The number of inundated houses)

2.3 Past heavy rainfall disaster in Aichi Pref.

Table 2 shows the major heavy rainfall disasters after 1971 in Aichi Pref. Most of the events were caused by a combination of typhoon and stationary front. This combination also caused the severe disaster in the present instance. But large-scale sediment disasters such as those of July 1972 did not occur this time. This might account for the lesser damage to humans and housing in the present instance, though there was much precipitation.

The "Ise bay typhoon" in September 1959 is well-known as the cause of an especially large disaster around Aichi Pref. The number of dead or missing persons was 5,098 throughout the entire country(Aichi Pref. 3,251, Mie Pref. 1,273), about 830,000 houses were destroyed, and about 360,000 houses inundated. However, most of this damage was inflicted by the high tide. Two-day precipitation was 198 mm at Gifu(Gifu Pref.), 164 mm at Nagoya, and 265 mm at Ueno(Mie Pref.) etc. These values are much smaller than the 600 mm experienced at Nagoya in the present case.

3. Precipitation features

3.1 Precipitation before the heavy rainfall

In 2000, summer precipitation in Japan was so slight that concern was expressed regarding a water shortage. The ratios in relation to the normal precipitation in Tokai district of this year were from 70 % to 100 % in April and May, from 100 % to 120 % in June, and 40 % or less in July and August(JMA, 2000a-2000e). The five-day precipitation from April to September 2000 at Nagoya Local Meteorological Observatory is shown in **Fig.3**. No five-day precipitation exceeded the normal during this period. Rainfall was not recorded from the middle of May to the middle of June. In Baiu season (June to July), seasonal precipitation was slightly less than normal; very few rainfalls had occurred since August. The total precipitation at Nagoya was only 23 mm (four small rainfall events) from the beginning of August to 10 September.

3.2 Situation from 11 to 12 September

Figure 4 shows an isohyetal map of the two-day precipitation from 11 to 12 September. This figure is based on data gathered by the Ministry of Construction, Japan Meteorological Agency (JMA) and Aichi Pref. As the figure indicates, heavy

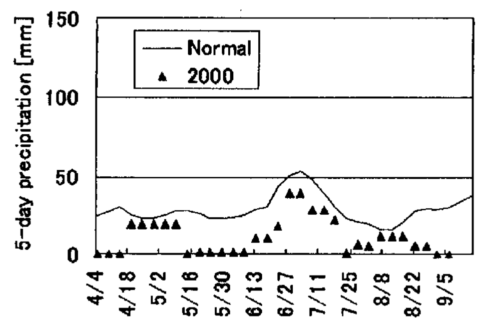

Fig.3 5-day precipitation at Nagoya (Normal year:average from 1961 to 1990)

Table 2 The heavy rainfall disaster Aichi Prefecture since 1971

Date	Death・missing	Damage of buildings (buildings) Ruined and half-ruined	Inundated	Weather condition
1971/8/30-8/31	4	67	0	Typhoon
1971/9/26-9/26		2	34500	Typhoon
1972/7/ 9-7/13	66	528	0	Stationary front *1
1972/9/14-9/17	2	315	0	Typhoon and occluded front
1974/7/ 7-7/ 7	2	69	8690	Typhoon and stationary front
1974/7/24-7/25		38	57620	Low passing along south coast
1975/8/21-8/23	3	2	997	Typhoon
1976/9/ 8-9/14	1	972	101100	Typhoon and stationary front *2
1979/9/24-9/24	2	0	24560	Typhoon and stationary front
1983/9/26-9/28	5	2	9886	Typhoon and stationary front
1989/9/19-9/20	2	2	12	Typhoon and stationary front
1991/9/18-9/19	2	9	13415	Typhoon and stationary front

*1 Heavy debris flow occurred on the Obara Village(East part of Aichi Pref.).
*2 Embankments were destroyed in the Nagaragawa river.

rainfall areas which received the total precipitation about 600 mm are in the southern part of Mie Pref., the eastern part of Aichi Pref., and around Nagoya City. The southern part of Mie Pref. and the eastern part of Aichi Pref. are regions that experience heavy rainfall, while Nagoya receives lesser amounts. It is notable that such heavy rainfalls occurred around Nagoya City in the present instance. For example, 618 mm was recorded for two days at the Miyagawa observatory (Miyagawa Village) in the southern part of Mie Pref. This is 1.18 times the normal amount of precipitation in September (522 mm). On the other hand, the two-day precipitation of 567 mm at Nagoya is 2.43 times the normal amount of precipitation in September (233 mm).

Figure 5 shows the hourly precipitation and cumulative precipitation at Nagoya and Yarigairi, which were selected as representative rain-gauges in the areas that received the heaviest amounts of rainfall. The heavy rainfall in the present instance occurred within about 24 hours. The first heavy rainfall occurred in Nagoya between 18:00 and 21:00 on 11 September. The second was from 23:00 on 11 Sep. to 04:00 on 12 Sep. Rain stopped around 08:00 on 12 Sep. **Table 3** shows the precipitation data gathered at the main observatories. The precipitation record of this time can be summarized as follows: the maximum hourly precipitation is about 110 mm; 24-hour precipitation is about 500 mm; and the total precipitation is about 600 mm.

3.3 Comparison with past heavy rainfalls

Table 4 shows the historical maximum daily and hourly precipitation at five Weather Offices (Local Meteorological Observatory and Weather Station, JMA) in Tokai district. Daily precipitation records shown in **Table 4** are rather small compared with records obtained in regard to the present event. However, investigating the records of other precipitation observatories in the district (213 locations), we found three events of more than 500 mm in a single day. Daily precipitation regarding the present case was especially heavy in relation to others in the past about 100 years.

Hourly precipitation (93 mm) slightly exceeded the historical maximum value (92 mm) in Nagoya Local Meteorological Observatory. However, as shown in **Table 4**, this can be regarded as comparable to the historical maximum over the past 100 years.

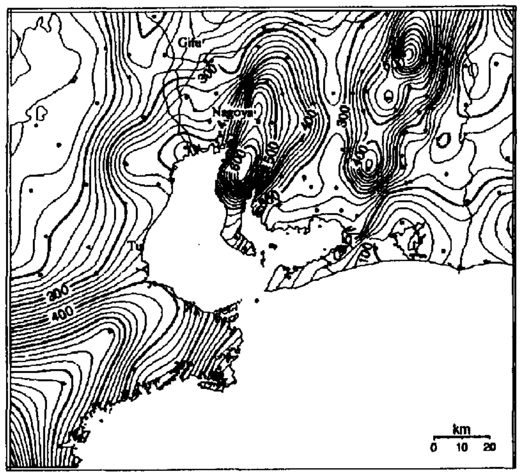

Fig.4 Isohyetal map of two-day precipitation from 11 to 12 September in Tokai District

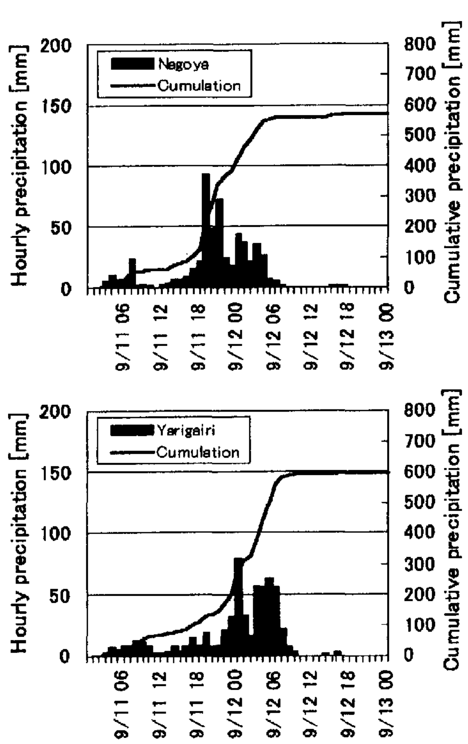

Fig.5 Hourly and cumulative precipitation at Nagoya and Yarigairi from 11 to 12 Sep., 2000

Frequency analysis by the GEV (general extreme-value) distribution using annual maximum daily precipitation data (1901-1999) at Nagoya showed that 100-year probable precipitation is 229 mm, while the 500-year is 334 mm. This analysis also indicated that the return period of the daily precipitation of 428 mm (11 Sep.) is 40,137 years. According to the Aichi Pref. Flood Control Plan (Aichi Pref. 2000), the 100-year hourly precipitation in the Nagoya district is 98 mm, and the

Table 3 Precipitation data at the main observatories

Station name	Municipality, Prefecture	Maximum Hourly	Precipitation (mm) Sep. 11	Sep. 12	2-day	Maximum 24-hour
Japan Meteorological Agency						
Inabu	Inabu Town, Aichi	70	222	245	467	438
Nagoya	Nagoya City, Aichi	93	428	139	567	535
Toyota	Toyota City, Aichi	61	217	196	413	388
Tokai	Tokai City, Aichi	114	492	97	589	557
Gifu	Gifu City, Gifu	34	204	38	242	224
Yokkaichi	Yokkaichi City, Mie	36	295	67	362	319
Tu	Tu City, Mie	25	284	70	354	284
Ministry of Construction						
Kamiyahagi	Kamiyahagi Town, Gifu	65	202	235	437	403
Yarigairi	Kamiyahagi Town, Gifu	80	278	317	595	552
Aichi Prefectural Office						
Uedagawa	Meitou Ward, Nagoya, Aichi	77	429	127	556	523
Agiu	Agiu Town, Aichi	80	498	124	622	588

Table 4 Historical maximum daily and hourly precipitations at Weather Offices in Tokai district

	Maximum daily precipitation Data(mm)	Date	Period	Maximum hourly precipitation Data(mm)	Date	Period
Gifu	260.2	1961/06/26	1883-1999	99.6	1914/07/02	1903-1999
Nagoya	240.1	1896/09/09	1891-1999	92.0	1919/07/18	1891-1999
Tu	288.2	1959/08/13	1889-1999	118.0	1999/09/04	1916-1999
Irako	337.1	1962/07/02	1947-1999	81.8	1962/07/02	1950-1999
Yokkaichi	271.0	1974/07/25	1966-1999	82.5	1971/07/07	1966-1999

100-year daily precipitation is 330 mm. It is clear that the heavy rainfall in 2000 greatly exceeded the heavy storms predicted at Nagoya based on past data.

4. Survey in Nagoya City

The heavy rainfall brought severe damages to the people and caused ten breakings of river embankment in Aichi prefecture as shown in **Fig.6**. Field surveys were conducted in three areas in Nagoya city on 13 Sep., 16 Sep. and 4 Oct., 2000. The three areas are (**4.1**) the breaking point of embankment of the Shinkawa river, (**4.2**) the overflow point of the Shonai river and (**4.3**) Nonami area along the Tenpaku river. These areas are marked in the figure with the number of 1 to 3. Reports on the three areas are as follows.

4.1 The breaking point of embankment of the Shinkawa river

Figure 7 is a map of surrounding area near the breaking point of the embankment of the Shinkawa. The hyetograph and hydrograph of water level in this area are shown in **Fig.8**. Two records of water-level were measured at the breaking point (Suiba River W.L. Sta.) and Kujino Water-Level Station located 4 km upstream from the point. The water-level of the Shinkawa was rising over the H.W.L. (TP 5.20m) at 19:40 on 11 Sep. and reached the maximum (TP 6.28m) at 3:20 on 12 Sep. Finally, the embankment was broken down ten minutes later. The main reason why such a high water level continued for about 8 hours is the urbanization of river basin, however, it is another reason that some part of flood in the Shonai river overflowed into the Shinkawa through the Shinkawa weir shown in **Fig.7**. The peak discharge diverged from the Shonai river was up to 270 m^3/s. The discharge was not small compared with the design discharge of the Shinkawa river (470 m^3/s). **Figure 9** shows the area and the cross section of the embankment which was temporarily refilled with sand. **Photo 1** was taken after the refilling work.

Generally speaking, reasons of river-bank fail-

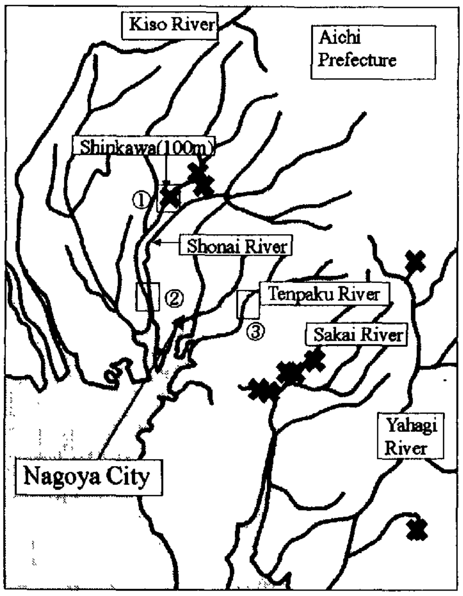

Fig.6 Location map of field survey and breaking points of embankment in Aichi prefecture

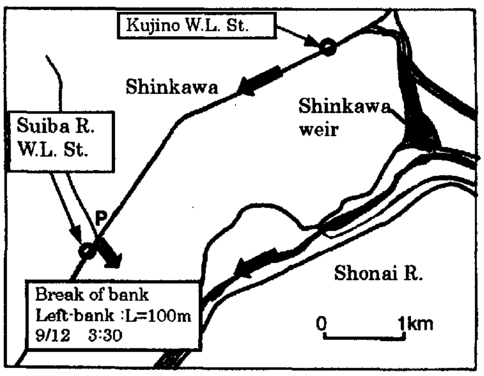

Fig.7 The breaking point of embankment of Shinkawa river

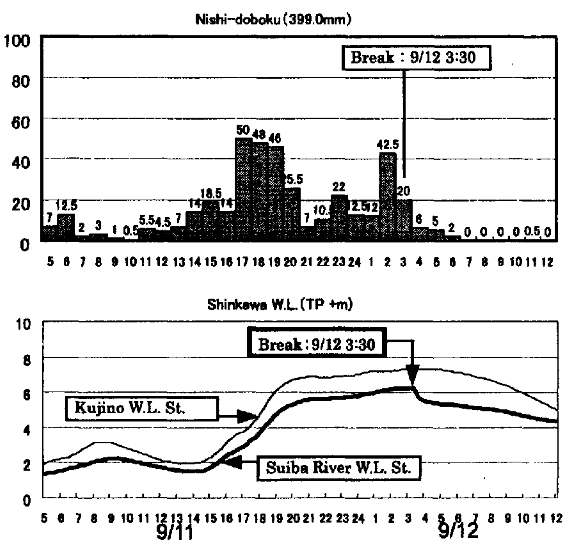

Fig.8 Hyetograph and hydrograph of water level in Shinkawa area

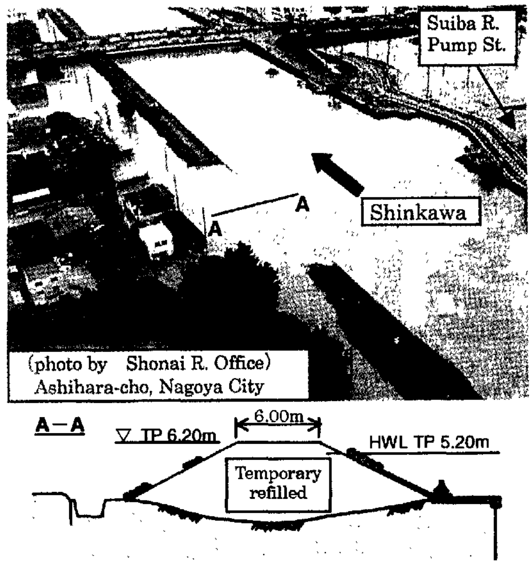

Fig.9 The breaking of Shinkawa's embankment and the cross section

ures are caused by overflow, seepage flow, erosion or others. As the river flow did not overflow the embankment in this case, it is considered that the main reason of the breaking was seepage flow in the embankment. Because the water level was higher than the H.W.L. for about 8 hours, and there was a man who watched some bubbles foamed on the bank.

4.2 The overflow point of the Shonai river

On the right bank of the Shonai river located 4.3-4.5 km apart from the river mouth, the river flow overflowed the embankment and flooded into the residential area (**Fig.10**). It was about two hours from 4:28 to 6:15, 12, Sep. **Figure 11** is the hyetograph and hydrograph of water level. The water level was measured at Shimono-issiki water level station shown in **Fig.10**. Top level of the embankment shown in **Photo 2** is TP 4.27 m. As the water level of the Shonai river was over the top level for about 3 hours, many sand bags were stacked on the parapet as shown in **Photo 2**. The depth of inundation was about 30 cm in the residential area.

4.3 Nonami area along the Tenpaku river

Nonami area is surrounded by three rivers as shown in **Fig.12**. The three rivers are the Tenpaku river, the Fuji river and the Goshita river. The ground level of this area is two meter lower than the top level of all embankments. This area has been attacked by floods, and many houses

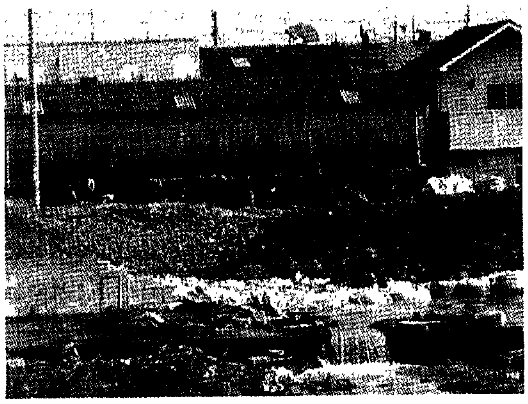

Photo 1 Temporarily refilled embankment of Shinkawa

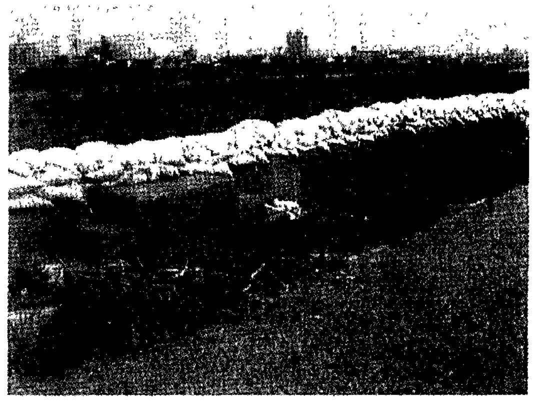

Photo 2 Sand bags stacked on the parapet of the bank of Shonai river

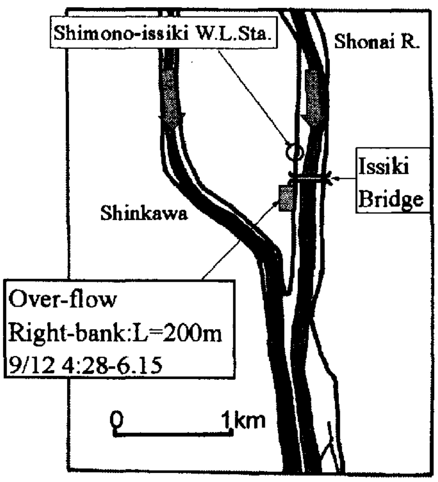

Fig.10 Map of the overflow point of Shonai river

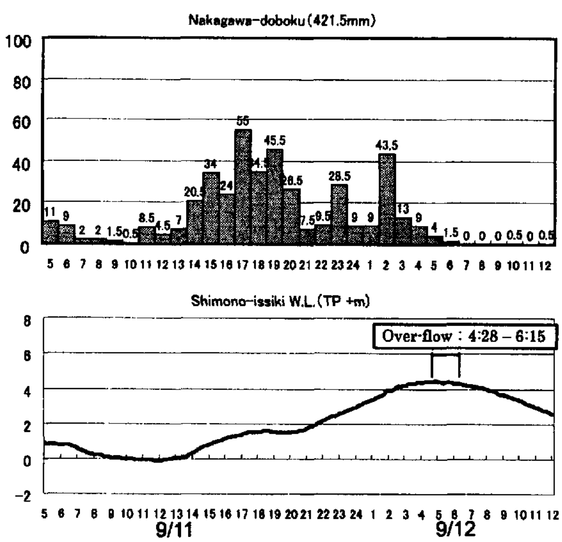

Fig.11 Hyetograph and hydrograph of water level in Issiki area

were inundated. Recently, this area was damaged by the typhoon 18th with heavy rainfall on 19, Sep., 1991.

(1) The Tenpaku river, the Fuji river and the Goshita river

Figure 13 is the hyetograph in this area and hydrograph of water level measured at the Tenpaku water level station in **Fig.12**. The water level was higher than the design H.W.L. of TP 8.66 m for nine and half hours during the flood. The maximum level was only 15 cm lower than the top level of embankment. It was very dangerous situation for the embankment. Some protection works for leakage from the embankment have been done along this river. In this river, the bank protection of main channel was broken as shown in **Photo 3**. Sand was sucked out from the back of the bank protection, and the wall sank down. There were plenty of same damages in Tokai district and 722 banks were restored by the government in Aichi prefecture.

The Fuji and the Goshita rivers are branches of the Tenpaku river. As the water level of Tenpaku river was very high during the flood, flows in the Fuji and the Goshita rivers were dammed up. Some marks of flood were observed along the Goshita river. The marks indicate that the flow in the Goshita river overflowed and flooded into Nonami area.

(2) Inundation Condition at Nonami District

According to the observation of residents in Nonami district, with heavy rainfall, the overflow

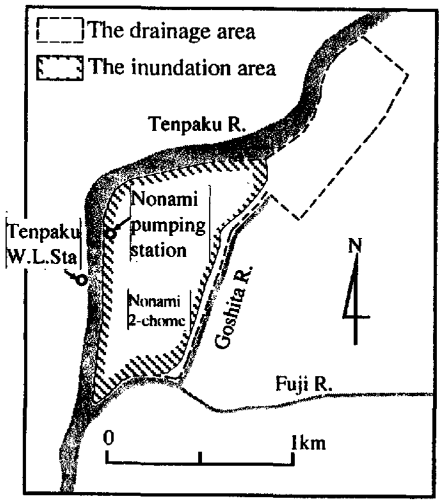

Fig.12 Map of Nonami area and its neighborhood

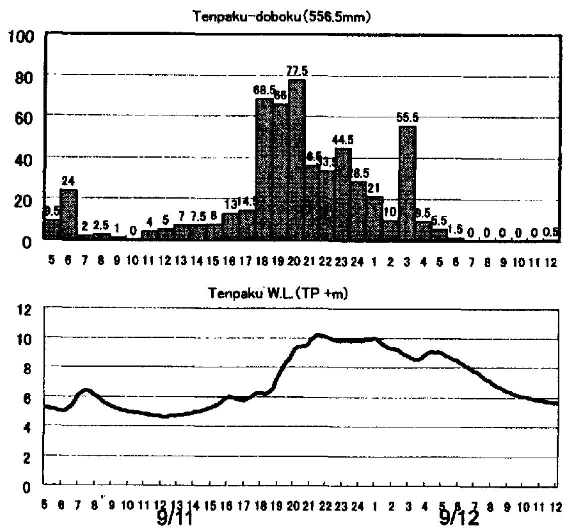

Fig.13 Hyetograph and hydrograph of water level in Nonami area

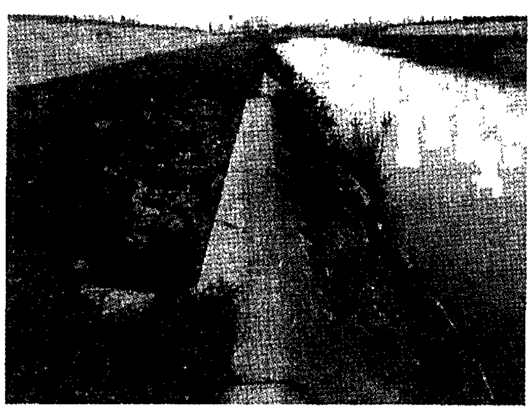

Photo 3 Damaged bank protection in the main channel of Tenpaku river

from the Goshita river started around 20:00 11 September, and the inundation depth increased suddenly in this district. The survey report issued by Nagoya municipal office describes that the maximum inundation depth around Nonami pumping station reached 2.4 m. Many floodmarks of 2 m height were also observed in our survey. The inundation area in **Fig.12** is about 0.7 km^2, and it was after 6:00 13 September when the inundation subsided around Nonami pumping station.

The drainage area of Nonami pumping station is 1.14 km^2 and its maximum drainage capacity is 8.6 m^3/s which corresponds to the disposal of 50 mm hourly rainfall. This inundation was caused by both the heavy rainfall over 50 mm hourly rainfall intensity and the overflow from the Goshita river. As the inundation water volume was beyond the drainage pump capacity, the inundation damage was enlarged. **Figure 14** shows the cumulative water volume drained from Nonami pumping station to the Tenpaku river (**a** in **Fig.14**), the cumulative inundation water volume (**b** in **Fig.14**) and the cumulative inner water volume (**c** in **Fig.14**). The inner water volume is calculated by the rainfall water volume per unit area multiplied by Nonami drainage area. The difference between **b** and **c** denotes the inundation water volume coming from the area except for Nonami drainage area. The overflowing water volume from the Goshita river is included here. The total inundation water volume was about 1.1 million m^3, of which 0.6 million m^3 was the cumulative inner water volume. The water volume coming from the area except for Nonami drainage

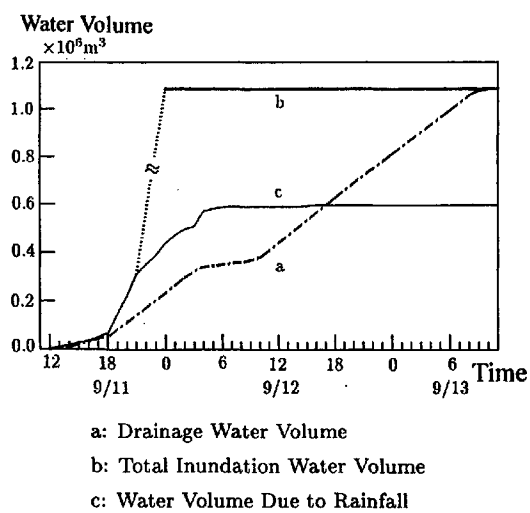

Fig.14 Cumulative drainage water volume and inner water volume

area was 0.5 million m^3, which was almost half of the total inundation water volume. By this huge inundation water volume, the pumping drainage lasted until the morning of 13 September.

4.4 Subway Damage by Inundation

At some stations of Nagoya municipal subways, inundation water flowed through station concourses into subway railways and subway services were suspended. At Nonami station of Sakuradori line, Shiogamaguchi station of Tsurumai line, and Heiandori station of Meijo line (see **Fig.15** and **Fig.16**), the inundations to railways occurred from 19:00 to 21:00 11 September. Also, at Kamiotai station of Tsurumai line, the inundation water by bank breach of the Shinkawa river flowed down and the water invaded into the station concourse around 6:00 12 September. By these inundations, the subway services began to suspend around 20:00 to 21:30 11 September. Sakuradori line and Tsurumai line were restored all the line at 18:00 and at 18:30 12 September, respectively, and Meijo line resumed its entire line service at 15:00 13 September. Consequently, many citizens were deprived of the means of transit.

Nonami station and Shiogamaguchi station are located in the low-lying area along the Goshita river and the Ueda river, both of which are the branches of the Tenpaku river, respectively, and inundation water on the surface flowed through subway entrances connected to concourses into subway railways. Flash boards of stair entrance were set at both stations. At Nonami station, the flash board of 40 cm height was set at each entrance (see **Photo 4**). However, as the surface inundation depth became higher than the flash board height, the inundation water invaded over the flash board. At Shiogamaguchi station, though wooden boards of 20 cm height were piled up, the inundation water could not be obstructed. And at Heiandori station, the new subway construction site adjacent to the station was submerged and the part of submerged water flowed into the subway railway from the drainage holes.

For considering inundation disaster countermeasures in the future, the lessons obtained through these inundation accidents are the following.

1. Setting of flash board of stair entrance is effective for inundation water protection, but the surface inundation depth is much influenced by the geographical condition around the station. Therefore, the review of past inundation records and the detailed check of geographical conditions around the station studied are very significant.
2. When the surface inundation extends suddenly, the inflow protection activities at plural entrances are expected to be very difficult. A sure preparation for controlling inundation water intrusion into subway station should be proceeded from ordinary times.

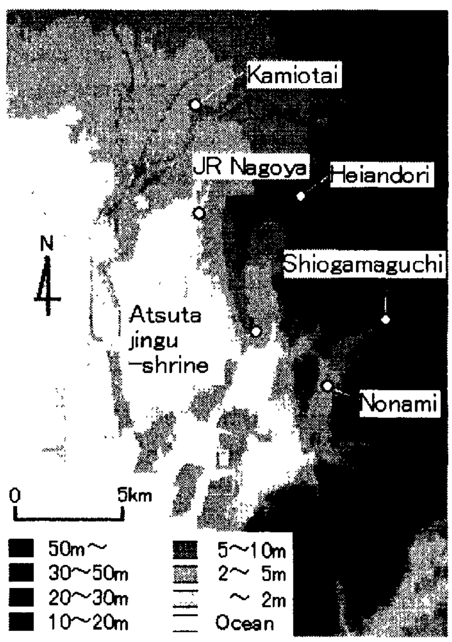

Fig.15 Location of subway stations

5. Information dissemination by the Internet

The information dissemination and information exchange over the Internet regarding such dis-

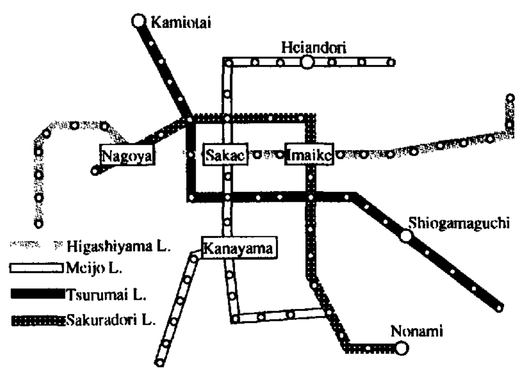

Fig.16 Subway routes

Photo 4 Flash board of stair entrance at Nonami station

asters have been actively performed since the Fukushima and Tochigi heavy rainfall disasters in 1998 (Ushiyama, 1999). We may say that the use of the Internet has become generalized during the current disaster. In the past, citizens and volunteer groups were the primary Internet users. However, the information dissemination by the Local Government has been enhanced in the present instance. Aichi Pref., Gifu Pref., the Ministry of Construction, etc. created homepages in regard to this disaster. The URL of the main homepage as of April 2001 is shown below.

- The River Bureau, The Ministry of Land, Infrastructure and Transport
  http://www.mlit.go.jp/bosai/disaster/bosai.htm
- Aichi Prefecture
  http://www.pref.aichi.jp/shobo/BOUSAI/index.html
- Gifu Prefecture
  http://www.pref.gifu.jp/s11115/sougou/index.htm
- The present author (USHIYAMA Motoyuki, DPRI, Kyoto Univ.)
  http://fmd.dpri.kyoto-u.ac.jp/~ushiyama/disaster/20000911/

After the disaster, all of these homepages were created within the course of a few days. However, differences existed regarding the contents of these homepages and how quickly they were created by their originators. It is noteworthy that a newspaper article (The Asahi News on 14 Sep.) pointed out that several public offices did not use the homepages for disaster information dissemination. However, we may say that homepage usage is becoming more widespread as a way to provide disaster information.

6. Conclusion

(1) The principal damage over the entire area of Japan was as follows: The death toll was 10; the number of inundated houses was about 71,300; ruined or half-ruined houses about 310. Most of damages occurred in Aichi Pref. The death toll and damaged houses were few, though the number of inundated houses was the highest in the last 18 years in Japan.

(2) In the heaviest rainfall area, two-day precipitation was about 600 mm, 24-hour precipitation was about 500 mm, and maximum hourly precipitation was about 110 mm. This record for daily precipitation was the highest in the past about 100 years in Tokai district, while the entire hourly precipitation was comparable with the historical maximum records, which had been recorded several times in the past about 100 years. There was little antecedent rainfall.

(3) An embankment of about 100 m was destroyed in the Shinkawa river in the Nishi Ward of Nagoya City. Besides this, embankments were destroyed at ten places in Aichi Pref., and much flood damage occurred around Nagoya City and the northern part of the Chita Peninsula. Because of lesser amounts of rainfall in upstream areas, damage due to water from upstream was not significant.

(4) The inundation to underground space occurred. It took about two days for the Nagoya Municipal Subway to completely restore its operations. Inundation of underground stations occurred at Shiogamaguchi Station (Tsurumai Line) and Nonami Station (Sakuradori Line), etc. Damage could not be prevented due to the size of the flood which exceeded the flash boards set up at the station entrances.

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2000年9月東海豪雨災害について

井上和也・牛山素行・石垣泰輔・戸田圭一・栗山健作*

*京都大学大学院　工学研究科

要旨

2000年9月11～12日，東海地方は台風14号の影響により活発化した停滞前線（秋雨前線）による激しい集中豪雨に見舞われた．名古屋市周辺では2日間最大雨量，日最大雨量，時間最大雨量がそれぞれ，600 mm，500 mm，114 mmに達した．

この豪雨により愛知県を中心に東海地方各地で大きな洪水被害が生じた．名古屋市およびその近郊の河川では，10箇所で河川の破堤が生じ，また多くの箇所で溢水が起こった．とくに新川左岸の破堤は大規模な外水氾濫をもたらした．自治省消防庁によれば，死者10名，家屋の損壊310棟，浸水家屋は71,300棟に達している．浸水家屋数は過去10年の浸水被害のなかで最大である．本報は名古屋を中心とした降雨状況および洪水被害を取りまとめ，災害の特徴を整理している．

キーワード：豪雨災害，浸水被害，破堤，都市水害，東海地方