Comparative Study of Zoned Roller Compacted Concrete versus Conventional Concrete Gravity Dam

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ABSTRACT:
In the recent days, due to the development of computing computer packages, modeling and analyzing of structures like roller compacted concrete dams becomes interesting for concerned engineers and researchers. The most interesting focus of the present study will be emphasized on the modeling and analysis of zoned RCC gravity dam using ANSYS finite element software package. The Gilgel-Gibe-III roller compacted-compacted concrete (RCC) dam hydroelectric power plant on the Omo River in Ethiopia has been taken as a case study. The non over section of the dam section which is 214m high has four RCC zones with different material properties. The RCC gravity dam is analyzed by considering zoned roller concrete gravity dam section and a typical uniform grade of concrete strength using various loading conditions. Nonlinear static analysis is used by considering the nonlinearity of the materials and interface element (contact element) between the zones. An interface element is used to model the nonlinearities of interaction between each zone and at the dam-foundation interface. Thus, the Maximum and minimum principal stresses are computed for the typical uniform grade of concrete and the zoned RCC at different elevation starting from the bottom level of the dam. The stresses developed in the different elevation of the dam section are compared with the allowable compressive strength of the material. In both cases the results of the analysis shows that the stress concentration in the entire section is safe and found below the allowable stresses of the concrete strength. Moreover the result of the analysis using the present study concluded that RCC gravity dam section is a convenient and economical than using uniform graded concrete gravity dam throughout the entire section.

Key words: Concrete Gravity Dams, Roller Compacted Concrete Dam, Dam-Foundation Interaction, FiniteElement method.Interface Elements, Nonlinear Analysis

1. INTRODUCTION

Adam is a hydraulic structure constructed across a river to store water on its upstream side. It is an impervious or fairly impervious barrier constructed across a natural stream so that a reservoir is formed which facilitates in utilizing water when needed. US Army Corps of Engineers, "Gravity dam design" (1995) defines that a gravity dam is a solid concrete or masonry structure which ensures stability against all applied loads by its weight alone without depending on arch or beam action [1]. Gravity dams are usually constructed using conventional mass concretes and or roller compacted concretes (RCC).

1.1. Roller compacted concrete (RCC) gravity dam

Concrete in general is defined as a composite construction material composed primarily of aggregates, cement and water. According to America Concrete Institute (ACI), Roller Compacted Concrete (RCC) is defines by department of the army, U. S. A. C. O. E. W., DC. (2000) as concrete compacted by roller compaction [2]. RCC is considered for application where no slump concrete that can be transported, placed and compacted by using the normal construction equipment that being used in earth fill and rock fill works. Parallel to this, [3] defines RCC as no slump consistency concrete that is placed in a thin horizontal lifts and compacted by vibratory rollers. The application of RCC is considered when it is economical competitive with other construction method and in this case is the application of RCC method for construction of a gravity type of dam. RCC dam construction requires four basic components which include ingredient for the concrete, production of the concrete, transportation and placement of the concrete to the dam.

The Construction of RCC is related in principle to soil-cement and other earthwork construction. RCC technology developed considerably in the 1980s, after early research by C[4]-[6] and the development of the roller-compacted dam (RCD) method in Japan in the 1970s.Also in the1980s, RCC was developed as a heavy-duty paving material for log sorting yards, tank hardstands, railroad sorting yards, and other industrial pavements. It also found application in roadways and parking areas. Roller-compacted concrete (RCC) has become an accepted material for constructing dams and pavements, rehabilitating and modifying existing concrete dams, and providing overflow protection of embankment dams and spillways. Its production provides a rapid method of concrete. The properties of RCC mainly depend on quality of raw materials used, the cementations material content, the degree of compaction and the quality control measures. For effective compaction, the mix should be sufficiently dry so that it can support the load of vibratory equipment and on the other side it should be sufficiently wet also to allow adequate distribution of paste binder throughout the mass.

The present work deals with the modeling and analysis of RCC gravity dam .The main objective of the study is to emphasize the advantage of zoned RCC gravity dam over uniformly graded RCC gravity dam over the entire section of the dam. Four types of zones of uniformly graded RCC gravity dam section are used in analyses. The grades of concrete used in the analysis are 7MPa, 10MPa, 12MPa & 15MPa. Each grade of concrete has its own maximum permissible stress to carry. Therefore, the entire section of the dam is divided in to four zones. To this effect, the four graded RCC will be combined according to their permissible stress values to form the zoned RCC gravity dam. Both analyses are carried out using finite analysis package. The present study limited on the nonlinear static analysis of the RCC gravity dam.

2. METHODOLOGY

2.1. Finite Element Method of Analysis.

Because of its diversity and flexibility as an analysis tool, it is receiving much attention in engineering and other related fields of science. A number of popular brand of finite element analysis packages are available commercially. In this study, ANSYS16 finite element package is used for modeling and analysis of the RCC Gravity dam.

Detail of Elements used in the Dam and Foundation

The nonlinearity of the contact surfaces is modeled by using CONTACT 172and TARGET 169 elements which are introduced to discretize the interface of the zoned RCC gravity dam and dam-foundation interaction. The contact elements themselves overlay the solid elements describing the boundary of a deformable body and are potentially in contact with the target surfaces, defined by TARGE169. This target surface is described by a set of target segment elements (TARGE169) and is paired with its associated contact surface via a shaded real contact set[7].

2.2 Boundary Conditions and Discretization

The geometry details of the dam are presented in Figure 1. The bottom of the foundation is considered as having a fixed end support and the upstream and downstream adjacent sides restrained not to translate to x and y direction and is free to translate in the z-direction. The self-weight of the dam as a body force, hydrostatic force on the upstream face of the dam and the uplift force at the interface between the dam and foundation are considered in the analysis. Drainage gallery and tail water in the downstream face are considered in the analysis. The boundaries of the rock mesh are specified at a distance horizontally 1.5 times the height of the dam (H) from upstream and downstream toe of the dam and a depth equal to the height of the dam. Both the foundation and the dam section are discretized using PLANE182 four nodded isoperimetric solid elements. Figs.2 and 3show modeling and FEM discretization of the RCC gravity dam respectively.

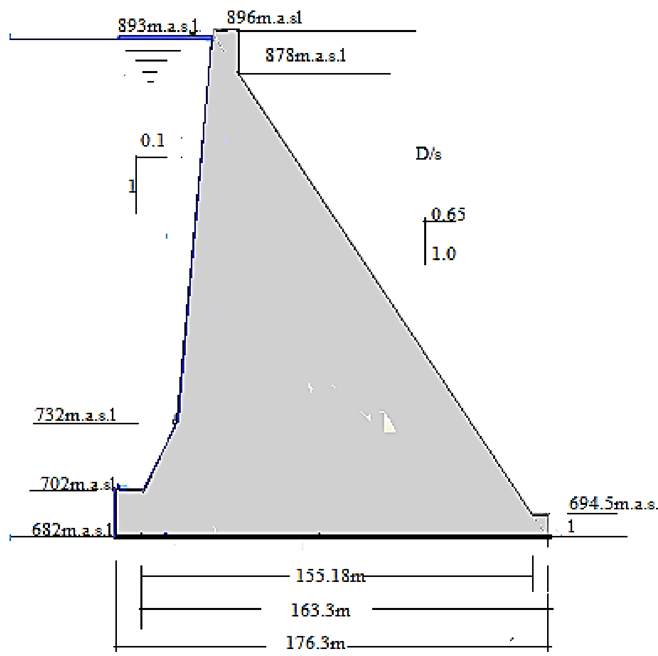

Fig.1 Geometry of Gilgel Gibe-III

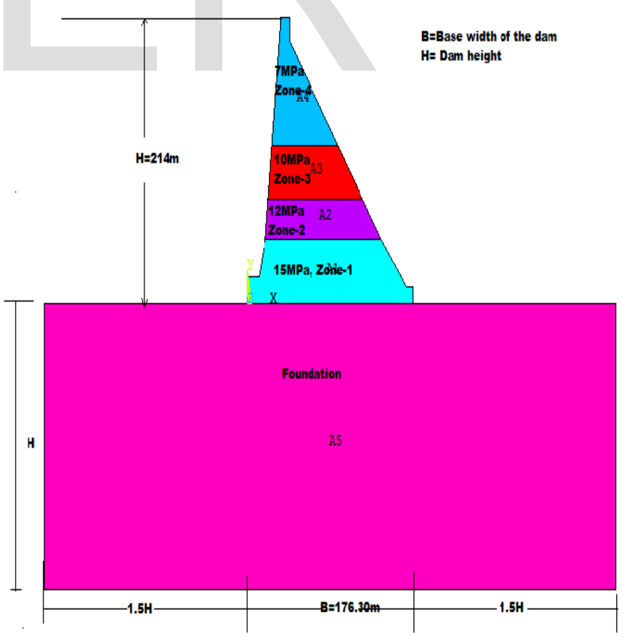

Fig.2 Modeling of Gibe-III RCC gravity dam

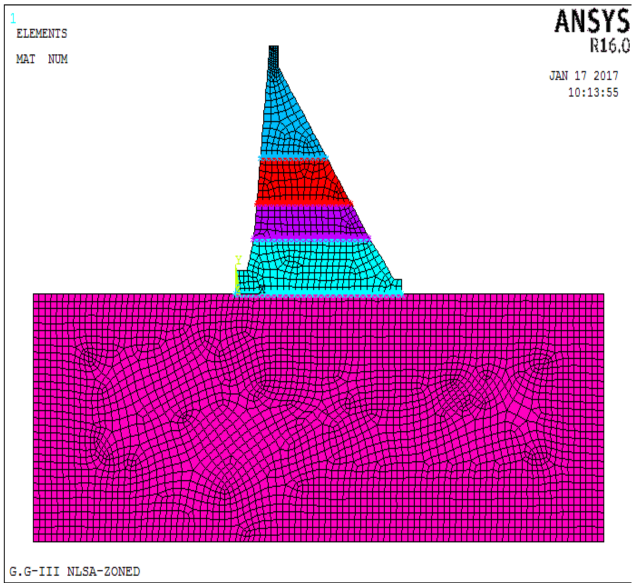

Fig.3 FEM discretization of Gibe-III RCC gravity dam

3. DETAILS OF THE PRESENT STUDY

3.1Details of the case Study (Gibe-III RCC Gravity dam)

For the present study the non-overflow section of Gilgel Gibe-III RCC gravity dam is considered to carry out stress analysis. The details of the dam geometry and material properties data are obtained from Ethiopian Electric Power Corporation (EEPCO), Gibe III,[8] are presented in Table 1,2 and 3 respectively.

Table 1 Geometrical Data of Gilgel Gibe-III RCC gravity dam

S. No	Description	Values
01	Height of the dam up to crest level	214m
02	Height of the dam up to full reservoir level	211m
03	Base width of the dam	176.3m
04	Top width of dam	9.75m
05	Downstream slope	0.65H:1V
06	Upstream slope	0.1H:1V

Table 2 Material properties of Gibe-III RCC gravity dam

Material	f_{ck} (MPa)	Material density (Kg/m^3)	Young's modulus (MPa)	Poison's ratio
RCC-Lower Layer	15	23.5	18000	0.2
RCC-Medium Layer	12	23.5	14400	0.2
RCC-Medium Upper	10	23.5	12000	0.2
RCC- Upper	7	23.5	8400	0.2
Rock- BASE		24	9000	0.15

Table 3Maximum and Minimum allowable stresses (MPa) for each RCC layer

Loading condition	Constriction loading condition		Normal operation condition	
f_{cK} (MPa)	σ_{max} comp.	σ_{max} Tensile.	σ_{min} comp.	σ_{min} Tensile
15	6.0	0	9.0	0.36
12	4.8	0	7.2	0.32
10	4.0	0	6.0	0.28
7	2.8	0	4.2	0.22

4. RESULTS AND DISCUSSIONS

The maximum and minimum principal stress variations obtained from the nonlinear static analysis are presented in Tables and Figures. The stress analysis of Gilgel Gibe-III dam is carried out for various loading conditions. Self-weight (construction), Normal operation condition (hydrostatic and self-weight) and Normal operation condition with uplift (hydrostatic, uplift pressure and self-weight) loading conditions are considered.

4.1 Stress Analysis of Gibe-III RCC Gravity Dam

The analysis of the present study is carried out by considering two cases: - Considering a typical uniformly graded concrete strength in the entire section, i.e. M15 (15MPa) is used (case 1) and (case 2) zoned or different grade of concrete in the entire section respectively. In case-1 the dam is analyzed by using typical grade of concrete strength. The analysis is carried out by using M15. In case-2 the analysis of concrete dam is carried out by using zoned (composition) dam of the four grades of concrete. The grades of concrete strength used are:-

- 7 MPa from 800m.a.s.l to 896m.a.s.l(zone-4)
- 10 MPa from 760m.a.s.l to 800m.a.s.l(zone-3)
- 12 MPa from 730m.a.s.l to 760m.a.s.l(zone-2)
- 15 MPa from 682m.a.s.l to 730m.a.s.l (zone-1)

The zoned RCC gravity dam is arranged according to their permissible allowable stresses that can be carried by specific grade of concrete. Generally as the height of the dam increases the stress decreases from the bottom of the dam to the top section. Therefore a lower grade of concrete is used at top of the dam and the higher grade one is used at bottom section of the RCC gravity dam. The zoned dam is modeled by introducing an interface element (surface-to- surface contact elements) in the dam-foundation and in between the different concrete strength contacts. The stress analysis are checked for each grade of concrete whether the required allowable compressive and tensile stresses needed in each of the compressive concrete strength are satisfied or not and a satisfactory result is obtained.

Tabular comparison of stresses between Zoned and Uniformly graded RCC gravity dam.

The following tables describe the value of maximum and minimum principal stresses for both the zoned and the typical uniformly graded RCC gravity dam varying along the height of the dam in the upstream and downstream face of the dam section. More over a shear stress (S_{XY}) along the base of the dam from the heel to toe is computed. The various stresses comparisons are summarized in Tables 4-10.

Table 4 Maximum Principal Stress (MPa), upstream face

El. (m. a.s. l)	Zoned RCC gravity dam			Uniformly graded RCC gravity dam(15MPa)		
	Con.	NOC	NOC &UPL	Con.	NOC	NOC &UPL
682	-0.50	-0.80	-0.52	-0.43	-0.74	-0.32
702	-1.00	-0.70	-0.71	-0.67	-0.75	-0.71
718	-0.13	-0.59	-0.60	-0.003	-0.65	-0.64
730	-0.10	-0.50	-0.54	-0.09	-0.58	-0.64
760	-0.002	-0.43	-0.43	-0.02	-0.44	-0.45
800	-0.01	-0.30	-0.30	-0.01	-0.31	-0.31
838	-0.01	-0.20	-0.21	-0.004	-0.20	-0.20
878	-0.004	-0.70	-0.69	-0.001	-0.67	-0.67
896	-0.0003	0.001	0.001	-0.001	0.0002	0.0003

Table 5 Maximum Principal Stress (MPa), in the D/s face

El. (m. a.s.l)	Zoned RCC gravity dam			Uniformly graded RCC gravity dam(15MPa)		
	Con.	NOC	NOC& UPL	Con.	NOC	NOC& UPL
682	-0.10	-0.23	-0.23	-0.10	-0.27	-0.26
702	-0.07	-0.14	-0.13	-0.12	-0.26	-0.25
718	-0.04	-0.04	-0.04	-0.06	-0.04	-0.03
730	-0.08	-0.18	-0.17	-0.07	-0.13	-0.04
760	-0.04	-0.06	-0.06	-0.04	-0.04	-0.04
800	-0.04	-0.07	-0.06	-0.05	-0.05	-0.05
838	-0.03	-0.05	-0.05	-0.03	-0.04	-0.03
878	-0.05	-0.08	-0.08	-0.05	-0.08	-0.08
896	-0.0001	0.000	0.0003	-	0.0002	0.0002

		3		0.0002		

Table 6 Minimum principal stress (MPa) in the upstream face

El. (m.a .s.l)	Zoned RCC gravity dam			Uniformly graded RCC gravity dam(15MPa)		
	Con.	NOC	NOC &UPL	Con.	NOC	NOC& UPL
682	-6.10	-2.50	-2.16	-5.87	-2.48	-2.25
702	-5.23	-2.00	-1.89	-5.39	-1.99	-1.94
718	-4.33	-1.70	-1.73	-4.49	-1.73	-1.76
730	-4.05	-1.70	-1.67	-4.20	-1.62	-1.62
760	-2.80	-1.40	-1.37	-2.80	-1.32	-1.32
800	-1.95	-1.00	-1.00	-1.91	-0.94	-0.94
838	-1.20	-0.60	-0.58	-1.22	-0.58	-0.58
878	-0.36	-0.20	-0.20	-0.14	-0.20	-0.19
896	-0.01	-0.01	-0.01	-0.014	-0.014	-0.014

Table 7 Minimum principal stress (MPa) in D/s

El. (m.a. s.l)	Zoned RCC gravity dam			Uniformly graded RCC gravity dam(15MPa)		
	Con.	NOC	NOC &UPL	Con.	NOC	NOC& UPL
682	-2.56	-7.20	-6.53	-2.52	-7.10	-6.81
702	-1.90	-6.00	-5.50	-2.01	-5.80	-5.60
718	-1.75	-5.20	-5.02	-1.65	-5.10	-5.15
730	-1.47	-2.00	-4.91	-1.50	-5.00	-5.05
760	-0.76	-3.70	-3.69	-0.81	-3.70	-3.81
800	-0.41	-2.40	-2.44	-0.43	-2.50	-2.50
838	-0.30	-1.40	-1.42	-0.27	-1.50	-1.50
878	-0.50	-0.80	-0.79	-0.50	-0.80	-0.79
896	-0.02	-0.002	-0.022	-0.023	-0.022	-0.022

Remarks of abbreviation! *Con=construction loading condition, NOP=Normal operation condition, UPL=uplift load, El.m.a.s.l= elevation meter above sea level, + /- signs for tensile and compression stresses respectively*

Table 8 Maximum Principal Stress (MPa) at the base of the dam

Distance from heel to toe(m)	Zoned RCC gravity dam			Uniformly graded RCC gravity dam		
	Con.	NOC	NOC& UPL	Con.	NOC	NOC& UPL
0.00	-0.50	-0.80	-0.52	-0.43	-0.74	-0.32
4.75	-0.63	-0.62	-0.27	-0.60	-0.61	-0.23
9.500	-0.60	-0.50	-0.21	-0.54	-0.50	-0.18
14.30	-0.50	-0.50	-0.47	-0.49	-0.51	-0.47
19.00	-0.70	-0.50	-0.52	-0.82	-0.53	-0.29
25.30	-0.80	-0.50	-0.46	-0.81	-0.53	-0.33
31.60	-0.80	-0.50	-0.46	-0.77	-0.55	-0.43
37.90	-0.80	-0.56	-0.50	-0.73	-0.57	-0.49
44.20	-0.70	-0.58	-0.53	-0.7	-0.58	-0.54
50.50	-0.70	-0.60	-0.56	-0.67	-0.6	-0.58
56.75	-0.70	-0.63	-0.60	-0.64	-0.62	-0.61
63.00	-0.60	-0.65	-0.61	-0.62	-0.64	-0.63
69.40	-0.60	-0.67	-0.64	-0.56	-0.66	-0.65
75.63	-0.60	-0.69	-0.66	-0.58	-0.68	-0.68
81.92	-0.60	-0.72	-0.69	-0.57	-0.71	-0.70
88.20	-0.70	-0.74	-0.71	-0.56	-0.74	-0.73
94.50	-0.55	-0.77	-0.74	-0.55	-0.77	-0.76
100.8	-0.54	-0.80	-0.76	-0.53	-0.79	-0.79
107.10	-0.52	-0.84	-0.79	-0.52	-0.83	-0.83
113.40	-0.52	-0.86	-0.81	-0.51	-0.86	-0.86
119.70	-0.51	-0.89	-0.84	-0.51	-0.91	-0.90
125.96	-0.50	-0.87	-0.84	-0.50	-0.91	-0.94
132.3	-0.50	-0.89	-0.87	-0.5	-0.93	-0.96
138.5	-0.50	-0.85	-0.85	-0.5	-0.89	-0.92
144.8	-0.48	-0.81	-0.83	-0.50	-0.91	-0.95
151.1	-0.42	-0.70	-0.75	-0.4	-0.66	-0.71
157.4	-0.41	-0.80	-0.85	-0.30	-0.52	-0.59
163.7	-0.31	-0.58	-0.66	-0.25	-0.44	-0.52
170.0	-0.12	-0.16	-0.30	-0.14	-0.18	-0.30
176.3	-0.08	-0.10	-0.23	-0.1	-0.14	-0.27

Remarks of abbreviation! *Con=construction loading condition, NOP=Normal operation condition, UPL=uplift load, El.m.a.s.l= elevation meter above sea level, + /- signs for tensile and compression stresses respectively*

Table 9 Minimum Principal Stress (MPa) along the base of the dam

Distance from heel to toe(m)	Zoned RCC gravity dam			uniformly graded RCC gravity dam		
	Con.	NOC	NOC& UPL	Con.	NOC	NOC &UPL
0.00	-6.10	-2.50	-2.16	-5.88	-2.43	-2.25
4.75	-5.70	-2.10	-2.14	-5.65	-2.01	-2.05
9.50	-5.00	-1.90	-2.30	-4.85	-1.85	-2.20
14.30	-4.30	-2.00	-2.38	-4.11	-1.86	-2.15
19.0	-3.90	-2.00	-2.04	-3.60	-2.03	-2.00
25.3	-3.50	-2.00	-1.82	-3.20	-2.04	-2.01
31.6	-3.20	-2.00	-1.89	-3.00	-2.10	-2.10
37.9	-3.00	-2.10	-2.00	-2.76	-2.15	-2.15
44.2	-2.80	-2.20	-2.11	-2.64	-2.22	-2.24
50.5	-2.64	-2.30	-2.22	-2.50	-2.28	-2.31
56.75	-2.52	-2.40	-2.34	-2.41	-2.37	-2.4
63.0	-2.42	-2.50	-2.46	-2.32	-2.45	-2.48
69.4	-2.33	-2.60	-2.58	-2.22	-2.55	-2.57
75.63	-2.26	-2.70	-2.70	-2.24	-2.64	-2.66
81.92	-2.00	-2.80	-2.82	-2.18	-2.75	-2.76
88.2	-2.14	-2.90	-2.95	-2.11	-2.86	-2.87
94.5	-2.08	-3.00	-3.08	-2.07	-2.99	-2.98
100.8	-2.04	-3.20	-3.212	-2.02	-3.12	-3.10
107.1	-2.00	-3.30	-3.36	-1.98	-3.27	-3.25
113.4	-1.97	-3.50	-3.52	-1.95	-3.42	-3.39
119.7	-1.95	-3.60	-3.70	-1.94	-3.91	-3.57
125.96	-1.94	-3.90	-3.89	-1.93	-3.81	-3.75
132.3	-1.93	-4.10	-4.12	-1.94	-4.06	-4.00
138.5	-1.96	-4.40	-4.39	-1.95	-4.32	-4.26
144.8	-2.02	-4.80	-4.74	-2.01	-4.72	-4.63
151.1	-2.11	-5.30	-5.20	-2.09	-5.19	-5.10
157.4	-2.24	-5.80	-5.66	-2.23	-5.83	-5.70
163.7	-2.52	-6.80	-6.507	-2.67	-7.28	-7.10
170.0	-2.62	-7.20	-6.77	-2.73	-7.57	-7.37
176.3	-2.56	-7.10	-6.53	-2.52	-6.98	-6.82

Remarks of abbreviation! *Con=construction loading condition, NOP=Normal operation condition, UPL=uplift load, El.m.a.s.l= elevation meter above sea level, + /- signs for tensile and compression stresses respectively*

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Table 10 Shear stress (MPa) along the base of the dam, SXY

Distance from heel to toe(m)	Zoned RCC gravity dam			Uniformly graded RCC gravity dam		
	Con.	NOC	NOC &UPL	Con.	NOC	NOC &UPL
0.00	-2.42	0.36	0.78	-2.40	0.38	0.88
4.75	-2.44	0.47	0.84	-2.42	0.48	0.86
9.50	-2.20	0.56	0.79	-2.10	0.65	0.71
14.30	-1.78	0.54	0.55	-1.70	0.62	0.67
19.0	-1.40	0.53	0.38	-1.40	0.54	0.60
25.3	-0.96	0.52	0.43	-1.00	0.55	0.60
31.6	-0.67	0.52	0.52	-0.70	0.55	0.59
37.9	-0.47	0.53	0.54	-0.50	0.56	0.58
44.2	-0.34	0.54	0.56	-0.30	0.57	0.59
50.5	-0.21	0.56	0.59	-0.20	0.59	0.60
56.75	-0.12	0.59	0.62	-0.10	0.62	0.61
63.0	-0.02	0.63	0.66	-0.03	0.65	0.64
69.4	0.05	0.68	0.71	0.06	0.69	0.67
75.63	0.12	0.73	0.76	0.12	0.74	0.71
81.92	0.18	0.79	0.82	0.18	0.78	0.76
88.2	0.24	0.86	0.89	0.23	0.84	0.81
94.5	0.29	0.93	0.95	0.29	0.91	0.87
100.8	0.35	1.01	1.03	0.33	0.98	0.94
107.1	0.39	1.01	1.11	0.38	1.06	1.02
113.4	0.44	1.19	1.20	0.43	1.16	1.11
119.7	0.49	1.29	1.30	0.47	1.26	1.21
125.96	0.54	1.43	1.43	0.52	1.38	1.33
132.3	0.59	1.57	1.56	0.57	1.51	1.46
138.5	0.65	1.75	1.72	0.64	1.7	1.64
144.8	0.73	1.98	1.93	0.70	1.89	1.82
151.1	0.84	2.31	2.22	0.82	2.25	2.20
157.4	0.91	2.52	2.41	0.95	2.65	2.56
163.7	1.10	3.11	2.92	1.21	3.42	3.30
170.0	1.23	3.50	3.22	1.30	3.70	3.50
176.3	1.14	3.30	2.96	1.14	3.30	3.15

Remarks of abbreviation! *Con=construction loading condition, NOP=Normal operation condition, UPL=uplift load, El.m.a.s.l= elevation meter above sea level, + /- signs for tensile and compression stresses respectively.*

Graphical Representation of Uniformly graded Compressive Strength M15 versus Zoned RCC gravity dam

The variation of maximum and minimum principal stresses along the base of the dam and at corresponding face of upstream and downstream slope change points and change of section properties of the dam section are analyzed using various loading combination and presented in figures.The figures illustrate the plot of maximum and minimum principal stresses variation between typical uniform graded RCC (15MPa) and zoned RCC gravity dam, for the three loading conditions with respect to height of the dam in the upstream and downstream face and along the base of the dam section. Moreover a shear stress alone the base of the dam is computed. Figs. (4-7) shows the plot of the maximum and minimum principal stresses versus elevation (from 682m.a.s.l bottom of the dam up to 896m.a.s.l crest level of the dam) variations between a typical uniform graded RCC(15MPa) and zoned RCC gravity dam in the upstream and downstream faces of the dam section for the various loading conditions. From Figures [8-10] a plot of the maximum, minimum and shear stresses along the base of the dam is presented.

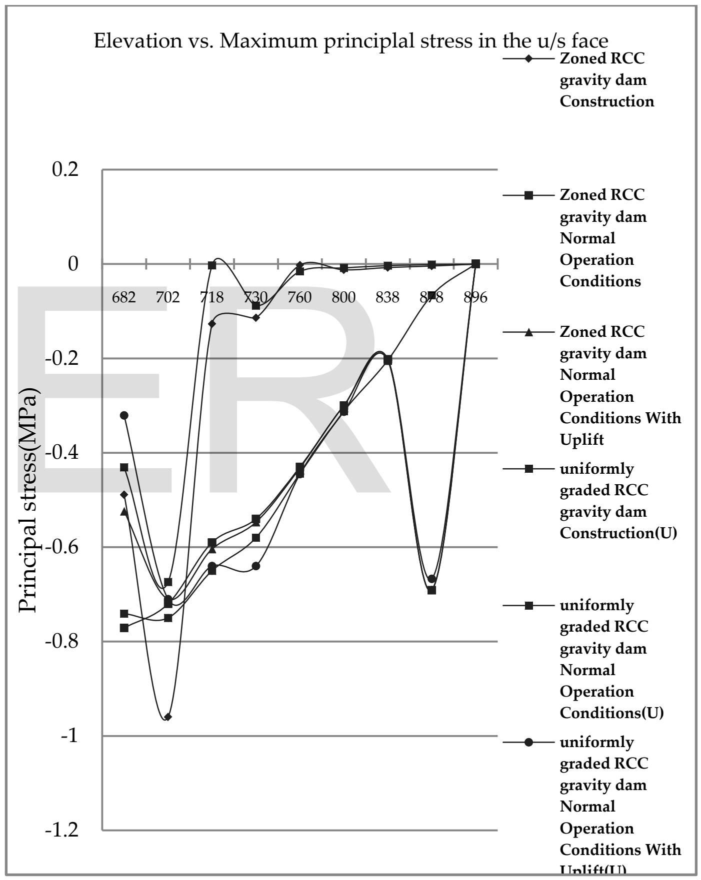

Fig.4 U/s variation Max Principal stress (MPa) for zoned vs. uniformly graded RCC

Fig. 4 and Table 4 represent the maximum principal stresses developed in zoned and typical uniform graded RCC for three loading conditions in the upstream face w.r.t the height of the dam. The results of compression stresses are obtained as a slightly higher value in the zoned one than the uniformed graded RCC due to the variation of material properties and the interface elements used. A very small tensile stresses are obtained in the normal operation loading condition case near the crest of the dam section. Moreover, the stresses computed in both cases of the RCC are occurred as below the maximum allowable compression and tensile stresses.

The maximum principal stresses results in zoned and typical uniform graded RCC for various loading conditions in the downstream face w.r.t the height of the dam is represented by Fig. 5 and Table 5. The values of compression stresses are slightly higher in the zoned than the uniformed graded RCC. A very small tensile stresses are observed in the normal operation loading condition case. The minimum principal stresses developed in zoned and typical uniform graded RCC for three loading conditions in the upstream face w.r.t the height of the dam is represented in Fig. 6 and Table 6. The results of compression stresses are higher in the zoned than the uniformed graded RCC. The stresses computed from both cases of the RCC are below the maximum allowable compression and tensile stresses.

Fig.7 and Table 7 describe the minimum principal stresses developed in zoned and typical uniform graded RCC for three loading conditions in the upstream face w.r.t the height of the dam. The compression stresses are observed as slightly higher in the zoned than the uniformed graded RCC. The compression stress values are getting decreased from the base to the crest of the dam and a small tensile stress values are observed in the normal operation loading condition cases. As a result the dam is safe in compression and tension in both cases.

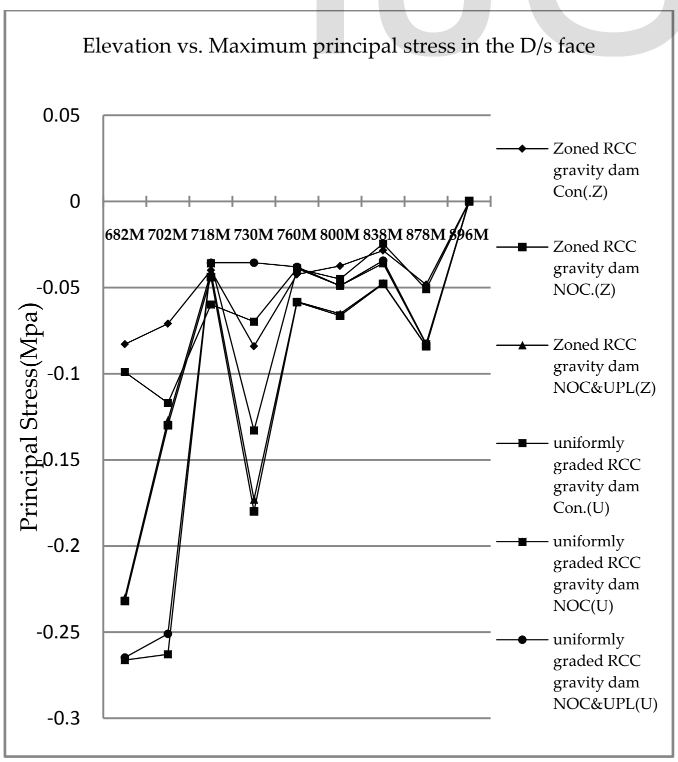

Fig.5 D/s Variation of Max Principal stress (MPa) for zoned vs. uniformly graded RCC

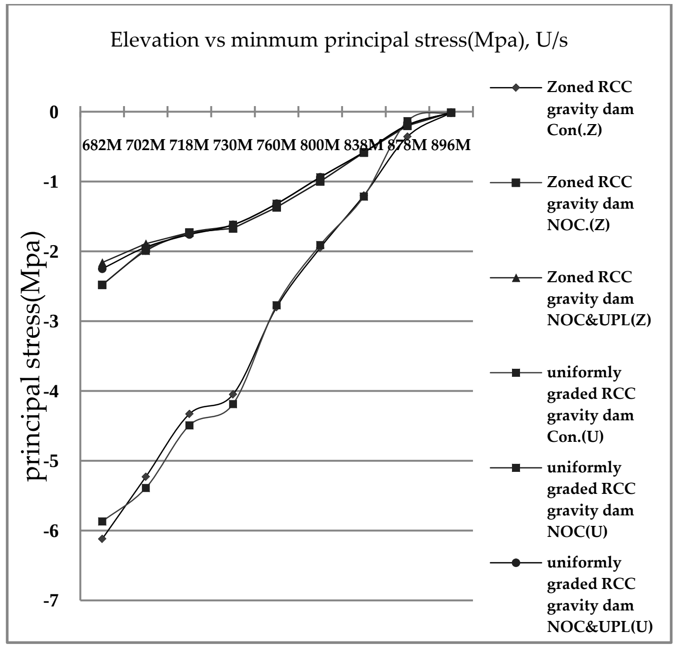

Fig.6 U/s Variation of Min. Principal stress (MPa) for zoned vs. Uniformly Graded RCC

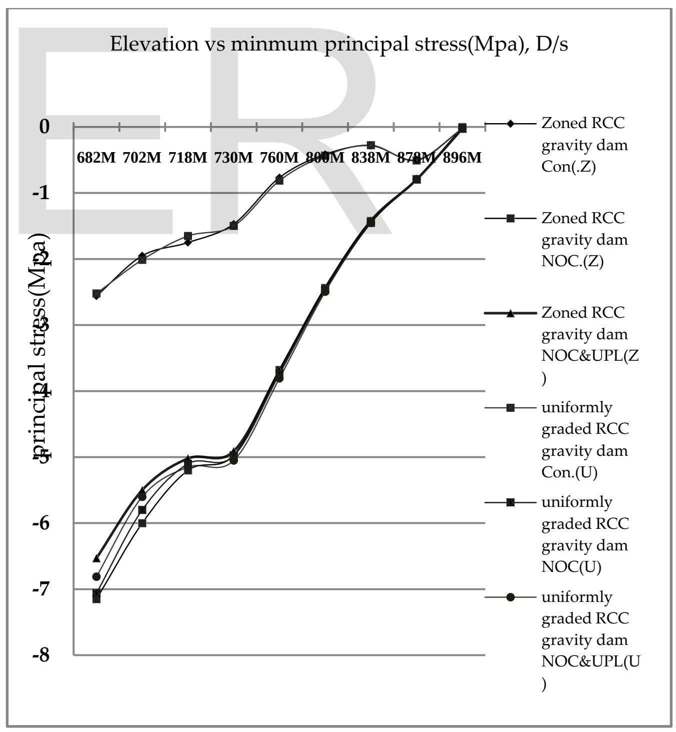

Fig.7 D/s Variation of Min. Principal stress (MPa) for zoned vs. uniformly graded RCC

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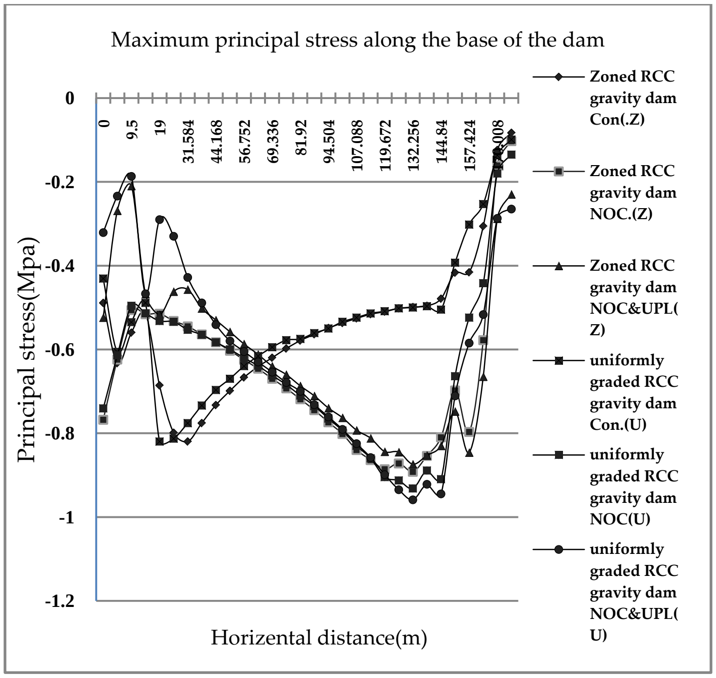

Fig.8 Maximum principal stress along the base of the dam

As shown in Fig. 8 and Table 8 the maximum principal stresses developed in zoned and typical uniform graded RCC for three loading conditions along the base of the dam starting from the heel to the toe is compared. From the results, compression stresses values are observed as slightly greater in the zoned than the uniformed graded RCC due to the variation of material properties and the interface elements used and the value of stresses decrease from the heel to the toe in both loading conditions.

The minimum principal stresses developed in zoned and typical uniform graded RCC for the three loading conditions along the base of the dam section are compared as shown in Fig. 9 and Table 9. The results of compression stress values are higher in the zoned than the uniformed graded RCC due to the variation of material properties and the interface elements used. Meanwhile, the value of compression stress increases from heel to toe in the normal operation conditions (NOC), whereas decreases in the construction loading cases (Con.) for both types of the RCC gravity dam.

The shear stresses developed in zoned and typical uniform graded RCC for three loading conditions at the base of the dam section extending from heel to toe, is represented Fig .10 and Table 10. Under the construction loading condition, the results of shear stresses shows that a negative stress is concentrated in the heel and as we get approach to the toe a positive stress are occurred. In the normal operation condition cases, the shear stresses value is positive and increases from hell to the toe of the dam section in both RCC gravity dams.

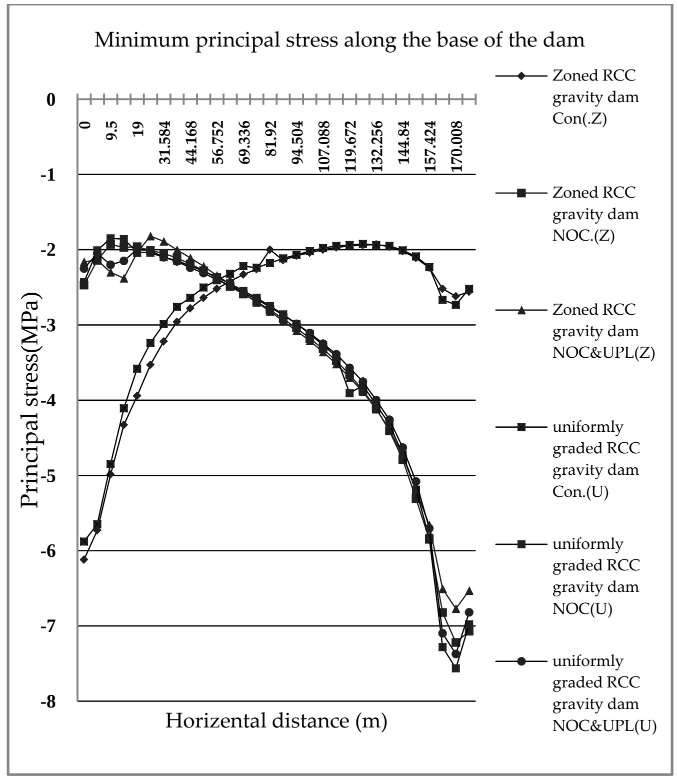

Fig.9Minimum principal stress along the base of the dam

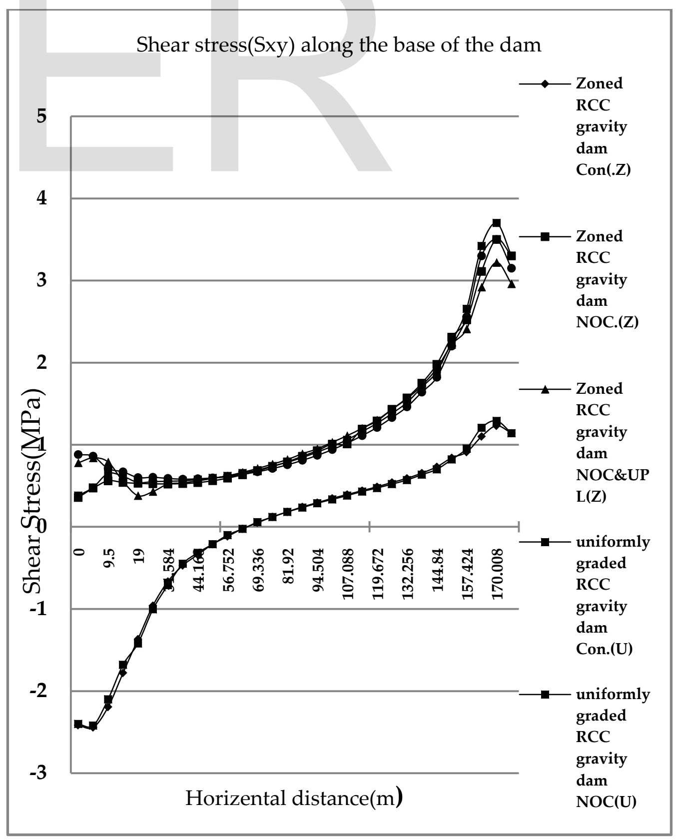

Fig.10 Shear stress along the base of the dam

5. SUMMARY AND CONCLUSSION

The summery and conclusions of the present study are described as:-

- The maximum and minimum principal stress values decrease from the bottom to the top of the dam section in both cases.
- By using different material concrete strength (grade of concrete) has no significant variation in terms of the minimum and maximum principal stress values in the upper section of the dam. Since, the concentration of stress is high at the base of the dam-foundation interaction related to the top of the dam section; it is advisable to use a material having more strength at the bottom of the dam section and less material strength at the top section up to the minimum requirement of the concrete material strength is satisfied.
- The zoned RCC gravity dam with interface elements gives slightly higher stress values than that of uniform material strength due to the change of material properties in the contact zone. But, the minimum and maximum principal stresses obtained from the analysis are below the allowable permissible stresses for both cases.
- The constructing and designing of zoned RCC gravity dam is more economical than the uniform concrete strength.
- From this study a proper designing and construction of RCC gravity dam can save both time and money than using the conventional mass concrete

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