International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075, Volume-8 Issue-6S, April 2019

Calculating Development of Cracks in Roller-Compacted Concrete Gravity Dams based on Self-Adaptive Finite Element Method in Ansys Software

Quang Hung Nguyen, Hoang Hung Vu, Thanh Duong Ha

Abstract: Using ANSYS mechanical APDL, the authors have developed a program to calculate formation of cracks and development of cracks in roller-compacted concrete gravity body dams based on self-adaptive finite element method with grid elements which are subjected to static and dynamic loading capacity. The reliability of the program has been validated through some experimental results found in the literature. Using the program, the authors have also carried out to calculate the crack development of Son La RCC dam under loading capacity combination of earthquakes. The results show some effects of the cracks development to the loading capacity of RCC dams.

Keywords—ANSYS-APDL, crack development, RCC dams, self-adaptive finite element, Son La dam.

I. INTRODUCTION

There are now many ways to simulate development process of cracks under effect of superimposed loading capacity or dynamic loading capacity. One of the first researches are mentioned, which is the research of Swartz et al.[1] executed in 1990. The calculation of cracks development by the self-adaptive finite element method of Swartz et al.[1] with the mesh of self-adaptive finite element method was not changed during the destructive process. Many studies on the development of this model applied the mesh of self-adaptive finite element method in the development process of cracks. At each step of superimposed loading capacity, the the mesh of self-adaptive finite element will be altered. After cracks in the integral point will be adjusted through the material properties to simulate cracking, the cracking method uses a distributed model that is not a discrete model. [2], [3]. Based on the APDL parametric programming language in ANSYS software (ANSYS Parametric Design Language), the author has developed a "RCCD_CRACK Calculation Program", its aims is to calculate the cracks formation, and develop the cracks in the body of dam with roller-compacted concrete gravity based on self-adaptive finite element method with the mesh of element that is influenced by dead loading capacity and dynamic loading capacity. From there, it is the basis for studying the effect of cracks on the dam' s loading capacity and the gravity of the roller-compacted concrete (RCC).

Revised Manuscript Received on December 22, 2018.
Quang Hung Nguyen, Thuy Loi, University, Hanoi, Vietnam.
Hoang Hung Vu, Thuy Loi University, Hanoi, Vietnam.
Thanh Duong Ha, Thuy Loi University, Hanoi, Vietnam.
.

II. THEORY

A. Basic equations

Dynamic equations for the FE regions of solid can be expressed in the incremental form as:

$$[M_d]\{\Delta\ddot{u}_d\}_n + [C_d]\{\Delta\dot{u}_d\}_n + [K_d]\{\Delta u_d\}_n = \{\Delta P_{df}\}_n + \{\Delta P_{dr}\}_n \qquad (1)$$

Where [M] and [K] are the mass and stiffness matrices; [C] is the Rayleigh damping matrix that is a linear combination of the mass and stiffness matrices; {ΔP} are the incremental vectors representing the dam-foundation, dam-reservoir, {Δu} are the incremental displacement vectors; the subscript n denotes a time step. In this study, Newmark β scheme is used to approximate the derivatives:

$$\begin{aligned}\{\Delta\ddot{u}\}_n &= \frac{1}{\beta\Delta t^2}\{\Delta u\}_n - \frac{1}{\beta\Delta t}\{\dot{u}\}_n - \frac{1}{2\beta}\{\ddot{u}\}_n \\ \{\Delta\dot{u}\}_n &= \frac{\delta}{\beta\Delta t}\{\Delta u\}_n - \frac{\delta}{\beta}\{\dot{u}\}_n - \frac{\delta-2\beta}{2\beta}\{\ddot{u}\}_n\Delta t\end{aligned} \qquad (2)$$

Where Δt is time interval, γ and β are integration parameters. Equation (1) can be solved by the Newmark β-method. According to this method, equation (1) is rewritten as:

$$\begin{aligned}&\left[\frac{1}{\beta\Delta t}[M_d]+\frac{\delta}{\beta\Delta t}[C_d]+[K_d]\right]\{\Delta u\}_n = [D_f]\{\Delta F\}_n + \\ &\left[\frac{1}{2\beta}[M_d]+\frac{\delta-2\beta}{2\beta}[C_d]\Delta t\right]\{\ddot{u}\}_n + \left[\frac{1}{\beta\Delta t}[M_d]+\frac{\delta}{\beta}[C_d]\right]\{\dot{u}\}_n\end{aligned} \qquad (3)$$

Where Δt is time interval, δ and β are integration parameters and the subscript t denotes a time step.

B. Smeared crack model of concrete

The nonlinear tensile behavior of concrete is represented by the smeared crack model [4]. The initiation and propagation of cracking are based on the strength criterion. The principal stress of an element is checked in terms of a bilinear failure criterion. If the failure criterion is met, cracking takes place over the element in the direction normal to the maximum principal stress. After cracking, the stiffness

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

of the concrete normal to the crack plane is reduced to zero and the concrete model becomes orthotropic. When the strain normal to the crack plane is less than zero, the crack is considered to become closing and the concrete recovers its original stiffness in the direction normal to crack plane without the tensile strength recovered. Any tensile stress normal to the closed crack will bring about reopening of the crack.

III. Programming the Calculation on Development of the Crack in the Body of Dams with Roller-Compacted Concrete Gravity by the Programming Language of APDL Parameter.

A. Structural simulation of the roller-compacted concrete dams

The highlight of ANSYS software is the ability to use the parametrization language to design the APDL (a type of FORTRAN programming language) that programmatically generates a general problem based on predefined parameters [5].

For the cross-sections of the dams with normal concrete gravity, these are classified into five material areas, and the ground is divided into horizontal geologic layers [6]. Depending on the specific problem to choose the corresponding size.

The stimulation of the dam 's structure in terms of stereometrical problem by finite element method consists of two types of elements:

- The element of dam's body is the SOLID65 block element, which simulates the material properties of the concrete.
- The foundation elements are SOLID45 block elements simulating the characteristics of foundation.

Simulating the dam's structure using adaptive mesh under finite element method, all input data is made through the user interface, which is very convenient and easy to test. [7-9]

B. Checking the reliability of the program

For the purpose of assessing the reliability of the "RCCD_CRACK Calculation Program" in the APDL programming language, the authors calculated the stress, deformation and fracture strength of the Koyna-India gravity dam with the conic cross section size. The Koyna gravity Dam is one of the few concrete dams in the world that was damaged during the earthquake. Historical acceleration - the time of the Koyna earthquake recorded in 1967 in the vertical and horizontal directions, shown in **Fig.** 2 [3]. Many studies in the world have performed computational and empirical simulations and experimental research on the destruction of the dam. A typical example is a recent research of Mridha S in 2014 [2].

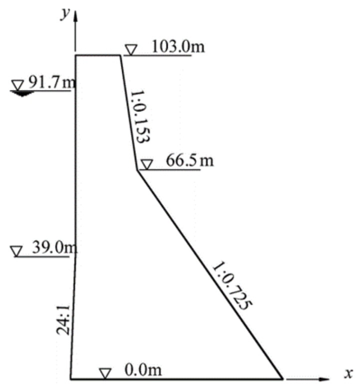


Fig. 1. Cross section of the Koyna dam – India

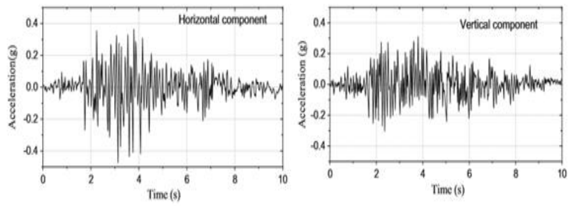


Fig. 2. Koyna earthquake in November 1967

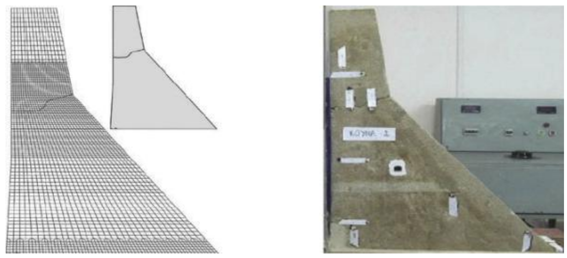


Fig. 3. Numerical simulation results on ABAQUS software and experiments

Fig. 3 shows the final crack of the Koyna dam under the influence of the earthquake in 1967, from a numerical simulation using ABAQUS software with unmodified particle mesh and experimental model with mechanical norms of concrete given in Table 1 [2]. The result of simulation and experiments are relatively uniform in terms of destructive forms.

Table 1. Physico-mechanical properties used in the calculation of the Koyna dam

Material	E (kN/m^2)	Poisson coefficient	ρ (T/m^3)	ft (kN/m^2)	fc (kN/m^2)
Concrete	3.1×10^7	0.2	2.643	2.9×10^3	24.1×10^3

When using the "RCCD_CRACK Calculation Program" in the APDL programming language to calculate stress states, deformation and crack development of Koyna gravity concrete dams with the above and below dimensions, and the effect of the accelerated earthquake has the final cracking effect as shown in Fig. 4. The results of fracture development calculations are

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

consistent with Mridha S's experimental study [2]. This is the basis for ensuring the reliability of "RCCD_CRACK Calculation Program".

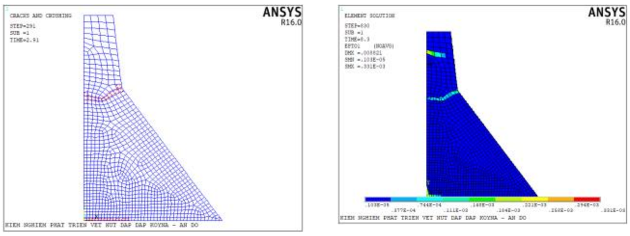


Fig. 4. Damaged area of Koyna Dam by RCCD_CRACK Calculation Program

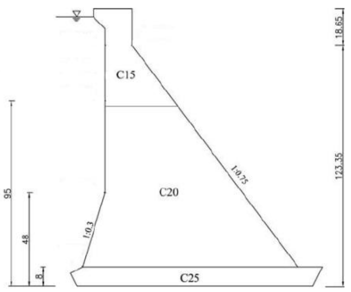


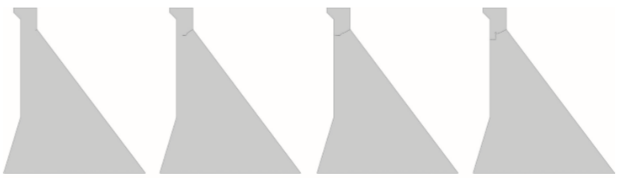
Fig. 5. Cross section of the Guandi Dam

Another example of destructive research on Guandi concrete gravity dam construction in China under the effect of the Koyna earthquake [3],[10]. The cross-sectional area of the Guandi dam is given in Fig.5 . The physicomechanical properties of the concrete are shown in Table 2.

Table 2. The physicomechanical properties used in Guandi dam calculation

Material	E (kN/m^2)	Poisson coefficient	ρ (T/m^3)	f_t (kN/m^2)	f_c (kN/m^2)
C15	5.6×10^7	0.167	2.552	1.453×10^3	14.53×10^3
C20	5.76×10^7	0.167	2.552	1.94×10^3	19.38×10^3
C25	5.88×10^7	0.167	2.552	2.15×10^3	21.45×10^3

In the results of Gaohui Wang's study, Wang et al [3] found that when the dam was affected by the earthquake, the first crack appeared at the lower section of the dam and developing the upstream. The next crack destroys from the upstream at the break into several sections site and develops the lower section of the dam, damaging the dam structure, see Fig. 6.



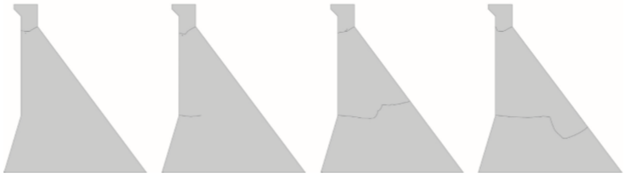


Fig. 6. The destruction of the Guandi Dam under the effect of Koyna earthquake [3]

The calculation of the Guandi dam use "RCCD_CRACK calculation" method, gave the results of displacement and stress before the dam was completely destroyed Fig.7 and Fig.8. The last damaging area in the dam was shown in Fig.9. This result is in line with the results of Gaohui Wang's research. Once again, we can confirm the reliability of the "RCCD_CRACK calculation program" set up by the author.

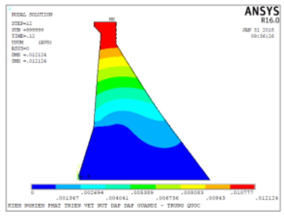


Fig. 7. Distribution of general displacements

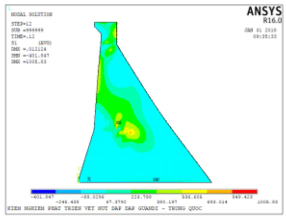


Fig. 8. Distribution of the main stress S1

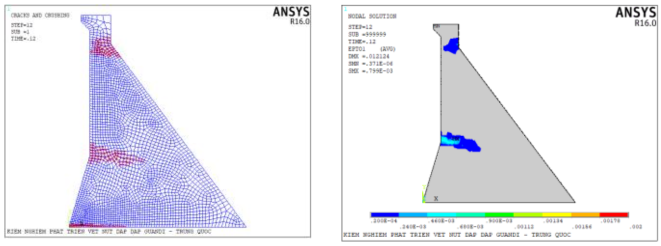


Fig. 9. Destructive area caused the crack of Guandi dam by the RCC_CRACK Program

IV. DESTRUCTION LEADING TO THE CRACK OF SON LA ROLLER-COMPACTED CONCRETE DAM

The Son La roller-compacted concrete dam is the tallest roller-compacted concrete gravity dam in Vietnam up to now. The dam is the 138.1m height, 105m width, the peak 's width of 10m. The physicomechanical properties of the materials are given in Table 3.

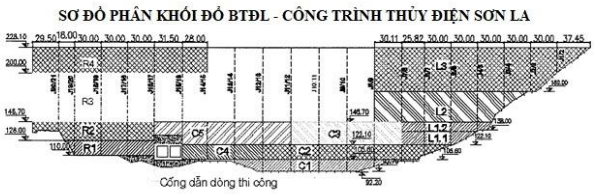


Fig.10 Diagram of dam construction block

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication

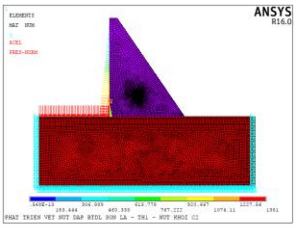


Fig. 11. Adaptive mesh of the Sơn La dam

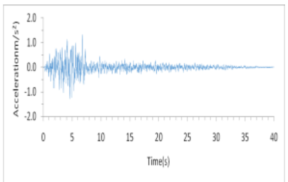


Fig. 12. Earthquake accelerator tape designed for SonLa dam

Table 3. The physicomechanical properties of the physicomechanical properties' materials

Material	E (kN/m^2)	N	ρ (T/m^3)	f_t (kN/m^2)	f_c (kN/m^2)	α	B
RCC	2.5×10^7	0.167	2,4	1.2×10^3	16.0×10^3	0.32	0.52

Using the "RCCD_CRACK calculation program" in order to calculate the crack development of Son La roller-compacted concrete dam under the effect of a special loading capacitying capacity combination of the earthquake. displacement at the top of the dam is shown in the Fig. 10 and Fig.11. The fracture behavior is shown in Fig. 12. The first crack appeared at the upstream of dam footing, then the upstream surface two thirds above the dam bottom and eventually developing lower section near the top of the dam. The dam is destroyed when the cracks cross from upstream to downstream (Fig. 13).

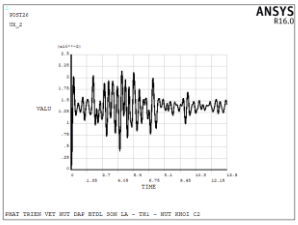


Fig. 10. horizontal displacement of the crest

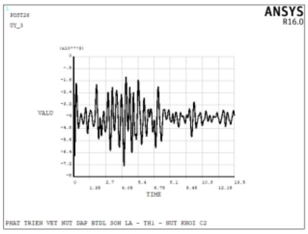


Fig. 11. displacement in the vertical direction of the crest

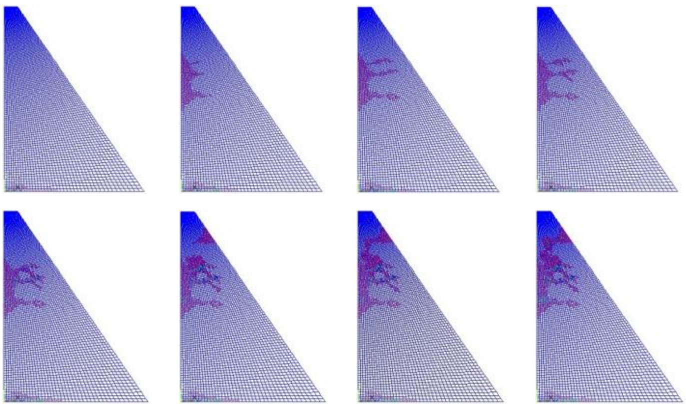
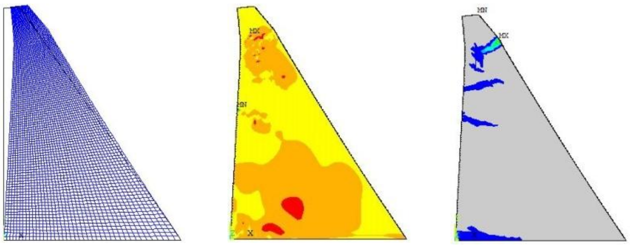


Fig. 12. The destructive process of Son La roller-compacted concrete dam under the effect of earthquake loading capacitying capacity.



(a) *(b)* *(c)*

Fig. 13. The result at the time, the roller-compacted concrete dam is completely destroyed

(a) Deformation of the element mesh; (b) The distribution of the main stress S1; (c) Destructive area

V. CONCLUSION

The author has set up a specialized program for calculating the deformation, stress, and cracking of the roller-compacted concrete dam, called RCCD_CRACK through using the parametric programming language (APDL). The input data is imported through the user's interface and the output is shown thanks to the ANSYS software functions, so it is very easy and convenient for the user without any difficulty.

On the basis of the roller-compacted concrete dam calculations using the RCCD_CRACK calculation program with APDL programming language in ANSYS software, it is enough reliability to calculate the crack development of the Son La roller-compacted concrete dam under the effect of earthquake loading capacity. The results show clearly the destructive process of the dam.

REFERENCES

1. S. E. Swartz and N. M. Taha, Mixed mode crack propagation and fracture in concrete, Eng. Fract. Mech., vol. 35, no. 1, pp. 137–144, (1990).
2. S. Mridha and D. Maity, Experimental investigation on nonlinear dynamic response of concrete gravity dam-reservoir system, Eng. Struct., vol. 80, pp. 289–297, (2014).
3. G. Wang, Y. Wang, W. Lu, C. Zhou, M. Chen, and P. Yan, XFEM based seismic potential failure mode analysis of concrete gravity dam–water–foundation systems through incremental dynamic analysis, Eng. Struct., vol. 98, pp. 81–94, (2015).
4. H. Zhang and T. Ohmachi, 2 dimensional analysis of seismic cracking in concrete gravity dams, J. Japan Soc. Dam Eng., vol. 8, no. 2, pp. 93–101, (1998).
5. ANSYS, Inc. Theory Reference. ANSYS Release 9.0[M]. Copyright 2004 SAS IP, Inc.
6. Nguyen Quang Hung, Nguyen Van Mao, Vu Hoang Hung. Calculation of gravity concrete dam and arch dam. Viet Nam Construction publishing House, (2014)
7. Zienkiewicz O.C., Zhu J.Z., A simple error estimator and adaptive procedure for practical engineering analysis, International Journal for Numerical Method in Engineering, 1987, 24(2): 337-357
8. Zienkiewicz O.C., Zhu J.Z., The superconvergent patch recovery and a posteriori error estimates. Part 1: The recovery technique, International Journal for Numerical Method in Engineering, 1992, 33(7): 1331-1364
9. Zienkiewicz O.C., Zhu J.Z., The superconvergent patch recovery and a posteriori error estimates. Part 2: Error estimates and adaptvity, International Journal for Numerical Method in Engineering, 1992, 33(7): 1365-1382

10. Gaohui Wang, Yongxiang Wang, Wenbo Lu, Mao Yu, Chao Wang, Deterministic 3D seismic damage analysis of Guandi concrete gravity dam: A case study, Engineering Structures, Vol 148, 2017, 263~276.

AUTHORS PROFILE

Quang Hung Nguyen was born in 1975 in Hanoi, Viet Nam. He received the Engineering's degree and M.S. degrees in hydraulic construction from the Thuyloi University of Vietnam, in 1997 and 2000 and the PhD. degree in hydraulic structure from Wuhan University, China. Since 1998, he is a lecture in Faculty of Civil Engineering, Thuyloi University and becomes Associate Professor since 2009. From 2007 to 2013, he was Deputy Director of the Institute of Civil Engineering, designed and built many key projects of Vietnam. He is also principal investigator and member of many national science projects as well as Vietnam Ministry of Agriculture and Rural Development. Since 2013, he has been a senior expert in hydraulic construction of Vietnam Ministry of Construction. He is the Advisor of more than 200 bachelors, 40 masters, 2 PhD specialized in hydraulic construction.

Hoang Hung Vu was born in 1978 in Hanoi, graduated from Thuy Loi University, received a Doctorate in Marine Structure Engineering from Hohai University - China, Associate Professor of Thuy Loi University. He teaches hydraulic structures, chairs and participates in many scientific research projects at all levels, verifies many large hydropower projects. Main areas of research are simulation of structure and safety of large concrete dam structures, earthquakes and heat effects on water works, large span valve gates

Thanh Duong Ha was born in 1979 in BacNinh, graduated from Thuy Loi University. He is a PhD student in ThuyLoi University. His research focus on hydraulic contruction

Published By:
Blue Eyes Intelligence Engineering
& Sciences Publication