論 文 の 内 容 の 要 旨

論文題目　Laboratory and analytical study of surge-induced impact pressure on a vertical wall
(Surgeにより直立壁に作用する衝撃圧に関する水理実験及び解析的研究)

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Devastating impact pressure could be generated when water surge impinges onto a solid surface (a typical example is a vertical wall). As of now, engineers are using empirical formulas obtained from laboratory experiments to evaluate the surge-induced impact pressure. In laboratory studies, although it is a very difficult task to measure the velocity field near the wall, the impact pressure has been recorded by highly sensitive pressure sensors on the wall. However, in many of those studies, it has been repeatedly reported that the surge-induced impact pressure is a highly stochastic variable. Therefore, the existing deterministic empirical engineering formulas for the impact pressure obtained by different authors fail to agree with each other, and there is no stochastic model has been proposed as of now. Also, due to the lack of a sound theoretical physical foundation, these formulas involve different physical parameters from each other.

Numerical calculations on this issue have recently become popular with various sophisticated computational tools. Although some numerical models successfully provided detailed information of the velocity and pressure fields during surge impact events for small-scale cases, it is simply too time-consuming and expensive to conduct accurate calculations for large-scale problems. Also, the abrupt changes in the velocity field and free water surface during the impingement are not handled well by most computational models as of now, which is calling for a physical insight of the fluid motions at the first contact between surge and structure.

The number of analytic theories describing the surge impingement onto a vertical wall is surprisingly limited. The main reason is the difficulty in handling the sudden changes in the velocity field of water motions during the impingement process. This transient process usually involves singularities in its mathematical description, and thus different physical assumptions have been introduced to simplify the problem. However, some major assumptions in the past analytic studies yielded peculiar results at times, and few verification has been made for them. This situation prevented people from having a further insightful view of physics and may result in misunderstanding of the governing physical parameters of the impact pressure.

The main objective of the present study is to advance and renew people's knowledge on the physics of surge-induced impact pressure, including the governing equation, boundary conditions, initial conditions and its stochastic nature. This study improves the shortcomings, as introduced, in the existing literature. The following two issues are supportive of this main objective.

① This study clearly reveals the governing and trivial physical parameters of surge-induced impact pressure, providing a sound theoretical basis for laboratory and numerical studies.

② This study presents a pioneer work on quantifying the stochastic nature of the surge-induced impact pressure, proposing a specific extreme value distribution for it.

In the theoretical derivations of the analytic solution, the velocity field near the bed is directly obtained from the simplified vorticity transport equation. A self-similarity system without any representative length is proposed for the horizontal velocity component with clearly defined boundary conditions and initial conditions. Following the solution of the velocity field, the pressure field during the impingement is derived in an explicit form. Consequently, the impact pressure applied on the vertical wall could also be clearly calculated, and it converges to a specific finite value. Through this analytic investigation, the impactive process right after the first contact between surge and wall is reasonably interpreted, and the governing and trivial factors of the impact pressure are also revealed theoretically.

Carefully controlled laboratory experiments are conducted to reveal the stochastic nature of the impact pressure. The experiments are carried out in a small-scaled acrylic flume with a dam-break device and a vertical wall. The surges and the impact pressure generated in four different experimental cases are repeatedly recorded by a high-speed camera and pressure sensors near the corner where the vertical wall and the flume bottom meet. An extreme value distribution model, Fréchet distribution, is used to quantify the stochastic relationship between surge front velocity and impact pressure explicitly. On the other hand, the laboratory data agree with the conclusion on the governing factors made in the analytic solution. Moreover, the resulting predictive stochastic formula demonstrates a wide applicable range for actual engineering works.

Numerical verifications on the velocity and pressure fields during a surge impingement event are carried out with a CFD software, Flow-3D. The experimental cases in the laboratory works are reconducted numerically with different computational conditions. With the numerical results, the soundness of the analytic solution is verified. Also, the numerical results are shown to be consistent with the laboratory data.

With the analytic, laboratory experimental studies, and numerical verifications introduced above, the essential characteristics of the surge-induced impact pressure are studied comprehensively, renewing the achievements in the existing literature. The analytic solution proposed in the present study provides people an insightful view on the physics of surge impingement, describing the velocity and pressure field during the impingement and clearly indicating the governing factor of the impact pressure. On the other hand, the laboratory study suggests a way of predicting the impact pressure in actual engineering works, using a specific stochastic distribution.