Equilibrium in Civil Engineering from Ohio River to Dujiangyan: An Ohio Experience

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Summary

Equilibrium is defined in civil engineering, indeed in all engineering of mechanics and physics, if sum of forces and sum of moments are both equal to zero. However, equilibrium has been used in many areas, including the famous Nash Equilibrium in the non-cooperative game theory, which resulted in Nash's 1994 Nobel Prize in economics. Based on the author's research at Ohio University including projects from Ohio River in the United States to Dujiangyan in China, this presentation will discuss three varied equilibria, equilibrium of water resources, equilibrium of zebra mussels, and equilibrium of research and education at universities.

The equilibrium of water resources: Ohio River is not the largest tributary of Mississippi River, but it has a larger discharge than that of Mississippi River when they join at the confluence in Cario Illinois (Figure 1). Floods have been the most common problems in the Ohio River Basin. Indeed, the well-known Muskingum flood routing method was developed at the heart of the basin by the U. S. Army Corps of Engineers. While most of dams and reservoirs in the Ohio River Basin are constructed for flood control purposes, droughts do frequently occur in which the equilibrium concept will be discussed how to use existing flood-control reservoirs for drought management. Similarly, Minjiang River of Dujiangyan is not the largest tributary of Yangtze River in China, but its discharge is larger than that of Yangtze River at the confluence of Yibin (Figure 2). Dujiangyan has diverted flooding water for irrigation for over two thousand years. Unlike the Three Gorge Dam that is massive, Dujiangyan is naturally ordinary and looks like a miniature compared with famous hydraulic structures in the world. For those visitors who pay much attention to Erwang Temple, the temple in memory of Lee father and son, and other park scenery, they may not even notice the weir structures because they look like parts of nature. However, Dujiangyan is an engineering structure built 2,280 years ago and is still functionally in use today. Indeed, it worked in a similar way as conceived and constructed in 256 BC before any modern hydraulic theories were developed and established. Based on the most rigorous analyses, the existing functionalities of Dujiangyan are not only consistent with hydraulic theories taught in engineering classrooms of today, but also refined to the best. For instance, the Minjiang River above Dujiangyan is in an active earthquake zone and its bed slope does not become mild until Dujianyan (0.2% vs. 0.7% above). Hence, the selection of construction site may have been elaborated given no modern survey equipment then. The three most important elements of Dujiangyan are Yuzui Water Dividing (魚嘴分流), Baopingkou Water Inlet (寶瓶口取水口), and Feishayan Spillway (飛沙堰). First, Yuzui divides Minjiang River into Outer River and Inner River, the former wide and shallow and the latter narrow and deep. During the flooding season, 60% of water will flow through the outer river and 40% through the inner river while during the dry season, 60% of water will flow through the inner river and 40% through the outer river. Then, Baopingkou was constructed in the Inner River site to divert water to the Chengdo plain for the purpose of irrigation. Indeed, the irrigation area has been widened today through an increase of irrigation channels though the functionality is the same as it was. Finally, the Feishayan was constructed at the end of the inner river to discharge sediment using the centrifugal force of the curved inner river. The concept of taking advantage of

centrifugal force due to curved channel for solving the most common problems of sedimentation in dam construction is more than amazing even for today's standards.

The equilibrium of zebra mussels in the Ohio River Basin: zebra mussels, Dreissena polymorpha, came to the Great Lakes in 1986 or 1987, most likely in the ballast water of an ocean-going ship that came from Black Sea or Aral Sea, zebra mussels' native region (Figure 3). Adult mussels were spotted in 1988 in Lake St. Claire, near Detroit, Michigan. Zebra mussels live between three and five years and have four stages in their life cycle. They reproduce sexually and a female mussel can lay more than one million eggs per spawning event. Their eggs are fertilized by gametes in the water column become free-swimming larvae called veligers which swim and crawl on surfaces until a suitable substrate is found (Figure 4). Then, the veliger attaches itself to the substrate via byssal threads. The attachment strength depends upon the type and condition of the surface to which the veliger attaches. In the post-veliger stage, zebra mussels produce hard shells and a siphon for feeding. Mortality is 97% during the post-veliger state. Finally, as the mussels enter the adult stage, their feeding and adhesion mechanisms complete development and they close the life cycle by reproducing. To date, the spread and infestation of zebra mussels in North American waters have been nothing short of legendary. Zebra mussels have adapted readily to North American waters and now are endemic to not only the Great Lakes and St. Lawrence Seaway, but have spread through the upper and lower Mississippi, the Ohio River, the Arkansas River, the Tennessee River and the rivers and lakes of upstate New York. However, a biological equilibrium has been reached in the Ohio River Basin while infestation of zebra mussels continues.

The equilibrium of research and education at universites: Universities in the United States were originally established for the purpose of teaching and learning, but they have gradually evolved into research and sponsored funding. In research-oriented universities, research has become their major function and activity from which fundings of universities are derived. Indeed, universities have been classified into Research 1 (R1) and Research 2 (R2) institutions. R1 institutions are defined as those that have $50 million USD in research expenditure and grant 70 research doctorates. On the other hand, R2 institutions, if they graduate about 20 doctoral students each year and spend about $5 million a year on research activities. The author will present a research and educational project titled, Boat of Knowledge in the Science Classroom (BooKS), which was funded by the U.S. National Science Foundation through Ohio University from 2010 to 2018 (Figure 5). The project was aimed to enhance communication skills of science and engineering graduate students and provide high school teachers and students with opportunities working with graduate students on science and engineering research. Activities of the BooKS project range from on-boat water sampling and testing related to students' research projects along the Ohio River from Marietta to Gallipolis, to inquiry-based lesson plan development and virtual boat games and virtual lab bench demonstrations (Figure 6). In addition, the extension of BooKS project provided opportunities for graduate students to enhance developed lesson plans and reformat them into interactive lesson plan videos, https://sites.google.com/view/boatofknowledge (click logo to start). Further, the supplementary funding had provided participating students with opportunities working with their counterparts at Tsinghua university in Beijing, China with a hope to reach more balanced research and education.

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Figure 1. Ohio River Basin

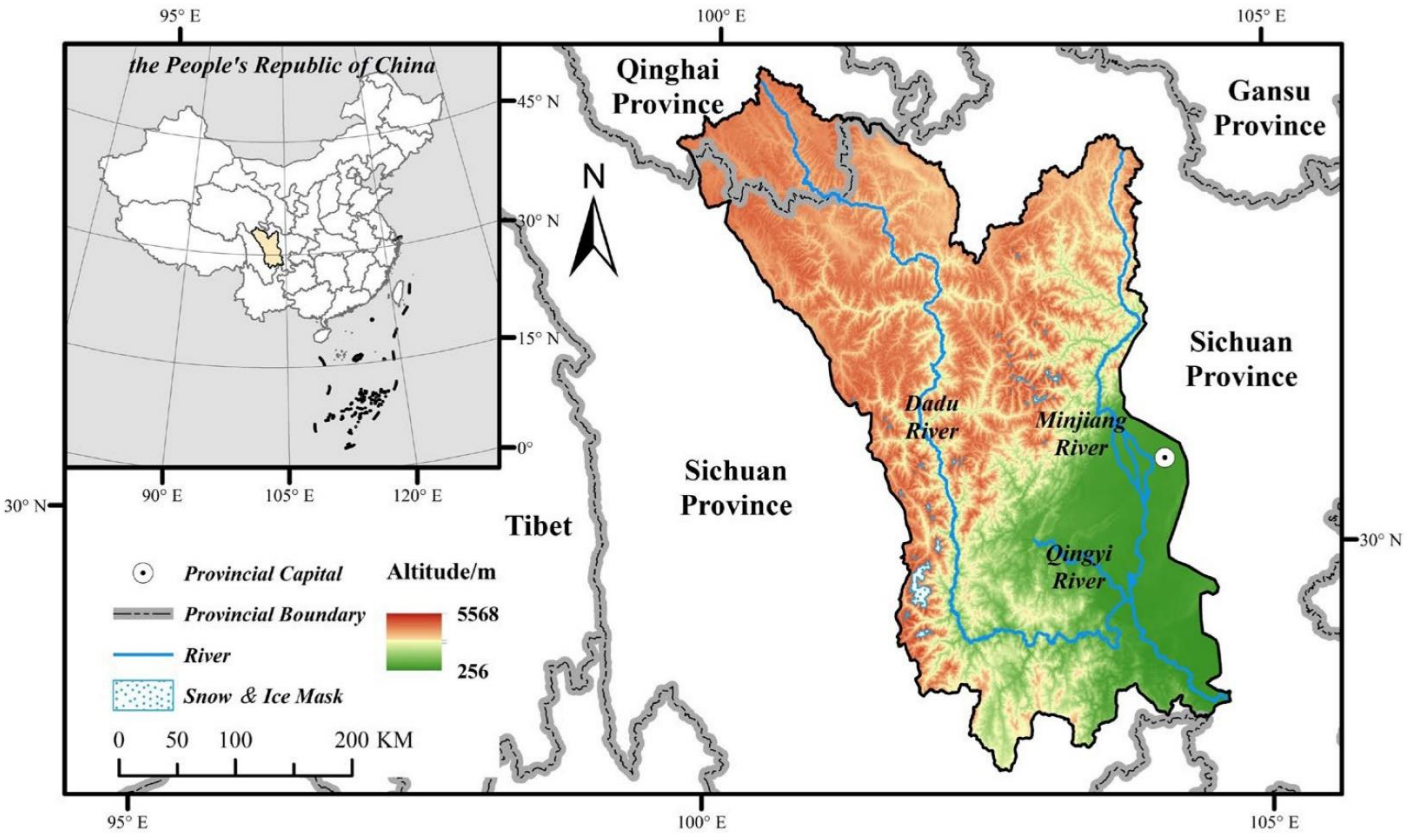

Figure 2. Minjiang River Basin

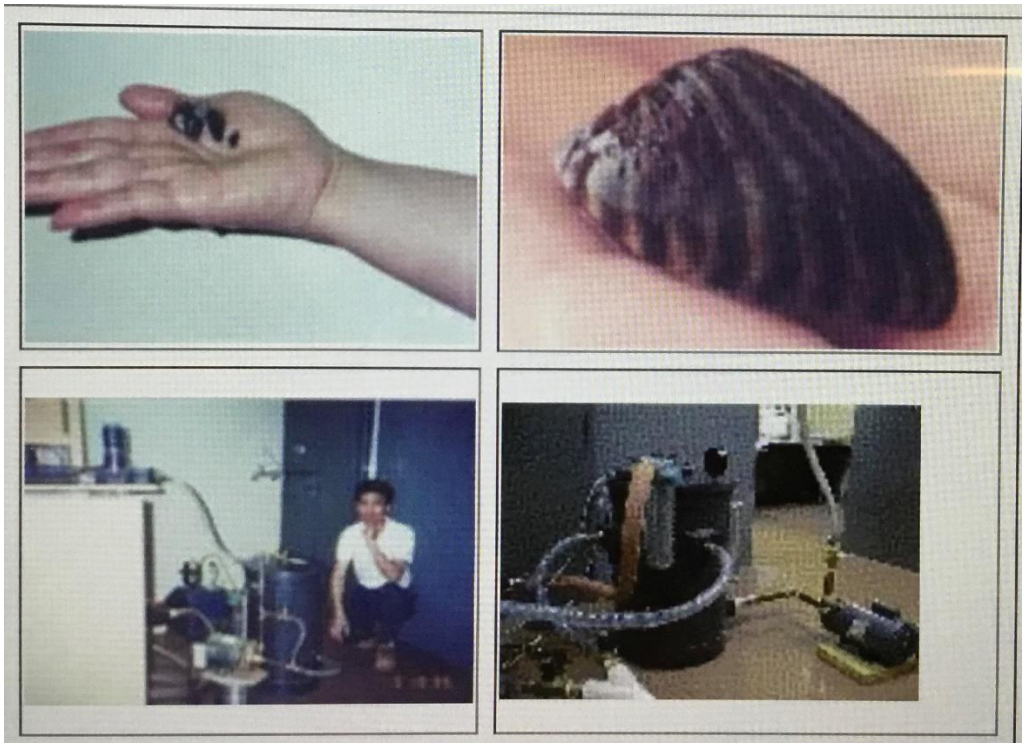

Figure 3. Zebra mussel research at Ohio University

Figure 4. Zebra mussel problems

Figure 5. BooKS project at Ohio University

Figure 6. Students participated in the BookS project at Ohio University