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Research on the Application Technology of Low-carbon Construction in the Whole Life Cycle of Highways

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Abstract: Focusing on the four dimensions of "carbon calculation, carbon reduction, energy replenishment, and carbon sink", corresponding suggestions are put forward for highway construction from the perspective of the whole life cycle, and technologies such as low-carbon roadbed pavement construction, low-carbon construction of bridge and tunnel engineering, green zero-carbon service area, and zero-carbon energy are used to promote and apply the results of carbon reduction from the planning and implementation.
Keywords: Highways; Whole Life Cycle; Green and Low-carbon.

I. Introduction

In the face of the severe challenges brought about by the deterioration of the global ecological environment, climate change, and shortage of energy resources, there is an urgent need to accelerate the transformation of transportation development and construction technology mode innovation. Energy conservation in highway engineering is an important part of energy conservation and consumption reduction in the transportation industry, and an important field to achieve the development of green transportation. Therefore, in the process of green highway construction, the design and construction of highway engineering should be optimized from the perspective of reducing energy consumption to reduce energy consumption in the whole life cycle of highway engineering.

1. Low-carbon construction of highways throughout their life cycle
1.1 The idea of low-carbon construction in the whole life cycle
Focusing on the concept of low-carbon construction of highway infrastructure, carrying out low-carbon construction throughout the life cycle of design, construction, operation and maintenance, focusing on the evaluation of carbon emissions of low-carbon highways, the use of low-carbon engineering materials, low-carbon construction technologies and the application of renewable energy, and carry out technical research and promotion.
1.2 The path to realize low-carbon construction in the whole life cycle of highway engineering
Implement the concept of low-carbon construction in the whole life cycle in all aspects, build evaluation indicators in four dimensions: carbon calculation, carbon reduction, energy supplementation, and carbon sink, support the implementation of relevant strategies from multiple dimensions, plan low-carbon construction paths in combination with the actual situation of the project, and extensively investigate carbon emission evaluation methods at home and abroad for the carbon emissions of machinery and equipment, main building materials selection, key technologies and processes in the highway construction process; For vegetation restoration and landscape greening, the carbon sink analysis methods suitable for highway greening are widely

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analyzed, referenced and screened. In view of the representative and difficult problems in the construction of highway engineerings such as high energy consumption, high pollution emissions, cracking and rutting during the operation period of roadbed pavement during construction, through the integration of high-performance materials, equipment and low-carbon technologies such as durable and long-life processes and quality engineering technologies, the low-carbon construction of individual projects such as the construction of zero-carbon service areas and tunnel green blasting technology is innovated, and the construction technology is innovated. At the same time, combined with the low-carbon evaluation in the process, the selection and optimization of materials and processes, the optimization of energy substitution, and the selection and matching of ecological restoration landscape greening plants were optimized, and the innovation of technology application was promoted.

2. Construction of highway projects

2.1 Quantitative low-carbon evaluation methods

2.1.1 Accounting and evaluation of carbon emissions throughout the life cycle

Based on the theory of life cycle assessment, by analyzing the main sources of carbon emissions in typical highway sections, and aiming at the problems of unclear carbon emission accounting systems and low-carbon technology evaluation methods for highway infrastructure construction, as well as the unclear base of high energy consumption and high emission in the whole process of the project, this study proposes low-carbon management countermeasures and construction technologies covering the whole process of highway planning and design, bidding, construction, completion and acceptance, proposes a carbon emission accounting model for the whole process of highway construction, and establishes a carbon emission accounting and evaluation method for the whole life cycle of the highway. The evaluation of the energy conservation and carbon reduction effect of the project is realized, and the technical and theoretical basis is provided for the evaluation and management of the energy conservation and carbon reduction level of the expressway.

2.1.2 Measurement and improvement technology of vegetation carbon sequestration capacity in the highway area

Based on the application of carbon sequestration technology, drawing on the research results of forestry departments at home and abroad, combined with the practice of highway engineering, through the core technologies such as the allocation of carbon sequestration plants in the road area and the management and improvement of carbon sequestration in the road area, the concept of carbon sink in the highway area is proposed, and the technology application of the measurement and improvement of vegetation carbon sink capacity in the road area is carried out, including the evaluation of vegetation carbon sink capacity, the calculation of carbon sink capacity and the improvement of vegetation carbon sink, etc., to provide a reference for the vegetation restoration management of the project during the construction period and operation period, and provide an optimization scheme for the target community configuration and plant selection in the greening project. The use of interchange areas, slopes, middle zones and other areas to optimize the selection and matching of greening species, optimize the form of slope protection, and promote ecological slope protection technology can not only save project costs but also improve the carbon sink capacity of road areas. Through the application of this technology, the carbon sink capacity of vegetation in the road area can be improved by about 15%, and the vegetation can sequester about 200 tons of carbon in total.

3. Application of technical measures for low-carbon highway construction

The carbon emission sources of expressways include resource occupation, material use and energy consumption, which are divided into two categories: endogenous carbon emissions that directly emit carbon dioxide during the whole life cycle of construction, operation and maintenance, and exogenous carbon emissions that have emitted carbon dioxide in the production of steel, cement, asphalt, cables, fuel oil and other materials consumed in the production of external industrial systems. Therefore, the highway carbon reduction path mainly has the following technical applications.

3.1 Construction of low-carbon roadbed pavement throughout the life cycle

3.1.1 High-performance subgrade construction technology of 100-year-old quality engineering

The topography and geological conditions of the project are complex and the rainwater of the mountain highway is easy to collect, and the subgrade height difference is large, which is easy to lead to the difference in settlement of the subgrade and the cracking of the subgrade pavement. By adopting the high-performance subgrade construction technology of the century-old quality project, improving the technical index system, control standards and specific technical measures of the high-performance subgrade of the century-old quality project, optimizing the combination of subgrade filler, construction technology and mechanical equipment, improving the performance index of the subgrade, ensuring the overall stability of the subgrade, controlling the settlement after construction, ensuring the strength and durability of the subgrade, reducing the use of high-energy-consuming materials, reducing the maintenance cost in the later stage, greatly reducing carbon emissions, and reducing the cost of the whole life cycle.

3.1.2 Research and engineering application technology of asphalt pavement with large particle size and long life

Given the problem of cracking of semi-rigid base layer of highway pavement, the research and application of LSAM-50 flexible base material with large particle size were carried out, including the research on the preparation and performance evaluation method of LSAM-50 asphalt mixture specimen, the construction of ultra-large particle size asphalt pavement material model, and the construction of mechanical model of large particle size asphalt pavement wheel-pavement structure, which greatly reduced the occurrence of reflection cracks in the later stage and met the major strategic needs of the provincial and national transportation industry related to long-life pavement ATB-30 can be increased by more than 40% and 450% respectively, and the oil-to-stone ratio is reduced to 2.8%, which effectively improves the durability of the pavement and reduces the special investment in pavement maintenance in the later stage.

3.1.3 Low-carbon construction technology of asphalt pavement based on mechanical foaming device

The ecological environment along the project is sensitive, and the mechanical foaming warm mix asphalt technology is used to form foamed asphalt through the mechanical foaming equipment, to increase the surface area of the asphalt and reduce the viscosity of the asphalt binder, to be able to mix with coarse and fine aggregates and mineral powder at a lower temperature in the mixing building, improve the construction and workability of the asphalt mixture, and reduce the construction temperature by 20 °C ~ 40 °C on the premise of ensuring the road performance of the asphalt mixture, to improve the construction environment and protect the ecological environment along the line to the greatest extent. This technology is used to reduce asphalt smoke emissions by more than 80% and CO_2emissions by more than 50%.

3.1.4 Production and construction technology of hot mix asphalt mixture with clean odor, smoke suppression and low emission

In long tunnels and environmentally sensitive areas, the hot-mix asphalt mixture not only pollutes the surrounding environment but also endangers the health of construction personnel. In the asphalt mixing process, add odorless smoke suppression environmental protection additives, and regulate its adaptability, the use of odorant BPF can effectively improve the working conditions of the asphalt mixture construction site, basically have no impact on the road performance of asphalt and asphalt mixture, study the material function and environmental synergy of deodorant materials and projects along the highway, reduce the impact on the surrounding ecological environment, the degradation rate of hydrogen sulfide can reach more than 20%, and the degradation rate of nitrogen oxides and sulfur dioxide can reach more than 25%.

3.2 Low-carbon construction of bridges and tunnels

3.2.1 Green blasting technology for efficiency-enhancing and carbon-reduction tunnels

The tunnel is mainly located in the mountain section, the surrounding rock of the tunnel body is dominated by strong weathering and medium weathering rock mass, and the surrounding rock of the tunnel entrance section is dominated by strong weathering rock mass, and the application of green tunnel blasting technology for efficiency enhancement and carbon reduction is carried out, including the selection of the material of the slit pipe, the determination of the amount of explosives in the slit package, the selection of filling materials and water bags, the filling design of key blast holes and the overall blasting design, etc., to ensure the tunnel excavation footage while minimizing the amount of blasting charge, reducing the disturbance intensity of blasting to the surrounding rock, and reducing the impact on the surrounding ecological environment. Reduce the consumption of explosives by a total of 2 tons, improve the energy utilization efficiency of explosives when exploding, increase the footage of tunnel blasting by about 3%, reduce the rock powder content in the tunnel air, shorten the ventilation time after tunnel blasting by about 6%, and improve the tunnel operating environment.

3.2.2 Low-carbon design and construction technology of new composite structure bridges

Highway landscape bridges are mostly arch bridges, suspension bridges, cable-stayed bridges and other special structures, which need to solve the problems of deep-water foundation support construction, which is difficult to construct and has poor environmental protection; The traditional long-span bridge concrete has problems such as large dosage, structural self-weight, and web cracking. Carry out the application of the complete set of corrugated steel web beam technology, including the combined application of the beam-arch composite system and the corrugated steel web, the determination and optimization of the tensile force of the boom of the beam-arch composite system, etc., and adopt the corrugated steel web prestressing technology and the beam-arch combination system in this technology to reduce the self-weight of the main beam structure by about 25% and reduce the carbon emission by about 10%.

3.2.3 Vibration Mixing Technology for high-performance Concrete

Vibrating stirring will vibrate and crush the cement mass and ash mass in the mixture, so that it is evenly distributed in the mixture, effectively preventing the segregation of the mixture, making the cement fully hydrated, the cement hydrate and fine aggregate will evenly wrap the coarse aggregate, and the surface of the coarse aggregate with large particle size is equivalent to evenly coated with a layer of “lubricant”, and when the aggregate is moving, the friction resistance is reduced, and the compaction work is easier to pass downward. The large aggregate of the vibrating stirring water stabilized base layer is evenly distributed up and down, the bottom of the core sample is complete and compact, and the overall durability of the base layer is significantly improved. The stirring time is generally about 50s under traditional stirring, while the stirring time is 35~40s under vibrating stirring, and the output efficiency is greatly improved. Under the same conditions, when the amount of cement remains unchanged, the strength of vibrating mixed concrete is higher than that of traditional forced (static) mixing concrete

Soil strength increased by more than 8%; When the strength of the concrete remains unchanged, vibration mixing can save 5% ~ 25% of cement, shorten the mixing time by more than 20%, and save about 30% of energy.

3.3 Zero-carbon green service area energy supplemental construction

Given the problems of large traditional energy consumption and high carbon emission in the service area, based on analyzing the characteristics and needs of the application scenarios of the multi-energy complementary system, combined with the construction and operation conditions of the service area, the technical path to achieve the zero-carbon construction goal of the provincial highway service area was studied, and the research and application of the design and construction technology of the zero-carbon service area were carried out, including the establishment of a multi-energy complementary integrated technology system and the construction of an AC and DC flexible microgrid system. Through the application of a multi-energy complementary integrated technology system and intelligent control energy matching, we can make full use of the limited space conditions of the service area to explore the potential of renewable energy utilization, realize new energy power generation of about 500,000 KW·h per year, and realize the monitoring, statistics and intelligent management of energy consumption in the service area. Reduce the consumption of municipal power supply in the service area from the source, and achieve the goal of zero carbon emission indicators in the service area during the operation period.

Establish a multi-energy complementary AC and DC flexible microgrid system, and realize the efficient and high proportion of renewable energy consumption and conversion utilization of solar energy through multi-energy complementarity and cascade utilization. Solar power supply, air energy or geothermal energy heating (cold), and auxiliary heat storage, power storage and other technologies to achieve the integration of cooling, heating and electricity. According to the scale of the service area, the energy demand and the characteristics of the natural environment, a multi-energy complementary system should be established to realize the mutual conversion of cold, heat and electricity of ground source heat pump, air source heat pump and heat storage system, to improve energy utilization efficiency. Build an intelligent energy system management and control platform to achieve optimal system energy scheduling. Under the double unstable fluctuation of renewable energy input and multiple loads, the real-time matching and balance of source-storage-load can be realized. Promote the local consumption of renewable energy to the greatest extent, improve the energy utilization, economy and stability of the energy system in the service area, and reduce the energy demand of the service area from the outside world.

3.4 Carbon reduction accounting for distributed energy resources along highways

Highway service areas, tunnels, etc. are 24-hour all-weather energy-consuming units, and the demand for stable power output is very strong. The project carries out the application of distributed photovoltaic and photovoltaic storage integration technology, adopts 450 Wp monocrystalline silicon photovoltaic modules, and has a total system installation capacity of 1000 KWp, making full use of the advantages of photovoltaic power generation technology, maximizing the proportion of clean energy development and utilization in service areas and tunnels, effectively reducing the solar oxidation of buildings, prolonging the service life of buildings, using clean energy, improving the self-sufficiency rate of highway energy consumption, and saving the whole life cycle cost of highway construction and operation.

Based on the total efficiency of the system of 80% and solar radiation data, the annual power generation is calculated as follows:

Annual power generation = installed capacity of the system × number of effective utilization hours per year× total efficiency of the system = 1,000 KWp×1460.28 h×80%
=1,168,224 KW·h

The project is expected to generate a total of 1,168,224 KW·h in the first year. According to the estimation of the operation period of 25 years, the power of the photovoltaic module during the operation period is non-linearly attenuated, with an attenuation of 2% in the second year and linear attenuation in the 3rd ~ 25th year, with an average annual attenuation of 0.6%. Then, the total power attenuation of the PV module over a 25-year operating period is 20%. It is assumed that the decay rate of the total efficiency of the PV system is the same as that of the PV module, that is, the conversion efficiency of the inverter has not decayed. The 25-year project generates approximately 26,829,818 KW · h, with an average annual power generation of about 1,073,193 KW · h。

The energy-saving and carbon-reduction effects of the distributed photovoltaic application pilot project are calculated as follows.

Annual carbon reduction = annual electricity generation × marginal emission factor of electricity $\times 10^{-3}$; The marginal emission factor of electricity refers to the “2019 Emission Reduction Project Baseline Emission Factor of China’s Regional Power Grid” issued by the National Development and Reform Commission, which is 0.8587 tCO_2/MW · h； The calculated results show that the carbon reduction due to distributed photovoltaic power generation is about 23,039 t, and the average annual carbon reduction is about 922 t.

3.5 Increase the proportion of zero-carbon energy use

With the development of renewable energy such as wind power and photovoltaic and the continuous maturity of production technology, actively promote wind power, photovoltaic power generation and other technologies to become the main body of new energy supply in the design of expressways, which can greatly reduce the carbon emissions generated in highway operation. The smart highway has set up various kinds of monitoring, monitoring, information release and other IoT sensing layer equipment as well as edge computing, 5G micro base stations and other transmission and control equipment in the whole road to improve the stability and reliability of power supply of various facilities along the road, which plays a very important role in the normal operation of the smart expressway. At present, the highway smart energy power supply system is mainly designed from several aspects such as power management and control, power distribution monitoring, and remote power supply, but it lacks consideration for factors such as sudden large-scale power outages, local equipment failures, and cable theft. The design idea is to establish a grid-connected smart energy power supply system based on remote power supply mode and supplemented by a new energy microgrid. In the design of the smart high-speed power supply and distribution system, solar power generation equipment can be laid on the slope, interchange green space, carport and roof in the station area in combination with the road alignment, surrounding environment and meteorological conditions, and wind power stations can be set up at the mouth of the river and the mountain passes, to realize the grid-connected power generation and electricity consumption of the equipment along the road and the station buildings along the line. At the same time, the energy storage system is set up according to the load distribution of equipment along the road, supplementing the adjustable and controllable power supply in the power supply system, smoothing the power generation capacity of solar and wind energy, improving the utilization rate of solar energy and wind energy, and meeting the needs of various smart high-speed new loads.

4 Conclusion

Based on the actual situation of expressway construction, this paper integrates the concept of green and low-carbon, quantifies the low-carbon evaluation method in the design stage, consolidates the theoretical and methodological foundation, considers the benefits of carbon reduction and carbon reduction based on ensuring reasonable design, and balances the construction cost. In the construction stage, we will make breakthroughs in low-carbon construction technology, innovate green and low-carbon processes, and plan and introduce low-carbon technologies in combination with the actual situation of the project, to ensure the effective play of material performance and the improvement of energy-saving effects in the process of material use, and reduce the project cost. In the operation and maintenance stage, we will explore a low-carbon iterative path to achieve a win-win situation of quality and low-carbon, fully explore the application of renewable energy along the route, the comprehensive utilization technology of distributed energy in management facilities along the expressway, establish a multi-energy complementary and integrated technology system, and carry out a summary and evaluation of carbon emissions from low-carbon highways around the application of low-carbon construction throughout the life cycle technology.

References:

[1] Xu Xinquan, Wu Chuanhai, Zhong Dingwen. Research on the Management Mechanism of

Transportation Science and Technology Demonstration Project in Guangdong Province[J]. Guangdong Highway Transportation,2017(03):58-61.
[2] Liang Yuanlu, Liu Jia, Zhao Yanna. Green Road on Red Soil: Application of Green Highway Technology in Guangxi Expressway[J]. China Highway,2017(21):91-93.
[3] Li Xiang. A preliminary study on the design and analysis tools of carbon footprint in the whole life cycle of buildings[D]. Xi'an:Xi'an University of Architecture and Technology,2018(in Chinese).
[4] Liu Yuanyuan. Research on the theory and method of carbon dioxide measurement in highway life cycle based on ALCA[D]. Xi'an:Chang'an University,2019(in Chinese).
[5] Xu Jianfeng. Research on calculation method and prediction model of carbon emission in highway tunnel construction[D]. Chengdu:Southwest Jiaotong University,2021(in Chinese).
[6] Lü Zhichen, Hu Angang. Building a Green, Low-Carbon and Circular Modern Economic System in China: Realization Path and Practical Significance[J]. Journal of Beijing University of Technology (Social Sciences Edition),2021(06):35-43.
[7] Li Hui, Peng Xiaqing, Zhang Jingxiao. Life cycle carbon emission assessment and sensitivity analysis of highways[J]. Highway Engineering,2021(02):132-138.
[8] Wang Wen, Liu Jintao, Zhao Yue. Carbon neutrality and China's future[M]. Beijing: Beijing Normal University Press, 2022.