Discussion on Integrated Design of Emergency Storage Facilities for Dangerous Chemicals Transportation Accidents and Bridge Drainage Run off Treatment Facilities of Expressway

JingZhao[1], ShegangShao[1*], DongNi[1], MinminYuan[1], DongZhang[1] and DanWang[1]

[1]Research Institute of Highway Ministry of Transport, Bei jing, 100088, China

Abstract. Based on the investigation on the collection and treatment of the runoff from the bridge-deck of some expressways involving sensitive water bodies, this paper proposed an integrated design idea of the emergency storage facility and the bridge-deck rainwater runoff treatment facility for the transportation accident of dangerous chemicals in the expressway. The integrated design idea improves the disadvantages of simultaneous treatment of rainwater and accident-water in the bridge-deck runoff treatment system. The process flow, plane layout, functional unit volume design, conversion device, and control system involved in the integrated design are discussed.

1 Introduction

The water environmental safety risk caused by the leakage of dangerous chemicals transportation accident is the leading environmental risk during the operation period of the expressway in the centralized drinking water source area, water source protection area, class II and above surface water body and other water environment sensitive areas.

In case of leakage of dangerous chemicals transportation accident in the road of water environment sensitive area, especially on the cross-water bridge, it will cause not only massive casualties and property losses but also cause severe damage to the surrounding environment, especially the water environment.

To prevent the environmental risk of hazardous chemicals transportation accidents during the highway operation period, the former State Environmental Protection Administration, the National Development and Reform Commission and the former Ministry of communications jointly issued the notice on *Strengthening the Environmental Impact Assessment of Highway Planning and Construction* (HuanFa [2007] No.184). This notice requires that for bridges crossing sensitive water bodies, on the premise of ensuring safety and technical feasibility, a bridge-deck runoff collection system should be set up on the bridge, and sedimentation tanks should be set up on both sides of the bridge to deal with the bridge-deck runoff after a pollution accident, so as to ensure the safety of drinking water.

The above environmental protection requirements have been better implemented in highway construction with the strengthening of highway environmental protection acceptance management.

However, according to the environmental protection acceptance survey of several expressways, it is found that most of the bridge-deck runoff is treated by setting a sedimentation tank at the end of the centralized drainage facilities. Based on the sedimentation tank treatment, some projects are also united with the constructed wetland, sand filter and other rainwater runoff advanced treatment technologies, and the sedimentation tank is also used as the emergency storage facility for hazardous chemicals leakage.

As the rainwater runoff is treated together with the accident-water containing the leakage of hazardous chemicals transportation accident, once the leakage of hazardous chemicals transportation accident occurs and enters the treatment system, the advanced treatment process unit will lose the rainwater treatment function permanently.

In case of dangerous chemical transportation accidents in the later stage of rainfall, the accumulated runoff in the early stage of rainfall occupies a certain space, so the volume of sedimentation tanks is often not enough to store the leakage of dangerous chemicals accident.

Therefore, it is very important to deal with the leakage of rainwater runoff and hazardous chemical transportation accidents separately.

2 Investigation and Analysis of the current situation of emergency storage facilities for dangerous chemicals transportation accidents

To understand the current situation and problems of emergency storage facilities for hazardous chemicals transportation accidents in China, the author selected

*Corresponding author's e-mail: sg.shao@rioh.cn

some expressways involving sensitive water bodies for field investigation. The following conclusions can be drawn:

(1) The existing roads involving sensitive water bodies have built a bridge-deck runoff collection system, and the bridge-deck runoff is led to the treatment system set at both ends of the bridge through longitudinal PVC drainage pipes for disposal;

(2) The emergency storage facilities for hazardous chemicals transportation accidents are mainly in the form of sedimentation tanks, with the primary purpose of dealing with rainwater runoff, and also have the function of accident-water storage. The rainwater and accident-water are mixed for disposal and discharge;

(3) All functional units of emergency facilities for hazardous chemicals transportation accidents are connected in series. In case of accident leakage, the function of each functional unit will be damaged by accident runoff, especially the rainwater advanced treatment unit such as constructed wetland, which is difficult to recover after damage;

(4) The volume of the sedimentation tank is too small, or the location setting is unreasonable. There is no sedimentation tank at the end of the longitudinal PVC closure pipe of some bridges. The longitudinal drainage pipe leads the bridge-deck runoff water out of the water surface range and then discharges it locally. The drainage finally flows into the water body through the surface overflow;

(5) The treatment system does not have the function of timely emptying after rain and ready to receive accident runoff at any time. Most of the sedimentation tanks do not have the necessary devices such as emptying pipe valve and overflow pipe. The part that remains in the tank after rain and cannot overflow only depends on natural evaporation and dissipation, which causes the sedimentation tank to be occupied by the bridge-deck rainwater runoff of the front field rainfall for a long time after rain, and has no volume ready to receive accident runoff at any time The emergency function is lost.

Through the above investigation and analysis, it can be seen that it is essential to build the emergency treatment system of hazardous chemicals transportation accidents with reasonable structure and function, and improve the effectiveness of the initial rainwater runoff treatment function and the emergency storage function of hazardous chemicals transportation accidents.

3 Research on the integrated structure of emergency storage facilities for hazardous chemicals transportation accidents and bridge-deck rainwater runoff treatment facilities

3.1 Functional requirements for emergency storage facilities for hazardous chemicals transportation accidents

Hazardous chemicals refer to highly toxic chemicals and other chemicals that are toxic, corrosive, explosive, combustion and combustion-supporting, and are harmful to the human body, facilities and the environment. The environmental events caused by road transport accidents refer to the environmental events that the vehicles transporting hazardous chemicals or substances liable to pollute the environment cause leakage of the carriage into water bodies, soil or atmosphere due to fault or accident, or may cause severe threats to the ecological environment and people's life and property—such as leakage, burning, explosion. Those accidents cause not only direct casualties and property losses but can also cause secondary pollution to the surrounding atmosphere, water and soil environment.

Due to the poisonous, corrosive, explosive, burning, and combustion-supporting properties of hazardous chemicals, the actual hazards and possible hazards caused by accidents to humans, animals, plants, soil, water and atmosphere should be dealt with after the leakage of hazardous chemicals transport accidents. Quickly take measures such as closure, isolation, decontamination, and the leakage (solid or liquid) or accident-water generated during on-site disposal needs to be collected and disposed of by professional departments. Therefore, emergency transportation facilities for road hazardous chemicals transportation accidents should have the function of temporarily storing dangerous materials leakage accidents or accident-water and isolating their connection with water bodies and soils. That is to say, emergency transportation facilities for road hazardous chemicals transportation accidents should have sufficient space and proper environmental pollution isolation protection function. From the perspective of function, it should be independent. Generally, it is not suitable to be used in combination with other non-hazardous chemical accident emergency functions.

3.2 Functional requirements for bridge-deck rainwater runoff treatment facilities

The primary goal of the bridge-deck rainwater runoff treatment facility is to treat the initial rainwater runoff and discharge it into the natural water system to meet the corresponding discharge standard to reduce the pollution of the surrounding water body by the bridge surface runoff. The prime pollutants of the initial rainwater are SS, COD. The properties of pollutants are quite different from those of hazardous chemicals and domestic sewage. There are no characteristics of hazardous chemicals such as poison, corrosion, explosion, combustion and combustion, and the concentration of pollutants is also far less than domestic sewage. Therefore, the bridge surface runoff treatment facility only needs to meet the requirements of the structural unit, residence time and anti-seepage of different treatment processes.

At present, the rainwater runoff pollution control measures for bridge-decks mainly include vegetation control, setting up detention ponds, oxidation ponds, constructed wetlands, and percolation systems. Excluding detention pond, other means involve soil,

plants and microorganisms. Once the leakage of hazardous chemicals or accident-water enters the engineering unit composed of the above measures, the system structure and function will be damaged. In severe cases, the natural soil and water outside the treatment system will be polluted, and then the surrounding ecosystem will be destroyed.

3.3 Integrated design of emergency storage facilities for hazardous chemicals transportation accidents and bridge-deck rainwater runoff treatment facilities

(1) System process design

According to the functional requirements of emergency storage facilities for hazardous chemicals transportation accidents and bridge-deck rainwater runoff treatment facilities, these facilities should be considered as two different functional units in design. Due to the limitation of current technology, it is less feasible to collect the leakage of hazardous chemicals transportation accident (or the accident-water) and the rainwater runoff of bridge-deck respectively. In case of accident, that two can only be mixed and then collected by the collection system and transported to the treatment system at both ends of the bridge. In order to avoid dangerous chemicals leakage or accident-water entering into the bridge-deck rainwater runoff treatment facility and damaging its function, the emergency storage facility and the bridge-deck rainwater runoff treatment facility should not adopt the series connection mode, but utilize the parallel connection mode, which can realize the separate treatment of accident-water and non-accident rainwater runoff through the shunt conversion device set between the two facilities. The schematic diagram of the process flow is shown in Fig.1.

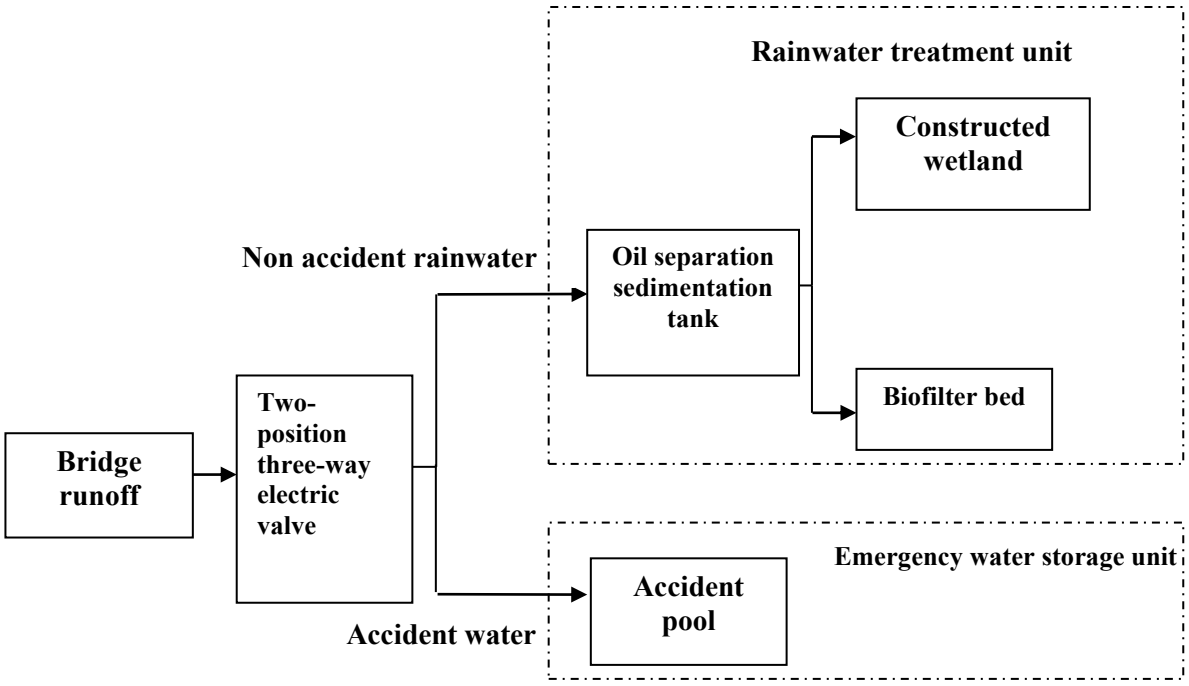

Fig.1 Integrated design process flow diagram of emergency storage facilities for hazardous chemicals transportation accidents and rainwater runoff treatment facilities on bridge-deck.

The working principle of the system is as follows: The end, which leading to the oil separation and sedimentation tank, of the two-position three-way valve, is in the normal-open state. The bridge-deck runoff under regular rainfall enters the oil separation and sedimentation tank. It then enters the follow-up rainwater runoff advanced treatment unit after oil separation, sedimentation and stable regulation. After meeting the specified discharge standard, it will overflow and discharge automatically; In case of transportation-accident leakage of hazardous chemicals, turn the two-position three-way valve to make the end of the valve leading to the oil separation and sedimentation tank closed, and open the valve leading to the accident tank at the same time. The accident-water will enter the accident tank for temporary storage and submit to the professional department for disposal.

(2) Overall layout of the system and volume design of the functional unit

① Overall layout of the system

To facilitate the integrated construction, it is recommended to arrange the accident pool in the accident-water emergency storage unit together with the oil separation sedimentation tank in the rainwater runoff treatment unit. The accident pool and the oil separation sedimentation tank are both constructed with reinforced concrete. That two are connected by a two-position three-way electric valve, and its overall plan abridged general view map is shown in Figure 2.

② Emergency storage unit volume design

The emergency storage unit is composed of an accident pool, the primary purpose of which is to store the accident runoff of dangerous chemicals. The valve of the accident pool is normal-close and only opened in the case of hazardous chemicals transportation accident. Therefore, the accident pool is in a state of emptying at ordinary times and is only used to store accident-water.

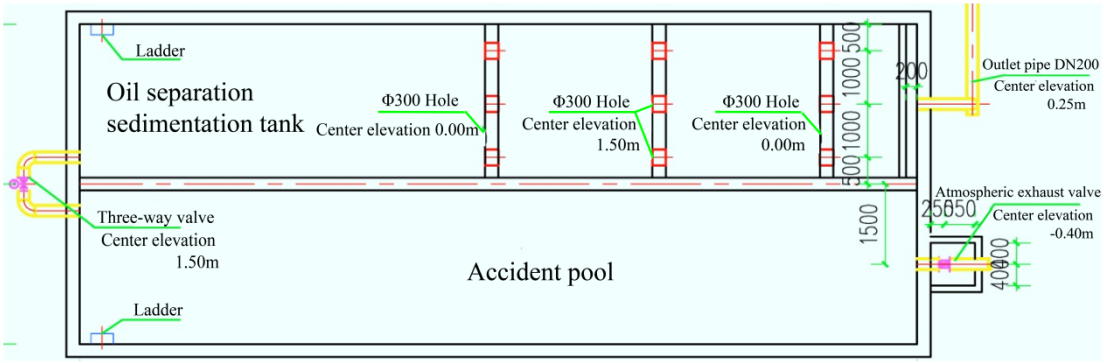

Figure 2. Integrated layout of emergency storage facilities for hazardous chemicals transportation accidents and rainwater and runoff treatment facilities on bridge-deck.

The purpose of the accident pool is to receive the accident runoff, and its volume should meet the requirements of the general hazardous chemicals accident runoff. According to the investigation, at present, the conventional vehicles for transporting dangerous liquid chemicals in China include tank trucks for transporting oil products and liquid chemical trucks with a volume of 2-50m^3, and the more common ones are less than 30m^3. The probability study of the probability of various leakages in the accident of a tank truck in foreign countries shows that the total chance of leakage of specific accidents of tank trucks is 0.064%, that is, the leakage caused by general accidents is often a few cubic meters. The limit case shall be considered in the design of accident pool volume, that is, assuming that under the condition of designed rainstorm intensity, all the dangerous liquid chemicals carried by the transport of hazardous chemicals vehicles leak on the bridge, and the accident runoff formed by the mixture of the leakage and rainwater enters the accident pool after being intercepted by the closure pipe. The capacity of the accident pool shall be the sum of the volume of hazardous liquid chemicals and the quantity of rainwater during the period from the beginning of leakage of hazardous chemicals to the cleaning of the bridge-deck.

According to the above analysis results, when calculating the accident pool capacity, the time from the leaking to the scouring clean of the hazardous chemicals should be determined first. To ensure the feasibility of the calculation, this paper assumes that the hazardous liquid chemicals and the rainfall-runoff are discharged separately on the bridge-deck. First, the hazardous liquid chemicals elimination time is calculated, and then the rainwater runoff during the hazardous liquid chemicals elimination period is calculated according to the time. The sum of the volume of hazardous chemicals and the rainwater runoff during the exclusion of hazardous liquid chemicals is the required capacity of the accident pool. The calculation process and method are as follows:

a. Calculation of drainage capacity of the longitudinal intercepting pipe

According to the *Code for Design of Highway Drainage (JTJ 018-97)*, the drainage capacity of the ditch or pipe is calculated as follows:

$$Q_c = vA \tag{1}$$

In the formula:

Q_c ——the drainage capacity of the ditch or pipe (m^3/s);

V——the average flow rate (m/s) in the trench or tube;

A——cross-water cross-sectional area (m^2);

The average flow rate in the trench or tube is calculated as follows:

$$v = \frac{1}{n} R^{\frac{2}{3}} I^{\frac{1}{2}} \tag{2}$$

In the formula:

N——the roughness coefficient of the trench wall or the pipe wall (m^3/s);

R——water radius (m), R=A/ρ;

P——wet circumference (m);

I——hydraulic gradient.

b. All hazardous chemicals are transported to the treatment system for calculation

According to the survey results of vehicles commonly used in China to transport hazardous liquid chemicals, this study sets the volume of hazardous liquid chemicals to 30m^3, and the formula duration time of that liquid delivered to the treatment system is simplified as follows:

$$t = 30 / Q_c \tag{3}$$

In the formula:

t——Time required for hazardous liquid chemicals to be delivered to the treatment system (s);

Q_c ——Discharge capacity of ditch or pipe (m^3/s).

c. Rainfall-runoff during hazardous liquid chemicals exclusion

The rainfall-runoff during the exclusion of hazardous liquid chemicals is calculated as follows:

$$Q_0 = tQ \tag{4}$$

In the formula:

Q_0 ——Rainfall-runoff during hazardous liquid chemicals removal(m^3);

t——time required for hazardous liquid chemicals to be delivered to the treatment system (s);

Q——Design runoff(m^3/s), calculated as follows:

$$Q = \psi F I_r \tag{5}$$

In the formula:

ψ ——Runoff coefficient, the asphalt concrete pavement is 0.95, and the cement concrete pavement is 0.90;

F——The catchment area is equal to the product of the road width W and the length L of the drainage section（hm^2）;

I_r——Rainstorm intensity, the rainfall intensity corresponding to the collection time（L/（s·hm^2））.

d. Volume required for the accident pool

Calculate as follows:

$$Q_s = 30 + Q_0 \tag{6}$$

③ Rainwater runoff treatment unit volume design

Oil separation sedimentation tank is a necessary facility of rainwater runoff treatment unit. It can not only be used for rainwater runoff treatment alone but also be combined with other rainwater runoff treatment processes to form multi-level series combination control measures. It can be used as pretreatment links and regulating pools of other treatment measures.

The First Flush Effect refers to the phenomenon that the initial rainwater runoff disproportionately carries most of the pollution load of the entire runoff. Based on this theory, the volume of the oil separation sedimentation tank should at least meet the needs of the initial rainwater runoff. Therefore, in the design of the oil separation sedimentation tank, the initial collection time of the rainwater runoff should be determined first. According to the research results at home and abroad, the COD and other pollutants in the bridge runoff have a good linear correlation with SS. Therefore, SS can be used as the characteristic pollutant of bridge runoff to study its sewage discharge law, and then determine the initial rainwater runoff time to be collected.

The joint scientific and technological research project of transportation industry "Research on Key Technologies of water environment security along expressway" jointly completed by Yongxiu Wuning Expressway Construction Project Office of Jiangxi Provincial Department of transportation and Highway Science Research Institute of the Ministry of transportation, etc. For the first time, artificial rainfall experiment was used to fit the coupling between rainfall intensity, rainfall duration and road runoff pollutant concentration Based on the relationship, a runoff erosion model was established. According to the research results of this project, the variation of SS concentration in bridge runoff with the change of storm intensity and rainfall duration can be characterized by the following formula:

$$C_t = C_0 e^{-\left(\frac{x}{0.2855} + \frac{y}{9.0349}\right)} \tag{7}$$

In the formula:

C_t——Concentration of pollutants in surface runoff at various time points for each rain intensity;

C_0 ——Initial concentration of pollutants, SS is a characteristic pollutant, and each region can be determined by experiment. It is set to 450mg/L in Jiujiang area of Jiangxi Province.;

x——Normalized rainfall duration value, dimensionless method: x=t/60, t is the duration of the rain, the unit is min;

y——Normalized rain intensity value, dimensionless method: y=q/108, q is rain intensity, the unit is mm/h.

Therefore, when determining the volume of the oil separation sedimentation tank, the limit value of SS in the corresponding discharge standard can be selected as the design value according to the water sensitivity from *The Integrated Wastewater Discharge Standard*. According to equation (7), the rainfall duration meeting the discharge standard can be calculated. Then the runoff flow can be calculated according to the catchment area, which is the volume of oil separation sedimentation tank.

(3) Design of conversion device and its control system

In order to realize the separate treatment of hazardous chemicals accident runoff and rainwater runoff, the conversion device needs to have the role of diversion. In this paper, it is suggested to use two-position three-way electric valve (or solenoid valve) as the connection and conversion device between the accident valve and rainwater valve.

According to the working principle of the integrated design of emergency storage facilities for hazardous chemicals transportation accidents and rainwater runoff treatment facilities on the bridge-deck, how to determine whether hazardous chemicals transportation accidents occur is the key to the automatic control of the conversion device. In view of this, this paper proposes two automatic control strategies as follows.

① Automatic control strategy based on video image detection technology of hazardous chemicals transportation accidents

Through the high-definition camera and its video image detection function set in the sensitive water section, the operation status of dangerous chemical transport vehicles in the sensitive water section can be automatically identified. The abnormal situation is fed back to the highway monitoring system. The monitoring personnel determine the accident status and decide whether to implement the conversion between the accident valve and the rainwater valve. This paper to prevent traffic accidents caused by the illegal transportation of dangerous chemicals by ordinary vehicles in sensitive water sections, the scope of video image monitoring should be regulated. This study suggests that video image detection range should include the parking, traffic accidents and other abnormalities in vulnerable water sections.

② automatic control strategy based on runoff quality monitoring results

When the dangerous chemicals transportation accident runoff is mixed with rainwater, it will generally

cause the changes of water quality indexes such as pH value, petroleum and conductivity of runoff. Therefore, in this paper, it is suggested to set a water collecting well in front of the three-way valve. By measuring the water quality of the runoff in the water collecting well, when the water quality index is abnormal, the system automatically starts the conversion function between the emergency valve and the rainwater valve.

The automatic control strategy and scheme of the emergency storage facility for hazardous chemicals transportation accident and the conversion device of the bridge-deck rainwater runoff treatment facility proposed in this paper are shown in Figure 3.

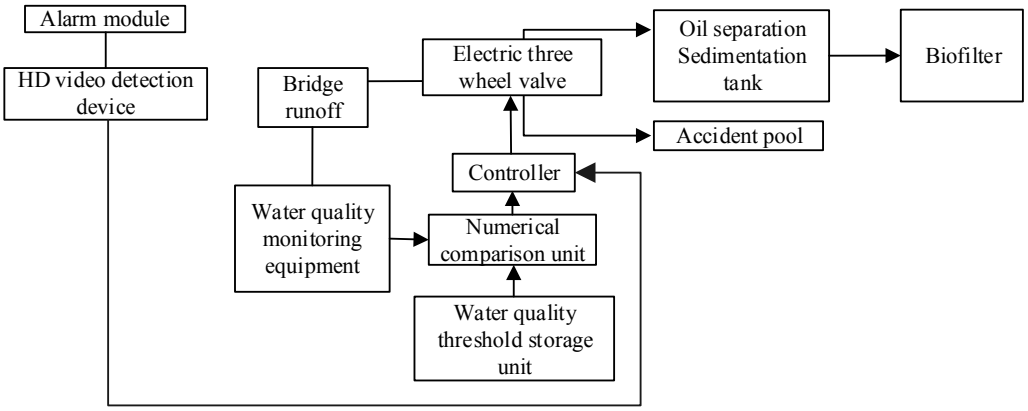

Figure 3. Automatic control strategy of conversion device between emergency storage facilities for hazardous chemicals transportation accidents and bridge-deck rainwater runoff treatment facilities.

4 Conclusions

Through the above research and analysis, some conclusions can draw as follows.

(1) An integrated design idea of emergency storage facilities for hazardous chemicals transportation accidents and rainwater runoff treatment facilities on the bridge-deck is proposed. Its working principle is as follows: one end of the two-position three-way valve leading to the oil separator is normally open, and the bridge-deck runoff under normal rainfall enters the oil separator; in case of leakage of hazardous chemicals transportation accidents, rotate the two-position three-way valve to lead to the oil separator One end of the lake is closed, and the valve leading to the accident pool is opened at the same time. The accident-water enters the accident pool for temporary storage.

(2) To realize the separate treatment of hazardous chemicals accident runoff and rainwater runoff, the conversion device needs to have the role of diversion. It is recommended to use a two-position three-way electric valve (or solenoid valve) as the connection and conversion device between the accident valve and rainwater valve. Its automatic control strategy includes automatic control based on the video image detection technology of hazardous chemicals transportation accident and monitoring results of runoff quality Automation control strategy.

References

1. Expressway Construction Project Office of Jiangxi Provincial Department of transportation, Highway Science Research Institute of the Ministry of Transportation, etc. General Report on Key Technologies of Water Environment Security Along The Expressway [R],2013.(in Chinese)
2. Chui T W, Mar B W, Horner R R. Pollutant Loading Model for Highway Runoff [J]. J. of Envir. Engrg. Division, ASCE, 1982, 108(6):1193～1210.
3. Deletic A. B., Maksimovic C. T. Evaluation of Water Quality Factors in Storm Runoff from Paved Areas [J]. J. of Envir. Engrg, ASCE, 1998, 124(9):869～879.
4. Zhao J., Qiu Y. Discussion on road runoff pollution and control technique [J]. Journal of Architecture and Civil Engineering,2004, 21 (3) : 50-53.. (in Chinese)
5. Xiao F., Wang X. Recent Progress of Diffuse Pollution on Loading,Control and Management [J]. Journal of Capital Normal University ,2002, (1):91-96. (in Chinese)
6. Ministry of communications of the people's Republic of China. JTJ 018-97 code for design of highway drainage [S]. Beijing: China Communications Press,1997-08-04. (in Chinese)
7. Zhou Z. Simplified formula for calculation of runoff in bridge-deck design and its applicable span [J]. Highway, 2012, (08): 111-116. (in Chinese)
8. Gao H., Huang L., Li H. Design of Huge Highway Bridge Runoff Collection System [J]. China Water & Wastewater,2008,24(10):45-47. (in Chinese)
9. Chen Y. Design method for emergency drainage system of bridge across ecology water area [J]. Journal of Chang'an University(Natural Science Edition),2008,28(5):81-85. (in Chinese)