The Assessment of The Integrated Structural Flood Control System in The Jingjiang Reach of The Yangtze River on Mitigating a Catastrophic Flood

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Abstract. In order to mitigate the flood disaster, an integrated structural flood control system, mainly incorporating levees, reservoirs, and flood diversion and detention zones, has been established in the Jingjiang Reach of the Yangtze River by the efforts of Chinese government after several decades. The flood control effect of the integrated structural flood control system on mitigating the most catastrophic flood in history record which did occur in 1870 was assessed. According to the results, the used storage for flood control of the Three Gorges Reservoir is 18.4 billion m³ and the used storage for flood control of the other upstream reservoirs is 9.3 billion m³. The used flood storage of the Jingjiang Flood Diversion Zone is 5.4 billion m³ and the highest water level at Shashi Station is 45.00 m. It shows that the flood control safety in the Jingjiang Reach is ensured to reach the achievement that controlling the highest water level at Shashi Station no more than 45.00 m in the flood of 1870 to avoid the likely catastrophic flood disaster in the Jianghan plain and Dongting Lake plain along the Jingjiang Reach.

1. Introduction
The Jingjiang Reach, which has a length of 347 km, is located between Zhicheng and Chenglingji in the Middle Yangtze River, China. The Jingjiang Reach with the Jianghan plain at the north bank and Dongting Lake plain southwards is the most flooding-vulnerable reach of the Yangtze River during the flood season. This is because the water level in the river during the flood season is about 6-17 m higher than the floodplain, as a consequence of the silt deposition on the river bed for long time. And water flows slowly in the highly meandering river channel of the Jingjiang Reach, which leads to a longer flood retention time and a higher flood level. As the historic records indicate, there had been 216 floods during the 2000 years, averaging almost once every ten years. If the flood overflows the banks of Jingjiang reach, devastating disasters will render millions of people homeless and cause huge amount of property loss.

In order to mitigate the flood disaster, an integrated structural flood control system, mainly incorporating levees, reservoirs, and flood diversion and detention zones, has been established in the Yangtze River by the efforts of Chinese government after several decades. The integrated structural flood control system follows the principles of “combining storage and release, and focusing on release”. According to the principle, structural flood control measures include: properly raising and rehabilitating the bodies of the levees, constructing reservoirs on the Yangtze mainstream and its tributaries, planning and constructing flood diversion and detention zones. With stem levees as basis,
key reservoirs and multi-purpose projects as core and flood diversion and detention zones as reserve, the integrated structural flood control system improves the standard of flood protection for Yangtze River significantly.

In order to analyze the ability of the integrated structural flood control system for flood protection in the Jingjiang reach of the Yangtze River, the flood control effect of the integrated structural flood control system on mitigating the most catastrophic flood in history record which did occur in 1870 will be assessed.

![Figure 1. The study area of the Jingjiang Reach in the Yangtze River](image)

### 2. Integrated structural flood control system in the Jingjiang Reach

#### 2.1. Levees

The levee on the north bank of the Jingjiang Reach of the Yangtze River is the Jingjiang Levee with a total length of 182.35 km. The levee on the south bank of the Jingjiang Reach of the Yangtze River is the Jingnan Levee with a total length of 189.32 km. The Jingjiang Levee and the Jingnan Levee has a long history of development, which can date back to 16th Century, Ming Dynasty. After the great flood in 1998, the levees along the Jingjiang Reach has been raised and rehabilitated to reach the planning standard. The levee design water level for the Jingjiang Reach at Shashi station is 45.0 m
(Wusong Elevation), which means that flood under 10-year-recurrence can be fought effectively only by the levees of two banks in the Jingjiang reach.

Table 1. Basic information on the levees along the Jingjiang Reach of the Yangtze River

| Name          | Side       | Length (km) | Level of importance | The height between levee top and the design water level (m) |
|---------------|------------|-------------|---------------------|----------------------------------------------------------|
| Jingjiang levee | north bank | 182.35      | 1                   | 2.0                                                      |
| Jingnan levee  | south bank | 189.32      | 2                   | 1.5-2.0                                                  |

2.2. Reservoirs
At present, a number of reservoirs for comprehensive water resource utilization including flood control, such as Three Gorges Reservoir, Xiluodu Reservoir and Xiangjiaba Reservoir, have been built in the upper reaches of the Yangtze River (above the Jingjiang Reach), with a large storage capacity and flood control capacity. Among these reservoirs, the total number of large reservoirs which has a total storage capacity of more than 100 million m³ is 102. According to the statistics, the total storage capacity of the 102 large reservoirs is 80 billion m³, and of which the reserved flood control capacity is 39.6 billion m³. The Three Gorges Reservoir which has a total storage capacity of 39.3 billion m³, of which 22.15 billion m³ is for flood control, plays the most important role in the flood control for the Jingjiang Reach. The flood control standard in the Jingjiang reach of the Yangtze River is raised from less than 10-year-recurrence to 100-year-recurrence as a result. Other upstream reservoirs which have the flood control task for the Jingjiang reaches cooperate with the Three Gorges Reservoir to regulate upstream flood.

![Diagram of Main Reservoirs on the Upper Yangtze River above Jingjiang Reach.](image)

2.3. Flood diversion and detention zone
In order to ensure the flood control safety of the important area, such as Jingzhou City, 4 flood diversion and detention zones with an effective storage capacity of 7.16 billion m³ are planned and constructed in the Jingjiang reach of the Yangtze River. Once a great flood more than 100-year-recurrence happens, the floodgates of the flood diversion and detention zones will be opened in time to keep the flood water level in the river channel no higher than the design water level of the levee along the Jingjiang reach. Jingjiang Flood Diversion Zone is the largest one, which has an flood storage area of 920 km² and can take 5.4 billion m³ of water. Jingjiang Flood Diversion Zone was built in 1952. During the flood season in 1954, the floodgate of Jingjiang Diversion Basin was operated three times to ensure the safety of the Jingjiang Levee and Shashi city located downstream from the Jingjiang Flood Diversion Zone. This prevented about 30,000 of fatalities.
Table 2. Basic information on the flood diversion and detention zones of the Jingjiang Reach

| Name                                | Flood storage area (km²) | Cultivated area (10³ ha) | Population (10⁴) | Effective storage capacity (10⁹ m³) |
|-------------------------------------|-------------------------|--------------------------|------------------|-----------------------------------|
| Jingjiang Flood Diversion Zone      | 920                     | 34.0                     | 516              | 5.4                               |
| Yuanshi Flood Diversion and Detention Zone | 96                      | 5.8                      | 68               | 0.2                               |
| Renmin Flood Diversion and Detention Zone | 255                     | 18.4                     | 212              | 1.18                              |
| Huxi Flood Diversion and Detention Zone | 86                      | 5.1                      | 60               | 0.38                              |

3. The operation guideline of integrated structural flood control system in the Jingjiang Reach

3.1. Mitigating Flood less than 100-year-recurrence
Make full use of the river channel to discharge flood. Dispatch the Three Gorges Reservoir and its upstream reservoirs jointly to store the flood. Use the Qingjiang cascade reservoirs timely to stagger the peak. Wait for an opportunity to use the floodplains and bars between levees to discharge and store flood to control the water level at Shashi Station no more than 44.50 meters.

When floods occur in the Qingjiang River and the Juzhang River, make full use of the reservoirs of Geheyan, Shuibuya and Zhanghe to store flood, cut down flood peak and stage flood peak to alleviate the downstream flood control pressure.

3.2. Mitigating Flood over 100-year-recurrence
Make full use of the reservoirs such as the Three Gorges Reservoir to store floods jointly to control the maximum flow discharge at Shashi station no more than 80,000 m³/s. According to the real-time conditions of flood flow and flood control projects, use Jingjiang Flood Diversion Zone, Yuanshi Flood Diversion and Detention Zone, Huxi Flood Diversion and Detention Zone and Renmin Flood Diversion and Detention Zone orderly to diverse and store flood in the aim of controlling the water level at Shashi station no more than 45.00 meters.

4. Case study of the catastrophic flood of 1870
According to the investigation of historical floods in the Jingjiang Reach, the flood occurred in 1870 was the largest since 1153. The discharge of the flood peak at Zhicheng is about 110,000 m³/s. Songzi River liking the mainstream of the Jingjiang River to the Dongting Lake was formed due to the one of the many levee breaches. It is estimated that the catastrophic flood inundated more than 40,000 km² in the middle reach of the Yangtze River. In the following, how the integrated structural flood control system in the Jingjiang Reach work to mitigate the flood is assessed.

4.1. Reservoirs Storage
When the inflow of the Three Gorges Reservoir reached 61100 m³/s on July 16. The Three Gorges Reservoir started to control the discharge at Zhicheng no more than 56,700 m³/s to control the water level at Shashi Station no more than 44.50 meters The other upstream reservoirs, such as Xiluodu and Xiangjiaba, stored base flow at the same time. On July 20th, the water level of the Three Gorges Reservoir rose to 171.17m. Then the Three Gorges Reservoir started to control the discharge at Zhicheng no more than 80,000 m³/s. Due to the regulation of upstream reservoirs, no flood discharge more than 80,000m³/s at Zhicheng occurred in the rest time of the flood event.

After the flood event of 1870 ended, the used storage for flood control of the Three Gorges Reservoir is 18.4 billion m³ and the used storage for flood control of the other upstream reservoirs is 9.3 billion m³.
4.2. The joint operation of the levees and flood diversion and detention zone

On July 20th, the storage water level of the Three Gorges Reservoir reached to 171.0m. At 18:00 pm, the water level of Shashi Station rose to 45.00m, and was going on rising. According to the flood control operation rules, the North Gate of Jingjiang Flood Diversion Zone was opened gradually. At 04:00 am on July 21rd, the North Gate of Jingjiang Flood Diversion zone was fully opened. Considering the loss of opening Lalinzhou gate in Jingjiang Flood Diversion Zone, Lalinizhou gate was not opened. At 20:00 pm on July 22, the water level of Shashi Station fell below 45.00m and the North Gate was closed. The water level in the Jingjiang Reach rose again at 07:00 am on July 29. The water level at Shashi Station reached 45.00m at 4 am on July 30 and continued to rise. According to the flood control operation rules, the North Gate of Jingjiang Flood Diversion Zone was opened gradually at the second time. At 03:00 am on July 31, the North Gate was fully opened, and the rising trend of water level at Shashi Station could not be controlled. Then, the Lalinizhou gate in Jingjiang Flood Diversion Zone was actived to control the water level at Shashi Station no more than 45.00m. At 00:00 pm on August 4, the water level in the Jingjiang Reach began to decline, which meant the catastrophic flood was going to the end.
During the flood event of 1870, the flood storage of the Jingjiang Flood Diversion Zone is 5.4 billion m$^3$ and the highest water level at Shashi Station was 45.00m. The results show that the flood control safety in the Jingjiang Reach is ensured to reach the achievement that controlling the highest water level at Shashi Station no more than 45.00m in the flood of 1870.

5. Conclusion
In order to mitigate the flood disaster, an integrated structural flood control system, mainly incorporating levees, reservoirs, and flood diversion and detention zones, has been established in the Yangtze River by the efforts of Chinese government after several decades. The flood control effect of the integrated structural flood control system on mitigating the most catastrophic flood in history record which did occur in 1870 was assessed. According to the results, the used storage for flood control of the Three Gorges Reservoir is 18.4 billion m$^3$ and the used storage for flood control of the other upstream reservoirs is 15.5 billion m$^3$. The flood storage of the Jingjiang Flood Diversion Zone is 5.4 billion m$^3$ and the highest water level at Shashi Station was 45.00m. It shows that the flood control safety in the Jingjiang Reach is ensured to reach the achievement that controlling the highest water level at Shashi Station no more than 45.00m in the flood of 1870.

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