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THE EFFECTS ON SHAPE-MODELING OF CONCRETE GRAVITY DAMS IN EARTHQUAKE RESPONSE ANALYSES

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To clarify the effects of seismic response of concrete gravity dams under large earthquake, finite element method (FEM) analyses were carried out. In analyses, the height of dam and material properties of concrete and basement rock are same. The 2-dimensional (2D) and the 3-dimensional (3D) FEM model were made and used in earthquake response analyses. The contraction joints between dam block are concerned in 3D non-linear FEM analysis. In the case of same height of dam, the numerical results of damage states and placements in dam are different between 2D FEM model and 3D FEM model, due to the effect of difference in vibration mode of dam. In the 2D FEM model, the damage of top in cross-section becomes remarkable. In the 3D FEM model, the damage of attachment between dam body and basement rock at high-elevation becomes remarkable. The damage of 3D FEM model is smaller than that of 2D FEM model for the same acceleration level of earthquake. The influence of seismic response on contraction joints of 3D non-linear FEM dam model is smaller, which is as same as that of 3D linear FEM dam model. From the above results, the 2D FEM model gives a conservative assessment compared to the 3D FEM model.

Keywords: Damage evaluation, Seismic performance, Performance verification.

1 INTRODUCTION

Proper maintenance and operation of hydropower facilities owned by electric power companies in japan are important in terms of provision for stable electric power supply and renewable energy utilization while the number of such facilities was constructed more than 50 years ago and the aging is progressing. In recent years, changes which appear in environments surrounding forests along rivers and reservoirs are remarkable, and the preservation of facility environments including sediment management becomes important subject. In addition, the number and scale of natural disasters such as big earthquakes and rainfalls severely affects hydropower operations. At the point of safety and accountability, confirmations of seismic performance of dams were requested for the society.

There are about three hundred dams owned by electric power companies in japan, in them almost are concrete gravity dams, about two hundred and fifty. To clarify and confirm of seismic performance of concrete gravity dams were important. In this study, several seismic analyses of concrete gravity dams were calculated to clarify the effect of numerical modeling of dam body, such as 2D cross-section and 3D whole body at the points of damage extension.

2 OUTLINE OF THE ANALYSIS

2.1 Method and Modeling in Analysis

The linear and non-linear seismic response analysis modeling dam, basement rock (foundation rock) and reservoir were carried out. The non-linear properties considered in analysis were cracks of concrete and basement rock, slip and slide on contact between dam and foundation rock, and contraction joints in dam. The analytical program "ABAQUS(ver.6.5-6)" was used in FEM analysis. There are two FEM models, one is 2D and the other is 3D. The 2D model is usually used in the case of basic design in Japan. The 3D model is the fine case. The cross section of dam in 2D and 3D model are same shape and size. The cross section and down stream face of model dam are shown in Figure 1.

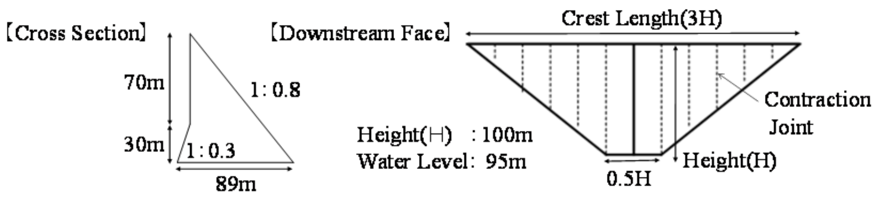

Figure 1. The cross section and down stream face of model dam.

The 2D and 3D FEM model in analysis are shown in Figure 2. The seismic wave of earthquake is loaded to stream direction in the bottom of FEM model. As boundary condition, the bottom is horizontal roller and vertical fixed and hole sides are horizontal roller in analysis.

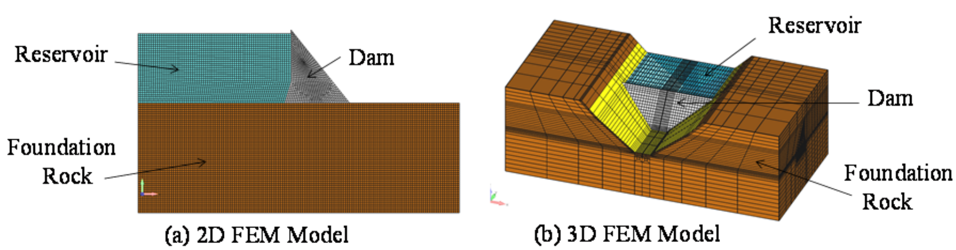

Figure 2. The 2D and 3D FEM model in analysis.

2.2 The Load Conditions and Material Properties

The static loads are self-weight, hydrostatic pressure, uplift, and siltation pressure. The uplift is triangular distribution according to water level (zero to one-third). Siltation level is 30% in dam's height. The dynamic loads are hydrodynamic pressure and seismic wave. Hydrodynamic pressure is calculated by fluid element and interface element of ABAQUS.

The material properties for seismic response analysis are shown in Table 1. The non-linear material properties of dam, foundation rock and boundary section of dam-foundation contact (contact zone) are shown in Figure 3. The damages were handled as non-linear failure model under tensile stress. The non-linear failure model of contact zone is referred to similar experiments (Nishiuchi 1995, Nishiuchi 2012) and numerical analysis (Nishiuchi and Sakata 2006).

Table 1. The material properties in analysis.

	Concrete	Foundation	Contact (dam–foundation)
Modulus of elasticity (N/mm^2)	2.5×10^4	1.5×10^4	2.5×10^4
Unit weight (ton/m^3)	2.3	2.6	2.3
Poisson ratio	0.2	0.2	0.2
Tensile strength (N/mm^2)	1.92	0.98	0.34
Damping ratio (%)	5	5	5

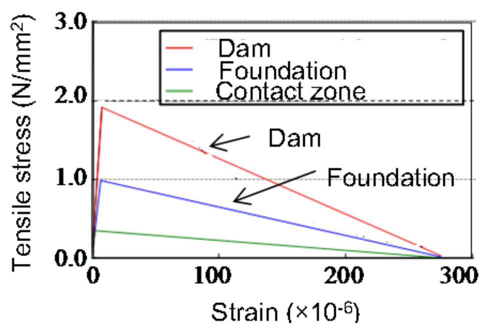

Figure 3. The non-linear fracture model on dam, foundation rock and dam-foundation contact.

The seismic wave was made, based on “Seismic performance verification guideline for dams under large earthquakes”, published in March 2005 from the Ministry of Land, Infrastructure and Transport in Japan. The earthquake ground motion was evaluated by “SHAKE” code, and the modified ground motion was applied in the stream direction at the artificial boundary of the foundation rock.

The maximum acceleration level of seismic wave prepared this Guideline was too small to damage this model dam. To give more damage and to clarify the scale effect of the earthquake ground motion, the maximum acceleration level of seismic wave was raised about two times larger than that of original seismic wave. The seismic wave used in analysis is shown in Figure 4.

The analysis number and places considered non-linearity are shown in Table 2.

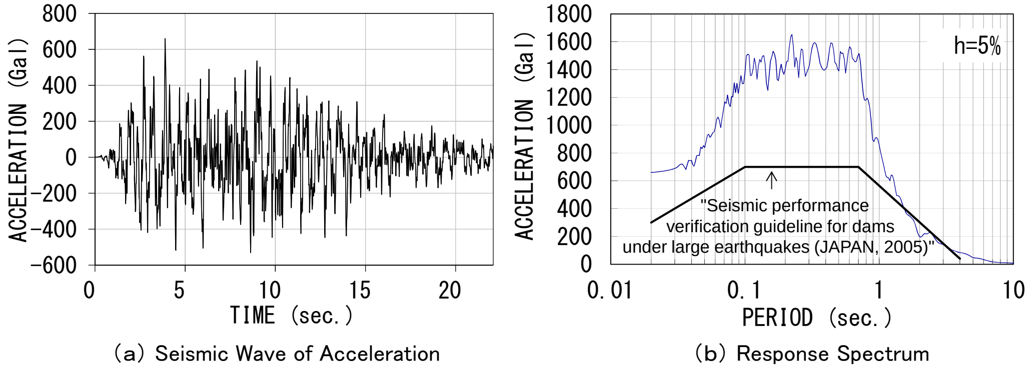

Figure 4. The seismic wave of earthquake used in analysis.

Table 2. The case number and places considered non-linearity.

No.	FEM model	Places of non-linear property
1	2-dimensional(2D) model	Non (Linear)
2		Dam, Dam-foundation contact
3		Dam, Dam-foundation contact, Foundation
4	3-dimensional(3D) model	Non (Linear)
5		Dam, Dam-foundation contact
6		Dam, Dam-foundation contact, Foundation
7		Contraction joints in dam

3 RESULTS OF SEISMIC RESPONSE ANALYSIS

3.1 Maximum Acceleration Response Ratio between Crest and Bottom in Dam

The maximum acceleration response ratio between dam crest (top) and bottom in cross section of dam are shown in Figure 5. The results of 2D analysis are shown in Figure 5(a) and that of 3D analysis are shown in Figure 5(b).

On the results of 2D analysis, the maximum acceleration response ratios at the dam crest of non-linear analysis are bigger than that of linear analysis, due to the effect of damage penetration at near dam crest. On the results of 3D analysis, as same as the results of 2D analysis, the maximum acceleration response ratios at the dam crest of non-linear analysis are bigger than that of linear analysis. The maximum acceleration response ratios at the dam crest in 2D analysis are bigger than that of 3D analysis, because of the effect of restriction from side and near foundation rocks.

On the results of 3D analysis, there is no effect of contraction joint because of non-linear behaviors at contraction joints are small. The non-linear behaviors at contraction joints are shown in Figure 6.

3.2 Progression of Seismic Damages in Dam and Foundation Rock

The progression of seismic damages in 2D non-linear analysis is shown in Figure 7.

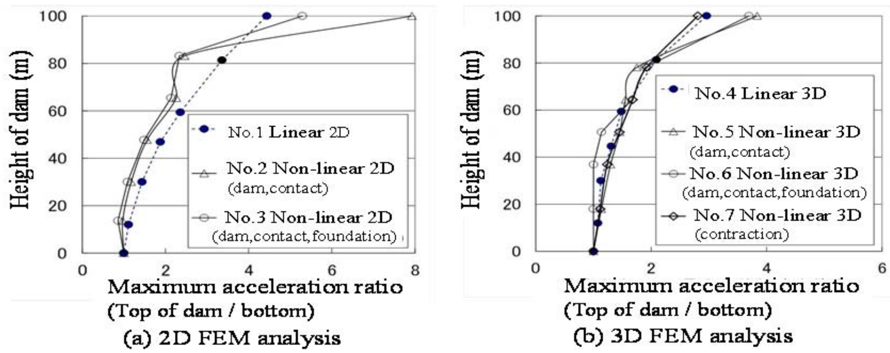

Figure 5. The maximum acceleration response ratio of cross section in analysis.

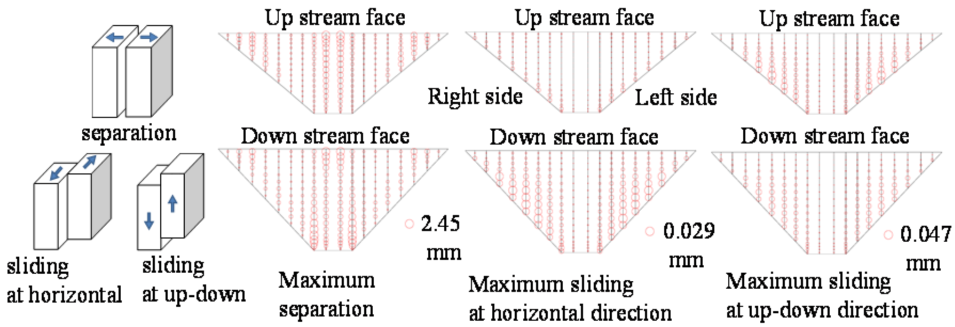

Figure 6. The non-linear behaviors at contraction joints in 3D analysis.

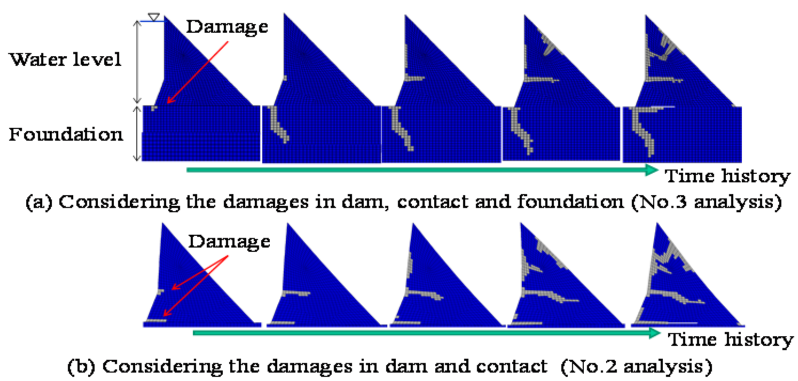

Figure 7. The progression of seismic damages in 2D non-linear analysis.

The first damage starts at the contact zone in upstream surface between dam and foundation rock. After that, the damages are progressing inner dam body, contact zone and foundation rock. Finally, the damage is penetrated from upstream to downstream direction at dam top. In the case of non-linear properties except foundation rock, the damages are more progressing inner dam body and contact zone, because of the restriction of non-damaged foundation rock.

The progression of seismic damages in 3D non-linear analysis except modeling contraction joints are shown in Figure 8.

As same as the results of 2D dam model, the first damage starts at the contact zone in upstream surface between dam and foundation rock. After that, the damages are progressing inner foundation rock and contact zone. There is no damage inner dam body. Finally, the damage is penetrated from upstream to downstream direction at contact zone and surface of foundation rock.

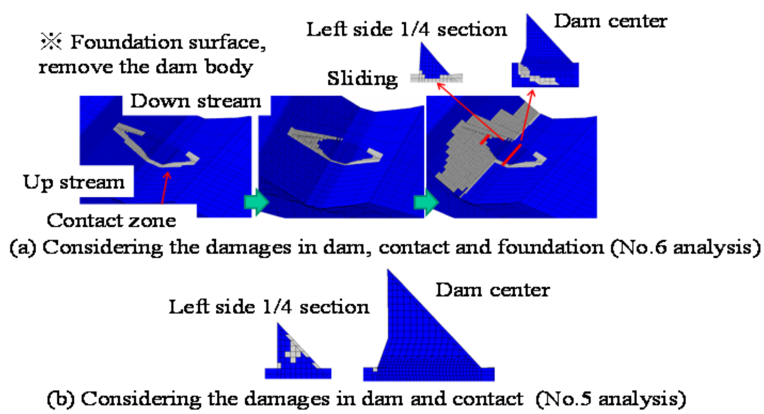

Figure 8. The progression of seismic damages in 3D non-linear analysis.

4 CONCLUSION

The seismic response and damage of the concrete gravity dams were clarified with 2-dimensional and 3-dimensional seismic response analyses which supposed the damages of the dam body and the foundation rock etc.

Based on the analyses results, seismic response of 2-dimensional dam model is bigger than that of 3-dimensional dam model, and seismic damage area of 2-dimensional dam model is wider than that of 3-dimensional dam model.

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