Research on Construction of Sponge Airport in China

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Abstract. This article is an introduction to the practices of sponge projects for airports in China. The objective of this paper is to point out the main problems existing in the construction of sponge airports and seek ways to improve the storage volume of airports. Data investigation, technical analysis, and engineering cases are used to conduct the research. The result shows that the main problem in the construction of sponge airport is the lack of effective sponge measures in the airfield area. Addressing the challenges and implementing effective sponge measures in airfield area is feasible and crucial for advancing sponge city concepts in airport construction. The elevation of pavement, particularly in creating sponge storage in unpaved areas, and using a drainage layer for the pavement and the shoulder stands out as a successful approach and should be considered in the design of airfield area projects.

1. Introduction

The concept of a “sponge airport” is derived from that of a “sponge city”[1]. In China, the concept of a sponge city typically encompasses water ecology, water environment, water resources, water safety, and more, forming a broad concept of a “large sponge.” The concept of a “sponge airport” discussed in this paper aims to return to the fundamental properties of a sponge, meaning that the designed and constructed airport can function like a sponge, with the ability to permeate, store, and drain water during rainfall, and release and utilize stored water as needed. Therefore, the storage capacity of the sponge, known as the sponge storage volume, is the most critical parameter for a sponge airport.

Chinese airports have two requirements for the construction of sponge storage volume[2]. One is the provision of storage volume corresponding to the unit-hardened area. That is, in the hardened ground of the new project, every 10,000 square meters of hardened area shall be equipped with no less than a certain area of rainwater storage measures; The other is the volume capture ratio of annual rainfall, which is calculated based on statistical analysis of multi-year daily rainfall data. Through natural and artificial measures, the percentage of water not discharged throughout the year is determined relative to the total annual rainfall. The target volume capture ratio of annual rainfall is used to select the design rainfall, from which the storage volume is calculated. China’s policies regarding sponge storage volume include guidelines from the Ministry of Housing and Urban-Rural Development, such as the "Technical Guidelines for Sponge City Construction" and the "Technical Specifications for Rainwater Control and Utilization Projects in Buildings and Communities," as well as the "Technical Guidelines for the Compilation of Sponge City System Schemes" by the China Association for Engineering Construction Standardization(CECS). Additionally, there are specific sponge construction requirements in some provinces, cities, and regions.

The control of sponge storage volume in Chinese airports mainly relies on volume capture ratio of annual rainfall, with the index typically ranging from 65% to 85% in completed sponge airports, depending on the region.

Currently, the primary technical measures for sponge airports involve the adoption of Low Impact Development (LID)[3] measures commonly used in municipal engineering. Research on sponge airports mainly focuses on evaluating the effectiveness of LID applications in airport settings. Researchers such as Peng Jing and Zhao Ying used SWMM software to simulate and assess the application of LID measures at airports, concluding that LID facilities can reduce stormwater runoff and enhance the airport’s capacity to cope with flood disasters[4][5]. Geng Liang and his colleagues suggested that a sponge airport drainage system design based on Building Information Modeling (BIM) can significantly reduce airport runoff[6].

However, there is a lack of relevant research and engineering practices on how to design and construct effective sponge capacity for airports, especially in achieving sponge capacity within the airfield area. Some still believe that it is not appropriate to set sponge facilities in the airfield area, and the rainwater in the airfield area should be quickly discharged. Instead, they propose the installation of large regulating ponds at the end of the drainage system to achieve sponge capacity for the airport. This article aims to explore ways to improve the storage volume of the airfield area.
2. Sponge Airport Construction Practices in China

Since the introduction of the concept of sponge cities, the construction of sponge airports with effective storage capacity has garnered significant attention from managers and builders. The Qingdao Jiaodong International Airport, in its overall planning, positioned itself as China's first green "sponge airport." The Beijing Daxing International Airport incorporated the "sponge city" concept into its airport planning, design, construction, and operational management, becoming the first demonstration project for a sponge airport in China. Subsequently, several major airports in China, including Guangzhou Baiyun, Jinan Yaoqiang, Shenzhen Bao'an, and Chengdu Tianfu, have largely adjusted pond at the end of the stormwater system.

Due to safety considerations, the drainage design in the airfield area accounts for the highest proportion of the land area of the airport. That is, more than 71% of the airfield area is still based on the rapid drainage system, so if the airfield is exempted from the index because the airfield area accounts for the highest proportion of the land area of the airport, the volume capture ratio of annual rainfall for some airports in China.

Table 1. Volume capture ratio of annual rainfall for selected airports in China.

<table>
<thead>
<tr>
<th>Airport</th>
<th>Volume capture ratio of annual rainfall(%)</th>
<th>Sponge measures used</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qingdao Jiaodong</td>
<td>75</td>
<td>Sunken greenbelt, Permeable pavement, Adjusting pond</td>
</tr>
<tr>
<td>Beijing Daxing</td>
<td>85</td>
<td>Sunken greenbelt, Permeable pavement, Permeable ditch, Adjusting pond</td>
</tr>
<tr>
<td>Guangzhou Baiyun</td>
<td>74</td>
<td>Sunken greenbelt, Permeable pavement, Adjusting pond</td>
</tr>
<tr>
<td>Jinan Yaoqiang</td>
<td>75</td>
<td>Ecological roof, Permeable paving, Adjusting pond</td>
</tr>
<tr>
<td>Shenzhen Baoan</td>
<td>65</td>
<td>Sunken greenbelt, Permeable pavement, Adjusting pond</td>
</tr>
<tr>
<td>Xi'an Xianyang</td>
<td>70</td>
<td>Sunken greenbelt, Permeable pavement, Adjusting pond</td>
</tr>
<tr>
<td>Chengdu Tianfu</td>
<td>80</td>
<td>Sunken greenbelt, Permeable pavement, Grass planting ditch, Storage tanks, Stormwater wetland parks, Storage tanks, Greenbelt, Wider and slower ditches</td>
</tr>
</tbody>
</table>

Due to the maturity and effectiveness of sponge measures in municipal engineering, sponge measures in airport engineering are mainly used on the landside. The sponge measures in the airfield area, which covers the largest area, are mainly based on the construction of a large adjusting pond at the end of the stormwater system. This is mainly because the airfield area is affected by aircraft operation, to ensure flight safety, the feasible sponge engineering measures and the available sponge storage capacity in the airfield area are still limited. The table below outlines the application and function of major sponge measures at some airports in China.

3. Issues and Analysis in Sponge Airport Construction

The introduction of sponge storage volume indicators and the application of sponge measures in airports have played an obvious effect on the reuse of airport rainwater, the reduction of flood peaks, and the control of total outflow. However, from the current status of airport sponge construction, it can also be seen that due to the limited sponge measures in the airfield area, the construction of sponge airports in China still has the following deficiencies:

1) The volume capture ratio of annual rainfall is low.
2) Due to safety considerations, the drainage design in the airfield area is still based on the rapid drainage system, so the volume capture ratio of annual rainfall of many airports in China is exempted in the airfield area. Taking an airport in the south as an example, the zoning index requirements for the total volume capture ratio of the airport are: terminal area ≥80%, roads in public area ≥60%, greenbelt in public area ≥80%, buildings in public area ≥60%, thus achieving the total volume capture ratio of the airport ≥65%. It can be seen that the index of the volume capture ratio was exempted in the airfield area. However, it will be very difficult to realize the whole design storage volume if the airfield is exempted from the index because the airfield area accounts for the highest proportion of the land in the airport. Taking Guangzhou Baiyun Airport as an example, the total area of the airfield will reach 25 km² after the third phase of the project, accounting for more than 71% of the total area of the airport. That is, more than 71% of the rainfall in the airfield area needs to be undertaken by the airfield area. If the index of the airfield area is exempted, the airport has to use 29% of the landside area to achieve the sponge index of the entire airport, which must
pay a high price. For smaller airports, the proportion of land occupied by airfield area is even higher, making it even more difficult.

(2) The volume capture ratio of annual rainfall is calculated incorrectly. Also due to the lack of sponge measures in the airfield area, only large adjusting ponds and pump stations are set at the end of the airport drainage system to meet the volume capture ratio. Adjusting ponds have been proven to be effective in reducing the peak flood flow, but reducing the peak flood flow does not mean storage. In actual operation, it is impossible to make the adjusting pond volume equal to the storage volume. Especially for airports that are overly cautious in judging subsequent rainfall, this volume will even completely lose its effectiveness as a sponge volume. If the volume of the adjusting ponds is used directly to calculate the storage volume, the design storage volume will be distorted.

(3) Sponge measures lead to increased investment.

In one case, when the airfield index is exempted, the pressure of the landslide sponge index increases, and the optimized engineering design scheme cannot meet the index requirements. Therefore, special sponge projects have to be added; In another case, the sponge storage capacity in the airfield is adjusted by wider and slower drainage ditches and large adjusting ponds and pumping stations at the end of the stormwater system. The engineering can significantly increase construction and later operational costs.

4. Technical Challenges and Necessity of Sponge Measures in the Airfield Area

As analyzed earlier, the key challenge in sponge airport construction lies in the airport's airfield area. To overcome existing sponge indicators at airports, a breakthrough in sponge measures within the airfield area is essential. Given that the airfield area is where aircraft take off, taxi, and park, facing significant operational loads and high operational requirements, implementing sponge measures in the airfield area involves several technical challenges:

(1) Permeable pavement that can withstand heavy load in the airfield areas. The hardened pavement is for aircraft and requires high pavement structure performance. The existing technology can not realize the economical and feasible permeable pavement structure under heavy loads[2].

(2) Water storage in the airfield area causes changes in the dry humidity of the adjacent soil, which affects the strength and stability of the subgrade.

(3) Restrictions on sponge measures due to the special requirements of the terrain and drainage of the airfield area. In the airfield area, the runway strip, the runway end safety area, the taxiway strip, the critical/sensitive area of the navigation station, etc., have special requirements for soil compaction, ground slope, the selection of drainage ditch, and even the surface covering material, which limits the setting of sponge measures.

(4) The friendly water environment in the airfield area may attract birds to roost and affect the safety of aircraft take-off and landing.

Despite the above technical challenges that must be addressed, it is very necessary to realize the sponge airfield area. In addition to the problems caused by insufficient or improper sponge measures in the airfield area in Section 3, sponge measures in the airfield area also have the following advantages: (1) Reducing the risk of flooding in the airfield area. The airfield area itself has higher requirements for flood drainage than the other areas of the airport. The airfield area needs to meet the requirements of normal take-off and landing, with no water accumulation on the pavement surface and shoulder and no flooding of communication and navigation equipment during the recurrence interval of the design storm. (2) Sponge measures in the airfield area can achieve greater benefits with less cost. The structure of the airfield area is single, and the green rate is high. If the technical difficulties are handled properly, it has the advantage of realizing the sponge airport.

5. Analysis of Sponge Measures in the Airfield Area

Sponge measures in the airfield area should be implemented according to the characteristics of airfield engineering, and the practice of municipal sponges should be reformed according to local conditions. The refined sponge volume design is carried out from the general layout of the airport, terrain slope design, pavement structure design, internal drainage design of pavement structure, blind ditch design, coordination design of terrain and drainage ditch, ditch structure design, and other dimensions.

The general layout design of the airport should be as simple as possible, and the pavement should be set according to the actual operation needs of the aircraft's main wheels. Using computer software to simulate tire trajectory can reduce the setting of track addition pavement. Reasonable plane design can reduce the comprehensive runoff coefficient of the airport while reducing the hardened area and investment.

In the design of pavement structure, although permeable pavement under heavy load can not be realized, pavement areas with low load requirements, such as runway shoulder, taxiway shoulder, runway blast pad, patrol road, etc. can still use permeable pavement. For different paviing, the design should be refined and differentiated. The use of permeable pavement should not be rejected just because the airfield area is the operation area of aircraft.

In China, airport pavement water damage often occurs, one of the important reasons is that the airport drainage system usually does not consider the underground pavement drainage system. In other countries, airports or highways use asphalt drainage layer with a porosity of about 20% under the pavement structure layer, permeable layer under the pavement shoulder and drainage pipe, and set drainage blind ditch in the soil area outside the pavement area[13], which can not only improve the drainage condition inside the concrete pavement and improve the overall life of the pavement structure but also provide the storage volume for the airport. Therefore, China's sponge airport
should also consider the design of underground pavement drainage system.

To solve the contradiction between the dry humidity of the foundation and the water storage in the adjacent soil area, the elevation scheme of the airfield area can learn from the design concept of the expressway, raise the elevation of the runway and taxiway as much as possible, form a large height difference with the ditch in the soil area, and form a rain storage space.

Other sponge measures in airfield areas can also be used, for example, the permeable drainage ditch, the adjusting pond (only the sponge volume part), etc.

6. Engineering Case Study

This study analyzes the feasibility of applying sponge measures using the example of a newly constructed runway and taxiway at a Chinese airport. The airport is located in a semi-arid region, experiencing an annual precipitation of 398 mm. The selected area (Figure 1) is within the airfield and is characterized by loess, clay, and sandy soils. The runway has a length of 3800 m, and the taxiway is of equal length to the runway. The total area of the region is 68.4 ha, with a hardened pavement area of 33.6 ha and an unpaved area of 34.8 ha, resulting in a comprehensive runoff coefficient of 0.595. The annual runoff control rate for this region is required to be between 80% and 85%, corresponding to a design rainfall of 18.2 to 22.0 mm. Based on a design rainfall of 22 mm, according to formula 1, the design storage volume is calculated to be 8950 m³.

![Fig. 1. Layout Plan of the Engineering Case.](image)

Traditional design provides zero sponge storage capacity in this area. Following the measures outlined in Section 5 of this article, a sponge design is implemented in this area to achieve the maximum possible storage capacity. The key measures adopted for the design in this area include:

- Measure 1: Designing an elevation increase in the pavement to create sponge storage capacity in the unpaved area while meeting the moisture requirements of the roadbed;
- Measure 2: Using a drainage layer with a thickness of 8 cm and a porosity of 20% for the pavement;
- Measure 3: Employing a drainage layer for the shoulder with a thickness of 30 cm and a porosity of 20%;
- Measure 4: Installing drainage pipes within the shoulder structure;
- Measure 5: Implementing a drainage blind ditch in the unpaved area with a width of 1 meter, height of 1 meter, and porosity of 20%. These measures collectively contribute to a total storage volume of 22,300 m³ in the designated area (Figure 2).

![Fig. 2. Sponge volume obtained by sponge measures in the airfield area](image)

7. Results and Discussion

(1) The designed sponge storage volume in this engineering case, totaling 22,300 m³, significantly surpasses the inability of traditional runway and taxiway areas to provide sponge storage capacity. It fully meets the requirement for a storage capacity of 8,950 m³ under the 85% volume capture ratio of annual rainfall, demonstrating the potential to achieve and exceed current sponge indicators.

(2) Among the various sponge measures, Measure 1 proves to be the most effective. Moreover, Measure 1 involves optimizing elevation without introducing specific additional sponge facilities, minimizing the impact on project investment.

(3) Measures 2-5 contribute an additional sponge capacity of 10,300 cubic meters, a substantial and noteworthy increase. The permeable base layer and cushion layer are integral parts of the pavement structure, not causing additional investment. Although drainage blind ditches and rainwater pipes may require additional installation, they serve as crucial components of the internal drainage system, enhancing the lifespan of the pavement structure.

(4) In Measure 1, the depth of water accumulation in the unpaved area is controlled to not exceed 30 cm, with an infiltration time within 24 hours. Short-term water accumulation is considered less likely to attract nesting birds compared to long-term regulating pools.

The case does not consider the scenario where the navigation station protection area is located between the runway and the taxiway. In such case, the sponge storage capacity in the unpaved area needs adjustment, and the storage capacity of Measure 1 may be reduced.

8. Conclusions

More and more airports in China are incorporating the volume capture ratio of annual rainfall indicator from sponge city concepts. Major issues in current sponge construction include low annual runoff control rates, distortion in these rates, and increased engineering investment. The primary cause is the inability to implement effective sponge facilities in the airfield areas. Sponge measures in airfield area can be effectively implemented through detailed design considerations, etc.
of terrain and drainage ditch designs. The analysis of the runway and taxiway system in the airfield area reveals the feasibility of achieving and surpassing current requirements for the volume capture ratio of annual rainfall in sponge airports. The practice of elevating pavement elevation to create sponge storage in unpaved areas and using a drainage layer for the pavement and the shoulder stands out as successful approaches and should be considered in the design of airfield area projects.

References


6. Geng, L.S., Hu, J. Construction and design of whole site drainage system of sponge airport based on BIM. ICSI 2022. 2022, Nanjing, China


