Construction Technology and Measures of Sponge Airport in China

Jing Peng[1,a,*], Lei Yu[2], Jiayi Ouyang[1] and Haili Zheng[1]

[1]College of Airport Engineering, Civil Aviation Univ. of China,
No. 2898 Jin Bei Road, Dongli District ,Tianjin, China
[2]Tianjin Lonwin Technology development Co., Ltd.,
No. 15 Longtan Road, Hedong District ,Tianjin, China
a. pengjingtd@163.com
**Jing Peng*

Keywords: Sponge airport, low-impact development facilities, rainwater runoff control scheme, flood control.

Abstract: The rapid development of urbanization and impact of climate change make the airports frequently hit by rain, leading to flood. And the size and passenger flow of airports have increased year by year, and water resources are in short supply. The rainwater rapid drainage model of traditional airport construction can't meet the requirements. This paper puts forward the connotation of sponge airport and designs the construction target and control index of sponge airport. Considering particularity of the airport, it should not only consider the goal of "infiltrate, stagnation and storage" in the construction of airport, but also meet the requirements of "discharge and use" in the safe operation. According to the characteristics of each function area, the design of the low-impact development facilities of sponge airport and the rainwater runoff control scheme are carried out. It has important theoretical and practical significance for constructing sponge airport.

1. Introduction

With the rapid development of urbanization and the impact of climate change, many cities in China are frequently hit by rainstorms, resulting in serious flood disasters, and urban waterlogging has aroused widespread concern [1]. Airport is important infrastructure of air transport system. The scale and number of airport construction in China continue to grow rapidly, and the contradiction of water resources in airports is also increasingly large. The large area of impervious surface construction in airports makes the original state of hydrologic cycle is destroyed, which makes the pressure of drainage pipe network facilities increase due to short-term heavy rainfall, is causes a series of rain flood problem [2]. In addition, the planning of drainage pipe network facilities has many problems: the standard of the design is low, imperfection of system facilities maintenance and management does not reach the designated position. These problems lead to the pipe network facilities can't meet the short-term violence of rain, the rainwater can't rapid emissions, the waterlogging of the airport occurred frequency increasing, which caused serious influence to the normal operation of the airport.

A sudden rainstorm exceeding the drainage design standards of the airport can result in waterlogging in various functional areas of the airport, paralyzing the roads in and out of the airport; It also leads to flight delay and operation interruption of the airport, which brings serious harm to people's life and property. In July 2016, the water in the service lane of the airport apron from 171 to 307 of Chengdu Shuangliu Airport was deep due to the heavy daily rainfall, leading to a large area of flight delay. In June 2018, days of torrential rain have left Guangzhou Baiyun Airport badly flooded. The water depth of the airport was above the knee, causing massive flight delays and hundreds of flight cancellations. In August 2018, Haikou Meilan Airport became a vast ocean due to the rainstorm, with much leakage in many places of the airport terminal and water accumulation on the tarmac of more than 20 Centimetres, and some flights were delayed or forced to cancel.

According to Boeing's current market outlook report, the airport passenger traffic will continue to grow at an average rate of 5.3% between 2009 and 2029, while the cargo traffic will grow at a rate of 5.9% [3]. The average water consumption of airport passengers is about 20 L, and that of ordinary airports is about 8.0×105 m^3. In general, the annual water consumption of a large airport is almost the same as that of a small city [4]. The airport is short of water resources. Meanwhile, heavy rainfall can’t be timely drainage, causing flood, flight delays and huge economic losses for the airport.

Collecting and utilizing rainwater in airports will greatly relieve the shortage of water supply, improve the situation that water supply depends solely on urban tap water, reduce the risk of waterlogging, and improve the airport ecological environment. Many foreign airports have adopted a series of advanced technologies to collect and utilize rainwater. In order to make sustainable use of water resources and minimize the risk of airport rainstorm waterlogging, Heathrow Airport carried out rainwater collection and reuse work, which reduced the consumption of water resources at the airport [5]. Rainwater harvesting and utilization has also been carried out at Adelaide Airport in South Australia. The design capacity of the rainwater harvesting project is 270 million litres, which is used to collect, store and treat rainwater inside the airport. The treated rainwater is used for industrial, commercial and irrigation purposes. It is expected that the use of drinking water will be reduced and the water shortage situation in Adelaide will be greatly improved [6].

The length of rainwater harvesting system at Frankfurt Airport in Germany is 200 km. There are 23 rainwater harvesting areas, which can collect and store rainwater 1.0 × 105 m^3. The rainwater collected at Orly Airport will be used for air conditioning cooling of terminal buildings. By 2005, water resources will be saved by an average of 7.0×10^4 m^3 per year. Singapore Changi Airport can collect 63500 tons of rainwater every month to flush toilets and air conditioning systems of terminal buildings, saving about $\$3.9 \times 10^5$ a year [7]. At Brussels Airport, the roof is equipped with six 10 m^3 rainwater storage tanks, which connect directly to the pipe network for toilet flushing. Three 11.37 m^3 storage tanks are installed to collect rainwater on the roof of the terminal building of Atlanta Airport. Each tank can collect 36.37 m^3 of rainwater monthly on average during the rainy season [8]. Chicago Airport's green roof can effectively reduce indoor temperature by 3-7 degrees, reduce air conditioning energy consumption by 10%, and save water resources by 60% [9].

The airport of China on rainwater utilization is still in its infancy stage. The roof of T2 terminal of Nanjing Lukou Airport adopts siphon system to reuse rainwater, and the underground floor is equipped with 1300 m^3 storage tank, which can meet the 3-day flushing water volume of terminal building [10]. In order to embody the concept of green building, the new terminal building of Changzhou Airport has constructed a rainwater utilization project. The rainwater is collected by landscape lakes, which is used for greening irrigation of 50500 m^2 green areas [11]. In the process of design and construction of Beijing New Airport, rainwater collection and utilization are fully taken into account. Through the complementary forms of source and terminal, ground and underground, green and grey, the principle of "infiltrate, detain, storage, purify, reuse and drainage"

is fully implemented. The objectives of flood control and rainwater resource management of the airport are realized through a series of rainwater management measures. The New Beijing Airport will be able to collect and store rainwater effectively and make rational use of rainwater [12]. As one of the national "sponge city" pilot cities, Qingdao's new airport also plans to design and construct a green sponge airport, and plans to use concave green space, permeable pavement and biological detention facilities for rainwater runoff control [13].

Tang explored the construction mode of sponge city in the airport taking a coastal airport in southern China as an example. Through implementing the sponge airport, the pressure of drainage and waterlogging prevention of the airport was reduced, and the sponge city construction of the large-area hardened flying area, parking apron area and other special areas was designed. The whole process control of airport rainwater system is strengthened from the aspects of source reduction, process control and terminal treatment [14].

In a word, the contradiction between supply and demand of water resources in airport is very great, and the water consumption cost is very high; meanwhile, the airport will be flooded and flight delays because the heavy rainfall can't be discharged in time, and resulting in huge economic losses. Traditional airport construction is mainly based on hardened pavement, drainage through various underground pipelines and open channels. How to apply the concept of sponge city to airport, design and construct a sponge airport which can store and discharge naturally, and make reasonable infiltrate, detain, storage, purify, reuse and drainage of rainwater resources in the airport, so as to effectively reduce the airport waterlogging crisis, realize the recycling of airport rainwater resources, improve the ecological environment to the greatest extent, and realize the natural purification and infiltration of airport rainwater resources. It is an urgent problem to promote the sustainable development of airport and ensure the safety of airport operation.

2. The Connotation of Sponge Airport

In China, an average 180 cities are flooded every year, and the number of waterlogged cities increased from 234 in 2013 to 258 in 2016. Flood disasters and water shortage caused by urban rainstorms are becoming serious, which attracts more and more attention. In response to the increasingly serious urban waterlogging problem, the Chinese government has put forward a sponge city construction plan, and launched a pilot sponge city construction in January 2015. The effect of sponge city construction is remarkable [15, 16].

The traditional airport construction is mainly based on hardened pavement, which is drained by various underground pipes or open channels, emphasizing the fast drainage mode of rainwater. In addition to certain economic service requirements, modern airport construction also puts forward the requirements of green construction. Reasonable technical measures are taken to improve the environmental performance of the airport and realize the recycling of rainwater resources. In order to make the utilization of rainwater more close to the natural hydrological cycle and make the airport construction reflect the concept of respecting, conforming to and protecting nature, it is increasingly necessary to design low-impact development facilities for the airport. The application of Low Impact Development facilities (LID) is urban storm water management idea, which can maintain and protect the hydrological features of the site, effectively alleviate the peak flow, runoff coefficient caused by impervious area increasing through the scattered, small source control facilities [17]. LID is applied to the construction of the airport, achieving the effect purpose of controlling the heavy rain storm runoff. George has studied the application of LID in airports, and the results show that the adoption of LID in airports can effectively improve the drainage efficiency, reduce flight delays and save water resources [18]. Starting from the connotation of low-impact development, Ouyang combined the characteristics of each functional area of the airport and water

quality characteristics, designed the framework of the airport rainwater management system based on low-impact development [19].

The concept of sponge airport was put forward referring to the concept of the sponge city. The purpose is to develop the construction of rainwater system through the low impact development, so that the airport can have good "flexibility" in adapting to environmental changes and coping with natural disasters. Like a sponge, the airport has the function of infiltration, stagnation, storage, purification, use and drainage when it rains. Meanwhile it can "release" and utilize the stored water when the airport needs it. The design and construction of a sponge airport that can store and discharge the rainwater reasonably, thus effectively reducing the waterlogging crisis of the airport, realizing the recycling of water resources, improving the ecological environment, realizing the natural purification, natural infiltration and natural storage of the rainwater resources of the airport, promoting the sustainable development of the airport and ensuring the safety of the airport operation.

3. Construction Technology and Measures of Sponge Airport

3.1.Construction Objectives and Indicators of Sponge Airport

At present, many airports in China have both drainage difficulties and shortage of water resources. The construction of sponge airport has also received extensive attention from civil aviation authorities and airports around the country. The construction of sponge airport is based on the interconnection of various functional zones and systems of the airport. Considering the special requirements of airports in terms of road flour strength, drainage system and bird attraction, a feasible development facility and rainwater runoff control scheme are designed according to the characteristics of different zones. A sponge airport integrating "infiltration, stagnation, storage, purification, utilization and drainage" is designed to realize the main control objectives of the sponge airport construction, such as rainwater runoff total amount control, rainwater runoff peak control, management and utilization of rainwater resources, so as to improve the airport's rapid response capability to rainstorm, reduce the risk of waterlogging in the airport and ensure the safety and stability of airport production and operation.

In order to promote the construction of the sponge city, considering the problems existing in the airport's water environment, water ecology, water safety and other aspects, and in accordance with the principles of scientificity, typicality and embodying the characteristics of the airport's location, and in accordance with the relevant national policy requirements such as "The Sponge City Construction Technical Guidelines-Construction of Low Impact Development System (Trial)" and "The Sponge City Construction Performance Evaluation and Assessment Measures (Trial)", and referring to the relevant requirements of the airport's location, the construction objectives and indicators of sponge airport are determined, as shown in Table 1.

Table 1: The construction objectives and indicators of sponge airport.

Category	Indicators	Objectives
Water ecology	Annual runoff total control rate	The value shall be taken according to the provisions of the "Technical Guide for Construction in The Sponge City-Construction of Low Impact Development System (Trial)", and the requirement that the storage volume allocated for construction per square kilometer of hardened area shall not be less than the specified volume of rainwater storage facilities in the "Design Code for Rainwater Control and Utilization Engineering" shall be met.
Water environment	Surface water quality standard	The water quality of reservoirs and drainage rivers meet the specified requirements.
Water safety	Rainwater canal and Waterlogging Control Standards	According to the requirements of hydrology, topography and water safety level of the airport.

3.2. The Method of Sponge Airport Construction

3.2.1. Low Impact Development Facilities Design for Sponge Airport

Sponge Airport uses rainwater control and utilization facilities to adjust the peak flow and total flood volume. The objectives of "infiltration, stagnation, storage, utilization, purification and drainage" of rainwater are realized through the design of low-impact development facilities, so that the impact of rainstorm on various areas of the airport is minimized as much as possible. According to different land use functions, airports can be divided into working areas, cargo areas, maintenance areas, airfield areas, terminal area, etc. The land use conditions are similar in the first three areas. The main land use type is the construction area in the site. Other site conditions include roads, green land and water. Low-impact development facilities such as sunken green belt and rain garden can be used to control the total amount of rainwater runoff. When the local runoff coefficient in freight transportation areas and other areas is high and large-scale storage facilities cannot be built, infiltration paving, regional green space and local construction of storm detention tank can be adopted to absorb rainwater and reduce rainwater runoff coefficient.

The site conditions in the flight area are mainly runway, taxiway and green space. The design of runway and apron shall be carried out in accordance with relevant specifications. Rainwater is mainly "drained" and "infiltration and retention" should be used with caution considering the waterproof requirements of foundation, and the normal operation of runway and apron should not be affected. For green areas around runways and taxiways, sunken green belt and biological detention facility can be used to adjust the total amount of rainwater runoff, thus reducing the rainwater runoff coefficient in the airfield area and adjusting the peak flow. Special requirements such as preventing bird strike at the airport should be considered when designing low-impact development facilities. At the same time, rainwater can be discharged by setting grass-planting drainage ditches in some place of the airfield area, and a storage tank is set for storage inside the airfield area. In the process of rainwater transfer, some rainwater seeps into the ground and replenishes the groundwater. The surplus rainwater is finally discharged into the downstream large-scale storage tank and is absorbed through the functions of infiltration, evaporation, landscape and fire water.

Land conditions in terminal area include terminal buildings, roads, parking lots, etc. Rainwater buckets can be used to collect rainwater near the rainwater pipes of the terminal building, permeable pavement can be used for roads to reduce rainwater runoff, and biological detention facility or sunken green belt can be used for greenbelts around the parking lot.

Low Impact Development (LID) facilities at Sponge Airport mainly include: biological detention, grass planting ditches, rain buckets, permeable pavement, sunken green belt, etc. The design and application positions and functions of various low impact development facilities can be shown in Figure 1.

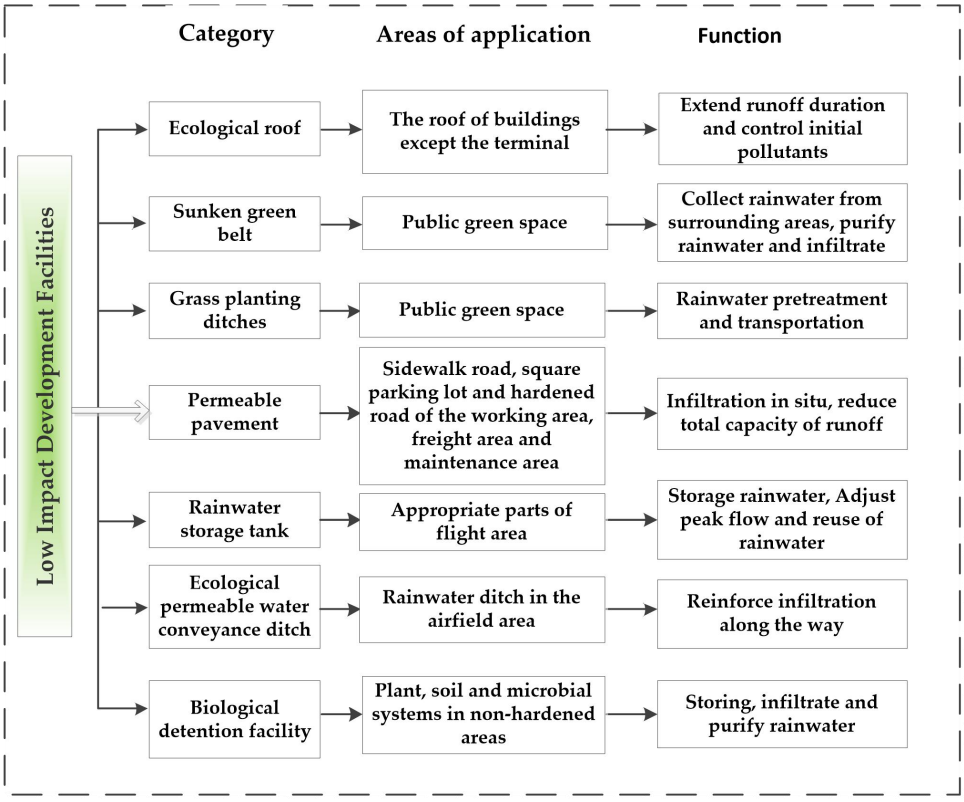

Figure 1: The application and function of low impact development facilities in sponge airport.

3.2.2. Design of Rainwater Runoff Control Scheme for Sponge Airport

The construction of sponge airport aims at controlling the total amount of rainwater runoff and managing rainwater resources to realize flood control and disaster reduction, rainwater resources utilization and ecological restoration of the airport. The objectives of "infiltration, stagnation, storage, purification, utilization and drainage" of rainwater at the airport are realized by the design of rainwater runoff control scheme of sponge airport, and the airport's resistance to extreme rainstorm is improved.

According to the overall construction target of sponge airport, a full-system green rainwater management system is designed, which is "Storing rainwater and reducing emission at the source + green control management in the process + ecological storage and infiltration at the terminal". Through the drainage system of source impoundment, process control and terminal storage, a sponge system is constructed from the four aspects of water ecology, water environment, water safety and water resources, which finally achieves various effects of effectively reducing rainwater discharged, controlling point source and flour source pollution, and realizing rainwater runoff control and reuse. Among them, the control at the source mainly refers to setting green roofs on the

building tops of the maintenance room, setting rainwater buckets near the building rainwater pipes, adopting sunken green belt and biological retention at a certain distance nearby parking lots and roads, so the total amount of rainwater runoff can be controlled and the discharge of rainwater can be reduced. The process control measures are mainly implemented in the process of rainwater runoff discharge, mainly through setting permeable pavement on impermeable paving road, setting grass-planting drainage ditches in some place of the airfield area and other low-impact development facilities suitable for the land use characteristics of various regions of the airport. It can reach adjusting the rainwater peak flow and prolonging the peak inflow time. Terminal control measures mainly refer to controlling the total amount of rainwater runoff and peak flow through measures such as landscape water body, ecological bank and rainwater wetland around the airport on the basis of combining source control and process control measures. By controlling the whole process of rainwater from the source to the end, the rainwater runoff control scheme organically combines rainwater infiltration, stagnation, storage, purification, utilization and drainage to jointly promote the construction of sponge airport, improve the regional heat island effect and ensure the safety of the airport in flood season. To sum up, the design of rainwater runoff control scheme for sponge airport is shown in the following figure.

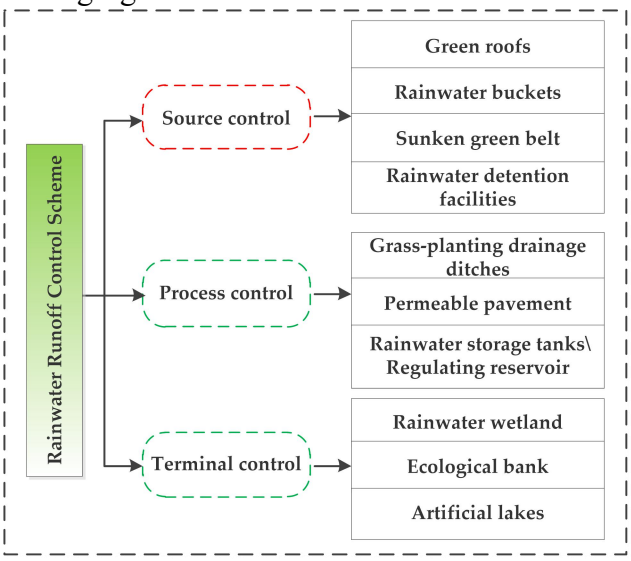

Figure 2: Rainwater runoff control scheme of sponge airport.

4. Conclusions

This paper puts forward the connotation of spongy airport starting from the concept of spongy city. Through the construction of rainwater system with low impact development of the airport, the airport can be like a sponge with good "flexibility" in adapting to environmental changes and coping with natural disasters. When it rains, the airport will absorb, store, infiltrate, and purify rainwater; the storage rainwater will be released and utilized when the airport needs it. The construction target and control index of sponge airport are designed from three aspects of water ecology, water environment and water safety. On this basis, the design of low-impact development facilities of sponge airport is carried out from the characteristics of each functional area of the airport. Considering the particularity of the construction of sponge airport, it should not only consider the goal of "infiltrate, stagnation and storage" in the construction of sponge airport, but also meet the requirements of "discharge and use" in the safe operation of the airport. A rainwater runoff control scheme of sponge airport with source reduction, process control and terminal storage is formed through the design of a full-system green rainwater management system of "source

storage and emission reduction + process green control management + terminal ecological storage and infiltration". This study can provide theoretical guidance and technical support for the design and construction of sponge airport in China and has important research significance.

Acknowledgments

This work was funded by [Civil Aviation Univ. of China Central University Fund] grant number [3122018C015] and [Tianjin Natural Science Foundation] grant number [TJZRJJ2019QN006].

References

[1] Zhou, J.J.; Liu, J.H.; Shao, W.W.; Yu, Y.D.; et al. Effective Evaluation of Infiltration and Storage Measures in Sponge City Construction: A Case Study of Fenghuang City. Water. 2018, 10, 937.

[2] Li Peng. Research on technical framework of rainwater system in Sponge Airport. Civil aviation university of china [Master Thesis], 2018.

[3] AirplanesBC(2010)Currentmarketoutlook: 2010–2029.Seattle,USA.

[4] Isabella de Castro Carvalho, Maria Lucia Calijuri, Paula PeixotoAssemany, et al. Sustainable airport environments: A review of water conservation practices in airports. Resources, Conservation and recycling. 2013, 74: 27-36.

[5] AMEC. Heathrow's north-west runway sustainable drainage assessment. United Kingdom. 2014. Available online.

[6] Jaiyeola A. T. The management and treatment of airport rainwater in a water-scarce environment. Int. J. Environ. Sci. Techno. 2017, 14: 421-434.

[7] Roshan Raj Shrestha. Rainwater Harvesting and Groundwater Recharge for Water Storage in the Kathmandu Valley. Sustainable Mountain Development. 2009, 56: 27-30.

[8] Atlanta Department of Civil Aviation Hartsfield-Jackson Atlanta International Airport. Annual environmental report. 2010.

[9] Jin Xiaoli. Creating Ecological Civilization Business Cards to Boost High-quality Development of Civil Aviation — — Understanding and Thinking on Green Airport Construction. Air Transport & Business. 2018, 400:17-18.

[10] J Peng; XM Zhang; YH Zhang. Study on combining flood control with rainwater utilization of airports in China. IOP Conference Series Earth and Environmental Science. 2018, 191(1):012133.

[11] Ji Zhen; Ding Lei; Fu Erkang. Design and Operation of Rainwater Utilization Project in Changzhou Airport. Water and Wastewater Engineering. 2013, 39: 432-434.

[12] Ren Yuan; Meng Ruiming; Luo Kai; et al. Construction of Rainwater System in Water Sensitive Areas-A Case Study of Beijing New Airport. Water and Wastewater Engineering. 2017, 9: 25-32.

[13] Qingdao New Airport Plans to Build the First Green Sponge Airport of China. Available online: http://news.carnoc.com/list/381/381721.html.

[14] Tang Zhong; Zhang Liang; Lu Yu; Le Zheng; Niu Yuanyuan. Sponge airport Construction Strategy of a Coastal Airport in South China. China Water and Wastewater. 2018, 34(20):1-6.

[15] Hu, M.; Zhang, X.; Siu, Y.L.; Li, Y.; Tanaka, K.; Yang, H.; Xu, Y. Flood mitigation by permeable pavements in Chinese sponge city construction. Water. 2018, 10, 172.

[16] Zhang, S.H.; Li, Y.K.; Ma, M.H.; Song, T.; Song, R.N. Storm Water Management and Flood Control in Sponge City Construction of Beijing. Water. 2018, 10, 1040.

[17] Kyle Eckart; Zach McPhee. Tirupati Bolisetti. Multiobjective optimization of low impact development stormwater controls. Journal of Hydrology. 2018, 562: 564-576.

[18] Bezerra George C.L.; Gomes Carlos F. Performance measurement practices in airports: Multidimensionality and utilization patterns. Journal of Air Transport Management. 2018, 70:113-125.

[19] Ouyang Jie; Li Peng. Research on Architecture of Airport Rainwater Management System Based on Low Impact Development. Water and Wastewater Engineering, 2017, 43: 27-29.