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河岸凹槽水动力特性与漂浮垃圾收集模拟试验

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摘要：河道漂浮垃圾引起的水体环境污染问题日益严重，对生物多样性及人体健康安全和生态环境具有重要影响。以日本爱知县名古屋市的庄内川水系中的一级河川堀川为研究对象，根据河岸凹槽水动力特性，设计漂浮垃圾收集装置。利用装置内挡水板改变水流状态，引导水流带动漂浮垃圾流入凹槽结构，达到收集效果。首先采用模拟软件 iRIC 对河道进行数值模拟，确定合适的试验模型尺寸比例，设计室内试验装置，在一定的水动力条件下，进行室内模型试验研究，通过调整收集装置内凹槽长度和内墙长度，设定不同工况进行试验，获得具体漂浮垃圾收集率结果。在此基础上，对试验结果进行分析比较，发现随着凹部长度和内墙长度的增加，装置的收集效率都会呈现出不同程度的提高。

关键词：河岸凹槽；水动力特性；漂浮垃圾；收集装置；模拟试验

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近年来，河流携带的大量漂浮垃圾通过河流入海口进入海洋，造成海洋污染并引发生态环境问题，长此下去不仅会危及海洋生物的生存，还会对人类健康安全产生不利的影响。据有关统计资料表明[1]，人类活动产生的海洋垃圾数量惊人，全球每年大约有 640 万 t 垃圾进入海洋，而每天就有大约 800 万件垃圾进入海洋。全球年塑料消费量现已超过 3.2 亿 t，在过去十年中生产的塑料比以往任何时候都多。生产的大量产品或材料起了短暂的作用后，有些迅速转化为废物，小部分可能被回收或焚烧，而大多数将被收集到垃圾填埋场或丢弃在自然环境中[2]。许多海洋中的垃圾是通过河道输运进入的，因此，要减少进入海洋的垃圾量，就需要重视入海河道内的垃圾收集与处置工作，其中漂浮垃圾处理更是急需解决的问题。堀川作为日本名古屋境内的一条河流，其功能和污染情况与我国大部分城市河流类似。此外，堀川与中川运河交汇处并由松重闸门隔开的凹部结构，为本设计提供了有利的先决条件，故本研究以日本堀川作为研究对象。

1 国内外漂浮垃圾治理现状

在国外，对河道漂浮垃圾的治理非常重视，美国国家环保局（USEPA）和英国、德国、加拿大（CAEPB）、澳大利亚等国的环保机构都专门制定了江面垃圾管理法规和检测采样技术标准[3]，并研制出了相应的垃圾打捞和收集装置，如美国 United Marine International Limited Co.（UMI 公司）和英国 Water Witch 公司相继开发出了水上漂浮垃圾打捞船（marine trash skimmers）、水生植物清捞船（aquatic weed harvesters）和水面油污清捞船（oil skimmers）等，在美国纽约及美国和加拿大交界的五大湖地区、巴尔的摩、韩国和我国香港地区等是河汉港湾水域得到了广泛应用，取得了比较好的效果，但这些治理技术的突出特点是针对平静水面研制开发的。

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我国上海的黄浦江，广州珠江和三峡库区等重要河流的水面漂浮垃圾问题一直十分严峻。据《2015年厦门市海洋环境公报》显示，2015年厦门海域的漂浮垃圾总量为1 600 t，与2014年基本持平。在三峡库区的漂浮垃圾以树叶、树枝、秸秆杂草为主，约占总量的70％以上；其次为木头、树根等，约占总量的10％以上；而塑料、泡沫等白色垃圾约占5％，由于其重量轻、体积大，不易降解，危害巨大[4]。在三峡库区清理垃圾时，主要采用长29.2 m、宽7 m的水上环境卫生作业船和长21 m、宽6 m的机械化清漂作业船。因清理漂浮垃圾的船体成本以及运转过程中产生的消耗都较高，在整个处理过程中需要投入较大的人力、物力和财力。

本文以日本爱知县名古屋市境内的入海河流堀川为研究对象，针对堀川中漂浮垃圾收集存在的问题，设置河岸凹槽结构以改变其河流水动力特性，设计出更为高效环保的漂浮垃圾收集装置，并通过室内模拟试验进行了研究。

2　收集装置

堀川是从庄内川取水，流经矢田川的地下河道，在名古屋城景区北侧流出转而向西绕过名古屋城，然后从名古屋市中心向南流出，并最终涌入名古屋港。堀川是一条穿越市区的河流，水污染问题一直备受关注。19世纪中期，大量污水曾排放至堀川。虽然在1965年建立了污水处理厂，但仍有强烈的异味不断散发。1966年，河流中BOD值达到54.8 mg/L，曾被称为“垂死的河流”，且至今没有得到很好的解决。

在对堀川的前期调研中，发现其下游部位在与中川运河交汇处有一凹形结构。此部位由松重闸门隔开，闸门长期关闭，这为利用此凹形结构提供了有利的先决条件。图1是通过截取谷歌地图，展示的凹形结构位置示意图。

图1　凹形结构位置

基于目前堀川存在的漂浮垃圾问题，提出一种河道内漂浮垃圾自动收集装置设计方案。装置依靠水流动力对漂浮垃圾运动轨迹的引导，使其流入预先设置好的凹形结构内完成垃圾收集工作。装置的前期投入较少，参照不同河道地形灵活设置，只需要增加挡水装置并对河岸进行小型开挖形成凹部即可。本次研究以堀川存在的天然凹形结构为原始模型，设计试验装置进行室内试验模拟。试验过程中，首先通过装置内挡水板对水流方向的引导，改变水体水动力特性，使漂浮垃圾随水流流向收集装置的凹槽结构内，然后利用滤网对漂浮垃圾进行阻拦，从而达到收集的目的。此过程完全实现零驱动运转，不消耗其他能源，且节能环保。最后，只需定期从凹部结构把垃圾回收处理。收集装置的示意图见图2。

图2　漂浮垃圾自动收集装置示意图

在图2中，各参数含义如下：L_s 为挡水板装置长度；B_m 为主河道宽度；B_w 为凹槽结构宽度；L_w 为凹部结构长度；L_p 为引导墙长度；L_m 为滤网长度；θ 为引导墙与岸边形成的夹角。

试验模型按照堀川1/80的规模进行设置，在固定河道结构参数的情况下，对收集装置进行试验研究。模型采用长12 m、宽60 cm的水槽，并设置水力梯度 $I=1/1\ 000$。在水流装置的右岸设置宽30 cm，高6 cm的PVC板，使水流宽度为30 cm。图3为装置的主体部分，设置在距上游4 m的位置。在凹槽收集装置的下游设置了长度为40 cm的金属网用来过滤漂浮垃圾。

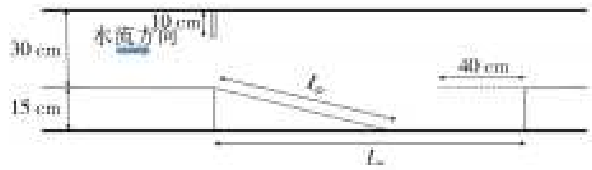

图3　结构尺寸

各个参数的改变都会对最后的收集效果产生一定的影响。这里着重探讨凹槽长度 L_w 和内墙长度 L_p 两个参数变化对装置收集效果产生的影响。实际水流中因底板糙率等问题造成水流不均匀的情况与试验设定的均匀流存在一定偏差，故为保证结果可靠性，进行数值模拟实际水力条件，并与试验结果进行对比分析。

3　数值模拟

以试验模型为基础，首先创建45 cm×400 cm的模型，然后剖分为边长为1 cm的正方形网格，利用iRIC软件进行两组模拟，试验设定的水动力条件

见表 1。在此水动力条件下,调整控制变量,分别改变凹槽长度和内墙长度进行模拟,整个模拟时间设置为 120 s,紊流模型采用 k-ε 方程模型进行计算,并对结果进行对比分析。

表 1　水动力条件

Q/(L·s^{-1})	h/cm	U_m/(cm·s^{-1})	Re($U_m h/\nu$)	Fr	I
1.0	3.0	11.1	3 300	0.41	1/1 000

3.1　凹槽长度改变的模拟研究

在装置设置上,需要研究凹槽尺寸变化对结果的影响。因此设计了凹槽长度为 0.96 m 和 1.2 m 两种方案进行对比。在内墙长度的设计上分别设置了 0.3 m 和 0.6 m 两种长度进行比较。凹槽长度改变的试验模拟工况见表 2。

表 2　凹槽长度为 0.96 m 和 1.2 m 的模拟工况

单位:cm

工况	B_m	B_w	L_m	L_s	L_w	L_p
C-96-30	30	15	40	10	96	30
C-96-60	30	15	40	10	96	60
C-120-30	30	15	40	10	120	30
C-120-60	30	15	40	10	120	60

分别模拟 2 种凹槽长度和 2 种内墙长度得到的结果见图 4 至 7。

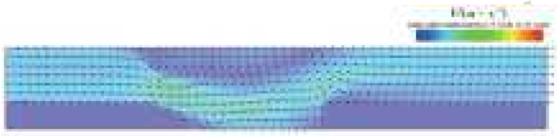

图 4　**C-96-30 模型水流速度和方向模拟**

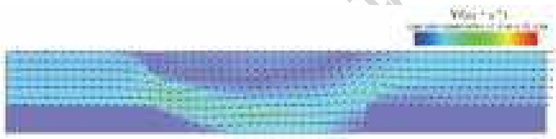

图 5　**C-120-30 模型水流速度和方向模拟**

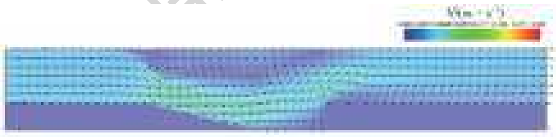

图 6　**C-96-60 模型水流速度和方向模拟**

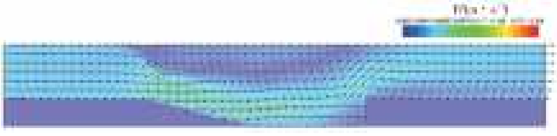

图 7　**C-120-60 模型水流速度和方向模拟**

通过模拟结果分析可知,水流模型凹槽长度为 0.96 m 的模型,其凹槽结构附近的水流更偏向左岸,使更多的上游垃圾无法流进凹槽收集结构,不利于漂浮垃圾的收集。而 1.2 m 模型的模拟结果相对较好。当凹槽长度一定,相较于内墙长度为 0.3 m 的情况,长度为 0.6 m 的模型种水流方向呈现出更利于漂浮垃圾收集的趋势。因此凹槽长度为 1.2 m 且内墙长度为 0.6 m 的模型模拟效果更优。

3.2　不同内墙长度的模拟研究

根据凹槽长度改变的模拟结果显示,模型 C-120-60的水流趋势更有利于收集。因此将凹槽长度固定为 1.2 m,然后进行更深入的研究。分别设置内墙长度为 0、0.2、0.24、0.3、0.4、0.5、0.6、1 m 的模型进行模拟,其工况见表 3。

表 3　凹槽长度为 1.2 m 时不同内墙长度的模拟工况

单位:cm

工况	B_m	B_w	L_m	L_s	L_w	L_p
C-120-0	30	15	40	10	120	0
C-120-20	30	15	40	10	120	20
C-120-24	30	15	40	10	120	24
C-120-30	30	15	40	10	120	30
C-120-40	30	15	40	10	120	40
C-120-50	30	15	40	10	120	50
C-120-60	30	15	40	10	120	60
C-120-100	30	15	40	10	120	100

随着长度不断的增加,内墙与河岸构成的夹角不断的减小,进而导致结构对于水体的影响也在不断的发生着变化。图 8、9 是没有内墙和最大内墙长度 1 m 的两个模型的模拟结果。

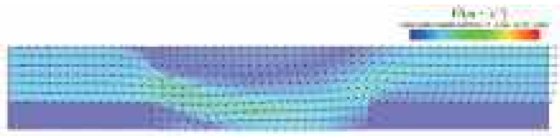

图 8　**C-120-0 模型水流速度和方向模拟**

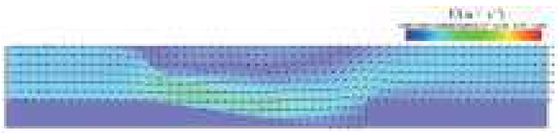

图 9　**C-120-100 模型水流速度和方向模拟**

从图 8 和 9 的模拟结果可以看出,设置内墙装置可以使水流运动方向更加趋向于凹槽内,这对漂浮垃圾的流动方向起到了很好的引导作用。其次,当没有内墙时,结构入口处水速较大,容易造成漂浮垃圾的不稳定性,而且水流的引导过程较短,对收集过程是不利的。因此,模拟结果说明拥有内墙的结构更有利于漂浮垃圾的收集。且内墙长度越长,对水流的引导效果越明显,漂浮垃圾进入凹槽被收集的概率也会更大。

4　试验研究和讨论

4.1　漂浮垃圾收集率

按照数值模拟时设计的不同尺寸模型进行试验验证,漂浮物采用直径 13 mm、比重为 0.91 的塑料弹性球模拟。弹性球投掷位置位于上游,距离装置的入口处 2.5 m。每次试验将 200 个塑料弹性球从上游位置投入主渠道内。投球时首先将球均匀摆放在与渠同宽的立方体盒中,然后抽走盒子前方挡板,保证实验球缓慢均匀进入渠道内。

待凹槽结构内弹性球数量稳定后,数出凹槽结构内球的数量并计算其收集率。收集率 R=凹部结构内弹性球数量/200,每个模型进行 20 次重复试验,然后计算平均收集率,以便于对试验结果进行分析对比。

在设置试验装置时,参照模拟结果进行设计。本次室内试验研究中,采用凹槽长度为 0.96 m 和 1.2 m 两种方案。首先,将内墙长度控制在 30 cm 的长度进行实验。得出凹槽长度为 0.96 m 和 1.2 m 的收集率分别为 42.55%和 46.475%。然后,再将内墙长度控制在 60 cm 的长度进行同样的试验。得出凹槽长度为 0.96 m 和 1.2 m 的收集率分别为 46.35%和 50.475%。两种方案的垃圾收集率对比见图 10。

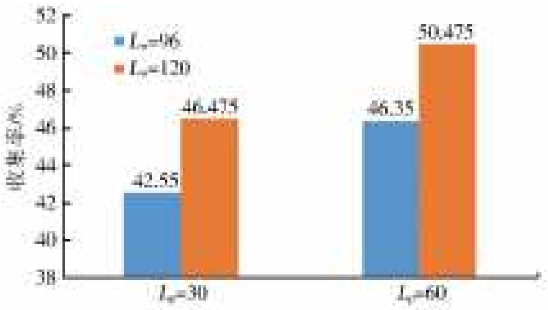

图 10　凹槽长度为 0.96 m 和 1.2 m 两种方案的垃圾收集率对比

由图 10 能够很直观的判断出,当凹槽结构长度为 1.2 m,且内墙长度为 0.6 m 时的收集率更好。试验结果与模拟结果一致。因此,在下面的试验中,重点讨论凹槽长度为 1.2 m 时,内墙长度的变化对收集率的影响。

图 11 是凹槽长度为 1.2 m 时,不同内墙长度的模型收集率以 box-plot 图的形式呈现出来的,以此反映出原始数据的分布特征。

在具体试验操作过程中,每种工况下重复试验 20 次,每次在投掷处投入 200 个弹性球。结果显示,同种模型的多次试验结果之间存在一定差别。图中"×"表示平均值,可以看出每次试验的结果之间偏差较大。捕捉率的差异可能与挡水板及背后水动力场形成涡流的作用影响有关。而内墙角度 θ 在 20°以下的收集率基本没有太大变化,平均可以捕捉到 50%以上。整体的影响趋势为内墙角度越小,长度越长,其捕捉率就会越高。

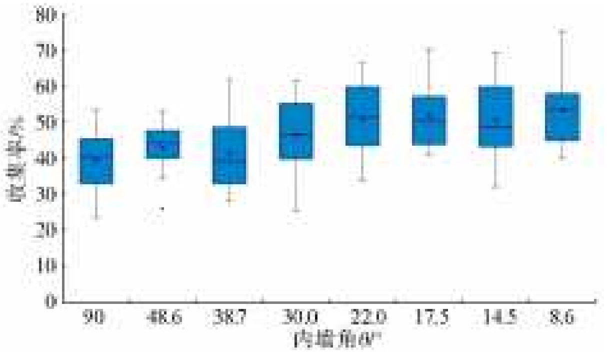

图 11　凹槽长度为 1.2 m 时不同内墙长度的垃圾收集率

4.2　表面水流向和横向速度

为了更直观的展示表面水流方向的变化情况。使用滑石粉作为显示剂,便于进行可视化的 PIV 法流速测量。利用数码相机,以1 280×780 像素和 30fps 的速度进行拍摄。试验过程中拍摄的图片见图 12。

图 12　滑石粉做显示剂的试验图片

利用 PIV 解析软件 FlowExpert 对图 12 进行相互相关性解析,得到了平均流速向量。图 13 和图 14 分别是内墙角度为 90°和 8.6°情形下通过 PIV 试验得到的模型 C-120-0 和模型 C-120-100 的水表面流向和横向流速处理图。

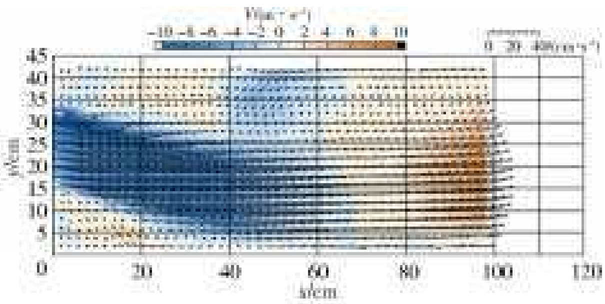

图 13　试验模型 C-120-0 水表面流向和横向流速处理

从处理图中可以看出,在挡水板处发生了由于剪切不稳定而产生的大规模漩涡,挡水板背后形成了长达 1 m 以上的循环流。在收集漂浮垃圾的过程中,希望水流能尽可能的趋向于凹部收集结构内,以此带动垃圾的收集。测量的试验模型中水流方向与模拟计算结果中水流方向一致。由此可知,内墙长度越长,水流越容易被引导并流向凹槽结构内部,

从而达到收集漂浮垃圾的目的。这一试验结果与模拟结果一致。

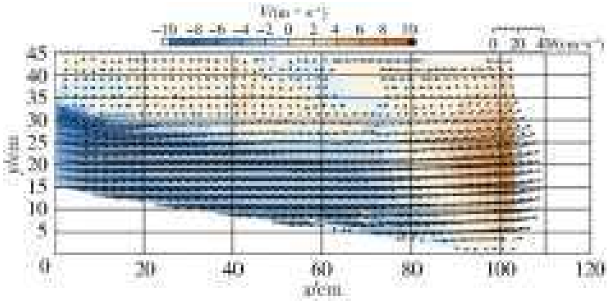

图 14　试验模型 C-120-100 水表面流向和横向流速处理

5　结　论

在本试验研究中,以收集河道漂浮垃圾为目的,通过数值模拟方法确定合适的试验模型尺寸比例,再根据室内试验研究获得具体收集结果,并对试验结果进行分析比较,得出主要结论。

(1)通过河道结构调整水流方向,利用河岸凹槽和挡水板所设计的装置能有效收集漂浮垃圾。

(2)凹槽长度对收集效果有一定的影响,本次试验中装置凹槽长度分别设定为 1.2 m 和 0.96 m,通过试验得到凹槽长度为 1.2 m 要比凹槽长度 0.96 m 对浮游垃圾收集率提高约 4%。

(3)随着装置内墙长度的增加,内墙角度减小的情况下,其捕捉率呈现出上升的趋势。因此,在设计河道漂浮垃圾自动收集装置时,可根据实际地况和水流条件等因素,尽可能延长凹部结构内墙的长度,从而获得更好的收集效果。

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·译文(Translation)·

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The simulation and experiment of fluted floating garbage collection device

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Abstract: Water environmental pollution caused by floating garbage in rivers is increasingly worse, and severely affects biodiversity, human health and ecosystems. In this paper, a floating garbage collection device is designed according to the hydrodynamic characteristics of the channel in Nagoya City, Aichi Prefecture, Japan. The retaining plate in the device is used to change the flow state, and the flow is guided to drive the floating waste into the groove structure, so as to achieve the collection effect. First of all, the simulation software iRIC is used to simulate the water, the appropriate scale of the test model is determined, and the indoor experimental device is designed. Under certain hydrodynamic conditions, the indoor model test research is carried out. By adjusting the groove length and the inner wall length of the collecting device, and setting different working conditions to carry on the test, the concrete floating garbage collection rate results are obtained. On this basis, the test results are analyzed and compared, and it is found that with the increase of concave length and inner wall length, the collection efficiency of the device will improve.

Key words: hydrodynamic characteristics; floating garbage; collecting device; simulation; experiment

In recent years, a large number of floating garbage carried by rivers have entered the ocean through estuaries, causing marine pollution as well as ecological and environmental problems. Such situation, if persists for a long period of time without prompt remedies, will not only threaten marine life, but also have a negative impact on human health and safety. According to relevant statistics[1], the amount of marine garbage due to human activities is astonishing; globally speaking, roughly 80 pieces of garbage is disposed into oceans on a daily basis and total of 6 400 kt annually. Global annual plastic consumption has now exceeded 3.2×10^5 kt. More plastics have been produced in the past decade than ever before. A large number of products or materials produced play a temporary role, some of which are quickly converted into waste. A small portion may be recycled or burned, while most will be collected to landfills or discarded in the natural environment[2]. Many marine garbage is transported through waterbodies. Therefore, in order to reduce the amount of garbage entering the ocean, we need to pay attention to the collection and disposal of garbage into the sea channel, among which floating waste disposal is an urgent problem to be solved. Horikawa river in Nagoya, Japan has very similar function and pollution with most rivers in China. In addition, the concave structure at the intersection of Horikawa and Nakagawa Canal and separated by loose heavy gate pro-

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vides a favorable prerequisite for this design. Therefore, this study takes Horikawa, Japan, as the research object.

1 Current domestic and global floating garbage management

Many foreign countries' environmental protection agencies including the US, UK, Germany, Canada, Australia, etc. have paid serious attentions to treating floating waste in rivers, and specially formulated river waste management regulations and technical standards for testing and sampling,[3] and developed corresponding garbage salvage and collection devices. For example, United Marine International Limited Co. (UMI Company) and the United Water Witch company in the US have developed floating garbage salvage boats (Marine Trash Skimmers), aquatic plant cleaning ship (Aquatic Weed Harvesters) and oil pollution removal vessels on the surface of the water (Oil Skimmers). In New York, Superior Lakes, Baltimore, South Korea and Hong Kong, etc., the river branch harbor waters have been widely used, and good results have been obtained, but the outstanding characteristics of these treatment technologies are developed for calm water surface.

The problem of floating garbage on the surface of important rivers such as Huangpu River in Shanghai, Pearl River in Guangzhou and Three Gorges Reservoir area has been very serious. According to "2015 Xiamen Marine Environment Bulletin", The total amount of floating waste in Xiamen sea area in 2000 is 1 600 t, and it is basically the same in 2014. The floating garbage in the three Gorges Reservoir area is dominated by leaves, branches and straw weeds, about 70% of the total, wood, tree roots, about 10% of the total, Plastic, foam and other white waste accounts for about 5%. Because of its light weight, large volume, not easy to degrade, great harm,[4] When cleaning up garbage in the three Gorges Reservoir area, long is mainly used 29.2 m Width 7 m Water sanitation operation ship and long 21 m Width 6 m Mechanized cleaning operation ship. Because the hull cost of cleaning floating garbage and the consumption in the operation process are high, a lot of manpower, material and financial resources were spent in the whole treatment process.

In this paper, Horikawa, a river entering the sea in Nagoya, Aichi prefecture, Japan, is taken as the research object. In view of the problems existing in floating garbage collection in Horikawa, the structure of riparian grooves is set up to change the hydrodynamic characteristics of the rivers, and a more efficient and environmentally friendly floating garbage collection device is designed.

2 Collection device

Horikawa fetches water from Nakagawa and flows through the underground channels of Yatagawa. It flows out of the north side of Nagoya Scenic spot and bypasses Nagoya City westward, then southward from Nagoya City Center, and eventually flows into Nagoya Port. Horikawa is a river that passes through the urban area, and the problem of water pollution has always attracted much attention. 1In the mid-9th century, a large amount of sewage was discharged into Horikawa. Although the sewage treatment plant was built in 1965, there is still a strong odour. In 1966, the BOD value of Horikawa has risen up to 54.8 mg / L, a phenomenon once known as the "dying river" and has not been well solved so far.

From previous investigation of Horikawa, it is found that there is a concave structure at the intersection of Horikawa Canal and Nakagawa Canal. This part is separated by the loose weight gate and the gate is closed for a long time, which provides a favorable prerequisite for the use of the concave structure. Fig. 1 is a schematic diagram of the concave structure (Google Maps screenshot).

Fig. 1 Schematic diagram of concave structure location

Based on the problem of floating garbage in Horikawa at present, a design scheme of automatic collection device for floating garbage in river course is proposed. The device relies on the guidance of the flow power to guide the floating garbage movement track, so that it flows into the preset concave structure to complete the garbage collection work. The early investment of the device is less, referring to the flexible setting of different river topography, only need to increase the water retaining device and small excavation of the river bank to form a concave part. In this study, the natural concave structure existing in Horikawa is taken as the original model, and the experimental device is designed for laboratory test simulation. In the test process, the hydrodynamic characteristics of the water body are changed by guiding the water flow direction by the water retaining plate in the device, so that the floating waste flows to the groove structure of the collecting device with the flow of water, and then the floating waste is blocked by the filter net, so as to achieve the purpose of collection. This process completely realizes zero drive operation which does not consume other energy and hence helps with energy saving and environmental protection. Finally, operators only need to collect and dispose garbage from the concave structure on a regular basis. A schematic diagram of the collecting device is shown in Fig. 2.

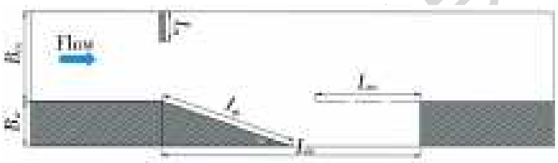

Fig. 2 Schematic diagram of floating garbage automatic collection device

L_s is the length of the water retaining plate device; B_m is Width of main channel; B_w is The width of the groove structure. L_w is the length of concave structure; L_p is the length of guide wall; L_m is the length of the filter, and the θ is the angle between the guiding wall and the shore.

The experimental model is based on 1/80 of Horikawai, and the collecting device is tested and studied under the condition of fixed channel structure parameters. The model adopts length 12 m, width 60 cm. And set the hydraulic gradient $I = 1/1\ 000$. Set width on the right bank of the flow device 30 cm, high 6 cm of PVC Plate, so that the width of the current is 30 cm. Fig. 3 set upstream for the main part of the device 4 m. The length is set downstream of the groove collector to be 40 cm. The metal mesh is used to filter floating garbage.

The change of each parameter will have a certain impact on the final collection effect. Here we focus on the two parameters of L_w and L_p influence on the collection effect of the device. There is a certain deviation between the uneven flow caused by the roughness of the floor and the uniform flow set in the experiment, in order to ensure the reliability of the results, the actual hydraulic conditions are simulated and compared with the experimental results.

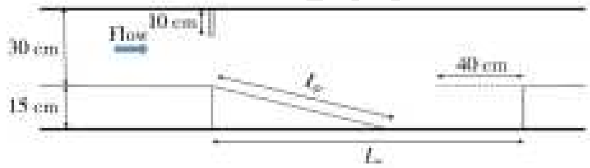

Fig. 3 schematic diagram of structure size

3 Numerical modeling

Based on the test results, we first create a 45 cm×400 cm model. Then the model is further divided into 1cm squares grids. IRIC software was used to simulate two groups, and the hydrodynamic conditions set by the test are shown in Tab. 1. Under this hydrodynamic condition, the control variables are adjusted to change the groove length and the inner wall length respectively, and the whole simulation time is set to 120 s. The turbulence model is based on k-ε and the results are compared and analyzed.

Tab. 1 Hydrodynamic condition

Flow $Q/(\mathrm{L \cdot s^{-1}})$	Depth of water h/cm	Velocity of water flow $U_m/(\mathrm{cm \cdot s^{-1}})$	Reynolds number R_e	Froude value F_r	Slope I
1.0	3.0	11.1	3 300	0.41	1/1 000

3.1 Simulation study of groove length change

In the setting of the device, it is necessary to study the influence of the change of groove size on the result. Therefore, the groove length is designed to be 0.96 m and 1.2 m. The two schemes were compared. In the design of the length of the inner wall, two lengths of 0.3 m and 0.6 m are respectively set for comparison. The experimental simulation conditions of groove length change are shown in Tab. 2.

Tab. 2 Comparison chart of 0. 9 m and 1. 2 m

Unit:cm

Case	B_m	B_w	L_m	L_s	L_w	L_p
C-96-30	30	15	40	10	96	30
C-96-60	30	15	40	10	96	60
C-120-30	30	15	40	10	120	30
C-120-60	30	15	40	10	120	60

The results obtained by simulating two kinds of groove lengths and two kinds of interior wall lengths are shown in Fig. 4-Fig. 7.

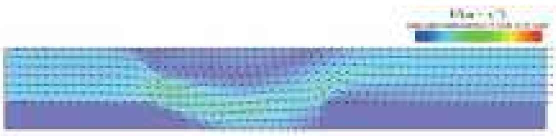

Fig. 4 Model C-96-30 flow velocity and direction simulation

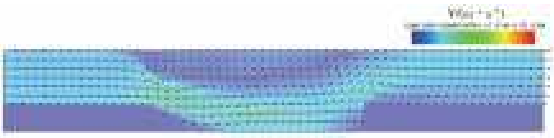

Fig. 5 Model C-120-30 flow velocity and direction simulation

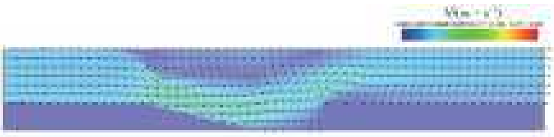

Fig. 6 Model C-96-60 flow velocity and direction simulation

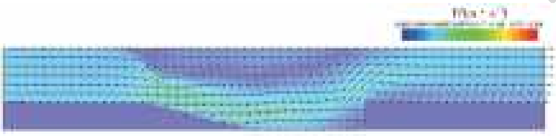

Fig. 7 Model C-120-60 flow velocity and direction simulation

Through the analysis of the simulation results, for the model with a groove length of 0. 96 m, the water flow near the groove structure is more inclined to the left bank, so that more upstream garbage cannot flow into the groove collection structure, which is not conducive to the collection of floating garbage. The simulation results of 1. 2 m model are relatively good. When the length of the groove is certain, compared with the condition that the length of the inner wall is 0. 3 m, the water flow direction of the model with a length of 0. 6 m is more conducive to floating garbage collection. Therefore, the model with a length of 1. 2 m for the groove and 0. 6 m for the inner wall has better simulation effect.

3. 2 Simulation study of different interior wall lengths

According to the simulation results of the change of groove length, the flow trend of model c-120-60 is more favorable for collection. Therefore, the length of the groove was fixed as 1. 2 m, and further research was carried out. Models with internal wall lengths of 0 m, 0. 2 m, 0. 24 m, 0. 3 m, 0. 4 m, 0. 5 m, 0. 6 m and 1 m were set for simulation, and the working conditions were shown in Tab. 3.

Tab. 3 Comparison simulation of different guide wall lengths when the embayment length is 1. 2 m Unit:cm

Case	B_m	B_w	L_m	L_s	L_w	L_p
C-120-0	30	15	40	10	120	0
C-120-20	30	15	40	10	120	20
C-120-24	30	15	40	10	120	24
C-120-30	30	15	40	10	120	30
C-120-40	30	15	40	10	120	40
C-120-50	30	15	40	10	120	50
C-120-60	30	15	40	10	120	60
C-120-100	30	15	40	10	120	100

With the increase of length, the angle between the inner wall and the bank of the river decreases, which leads to the influence of the structure on the water body is also constantly changing. Fig. 8 and Fig. 9 are the simulation results of two models with no inner wall and a maximum length of 1m inner wall.

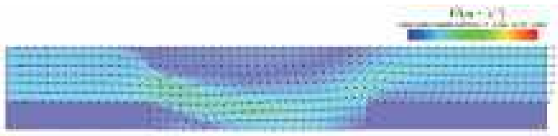

Fig. 8 Model C-120-0 flow velocity and direction simulation

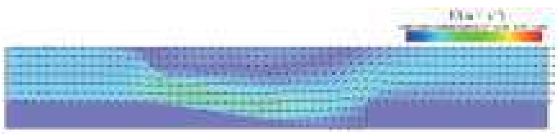

Fig. 9 Model C-120-100 flow velocity and direction simulation

From the simulation results of Fig. 8 and Fig. 9, it can be seen that the inner wall device can make the direction of water flow more inclined to the groove, which plays a good role in guiding the flow direction of floating garbage. Secondly, when there is no inner wall, the water speed at the entrance of the structure is large, which can easily cause the instability of floating garbage, and the guiding process of water flow is short, which is disadvantageous to the collection process. Therefore, the simulation results show that the structure with inner wall is more conducive to floating garbage collection. And the longer the length of the inner wall, the more obvious the guiding effect on the flow, and the greater the probability that floating garbage will be collected into the grooves.

4　Experimental and discussion

4.1　Floating garbage collection rate

According to the different size models designed in the numerical simulation, the floating object is simulated by plastic elastic ball with diameter 13 mm and specific gravity of 0.91. the experimental results are as follows: (1) the floating material is simulated by plastic elastic ball with diameter and specific gravity of 0.91. The elastic ball throwing position is located upstream, 2.5 m from the entrance of the device. In each experiment, 200 plastic elastic balls were put into the main channel from the upstream position. When pitching, the ball is evenly placed in a cubic box the same width as the canal, and then the front baffle of the box is removed to ensure that the experimental ball enters the channel slowly and evenly.

After the number of elastic spheres in the groove structure is stable, the number of balls in the groove structure is counted and the collection rate is calculated. The collection rate R is: $R=$ number of elastic spheres in concave structure/200

Each model carries on 20 repeated experiments, and then calculates the average collection rate to facilitate the analysis and comparison of the experimental results.

When setting up the test device, design with reference to the simulation results. In this laboratory test study, the two schemes of groove length of 0.96 m and 1.2 m were adopted. First, the length of the inner wall was controlled at 30 cm for the experiment. The collection rates of 0.96 m and 1.2 m were 42.55% and 46.475%. Then, the length of the inner wall is controlled to the length of the 60 cm for the same experiment. The results show that the collection rate of 0.96 m and 1.2 m is 46.35% and 50.475% respectively. The comparison of garbage collection rates between the two scenarios is shown in Fig. 10.

It can be intuitively judged from Figure 10 that the collection rate is better when the length of the groove structure is 1.2 m and the length of the inner wall is 0.6 m. The experimental results are consistent with the simulation results. Therefore, in the following experiment, the influence of the change in the length of the inner wall on the collection rate when the length of the groove is 1.2 m is discussed emphatically.

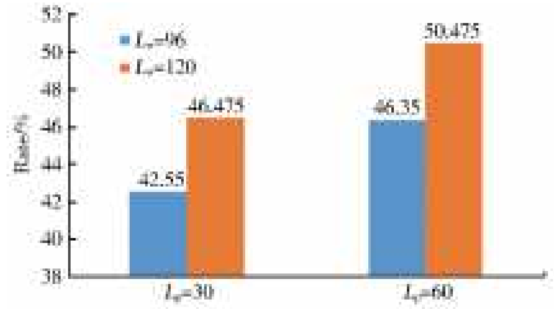

Fig. 10　The garbage collection rate comparison chart of 0.9 m and 1.2 m

Fig. 11 shows that when the length of the groove is 1.2 m, the model collection rate of different interior wall lengths is presented in the form of box-plot to reflect the distribution characteristics of the original data.

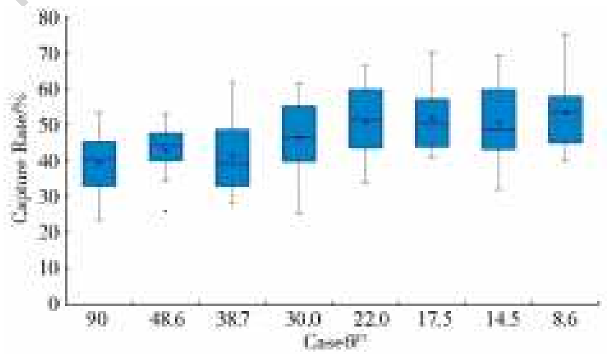

Fig. 11　Garbage collection rates of different guide wall lengths when the embayment length is 1.2 m

During the specific test operation, the test was repeated 20 times under each working condition, and 200 elastic balls were put into the throwing place each time. The results show that there are some differences between the experimental results of the same model. The "×" in the figure represents the average value, and it can be seen that the results of each experiment have a large deviation. The difference of capture rate may be related to the effect of eddy current formed by the water baffle and the hydrodynamic field behind it. While the collecting rate of θ below 20° was basically unchanged, and on average, more than 50% could be captured. The overall influence trend is that the smaller the Angle and the longer the length of the inner wall, the higher the capture rate will be.

4. 2 Surface water flow velocity and lateral velocity

In order to show the change of surface flow direction more intuitively. Using talc powder as display agent, it is convenient to carry out visual flow velocity measurement by PIV method. Take pictures with a digital camera at 1 280 × 780 pixels and 30fps. The pictures taken during the experiment are shown in Fig. 12.

Fig. 12 Experimental picture of talcum powder as display agent

The PIV analysis software Flow Fig. 12 Expert was used to analyze the correlation of and the average velocity vector was obtained. Fig. 13 and Fig. 14 are respectively the treatment diagrams of water surface flow direction and transverse velocity of model c-120-0 and model c-120-100 obtained by PIV test under the internal wall Angle of 90° and 8. 6° respectively.

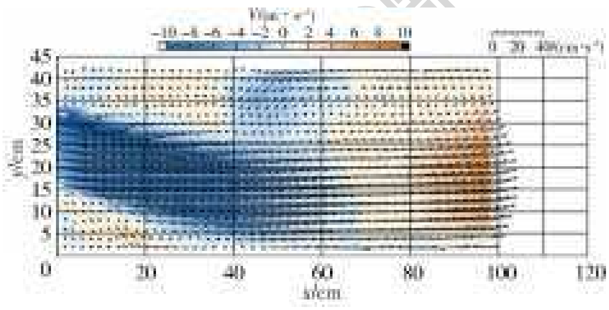

Fig. 13 Experimental model c-120-0 water surface flow direction and transverse velocity treatment diagram

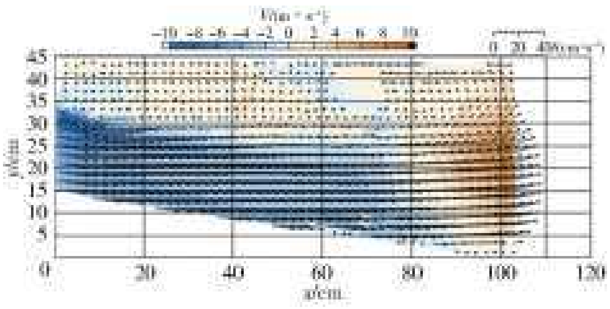

Fig. 14 Experimental model c-120-100 water surface flow direction and transverse velocity treatment diagram

As can be seen from the treatment diagram, a large-scale vortex caused by shear instability occurred at the water baffle, and a circulation flow of more than 1m was formed behind the water baffle. In the process of collecting floating garbage, it is hoped that the water flow can be as close to the concave collection structure as possible to drive garbage collection. The flow direction in the measured experimental model is consistent with the flow direction in the simulation results. It can be seen that the longer the inner wall is, the easier it is for water to be directed to the interior of the groove structure, so as to achieve the purpose of collecting floating garbage. The experimental results are consistent with the simulation results.

5 Conclusion

In this study, in order to collect floating waste in the river, the appropriate size ratio of the test model is determined by numerical simulation method, and then the specific collection results are obtained according to the laboratory test research, and the test results are analyzed and compared. Through a series of experimental studies, the following main conclusions are drawn.

(1) The flow direction can be adjusted by the river structure, and the floating garbage can be collected effectively by using the device designed by the riparian groove and baffle.

(2) the groove length has a certain influence on the collection effect. In this experiment, the length of the device's groove was set as 1. 2 m and 0. 96 m respectively. It was found that the length of the groove was 1. 2 m, which improved the collection rate of floating garbage by about 4% compared with the length of the groove of 0. 96 m;

(3) with the increase of the length of the inner wall of the device and the decrease of the angle of the inner wall, the capture rate shows an upward trend. Therefore, when designing the automatic collection device of floating garbage in river course, the length of the inner wall of concave structure can be prolonged as much as possible according to the actual ground conditions and flow conditions, so as to obtain better collection effect.

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