# Hydrodynamic Sub-Pressure Incremental Pattern in Dam-Reservoir Interaction System Subjected to Far Field and Near Field Ground Motions

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## Abstract

Hydrodynamic pressure distribution on upstream face of the dam depends on several parameters such as distance from fault, natural frequency of dam and etc. distance from fault cause significant effect on amplitude and frequency content of the motions. Frequency contents could cause significant effects on dam responses and hydrodynamic pressure distribution which is main goal of this paper. In hydrodynamic pressure fluctuations, sub-pressure occurrence cause cavitation problem on upstream face of the dam. Although cavitation effects in this case could not cause severe damage on dam body but it is not negligible especially near outlet structures. Results show frequency contents of the ground motion has a significant effect on hydrodynamic pressure distribution and sub-pressure occurrence.

**Keywords: hydrodynamic sub-pressure, cavitation, dam-reservoir interaction, near field, far field.**

## 1. INTRODUCTION

Dynamic analysis of dam-reservoir-foundation system and dam responses highly depends on frequency contents of the ground motions. Frequency contents of the ground motions also depends on several parameters. Distance from fault is the most important parameter which affect the frequency contents of the recorded motions. Far field recorded motions have wider frequency contents than the near fields motions.

Chopra et al in 2001, investigated on the effect of near field and far field ground motions on the behavior of the structures. They concluded, structures near the fault need more resistance to ground motions than the far structures [1]. Bayraktar et al in 2009 investigated on the effect of near field and far field motions on response of concrete gravity dam. The results show, displacements and stresses in dam body are greater in case of near field motions [2]. Hajihoseini et al in 2011, investigated on the damage pattern on concrete gravity dams due to near field and far field ground motions. They considered Koyna dam on rigid body and concluded the dam body cracked under near field recorded motions of Bam earthquake. The cracks located on downstream face where the slope changes [3]. Zhang et al in 2013 studied the effect of near field and far field ground motions on dynamic response of dam-reservoir-foundation system. They selected Koyna dam as their case study and the results show displacement response of the dam in case of near field motions are completely different with far field motions [4]. Roshanravan et al in 2015 studied the recorded vibrations on Karun3 dam using system identification and continues wavelet transform (CWT) [5].

In this paper, hydrodynamic Sub-pressure and cavitation occurrence on upstream face of the dam for near field and far field ground motions investigated. Frequency of hydrodynamic pressure also calculated.

## 2. CONTINUES WAVELET TRANSFORM (CWT) METHOD

CWT is a mathematical transform which can analyze signals in both time and frequency domain with variable resolution. The main equation of CWT is:

$$CWT_x^{\psi}(a,b) = \frac{1}{\sqrt{a}}\int_{-\infty}^{+\infty} x(t)\overline{\psi}\left(\frac{t-b}{a}\right)dt \qquad (1)$$

Where “b” and “a” are translation and scale parameters respectively. “x” is signal and “t” indicates that the signal is in time domain and “ψ” is wavelet function. In this research the modified Morlet wavelet is used as wavelet function. Mathematical representation of modified Morlet wavelet is:

$$\psi(t) = \frac{1}{\sqrt{\pi f_b}} e^{i2\pi f_c t} e^{-t^2/f_b} \tag{2}$$

Where $f_b$ and $f_c$ are band pass and central frequency of wavelet respectively.
As mentioned above Wavelet transform is a multi-resolution transform that resolutions are depend on wavelet parameters. Wavelet time and frequency resolutions represents as:

$$\Delta t_i = \frac{f_c}{f_i} \frac{\sqrt{f_b}}{2} \tag{3}$$

$$\Delta f_i = \frac{f_i}{f_c} \frac{1}{2\pi\sqrt{f_b}} \tag{4}$$

As is clear by changing the value of $f_b$ and $f_c$, different resolutions obtained. So these parameters should be optimized to obtain better results. Here, a trial and error process hired to optimize wavelet parameters. The requested domain for wavelet parameters should satisfy Equation5 [6].

$$\sqrt{f_b} f_c = (2\alpha) \frac{f_{i,i+1}}{2\pi \Delta f_{i,i+1}} \tag{5}$$

Where $\alpha$ is the parameter defining the overlap between the adjacent Gaussian windows of the modified Morlet wavelet. Kijewski and Kareem suggested the empirical value $\alpha$=2 is generally sufficient to distinguish two adjacent frequency components [7].

## 3. FINITE ELEMENT MODEL

The Koyna Dam is one of the largest dams in India. The dam has withstood many earthquakes in the recent past, including the devastating 1976 Koynanagar earthquake, resulting in the dam developing some cracks. Dam height, crest length and reservoir capacity of the dam are 103 m 807.2 m and 2.8 MCM respectively. Koyna dam-reservoir-foundation system modeled using ABAQUS software. Finite element model of the Koyna dam showed in figure 1. Reservoir length and foundation depth are considered 3 times and 2.5 times of the dam height respectively.

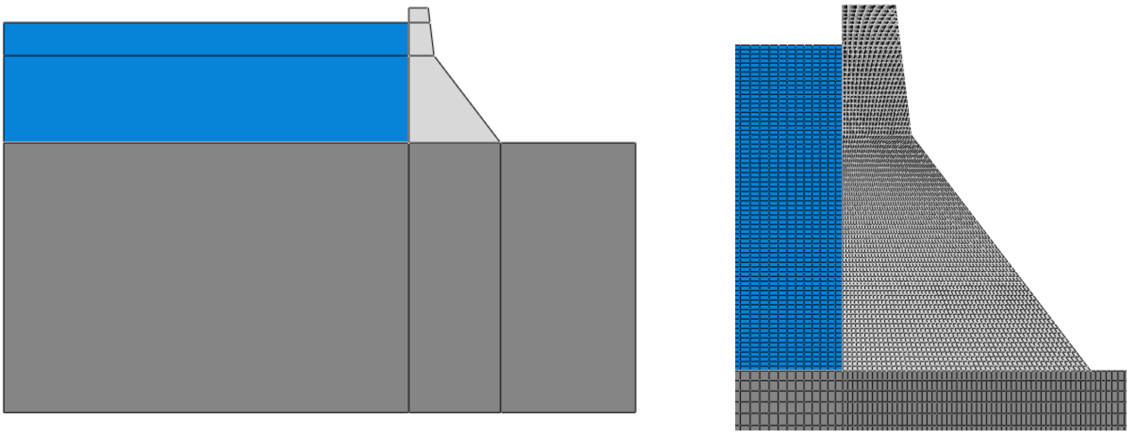

**Figure 1-Finite element model of dam-reservoir-foundation system**

## 4. GROUND MOTIONS

As discussed above, the main goal of this paper is to investigate the sub-pressure on upstream face of the dam due to near field and far field ground motions and compare them to each other. So near field and far field recorded motions of Kobe earthquake hired to analyze the finite element model. Horizontal and vertical components of the ground motions and their frequency contents showed in figures 2 to figure 9.

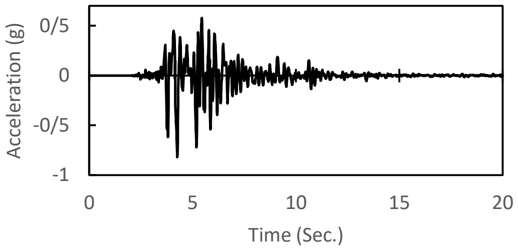

Figure 2-Horizontal component of Kobe near field motion

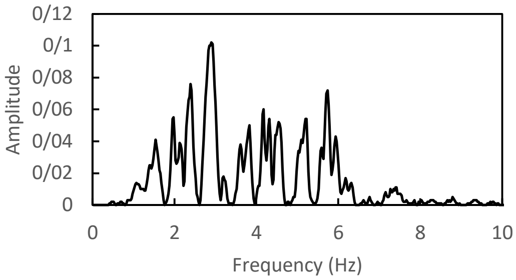

Figure 3-PSD spectrum of horizontal component of Kobe near field motion

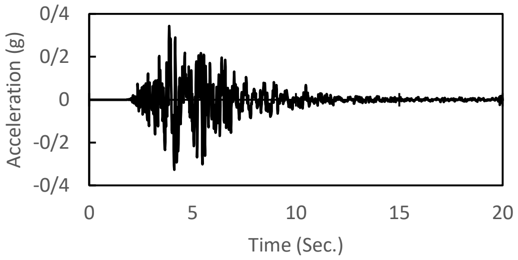

Figure 4-Vertical component of Kobe near field motion

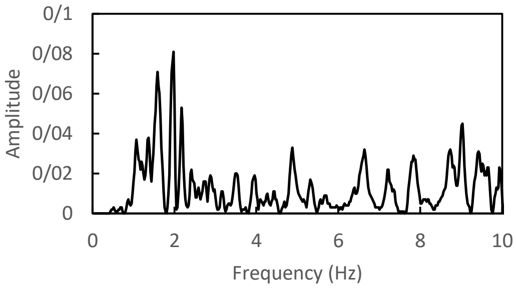

Figure 5-PSD spectrum of vertical component of Kobe near field motion

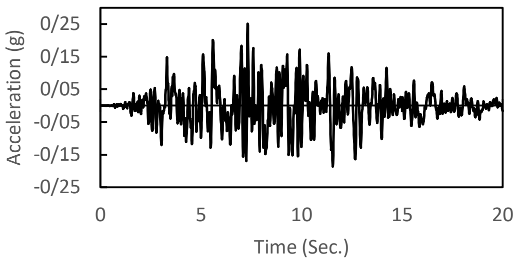

Figure 6-Horizontal component of Kobe far field motion

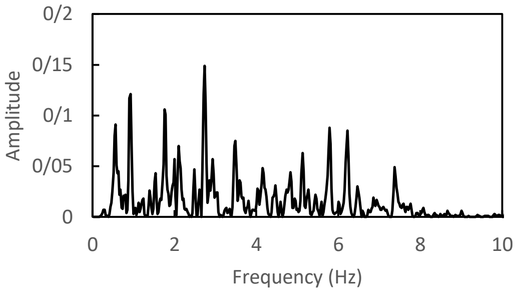

Figure 7-PSD spectrum of horizontal component of Kobe far field motion

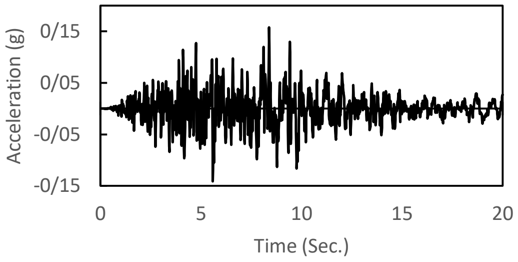

Figure 8-Vertical component of Kobe far field motion

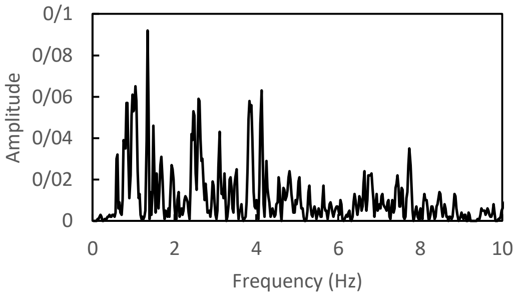

Figure 9-PSD spectrum of vertical component of Kobe far field motion

Far field recorded motion belongs to Kakogawa station which is 22.5 km far from the site and near field recorded motion belongs to Kjma station which is 1 km far from the site.

## 5. RESULTS

Recorded motions showed in previous section applied to finite element model of Koyna dam-reservoir-foundation system. transient stress distribution in dam body and hydrodynamic pressure fluctuations in the reservoir achieved. Hydrodynamic pressure time history and its frequencies presented below. Location and magnitude of maximum hydrodynamic sub-pressure on upstream face of dam body also discussed later.

### 5.1. FLUCTUATION FREQUENCY OF HYDRODYNAMIC PRESSURE

Hydrodynamic pressures on upstream face of the dam are due to impact of dam to water behind it. So it is expected that identified frequency of dam motions and hydrodynamic pressure be the same. The frequency of hydrodynamic pressure fluctuations also highly depends on the frequency contents of the ground motions. In fact, hydrodynamic pressure fluctuations depend on both dam body natural frequencies and ground motion frequency contents.

Hydrodynamic pressure time history at dam heel due to Kobe near field is showed in figure10 and its identified frequency using CWT presented in figure11. Hydrodynamic pressure time history at dam heel due to far field motions and its CWT also presented in figure12 and figure 13 respectively.

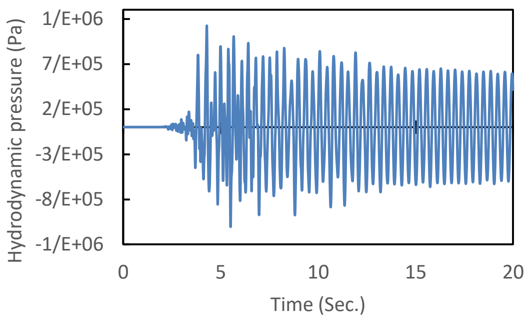

**Figure 10-Hydrodynamic pressure at dam heel due to Kobe near field motion**

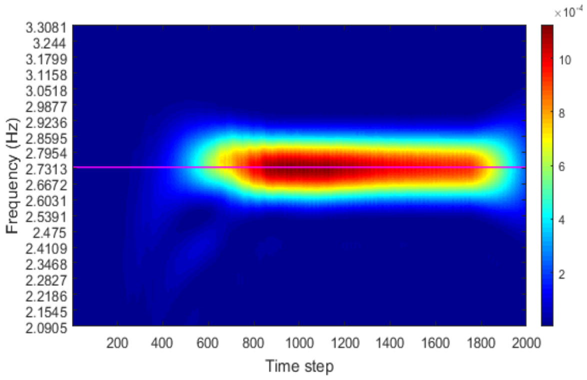

**Figure 11-CWT of hydrodynamic pressure at dam heel due to Kobe near field motion**

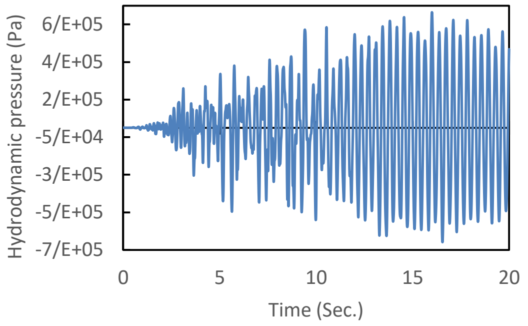

**Figure 12-Hydrodynamic pressure at dam heel due to Kobe far field motion**

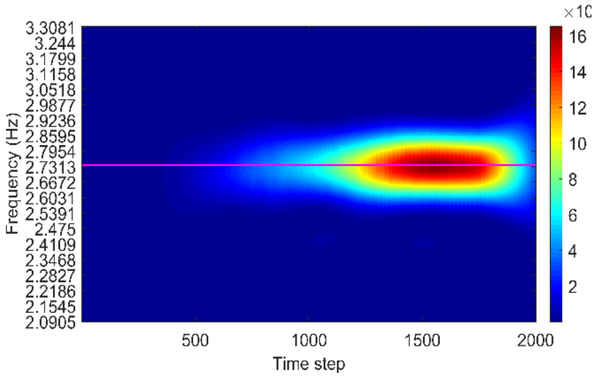

**Figure 13-CWT of hydrodynamic pressure at dam heel due to Kobe far field motion**

From the figure 10 to figure 13, it is obvious that hydrodynamic pressure due to far field motions have wider frequency contents and also it takes more time to take a constant frequency. On the other hand, hydrodynamic fluctuations in case of near field motions have a constant frequency in most of the earthquake duration. It is related to far field input motions which have wider frequency contents than the near field motions. Both figure 11 and figure 13 show similar frequency which is about 2.73 Hz. It shows in both cases, dam body motions frequency converged to 2.73 Hz in lapse of time.

### 5.2. HYDRODYNAMIC PRESSURE INCREMENTAL PATTERN

In previous section, hydrodynamic pressure time history at dam heel presented. Here, hydrodynamic pressure time history on upstream face of the dam presented as an incremental pattern in figure 14 and figure 15. These patterns show hydrodynamic pressure on upstream face of dam body in all time steps.

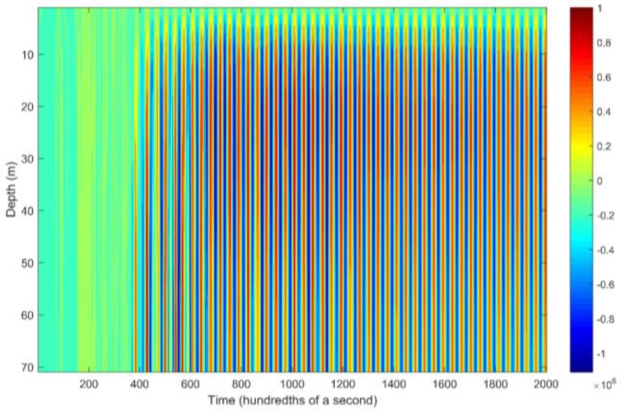

**Figure 14-Incremental pattern of hydrodynamic pressure distribution due to Kobe near field motion**

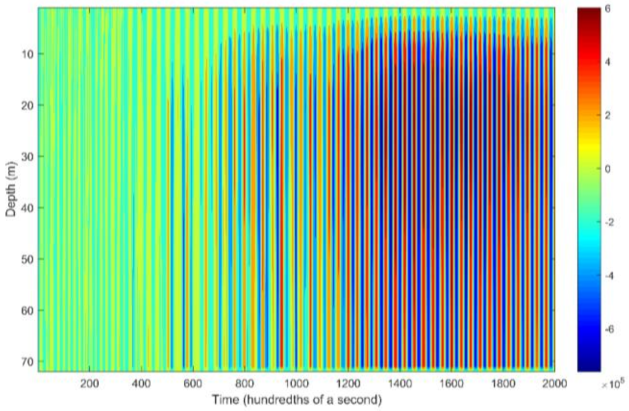

**Figure 15-Incremental pattern of hydrodynamic pressure distribution due to Kobe far field motion**

As shown in figure 14, the fluctuations are approximately uniform which means in a specific time, all dam upstream face is under either positive or negative pressure. In another word, there is no time step in which positive and negative pressure occur simultaneously. Maximum hydrodynamic sub-pressure in case of near field ground motion occurred in 5.51 s at dam heel. But in the case of far field ground motion, the maximum hydrodynamic sub-pressure occurred in 13.63 s at dam mid height. With respect to figure 11 and figure 13 these time steps are those in which hydrodynamic pressure fluctuations take 2.73 Hz as constant frequency.

### 5.3. STRESS DISTRIBUTIONS AND HYDRODYNAMIC CONTOURS

Stress distribution in dam body and hydrodynamic pressure distribution in reservoir, at the maximum hydrodynamic sub-pressure time step, due to near field and far field ground motions are presented in figure 16 to figure 19.

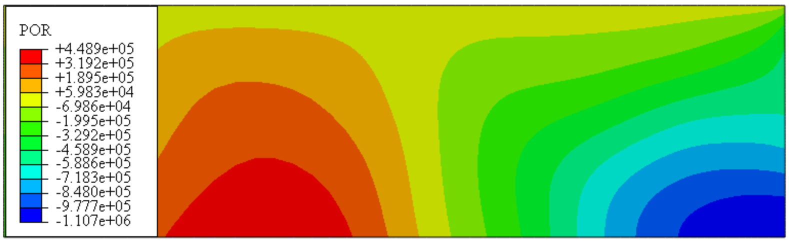

**Figure 16-Contours of hydrodynamic pressure in 5.51 second due to Kobe near field motion**

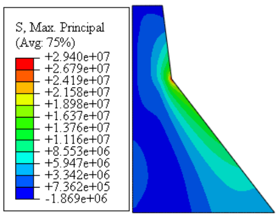

**Figure 17-Contours of max principal stress in 5.51 second due to Kobe near field motion**

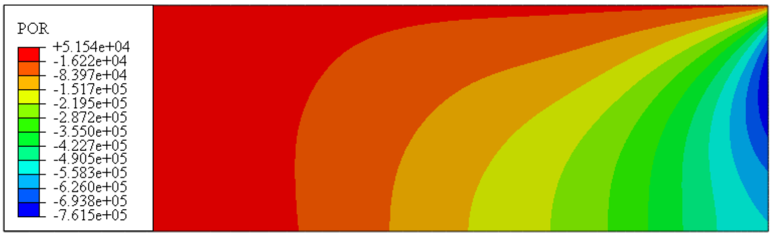

**Figure 18-Contours of hydrodynamic pressure in 13.63 second due to Kobe far field motion**

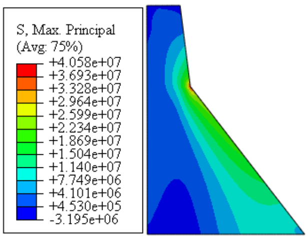

**Figure 19-Contours of max principal stress in 13.63 second due to Kobe far field motion**

## 6. CONCLUSIONS

Hydrodynamic pressure distribution on upstream face of the dam has been studied in this paper. The main goal of this paper is to investigate the effect of near field and far field ground motions on hydrodynamic sub-pressure which cause cavitation on upstream face of the dam. For this purpose, Kobe earthquake records hired to analyze Koyna gravity dam. Far field ground motions have wider frequency contents and also lower amplitude. Because of these differences in frequency contents, they could affect different modes of the dam.

In case of near field motion, in the initial time steps hydrodynamic pressure shows a constant frequency of 2.73 Hz but on the other hand in case of far field motion, it takes time to show constant frequency of 2.73 Hz. It is because of wider frequency range of far field motion. In addition, the results show maximum hydrodynamic sub-pressure occurred just when hydrodynamic pressure fluctuations converged to constant frequency of 2.73 Hz which happen in 5.51 s and 13.63 s for near field and far field motion respectively. Wider frequency content for far field motion also caused hydrodynamic pressure in low amplitude in initial time steps. Another difference between these two cases is about location of maximum hydrodynamic pressure which is in dam heel for near field motion and mid height of the dam for far field case.

## 7. REFERENCES

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