A Matlab based GUI application in Hydroseismicity of the Koyna – Warna Region, India.

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ABSTRACT

Hydroseismicity was proposed to explain the occurrence of intraplate earthquakes in regions. Koyna - Warna region one of the reservoir triggered seismicity zone in India, which is an example of intraplate earthquake region. The seismicity is continuing after 45 years of impoundment of the Koyna reservoir in 1961 and 25 years of impoundment of Warna reservoir in 1985. The excess of previous maximum water level, the annual rise of water level in the reservoirs and filling rate of these reservoirs are some of the important factors in increasing the pore pressure. In this study, we used the daily changes in the water levels in both the reservoirs and calculated the pore pressure from starting of the impoundment of the reservoir up to 2008. We also studied the pore pressure changes with depth for various values of hydraulic diffusivity. An automatic formulation has been developed in Matlab for computing and plotting the pore pressure history.

Key words: Koyna reservoir, pore pressure diffusion, Reservoir-induced seismicity, stress memory, strain hardening.

1. INTRODUCTION

The Koyna -Warna region in the Southwestern part of the Deccan volcanic province is a unique site in the world from seismological point of view. Globally, Koyna, located near the western coast of India, continues to be the most significant site of reservoir triggered earthquakes, which started soon after the impoundment of Shivaji Sagar Lake created by the Koyna Dam in 1962. The site also has the distinction of having so far the largest and most damaging reservoir triggered earthquake of M 6.3, on December 10, 1967 (Gupta; 1992, 2002, and Gupta et al.2002). From 1967 to till today nearly ten earthquakes of magnitude greater than M>5 occurred in this region .Until 1992, earthquakes near Koyna Dam were mostly confined to a 20 km long seismic zone extending south of Koyna Dam. However, during 1993-94 a

southward shift in the earthquake activity was observed, and it was attributed to the filling of the Warna reservoir (Rastogi et al., 1997), located south-east of Koyna at a distance of about 35 km. From all these observations it is seen that earthquakes in Koyna -Warna region are confined to an epicenter region of about 30×15 km^2 (Fig.1). Pore-pressure changes occur near a reservoir in response to lake-level changes. Although these processes are at work near almost all reservoirs, only at some locations do they lead to perceptible seismicity.
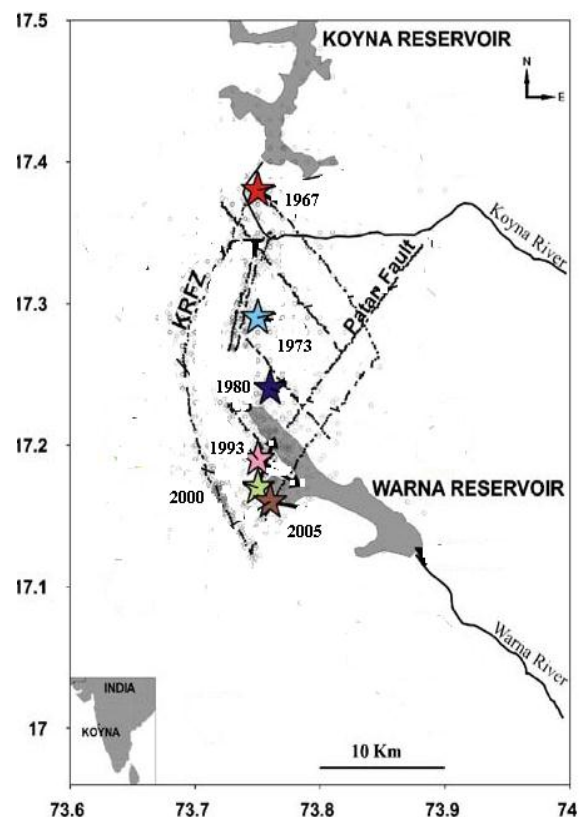
Fig 1: Location of the Koyna – Warna Reservoirs, Star (*) indicates the earthquakes of magnitude greater than or equal to 5.

The mechanism of reservoir triggered seismicity (RTS) is controlled by various factors like the ambient stress

field, availability of faults/fractures, hydro geologic properties of the medium and the hydraulic and spatial characteristics of the reservoir. Impoundment of reservoirs and changes in lake levels can trigger earthquakes by two processes of stress modifications i.e. direct loading effect of the reservoir and diffusion through various faults and fractures.

Graphical user interface **(GUI)** packages in Matlab are becoming very popular in scientific research areas. Witten (2004) developed a sequence of Matlab m-files and two graphical user interfaces to display raw or processed geophysical data to produce the final graphics. In this work, we developed a simple graphical user interface viewer, which is a MATLAB based software consisting of m-files and it computes the pore pressure changes. This GUI based Matlab utility is to understand the pore pressure changes for different cases. The existing models give the different input limitations like hydraulic diffusivity, etc. Here, we incorporated the deterministic as well as random values for the hydraulic diffusivity in the pore pressure diffusion equation and showed the results for general cases. The results are useful in any field applications.

2. MATHEMATICAL FORMULATION

Roeloffs (1988) calculated the pore pressure due to reservoir lake level changes behind a dam with time 't' and at a depth 'z'. The total pore pressure p (z, t) can be expressed as the combined effect of diffused pore pressure and undrained pore pressure. (Talwani, 2007)

$$p(z,t) = (1-\alpha).p_o erfc[z / \sqrt{(4ct)}] + \alpha.H(t).p_o$$

(1)

And

$$\alpha = B.(1-v_u)/[3.(1-v_u)]$$

Where erfc is the complementary error function, H(t) is the Heaviside unit step function, B is the Skempton's coefficient, v_u is the undrained Poisson's ratio, z is the depth beneath the reservoir, p_o is the vertical stress at a depth z = 0, c is the hydraulic diffusivity and t is the time. The pore pressure increase due to compression (undrained response) at a distance r from the reservoir is

$$\Delta P_u(r) = -B\Delta\sigma_{kk}/3 \qquad (2)$$

Where $\Delta\sigma_{kk}/3$ is the change in the mean stress at the given distance r. Talwani et al , 1999 showed that the undrained response is around 20 kPa for an earthquake at a depth of 4 km and a radial distance of 2 km with water height of 70 m. Gomez and Talwani, 2009 calculated the untrained effect and the values are lower than the expected and then concluded that the changes in pore pressure are due to diffusion process only. Considering only the diffused pore pressure component in the equation, it reduces to

$$p(z,t) = p_0.erfc[z / \sqrt{(4ct)}]$$

(3)

The pore pressure at a distance away from the reservoir has been calculated by Rajendran and Talwani (1992) and Chen and Talwani (2001) then it is revised for one-dimensional pore pressure diffusion using the superposition principle (Roeloffs (1988)), it can be expressed as

$$P_n = \delta p_1.erfc[r / \sqrt{(4cn\delta t)}] + \\ \delta p_2.erfc[r / \sqrt{(4c(n-1)\delta t)}] + \\ \delta p_3.erfc[r / \sqrt{(4c(n-2)\delta t)}] + - - - - - - + \\ \delta p_n.erfc[r / \sqrt{(4c\delta t)}]$$

(4)

Where δt is a fixed increment of time (i.e., 1day), n is the number of time increments (number of days), δp_0 is the water load change for the nth day, r is the distance form the reservoir, c is the hydraulic diffusivity and erfc is complementary error function.

3. NUMERICAL RESULTS AND DISCUSSIONS:

Water level data in the Koyna reservoir is considered from the impoundment of the Koyna reservoir i.e., from 1961 to 2008 and also for the Warna reservoir i.e., from 1985 to 2008 showed in Fig 2. The pore pressure diffusion is restricted to the faults and fractures (Cornet and Yin, 1995; Talwani et al., 1999; Evans et al., 2005), based on that the hypocenter distance 'r' is calculated by using the hypocenter depth and the horizontal distance along the surface. Considering the uncertainties in the horizontal distance and the depth, the range of the hypocenter distance are taken as minimum 5 km

to maximum 30 km. Talwani et al. (2007) has considered the reservoir water level data up to 2000 and given the range of hydraulic diffusivity between 1 to 10 m^2/s . We considered these values of hypocenter distance and the hydraulic diffusivity to calculate the diffused pore pressures in the Koyna-Warna region.

a

b
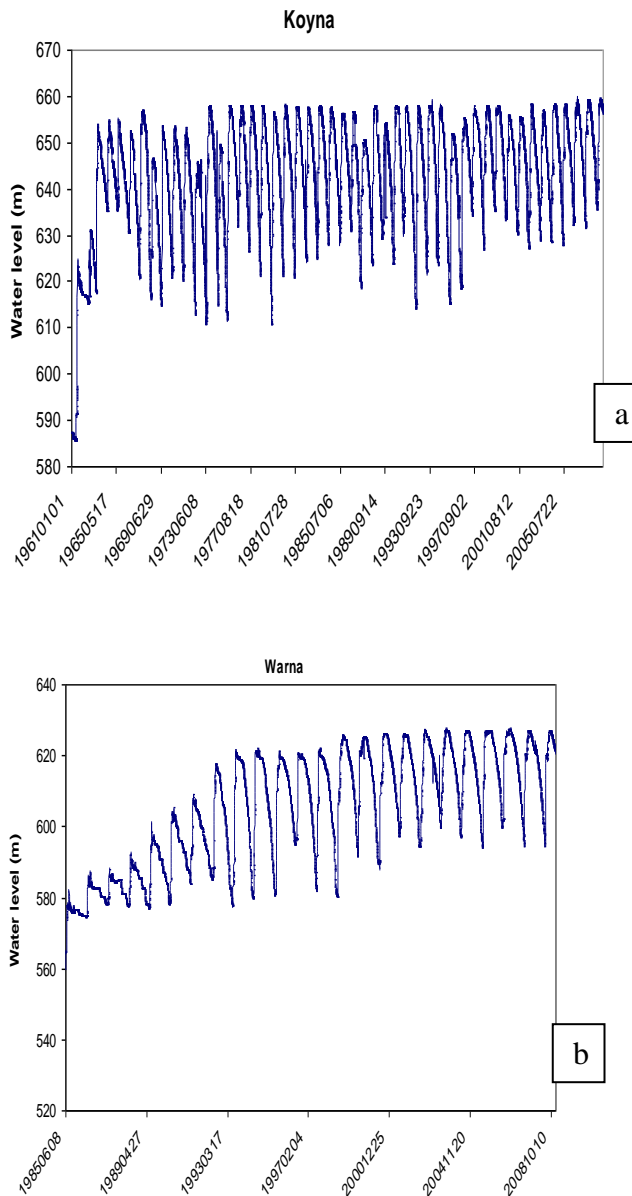
Figure 2: (a) Koyna reservoir water level from 1961 to 2008. (b) Warna reservoir water level from 1985 to 2008.

The numerical results of pore pressure changes have shown in the Fig. 3 for a constant value of hydraulic diffusivity for a particular value of r in Koyna reservoir. In GUI the input-controlling limitations like distance 'r', the hydraulic diffusivity 'c' are given directly on the screen in the boxes and the results calculated instantaneously and graphically displayed on the screen and the corresponding numerical values are saved in a file.
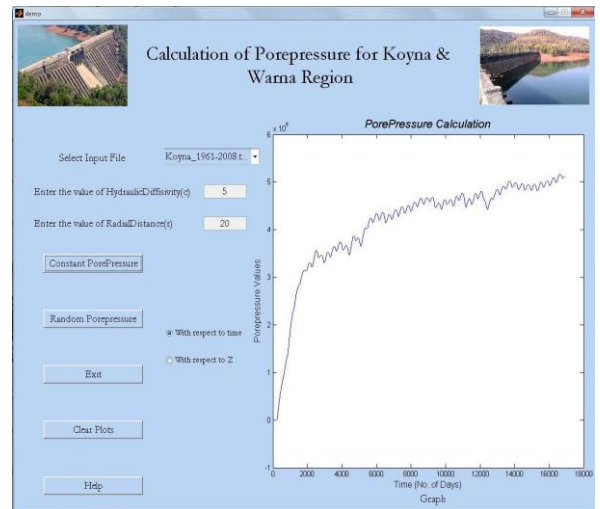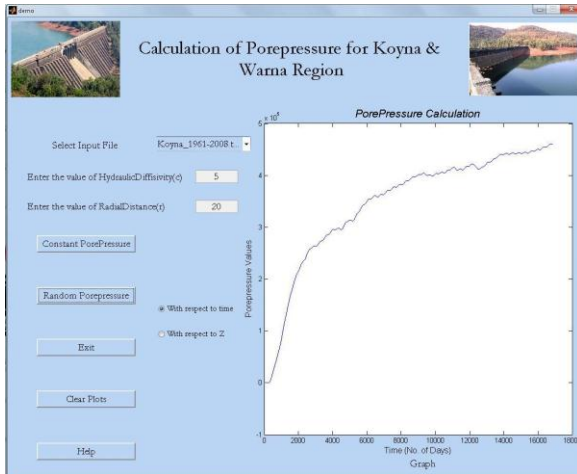

Fig 3: GUI of pore pressure calculations at Koyna from 1961-2008 for hydraulic diffusivity 5 m^2/sec.

3.1 KOYNA 1961-2008

The pore pressure has been calculated for constant values of r and c from the staring time of the pore pressure accumulation i.e. from the time of impoundment of the reservoir (1967 for Koyna) to end of the data set i.e., up to 2008 in this case. The calculated pore pressure for a particular data sets with c = 1 r=10; and c=5r=10; and further c=10 r=10 are obtained as 50 kPa, 58 kPa and 61 kPa respectively. From these values it is concluded that the maximum build pore pressure till now is around 61 kpa.

To consider the uncertainty in the hydraulic diffusivity (Talwani, 2007), the values of hydraulic diffusivity are generated randomly between 1 and 10 with the mean 5. The numerical values of the pore pressure have been calculated for all these different values of diffusivity. From these results the mean and the standard deviation of the pore pressure have been calculated for 50 random values of c. The mean and one standard deviation of the pore pressure are shown in Fig 4.
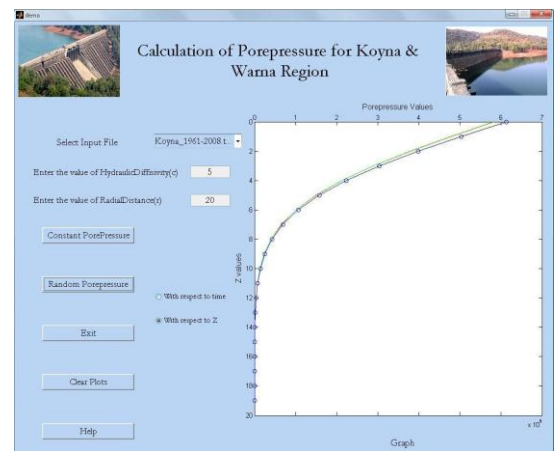
Fig 4: GUI of pore pressure calculations at Koyna from 1961-2008 for random hydraulic diffusivity 5 m^2/sec.

The pore pressure at different times after the impoundment of the reservoir or from the starting time of the event of magnitude greater than **5** with depth has also been calculated at different distances r and displayed in the plot as Fig 5. In this calculation the constant value of hydraulic diffusivity and a particular value of r have been considered. From the results it is seen that the pore pressure decreases with depth and will become zero at certain depths at different cases. In Koyna region mostly the depth is around 10 to 15 km and it can be correlated with the maximum depth of occurrence of the Koyna earthquakes. Based on these values one can conclude that the maximum epicenter depth of region for the earthquakes of M > 5.
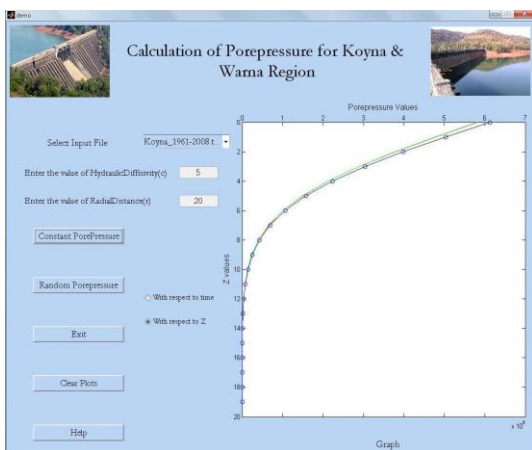
Fig 5: GUI of pore pressure calculations at Koyna from 1961-2008 for hydraulic diffusivity 5 m^2/sec with respect to Z.

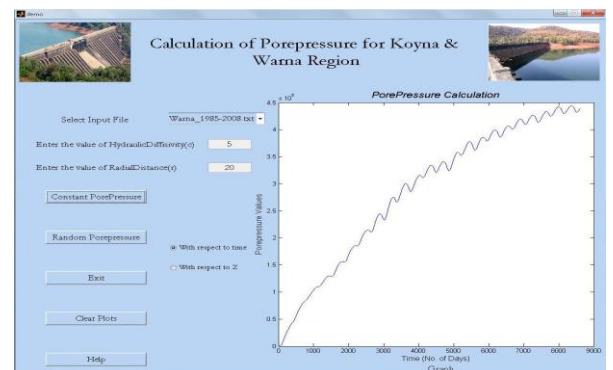The hydraulic diffusivity in Koyna - Warna region are given from 1.0 m^2/s to 10m^2/s (Talwani, 2007) .To see the full range of changes in pore pressure due to hydraulic diffusivity the fifty values of hydraulic diffusivity are generated randomly between 1m^2/s and 10 m^2/s and used to compute the pore pressure with depth at different times. From the results the mean and standard deviation of the pore pressure with depth has been calculated and displayed in Fig 6. These results also show the maximum depth of nullified pore pressure is not more than 15 km.

Fig 6: GUI of pore pressure calculations at Koyna from 1961-2008 for random hydraulic diffusivity with respect to Z.

3.2 WARNA 1985-2008

The pore pressure with time has been calculated from 1985 to 2008 for Warna reservoir water level data for particular values of r and c and shown in Fig 7. Here, the input data file will be given in the box on the screen along with the other input values like distance r and hydraulic diffusivity c. The results show that the maximum value of pore pressure is 55 kPa.
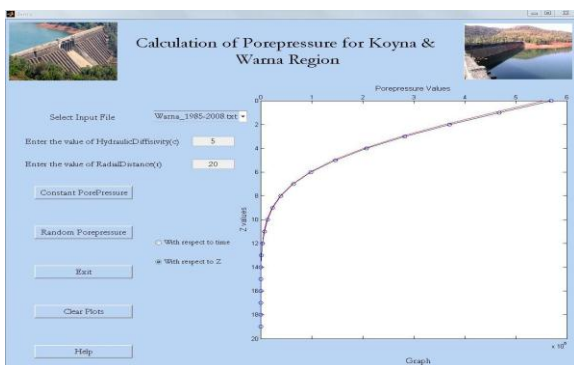

Fig 7: GUI of pore pressure calculations at Warna from 1985-2008 for hydraulic diffusivity 5 m^2/s.

To see the uncertainty in the hydraulic diffusivity on the pore pressure the values hydraulic diffusivity between 1 and 10 m^2/s is generated randomly and corresponding mean pore pressure values are computed and plot the error bounds on pore pressure history in Fig 8.
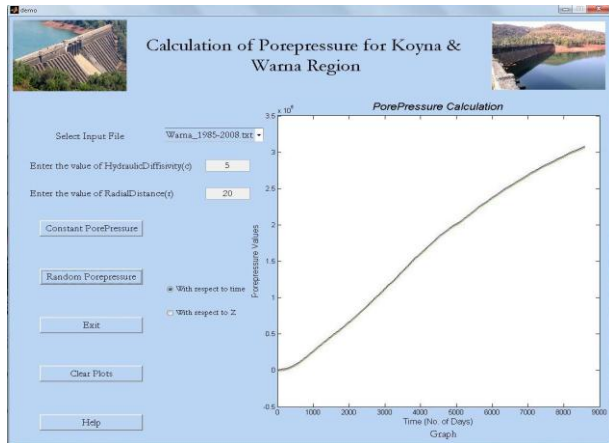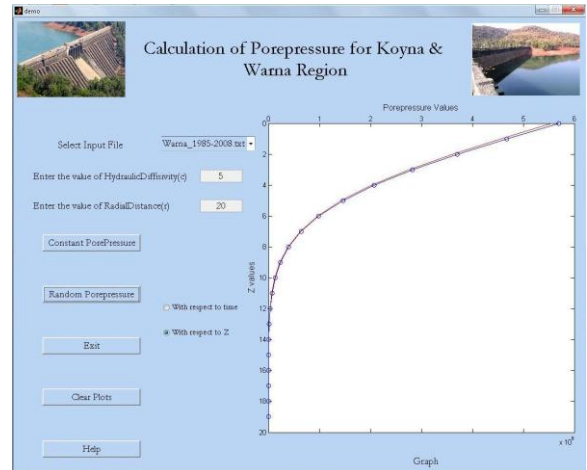

Fig 8: GUI of pore pressure calculations at Warna from 1985-2008 for random hydraulic diffusivity.

A package has been developed to see the pore pressure variation with depth for constant value of c. The numerical results have been calculated for pore pressure with depth at different times and showed in Fig 9. The pore pressure decreases with depth from the initial pore pressure P (0) at a time t = 0 years, the green curve in the Fig. 9 shows the pore pressure with depth at t = 10 years. The pore pressure reaches to zero at depth Z = 12 Km. these result gives the validation of the focal depth for most of the Koyna - Warna events are not exceeding these depths. The mean and one standard deviation of pore pressure with depth is also displayed in Fig.10 for 50 random valued of the hydraulic diffusivity for Warna reservoir water levels.

Figure 9: GUI of pore pressure calculations at Warna from 1985-2008 for hydraulic diffusivity 5 m^2/sec with respect to Z.

Figure 10: GUI of pore pressure calculations at Warna from 1985-2008 for random hydraulic diffusivity with respect to Z.

4. CONCLUSIONS:

The seismicity in the Koyna-Warna region is curbed in a very limited area. The earthquakes in the region are being influenced by increase in pore pressure due to reservoir load in both the Koyna and Warna reservoirs. The principal mechanism of triggering earthquake activity is the diffusion process in the Koyna-Warna region, which generates changes in pore fluid pressure at hypo central depths. The GUI utility is developed by using the Matlab to understand the pore pressure changes for different values of hydraulic diffusivity and the radius of the dominated seismicity of the region with time and depth respectively. Pore pressure changes with depth reveals that the epicenter distance of the Koyna - Warna earthquakes are not greater than 15 Km. The pore pressure change with the time shows that the maximum build up pore pressure is 61 kPa in the Koyna- Warna region. This GUI package is useful to analyze the pore pressure history and achieve good generalized performance.

5. ACKNOWLEDGEMENTS:

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