Research on the Optimization of Municipal Water Supply and Drainage Design Based on the Sponge City Concept

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Abstract: The quality of water supply and drainage engineering directly affects urban operation and management levels. It is necessary to apply sponge city technologies to improve the water ecological resilience of cities, thereby achieving rapid absorption and allocation of water resources, meeting urban water requirements, and promoting efficient water resource allocation. This article takes the sponge city concept as the core, elaborates on its application significance in enhancing water resource utilization efficiency, strengthening urban disaster prevention and control resilience, and optimizing the ecological environment in municipal construction. It analyzes the core principles, typical strategies, and combination logic for selecting municipal drainage technologies. Finally, it explores the design optimization of municipal water supply and drainage in road systems, pipe networks, ancillary facilities, and ecological elements, aiming to provide reference opinions for relevant designers.

1. Introduction

The public has proposed new and higher demands on the operational quality and efficiency of water supply and drainage systems. Under this background, it is imperative to enhance the implementation of the sponge city concept in water supply and drainage sector and integrate it into the planning and construction of municipal water supply and drainage facilities. Through this, the collection effect of rainwater resources and their drainage roles can be enhanced, and the water storage and drainage effect of large-scale urban water supply and drainage systems can also be realized to further promote optimal allocation of all urban water resources.

2. Application Significance of the Sponge City Concept

In practice, the value of sponge city concept in municipal construction is primarily reflected in three aspects. In the first place, it facilitates a gradual and systematic enhancement of water resource utilization efficiency. Rationalizing functions of municipal water supply and drainage system according to actual needs, rainwater can be turned from a "drainage burden" into an "available resource." Through rainwater collection, the reuse of non-potable water (e.g., greening irrigation, sanitation cleaning) can reduce dependence on municipal supply and alleviate the contradiction between urban water supply and demand to form a recirculation chain of water extraction, utilization, storage and reuse [1]. Second, it enhances urban disaster prevention and control capability. A flexible facility design minimizes the peak operating pressure of this system to avoid sewage overflow caused by overload of the pipeline network under extreme rainfall events. At the same time, by encouraging rainwater infiltration and storage it reduces surface runoff from the source control of "urban waterlogging" to avoid a rise in the probability of timely paves the way for urban floods turned to active flood fighting passive flood fight transformed into "active storage regulation." Thirdly, it helps for the restoration and optimization of urban eco-environment. Deeply integrating the sponge city concept with environmental protection concepts can reduce the obstacle of soil infiltration caused by hard paving, raise groundwater recharge, and also reduce the impact of pollutants carried by rainwater runoff on natural water bodies, improve local city micro-ecology. This is to help ease ecological damage due to conventional water supply and drainage systems, as well as improve the quality of life in cities.

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3. Selection of Municipal Drainage Technologies Based on the Sponge City Concept

3.1 Core Principles for Technology Selection

It should prioritize the adaptability of the site for technology selection, make a comprehensive decision on soil permeability, underground space distribution and site such as topography characteristics [2]. Where soil permeability is limited, permeable paving and bioswales are encouraged to prevent reliance solely on infiltration-based technologies. Where underground spaces exist, permeable paving must be overlaid with a cover and drain layer of at least 0.6 m thickness to prevent infiltration risk on sites with these features. Bioswales with a longitudinal slope > 4% should be constructed as stepped and fitted with energy dissipation devices to limit flow velocity. On the other hand, functional requirement for differentiated selection of technologies should also influence your selection. Permeable paving is one suitable option but if the core focus of rainfall management practices is peak shaving and groundwater recharge, permeable paving should be used. On motorways, permeable asphalt concrete will be used while on non-motorways permeable bricks and stones can be used. Also, a maintenance plan for clogging prevention should be planned at the same time. When balancing water treatment versus ecological restoration, bioretention provides an excellent option. In areas polluted, anti-pollution methods such as grassed swales with sedimentation should be reinforced; water-resistant plants and very permeable soils should be chosen. In situations where specified needs can be imposed on rainwater reuse, construction of below ground storage tanks ought to nevertheless get preference. These creations do not only have a low chance of pollution, but they can be integrated into the current drainage network. They are advised against in badly polluted areas, however. For area basins no less than 1 hm^2, infiltrating ponds are more economical. When constructing them, such as sand sedimentation tanks before, should be equipped with pre-facilities. In the winter snowmelt region, anti-salt damage facilities must also be installed. In addition, environmental risk control to avoid using the technology effects is also essential. Best suited bioretention technology should be analyzed first; as the cost for soil replacement in high-altitude regions is immense. Where that cost is excluded, bioswales and storage tanks may be used in combination. Far from residential areas, of course, infiltration ponds If the water body pollution is near, the anti-seepage design needs to be reinforced. Water must be tested for quality before the construction of storage tanks. If pollution exceeds standards in areas transfer-type facilities (e.g., transfer bioswalestype facilities) should be used instead.

3.2 Selection Strategies for Typical Technologies

First of all, permeable paving is used for hard pavement area, such as urban road and square. This is reflected in two points when it comes to selecting. When the road surface strength is poor, it may choose a semi-permeable structure to determine balance between bearing capacity and permeability functions. In addition, it can also be mixed with non-permeable paving and combine the point-line-plane mixing method to refine high-frequency use areas. Secondly, bioretention technology is suitable for sites such as residential green spaces and road green belts. The selection key points must centre around soil infiltration rate and drainage time control. When soil infiltration is less than 12.5 mm/h, a drainage layer should be added to make it a partial suction type. An additional reference to the standards of T/CUWA 40052-2022 should keep drainage time designed in less than 12-24 h, and extended no more than 48 h especially for young vegetation with less human activity [3]. Third, infiltration basins are fit for big parks and ecological corridors. The extra points for selection are controlling of pond parameters and the interconnections of system. The distance from the pond bottom to the groundwater level should not be less than 1 m, and the side slope slope 1:3. The level of the overflow water should be raised to more than 0.6 m from the pond bottom. Furthermore, fluids can be conducted in a system rather than transferring fluids from pump to pipe and wire through bioswales, which is smarter because it replaces the functional role of pipelines. Lastly, the storage tanks and bioswales selection must be more clearly distinguished. In the case of major structures, storage tanks ought to be made from strengthened concrete; in minor architecture jobs, it is best to use brick and stone material [4]. In addition, storage tanks must be designed in closed and sealed forms to avoid mosquito breeding. Bioswales that help storage tanks can be dry or wet types. If only used for transfer, transfer-type bioswales should be selected, and the cross-section is best to adopt the shape of inverted parabola or inverted trapezoid.

3.3 Application Logic for Technology Combination

This requires single technology method can no longer satisfy all-process needs of the sponge city construction infiltration, transfer, purification and reuse methods. Hence, a collaborative system should be developed [5]. To begin with, onsite drainage system of road regions could be made by permeable paving mixed with bioswales and sand sedimentation tanks. It can be a closed purification of this combination, which can improve the drainage efficiency in road area. Second, the drainage and reuse system of bioretention facilities, underground storage tanksand bioswales can be combined to create a residential landscape recycling. Rain water is captured with bioswales, processed with bioretention facilities and stored in storage tanks to satisfy the requirements of landscape irrigation and reuse. Third, large green space can construct ecological drainage system by combination of infiltration ponds, pre-ponds and ecological buffer zone. The combination of the two can enhance the peak shaving effect and groundwater recharge function, so that oil drainage in large green spaces meets ecological drainage requirements.

4. Optimization of Municipal Water Supply and Drainage Design Based on the Sponge City Concept

4.1 Optimization of Drainage Design in Municipal Road Systems

First, it is the roadbed design should be closely coordinated with pipeline planning. Designers should use the Building Information Modeling Method (BIM) technology to introduce building information modeling at the design stage, model and analyze road layout and underground water supply and drainage pipelines, optimize spatial planning scheme in real time, avoid the situation of drainage blockage due to pipeline conflicts. On the other hand, for roadbeds with poor permeability, it is necessary for the construction team to take improvement measures such as rolling, sun-drying and backfilling to improve the permeability of roadbed materials and reduce surface water at source. Meanwhile, designers should make clear the layout requirements of water supply and drainage pipelines according to current standards so that road surface engineering design can be improved at the same time, thus making roadbed and pipeline joint actions [6]. The second is to carry out differential optimization of road surface design according to different use scenarios. For design of sidewalks, Designers need to adopt economical, ventilate and high permeability new materials, and make drainage routes coordinated with urban landform characteristics to ensure that the road surface rainwater can rapidly infiltrate. Designers of the lanes within a vehicle must strike a balance between secure transport and efficient drainage. It must enhance the drainage density and other aspects of improvement with the aim of enhancing surface structure flatness to adapt high-speed vehicle running adaption. On the other hand, it also should pay attention to improve drainage performance and select good quality new material so that rainwater liquid can quickly move off of the road surface. Last but not least, the green belt design needs to contain water storage, filtration, and reuse functions. Designers can reasonably make the height of green belts and the layout of rainwater collection points, control the height at which Grasses are collected between green belts and sidewalks, use collection inlets that only have a few filters to prevent blockages by debris too large. Thereby, during the construction of the ecological road green belt design, the designers must lay planting soil at the bottom and use upper layer gravel as well as strip permeable pipes to create a simplified rainwater filtration system for primary purification of rainwater. In addition, designers need to provide drainage ditches and overflow systems. The former can help with water storage to relieve drainage stress in the rainy season, and the latter connects directly to a supply and drainage system to enhance hydraulic performance of the irrigation project. One example is to use to store rainwater for irrigation of greening, which can improve the efficiency of utilization of water resources.

4.2 Optimization of Water Supply and Drainage Pipe Network Design

The first is to strengthen pre-survey and differentiated zoning at the design of pipe network. Designers need to do pre-surveys at the pipe network design stage, clarify the specific locations and depths of urban drainage pipe networks, and prevent damage of existing facilities due to new pipe network construction. On the other hand, fire water supply pipe networks should be distinguished from municipal water supply pipe networks based on functional differences for the water supply system. The water supply pressure of municipal water supply pipe networks is generally controlled below 0.3-0.4 MPa, while the pressure of fire water supply pipe networks must be more than this standard. Designers should prevent the impact of pressure confusion on water supply systems or pipe leakage, and reasonably use the residual pressure of water supply systems to improve energy utilization efficiency. Pipe network parameters and layout design should consider practical and maintainability factors. For pipeline design, it is suggested to choose the direction of intersection points on straight lines when laying pipelines and arrange the corners of pipelines at positions that facilitate operation; together with building inspection wells at the same time to limit interface leakage problems or blocking. Furthermore, during the design phase, designers should integrate advanced geophysical prospecting technology and BIM technology to reduce the distance between drainage pipes and existing pipelines as much as possible in order to achieve a rational assembly [7]. Not only that, designers should perform accurate calculations on pipe diameters and wall thickness of pipes according to local meteorological and rainfall characteristics, as well as water supply pressure and transmission distance of the pipe network so that it can adapt to different working conditions of drainage needs. Finally, pipe material selection should adhere to the principle of adaptive. Therefore, designers can compare the performances of different pipe materials, such as concrete and cast iron types1; through the combination between good weather resistance and anti-leakage performance with factors such as pressure requirements during transmission and transmission environment to reduce the leakage problems happened when improper pipe material is used and improve long-term drainage stability of urban water supply pipe network.

4.3 Optimization of Integrated Design of Ancillary Facilities and Ecological Elements

Introduction The design of ancillary facilities shall promote integrated optimization. In the early design stage of ancillary facilities, designers should carry out general investigation research on urban water supply and drainage engineering status, to make clear sketchy situation whether such various design indicators satisfy relevant regulations. According to this, they must optimize the functional mechanism of support facilities. At the same time, designers had better optimize the selection of building materials and construction schemes, so as to improve its durability and drainage adaptability. The combination of rainwater diversion, and sunken greening measures can enhance the capabilities of these two systems to retain rainwater. Also designers should focus on the relationship between greening nodes and ancillaries, introduce new technologies and concepts to promote drainage performance, make ancillary facilities and the main drainage system coordinated operation so as to improve overall drainage efficiency.

On the other hand, plant selection should place an emphasis on ecological adaptability to better utilize their roles in soil reinforcement and rainwater purification mechanism. Plants with deep, extensive root systems that will hold soil in place and prevent it from being scoured by rainwater are the horticultural saviors designers should seek. These plants should have a potent ability for rainwater purification and filtration to allow them to be used in engineered scenarios such as rain gardens and sunken green spaces or "temporary reservoirs for storing rainwater". They also should have both flood and drought tolerance characteristics in order to survive and function in non-natural precipitation rainfall scenarios [8]. Designers should likewise integrate local weather factors and ship expenses with post-maintenance needs to limit maintenance loads by the use of native plants. So that through the reasonable selection and combination of multi-species can not only meet the drainage, purification needs, but also improve the ecological landscape effect of urban greening plants to achieve win-win between ecological benefits and drainage function.

5. Conclusion

As a systematic innovative mode for the field of municipal drainage, the sponge city concept takes breaking through the traditional rigid drainage mode and realizes cooperative coexistence of city and natural hydrology as its essence. Technological selection based on the adaptabilit y phase of sites, functio nal requirements and risk prevention and control, design optimizations targeted at road systems, water supply and drainage pipe networks, supplementary ecological components through coordinated actions of "infiltration.storage.utilization.d rainage" so that rainwater is "sediment" collected and transformed into a resource alongside improvement of urban flood prevention conduction capabilities.

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