Classification and applicability analysis of ecological revetment in different types of river

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Abstract. In this paper, we classified and summarized 25 kinds of ecological revetment commonly used at home and abroad in recent years according to river hydraulic characteristics and special functions. This paper focuses on the characteristics, materials and technical methods of these ecological revetments, and analyzes the advantages and disadvantages of ecological revetments from the aspects of ecology, landscape, construction, structure, economy and application. Combined with the ecological effects of these ecological revetment, the application scope and promotion significance of these ecological revetment are given, which plays a positive role in the promotion and application of ecological revetment.

Keyword: Different types of river; Ecological revetment; Classification; Applicability; Promotion and application

1. Introduction
Traditional hard bank revetment is mainly made of concrete, masonry and other materials, which mainly considers the safety, durability and flood control function of the revetment, but it ignores the ecological function of the river. Since the 21st century, the ecological function of rivers has been paid more and more attention, and many researches have been carried out and applied to engineering practice [1-2]. At present, there are more than 50 ecological revetments in China, among which nearly 30 types of ecological revetment structures have been patented in 2019 (such as Wang Q, Zhao J Y and et al applied a flexible anchorage frame and its ecological revetment structure [3], Ma D G, Wang H and et al applied A fan-shaped ecological revetment and its revetment structure [4], Hu T Y, Guo G G and et al applied a honeycomb ecological bag ecological revetment structure and construction method[5], etc.). Many types of ecological revetment structures are widely used in inland waterway engineering construction, but there is no unified standard for structure selection. On the basis of the classification method proposed by Hou J [6], this paper classifies 25 types of ecological revetment commonly used at home and abroad, and summarizes the applicable scope, ecological effect and popularization application of different types of river ecological protection construction conditions, which will have positive guiding significance and reference value for the construction of river regulation works.

2. Definition of ecological revetment
Ecological revetment is a "permeability" of the bank protection, which is a new type of revetment combining plants or plants with civil engineering [7]. The revetment can provide beneficial to the
growth of aquatic plants as the main body of the amphibious creature symbiotic environment, and it has a riparian basement, the permeability of natural river bed and bank rich river geomorphology, which can fully guarantee land and water exchange and the ecological function [8].

Ecological revetment is to introduce ecological design into the construction of river revetment. On the premise of ensuring the basic functions of flood control security and structural stability of river course, it maximizes the protection of coastal ecological environment, keeps the balance of nature, creates a natural and harmonious riverbank environment, and promotes the sustainable development of inland water transportation.

3. Classification and applicability of ecological revetment for different types of river channel

In this paper, according to the hydraulic characteristics and special functions of river channel, different types of river were divided into river channel with less erosion of slow-flow, river channel with large erosion of rapids, river channel with large variation of water level difference, tidal reach and river channel with special functions, special function river ecological revetment is divided into urban river and revetment modification river [6].

The river channel with less erosion of slow-flow refers to the river course with designed flow velocity less than 2m/s and small water surface slope.

The river with large erosion of rapids refers to the river course with designed flow velocity between 2~6m/s and large water surface slope.

The river with large variation of water level difference is to point that the river shoal is open, and water level drop is bigger. In dry water period, river course discharge is small river course discharge is big when river course flows through in main river channel. During flood period, river course discharge is large and river course flows over flood plain.

Tidal reach is the reach between the mouth of the estuary and the boundary of the tidal limit. Tidal reach is affected by both estuary tidal wave and upstream river runoff [9].

Urban river refers to the river channel that flows through densely populated areas such as towns and cities.

Revetment modification river refers to the revetment of traditional hard concrete riverbank so that the ecological environment of the river can be restored, and the natural landscape can be beautified.

3.1. Ecological revetment suitable for less erosion river of slow-flow

In river with less erosion of slow-flow, the general main channel is wide and smooth flow, and has a wide beach, anti-erosion requirements is low, small variation range of water level. The bank slope can be protected by natural hydrophilic plant materials such as grass, reed and willow. These plants thrive in a moist environment, creating a rich natural ecological environment along the shore while protecting the bank slope [6].

3.1.1. Grass revetments. Grass is the most commonly used material in ecological revetment engineering. It can increase the slope coverage by laying grass on the bank slope to prevent soil erosion and can improve the ecological environment. Herbaceous plants have developed roots that stabilize river Banks and purify the environment.

3.1.2. Willow revetment. Willow has a very developed and strong root system, which can not only grow and spread rapidly in a short time, but also has a strong ability to resist erosion, so it is widely used in the restoration of natural landscape and flood control. In the application of revetment, it can be divided into two kinds: one is directly used as revetment material, the wicker is made into a handle fence directly revetment; the other is used in combination with stones, concrete blocks and other materials to fix the soil between the stones and cracks through the developed roots of willow trees, so as to prevent soil erosion [10].
3.1.3. **Coir revetment.** A coir roll is a cylindrical structure consisting of the fibers of the outer shell of the coconut and the strings of the coir roll. Coir is a byproduct of coconut fibre with moderate thickness, light weight, high strength, good elasticity, strong permeability, etc., and it can form a mesh structure. The mesh can provide growth environment for plants and microbes, and provide habitats for aquatic animals, can prevent the slope erosion, and create the sedimentary environment, facilitate the plants to grow in the coconut fiber [6,11].

3.1.4. **Vegetative structure revetment.** Bionic straw mat is a kind of imitated flexible vegetation, which is composed of reinforced 3D net mat, 3D net strip (bionic aquatic blade) and base. The long net was sewn against the direction of water flow on the net mat to simulate the form of aquatic, and the effect of promoting silting was realized in the slow flow area of river shoal, avoiding the problems of difficult seed selection, large investment and high maintenance requirements of natural vegetation materials.

3.1.5. **Aquatic plants slope protection.** Through the system of roots, stems and leaves of some aquatic plants, a protective riparian is formed in the coastal waterline, which can reduce the flow rate and effectively protect the bank slope and promote sediment precipitation. Aquatic plants can absorb the nutrients phosphorus, nitrogen and organic matter in the water to purify the water. Integrated planting of lush shrubs and grasslands on the ecological revetment can shape the landscape on the whole and make the revetment beautiful [6,12].

3.1.6. **Macmat-R revetment.** The macmat-R is a kind of reinforced 3D-geomat, which is formed by extruding polyester material on the hexagonal twisted steel wire mesh surface. It has the characteristics of high strength, good consistency, small loss, simple construction, good anti-erosion performance and good effect of promoting deposition [13].

After summary, the main characteristics of ecological revetment commonly used in river channel with less erosion of slow-flow are shown in Table 1.

| Name                  | Ecosystem                     | Landscape                  | Construction               | Structural                  | Economy                        | Application          |
|-----------------------|-------------------------------|----------------------------|----------------------------|----------------------------|-------------------------------|----------------------|
| Grass revetment[14]   | Less disturbance to ecosystem; good ecological effect. | General                   | Simple construction process; fast construction speed. | Shock resistance velocity isn't more than 2m/s; general durability. | The early cost is less, but the later maintenance cost is higher. | Good                 |
| Willow revetment [10,14] | Willow roots developed, fast growth, good effect of slope protection. | Restore the river's natural landscape. | Convenient construction; no much late maintenance is required. | Strong resistance to erosion; good protective effect; good durability. | Low               | Better              |
| Coir revetment [6,11] | Better                        | General                    | Low construction efficiency. | General erosion resistance; the life span is 6-10 years. | Higher                        | Poor                 |
| Vegetative structure revetment | Poor                     | Poor                       | Low construction efficiency. | Shock resistance velocity isn't more than 1.2m/s; poor durability. | High                           | Poor                 |
Aquatic plants slope protection [6] A habitat for aquatic life; to purify the water; good ecological effect. Strong The construction efficiency is general. It is only suitable for water channel with water depth of 0.5-1.0m and low velocity, good durability. High Good

Macmat-R revetment[15] Good In the high water level above: better; in the water level fluctuation area: poor. Simple construction; fast construction speed. Shock resistance velocity isn't more than 1.5m/s; good durability. Low Good

It can be concluded from table 1 that the grass revetment, willow revetment, aquatic plants slope protection and Macmat-R revetment have the advantages of good ecology, high construction efficiency, good structural stability and so on. Among them, the grass revetment is weak in erosion resistibility, and it is used in the bank slope where the water flow velocity is small, the slope is slow, heavy machinery is not easy to reach the construction site and the bank slope soil content is high. Willow revetment has the advantages of low cost, simple construction technology, good structural stability and ecological property, etc., but its landscape is relatively simple, and it is used in plain area with abundant land resources and more willow trees [16]. The cost of aquatic plants slope protection is high, but the sense of landscape layer is strong, so revetment can be recommended in the scenic area. At present, the most common revetment is the composite revetment of aquatic plants, block stone, sand free concrete comprehensive application [12]. Macmat-R revetment has the advantages of good ecology, good structure durability and high construction efficiency, but the plant growth in the water level fluctuation area is poor, so it is recommended to use in the slope protection above the high water level.

3.2. Ecological revetment suitable for large erosion of rapids
In river with large erosion river of rapids, general main channel is straight, river flow velocity is larger, and there is a certain erosion on both sides of the river. It is easy to be damaged by erosion Simply using natural materials such as turf, willow and aquatic plants for bank revetment. Therefore, it should combine hard solid materials such as concrete, geosynthetic materials and stone, to strengthen the durability of revetment and scour resistance [6].

3.2.1. Gabion revetment. Gabion mesh is the use of corrosion resistance, high strength, flexible good double twisted hexagon machine woven steel wire braided rectangular grid unit, and its filled with stone, with rust, aging, corrosion resistance and other characteristics. The structure is a flexible structure with high compressive resistance, which can well adapt to the deformation of the foundation, there is a gap between the stone, which can effectively reduce the pore water pressure [17-18].

3.2.2. 3D-geomat revetment. Also called 3D vegetation mattress, it is made of high strength, flexibility, good polypropylene or polyethylene fibers by extrusion, stretching, and it processes to form composite fence, gauze pad contains a large number of pores, can fill soil, sow seeds on bank slope protection and vegetation restoration. After taking root, the roots of the grass, gauze pad and soil form a reinforcement, which improves the stability of bank slope and plays the role of bank revetment [2,19-21].
3.2.3. Anti-impulse biological blanket revetment. Anti-impulse biological blanket is composed of composite fiber fabric, anti-filtration geotextile and diversified grass species, turf and other supporting new integrated ecological slope protection materials, in the prevention of river embankment hydraulic erosion, soil erosion at the same time, it can achieve the slope ecological repair, landscape greening effect. The anti-impulse biological blanket structure has 4 layers. The first layer of composite fiber fabric, mainly to withstand water flow, to ensure the anti-erosion performance; the second anti-filtration layer, made of non-woven fabric, mainly plays the role of anti-filtration; the third layer of grass seed and fertilizer; the fourth layer of composite fiber fabric plays the role of fixing grass seed [22].

3.2.4. Ecological bags revetment. Ecological bag is made of polypropylene and other polymer composite polymer ecological bag, which has the function of filtering water-permeable and impermeable soil, its good soil-fixing function, make the plant through the bag body freedom growth, roots into the soil at the grass-roots level of engineering, like countless anchor complete solid effect, the longer the time, the more strong, to achieve permanent slope stability, greatly reduce maintenance costs [23].

3.2.5. Prefabricated ecological concrete revetment. Ecological concrete is also known as planting concrete. In 1995, Japan concrete engineering association put forward the concept of "ecological concrete" [2]. In foreign countries, this kind of ecological revetment has become the mainstream of protection engineering. The ecological concrete ball (block) is a kind of ecological concrete member with strong surface-attached vegetation ability, which is composed of several concrete ball (block) members. Single ball that there was a gap between the member center equipped with hole, the concrete pore rate is between 5-35%, in cast-in-situ concrete compressive strength reach 8MPa, using sand free big pore permeability and water permeability habitats provide nutrients for plants and aquatic animals mentioned [24-25]. Ecological concrete ball (block) laid on the river bank, is helpful for the ecological construction on both sides of the river, is beneficial to the growth of small trees, through holes or gaps Make it firmly connected with river embankment [26].

3.2.6. Rongxun ecological revetment. The ecological structure of Rongxun retaining wall is not to make a hole in the block, but is to leave the ecological hole in the block when the block is forming the wall. Water ecological hole can plant lianas, herbs, small shrubs and other plants. Due to the abundance of ecological holes, plants can quickly fill the full facade, covering blocks and beautifying the retaining wall. The ecological hole is directly connected with the soil behind the retaining wall, and the plant is rooted in the soil on the back of the wall, which is not easily affected by drought and has good growth conditions, which can meet the greening requirements of fast, continuous and low maintenance cost in the later period, and can make the honor retaining wall become a garden-style retaining wall [27].

3.2.7. Interlocking block revetment. Interlocking block revetment is a kind of flexible pavement structure, leaving space between the block assembly for planting green plants, reducing the adverse impact of revetment on the ecology. It has been highly praised in recent years due to its functions of anti-impact and ecology and landscape[28].Shao Q put forward the 3D ecological interlocking brick structure, on the basis of the 2D interlocking brick, the column and the tooth ridge were added, which could better play the anti-erosion and anti-sliding performance of the fixed end [29].

3.2.8. Articulated concrete block revetment. Articulated concrete block revetment is a kind of high strength concrete pavement technology, as a new type of ecological slope protection technology, not only can effectively solve the rigid pavement is not flexible, shortcomings and so on is not easy to grow grass, can effectively solve the weakness of flexible pavement overall lack of security, to prevent the erosion of soil and water loss and prevent erosion and enhanced stability compared with the
traditional protection has excellent performance, can improve the content of ecological slope protection system, traditional slope protection system is an effective, reliable, beautiful and high performance substitute [30].

After summary, the main characteristics of ecological revetment commonly used in river channel with large erosion river of rapids are shown in table 2.

**Table 2. Summary table for ecological revetment of river channel with large erosion river of rapids.**

| Name                                      | Ecosystem                                         | Landscape | Construction              | Structural       | Economy     | Application                                      |
|-------------------------------------------|---------------------------------------------------|-----------|---------------------------|------------------|------------|-------------------------------------------------|
| Gabion revetment [1,15,18,31-32]          | Less disturbance to ecosystem; allow matter to communicate. | Poor      | Stone cage weaving process complex; dry land construction is required. | Anti-impact velocity can reach 6m/s; better durability. | High       | Poor overall plant growth; not suitable for promotion. |
| 3D-geomat revetment [18-19]               | Protection mat can grow a variety of herbs; the ecological effect is better. | General   | Simple and convenient construction; not affected by season or temperature; high construction efficiency. | Anti-erosion flow rate can reach 5m/s; better durability. | Low        | Rapid development; it is favored in engineering construction. |
| Anti-impulse biological blanket revetment [22] | It can achieve ecological and landscape effects. | Good      | Simple and convenient construction; high construction efficiency. | Impact resistance velocity up to 3-4m/s; good durability. | Low        | General                                          |
| Ecological bags revetment [15,21,23,31]   | Its follow-up basically no plant growth.          | Poor      | Construction is simple, fast and convenient. | Shock resistance velocity isn't more than 3m/s; poor durability. | High       | Not suitable for promotion.                     |
| Prefabricated ecological concrete revetment [1,18,21,26] | Ecological concrete is porous and permeable, which can provide a habitat for amphibians and maintain biodiversity. | Good      | High degree of mechanization; it can be sprayed comprehensively; high construction efficiency. | Shock resistance velocity up to 5m/s; better durability. | Higher     | It has been widely used in protection engineering at home and abroad. |
| Rongxun ecological revetment [27,32]      | The inner and outer walls are interlinked, which can provide good shelter and living environment for aquatic organisms. | Better    | Factory production; easy to control quality; high construction efficiency. | Good shock resistance; good durability. | High       | It has been successfully applied of Haichao River in Lijiang city. |
| Interlocking block                        | High porosity helps aquatic                       | Good      | Convenient construction; Strong resistance to | Low               | It is used more where                            |
revetment [1,15,22,28,33] plants to root and aquatic animals to inhabit. high construction efficiency. erosion; good durability. the site is not restricted.

Articulated concrete block revetment [15,30] Holes and crevices can play a role in seepage and drainage, increasing beautifying the environment. Factory production; high construction efficiency; late maintenance is difficult. Strong resistance to erosion; overall stability is good. Low It is applied in the waterway regulation project of Zhijiang river.

Note: the economy of this paper is mainly the ecological revetment project in the waterway regulation project of Nantong section of Lianshen waterway [15] and the project cost in the ecological revetment mode of Guhe River levee project as reference [22]. Due to the ecological protection in recent years, it is forbidden to open mountains and stone quarrying, the price of block stone is high, and the cost of stone cage revetment is increased.

From table 2, it can be concluded that 3D-geomat revetment, prefabricated ecological concrete revetment, Rongxun ecological revetment, Interlocking block revetment and articulated concrete block revetment have the advantages of good ecology, high construction efficiency, good structural stability, and good promotion and application.

In addition to the above advantages, the 3D-geomat revetment has the advantages of the erosion resistance velocity up to 5m/s, can be used in the place where the erosion resistance requirements are relatively high, at the same time by its construction restrictions less, in the highway, railway, water conservancy, mining, municipal engineering slope protection application is wide, is the first choice of the garden environment green environmental protection material.

In the production process of prefabricated ecological concrete revetment, industrial waste can be added to realize the recycling of resources, which has been widely used in water conservancy, transportation and urban construction projects. It is believed that it can replace traditional concrete in revetment projects in the near future.

In addition to the above advantages, Rongxun ecological revetment also has a strong earthquake resistance and adaptation to deformation capacity, currently in Zhejiang province and Fujian province is more widely applied, can be promoted throughout the country.

Interlocking block revetment is suitable for rural river, the site is relatively large, slope layout.

Articulated concrete block revetment has many advantages, but its later maintenance is difficult, which is an urgent problem to be solved, so the structure selection should be careful.

Gabion revetment in the market in addition to the stone cage products intermingled, quality is difficult to control, the overall growth of plants poor shortcomings, but also because of the ecological protection of the reasons prohibit quarries, so it is not appropriate to promote.

Ecological bags revetment compared with other bank protection structure, its erosion resistance is a bit weak, cost is higher. Due to poor ecological bag filling sandy soil water retention performance, basic no plant growth on metope, late poor ecological effect, the wall deformation is larger, the wall after the leakage of soil is serious, can be used as a low wall promotion [15].

3.3. Ecological revetment suitable for large variation of water level difference
In the river with large variation of water level difference, the growth of plants is not used, which will lead to an inharmonious ecological landscape [6]. The bank revetment of compound structure and the bank revetment of palisade steps are adopted, and the ecological bank revetment can be constructed in stages to play the role of ecology and landscape beautification.

3.3.1. Compound structure revetment. The compound structure revetment is composed of the main channel and the floodplain, and ecological revetment needs to be constructed respectively. When the flow rate is relatively small in the dry period, the water flows in the main channel, and the water level
rises into the flood plain in the flood period, so as not to affect the plant growth and landscape effect in the dry period, but also conducive to the flood discharge in the flood period. There are a variety of structures combined into a complex structure revetment.

3.3.2. Palisadestep revetment. Palisade step revetment choose some waste wood (such as felling, abandoned sleepers) and other wood materials, step by step on bank slope decorate a palisade, can withstand the erosion by ship wave, the palisade above the slope of plant root development and view and admire a gender strong aquatic plants, so that we can form a ladder-like revetment form [6,12,14,21].

After summary, the main characteristics of ecological revetment commonly used in river channel with large variation of water level difference are shown in table 3.

Table 3. Summary table for ecological revetment of river with large variation of water level difference.

| Name                      | Ecosystem                                                                 | Landscape                                                                 | Construction                                                                 | Structural                                                                                     | Economy | Application                                    |
|---------------------------|---------------------------------------------------------------------------|---------------------------------------------------------------------------|----------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|---------|------------------------------------------------|
| Compound structure revetment | When the time of low water level is long, the ecological effect is poor. | When the time of low water level is long, the landscape effect is poor. | The construction is complex and the construction efficiency is low. | Its anti-erosion ability is strong, and the structure stability is good. | High     | It has wide applicability.                      |
| Palisadestep revetment    | There are gaps between the palisades to provide places for aquatic animals. | Better                                                                   | Its construction is simple, and the construction efficiency is high.     | Strong resistance to erosion; poor; durability                                              | Low     | Its popularization has certain limitations.    |

From table 3, it can be concluded that the compound structure revetment can be made up by a variety of structures, the disadvantage is that occupy more water section, does not apply to narrow channel, and the high cost, the construction of the complex [34]. At the same time the design should grasp duration of the river low water level, ordinary water level and high water level, when in low water level for a long time, the structure of the ecological effect and landscape effect is poorer, careful with this structure. The construction of fence ladder revetment is simple, strong anti-erosion ability and good ecological effect.

3.4. Ecological revetment for tidal reach
The soft mattress revetment is mainly used in the main channel protection engineering of the coastal river estuary section. Due to the tidal reach of the two-way flow caused by the inconvenience of the construction of the software row, the use of the soft mattress instead of the flexible mattress, although the cost of the soft mattress is slightly higher, but the construction is more convenient. The design process of soft mattress is basically similar to that of flexible mattress. The difference is that soft mattress adopts double layer polypropylene cloth, the flexible mattress single layer polypropylene cloth, in order to improve the construction quality. See table 4 for details.

Table 4. Summary table for ecological revetment of tidal reach.

| Name                      | Ecosystem                                                                 | Landscape     | Construction                                                                 | Structural                                                                                     | Economy | Application                                    |
|---------------------------|---------------------------------------------------------------------------|---------------|----------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------|---------|------------------------------------------------|
| Soft mattress revetment   | More pores can provide habitat for amphibians and maintain                | General       | Factory production; easy to control quality; high construction             | Strong anti-erosion ability, strong adaptability to deformation, good toughness and              | Low     | Tidal river section are widely used.            |
| [35-37]                   |                                                                          |               |                                                                           |                                                                                                |         |                                                |
biodiversity. efficiency. durability.

We can see from table 4, the soft mattress revetment construction mechanization degree is high, the construction efficiency is high, the anti-erosion ability is strong, the durability is good and so on the advantages, in the river channel dangerous work management project and tidal reach can be popularized.

3.5. Ecological revetment with special functions

3.5.1. Ecological revetment for urban river. Urban river is between artificial and natural river channel of the river, the general channel is narrow, on both sides of the building, river broaden the limited, higher requirements for flood control, and the Banks mostly erect a steep slope, can be conducive to the space is lesser, therefore in the urban river ecological revetment structure selection to give full consideration to these conditions, suitable for urban river ecological revetment structure is as follows:

1. Self-embedded retaining wall revetment

Self-embedded retaining wall is a form of reinforced soil retaining structure, also is a new type of gravity structure, it mainly rely on containment and filtration geotextile, layering, laying geogrid and soil tamping, formed by geogrids and anchor just connect complex gravity to dynamic and static load resistance, achieve the effect of stable [38].

2. Permeable precast concrete caisson revetment

The revetment adopts precast concrete caisson wall, whose retaining wall can be designed as hollow pattern structure to face the water, which is not only beautiful, but also provides a habitat for aquatic animals, and at the same time has the function of wave elimination and wave reduction [28].

3. Tank type planting concrete revetment

Tank type planting concrete retaining wall composed of prefabricated concrete block packing, filling porous concrete, is a collection of protection, ecological, self-purification, landscape functions as one of the new type of retaining wall, frame concrete occlusion, internal no-fines concrete besides aggregates, cement, concrete and water-retaining material, etc. It can create plant root growth and attachment space, realize ecological concrete, structure of the block combined with reinforced earth technology can maintain the overall stability [39-41].

4. Split concrete block revetment

Split concrete block is a new type of concrete building material, the technology developed by Australian Anchor company design, use of industrial waste, such as electric furnace slag system made through scientific program block, the block production as well as local materials to reduce the production cost, and can reduce the damage to the environment and industrial pollution, to protect the environment and save stone resources is of great significance. This structure has high quality engineering, decoration and environmental protection [28].

After summary, the main characteristics of ecological revetment commonly used in urban river courses are shown in table 5.

| Name | Ecosystem | Landscape | Construction | Structural | Economy | Application |
|------|-----------|-----------|--------------|------------|---------|-------------|
| Self-embedded retaining wall revetment [15-16,38] | There is basically no plant growth on the water level; the ecological effect is general. | Its integral landscape effect is outstanding; improve the visual grade of the environment. | Simple construction; high construction efficiency. | Its anti-erosion ability is strong; durability is better. | Higher | It has been successfully used in Jimintong river channel. |
| Permeable precast concrete | Good | General | easy to control quality; high construction | Its anti-erosion ability is | Higher | It has wide applicability. |
caisson revetment [28]

| Tank type planting concrete revetment [39,41-42] | High porosity and multi-velocity zone can provide habitat for aquatic animals. | Create a vertical ecological corridor and a water-friendly green belt. | Its construction is quick, and the construction efficiency is high. | Shock resistance velocity isn't more than 5m/s, good durability. | Higher | There are broad prospects in urban river management. |
|---|---|---|---|---|---|---|

| Split concrete block revetment [28,43] | Utilization of industrial wastes; saving mineral resources. | Advanced production technology; project quality control; easy to operate and maintain. | Corrosion resistance; good frost resistance; strong resistance to erosion. | Reasonable construction cost; low maintenance cost. | Good | It was successfully applied in Nanjiao River |

Note: the economy of this paper is mainly the ecological revetment project in the waterway regulation project of Nantong section of Lianshen waterway as reference [15].

Through the contrastive analysis of table 5, we may draw a conclusion that, Self-embedded retaining wall revetment have modelling changeable, less land, less construction constraints, and the advantages of good vibration resistance, but its basic no plant growth, water ecological effect in general, it can leave on the preform surface hole, used as underwater ecological revetment structure [15,40]. Permeable precast concrete caisson revetment is generally used for heavy protection areas. In the ecological pro-water area, it can be combined with other ecological revetment to form a variety of revetment types. It is generally used for urban river courses with limited construction sites. Tank type planting concrete revetment porous structure plays the role of water purification, improve the water quality of the river, vertical wall layout, not only solve the problem of urban land, but also improve the urban ecological landscape, especially suitable for urban river renovation projects with limited land use. The split concrete block revetment such as advanced technology, controllable project quality and reasonable project cost, have been widely used in water conservancy, waterway, municipal and highway projects [28].

3.5.2. Ecological revetment for revetment modification. The traditional concrete bank revetment has a poor landscape effect and destroys the ecosystem of the river, but its flood control function cannot be completely denied. If it is completely dismantled, it will not only cause a waste of resources, but also cause a certain amount of environmental pollution, which is too risky and economically unfeasible. In addition, a large number of vertical revetments have been built on both sides of the urban river, so it is too expensive to dismantle and rebuild the revetment, or the original revetment needs to be transformed in order to protect the ancient town [44]. Therefore, the construction of ecological revetment of this kind of river needs to be reformed by ecological engineering method on the basis of the original revetment [11].

1. Virescence technology revetment of sheet pile

For the river bank protected by the concrete sheet pile, the wood row fence can be set on the upstream face the pile plate, and the willow tip handle can be inserted between the sheet pile and the wood pile of the wood row top fence. By using the growth of willow tree, the willow branches before the sheet pile bank protection can be luxuriant and the waterside is tree-lined [6].

2. Slope holing and backfilling revetment

By making holes or nests in the existing concrete surfaces and backfilling them with gravelly soil, the environment for plants to grow can be provided and the holes can be used as hiding places for insects and amphibians [6].
3. Using original revetment material revetment
   For projects with removable concrete revetment, the dismantled concrete blocks or dry masonry can be built into concealed revetment and then covered with soil, so as to build a stable and natural ecological revetment [6].

4. Original gravity retaining wall greening revetment
   The original gravity retaining wall is used as the inner base, the surface layer of concrete structure is afforested, and the field layer is cultivated by certain garden technology. This kind of revetment structure will not cause damage to the original wall and will not affect the stability of the wall, while the chlorinated concrete can provide a production site for microorganisms or other aquatic animals and plants, increasing biodiversity, and the restored retaining wall forms a certain green belt, which is natural and beautiful [41,44].

After summary, the main characteristics of ecological revetment commonly used in revetment modification river are shown in Table 6.

Table 6. Summary table of ecological revetment suitable for revetment modification river.

| Name                                      | Ecosystem                                                                 | Landscape | Construction                                           | Structural                                      | Economy          | Application |
|-------------------------------------------|---------------------------------------------------------------------------|-----------|--------------------------------------------------------|------------------------------------------------|-----------------|-------------|
| Virescence technology revetment of sheet pile | The gap between the pile plate and the wooden pile can restore biological growth and provide a breeding habitat. | Better    | Convenient construction; not much late maintenance is required. | Strong resistance to erosion; better durability. | Low             | Better      |
| Slope holing and backfilling revetment     | Holes provide hiding places for insects and amphibians.                    | Good      | Slooped holes will cause the collapse of the wall; the construction time is long. | Strong resistance to erosion; better durability. | Slightly higher | Poor        |
| Using original revetment material revetment | The demolished concrete blocks are stacked with holes in the middle to facilitate water exchange and provide habitat for aquatic animals. | Better    | The construction is cumbersome, so the efficiency is general. | Poor erosion resistance; good permeability; general durability. | Low             | Poor        |
| Original gravity retaining wall greening revetment[41] | Effective pores can satisfy vegetation root growth and aquatic animal habitat. | Better    | The construction is simple and convenient. | Strong resistance to erosion; better durability. | Low cost     | General     |

Through the comparative analysis in table 6, it can be concluded that: compared with other 4 kinds of revetment structures, virescence technology revetment of sheet pile has the advantages of good ecology, good landscape, convenient construction, good stability and low cost, which can be popularized in the country. Slope holing and backfilling revetment will reduce the durability of the wall, the use effect is poor, promotion has certain limitations. Using original revetment material revetment are used for the bank revetment construction, which is complicated and has a great disturbance to the ecosystem. Original gravity retaining wall greening revetment afforestation revetment can create a green belt, but it does not change the permeability of the wall, and it is difficult
to ensure the exchange of water and soil, which is not conducive to ecological reproduction and habitat and the establishment of water ecosystem [44]. It can be used in river channel reconstruction with low ecological effect requirements.

4. Conclusions
This paper classifies and compares 25 kinds of ecological revetment, which are commonly used at home and abroad, in terms of application scope, ecological landscape effect, structural durability, economy, construction and application, and summarizes the application scope of each kind of ecological revetment, and gives the selection control standard, and selects the appropriate ecological revetment structure according to the local hydrogeology conditions. In addition, when combing, summarizing and summarizing, it is found that the descriptions of structural durability, construction and economy of revetment are basically the same, while the descriptions of landscape effect, ecological effect and promotion and application are not the same, especially the differences of ecological effect are more obvious. At present, there is no unified standard and technical guide in China, and the quality control and evaluation system are not uniform. Therefore, it is urgent to formulate technical guidelines and industry standards for ecological revetment construction to guide engineering practice, and further develop a scientific and unified comprehensive evaluation system for ecological remediation effect.

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