Estimation of upward transmitting wave at the bedrock of Aratozawa dam base in the 2008 Iwate-Miyagi Nairiku Earthquake by using a soil-water coupled analysis

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A distinctive strong ground motion was observed at the rock base of the Aratozawa dam bottom in the 2008 Iwate-Miyagi Nairiku Earthquake (2008 IMNE)[1)]. The maximum acceleration reached to 1024 Gal at an inspection gallery on the rock base under the dam. The record over 1000 Gal at the bottom of dam foundation has never been observed before except this Aratozawa case record. On the other hand, the maximum acceleration observed at the mid height in the central core zone was only 535 Gal, and the maximum acceleration at the top of the dam was also only 525 Gal. In other words, amplification ratios sharply fell to almost point five below 1, which is again very much unusual experience. Hatano et al.[2)] evaluated the non-linearity of rock-fill dams and captured the decreasing phenomenon of amplification factors by using the equivalent linear elastic analysis and a sequential non-linear analysis with the modified R-O model.

As a matter of course, the above-mentioned strong ground motion over 1000 Gal recorded at the base of the dam must contain reflection waves from the surfaces of the dam. In addition, the reflection waves must be subjected to direct influence of the material non-linearity of the dam body and complex reflection and refraction phenomena that should occur in the dam. Therefore, recorded acceleration can never directly be regarded as an input upward transmitting wave at the bedrock. Shortly speaking, the distinction between E+F and E, at the bedrock, is very much important in the earthquake resistant design of structures, where E is the upward transmitting wave while F, the downward wave.

Based on this background, we tried to conduct numerical simulations to reproduce the properties of the above-mentioned records and to estimate the upward transmitting wave E, at the bedrock on the same point by using a soil-water coupled finite deformation code ***GEOASIA***[3)], which has been developed by the authors' research group. ***GEOASIA*** is a finite element code that integrates sequentially the rate type equation of motion in the time domain. The newly developed "combined loading elasto-plastic constitutive model[4)]" was first employed in this nonlinear dam analysis. The model can present combined loading state of SYS Cam-clay model and non-associated Drucker-Prager model. In addition, the estimation method of upward transmitting wave at the bedrock that was proposed by the autors[5)] is again adopted. This method utilizes the "viscous boundary", and using the observed ground motion (E+F) at the base during the earthquake as an input data of the analysis, the method first calculates all the responses of the structures like dams during and after the earthquake, and at the same time, the method estimates upward transmitting wave at the foundation base of the structures during the 'quake. In this calculation and/or estimation procedure, all the effects of material non-linearity and all the influences of multi-dimensional fluctuation propagation due to inhomogeneous geometry of the structures are totally taken into consideration.

The numerical simulation results displayed that while the responses with in the core and at the top of the dam increased compared with that on the bedrock in the case of middle and small earthquake, amplitude ratios of the same points fell below 1 when using the observed record in 2008 IMNE, as well as Hatano et al. This type of phenomena occurred due to the effect of hysteresis dumping of dam body materials. The estimated upward transmitting wave at the basement was around half of the record. The reason why the response on the bedrock increases nearly double (E+F is nearly equal to 2E) is that almost total reflection phenomenon occurs because dam body material exhibits degradation highly during cyclic loading.

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