The Probability Of Khuzestan Environmental Pollution Due To Seismic Response Of Upper Gotvand Dam

Zaniar Tokmechi

Department of Civil Engineering, Mahabad Branch, Islamic Azad University, Mahabad, Iran

ABSTRACT

Upper Gotvand Dam or simply the Gotvand Dam is an under construction embankment dam on the Karun River in Khuzestan Province, Iran. It will have an installed generating capability of 2,000 MW which is split into two 1,000 MW phases. It is estimated to be complete in 2015 and is going to become one of Iran's largest power stations. Khozestan is one of the 30 provinces of Iran. It is in the southwest of the country, bordering Iraq's Basra Province and the Persian Gulf. Its capital is Ahwaz and covers an area of 63,238 km². In this paper, the probability of environmental pollution due to heavy metals caused by Upper gotvand dam failure is studied. Finite Element and ZENGAR methods are used to analyze the probability of pollution at dam downstream. Different dam cross sections and various loading conditions are considered to study the effects of these factors on the seismic behavior of the dam. Results show that the effect of the highest cross section is not the most significant for heavy metals pollution at the dam down stream. Pollution coefficient due to stress along Y axis (S_y) is always the determinant pollution. While, in all sections S_x and S_y are the determinant parameter affecting downstream heavy metal pollution and normally are bigger than S_z. And, S_z which can never be a determinant. According to results, when the earthquake accelerations are bigger, maximum pollution coefficient due to tensile stress at dam basement is increased. While, the pollution due the maximum compressive stress at dam basement depends on both earthquake acceleration and loading condition.

Key words: Environmental pollution, Seismic Response, Upper gotvand dam, ZENGAR, FEM.

Introduction

Upper Gotvand Dam or simply the Gotvand Dam is an under construction embankment dam on the Karun River in Khuzestan Province, Iran. It will have an installed generating capability of 2,000 MW which is split into two 1,000 MW phases. It is estimated to be complete in 2015 and is going to become one of Iran's largest power stations (Figure 1).

Historically Khuzestan is what historians refer to as ancient Elam, whose capital was Susa. The Achaemenid Old Persian term for Elam was Huiya, which is present in the modern name. Khuzistan, meaning the Land of the Khuzi refers to the original inhabitants of this province, the Susian people, Old Persian Huza or Huja (as in the inscription at the tomb of King Darius I at Naqsh-e Rostam, the Shushan of the Hebrew sources) where it is recorded as inscription as Hauja or Huja. This is in conformity with the same evolutionary process.
where the Old Persian changed the name Sindh into Hind /Hindustan. In Middle Persian the term evolves into Khuz and Kuzi. The pre-Islamic Partho-Sassanid Inscriptions gives the name of the province as Khwuzestan.

The seismic action on dams is the most important to be considered in dams safety studies and its effects on the environmental pollution (United States Army Corps of Engineers, 1990). In 21st century, hydraulic power exploitation and hydraulic engineering construction have been improved in many countries. Some high dams over 200m, even 300m in height, have been built in many areas of the world (Jianping et al., 2006).

Pollution is the introduction of contaminants into a natural environment that causes instability, disorder, harm or discomfort to the ecosystem i.e. physical systems or living organisms (Mohsenifar et al., 2011; Allahyaripur et al., 2011). Pollution can take the form of chemical substances or energy, such as noise, heat, or light. Pollutants, the elements of pollution, can be foreign substances or energies (Arabian and Entezarei, 2011), or naturally occurring; when naturally occurring, they are considered contaminants when they exceed natural levels (Arbabian et al., 2011; Hosseini and Sabouri, 2011). Pollution is often classed as point source or no point source pollution.

Pollution has always been with us. According to articles in different journals soot found on ceilings of prehistoric caves provides ample evidence of the high levels of pollution that was associated with inadequate ventilation of open fires. The forging of metals appears to be a key turning point in the creation of significant air pollution levels outside the home (. Core samples of glaciers in Greenland indicate increases in pollution associated with Greek, Roman and Chinese metal production.

According to the statistics, the construction regions in many areas, are notable for their high environmental pollution (Wang and Li, 2006; Qasim et al., 2010 a; Qasim et al., 2010 b). Therefore, environmental studies affected by the seismic safety of large dams is one of the key problems that need to be solved in the design of dams. While, difficulties exist in determining the seismic response of dams (United States Army Corps of Engineers, 1995). The most important difficulty is dams complex geometry and forms, motivated by the topography and geotechnical character of the implantation zone and controlling the project pollution effects.

According to the previous studies, usually 2D models corresponding to the higher section the dam have been used in the structural seismic analyses of the dams (Fenves and Chopra, 1984). While, normally there is a lot of variation in the dam foundation geometry which can be extremely make the study of the dam downstream pollution difficult.

In this paper, the probability of environmental pollution caused by Upper gotvand dam failure is studied. Finite Element and ZENGAR methods are used to analyze the probability of pollution at dam downstream. Different dam cross sections and various loading conditions are considered to study the effects of these factors on the probability of environmental pollution due to seismic behavior of the dam.

Materials And Methods

Khozestan Province:

Khozestan is one of the 30 provinces of Iran. It is in the southwest of the country, bordering Iraq's Basra Province and the Persian Gulf. Its capital is Ahwaz and covers an area of 63,238 km². Other major cities include Behbahan, Abadan, Andimeshk, Khorramshahr, Bandar Imam, Dezful, Shushtar, Omidiyeh, Izeh, Baq-e-Malek, Mah Shahr, Dasht-i Mishan/Dasht-e-Azadegan, Ramhormoz, Shadegan, Susa, Masjed Soleiman, Minoo Island and Hoveizeh. Figure 2 shows the place of Khozestan in Iran.
The Persians settlers had by the 6th century BC, mixed with the native Elamite population. The assimilation, however, does not seem to have concluded until after the Islamic invasion of the 7th century, when the Muslim writers still mention Khuzi to be the primary language of the inhabitant of the province.

The seat of the province has for the most of its history been in the northern reaches of the land, first at Susa (Shush) and then at Shushtar. During a short spell in the Sasanian era, the capital of the province was moved to its geographical center, where the river town of Hormuz-Ardasher, founded over the foundation of the ancient Hoopahpir by Ardashir I, the founder of the Sassanid Dynasty in 3rd century AD. This town is now known as Ahwaz. However, later in the Sasanian time and throughout the Islamic era, the provincial seat returned and stayed at Shushter, until the late Qajar period. With the increase in the international sea commerce arriving on the shores of Khuzistan, Ahwaz became a more suitable location for the provincial capital. The River Karun is navigable all the way to Ahwaz (above which, it flows through rapids). The town was thus refurbished by the order of the Qajar king, Naser al-Din Shah and renamed after him, Naseri. Shushtar quickly declined, while Ahwaz/Naseri prospered to the present day.

Currently, Khuzestan has 18 representatives in Iran's parliament, the Majlis, and 6 representatives in the Assembly of Experts.

Etymology:

Khouzi is referred to as people who make raw sugar from sugar cane fields of northern Sassanian planes up to Dez River side in Dezful. Khouzhestan has been the land of Khouzhies who used to cultivate sugar cane even to day in Haft Tepe. The name Khuzestan means "The Land of the Khuizi", refers to the original inhabitants of this province, the "Susian" people (Old Persian "Huza", Middle Persian "Khuzi" (the Shushan of the Hebrew sources) in the same evolutionary manner that Old Persian changed the name Sindh into Hind”). The name of the city of Ahwaz also has the same origin as the name Khuzestan., being an Arabic broken plural from the compound name, "Suq al-Ahwaz" (Market of the Huzis)--the medieval name of the town, that replaced the Sasanian Persian name of the pre-Islamic times.

The southern half of the province (south of the Ahwaz Ridge) was still known as "The Khudhi or The khouji” until the reign of the Safavid king Tahmasp I and the 16th century. By the 17th century, it had come to be known—at least to the imperial Safavid chancery as Arabistan. The great history of Alamara-i Abbasi by Iskandar Beg Munshi, written during the reign of Shah Abbas I the Great, regularly refers to the southern half of the province as "Arabistan" and its ruler as the "wali of Arabistan," from whence Shah Abbas received troops. Some tribes from as far away as Yemen had settled the southern half of the province since the 7th century AD, giving rise to some of the most prominent Arab poets such as Abu Nuwas Ahwazi. They remain an integral part of Khuzistan up to now.

There has been many attempts at finding other sources for the name, none however being tenable.

Geography And Climate:

The province of Khuzestan can be basically divided into two regions, the rolling hills and mountainous regions north of the Ahwaz Ridge, and the plains and marsh lands to its south. The area is irrigated by the Karoun, Karkheh, Jarahi and Maroun rivers. The northern section maintains a Persian (Lur, Bakhtiari, Khuzi) majority, while the southern section had an Arabic speaking majority until the great flood of job seekers from all over Iran inundated the oil and commerce centers on the coasts of the Persian Gulf since the 1940s. Presently, Khuzestan has several minority and ethnic groups of Lors-Bakhtiyaris-ghashghayee- Arabs and Persians from periods of history that arabs were not mentioned anywhere.

Khuzestan has great potentials for agricultural expansion, which is almost unrivaled by the country's other provinces. Large and permanent rivers flow over the entire territory contributing to the fertility of the land. Karun, Iran's most effluent river, 850 kilometers long, flows into the Persian Gulf through this province. The agricultural potential of most of these rivers, however, and particularly in their lower reaches, is hampered by the fact that their waters carry salt, the amount of which increases as the rivers flow away from the source mountains and hills. In case of the Karun, a single tributary river, Rud-i Shur ("Salty River") that flows into the Karun above Shushtar contributes most of the salt that the river carries. As such, the freshness of the Karun waters can be greatly enhanced if the Rud-i Shur could be diverted away from the Karun. The same applies to the Jarahi and Karkheh in their lower reaches. Only the Marun is exempt from this.

The climate of Khuzestan is generally hot and occasionally humid, particularly in the south, while winters are much more pleasant and dry. Summertime temperatures routinely exceed 50 degrees Celsius (record striking temperatures of over 60 degrees air temperature also occur with up to 90 degrees surface temperature) and in the
winter it can drop below freezing, with occasional snowfall, all the way south to Ahwaz. Khuzestan province is
known to master the hottest temperatures on record for a populated city anywhere in the world. Many
sandstorms and dust storms are frequent with the arid and desert style terrains.

History

Pre-Islamic History:

The province of Khuzestan is one of the centers of ancient civilization, based around Susa. The first large
scale empire based here was that of the powerful 4th millennium BC Elamites.

Archeological ruins verify the entire province of Khuzestan to be home to the Elamite civilization, a non-
Semitic, and non-Indo-European-speaking kingdom, and "the earliest civilization of Persia".

As stated in the preceding section, the name Khuzestan is derived from the Elamites (Ūvja).
In fact, in the words of Elton L. Daniel, the Elamites were "the founders of the first Iranian empire in the
geographic sense." Hence the central geopolitical significance of Khuzestan, the seat of Iran's first empire.

In 640 BC, the Elamites were defeated by Ashurbanipal coming under the rule of the Assyrians who
brought destruction upon Susa and Chogha Zanbil. But in 538 BC Cyrus the Great was able to re-conquer the
Elamite lands. The city of Susa was then proclaimed as one of the Achaemenid capitals. Darius the Great then
erected a grand palace known as Apadana there in 521 BC. But this astonishing period of glory and splendor of
the Achaemenian dynasty came to an end by the conquests of Alexander of Macedon. And after Alexander, the
Seleucid dynasty ruled the area. Figure 3 and 4 show some historical places in Khozestan.

Fig. 3: Daniel's shrine, located in Khuzestan

Fig. 4: The ziggurat of Choqa Zanbil

As the Seleucid dynasty weakened, Mehrdad I the Parthian (171-137 BC), gained ascendancy over the
region. During the Sassanid dynasty this area thrived tremendously and flourished, and this dynasty was
responsible for the many constructions that were erected in Ahwaz, Shushtar, and the north of Andimeshk.

During the early years of the reign of Shapyyuur II (A.D. 309 or 310-379), Arabs crossed the Persian Gulf
from Bahrain to "Ardashir-Khorn" of Fars and raided the interior. In retaliation, Shapur II led an expedition
through Bahrain, defeated the combined forces of the Arab tribes of "Taghleb", "Bakr bin Wael", and "Abd Al-
Qays’ and advanced temporarily into Yamama in central Najd. The Sassanids resettled these tribes in Kerman and Ahwaz. Arabs named Shapur II, as "Shabur Dhul-aktāf" after this battle.

The existence of prominent scientific and cultural centers such as Academy of Gundishapur which gathered distinguished medical scientists from Egypt, India, and Rome, shows the importance and prosperity of this region during this era. The Jondi-Shapur Medical School was founded by the order of Shapur I. It was repaired and restored by Shapur II (a.k.a. Zol-Aktaf: "The Possessor of Shoulder Blades") and was completed and expanded during the reign of Anushirvan.

Earthquake and ZENGAR Method:

Earthquake as a special and challengeable load condition is one of the most significant loads that is considered in the dam designing and its effects could not be negligible. In this paper, ZENGAR method is used to model the earthquake loading condition (Omran and Tokmechi, 2008). According to this method, hydrodynamic pressure of water can be derived by the equation 1.

\[ P = C \alpha_h \gamma_w H \]  

where \( \alpha_h \) is the maximum horizontal acceleration of the earthquake, \( \gamma_w \) is water mass density, \( H \) is the water depth and \( C \) is a coefficient which is given by

\[ C = C_m \left( \frac{Z}{H} \right) \left( 2 - \frac{Z}{H} \right) - \frac{Z}{H} \]  

where \( Z \) is the depth of the point from the water surface and \( C_m \) is a coefficient which is given by

\[ C_m = 0.73\left( \frac{90 - \phi}{90} \right) \]  

where \( \phi \) is the upstream slope.

The inertia load due to the vertical acceleration of the earthquake can be also given by

\[ E = \alpha_v W \]  

where \( \alpha_v \) is the maximum vertical acceleration of the earthquake and \( W \) is the weight of the dam.

In this study, a sample earthquake condition properties have been taken as shown in Table 1 (Omran and Tokmechi, 2008). Also, eight different loading conditions, mentioned in Table 2, have been considered to study the seismic response of the dam (Omran and Tokmechi, 2008).

<table>
<thead>
<tr>
<th>Earthquake Level</th>
<th>Maximum Horizontal Acc. (g)</th>
<th>Maximum Vertical Acc. (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DBL</td>
<td>0.28</td>
<td>0.20</td>
</tr>
<tr>
<td>MDL</td>
<td>0.34</td>
<td>0.25</td>
</tr>
<tr>
<td>MCL</td>
<td>0.67</td>
<td>0.55</td>
</tr>
</tbody>
</table>

Table 1. Earthquake Condition

<table>
<thead>
<tr>
<th>Loading Condition</th>
<th>Body Weight</th>
<th>Hydrostatic Pressure</th>
<th>Uplift Pressure</th>
<th>Earthquake</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC1</td>
<td>*</td>
<td>-</td>
<td>*</td>
<td>-</td>
</tr>
<tr>
<td>LC2</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>-</td>
</tr>
<tr>
<td>LC3</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>DBL (1st mode)</td>
</tr>
<tr>
<td>LC4</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>DBL (2nd mode)</td>
</tr>
<tr>
<td>LC5</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>MDL (1st mode)</td>
</tr>
<tr>
<td>LC6</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>MDL (2nd mode)</td>
</tr>
<tr>
<td>LC7</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>MCL (1st mode)</td>
</tr>
<tr>
<td>LC8</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>MCL (2nd mode)</td>
</tr>
</tbody>
</table>

Table 2. Loading Conditions

I: Earthquake inertia loading and dam body weight act in the same direction.
II: Earthquake inertia loading and dam body weight act in the apposite direction.

Finite Element Method:
In this study, Constant Strain Triangle element is used (Chandrupatla, 1997). Equation 5 is used to calculate the element stresses. The calculated stress is used as the value at the center of each element.

\[ \sigma = DBq \]  

Where D is material property matrix, B is element strain displacement matrix, and q is element nodal displacement from the global displacements vector Q.

For plane strain conditions, the material property matrix is given by Equation 6.

\[ D = \frac{E}{(1+\nu)(1-2\nu)} \begin{bmatrix} 1-\nu & \nu & 0 \\ \nu & 1-\nu & 0 \\ 0 & 0 & 1-2\nu/2 \end{bmatrix} \]  

(6)

Element strain-displacement matrix is given by Equation 7.

\[ B = \frac{1}{\det J} \begin{bmatrix} y_{23} & 0 & y_{31} & 0 & y_{12} & 0 \\ 0 & x_{32} & 0 & x_{13} & 0 & x_{21} \\ x_{32} & y_{23} & x_{13} & y_{31} & x_{21} & y_{12} \end{bmatrix} \]  

(7)

In which, J is Jacobian matrix, and the points 5, 6, and 7 are ordered in a counterclockwise manner. Jacobian matrix is given by Equation 8.

\[ J = \begin{bmatrix} x_{13} & y_{13} \\ x_{23} & y_{23} \end{bmatrix} \]  

(8)

Global displacements vector Q is given by Equation 9.

\[ KQ = F \]  

(9)

In which, K and F are modified stiffness matrix and force vector, respectively. The global stiffness matrix K is formed using element stiffness matrix ke which is given by Equation 10.

\[ k^e = t_e A_e B^T \]  

(10)

In which, te and Ae are element thickness and element area, respectively.

**Results And Discussion**

**Seismic Response:**

Using Finite Element, ZENGAR and probability studies methods, study of the probability of environmental pollution due to Upper gotvand dam failure has been done and different loading conditions were considered. Fig. 5 to Fig. 15 show the probability of environmental pollution due to failure (Named PEP) caused by maximum compressive stress values in different cross sections. The PEP due to maximum tensile stress values are also shown in Fig. 16 to Fig. 26. The PEP due to vertical stress distribution across dam basement due to different loading conditions are the other key factors for controlling dam safety, and they are shown in Fig. 27 to Fig. 37. In all Figures Sx, Sy, and Sz are stand for PEP due to stress along X, Y, and Z axis, respectively.

As it can be seen from Fig. 5 to Fig. 15, the PEP due to maximum compressive stress changes due to different loading conditions are similar for different cross sections. While, comparing Fig. 20, Fig. 22 and Fig. 25 there is no response similarity for different cross sections and the PEP due to maximum tensile stress changes are vary from a cross section to another.

![Fig. 5: PEP Due To Maximum compressive stress (1st section)](image-url)
Fig. 6: PEP Due To Maximum compressive stress (2nd section)

Fig. 7: PEP Due To Maximum compressive stress (3rd section)

Fig. 8: PEP Due To Maximum compressive stress (4th section)
Fig. 9: PEP Due To Maximum compressive stress (5th section)

Fig. 10: PEP Due To Maximum compressive stress (6th section)

Fig. 11: PEP Due To Maximum compressive stress (7th section)
Fig. 12: PEP Due To Maximum compressive stress (8th section)

Fig. 13: PEP Due To Maximum compressive stress (9th section)

Fig. 14: PEP Due To Maximum compressive stress (10th section)
Fig. 15: PEP Due To Maximum compressive stress (11th section)

Fig. 16: PEP Due To Maximum Tensile stress (1st section)

Fig. 17: PEP Due To Maximum Tensile stress (2nd section)
Fig. 18: PEP Due To Maximum Tensile stress (3rd section)

Fig. 19: PEP Due To Maximum Tensile stress (4th section)

Fig. 20: PEP Due To Maximum Tensile stress (5th section)
**Fig. 21:** PEP Due To Maximum Tensile stress (6th section)

**Fig. 22:** PEP Due To Maximum Tensile stress (7th section)

**Fig. 23:** PEP Due To Maximum Tensile stress (8th section)
Fig. 24: PEP Due To Maximum Tensile stress (9th section)

Fig. 25: PEP Due To Maximum Tensile stress (10th section)

Fig. 26: PEP Due To Maximum Tensile stress (11th section)
Fig. 27: PEP Due To Basement Stress (1st section)

Fig. 28: PEP Due To Basement Stress (2nd section)

Fig. 29: PEP Due To Basement Stress (3rd section)
**Fig. 30:** PEP Due To Basement Stress (4th section)

**Fig. 31:** PEP Due To Basement Stress (5th section)

**Fig. 32:** PEP Due To Basement Stress (6th section)
Fig. 33: PEP Due To Basement Stress (7th section)

Fig. 34: PEP Due To Basement Stress (8th section)

Fig. 35: PEP Due To Basement Stress (9th section)
It is clear from Fig. 5 to Fig. 26 that the first modes of the earthquake, LC3, LC5 and LC7, develop PEP due to bigger compressive stress. While, the second modes of the earthquake, LC4, LC6 and LC8, develop bigger PEP due to tensile stress. That means for the safety study of RCC dams both modes of earthquake should be analyzed. In addition, Fig. 5 to Fig. 26 show that when the earthquake accelerations are bigger, both PEP due to maximum tensile and compressive stress of dam body are increased.

Comparing Fig. 9 and Fig. 15, it is obvious that the PEP due to maximum compressive stress is not developed in the highest cross section of the dam. Also, comparing Fig. 20 and Fig. 22, it is clear that the PEP due to maximum tensile stress develops in D-D section which is smaller than E-E section. Thus, the highest cross section of the dam is not the most significant cross section for analyzing.

Moreover, Fig. 15 and Fig. 18 show that the PEP due to maximum compressive and the maximum tensile stress are not developed in the same cross section. That's why, as it is mentioned previously, all cross sections should be analyzed to determine the dam PEP due to seismic response.

According to the findings, S_y is always the determinant PEP due to compressive stress. In the other word, PEP due to stress along Y axis is the biggest compressive stress and it is bigger than both Sx and Sz. While, the determinant PEP due to tensile stress depends on the cross section geometry and loading condition (Fig. 16 and Fig. 20). However, in all sections S_x and S_y are normally bigger than S_z. And, S_z can never be a determinant. In normal loading condition, when there is no earthquake loading, the determinant PEP due to tensile stress is S_x, and S_y can be ignored.
The PEP due to stress distribution across the dam basement under different loading conditions for all cross sections are shown in Fig. 27 to Fig. 37. Even though the PEP due to stress distribution for different conditions extremely depend on the cross section geometry and loading condition but, they can be divided into the groups for similar cross section. For example, as it can be seen from Fig. 30 to Fig. 32, there are some similarities between PEP due to stress distribution changes for sections E-E to I-I.

In general, results show that when the earthquake accelerations are bigger, PEP due to maximum tensile stress at dam basement is increased. While, PEP due to the maximum compressive stress at dam basement depends on both earthquake acceleration and loading condition.

Fig. 29 shows that the PEP due to maximum tensile and compressive stress at dam basement develop at section D-D. Thus, the highest cross section is not the most important cross section and all sections of a inharmonic glen located RCC dam should be analyzed.

Conclusions:

In this paper, the probability of environmental pollution caused by Upper gotvand dam failure is studied. Finite Element and ZENGAR methods are used to analyze the probability of pollution at dam downstream. Different dam cross sections and various loading conditions are considered to study the effects of these factors on the probability of environmental pollution due to seismic behavior of the dam. In general the results show that:

1. The PEP due to maximum compressive stress changes due to different loading conditions are similar for different cross sections. While, there is no response similarity for different cross sections and the PEP due to maximum tensile stress changes are vary from a cross section to another.

2. The first modes of the earthquake, when earthquake inertia loading and the dam body weight act in the same direction, develop bigger PEP due to compressive stress. In addition, the second modes of the earthquake, when earthquake inertia loading and the dam body weight act in the opposite direction, develop bigger PEP due to tensile stress. Thus, for the environmental safety study of dams both modes of earthquake should be analyzed.

3. When the earthquake accelerations are bigger, both PEP due to maximum tensile and compressive stress of dam body are increased.

4. The PEP due to maximum compressive and tensile stresses are not developed in the highest cross section of the dam. Thus, the highest cross section of the dam is not the most significant cross section for analyzing.

5. PEP due to stress along Y axis (Sy) is always the determinant PEP due to compressive stress. While, in all sections Sx and Sz are the determinant PEP due to tensile stresses and normally they are bigger than Sy. And, Sz which can never be a determinant.

6. In normal loading condition, when there is no earthquake loading, the determinant PEP due to tensile stress is Sx, and Sy can be ignored.

7. Even though the PEP due to stress distribution for different conditions extremely depend on the cross section geometry and loading condition but, they can be divided into the groups for similar cross section.

8. Results show that when the earthquake accelerations are bigger, PEP due to maximum tensile stress at dam basement is increased. While, PEP due to the maximum compressive stress at dam basement depends on both earthquake acceleration and loading condition.

References


