Proceedings of the 9ICEG
9th International Congress on Environmental Geotechnics
25-28 June, 2023 | Chania, Greece

https://doi.org/10.53243/ICEG2023-416

Enlightenment to the construction of resilient cities from the extraordinary rainstorm disaster in Zhengzhou, China

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ABSTRACT

Zhengzhou's "7.20" heavy rainstorm disaster is a particularly serious natural disaster caused by climate change and extreme rainfall, which leads to severe urban waterlogging, floods and landslides. As relevant government assessments show, stagnant water from the city pouring into underground tunnels, caused 14 deaths, and flash floods and landslides caused 251 persons missing and dying. In addition, it is found that the organizational problems such as no timely evacuation and emergency preparation, which caused major economic losses. The accident has drawn great attention from Chinese urban management, planning and design departments. Against the backdrop of frequent extreme climate events, it has become a consensus and vision to improve the resilience of city and overall level of urban disaster prevention and reduction. Based on the analysis of heavy rainstorm disaster in Zhengzhou, this paper proposes the measures and countermeasures of coping with and preventing major disasters in urban design, and expounds the concept and key technologies of resilient city.

Keywords: Climate Change; Prevention of waterlogging; Resilient cities; Risk assessment; Monitoring and early warning

1 INTRODUCTION TO THE EXTRAORDINARY RAINSTORM DISASTER IN ZHENGZHOU, CHINA

From July 17 to 23, 2021, China's Henan Province was hit by an unusually heavy rainstorm, resulting in severe floods. In particular, Zhengzhou suffered heavy casualties and property losses on July 20, with 380 people dead and missing, as well as a direct eco-nomic loss of 40.9 billion yuan. It is concluded according to an official investigation [1] that, the July 20 rainstorm in Zhengzhou, Henan Province, was a particularly severe natu-ral disaster that caused severe urban waterlogging, river flooding, mountain torrents and landslides, resulting in heavy casualties and property losses.

Under the climate background of abnormally northward subtropical high of the West-ern Pacific and strong summer wind, two typhoons formed at the same time converged and transported water vapor on the sea. In addition, they were superimposed with convec-tive system over Henan Province, and encountered the topographic uplift of Funiu Moun-tain and Taihang Mountain to form an extremely rare rainstorm process. The heavy rain-fall moved from west to east in Zhengzhou, and the river floods pooled and superim-posed. In addition, Zhengzhou's topography is high in the southwest and low in the north-east, which is a transition zone from hilly and mountainous areas to plain, resulting in ex-ternal floods and waterlogging.

From 20:00 on July 17 to 20:00 on July 20, Zhengzhou received 617.1mm of rainfall in three days (Fig. 1). The hourly precipitation and single-day precipitation have both bro-ken the historical records of 60 years since Zhengzhou station was established in 1951. Zhengzhou's annual average annual rainfall is 640.8mm, equivalent to the amount of the previous year in these three days. The extreme rainstorm far exceeded the existing flood drainage capacity and planning standards of Zhengzhou, and the public facilities of resi-dential communities were seriously flooded, with more than half (2,067) of the city's un-derground space and important public facilities flooded.

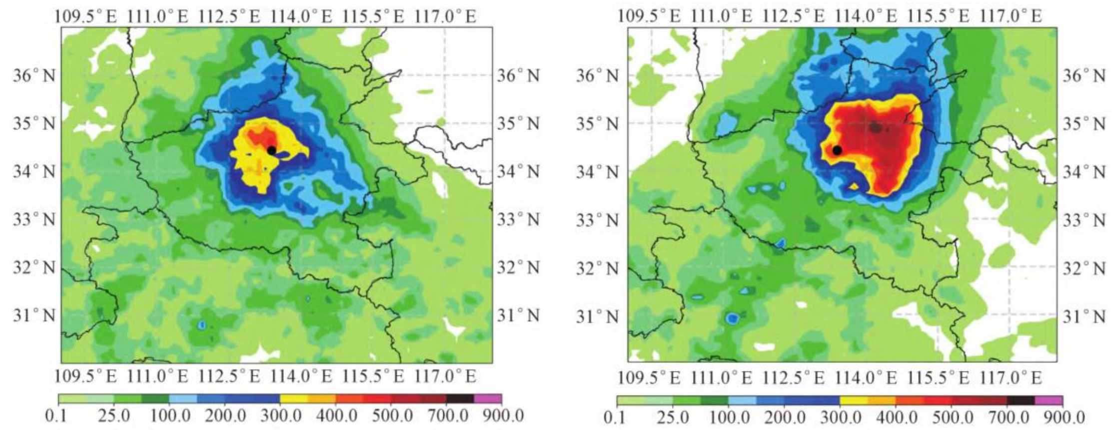

Figure 1. 24h accumulated precipitation in Zhengzhou from July 19 to 20, 2021(unit: mm)

2 ANALYSIS ON URBAN WATERLOGGING CONTROL MEASURES AND COUNTERMEASURES

The technical lessons from this disaster lies in the urgent need to integrate extreme weather and natural disaster prevention into major plans, projects and strategies for urban development, improve flood control and drainage standards, and ensure that urban disaster prevention and mitigation capabilities are commensurate with economic and social development. On the other hand, the safety guarantee capacity of major lifeline projects should be strengthened, key facilities located in underground spaces should be renovated such as standby power supply, drainage pumping stations and high-value equipment, and safety protection measures such as containment, anti-flooding and migration must be improved to ensure safe operation.

2.1 Overall planning

According to the China national standard "Technical Specification for Urban Water-logging Prevention and Control" (GB51222-2017) [2], the construction of urban waterlog-ging prevention and control facilities should be based on the overall urban planning and the special urban waterlogging prevention and control plan, and be coordinated with the special planning of sponge city, urban drainage, urban flood control, river system, road traffic and garden green space. Urban waterlogging control systems should include engi-neering facilities such as source reduction, drainage pipes and canals, and non-engineering measures such as emergency management, which should be connected with flood control facilities.

Source emission reduction facilities refer to controlling the generation of stormwater runoff, reducing stormwater pollution, collecting and utilizing stormwater, and reducing peak flow before discharging stormwater into the municipal drainage pipe system through infiltration, purification and retention measures. Infiltration facilities include permeable pavement, green roof, concave green space, biological detention facilities, etc. Transfer facilities include grass ditches and infiltration channels. Storage facilities include giving priority to open rainwater storage facilities such as natural depressions, ditches, ponds, ca-nals and landscape water bodies, or creating rainwater retention space through vertical de-sign.

Drainage pipe and drainage facilities may consist of a drainage pipe system, including road stormwater outlets, drainage pumping stations, etc., and storage facilities for drainage pipes. Pipeline and canal storage facilities include rainwater storage ponds, etc.

Waterlogging and risk relief facilities shall include urban water bodies, storage and regulation facilities and drainage channels. Urban green space can be used in the waterlog-ging control system for source regulation and storage and drainage risk control and stor-age. Sunken square can be used for flood drainage. In areas prone to waterlogging, dense-ly populated, complex underground pipelines, and difficult to transform existing drainage systems, tunnel storage engineering can be set up. In urban areas prone to waterlogging, some roads can be selected as drainage channels.

2.2 Flood control measures for underground space

At Surface-underground connection access, a water retaining system should be set up to prevent surface flood water from entering underground space. Steps with maximum height difference and enough safety factor should be set up at all the underground space inlet and outlet, vent, wellhead. Mobile water blocking facilities should be set in the inlet and outlet to deal with the small water leakage with large possibility, such as sandbags, wa-ter bags, water blocking plate and tablet telescopic door. When the water leakage is large, the fixed water baffle, waterproof door and other ways are proposed. For the lighting win-dow, shaft and vent, waterproof induction and water retaining devices can be set. When the water sensed reaches a certain standard, it will automatically pull up the waterproof door, close the vent and block the flood. A ventilation tower can also be set to raise the position of the vent and set the vent on the side of the ventilation tower to achieve water-proof effect. A hierarchical water retaining system is proposed for gateways in under-ground space.

In addition, the drainage system of underground space should be improved. Through drainage ditches or pipes, the water invading underground space is concentrated into the collection well or the collection ditch, and the drainage design is strengthened to improve the emergency disposal capacity. It is suggested to pump and discharge in advance to de-lay the time of flood irrigation by using high-power pumps, and to effectively improve the flood discharge emergency capacity.

Finally, construction of underground space water storage system is necessary, includ-ing underground regulation reservoir, underground river, underground flood passage, un-derground space storm storage tunnel, etc.

Other non-engineering measures include: (1) strengthening underground space flood warning and forecast, establishing rainfall information prediction system, underground space flood warning and forecast system, real-time monitoring of underground space wa-ter level, drainage scheduling; (2) Preparing flood risk maps, predicting the danger areas and degrees, and giving escape areas and escape routes, to ensure the safe evacuation of people in the underground space; (3) Establishing underground space refuge and disaster prevention system; (4) Implementing the flood insurance system.

3 INTRODUCTION TO RESILIENT CITY CONSTRUCTION

Resilience refers to the ability of a complex system to continue to function in the face of disruptive situations, including: the ability to resist and recover from chronic stress or extreme events; the ability to adapt to changing circumstances and make the necessary changes in the face of crisis. A resilient city is a city that can withstand disasters, mitigate losses, and deploy resources to recover quickly from disasters. In addtion, cities can learn from past disasters and become more resilient. The important prerequisites for the con-struction of resilient cities is the construction of a comprehensive monitoring and warning platform for urban safety risks, and the effective and reasonable simulation and prediction of disaster impacts.

3.1 Urban safety risk monitoring and warning platform

In view of the prominent problems in some Chinese cities, such as unclear safety risk base, low level of safety risk identification, backward safety management means and limited risk resolution ability, the Safety Production Commission of The State Council issued the “Guidelines for the Construction of a Comprehensive Monitoring and Warning Platform for Urban Safety Risks” in September 2021 [3]. It is proposed to establish a comprehensive monitoring and warning platform for urban safety risks, which can provide real-time monitoring, early warning and timely handling for the most prominent risks in urban security. The Guidelines define the content of building the platform and the requirements for supporting mechanisms, and highlight the unified leadership of the government and cooperation among departments in the construction of the platform. They are of great significance to ensure the continuous improvement of the capacity and level of monitoring and warning and emergency response for urban safety risks, as well as the safety of people's lives and property.

The Guidelines require that the platform should specifically include key links and functions such as risk monitoring, analysis and early warning, and joint treatment. (1) Risk monitoring is to build a three-dimensional network of risk perception at the city level, and carry out all-round and three-dimensional perception of risks such as urban lifeline, public safety, production safety and natural disaster; (2) Analysis and early warning is based on real-time monitoring of various risks, by setting alarm thresholds for different monitoring indicators and using relevant technologies such as big data coupling, data fluctuation feature recognition, correlation and comparison, to alarm sudden safety risks in real time. Through expert consultation and model deduction, the alarm information is studied and analyzed, so as to clarify the possibility and loss degree of accidents and disasters. Multi-level early warning is issued for the research and judgment results to lay the foundation for joint treatment; (3) Combined with urban emergency plans, joint disposal is to prepare the disposal process of early warning information and standardize the whole process of joint disposal of early warning information. The technical supporting measures for the above links include relevant technical standards and scientific models, network security management and technical prevention measures, data security and supervision measures, etc.

The objects covered by the warning platform include: (1) urban gas pipe network, water supply pipe network, drainage pipe network, heat pipe network, bridge, comprehensive pipe gallery and other lifeline projects; (2) Fire safety, traffic safety, safety of special equipment, safety of crowded places and other public safety; (3) Production safety of enterprises in high-risk industries such as hazardous chemicals, coal mines, non-coal mines, fireworks and firecrackers, building construction (including rail transportation); (4) Earthquake, geological, meteorological, flood and drought, marine, forest grassland fire and other natural disasters.

The Guide also provides the overall framework of the application system of the urban safety risk comprehensive monitoring and warning platform, which is based on the overall framework of "perception, transmission, knowledge and application" and includes "five layers and two wings". In addition, suggestions are given on the safety monitoring objects and indicators of urban lifeline projects.

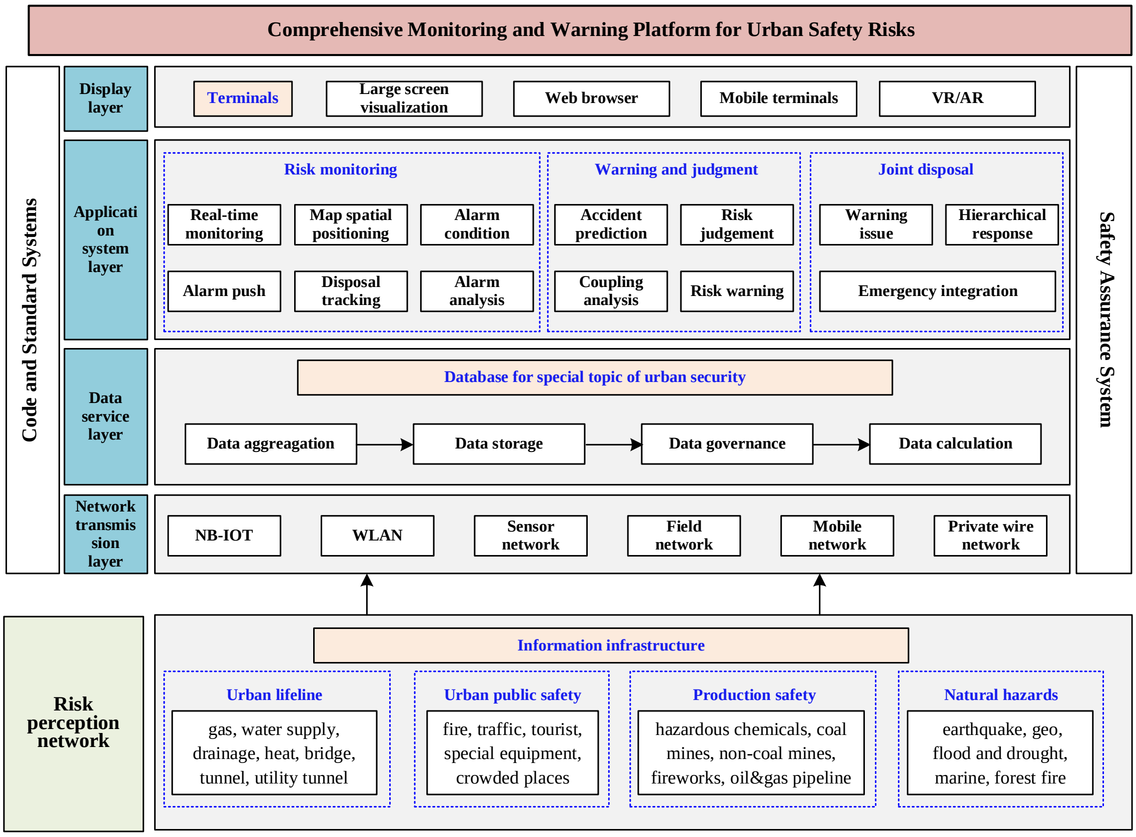

Figure 2. The overall framework of the application system of China's urban security risk monitoring and early warning platform

3.2 Forecasting and visualizing flood inundation information

Taking rainstorm and waterlogging prediction as an example, scholars have conducted a large number of studies, which can provide scientific and reasonable data support for disaster impact prediction [4-

10]. Prediction methods mainly include empirical model based on statistical methods [5], physical model based on hydrodynamics [6] and spatial model based on geographic information [7]. At present, hydrodynamic models are commonly used to predict urban waterlogging, including storm water management model, SWMM), InfoWorks integrated catchment management (InfoWorks ICM), etc. These models calculate the water flow state by solving the hydrodynamic equation with clear physical mechanism, and it is easy to obtain high-precision numerical simulation results. However, it is obvious that the efficiency of the model is insufficient under large scale and complex conditions, and it is difficult to meet the timing requirements of rainstorm waterlogging prediction.

In recent years, the application of artificial intelligence technology represented by machine learning has provided great potential for improving the efficiency and accuracy of rainstorm waterlogging disaster prediction [4,8-9]. Complex factors such as rainstorm intensity, rainfall duration, impervious rate, elevation, slope, topographic humidity index, distance from road and drainage network density can be considered. Some scholars [10] built a spatial-temporal rapid prediction model of urban rainstorm waterlogging based on machine learning method, and used the high-precision grid results simulated by the InfoWorks ICM as data-driven, and established a rapid prediction model of urban rainstorm waterlogging by comprehensively considering rainfall factors, geographic data and the distribution of drainage pipe network.

4 CONCLUSIONS

Under the background of frequent global extreme weather, the disasters caused by extreme rainfall in cities need to attract more attention of experts from various departments such as urban planning, underground structure design, emergency management. The concept of resilient cities should be deeply rooted in the construction of cities at all scales, including the consideration of the technical details of relevant planning and design specifications, and the use of resilience assessment, monitoring and early warning by urban management departments to carry out emergency treatment. We should draw all the lessons we can learn from the past Zhengzhou incident, accelerate the research and development of tool technology, and improve the level of urban management.

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