



**HAL**  
open science

## ew Series of Corers for Taking Undisturbed Vertical Samples of Soft Bottom Sediments

Jirong Xu, You-Shao Wang, Jinping Yin, Jinping Lin

► **To cite this version:**

Jirong Xu, You-Shao Wang, Jinping Yin, Jinping Lin. ew Series of Corers for Taking Undisturbed Vertical Samples of Soft Bottom Sediments. *Marine Environmental Research*, 2011, 71 (4), pp.312. 10.1016/j.marenvres.2011.02.006 . hal-00682417

**HAL Id: hal-00682417**

**<https://hal.science/hal-00682417>**

Submitted on 26 Mar 2012

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# Accepted Manuscript

Title: ew Series of Corers for Taking Undisturbed Vertical Samples of Soft Bottom Sediments

Authors: Jirong Xu, You-Shao Wang, Jinping Yin, Jinping Lin



PII: S0141-1136(11)00033-X

DOI: [10.1016/j.marenvres.2011.02.006](https://doi.org/10.1016/j.marenvres.2011.02.006)

Reference: MERE 3512

To appear in: *Marine Environmental Research*

Received Date: 7 January 2008

Revised Date: 18 February 2011

Accepted Date: 21 February 2011

Please cite this article as: Xu, J., Wang, Y.-S., Yin, J., Lin, J. ew Series of Corers for Taking Undisturbed Vertical Samples of Soft Bottom Sediments, *Marine Environmental Research* (2011), doi: 10.1016/j.marenvres.2011.02.006

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

## **New Series of Corers for Taking Undisturbed Vertical Samples of Soft Bottom Sediments**

**Jirong Xu<sup>1,2\*</sup>, You-Shao Wang<sup>1</sup>, Jinping Yin<sup>1</sup>, Jinping Lin<sup>3</sup>**

*1. Faculty of Architectural Engineering and Environment, Ningbo University, Ningbo 315211, P.R. China*

*2. South China Sea Institute of Oceanology, Chinese Academy of Sciences, Guangzhou 510301, P.R. China*

*3. School of Social and Environmental Enquiry, The University of Melbourne, Victoria 3010, Australia*

### **Abstract**

A new series of sediment corers—a Single Tube Gravity Corer and a Multiple Tube Gravity Corer—has been developed for taking undisturbed vertical soft sediment samples, and a Hydraulic Pressure Multiple Tube Corer has been preliminarily designed. The Single Tube Gravity Corer can be operated by hand easily without using a winch, and it might be the simplest and the cheapest core sampler available. The Multiple Tube Gravity Corer was developed based on the Single Corer, which normally consists of three coring tubes, however, it is possible to install up to six tubes. The Hydraulic Pressure Multiple Tube Corer has been designed based on the Multiple Corer, which would take undisturbed sediment samples, and would be controlled by a computer and monitored by an underwater video camera. The pore water collection and the sediment Eh measurement-subsampling process through the transparent plastic tube wall is straightforward. Compared to other types of coring devices, such as the famous KC Kajak sediment core sampler made in Denmark; these corers have greater reliability, being simple in structure, relatively light weight, easy and efficient to operate, highly adaptable, and relatively inexpensive to produce.

**Keywords:** New Corers; Undisturbed Sediment Cores; Application

## 1 **1 . Introduction**

2 Obtaining representative, undisturbed, vertical samples of soft bottom sediments is  
3 a fundamental prerequisite for much research in aquatic biology, ecology,  
4 geochemistry and environmental sciences conducted in fluvial, lacustrine, estuarine  
5 and marine situations. Unfortunately, the surface sediment may be disturbed during  
6 the sampling process; further, most soft sediment samplers (e.g. trawls, sledges,  
7 dredges, suction samplers, snap grabs, scoop, bucket, impact or hydrostatic corers)  
8 provide only semi-quantitative samples (Ankar 1977, Riddle 1989). Today greater  
9 demand for undisturbed benthic samplers is obvious in countless studies. Marine  
10 scientists cannot investigate benthic flux of materials, transfer of energy, nutrient and  
11 metal dynamics without proper attention to sediment sampling. Similarly, tracing  
12 aquatic pollutants, determining the vertical profiles of organisms and monitoring  
13 meio- and micro- fauna population density depends upon careful recovery of the  
14 upper sedimentary profile in an undisturbed manner.

15 Since the beginning of the 20th century, many different types of samplers for taking  
16 soft bottom sediments have been developed (Peterson and Jensen 1911, Ekman 1915).  
17 Soft sediment samplers fall into three main categories-grab samplers, box samplers  
18 and corers. Grab samplers of various designs are used to obtain surface samples. They  
19 perform well in soft, sandy or silty sediments, but are less effective when the substrate  
20 is gravely or rocky. Grab samplers disturb samples during digging and closing, so  
21 they are unable to recover sediment in an undisturbed way. Box samplers, in their  
22 original or modified versions, are the standard equipment for benthic research. They  
23 collect undisturbed samples, but, due to their size and weight constraints, whose use is  
24 limited to relative large-scale operations. Actually, box samplers also disturb sediment  
25 samples to some extent, because its mechanical closing structure is similar with grab  
26 samplers. Corers are generally simpler, easier to handle and more economical than  
27 other types of soft sediment samplers. Corers are often used to take undisturbed  
28 samples for microbial, biological and geochemical investigation incorporating the  
29 collection of the sediment-water interface.

30 Other corer-type sediment samplers have a number of deficiencies relative to the  
31 sampler described in this paper. The device described in Barnes (1960) has a diameter  
32 of only 1.0 cm, giving it a high wall friction co-efficient, outside the range for which  
33 entry characteristics can be calculated. The device described in Zullig (1953) has an  
34 internal diameter of 3.2 cm and a wall thickness of 0.4 cm and surprisingly, did not  
35 have a sharpened or bevelled edge, meaning it would displace or distort a high  
36 proportion of the core in a manner that could not easily be predicted or accounted for.  
37 With these deficiencies, it is not surprising that Elmgren (1973) found that the box-  
38 corer was superior to those with which it was compared. However, our wall thickness  
39 (polycarbonate) is 0.15 cm (1.5 mm), which is efficiently to overcome the problem.  
40 Samples were taken in stiff mud at 47 m depth with a grab-type box sampler, a van  
41 Veen grab sampler and three gravity core samplers. Results were compared to  
42 'control' cores obtained by SCUBA (self-contained underwater breathing apparatus)  
43 divers. The grab-type box sampler was shown to be suitable for collecting undisturbed  
44 samples for meiofaunal research, whereas the van Veen grab and three core samplers  
45 were not. The validity of studies employing the latter samplers is therefore open to a  
46 question.

47 Elmgren (1973) stressed the importance of sampling methods in all quantitative  
48 work on sublittoral meiofauna populations. Blomqvist (1985) examined the reliability  
49 of samples obtained using four lightweight, soft sediment sampling devices:Axelsson-  
50 Håkanson gravity corer, Kajak gravity corer, Jenkin bottom sampler and Ekman grab

51 (box corer). Each of these samplers was intended for use in soft sediments *in situ* by  
52 direct observation, measurement and photographic documentation by SCUBA divers.  
53 The results showed the relationship between compaction and sediment depth was  
54 dependent on core-tube diameter. These findings highlight the importance of sampler  
55 design in preserving stratigraphic integrity. Core description, penetration/compaction  
56 will depend largely on the sediment encountered and is not easily predicted in the case  
57 of layered sediments of different densities and water contents.

58 Blomqvist (1991) reviewed the development of samplers from the 1910s to the end  
59 of the 1980s, and suggested guidelines for the further design and development of  
60 samplers. He also predicted that the future samplers would be based around box and  
61 tube-coring samplers, because these would better suit the demand of providing  
62 representative quantitative (e.g. undisturbed) samplers.

63 Black *et al.* (2002) stated: “Blomqvist (1991) gives an analysis of techniques for  
64 sampling soft bottoms and concludes that the instruments best suited for quantitative  
65 sampling of soft bottom sediments appear to be those based on the coring principle.”  
66 After summarizing limitations and biasing factors to be considered, Blomqvist (1991)  
67 indicated that a perfect core should: (1) permit unimpeded water flow through the  
68 coring tubes to obviate formation of a bow wave, (2) work on a supporting stand,  
69 permitting it to settle down, before the coring tubes enter, (3) avoid disturbing sample  
70 during closing operation and withdrawal from the sediment, (4) avoid shorting the  
71 sample during the coring tubes entering sediment, and (5) be of adequate and suitable  
72 size in relation to the vessels’ size and facilities such as winches and frames.

73 A multiple corer for taking virtually undisturbed sandy and soft samples from  
74 shallow water sediments has been designed by them (Black *et al.* 2002). However, its  
75 mechanical structure is relatively complex, compared to the one described in this  
76 paper.

77 Nowadays, with the development of modern science and technology; it is possible  
78 to develop a modern corer to avoid factors such as impacts from water movements  
79 and from mechanical deficiencies (closing structure) to overcome disturbance of  
80 samples.

81 The purpose of this paper is to introduce a new series of corers for taking  
82 undisturbed soft sediment samples; these coreers having advantages of greater  
83 reliability, simplicity in structure, light weight, easy and efficient to operate, highly  
84 adaptable, and relatively inexpensive to produce.

85

## 86 **2. The New Series of Corers**

87 The Single Tube Gravity Corer was designed and developed first. Then, the Gravity  
88 Multiple Tube-Corer was developed based on this design but improved in order to  
89 take more cores synchronously.

90 The Single Tube Gravity Corer and the Multiple Tube Gravity Corer can  
91 successfully take undisturbed cores in calm conditions. However, when used in rough  
92 conditions such as strong currents, large waves, difficult sediment characteristics  
93 (such as when sampling of hard sediments is attempted) or when the equipment is  
94 operated incorrectly, some sample disturbance may occur. Therefore, it is always  
95 necessary to check if the core sample has been successfully collected in an  
96 undisturbed state. If our observations indicted that 1% or more of a core was  
97 disturbed, the core was discarded.

98 It is possible that most gravity corers enter into the sediment relatively quickly, so it  
99 is impossible to completely eliminate friction drag and prevent sediment smearing

100 against the tube wall, which might compact the sediment, disturb stratigraphy and  
101 cause sampling error.

102 For the reasons stated above, the Hydraulic Pressure Multiple Tube-Corer has been  
103 preliminarily designed, based on the Multiple Tube Gravity Corer. It is possible that  
104 this third corer will become available when or if the program is funded in the near  
105 future.

106

## 107 2.1 Single Tube Gravity Corer

108 The structure of the Single Tube Gravity Corer is shown diagrammatically in Fig 1  
109 and as a photograph in Fig 2. The head blade is made of stainless steel and the tube  
110 (inner diameter 50 mm, and length 1 m) is made of perspex (wall thickness 5 mm) or  
111 polycarbonate (wall thickness 1.5 mm). The head blade is not necessary if the tube is  
112 made of polycarbonate. The main board is made of stainless steel in order to support  
113 the whole sampler system. The valve body is made of perspex and the valve ball of  
114 ABS (acrylonitrile butadiene styrene). The low density sphere caged in the valve body  
115 is one of the most basic types of closing mechanisms. It is used as a directional flow  
116 valve to reduce water resistance. So ABS (density  $1.16 \text{ g/cm}^3$ ) was selected as the  
117 material for the valve ball. The valve and the valve ball are the key parts of the corer,  
118 which prevent the sample sliding from the tube when the corer is extracted from  
119 sediments. The fixing board is made of stainless steel and is fitted with screws. The  
120 lead ring is to keep the coring tube vertical while it descends through the water  
121 column and penetrates into the sediment. The total weight of the Single Corer is about  
122 25 kg.

123

124 **Fig1**

125

126 **Fig 2**

127

128 The operation of the Single Tube Gravity Corer is quite straightforward because of  
129 its mechanical simplicity. A defect of some other samplers is that the mechanism may  
130 foul or be triggered before samples have been obtained. Fig 1 shows the Single Tube  
131 Gravity Corer assembly prior to sediment collection. A metal handle can be used for  
132 sample retrieval in shallow water ( $< 4 \text{ m}$ ), and a rope attached in deeper waters.

133 Firstly, lower the corer into surface water slowly and wait for a moment, to make  
134 sure that the tube is vertical. It is an important step to sample sediment successfully.  
135 Secondly, lower the corer down slowly to 3 m above the bottom, and then let the corer  
136 go down as a free fall. The final step is when the tube penetrates into sediment to take  
137 a sample by gravity.

138 When the corer is cast into the water, the ball valve will float while the core goes  
139 down towards the bottom sediment. The valve ball will seat in the rubber O-ring and  
140 seal the tube by gravity to hold the sample as the tube is hoisted from the sediment  
141 and raised through the water column. Regulating the number of lead weights can  
142 control the depth of corer penetration into the sediment, enabling the sediment-water  
143 interface to be sampled. The corer has several advantages over other sediment  
144 samplers: (1) The structure is very simple, so, it is easy and economical to build, (2) It  
145 can be operated without a winch, (3) it is more reliable than others, because there is  
146 no mechanical movement during sampling, (4) It can be adapted to various situations  
147 and surroundings, (5) If the tube is perspex or polycarbonate, it is easy to drill a hole  
148 to collect sediment-water interface (pore water) and insert an electrode to measure  
149 sediment Eh (redox potential).

150

## 151 2.2 Multiple Tube Gravity Corer

152 The Multiple Tube Gravity Corer is a relatively simple modification of the Single  
153 Tube Gravity Corer. A detailed structure of the Multiple Tube Gravity Corer  
154 consisting of three tubes is shown in Fig 3. Compared to the structure of the Single  
155 Tube Gravity Corer (Fig 1), the main modified parts of the Multiple Gravity Tube  
156 Corer are the head blade (Part A in Fig 3) and the support frame (Part F).

157 The Multiple Tube Gravity Corer normally consists of three tubes, while it is  
158 possible to install up to six tubes. From our past sampling, the Multiple Tube Gravity  
159 Corer can efficiently take six cores, so long as the supporting frame is strong enough  
160 and spacing of the individual corers is sufficient. Each tube can collect a sediment  
161 core on its own without interfering with other corers.

162 The Multiple Tube Gravity Corer is an assemblage of the Single Tube Gravity  
163 Corer, so it has all the advantages of the Single Gravity Tube Corer. However, the  
164 Multiple Tube Gravity Corer needs a winch because of its increased weight when  
165 containing sediment samples.

166

**Fig3**

167

168

**Fig4**

169

## 170 2.3 Hydraulic Pressure Multiple Tube Corer

171 As stated in the section 2 above, our Hydraulic Pressure Multiple Corer is intended  
172 to solve the problems: sample disturbance in rough conditions, reducing friction drag,  
173 and preventing sediment smearing against the tube wall and provides almost  
174 undisturbed vertical core samples of soft bottom sediment. According to our design,  
175 several coring tubes (3-6 tubes) could be assembled on a support stand controlled by a  
176 hydraulic pressure device. The hydraulic pressure device will be designed to keep the  
177 tubes' movement slow and smooth during the operation, in order to keep the bottom  
178 sediment in its original and undisturbed state. A preliminary schematic drawing of the  
179 Hydraulic Pressure Multiple Corer (with three tubes) is shown in Fig 5. As it is stated  
180 above the Hydraulic Pressure Multiple Tube Corer is possible to become available  
181 when or if it is funded in the near future.

182

183

**Fig5**

184

185 The whole sampling process of the Hydraulic Pressure Multiple Tube Corer is  
186 controlled by a computer. An under-water video camera, which is fixed on the  
187 supporting frame, monitors the whole sampling process including sampling station  
188 selection. Firstly, the corer is lowered slowly to the bottom and the corer is prevented  
189 from sinking into the sediment by the supporting frame. Secondly, the hydraulic  
190 pressure device drives the sampling tubes penetration into the sediment slowly and  
191 smoothly controlled by the computer. The valve balls are floated to the top of valves  
192 to let water go through, when the sampling tubes enter the sediment. Then, when the  
193 sampling is finished, the hydraulic pressure device pulls the coring tubes out off the  
194 sediment, when the tubes have reached the predetermined depth and the valve balls  
195 fall back onto the rubber ring and seal the valve to prevent samples sliding out.  
196 Finally, the winch hoists the corer onboard the sampling vessel. Compared to other  
197 multiple corers driven by a hydraulic pressure device, our equipment is much simpler,  
198 more reliable and more efficient because there are no opening and sealing operations  
199 needed during sampling.

200

201 **3. Application**

202 Several Single Tube Gravity Corers and Multiple Tube Gravity Corers have been  
203 produced and used by us to take sediment samples in the Pearl River estuary and by  
204 other researchers in other places. All results showed that the corers were able to  
205 successfully collect sediment samples.

206 We would like to provide some details of the Pearl River estuary and the process of  
207 the sediment sampling there, as follows.

208 The Pearl River is the third largest river in China and the largest river in southern  
209 China, being 2214 km long and with a delta area of 453,690 km<sup>2</sup>. It is of a  
210 considerable economic and environmental importance. The Pearl River passes  
211 through the city of Guangzhou, which is one of the largest cities in China and the  
212 largest city in southern China with over 7 million inhabitants. Guangzhou is also an  
213 important trading centre as well as a busy port and an industrial base. The climate of  
214 Guangzhou is sub-tropical. The average year-round temperature is 22°C. August is the  
215 hottest month, with an average temperature of 28°C. January is the coldest month,  
216 with an average of 13°C. The rainy season falls between April and August. Average  
217 annual rainfall is 1,720 mm.

218 The Pearl River estuary receives and carries most of the outflow from the Pearl  
219 River. The discharge into the Pearl River estuary is around 1,500 m<sup>3</sup>/s during the dry  
220 season, whereas the flow could increase up to 20,000 m<sup>3</sup>/s during the wet season. It  
221 has 3.36×10<sup>11</sup> m<sup>3</sup> of freshwater discharge into the South China Sea every year. It is a  
222 bell-shaped estuary, nearly 60 km long and 50 km wide at its mouth (outlet). The  
223 depth of the estuary averages 9 m, but containing some deeper dredged channels; and  
224 its tidal range is 1-2 m.

225 Industrial and domestic wastewater from the Pearl River Delta area, especially from  
226 Guangzhou, has impacted the water quality in the river. Recently it was reported that  
227 the mean concentrations of BOD (biochemical oxygen demand) and TN (total  
228 nitrogen) in the Pearl River water have both increased by 0.4 mg/L over the last 20  
229 years (Xu 2003).

230 During our investigation, water samples were taken from all stations-ST1 to ST9;  
231 and only three sampling stations-ST2 (water depth 3.5 m), ST5 (7.7 m) and ST9 (18.7  
232 m)-were chosen for taking sediment cores for the research of nitrification,  
233 denitrification and nitrate reduction rate in sediments. The distance from the central  
234 Guangzhou to ST2 is about 14 km, to ST5 38 km, and to ST9 82 km. ST2, ST5 and  
235 ST9 represent as the upstream site, mid-stream site and downstream site of the  
236 estuary; respectively. All of them are along the main river-course axis in the Pearl  
237 River estuary. The details are shown in Fig 6.

238

239

240

**Fig 6**

241

242

243

244

245

246

247

248

Nine sediment cores were collected from ST2, ST5 and ST9 in April 2004 with the Single Tube Gravity Corer and the Multiple Tube Gravity Corer. Each core was examined visually (by eye) through the transparent sampling tube whether it had been disrupted or disturbed by sampling process. We adopted a criterion that the core would be discarded if it showed any sign (1% or more) of stratigraphic disruption as indicated in Section 2 above. However, none of our nine sediment cores showed any sign of disrupted stratigraphy when visually assessed. Six cores were used for measuring nitrification and denitrification rates. Sediment pore waters were extracted

249 from the other three cores. The pore water collection process is very simple and is  
250 completed by drilling holes through the transparent plastic tube wall and then  
251 collecting pore waters for the measurement of  $\text{NH}_4^+$  and  $\text{NO}_2^- + \text{NO}_3^-$ . The pore waters  
252 were obtained by compressing the whole core line at 0.5 cm intervals. The  
253 temperature and Eh were measured with a platinum wire electrode inserted into intact  
254 sediments within 6 hours of sampling.

255

#### 256 **4. Acknowledgements**

257 Authors are appreciated that the program has been financially supported by Chinese  
258 National Funding (No. 40676073). Authors are grateful to our colleagues Dr. Qingji  
259 Wang, Lei He, Fengqing Zhang and Cuici Sun for their assistance in testing corer's  
260 characteristics; to Dr. Robert Bernard Spies and two anonymous referees for their  
261 detailed and helpful comments and thoughtful editing on the manuscript; and  
262 especially to Phil Sinclair for assistance with English expression and clarification of  
263 some technical terms.

**References**

- Ankar, S., 1977. Digging profile and penetration of the Van Veen grab in different sediment types. *Contr. Askö Lab. Univ. Stockh.* 16, 1-22.
- Barnes, H., 1959. *Oceanography and Marine Biology*. George Allen & Unwin, London.
- Banes, J., Owens, N.P., 1999. Denitrification and nitrous oxide concentrations in the Humber estuary, UK, and adjacent coastal zones. *Marine Pollution Bulletin* 37, 247-260.
- Black, H.J., Dainat, M., Köster, M., 2002. A multiple corer for taking virtually undisturbed samples from shallow water sediments. *Estuarine Coastal and Shelf Science* 54, 45-50.
- Blomqvist, S., 1985. Reliability of core sampling of soft bottom sediment- an in suit study. *Sedimentology* 32, 605-612.
- Blomqvist, S., 1991. Quantitative sampling of soft-bottom sediments: problem and solutions. *Marine Ecology Progress Series* 72, 295-304.
- Ekman, S., 1915. Die Bodenfauna des Vattern, qualitative und quantitative untersucht, *Int. Revue ges. Hydrobiol. Hvdrogr.* 7, 146-204, 275-425.
- Elmgren, R., 1973. Methods of sampling sublitoral soft bottom meiofauna. *Oikos Suppl.* 15, 112-120.
- Law, C. S., Rees, A. P., Owens, N. J., 1992. Nitrous oxide: estuarine sources and atmospheric flux. *Estuarine Coastal and Shelf Science* 35, 301-314.
- Peterson, C.G.J., Jensen, P.B., 1911. Havets bonitering. □. Habundens dyreliv, dets næring og mængde. Beretning til Landbrugsministeriet fra Den danske biologiske Station 20, 1-78.
- Riddle, M.J., 1989. Bite profiles of some benthic grab samplers. *Estuarine Coastal and Shelf Science* 29, 285-292.
- Toshihiro U., Isao K., Norio O., 1998. Vertical profiles of nitrous oxide and dissolved oxygen in marine sediments. *Marine Chemistry* 59, 253-270.
- Xu Z., 2003. Marine environment of Zhujiang River estuary and its integrated treatment issues. *Journal of tropical oceanography* 22, 88-93.

**Figure captions:**

Fig 1. The structure of a Single Tube Gravity Corer (a. head blade, b. lead ring, c. eared screw, d. rope, e. coring tube, f. lead weight, g. main assembled board, h. rubber ring, I. valve ball, j. hole for water flowing, k. valve body, l. screw, m. fixing board, n. rope, o. pull ring and p. handle.)

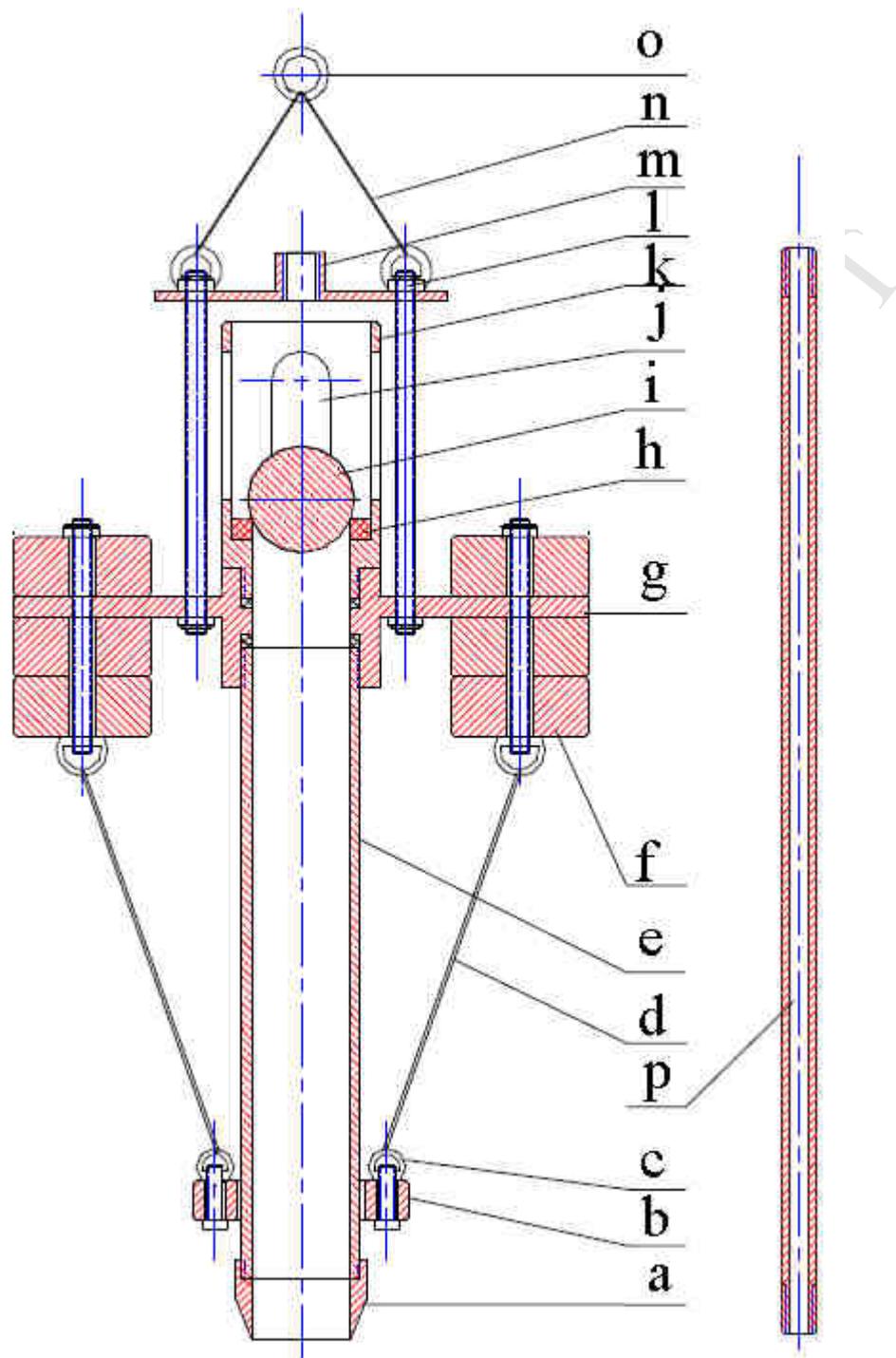
Fig 2. Photograph of a Single Tube Gravity Corer, tube inner diameter: 50mm, length: 1m and wall thickness 5mm (perspex) or 1.5mm (polycarbonate)

Fig 3. The structure of a Gravity Multiple Corer for three tubes (A. head blade, B lead weight. C. lead weight bracket,, D. rope, E. coring tube, F. support frame, G. valve body, H. valve ball, I. hole for water flowing J. rope, K. pull ring L screw joint and M. flat bar.)

Fig 4. Photograph of a Gravity Tube Multiple Corer, coring tube's dimensions are same as Fig 2

Fig 5. Sketch map of Hydraulic Pressure Multiple Corer (1. coring tube, 2. supporting frame, and 3. hydraulic pressure device)

Fig 6. The location of sampling sites



**New Series of Corers for Taking Undisturbed Vertical Samples of Soft Bottom Sediments**

- ◆ New single and multiple tubes gravity corers
- ◆ The simplest and cheapest equipment for Taking undisturbed sediment sample
- ◆ Successfully used to take undisturbed sediment sample in Zhujiang River

ACCEPTED MANUSCRIPT

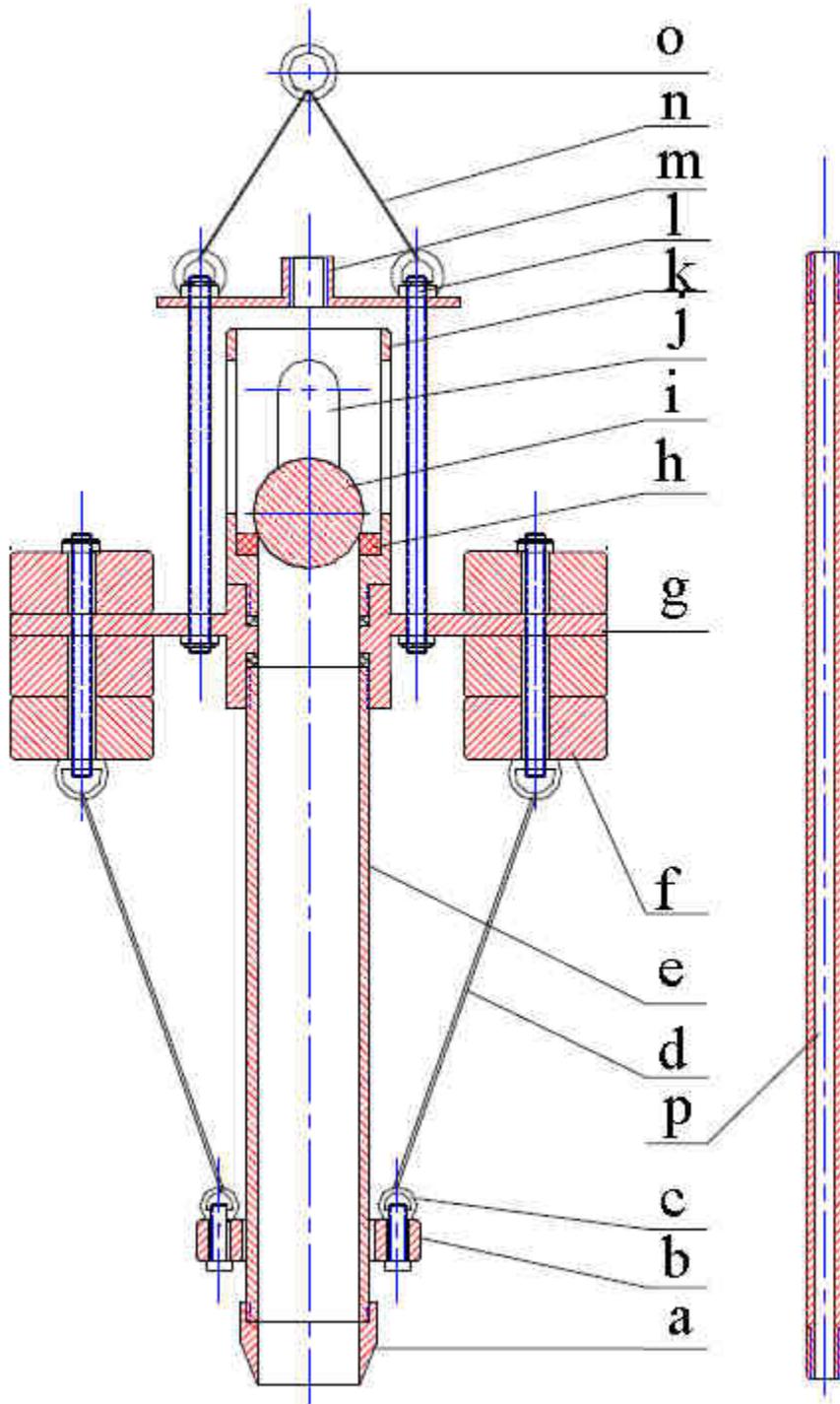


Fig 1



**Fig2**

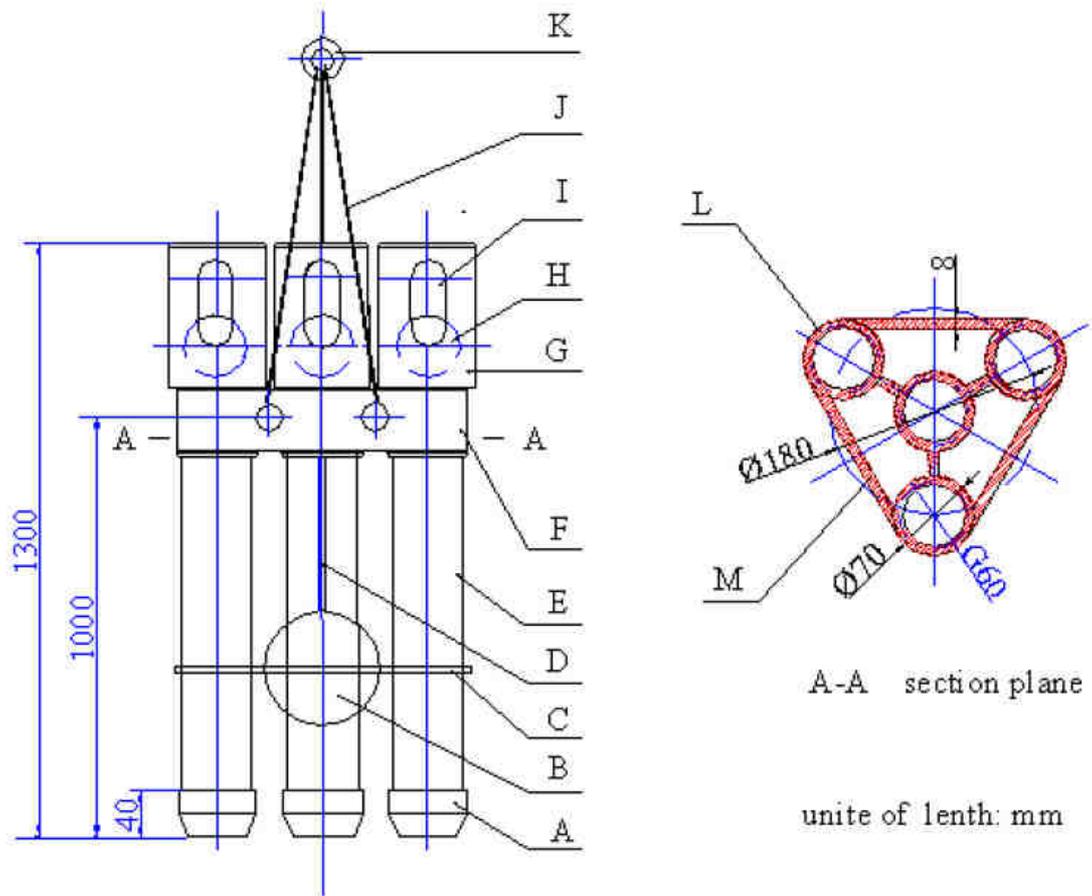


Fig3



**Fig 4**

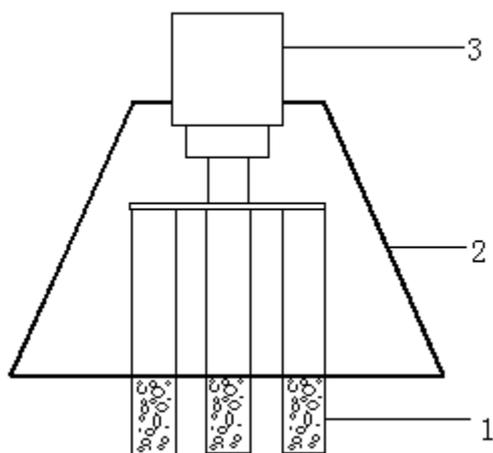


Fig 5

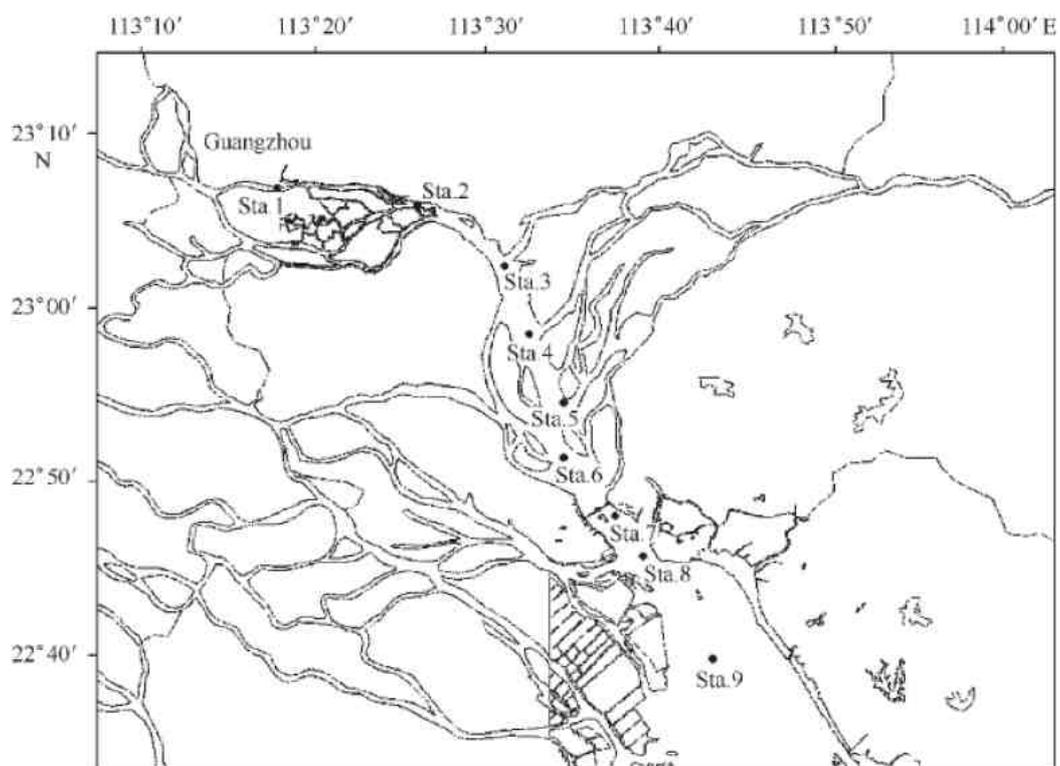


Fig 6