

Effects of Increasing the Base on Concrete Dam Stability

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Abstract: The concrete dam is one of the most important hydraulic infrastructures which play a vital role in providing a wide range of water services and helps prevent many potential disasters such as floods. The concrete dam subjected to many kinds of static and hydrodynamic forces which almost needs taking into account of design under different circumstances to satisfy the safety requirements. The shape of dam is pertinent to the stability of dam regarding the major forces and stresses. One of the most common ways which is necessary to solve the problems in design due to the cases of unsafely for any mode of failures is to add mass to the dam upstream face. In this work, a parametric study is made to investigate the effects of the increase in the base of dam on the principal and shear stresses developed in the dam. In all cases, all the relevant factors of safety are satisfied. The stability analysis for all possible modes of failures is carried out to check the performance of the initial section of dam due several loading conditions. Parameters of importance are studied, discussed and conclusions are drawn.

Keywords: Concrete Dams, Dams Stability

1. Introduction

Concrete dam is considered as one of giant and strategic hydraulic structures that support a wide range of high water heads in its reservoir and perform important functions relating to the water resources management and power generation. The dam is exposed to many types of static and dynamic loads and hence the stresses arising throughout the body of dam. All these forces may threat the stability of dam, thus, measures to ensure dam safety should intervene in the designer accounts. The material density and the geometry of such structures will bear the bulk of the resistance forces and stresses resulting therefrom. For the sake of the dam safety assurance, all modes of the expected failure should be subject to scientific examination and analysis starting with the primary section of design. Types of expected failures are linked to the types of forces and stresses in the required design and associated with the conditions and restrictions of the construction site as well as the nature of the functions achieved by dam establishment.

2. Previous Works

Many researches have been paid much more attention for stability analysis of concrete dam due its importance to satisfy the safety requirements for all considered modes of failures. M. Leclerc, et al (2003) used the CADAM software to evaluate the stability analysis for concrete dams regarding to many cases such as, compute crack lengths, and safety factors in addition to, (a) crack initiation and propagation, (b) effects of drainage and cracking under static, seismic, and post-seismic uplift pressure conditions, and (c) safety evaluation formats (deterministic allowable stresses and limit states, probabilistic analyses using Monte Carlo simulations).

The U.S.B.R. recommendations in seismic zone II of Bangladesh were used by Hazrat Ali, et al (2011) to design high concrete gravity dams. The different intensities of earthquakes horizontal component values which ranged from 0.10 g - 0.30 g with 0.05 g increment were used in carrying out the analysis. The analysis based upon the techniques of 2D gravity method, finite element method and ANSYS 5.4. The loads are considered to be constant whereas only the earthquake forces have been examined for various values. The study concluded that the righting moment is decreased with the increment of horizontal earthquake intensity and the construction of dam would not be possible in the case of horizontal component of earth quake intensity with more than 0.3 g.

The impact of earthquakes on Rupsiabagar Khasiyabara dam situated in Pithoragarh district of Uttarakhand in India is studied by Aryak et al (2012).The CADAM software is used to check whether the modify of structure by the seismic retrofitting is needed to improve the resistance of dam to earthquake. The peak value of ground acceleration is considered to ensure the safety of dam under the effects of different loading conditions which found as safe.

A two-stage procedure was proposed by Arnkjell (2013) for the elastic analysis phase of seismic design and safety evaluation of concrete gravity dams. The study is based upon the implantation of response spectrum analysis (RSA) and response history analysis (RHA) results to check the response of concrete dam to the effects of earthquake forces. Some modifications has been made to increase the performance of these soft wares and to cover a wide ranges of stability analysis cases. In addition, a comprehensive evaluation of the accuracy of the RSA procedure has been conducted, demonstrating that it estimates stresses close enough to the "exact" results (determined by RHA) to be satisfactory for the preliminary phase in the design of new dams and in the safety evaluation of existing dams.

Three dams Blue stone; Folsom; and Pine Flat, were investigated by Elyas et al (2014) to identify the effective parameters in stability of concrete gravity dams. Their study is based upon the ABAQUS and RS-DAM software's to observe the behavior of the sliding displacement along the base of dam which contact the foundation. The results show that the sliding displacement has no considerable change in each of the three nodes on heel and toe, and also in middle part of dam, and eventually is equal in each three and all parts of the dam's bottom and foundation.

3. Aim of the Study

The aim of current study is to check the stability of the random section of concrete dam for a wide range of reservoir heads. Many loads are considered and critical design section with full and empty reservoir cases is examined. The analysis is focusing on the effects of dam geometry on requirements of safety. Mostly the change in initial dam section would be satisfied by adding a specific amount of concrete to the upstream dam face, however, the challenge is due to the determination of required amount which should be provided, and hence ,it may need a lot of trials to be attained .In present study, stability analysis of concrete dam is performed over a wide range of water heads values (starting from 40 m up to 100 m with increment of 0.5 m), and for design cases considering empty as well as full reservoir conditions. The analysis calculates the various types of forces such as hydrostatic, uplift and seismic forces in order to determine the appropriate increase in the dam base to ensure dam's safety.

4. Forces acting on Concrete Dam

The following forces have been considered in analysis for both cases, empty reservoir with the earthquake forces are act vertically upward and horizontally towards heel, and full reservoir with earth quake forces are vertically upward and horizontally toward toe which represent the more critical cases (Santosh 2005). These forces, shown in figure (1), are ranged in general between the usual and extreme loads.

1. Water pressure (P),
2. Up lift pressure (Pu),
3. Pressure due to earthquake forces (F_{SV} and F_{Sh}),
4. Hydrodynamic Force (PE),and
5. Weight of the dam (W)

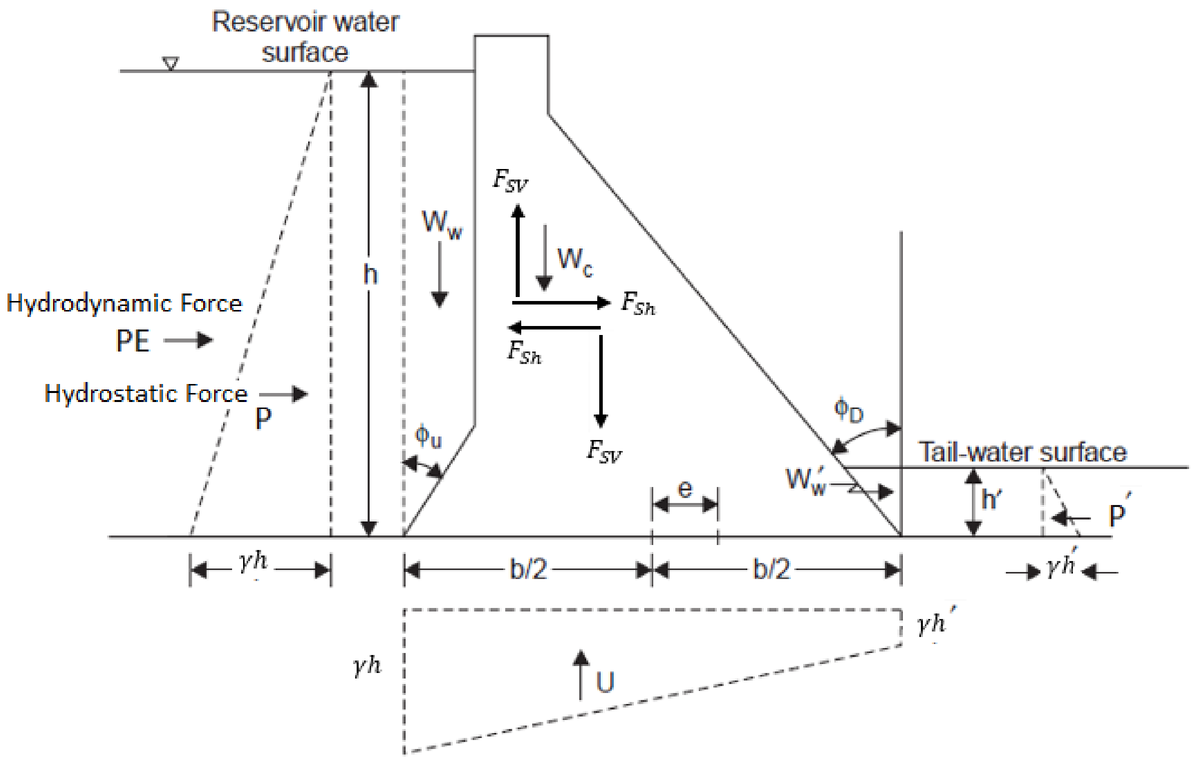

Figure 1: Forces acting on gravity dam (G.L.Asawa)

The forces can be estimated by the following equations:
The hydrostatic force can estimated from the following form:

$$P = \frac{1}{2} \cdot \gamma \cdot H^2 \quad (1)$$

Where:

P =Horizontal hydrostatic force, N,

γ =Unit weight of water,N/m^3, and

H = Depth of water, m

The uplift force which exerted by stream lines below the dam base can be obtained by using the formula:

$$Pu = \frac{1}{2} \cdot c \cdot \gamma \cdot H \cdot B \qquad (2)$$

Where

C: uplift pressure coefficient, and

B: Base width of dam, m.

The vertical and horizontal components of earthquake forces are function of weight of dam and can be obtained from the following expressions:

$$F_{SV} = W \cdot K_v \qquad (3)$$

$$F_{Sh} = W \cdot K_h \qquad (4)$$

Where

W =The total weight of the dam, N,

K_v =Vertical acceleration factor (mostly 0.05)

K_h =Horizontal acceleration factor (mostly 0.1)

The hydrodynamic force which represent the effect of earthquake force on reservoir it can be obtained from one of the following expressions:

i-The Von-Karman equation:

$$P_E = 0.555 \cdot K_h \cdot \gamma \cdot H^2 \cdot (\frac{4H}{3\pi}) \qquad (5)$$

$$M_e = P_E \cdot \frac{4H}{3\pi} \qquad (6)$$

ii- Zangar equation

$$P_E = 0.726 \cdot C_m \cdot K_h \cdot \gamma \cdot H^2 \qquad (7)$$

Where

P_E =Hydrodynamic force, N

P_e =Hydrodynamic pressure,

M_e =Moment of force about toe. And

$C_m = 0.735 \cdot (\frac{\theta^{\circ}}{90^{\circ}})$, where θ° =Angle in degrees, which the u/s face of the dam makes with horizontal and the moment of the force can be estimated from the equation (8)

$$M_e = 0.412 \cdot P_E \cdot H \quad (8)$$

In current study, the hydrodynamic force is assumed to be act toward the D/S of dam.

4-1 Modes of Failure of Gravity Dams

4-1-1. Overturning (rotation) about the toe.

$$FS = \frac{\Sigma Righting\ Moments}{\Sigma Overturning\ Moments} = \frac{\Sigma M_R}{\Sigma M_0} \quad (9)$$

ΣM_R: Anti clockwise moments, ΣM_0: clockwise moments

4-1-2. Crushing (compression)

$$P_{max/min} = \frac{\Sigma V}{B}(1 \pm \frac{6e}{B}) \quad (10)$$

Where:

e=Eccentricity of resultant force from the center to the base, m,

ΣV =Total vertical force, N, and

B =Base width, m.

4-1-3-. *Development of tension, causing ultimate failure by crushing.*

$$e \leq \frac{B}{6} \quad (11)$$

4-1-4. Shear failure called sliding.

F.S.S (factor of safety against sliding) $= \frac{\mu \cdot \Sigma V}{\Sigma H}$ (12)

S.F.F (shear friction factor) $= \frac{\mu \cdot \Sigma V + B' \cdot q}{\Sigma H}$ (13)

Where

B' =Width of dam at the joints,m

q =Average strength of the joint which varies from 140 t/m^2 for poor rocks, to 400 t/m^2 for good rocks, and,

μ =Friction coefficient (nearly =0.75).

4-2 Principle and Shear Stress

$$\sigma = P_v \cdot sec^2 a \tag{14}$$

Where

σ =Major principle stress which is not greater than allowable stress (f),

P_v =Minor principle stress,

a = Angle which (d/s) face makes with vertical

$$\sigma_{at\ toe} = P_v \cdot sec^2 a - (P' - P_e) \cdot tan^2 a \tag{15}$$

$$\sigma_1 = \sigma_{at\ heel} = P_v \cdot sec^2 \emptyset - (P + P_e) \cdot tan^2 \emptyset \tag{16}$$

Where

$\emptyset$ =Angle which (u/s) face makes with vertical

The shear stress near toe with the case of no tail water can be obtained from the following form:

$$\tau_0 = P_v \cdot \tan a \qquad (P' = 0) \tag{17}$$

And by considering the tail water and hydrodynamic in the direction toward the u/s side, the Eq. (19) would be change to be:

$$\tau_{0(toe)} = [P_v - (p - P_e')] \cdot \tan a \tag{18}$$

Similarly, the shear stress at heel can be expressed by the following equation:

$$\tau_{0(heel)} = [P_v - (P + P_e)] \cdot \tan \emptyset \tag{19}$$

$$X' = \frac{\Sigma M}{\Sigma V} \tag{20}$$

Where X': Centre of the base

$$e = \frac{B}{2} - X' \tag{21}$$

5. Results and Discussions

In present study, all the considered forces, principal and shear stresses were estimated and consequently, the relevant modes of failure have been checked for each specific reservoir head (H). Many iterations of stability analysis have been carried out for both empty and full reservoir cases up to attain the safety status. Accordingly, the width values of extra amount of concrete (b) were obtained corresponding to each (H). Then, the relationship between the wide range of heads and additional part of base width is presented in figure (2) in order to create an appropriate function which it may be useful for predicting the values of additional parts of the dam base (b) required to satisfy the safety conditions for each specific head (H). It can be seen from figure (2) that the values of (b) is increased uniformly as the head in reservoir increased .The range of variation of (b) will take more values when (H) becomes greater than (80) m. Also the fourth degree of polynomial function can be considered as the best relation between (b) and (H) which can be used to estimate the required values of additional base part for dam safety, Eq. (22).

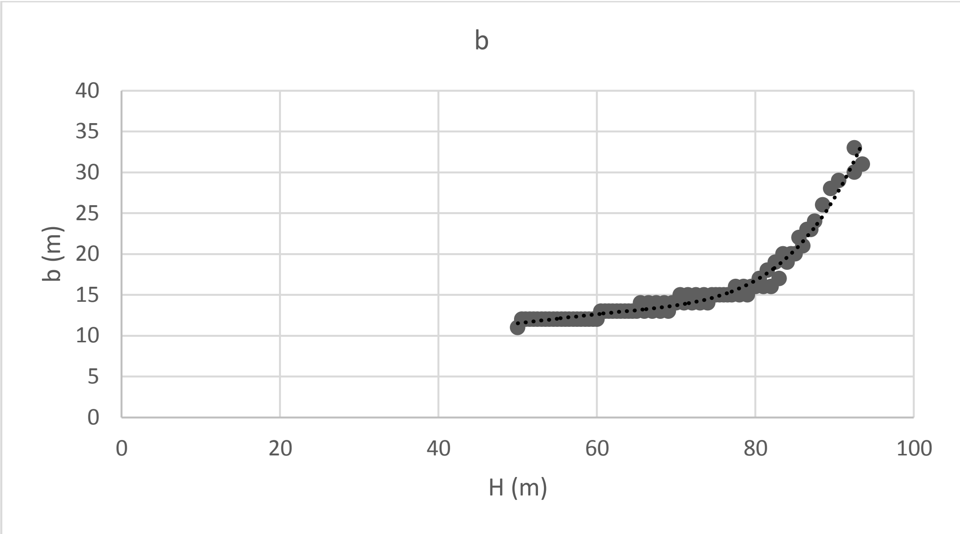

Figure 2: Relation between head and base (H & b) for full reservoir

$$b = 10^{-5}H^4 - 0.0031H^3 + 0.2694H^2 - 10.319\,H + 156.64 \qquad (22)$$

$R^2 = 0.9769$

The values and positions of eccentricity (e) are taken as main indictors for tension development along the base of dam .As it can be seen from figure (3), that the resultant force may moves toward toe in the case of full reservoir condition and hence the maximum stresses are created at toe and being reduced gradually toward the heel. The minimum normal stresses at heel will either be positive or negative. However, the values of (e) is influenced effectively by the movement of resultant force, accordingly, if the resultant force cut the dam base outside the middle third part, the tension will be produced on heel zone. In other words, if (e) is less than or equal to b/6, the stress is compressive all along the base and when (e) is greater than b/6 there can be tensile stresses on the base. In present study, the values of (e) are estimated for safe dam section and their relation with head (H) is shown in figure (4). It can be seen from the figure that the values of (e) are increasing when (H) is getting higher and the relation can be expressed by fourth degree polynomial function with high value of correlation coefficient, Eq. (23).

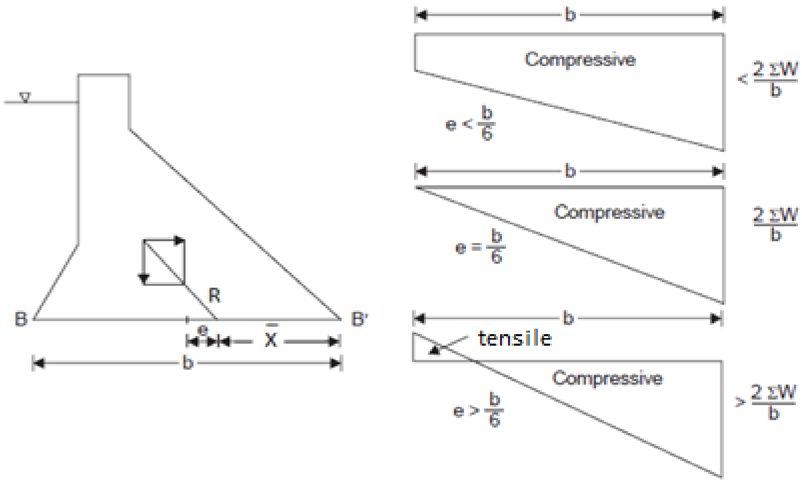

Figure 3: Maximum and minimum stresses on both toe and heel of full reservoir case

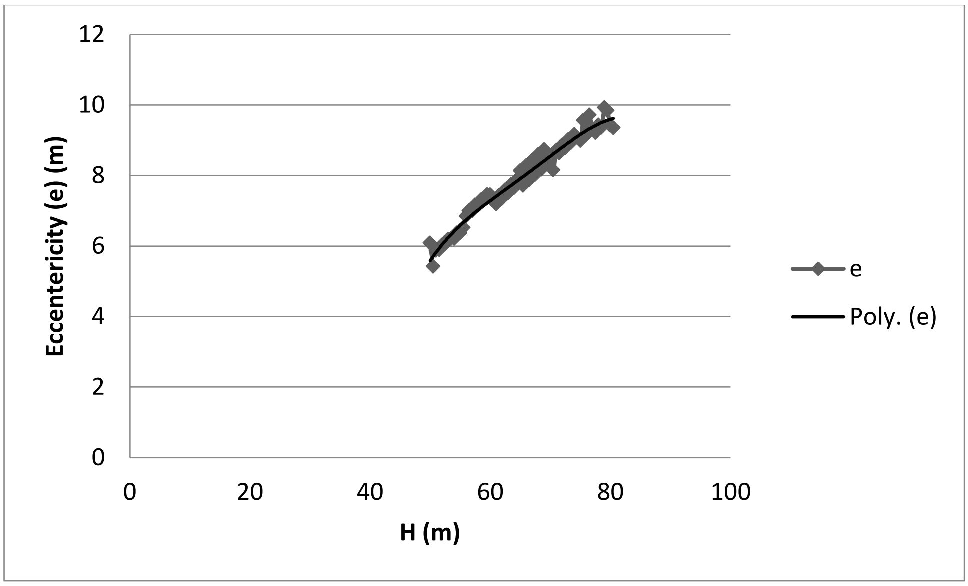

Figure 4: Relation between head (H) and eccentricity (e) for full reservoir

$$e = -9 \times 10^{-6} H^4 + 0.0023 H^3 - 0.2266 H^2 + 10.054\, H - 162.96 \quad (23)$$

$R^2 = 0.9717$

For the full reservoir case, if the components of earthquake forces are considered to be vertically upward and horizontally toward D/S, the case is classified as worst case with extreme loads. The whole forces applied on the dam lead to create the principal stresses on both upstream face rather than downstream face in the case of tail water existing. Figure (5) shows the variation of principal stresses (σ) with head of water in reservoir (H).It can be seen from the figure that the values of (σ)

are proportionally increased as (H) increased up to (H=80 m) beyond which the values of (σ) are subjected to some fluctuation. Eq. (24) represents the relationship between (σ) and (H).

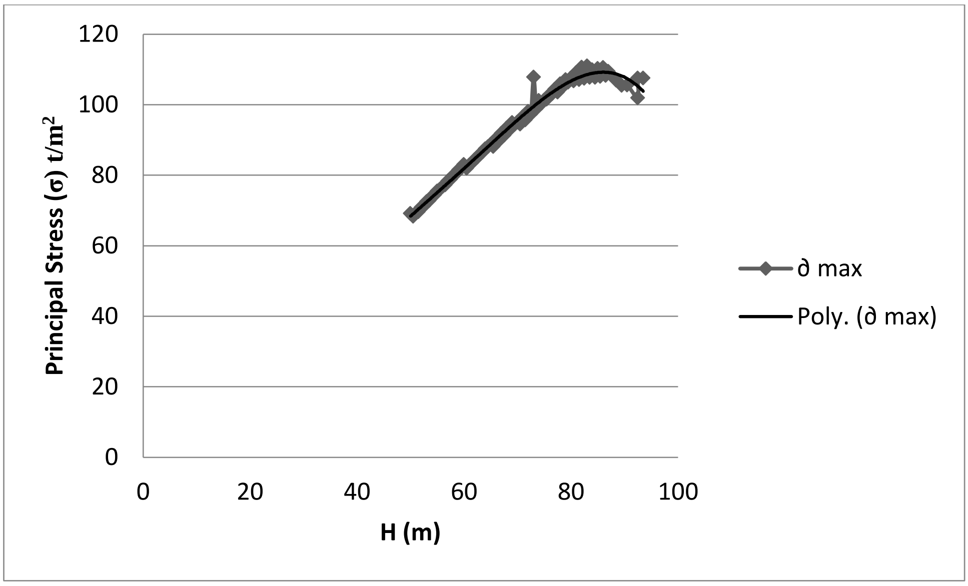

Figure 5: Relation between head (H) and (σ) for full reservoir

$$\sigma = -2 \times 10^{-5}H^4 + 0.0043H^3 - 0.3733H^2 + 15.661\,H - 203.47 \qquad (24)$$
$R^2 = 0.9881$

The general behavior of eccentricity (e) with (H) in the case of empty reservoir are similar to that in the case of full reservoir .The range of (e) values is bounded by minimum value (e=5) and maximum value (e=9) which less than those obtained for full reservoir analysis. Figure (6) shows the relation between (e) and (H) for case of Empty reservoir which also can be presented mathematically by fourth degree polynomial function, Eq. (25) .

$$e = 6 \times 10^{-8}H^4 + 2 \times 10^{-5}H^3 - 0.0054H^2 + 0.5311\,H - 10.339 \qquad (25)$$
$R^2 = 0.9973$

The relation between the head (H) and both and (σ) is shown in figures (7) It can be seen from this figures that for empty reservoir, the pattern of (σ) variation is same to that obtained from the case of full reservoir analysis. However, the range of values is seemed to differ from the results of full reservoir. The values of (σ) corresponding to each value of (H) can be calculated by using the fourth polynomial equation (Eq. 26).

$$\sigma = -2 \times 10^{-5}H^4 + 0.0045H^3 - 0.452H^2 + 22.061\,H - 359.53 \qquad (26)$$
$R^2 = 0.9981$

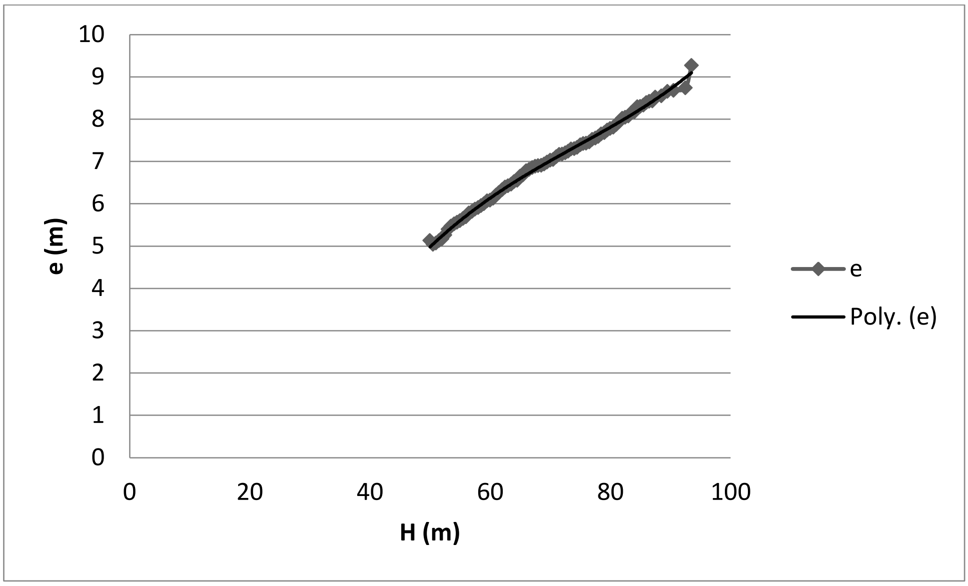

Figure 6: Relation between (H & e) for empty reservoir

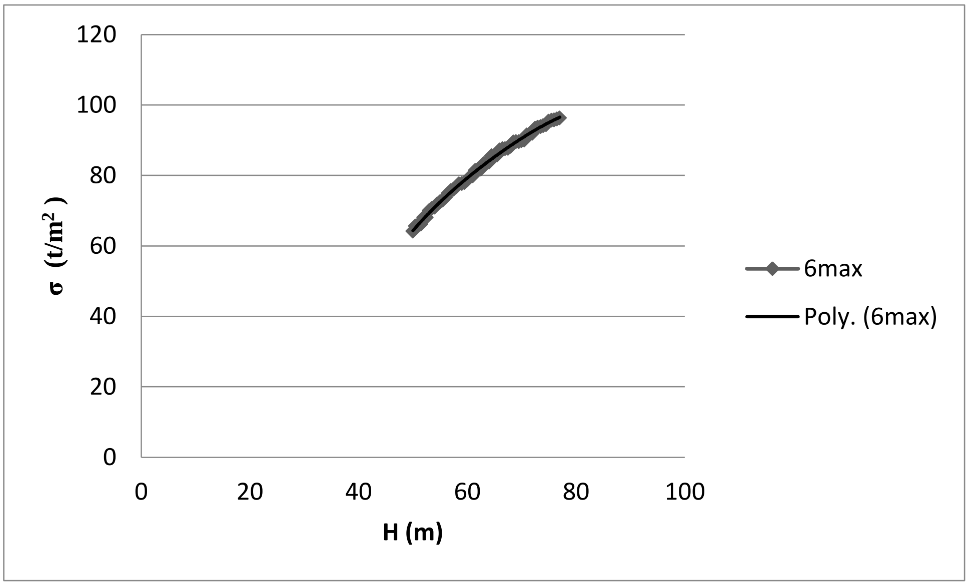

Figure 7: Relation between head (H) and (σ) for empty reservoir

6. Conclusions

The section of gravity dam should be chosen in such a way that it's the most economic section and satisfies all the conditions and requirements of stability. The higher the elevation gets the more incensement in base required to achieve stability.

In present project, the following conclusions have been obtained:

1- That for full reservoir , the values of (b) is increased uniformly as the head in reservoir increase .The range of variation of (b) will take more values when (H) becomes greater than (80) m.

2- The fourth degree of polynomial represents the best function to reflect the relation between (b) and (H) which can be used to estimate the required values of additional base part for dam safety.
3- For full reservoir, the values of (e) are increasing when (H) is getting higher and the relation between these two parameters can be expressed by fourth degree of polynomial function with high value of correlation coefficient.
4- The relation between (H & σ) for full reservoir is directly proportional and the fourth order of polynomial function is seem to be the best representative of the relation.
5- For empty reservoir , both of (σ) and (e) are directly proportional with (H).The range of values are less than those obtained from the analysis of full reservoir condition .The relations can also be expressed by fourth degree of polynomial functions with high values of correlation coefficients.

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