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Analysis of Environmentally Responsible Behavior in Cross-sea Bridge Projects

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Abstract: Given increasing concerns regarding environmental issues, environmentally responsible behavior during the construction of cross-sea bridge projects becomes critical. However, a systematic investigation of the topic remains absent. To bridge the knowledge gap, this study first defines environmentally responsible behavior from four perspectives: purposes, means, contents and influencing factors. Then, the study uses a grounded theory approach to code and analyze 101 documentations retrieved from 30 cross-sea bridge projects carried out by Chinese construction companies worldwide. Results show that environmentally responsible behaviors in cross-sea bridge projects are highly influenced by four factors, namely government policies, public opinions, goals of the projects, and construction companies' philosophy of environmental protection. Results also indicate that Chinese construction companies have used managerial, technical, and ecological means to ensure that the goals of environmentally responsible behaviors, namely minimization of damage to marine ecology; prevention of air, noise and visual pollution; and reduction of resource consumptions, are achieved. Lastly, suggestions for promoting and governing environmentally responsible behavior are proposed.

Key words: environmentally responsible Behavior, cross-sea bridge, grounded theory

1. Introduction

A sea-crossing bridge project is a large-scale construction project that involves building a bridge over water to connect two land areas or islands, in order to improve land transport connectivity. These projects often face unique challenges, such as dealing with special climatic and complex undersea geological conditions[1]. Furthermore, with the promotion of the "Belt and Road" initiative and the "dual carbon" target policy, enterprises must consider environmental protection when carrying out cross-sea bridge projects.

Currently, research on the environmental impact of sea-crossing bridges primarily focuses on the impact on water quality, hydrodynamics, and the ecological environment of the surrounding waters[2]-[4]. However, there is a knowledge gap regarding environmentally responsible Behavior under cross-sea bridge projects. This study aims to address the knowledge gap by using the grounded theory approach to define environmentally responsible Behaviors in terms of four dimensions: purpose, means, content and influencing factors, drawing on the definition of corporate environmental management Behaviors[5]. Such a study would help to expand the theory of environmental responsibility and enrich the theory of corporate social responsibility. Therefore, it can help guide enterprises to strengthen environmental management and protection in actual projects and improve their awareness and ability to exhibit corporate environmental responsibility.

Following the introduction, the paper is structured as follows: Section 2 provides a literature review of environmentally responsible behavior, analyzes typical cases, and introduces the theoretical framework of this study. Section 3 describes the research methodology based on the multi-case study

approach. Section 4 presents the research results. Section 5 discusses the main contributions of this study and proposes further areas of research.

2. Background

2.1 Environmentally responsible Behavior

We conducted on the theme of "environmentally responsible Behavior" from 2013 to 2023. A total of 522 articles were retrieved from the CNKI database, including 311 journal articles and 211 doctoral and master's theses. Of those, 274 articles pertained to environmental science and resource use, while 156 articles related to tourism. The remaining literature was scattered across various fields such as business, economy, and law. However, there was a noticeable lack of research in the field of construction engineering.

Currently, research on environmentally responsible Behavior primarily focuses on the field of tourism management. Wu and others have systematically compiled literature related to the environmentally responsible Behavior of residents in tourist destinations over the past 20 years[6]. Although there is limited research on environmentally responsible Behavior in the engineering field, Xie and others have investigated the formation mechanism of such Behavior in building construction enterprises[7]. In addition, Xu and others have conducted a study on environmentally responsible Behaviors in major projects from a group perspective[8].

The construction and use of sea-crossing bridges can have a detrimental impact on the surrounding environment. For instance, the Chesapeake Bay Bridge in the United States has been an area of serious water pollution for a long time due to the lack of attention to environmentally responsible Behavior. The decline in fish spawning in most areas can be attributed to long-standing river dams, culverts, and other hydraulic projects. Additionally, during its operational phase, the bridge has led to a substantial increase in the content of heavy metals and toxic organic compounds in the water and sediment[9]. Following the opening of the Hangzhou Bay Bridge in China, a significant number of birds were found dead on the bridge[10]. During the construction of a cross-sea bridge, it is possible to minimize the impact on the surrounding environment by implementing effective environmental Behavior. Throughout the construction and opening phases of Hong Kong-Zhuhai-Macao Bridge, the marine ecosystem in the surrounding area was continuously monitored, and a range of protective measures were implemented[11]. On the offshore artificial island of the bridge, a white dolphin sculpture facing the white dolphin breeding area raises awareness among tourists about the protection of white dolphins[12].

The environmental management and protection measures taken by enterprises during the construction and operation of a bridge may exacerbate the damage caused by the bridge. Therefore, it is necessary to conduct a systematic study of environmentally responsible Behavior in cross-sea bridge projects. This paper will use grounded theory to systematically analyse environmentally responsible Behaviors in cross-sea bridge projects .

2.2 Theoretical Framework

Grounded theory was first proposed by sociologists Glaser and Strauss in the 1960s as a bottom-up approach to constructing theories. It requires researchers to extract concepts, categories, hypotheses, and theories based on systematic data collection and induction of empirical data[13]. Grounded theory emphasises the development of new theories or concepts rather than the validation of existing theories. Therefore, as an exploratory study, this paper considers it appropriate to apply grounded theory to construct a systematic theory of environmentally responsible Behavior in cross-sea bridge projects.

The operational procedures of this research can be divided into the following aspects: identifying the problem, determining the research object, collecting the literature, and organizing and coding the information. The final conclusion is drawn after the initial construction of the theory. The compilation and analysis of data for grounded theory are conducted simultaneously. The research process typically involves three main stages: open coding, axial coding, and selective coding[14].

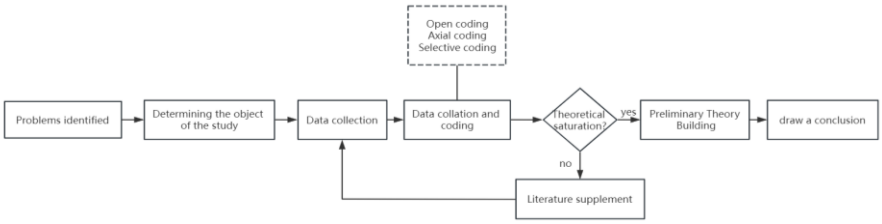


Figure 1. Grounded theory construction process

This study employs the Theory of Planned Behavior (TPB). According to this theory, people choose their actions based on their willingness and ability, and they adjust their actions based on their expected outcomes[15][16]. TPB is a widely used theoretical framework in social psychology and has been applied to various fields, including health, education, environmental studies and project management[7],[17]. This theory helps us to understand the determinants of individual Behaviors and predict their outcomes, specifically the relationship between attitudes, Behavioral intentions, and Behaviors. Therefore, this theory can be used as a basis for revealing the motivation behind environmentally responsible Behaviors in cross-sea bridge projects.

3. Methodology

3.1 Research design

This study employs a research methodology that combines the case study and literature review methods. The case study method can gain insight into the underlying mechanisms and complex relationships of a particular situation or phenomenon[18],[19]. Literature research method allows us to gain an in-depth understanding of and insight into a specific topic or issue[20]. In combination, the two methods can provide more comprehensive, reliable, in-depth, and varied findings. Thus, the methodology employed in this study through the case of a sea-crossing bridge is feasible.

Initially, 51 sea-crossing bridges were selected for this study. However, only 30 of them were ultimately chosen due to the absence of literature related to environmentally responsible Behavior in CNKI database, or because they were contracted by foreign construction companies. The 30 studies include 28 sea-crossing bridges in China and two abroad: the China-Maldives Friendship Bridge and the 1915 Çanakkale Bridge. The information related to the selected sea-crossing bridges was then examined in detail.

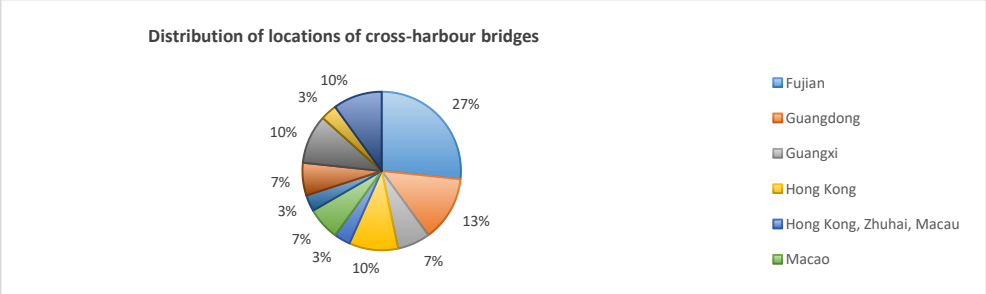


Figure 2. Distribution of locations of cross-harbour bridges

The selected cross-sea bridges are mainly located in Fujian, Guangdong, Macao and Hong Kong. The regional distribution of cross-sea bridges is extensive, and the case selection is comprehensive.

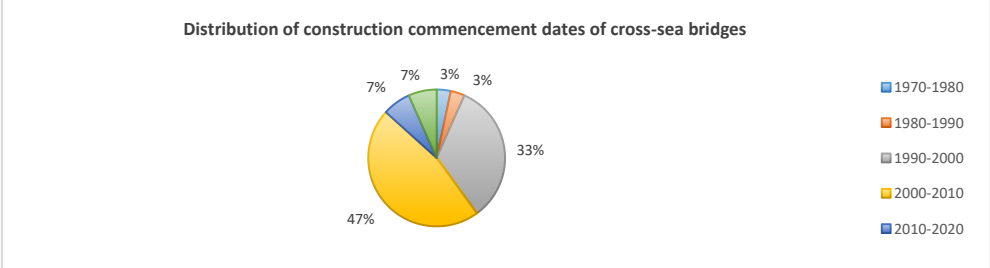
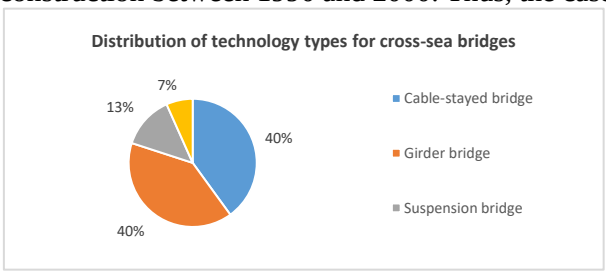


Figure 3. Distribution of construction commencement dates of cross-sea bridges

47% of the cross-sea bridges began construction between 2000 and 2010, while 33% began construction between 1990 and 2000. Thus, the cases selected were timely and comparable.



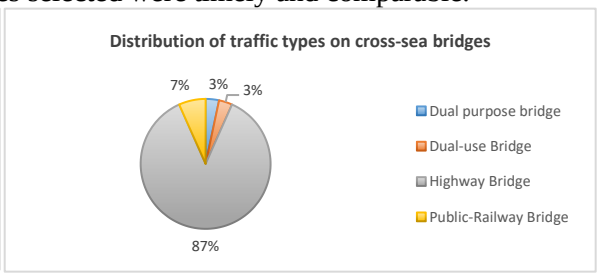


Figure 4. Distribution of technology types for cross-sea bridges **Figure 5.** Distribution of traffic types on cross-sea bridges

Finally, the majority of the sea-crossing bridges selected are girder bridges and cable-stayed bridges, primarily used for highways.

After identifying the cases to be studied, we searched for content related to environmentally responsible Behavior in the CNKI database and screened the literature. This search resulted in a total of 101 relevant pieces of literature, which were then coded and analysed using grounded theory.

The bridges were assigned code numbers, and the relevant documents were coded by the respective bridge code number in order. For example, "31" refers to the first document of Xiamen Bridge, while "3804" refers to the fourth document of Hong Kong-Zhuhai-Macao Bridge.

Table 1. Cross-sea bridges and documentation coding

nicknames	Name	Literature number	Number of documents
1	Cotai Bridge	13-16	4
3	Xiamen Bridge	31-33、35-36	5
5	Shantou Bay Bridge	51、53-54	3
6	Jiaozhou Bay Highway Bridge	61-62	2
8	Tsing Ma Bridge	81-85	5
9	Humen Bridge	91-99	9
10	Ting Kau Bridge	2701	（1）
11	Zhoushan and Dalian Island Link Project	1101-1102、1104-1111	10
12	Nan'ao Cross-sea Bridge	1201-1203	3
13	Haicang Bridge	1301-1303	3
16	Lianhua Bridge	1601-1602	2
17	Tieshangang Cross-sea Bridge	1701	1
18	Yanwu Cross-sea Bridge	1801	1
21	Xiwan Bridge	2101	1
22	Donghai Bridge	2201、2203	2
24	Ningbo Hangzhou Bay Bridge	2401-2406	6
26	Shenzhen Bay Highway Bridge	2601-2605	5
27	Stonecutters Bridge	2701-2702	2
29	Qingdao Bay Bridge	2901-2906	6
31	Xinglin Bridge	3101-3103	3
32	Jimei Bridge	3201	1
33	Changhuikou Cross-sea Bridge	3301	1
35	Xiamen-Zhangzhou Cross-Sea Bridge	3501-3507	7
36	Jiasao Bridge	3601-3603	3
37	Quanzhou Bay Bridge	3701-3702	2
38	Hong Kong-Zhuhai-Macao Bridge	3801、3803-3809	8

44	Pingtan Strait Bridge	4402	1
46	China-Maldives Friendship Bridge	4601-4602	2
48	Turkey 1915 Çanakkale Bridge	4801-4802	2
51	Guangxi Longmen Bridge	5101	1
Total number of bridges	30	Total number of documents	101

3.2 Data collection

As the authority and reliability of the literature listed in the CNKI database increases, studies based on it become more widely applicable. For instance, Zhao and others analysed research on thought visualisation in China using papers from CNKI[21]. Therefore, the main source of case study literature for this study is the CNKI database. To ensure a comprehensive data set, the literature search included academic journals, papers, conferences, newspapers and other publicly available sources. A total of 101 pieces of literature were screened, divided mainly into the following four categories:

(1) Academic journals: Bridge Construction, Environmental Protection, Marine Development And Management, china Harbour Construction, Journal of Civil Engineering, Management World, Railway Construction Technology, China Traffic Informatisation, Journal of Applied Fundamental and Engineering Sciences, China Science and Technology New Products, Prospecting Engineering, Surveying and Mapping Information and Engineering, China Engineering Consulting and more (88 in total).

(2) Newspapers: China Communications News, China Construction News, Global Times, People's Daily, Nanfang Daily, Zhejiang Daily, China Flower News, Shantou Daily, Ningbo Daily, Democracy and Law times and more (11 in total).

(3) Conferences: the proceedings of the National Bridge Academic Conference, the Chinese Highway Society of Bridge and Structural Engineering, the Chinese Society of Civil Engineering, the selections of Lu Peiyan's scientific and technical works and papers and more (8 in total).

(4) Academic papers and featured journals: academic papers from Zhejiang Ocean University and featured journals from the Belt and Road Report (2 in total).

When selecting information sources for academic research and thesis writing, it is important to choose research literature that is authoritative and reliable. This can be achieved by selecting research literature from official websites, which provides high-quality and dependable academic materials.

3.3 Data analysis

Initially, relevant literature was reviewed to comprehend the environmental impact of the cross-sea bridge project. Based on the first step's findings, grounded theory defines environmentally responsible Behavior in terms of four aspects: purpose, means, content, and influencing factors. Thus the documents were coded accordingly, resulting in 33 purpose, 117 means,149 content and 77 influencing facotrs original statements, respectively. Subsequently, suggestions for improvement are provided.

To understand the sources of environmental damage caused by each cross-sea bridge project, the relevant literature was consulted. Cao and others identified the main sources of pollutants during the construction period of the project[22]. Li and others identified several sources of seawater pollution during the bridge construction[23]. Cross-sea bridge projects causes environmental damage through the release of suspended solids, construction noise, construction and domestic waste, wastewater, exhaust gases, and pollutants into the bodies of water[11].

The impact of bridge construction on water quality is primarily due to sediment discharge and other pollution sources[24]. Hydrodynamics are also affected, including residual flow structure, water exchange, pollutant migration, and diffusion rate[25],[26]. The impact on aquatic organisms' survival is significant, particularly on fish eggs and juvenile fish resources. For example, the construction of the Xiamen-Zhanghai Bridge resulted in the loss of 14.0 tons of fish eggs and 96.8 tons of juvenile fish resources[27]. The construction of the Xiamen-Zhanghai Bridge also resulted in significant damage to the natural vegetation due to cutting slopes, excavation and filling, and mechanical rolling. Similar damage was caused during the construction of the Humen Bridge and the Henglin Bridge, which negatively impacted the mangrove ecosystems and the biodiversity of the area[28][29].

Additionally, these bridges have visible impacts on the living environment of surrounding residents. The growing number of marine projects of different types has damaged or is damaging the capacity of marine and coastal ecosystems to provide a range of products and services to humans[29]. The Jiaozhou Bay Cross-Sea Bridge has essentially eliminated the function of the port in Jiaozhou Bay, jeopardizing the prospects for sustainable development and the status of an international shipping center[30].

The following table displays the coding of the purpose, means, content, and influencing factors of the cross-sea bridge project's impact on the environment using grounded theory.

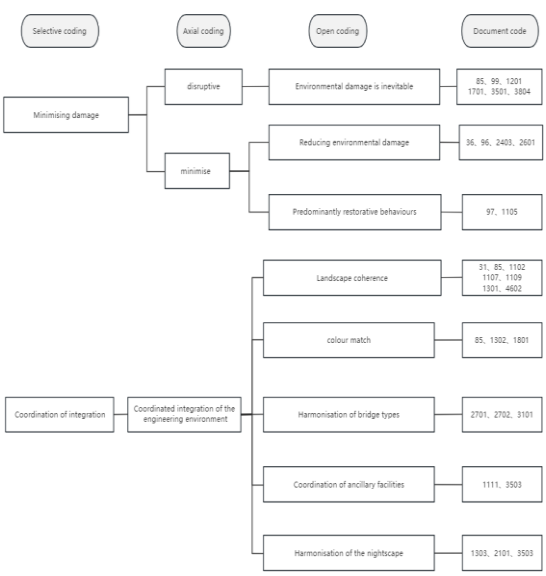


Figure 6. Purpose analysis of Behavior

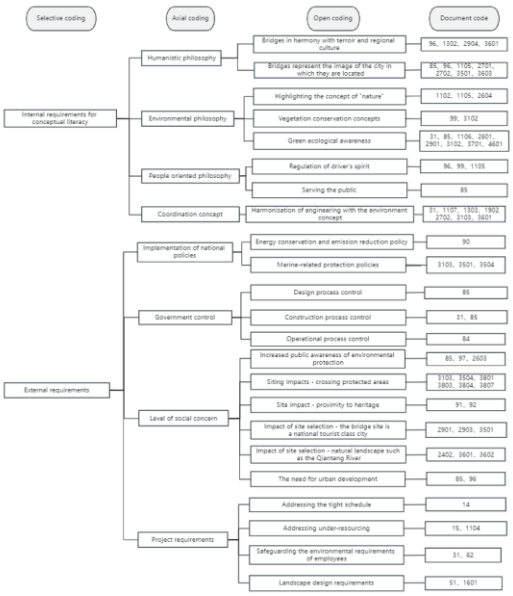


Figure 7. Analysis of factors influencing Behavior

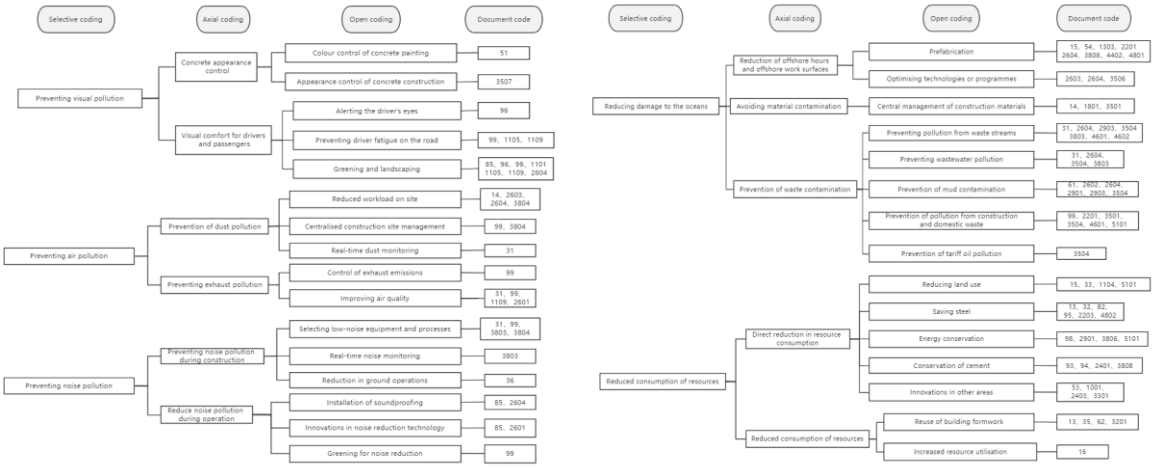


Figure 8. Content analysis of environmentally responsible Behavior

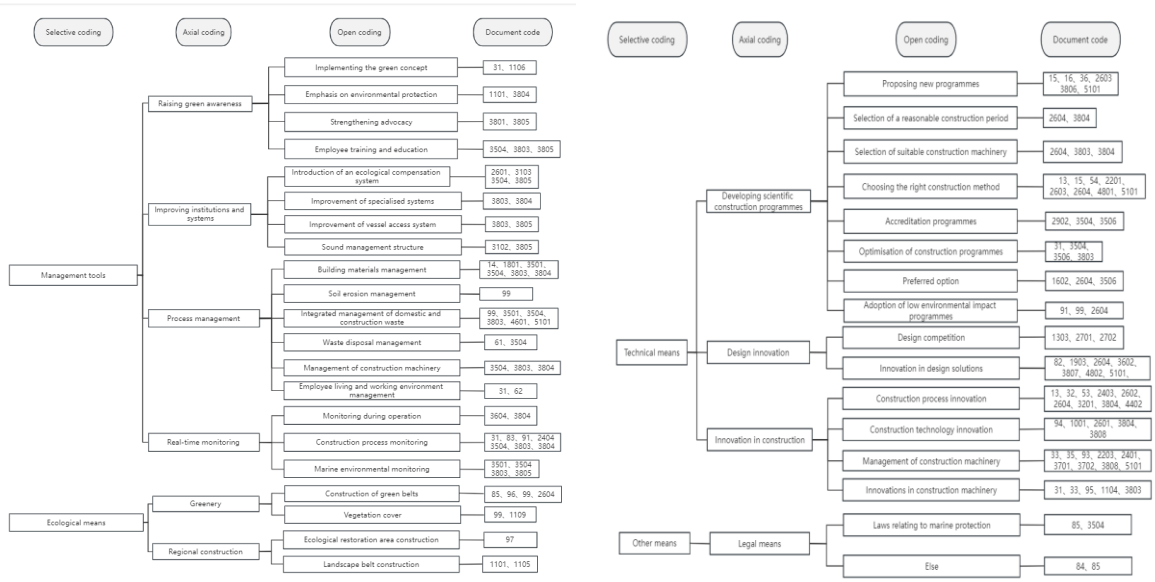


Figure 9. Analysis of means of environmentally responsible Behavior

4. Findings

This study revealed that the primary objective of environmentally responsible Behavior in constructing cross-sea bridges is to minimize the environmental damage caused by the project. Construction projects inevitably cause damage to the environment[11]. This damage includes not only the visible destruction of plants, animals, and marine life, but also economic impacts on sea performance and port capacity. Therefore, environmental responsibility requires restoration efforts[32]. The basic purpose of environmentally responsible Behavior is to minimize damage. The higher-level purpose is to ensure that the bridge project coordinates with the environment to form a whole, and potentially even a new landscape[31]. When coordinating and integrating bridge design, it is important to consider factors such as the bridge position, line shape, type, colour, night scenery, and ancillary facilities. It is also important to integrate landscape design ideas and combine engineering aesthetics and environmental humanities to create a local landmark bridge that is both functional and aesthetically pleasing[33].

The construction of cross-sea bridges can promote environmentally responsible Behavior through various means, including management, technical, ecological, and legal tools. Management tools involve raising awareness of green practices, improving institutions and mechanisms, strengthening process management, and implementing real-time monitoring. Technical tools include scientific construction programmes, design innovation and others. Ecological tools involve the use of greening and regional construction techniques. Legal means for protecting marine animals include marine-related laws and regulations, as well as national regulations specifically aimed at animal protection.

The content of environmentally responsible Behavior includes reducing marine damage; preventing air, noise, and visual pollution, minimizing resource consumption; preventing soil erosion; and protecting special objects. The use of new technology and techniques can help to reduce the consumption of steel, cement, and land resources during the construction process. For example, the auxiliary channel bridge of Humen Bridge utilized joint hanging baskets to achieve frameless construction, resulting in savings of 250 tons of steel compared to the original design using eight sets of hanging baskets[34]. To reduce visual bridge pollution[35] caused by sprayed concrete berms, a common method is to re-vegetate the constructed slope using cement anchor spray surface.

The protection of special objects pertains to the safeguarding of cultural relics, national flora and fauna, natural landscapes, and tourist attractions. In the construction of the Humen Bridge, preserving the Weiyuan Fortress, a national key cultural relic, was of the utmost importance. Therefore, designing the slope excavation and protection scheme was a crucial consideration for the Humen Bridge[36]. During the construction of the Hong Kong-Zhuhai-Macao Bridge, a special program was developed to protect the Chinese White Dolphin[37],[38]. Finally, as a national tourist city, Qingdao places great importance on environmental protection and must avoid polluting the surrounding sea during construction[39].

The factors that influence environmentally responsible Behavior in the construction of cross-sea bridges include both external and internal factors. External factors primarily consist of national policies, government regulations, social concerns, and project requirements. The heightened awareness of environmental protection among the public, the need for urban development, and the impacts of site selection, such as crossing protected areas, proximity to cultural relics, and location in a tourist city, have led to increased social concern. Thus, project requirements aim to address issues related to the construction period and limited resources, while also prioritising the environmental protection of the staff's working and living environment. The internal factors that influence these requirements are primarily focused on creating a humanistic and people-oriented environment, promoting green practices, and prioritising environmental protection. The construction company's conceptual literacy also plays a crucial role in achieving these goals. Idea literacy refers not only to the concept of construction personnel but also to the concept of the construction enterprise. In the construction of Jintang Bridge, China Railway Four Bureau Group No.2 Company followed the management policy of pursuing excellence in management, building high-quality projects, improving environmental behavior, and safeguarding health and safety[40].

The cross-sea bridge project stands out from other projects in terms of environmental responsibility due to its emphasis on protecting the marine environment. The enterprise achieves this by reducing offshore working surfaces and hours, and preventing the leakage of mud and waste oil. Additionally, special protection measures are taken for nationally protected animals.

Although cross-sea bridge projects may cause environmental damage, they still hold significance in environmental protection. They can improve the development and utilization of environmental resources, raise awareness of environmental protection, and foster awe and respect for nature. For instance, the Hong Kong-Zhuhai-Macao Bridge has installed a sculpture of a white dolphin and a viewing area to raise awareness among tourists about the protection of these animals[41].

5. Discussion and conclusion

The definition of environmentally responsible Behavior is as follows: The construction enterprise aims to minimize the damage caused to the environment by the cross-sea bridge project and to integrate it with the environment. This Behavior is achieved in conformance with the requirements of national policy, government control, social concern, project requirements, and its own environmental protection concept literacy. The enterprise reduces damage to the sea; prevents air, noise, and visual pollution; reduces resource consumption; reduces soil erosion, and protects special objects.

As public awareness of environmental protection increases, it is essential to research environmentally responsible Behaviors to help the company improve its environmental practices.

Construction companies should prioritize strengthening their environmental impact assessments. When planning and constructing cross-sea bridge projects, it is crucial to fully consider the impact on the surrounding environment. A scientific prediction of the environmental impact of the project provides a scientific basis for environmental protection work.

Construction enterprises should also enhance their environmental management and monitoring systems. It is essential to establish a comprehensive system for environmental management and monitoring during both the construction and operation phases of the project. This system will enable real-time monitoring of the entire process, prompt identification and resolution of any potential environmental issues, and ensure compliance with environmental protection requirements..

The government should enhance its laws, regulations, and standards for environmental protection. When implementing a cross-sea bridge project, strict compliance with relevant environmental protection laws, particularly the Marine Environmental Protection Law, is necessary to prevent pollution and damage to the surrounding environment during the project's construction and operation. Simultaneously, it is essential to enhance the dissemination of environmental protection laws, regulations, and standards among project personnel.

In addition, the implementation of the ecological compensation system needs to be strengthened. This system is a crucial tool for environmental protection as it promotes the protection and restoration of the ecological environment by providing financial compensation for the value of ecosystems and ecological services. Although ecological compensation systems have their challenges and limitations, they can help mitigate damage and loss to the environment, contributing to the protection of ecosystem integrity and stability.

To ensure that a project meets public expectations and requirements, it is necessary to actively engage in social interaction and public supervision. All sectors of society should have their opinions and suggestions fully heard, and the project's environmentally responsible Behavior should be closely monitored and assessed.

This study is limited to a systematic review of existing literature on environmentally responsible Behavior and does not include a field communication study. Analyzing environmentally responsible Behavior in cross-sea bridge projects is a complex and important topic that requires the joint efforts and participation of society as a whole. The paper aims to provide valuable insights for research and practice in related fields, and to promote better implementation and execution of environmentally responsible Behavior in cross-sea bridge projects.

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