FINITE ELEMENT SOLUTION OF DIM DAM UNDER STATIC LOADING USING DUNCAN CHANG MODELLING

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Abstract: Concrete faced rockfill dams (CFRD) are modern dam types have been started constracting worldwide after invention and usage of vibratory rollers for the rockfill construction which caused so much decrease post construction settlements of the dams comparing to the dumped rockfill dams. Cethana dam in Austraila is the first high dam among these type dams. Dim dam in Alanya having a 135 m height from foundation level is the first designed concrete faced rockfill dam in Turkey (designed between 1993 and 1994). However, Kürtün dam is the first CFRD dam wherein its construction completed before Dim dam. CFRD provides economy and minimizes costs due to its steeper rockfill slopes which leads a decrease in embankment volume and shorten derivation and spillway structure lengths. In general, post construction crest settlements of such type dams should be less than 20 cm for the behavior of stress-strain of the concrete face. Design and construction criteriums of those type dams are also quite different than the conventional clay core rockfill or earthfill dams.
In this study, to provide an example for dam designers, stresses and deformations of 135 m heigh Dim Dam located in Turkey is modelled by Duncan Chang and analyzed by FEM using program ANSYS WB. Then, amount of crest settlements are obtained. As a result, it is illustrated that all deformations found from this study are within acceptable amounts for this type dams.
Keywords: Alanya Dim Dam (Turkey), Concrete faced rockfill dams, Duncan Chang hyperbolic model, ANSYS, finite element.

Introduction

Concrete faced rockfilled dams (CFRD) is being built since mid-19th century. Cooke (1984), divided evolution of dams in to three stage which are early period, growing period and modern period. Heights of the CFRD, which were constructed in early and growing period, reach up to 75 m and 110 m. With developing construction techniques and increasing performance of CFRD, taller CFRD are constructed such as Shuibuya Dam (223 m) China. In the design phase of CFRD, empirical methods are used generally. Deformations, which will occur on the crest and concrete slab, are calculated from some formulas get by analyzing performance of early constructed dams.

Estimating behavior of dams in the design stage has a great importance due to safe and economic design. Therefore numerical model using for design should be compatible for real structure. Finite Element Method is the most common technique for numerical modeling of structures.The most important factor for simulating the behavior of dam body, three axial stress parameters of fill materials should be considered. Experimental data for CFRD are not available sometimes because size of rock fill materials can reach 120 cm and testing of these materials requires special laboratory conditions. Nevertheless, experimental parameters got from earlier studies (Marsal (1967), Fumagalli (1969), Leps (1970), Marachi vd. (1972), De Mello (1977), Duncan vd. (1980)) indicate that stress-strain behavior of rock fill materials is nonlinear, strain-dependent and inelastic.

To represent behavior of rock fill materials, Duncan and Chang (1970) is one of the most widely used material model. The mechanical properties of rock fill material have been shown in many of the analysis made by the hyperbolic model today. Saboya (1993), make comparison in Foz do Areia dam between deformations find by hyperbolic model and real deformations measured from site, he find that deformations are compatible with each other. Similarly, Khalid vd. (1990) conducted an analysis of deformations of Cethana Dam of same model.

In this study, a non-linear static analysis of 2-D plane strain deformations was made for post-construction of Dim Dam. Dim Dam was built at 2009 in Turkey and has a height of 135 m. Results are compared with measurements

made measured made at dam site and it is aimed to show how much chosen material parameters and modeling are compatible with earlier studies.
On the other hand, in Turkey, CFRD dam is built energy and irrigation purposes in recent years. Dim dam will contribute to future designing in terms of being an example of a great dam when considered lack of laboratory facilities for Material parameters. Material parameters for non-linear analysis are selected from earlier studies.

Dim Dam

2.1. Dam Characteristics

Dim Dam built in 2009 in the Alanya district of Antalya province in Turkey is located on Dim River. Dim Dam has height of 135 m from foundation, 123 m from thalweg and is designed for multipurpose such as water supply, irrigation, energy produce and flood control.

Its crest length is 365 m and wide is 7.81 m also dam body contains 5 million m^3 embankment volume. Dim Hydroelectric Power Plant has 38.3 MW installed capacity and produces 123 GWh yearly. Besides the energy production, Dim Dam provides 47.3 million m^3 water Alanya and Tourism centers for consumption. Location and typical section of Dim Dam are given in Figure-1 and Figure-2 respectively.

Figure 1. Location of Dim Dam

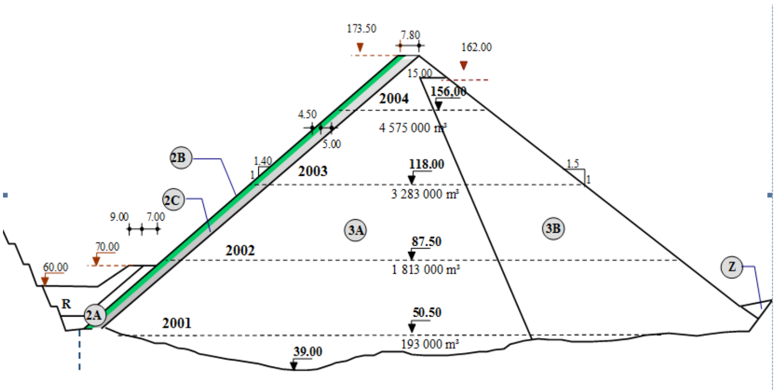

Figure 2. Typical section of Dim Dam (Çavuş, 1994)

2.2. Geology of Dam

Soil under the foundation is containing limestone and schistous rock. Construction site is located on metamorphic Alanya Massive rocks. The soil is formed by early Paleozoic basement rock units, limestone(Pbk) and schist(Pbs) which are highly affected by tectonics.

Limestone is composed of dolomite Cebireis and Bahçeli Formation limestones. Bahçeli Formation schist are formed by mica schist, chlorite schist, graphite schist. Schist may include limestone and calcschist layers. Stream bas is containing Quaternary alluvium(Qal) (Figure 2). Construction site is classified as IV degree seismic zone.

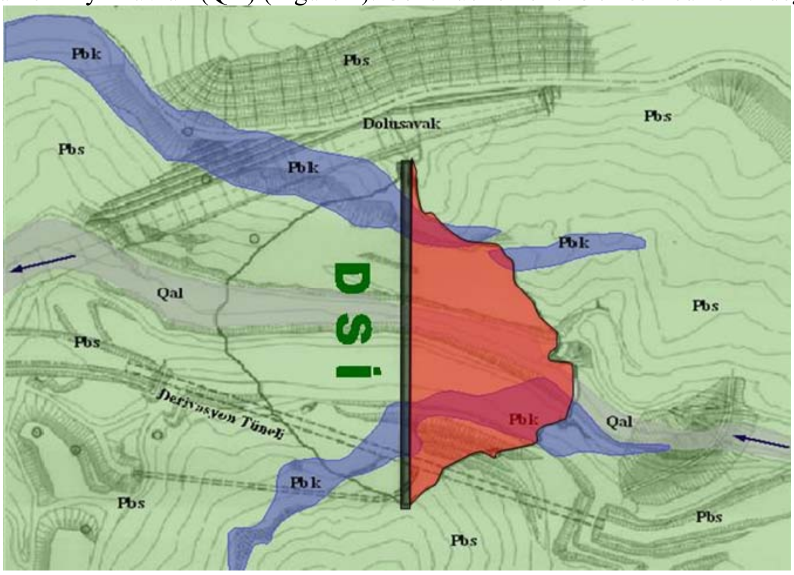

Figure 3. Geological map of Dim Dam (Koçbay, 2010)

2.3. Properties of Embankment Materials

Dim dam, which constructed as CFRD, has upstream and downstream slopes of embankment are respectively 1.4H:1V and 1.5H:1V. The embankment volume is 5 hm^3 and dam body is created by 4 zones. Typical section of dam is given in Figure-2. Location, compaction, gradation and water content of materials forming zones are given by Table-1.

Table 1. Embankment materials of Dim Dam

Loca tion,	Max.grain size (mm)	Material	Layer thickness (m)	Compaction	Water amount (litre)
2B	80	Pass	0.40	5-6 pas / 16 ton	100
2C	200	Pass	0.40	5-6 pas / 16 ton	100
3A	500	Rockfill	0.80	5 pas / 16 ton	150
3B	800	Rockfill	1.10	4 pas / 16 ton	150

Modelling and Analysis

3.1. Duncan-Chang Hyperbolic Model of Soil

Kondner(1963) for the first time mention about hyperbolic model showing non-linear soil behavior then model is improved by Duncan and Chang (1970). The model is based on principal of hyperbolic stress-strain relation and was developed with tri-axial soil tests. In present, most of the experiments conducted on rock fill embankment explain mechanical properties of materials by Hyperbolic Model. Saboya(1993) made a compared between deformation calculated by hyperbolic model and deformation measured from real structure and he find out that deformation result are compatible. Similarly, Khalid vd. (1990) calculated deformations in Cethana Dam with hyperbılic model. Hyperbolic strees-straan relation is shown by equation below.

$$\sigma_1 - \sigma_3 = \frac{\varepsilon}{\frac{1}{E_i}+\frac{\varepsilon}{(\sigma_1-\sigma_3)u}} \qquad (1)$$

Where σ_1 and σ_3 are the major and minor principle stresses, ε_1 is the major princible strain (axial strain), E_i is the intial tangent modulus and $(\sigma_1-\sigma_3)u$ ultimate deviator stress.

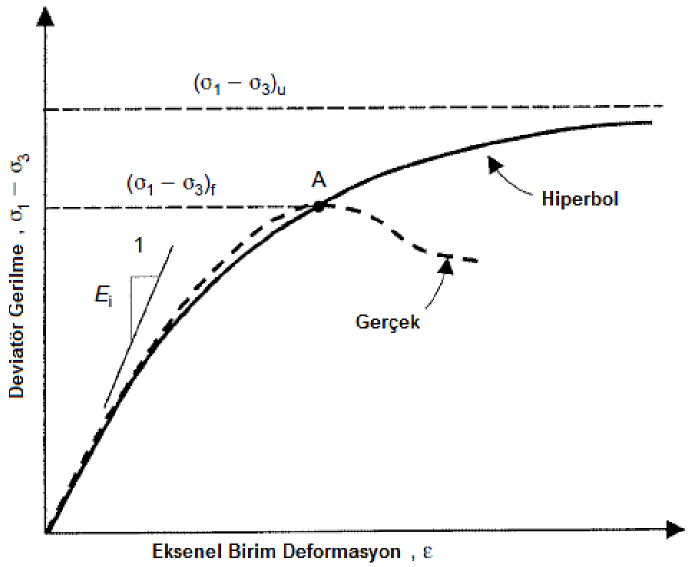

Figure 4. Hyberbolic stress-strain curve

Janbu (1963) is summarized relation between E_i the intial tangent modulus and σ_3 confining pressure with this equation.

$$E_i = K \cdot P_a \left(\frac{\sigma_3}{P_a}\right)^n \quad (2)$$

Where Pa is the atmosphere pressure(Pa=101,325), E_i is the intial tangent modulus, σ_3 is the confining(cell) stress, K is the bulk modulus number and n is the bulk modulus exponent. K and n is non- dimensional parameters.
The relation between (σ_1- σ_3)u ultimate deviator stress and (σ_1- σ_3)f deviator stress at failure are shown below.

$$(\sigma_1 - \sigma_3)_f = R_f(\sigma_1 - \sigma_3)_u \quad (3)$$

Where R_f is the failure ratio and value of R_f is always less than or equal 1.0 and veries from 0.5 to 0.9 for most soils.
Duncan and Chang show relation between classical Mohr-Coulomb shear stress and (σ_1- σ_3)f deviator stress at failure and σ_3 confining stress below.

$$(\sigma_1 - \sigma_3)_f = \frac{2c \cdot \cos\emptyset + 2\sigma_3 \cdot \sin\emptyset}{1 - \sin\emptyset} \quad (4)$$

Where c and φ are the effective stress Mohr-Coulomb cohesion intercept and friction angle respectively. This equation is used with others to determine slope of any point on the strain hyperbola. The resulting equation for the tangent modulus is

$$E_t = \left[1 - \frac{R_f(1-\sin\emptyset)(\sigma_1-\sigma_3)}{2c \cdot \cos\emptyset + 2\sigma_3 \cdot \sin\emptyset}\right] K \cdot P_a \left(\frac{\sigma_3}{P_a}\right)^n \quad (5)$$

This equation is used for calculate Young's modulus under any stress for Duncan-Chang hyperbolic model of soil. While conducting analsis, Duncan-Chang hyperbolic model of soil parameters are collected from previous studies(Khalid vd. 1990). The bulk modulus number K=2500, the bulk modulus exponent n=0.25, the failure ratio R_f=0.75 and effective stress Mohr-Coulomb cohesion c=0 are choosen.

3.2. Finite Elements Model

Parameters which are found by Duncan-Chang hyperbolic model of soil are used in ANSYS in order to conduct a analysis for 2-D plane strain deformation. While establishing numerical model, behavior of concrete crust where placed upstream side of dam is defined linear elastic and embankment fill materials are defined non-linear. Foundation is not included in to numerical model because of containing very stiff materials such as massive granite. Dam body is divided in to 10 layer each of has a thickness of 10 m. Rectangular and square components are used in analysis. Total amount of components is 9496 and total amount of node is 21706. General schemas of finite elements are given in Figure-6.

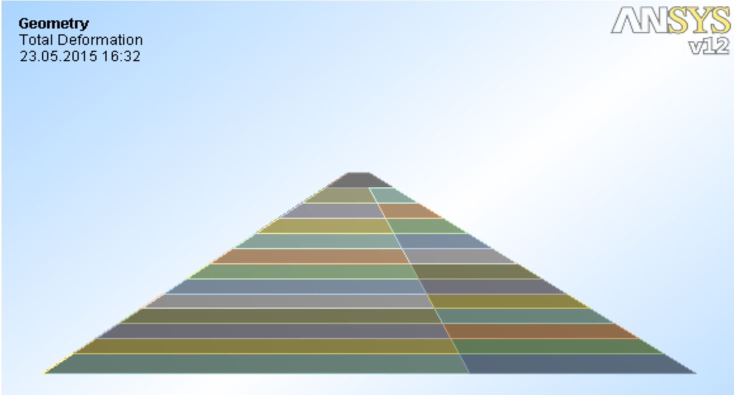

Figure 5. Dam body is divided in to 10 layer

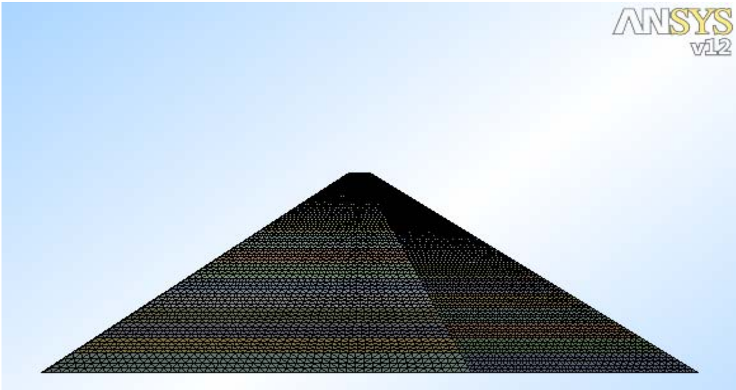

Figure 6. General schemas of finite elements

3.3. Analysis and Results

A non-linear static analysis, uses Duncan-Chang hyperbolic model, was made for "post-construction" of Dim Dam.

3.3.1. Parameters of Materials

Parameters related to rock fill materials and hyperbolicmodel are taken from literature. Since there is no laboratory test data related model parameters, parameters are obtained from Khalid vd. (1990) and Saboya (1993). They verified compliance of parameters with experimental data and analysis. For each of the 13 layer intial tangent modulus is calculated by equation 2. Boundary conditions and loading situations for post-construction and the maximum and minimum deformation occurring in the dam body is shown in Figure-7 and Figure-8 respectively. Moduli of elasticity for concrete crust is 2.80*107 kN/m^2, Poisson's ratio is 0.20 and unit volume weight is 25kN/m^3 are used.

3.3.2. Post-Construction State

At post-construction, dam body and upstream face of dam is completed but dam haven't retain water yet. Dam is only influenced by its self weight. In a such case, additional the rock fill embankment deformation, there will be settlements in crest and dam body until concrete crust completed and dam will start retain water. The parameters used for post-construction state are given in table-2

Table 2. Hyperbolic model and material parameters

Parametre	γ kN/m^3	υ	E kN/m^2	c kN/m^2	□	K	n	R_f	Pa kN/m^2
Zon C	22	0.22	-	-	46	2500	0.25	0.75	101.325
Concrete Face	25	0.20	$2.8*10^7$	-	-	-	-	-	-

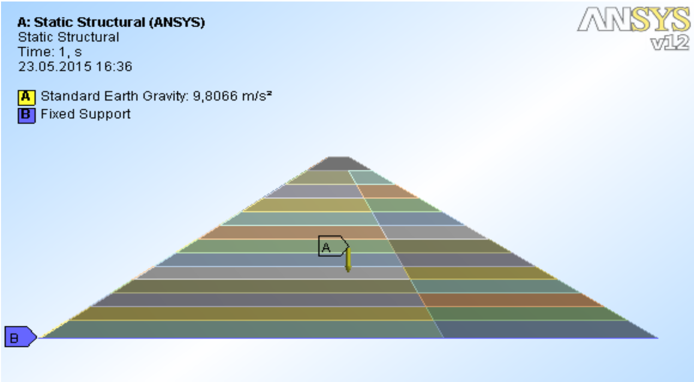

Figure 7. post-construction

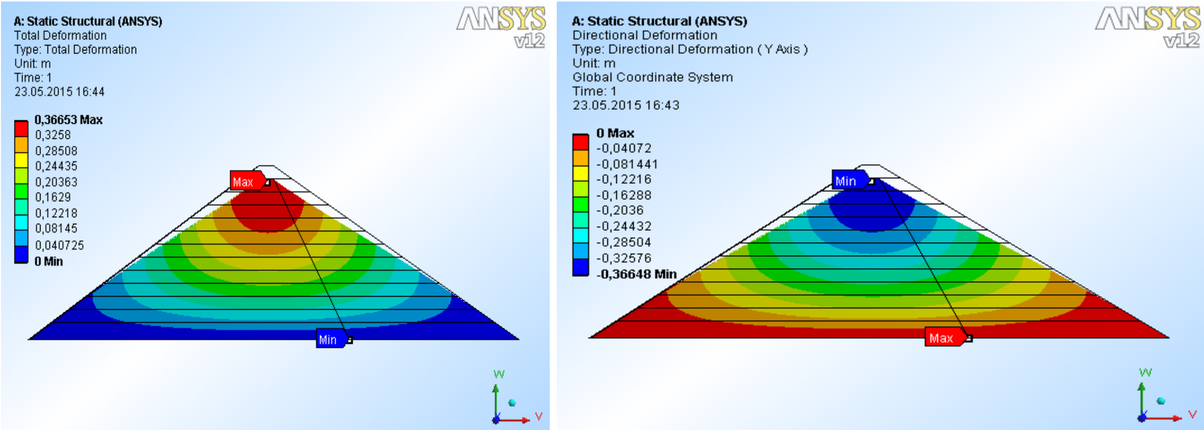

Figure 8. Settlemesnts at post-construction

In order to show deformation direction, graphs are enlarged about 29 times. The largest deformation is 36.65 cm and it was occurred on the crest. The maximum deformation of crest is corresponding about %0.27 of dam is smaller than threshold limit of %0.4 given by Sherard(1963)

Results

In this study, parameters which are selected from by Duncan-Chang hyperbolic model of soil are used in ANSYS in order to conduct a analysis for 2-D plane strain deformation and non-linear static analysis. Analysis are conducted for post-construction.

Settlment of crest is corresponding about %0.27 of dam is smaller than threshold limit of %0.4 given by Sherard (1963) Magnitude of settlements, calculated by Dunca-Chang hyperbolic model parameters, are under or cloose to settlement limist in literature. Also material parameters are consistent with parameters in literature and the the stress-strain relationship has also shown that accuracy to identify the material.

Duncan-Chang hyperbolic under the model parameters with the calculated deformation of the crest sitting boundary of the literature or to be close, consistent with the values of the material parameters of literature and the stress-strain relationship has also shown that accuracy to identify the material.

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