Advances in Environmental Biology, 9(2) January 2015, Pages: 645-650

AENSI Journals

Advances in Environmental Biology

ISSN-1995-0756 EISSN-1998-1066

Journal home page: http://www.aensiweb.com/AEB/

Study of Dynamic Behavior of Intake Towers Using Numerical Modeling

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ARTICLE INFO

Article history:
Received 12 October 2014
Received in revised form 26 December 2014
Accepted 1 January 2015
Available online 17 February 2015

Keywords:
Intake tower, Finite element software, finite elements, Numerical modeling.

ABSTRACT

Hydraulic structures such as intake towers are much important in dams due to their role in the period of dam construction and utilization. Hence, the mentioned structures must have a high immunity not only in normal conditions; but also, in critical conditions such as earthquake. In the resent study, an intake tower has been modelled numerically using finite element software by application of static and dynamic loads. The results indicate that, seismic response of the intake tower at x direction had a more appropriate situation than y direction due to lower hydrodynamic pressure.

To Cite This Article: Mohammad Doosti, Samad Zahermand, Seyedtaha Tabatabayi Aghda, Mohammadreza Keshavarz., Study of Dynamic Behavior of Intake Towers Using Numerical Modeling. ***Adv. Environ. Biol., 9(2),*** *645-650, 2015*

INTRODUCTION

Intake tower has two major and important duties when deviation and utilization. At deviation time, it acts as an entrance structure and conducts the flood into the deviation system, also it acts as intake tower when utilization by installation and construction of ducts, valves and lower discharger. Intake towers are mostly as concrete and high constructions with some valves for water discharge. Most of these structures have a control room to adjust and discharge the water of reservoir for public services such as drinking water, electricity power production, helping to the reservoir discharge in case of emergency and permission to the lake water level reduction for specific inspection and maintenance. Intake towers can be located inside or at contacting with concrete dams body or outside the dams. Hydraulic structures of water have interaction through hydraulic on the common surface of structure-water. Dynamic interaction between reservoir and intake tower is estimated using to add dynamic loads developed by Goyal and Chopra [4]. Generally during the earthquake, the structures are vibrated which causes vibratory movements of upstream surfaces which are in touch with water. These relative place variations of common surface of fluid-structure disturbs the situation of tension in the fluid mass compared to before earthquake and consequently, pressure waves are generated. This oscillatory system which spread in the reservoir fluid, causes to propagate pressure wave and reflection process in rigid border of the reservoir and its open surface. Dynamic reaction of an intake tower during an earthquake may have complicated properties. Water plays an important role inside or outside the tower to form the structure reaction. In the past, the three-dimension behavior of intake tower and reservoir was not considered, and the tower was modelled and investigated as two-dimension with hydrodynamic force and pressure elements as added hydrodynamic mass. Therefore, a three-dimension model of intake tower is needed to be produced for accurate study and design of the mentioned structure. In this regard, a simplified model with real size was selected from an instance intake tower of which geometry and dimensions have been showed.

The considered tower was modeled and analyzed using finite elements software, and was studied affected by static and dynamic loadings. Finite elements analysis is a numerical method of decomposing a complicated system to very small parts named finite elements.

In dynamic loadings, it is assumed that, the structure is at X and Y directions affected by earthquake. In this regard, a three-dimension model of the structure was drawn and then, loading and boundary conditions were applied on that.

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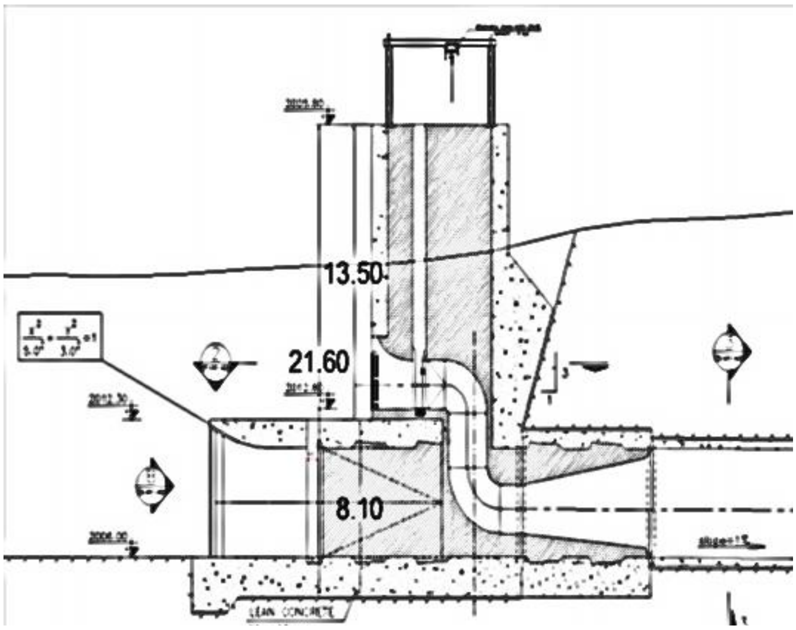

Fig. 1: Geometric dimensions of the studied intake tower.

2- Loading:

Generally, the loads entering the intake tower include:

A) Dead load including the weight of structure, and external load of hydrostatic pressure of water and sediment

B) Internal pressure of the liquids

C) Accidental pressure of which values are not predictable accurately. The loads resulted from temperature variations and effects of earthquake force on the structure and its around.

1-2- Static loading:

1- Dead load resulted from the weight of structure and water on the intake tower

2- Hydrostatic load of water pressure which is calculable through $P=\frac{1}{2}\gamma_{\omega} H^2$ and enters the tower comprehensively.

3- Triangular load resulted from sediment pressure which is calculated by the following equation: $P=\frac{1}{2}k_a \gamma H^2$

2-2- Dynamic loading:

In dynamic loading, dynamic loads of structure vibration and hydrodynamic forces of water around the tower (those occurwhen earthquake occurs) enter the structure in addition to the entered static loads.

To calculate hydrodynamic forces, there are various methods such as Chopra and proposed method of Lahmeyer regulations.

Considering the simplicity of Lahmeyer method (with regard to the available data) and its validity, it can be used to calculated hydrodynamic forces entering the intake tower.

In the mentioned method, hydrodynamic forces entering the intake tower with circular cross section are calculated through the following equation:

$$P=\pi R^2.H.\gamma_{\omega}.k_{hm}.f_{correct}$$

Where:

R: radius of the base, if the tower cross section is as a*b rectangular so: $R=\sqrt{(ab)/\pi}$

H: Height of the intake tower (immersed in water)

γ_{ω}: Specific gravity of water

k_{hm}: Corrected horizontal coefficient of earthquake for flexible structures.

$f_{correct}$: Correction coefficient of hydrodynamic force which is dependent to H/R ratio and is obtained from the curve of Fig. 2.

To compute k_{hm} ,it is necessary to calculate the main frequency period of the intake tower oscillation. Then, oscillation resonance coefficient will be calculable.

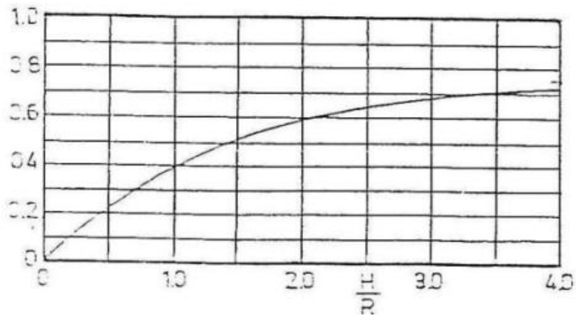

Fig. 2: Correction coefficient of hydrodynamic force.

Accordingly, main frequency oscillation period of charter with uniform mass and cross section is calculated by:

$$T = 1.79 L^2 \sqrt{\frac{q}{gEI}}$$

Where:
L: length of charter
q: mass of charter unit length
I: moment inertia of the cross section
E: elasticity module
g: acceleration of gravity
Considering the main period of oscillation:

$T \leq 0.2 \quad \sec \rightarrow f_{mag} = 1$

$0.2 < T \leq 1.0 \quad \sec \rightarrow f_{mag} = 5T$

$1.0 < T \quad \sec \rightarrow f_{mag} = 5$

After calculation we have:

$K_{hm} = k_h * f_{mag}$

The curve of Fig. 3, can be used to determine the effect point of hydrodynamic force.

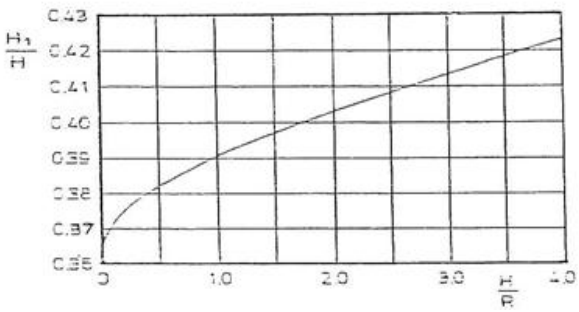

Fig. 3: The effect point of hydrodynamic force.

3- Loading compounds in Load and Resistance Factor Design:

Considering available loads, the loading compounds in concrete structures design by Load and Resistance Factor are as below:

$G_1 : 1.4D + 1.7L + 1.7\ F_w$

$G_2 : 0.75\,(G1 + 1.87\ F_{hd} + 1.87\ EQ)$

Where:
D: dead load (including weight of structure, weight of water and weight of soil)
L: Live load
F_w : Static side pressure of the fluid.
F_{hd} : Dynamic side over pressure while earthquake.
EQ:Earthquake force caused by vibration of different parts of the structure.

4- Calculation of the entered loads:

For calculation of static and dynamic loads entering the intake towers, the following parameters have been considered:
- Internal friction angle of the sediment materials.
- Specific gravity of the sediment materials at saturated state.
- Specific gravity of water.
- Ratio of horizontal component of earthquake to acceleration of gravity.
- Active coefficient of soil

By having the parameters above, the values of hydrostatics and soil active pressures include:

$$q_w = \gamma_\omega . H$$
$$q_a = k_a . \gamma' . H_s$$

Where:
γ' : Effective specific gravity of sediment
H_s : Height of sediment

Also, considering the dimensions of intake tower we have:

$$L = 1350 \quad cm$$
$$a \times b = 1000 \times 600 \quad cm^2$$
$$\Rightarrow R = \sqrt{(ab)/\pi} = \sqrt{(1000 \times 600)/\pi} = 437.1$$
$$I = 1.8 \times 10^{11} \quad cm^4$$
$$q = 650.7 \quad kg/cm$$
$$E = 217371 \quad kg/cm^2$$
$$g = 981 \quad cm/s^2$$

Therefore, main frequency period of tower oscillation is:

$$T = 1.79\, L^2 \sqrt{\frac{q}{g\,E\,I}} = 1.79 * 1200^2 \sqrt{\frac{732}{981 * 217371 * 6354166667}}$$

Considering $T < 0.2$ so:

$$T = 0.0134 \longrightarrow f_{mag} = 1 \qquad \longrightarrow K_{hm} = k_h * f_{mag} = k_h = 0.17$$

According to the curve of Fig. 2 and the ratio H/R, the correction coefficient can be obtained.

$$\frac{H}{R} = \frac{1350}{437.1} = 2.07 \ \rightarrow \ f_{correct} = 0.6$$

Accordingly, the amount of force entering the intake tower is equal to:

$$P = \pi \times 437.1^2 \times 1350 \times 0.001 \times 0.17 \times 0.6 = 82620 \quad kg$$

According to the figure curve and ration H/R, H_1/H can be obtained. Therefore, the effect point of the force entering the intake tower is 800 m distant above the tower.
In addition to the mentioned forces, the forces resulted from the structure vibration enter the structure too.

5- Investigating various loading states:

After modeling, loading and applying the boundary conditions, it is turn to generate mesh and model resolution.

Figures 4, 5, 6 show the values of the structure displacement caused by static and dynamic loadings.

Type of loading: state 1

Side pressure: side hydrostatic pressure of water- side pressure of sediment and the soil filling around- force of the structure weight.
The maximum generated displacement: 1.9 mm

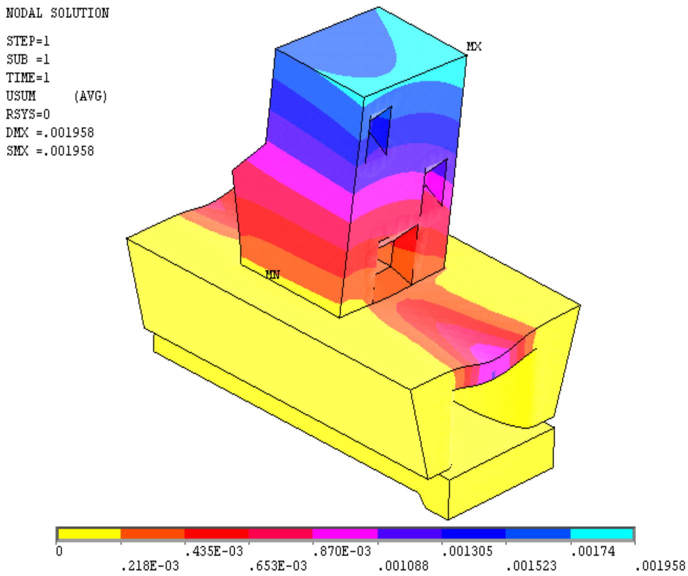

Fig. 4: Distribution of intake tower displacement-static.

Type of loading: state 2

Side pressure: hydrostatic pressure of water- sediment pressure- pressure of the soil filling the back of structure- dynamic overpressure of soil- hydrodynamic pressure of water- weight of the structure- side force of earthquake to the structure.

The maximum generated pressure: 6.1 mm

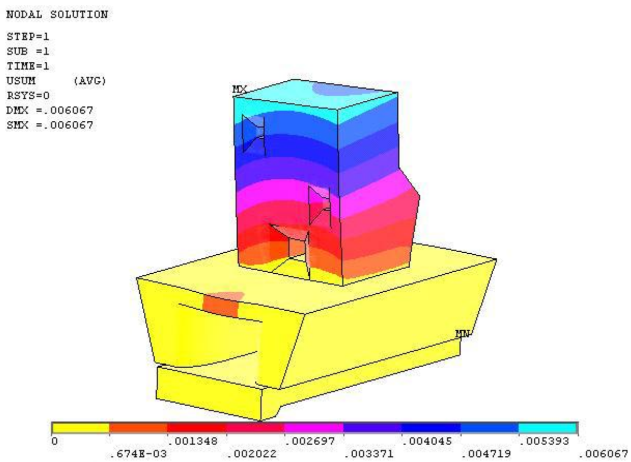

Fig. 5: Distribution of intake tower displacement- dynamic X.

Type of loading: state 3

Side pressure: hydrostatic pressure of water- sediment pressure- pressure of the soil filling the back of structure- dynamic overpressure of soil- hydrodynamic pressure of water- weight of the structure- side force of earthquake to the structure.

The maximum generated pressure: 9.3 mm

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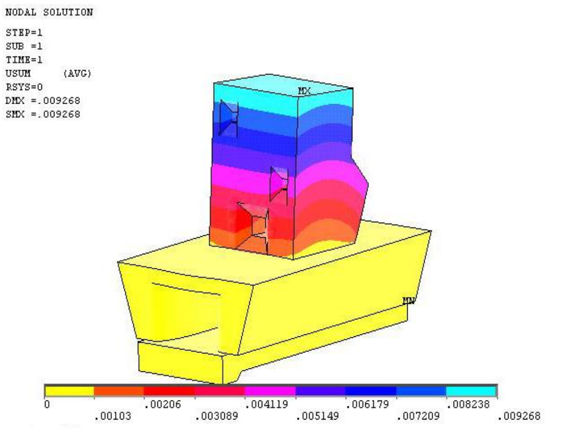

Fig. 6: Distribution of intake tower displacement- dynamic Y.

6- Conclusion:

According to the conducted analysis and modeling using finite element method it is found that, seismic response of the intake tower at x direction had a more appropriate situation than y direction due to lower hydrodynamic pressure.

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