Model device for bedrock erosion under high velocity open channel flows

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Abstract. Laboratory experiment is an effective method to reveal the mechanism of bedrock erosion. In this study, a model device for bedrock erosion under high velocity flow conditions is presented. The model device is mainly composed of a high water head tank, a tilting flume, and a water circulating system. It is able to continuously operate at constant flow conditions for extended periods of time, and it has the advantages of simple structure and convenient for model testing.

1. Introduction
The problem of bedrock erosion has always been an unsolved problem in the water conservancy project. Its influence factors are numerous, and its physical process is complex. It involves many disciplines, such as fluid mechanics, solid mechanics, rock mechanics and engineering hydrogeology. The scour of the unlined open channel and the scour of the spillway and the flood discharge hole are all involved with the bedrock erosion. During the last decade, there has been a rapid advancement in the development of models of mountain landscape evolution, but the analysis in view of the problems are not the same, the method also has such defects and limitations, there is still not a mature theoretical analysis method and unified modeling method, and the research on bedrock erosion is still in the exploratory stage [1–6].

Taking the upper reaches of Yangtze River for example, many alluvial rivers are characterized by the presence and exposure of soft bedrock that consists of mainly mudstone and sandstone with relatively lower compressive strengths. During flood season, the floods have become more and more frequent. These floods significantly erode the exposed soft bedrock and lead to damage to bridge pier foundations, diversion structures, and other infrastructure. Evaluation of bedrock erosion rate requires quantification of bedrock characteristics, together with hydraulic processes. Key geomorphic controls, such as rates of river incision or hillslope erosion, are often unknown, as valid data describing the relationships between rates of bedrock erosion and hydraulic processes are not sufficient. The engineers do not have clear formula and theory for lining of diversion bedrock. The evaluation of hedge brush is still mainly based on personal experience and engineering analogy. Due to the lack of research in this area, some of the good rock conditions, wastes a lot of manpower, material and financial resources to make reinforcement, but fails to achieve good engineering results. On the other
hand, if the bedrock does have the possibility of severe scour, it may lead to safety accidents during the construction period and threaten the safety of people's life and property.

Generally, the main mechanisms responsible for bedrock erosion including hydraulic scour (plucking of rock fragments by fluid shear stress or differential fluid pressure) and abrasive scour (interaction between rock and moving sediment particles) [7-10]. It is possible that hydraulic scour may dominate on one reach [11-13], whereas abrasive scour may dominate on another [14]. Alternatively, both mechanisms may operate concurrently to erode the bedrock on some rivers. A discussion of how to qualitatively identify the erosion mechanisms operating on a reach was presented by Whipple et al. (2000) [15]. A review was also provided by Lai and Greimann (2009) [16]. However, it is cautioned that the mechanisms are interrelated. Hydraulic scour can occur without the assistance of sediment particles but is influenced by sediments through particle-rock collision and sediment deposition. Similarly, abrasive scour is also strongly linked to hydraulic flow characteristics such as shear stress and turbulence.

In this study, only the hydraulic scour is considered, the purpose of model device is to solve the difficulties encountered in open channel hydraulic bedrock erosion test. The model device can realize constant high speed flow conditions for extended periods of time, and it has the advantages of simple structure and convenient for testing, it will provide effective technical support for the research of bedrock erosion.

2. Model device composition
The model test device comprises a storage tank, water tank, water pump, tilting flume and the return tank, the water inlet of the water storage tank and the water outlet is communicated with the return tank through a return pipe, wherein the water tank is arranged on the upper part of the water storage tank, the water inlet of the water tank is communicated with the water storage tank through a water inlet pipe, water pump is arranged on the water inlet pipe (figure 1). The outlet of water tank is communicated with the tilting flume by a declinational outlet pipe, in the declinational pipe is provided with an arc regulating water flow outlet door. The end of the tilting flume is leading to the return tank, the test section of the tilting flume is arranged with water flow velocity measuring device.

![Figure 1. Illustration of the model device used to conduct bedrock erosion experiments.](image)

The tilting flume is made by Plexiglas, and the bed slope of the test section can be adjusted from 0.001 to 0.04 according to the experimental requirements. In order to relate experimental studies to field conditions, as we propose to do, the upstream of this flume is equipped with a high head water
tank, by which high velocity open channel flows with a maximum value of 6.0 m/s can be generated. In the test section of the flume, there is a notch designed to fix bedrock samples (figure 2). Before each run, a bedrock sample is inserted into the notch, flush with the surface. It is noted that the shape of the notch can be selected from a cylinder or a rectangular shape according to the shape of the sample. The magnitude of erosion was determined by weighing the erodible sample block before and after the experiment and obtaining the mass loss.

![Figure 2. Illustration of the notch used to fix bedrock samples.](image)

### 3. Advantages of the model device

Because of the inherent difficulty of measuring bedrock erosion and relatively shear stresses in the field, laboratory experiment is certainly an effective method. Sklar and Dietrich (2001) developed an experimental bedrock abrasion mill designed to replicate the small-scale interaction of coarse bed load with the rock floor of an actively incising river channel [17]. Hsu et al. (2008) placed granular material in a 56-cm-diameter rotating drum to explore the relationship between erosion of a synthetic bedrock sample and variables such as grain size, shear rate, water content, and bed strength [14]. These valuable experiments have helped motivate the present work while limited to: one-dimensional, average inertial stress values for the case of single grain size flows. Chatanantavet and Parker (2008) conducted experiments in a tilting flume which is more tally with the actual field conditions, yet the employed bedrock sample was not natural but was fabricated using a mixture of sand, cement, and vermiculite [18]. More importantly, previous experiments basically focused on abrasive scour [19], while clear water flows with sufficiently high speed would also bring severe bedrock erosion process in natural settings.

The model device in this study is provided with a water circulating system, and in the upper part of the water circulation system there is a water tank, by pumping the water to the height of the water tank, and then flushing down from the water tank to tilting flume, resulting in a high speed flow, and water for the whole test process can be recycled.

The water level of the water tank of the model device can be adjusted freely, as the water tank is provided with two sets of cylinders arranged together. The bottom of the outer cylinder is connected with a water circulating system, and the top of the inner cylinder is provided with a water outlet, and the height can be adjusted freely. Through the cylinder to adjust the water tank, the water flow rate of different level is also different. The water level can be adjusted according to the need of velocity speed.
in the experiment. Further, the model device has an arc baffle door in the position of the water outlet pipe of the water tank, which can control the water level at the outlet of the water outlet, and can adjust the flow speed of the outlet pipe conveniently.

The test section of the tilting flume is equipped with flow velocity measuring device and camera system, by which the flow velocity can be measured and the erosion process can be recorded, and can provide more experimental material for the entire test. Besides, there is a notch designed to fix bedrock samples. Before each run, a bedrock sample is inserted into the notch, flush with the surface. The magnitude of erosion was determined by weighing the erodible sample block before and after the experiment and obtaining the mass loss.

Characteristics of the model device are summarized in table 1. We conducted 18 runs of erosion experiments at Changjiang River Scientific Research Institute in which we varied hydraulic condition and bedrock strength, prototype bedrock including mud-rock and sand-rock from the upper reaches of Yangtze River are employed as testing samples, and detailed measurements of the high speed flow and bedrock erosion processes are conducted [20]. Generally, the model device has the advantages of simple structure and convenient for testing, and can carry out various erosion tests for bedrock under the condition of open channel and high-speed flow.

| Table 1. Characteristics of the model device. |
|-----------------------------------------------|
| Bed slope | Flow speed | Testing sample | Constant flow duration |
| can be adjusted from 0.001 to 0.04 | with a maximum value of 6.0 m/s | prototype bedrock | normally not limited |

4. Conclusions

Bedrock erosion processes are believed to play important roles in the evolution of mountain river channels and their associated hydro-projects. In this study, a kind of bedrock erosion model device is presented to study the mechanism of bedrock erosion under high velocity flow conditions. The model device can realize constant high speed open channel flow conditions for extended periods of time, and provide effective technical support for the study of bedrock erosion with more accurate measurements.

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