STATIC AND DYNAMIC CHARACTERISTICS OF ARCH DAMS CONSIDERING NONLINEAR BEHAVIOR OF TRANSVERSE JOINTS

T.Mazda & Y.Endo
Kumamoto University,Japan

N.Okuma
Kyushu Electric Power Co., INC. Japan

SUMMARY:
There was no serious damage on dams caused by large earthquakes in Japan, because, they had large safety margin at the time of the design, but the soundness of a dam to the large earthquake more than assumption isn't evaluate appropriately. Arch dam is three dimensional thin wall structure and its static and dynamic characteristics is affected by base rock and interaction of reserved water. Opening and shear slip are confirmed at transverse joints located during construction. The evaluation of nonlinear behaviour of transverse joints is very important in modelling of arch dam. Analysis model considering the nonlinear behaviour of transverse joints is prepared. Based on existing arch dam, three dimensional real scale models considering base rock is established. Eigenvalue analysis and normal condition analysis are conducted using this model. Static and dynamic characteristics of existing arch dam are made clear.

Keywords: arch dam, transverse joints, mode shape, static behavior

1. INTRODUCTION

The number of dams which were constructed more than a half century ago has been increasing in Japan. The concrete dams of our country are currently designed in the allowable stress design method based on seismic coefficient method. There was no serious damage on these dams caused by large earthquakes in the past in Japan because they had a large safety margin at the time of the design. But it is pointed out that the evaluation on the soundness of a dam against a larger earthquake than expected is not appropriate enough. At the time of construction of arch dam, transverse joints are prepared in the direction of a dam axis at intervals of 15 to 20m in order to prevent the crack accompanying cooling contraction. In a previous research, transverse joints have been confirmed to open and slip affected by temperature change and change of storage water level. (Okuma 2008, Okuma 2010) Therefore, the dam body design for securing the safety and economical efficiency is left to a designer considering the geographical feature and the geology of a dam site. Dams with various shapes are constructed as a result. However, how a shape of dam body affects the seismic performance of a dam is not fully studied. This research has two purposes. One is to clear how the transverse joints influence the static and dynamic response of the dam. The other is to clear how the difference of the shape of a dam body, symmetry or asymmetry, influences its stress state and dynamic response. In this research, the analysis model in consideration of the nonlinear characteristics of a transverse joint was prepared. And, the analysis models with asymmetry and symmetry were created based on existing arch dam in Japan. Eigenvalue analysis was carried out to the each analysis model, and dynamic characteristic of each dam were reviewed. General purpose computer code TDAPIII was used for analysis.

2. ANALYSIS MODEL

Photograph 2.1 shows target for analytical study Kamishiiba dam. Kamishiiba dam is located in

Kyushu region, south part of Japan, constructed by Kyushu Electric Power Company in 1955 (aged 55 years). The dam is the first full-fledged arch dam in Japan, with technological corporation of Overseas Consultants Inc., in USA. The technology obtained through the construction of Kamishiiba dam has greatly contributed to the design and construction of arch dams subsequently constructed in Japan.

Photograph 2.1 Kamishiiba dam

As shown in Figure 2.1, the height and crest length of the dam are 110m and 341m, and crest and base thicknesses are 7.0m and 27.0m, and the dam has four inspection catwalks. The water level varies from 435.00m to 480.00m above the sea level. Dam body and rock foundation were modeled by using 8-mode hexahedron element. Dam body was divided to two in longitudinal direction in between neighboring transverse joints and five in transversal direction. The effect of dynamic water pressure was considered as additional mass. Table 2.1 shows basic property of the dam for analysis. Two types of model were prepared as shown in Figure 2.2. One is asymmetry model considering existing dam, another is symmetry model considering right bank part of existing dam. Nonlinearity of transverse joint was modeled based on Coulomb failure criterion with reference to previous study.(Nishiuchi 2006) Stresses were released after failure in joint contact direction and joint sliding direction. Only compressive stress was transmitted. Figure 2.3 shows transverse joint model.

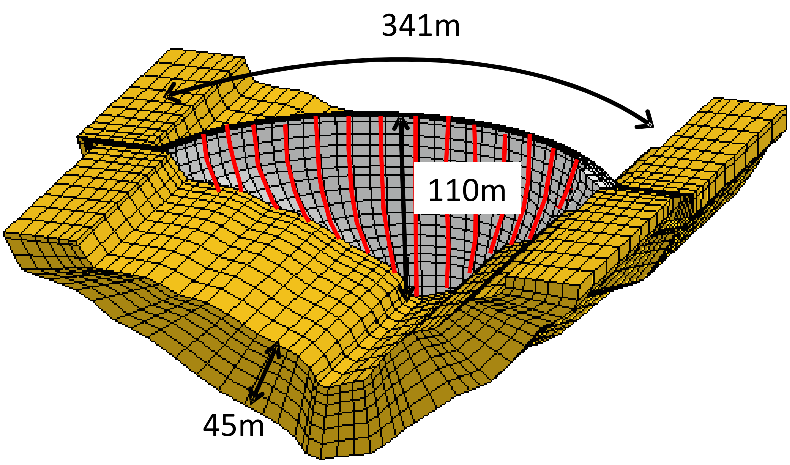
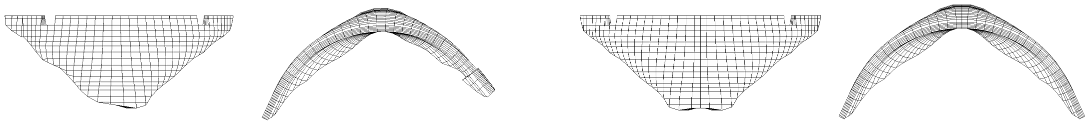


Figure 2.1 Analysis model

Table 2.1 Basic property

	Unit weight (kN/m^3)	Elastic Modulus (kN/mm^2)	Poisson's Ratio
Concrete	23.95	44.1	0.167
Transverse joint	23.95	8.83	0.167
Rock	25.50	19.6	0.200
Gate	1.71	0.44	0.167



(a) asymmetry model (b) symmetry model

Figure 2.2 Elevation view and top view

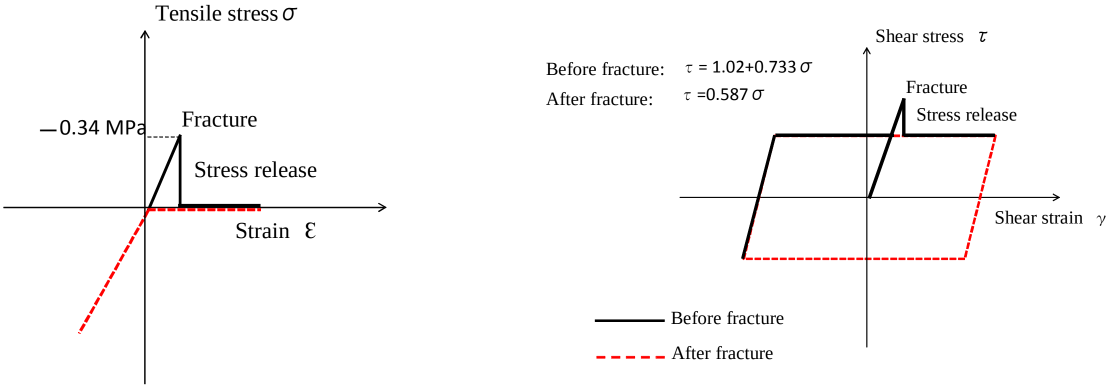
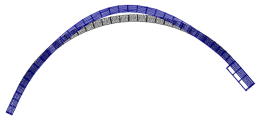


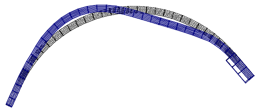
Figure 2.3 Model of transverse joint

3. EIGENVALUE ANALYSIS

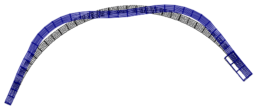
Eigenvalue analyses for two models with linear transverse joint were conducted. Condition of reserved water was the height of 100m. Figure 3.1 and Figure 3.2 show principal modes of asymmetry model and symmetry model with linear transverse model obtained from the result. Mode shapes of asymmetry model are relatively complicated than mode shapes of symmetry models shown in Figure 3.2. Symmetric modes were shown in second mode and third mode. And asymmetric modes were shown in first mode and fourth mode from Figure 3.2. It was confirmed from the result that vibration in longitudinal direction appeared in asymmetry model. Secondly eigenvalue analyses considering the nonlinearity of transverse joint based on the change of water level were conducted. The relationship between water level and 1st fundamental frequency of the dam is shown in Figure 3.3. It was confirmed that reduction of the frequency was derived from the nonlinearity of transverse joints depending on the change of the water level. The difference of the results between linear model and nonlinear model is relatively small in the cases of high water level. On the other hand, the dependency of the frequency on water level is very large in nonlinear model. The frequency of the dam decreases as the water level decreases. These phenomena are induced by the change of effective stiffness of the dam based on opening and slipping of transverse joints.



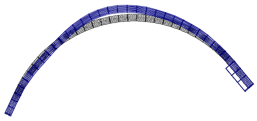
f_1=3.72Hz



f_2=3.88Hz

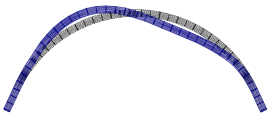


f_3=5.81Hz

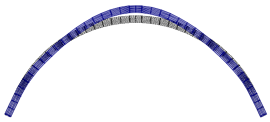


f_4=7.25Hz

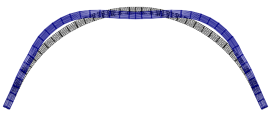
Figure 3.1 Fundamental frequency and mode of asymmetry model



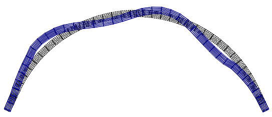
f_1=3.53Hz



f_2=3.59Hz



f_3=5.32Hz



f_4=6.68Hz

Figure 3.2 Fundamental frequency and mode of symmetry model

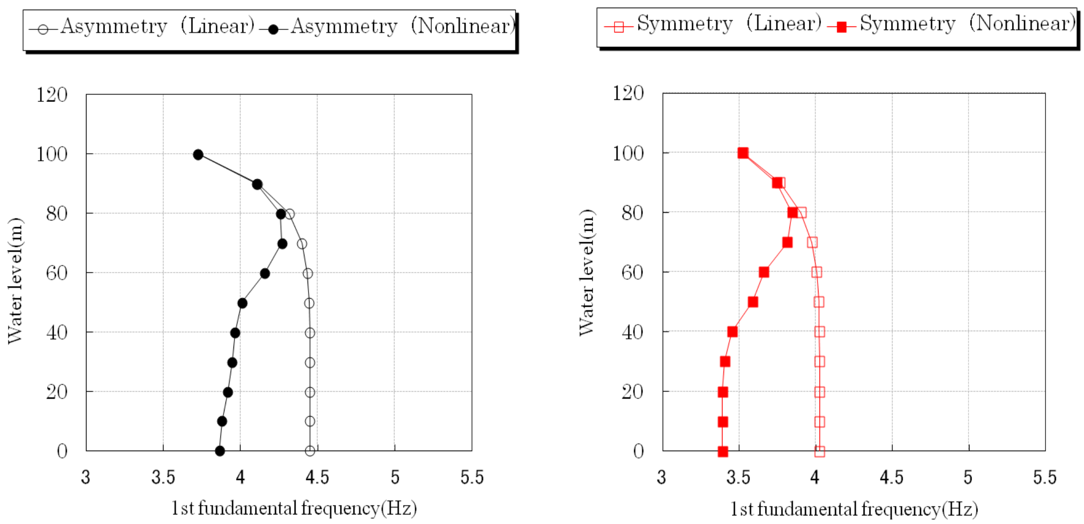


Figure 3.3 Relationship between water level and 1st fundamental frequency

4. NORMAL CONDITION ANALYSIS

Confirmation of normal condition of a dam is one of the important things in the evaluation of seismic behavior of the dam. Normal condition analysis was conducted using asymmetry model. Hydrostatic pressure, uplift pressure and dead load of the dam body were considered as static loads. Uplift pressure was assumed as triangle distribution. The pressure of upstream end of the dam is as same as hydrostatic pressure and the pressure of downstream end of the dam is zero. Reserved water level was varied from 0m to 100m. Figure 4.1 shows relationship between water level and displacement of dam body and Figure 4.2 shows Relationship between water level and displacement of dam top. The difference of the results between linear model and nonlinear model is relatively large in the cases of low water level. But the deformations of the dam body are almost same in the case of high water level.

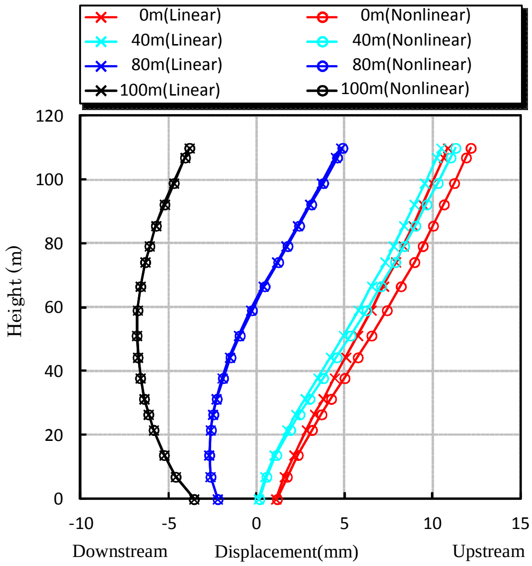


Figure 4.1 Relationship between water level and displacement of dam body

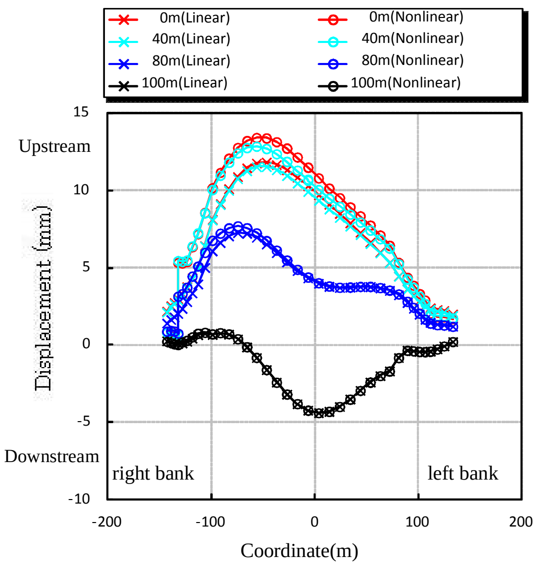
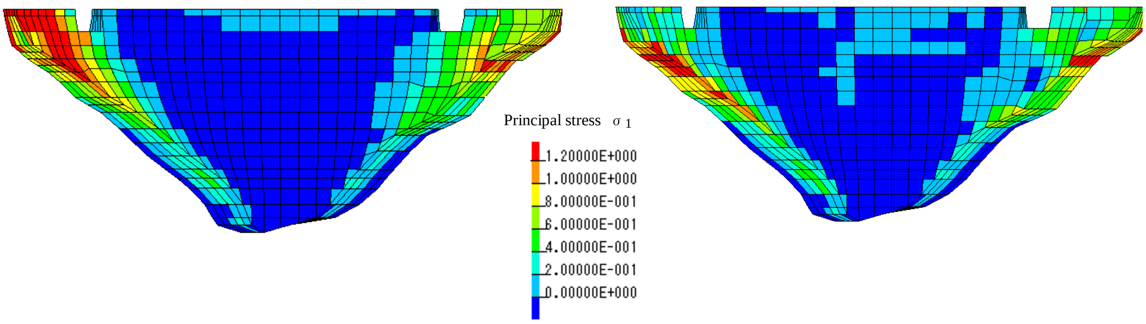
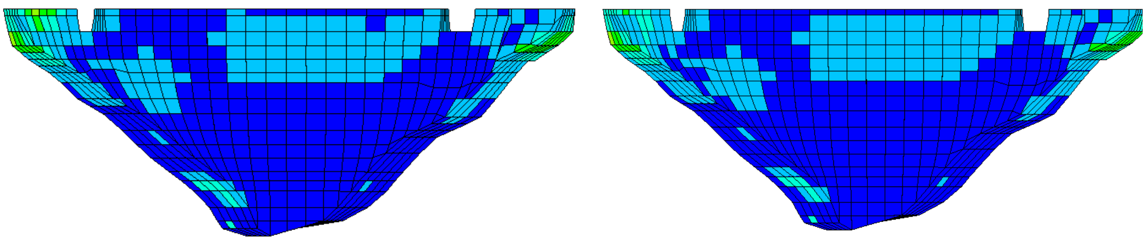


Figure 4.2 Relationship between water level and displacement of dam top

Comparison of maximum principal stress between linear model and nonlinear model are shown in Figure 4.3. From previous study, compressive strength of dam concrete is about 30MPa, tensile one is about 3~5MPa.(Hatano 1969) Maximum principal stress didn't exceed these allowable stresses. As same as former results, the difference of the stress is relatively large in the case of no water. This is caused by opening and slipping of transverse joint.



(a) No water (Linear) (b) No water (Nonlinear)



(c) High water level(Linear) (d) High water level(Nonlinear)

Figure 4.3 Maximum principal stress

5. CONCLUSION

From existing arch dam, two types of three dimensional analysis models were prepared. Eigenvalue analysis and normal condition analysis were conducted by using these models. Nonlinearity of transverse joints was modeled and evaluated. From obtained results, the relationship between water level and 1st fundamental frequency of the dam was made clear. It was confirmed that reduction of the frequency was derived from the nonlinearity of transverse joints depending on the change of the water level. In the case of high water, the effect of additional mass of water is dominant to fundamental frequency. On the other hand, the effect of nonlinearity of transverse joints is dominant to fundamental frequency in the case of low water. Based on normal condition analysis, dam body deforms to upstream in the case of no water and opening and slipping of transverse joints appear with reduction of arch effect in this case. Arch dam become stable by increase of arch effect in the case of high water. The effect of asymmetry of the dam body to static and dynamic behavior of the dam was not so large in this research.

REFERENCES

Okuma, N., Etou, Y., Kanazawa, K. and Hirata, K. (2008). Dynamic properties of a large arch dam after forty-four years of completion, *Proceedings of World Conference on Earthquake Engineering*, Paper No. 0173.

Okuma, N., Mazda,T. and Kanazawa, K.(2010). Structural Monitoring Test of Aged Large Arch Dams in High Seismicity Regions, *Proceedings of International Commission On Large Dams European Club Symposium 2010*, No.10671, 587-592

Nishiuchi, T. and Sakata, K. (2006). Investigation on static behavior of existing arch dams using finite element method considering nonlinear behavior of transverse joints (in Japanese). *Journal of Japan Society of Civil Engineering E*. **Vol.62:4**, 672-688

Hatano, T.(1969). Theory of failure of concrete and similar brittle solid on the basis of strain. *International Journal of Fractur.* **Vol.5:1**,73-99