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An investigation on the bulging phenomenon in the clay core of rockfill dam based on the stress and pore water pressure data

J. Bolouri Bazaz
Associate Professor, Civil Engineering Department, Ferdowsi University of Mashhad, Mashhad, Iran
bolouri@um.ac.ir

H. Gholami
M. Sc. in Geotechnical Engineering, Abpooy Consulting Engineers, Mashhad, Iran

M.T. Bolouri Bazaz
Ph. D. Student, Geotechnical Engineering, Abpooy Consulting Engineers, Mashhad, Iran

ABSTRACT

The Masjed Soleyman dam is a central clay core rockfill dam with the height of 177 meter and 490m long center core. Throughout the dam construction, reservoir impounding and operation comprehensive monitoring had been carried out to verify the dam behavior. The monitoring of the dam behavior was based on measurement data of instruments installed on the dam body and foundation. This research present research presents an overall review of the dam behavior during the first impounding and summarizes the recorded measurement of major instruments. These instruments are in the field of stresses and pore water pressure in the clay core. Also substantial rotation of the principal stresses direction had been investigated. The rotating angles of respective points were generally constant, but slight increases in the angles after full impoundment has been observed in the downstream side of the core. This is an indicative of a progressing shear zone and would lead to bulging of the core in the lower level. In the clay core due to the very low permeability of the clay material, the dissipating process of the pore water pressure hadn't been continuing with notable progress (in the past 13 years after the first impounding). So the clay behavior as an undrained material and volume change is not significant especially in the center area of core. This is the main reason for developing the lateral deformation in the clay core which called bulging.

Keywords: Rockfill dam, clay core, Masjed Soleyman dam, bulging, pore water pressure.

1- INTRODUCTION

The Masjed Soleilman (MES) dam is a 177 m high and 490 m long center core type rockfill dam (Engineering Report of MES dam, 1993). Construction of the dam body and power plant was commenced in December 1994 and the embankment of the main dam was completed in November 2000. The reservoir impounding was commenced on 19 December 2000 and the reservoir water level reached at el. 371 m on July 2002. Deformations due to the first impounding of dam reservoir can lead to changing of dam safety, which implies the importance the monitoring after the first impounding (Soroush and Araei, 2006).

Throughout the dam construction, reservoir impounding and operation comprehensive monitoring had been carried out to verify the dam behavior so that stability and safety of the dam were ensured (Engineering Report of MES dam, 1993). The monitoring of the dam behavior was based on measurement data of instrument installed in the dam body and foundation and geodetic survey results of the dam surface as well as daily visual inspection.

Noticeable numbers of the instruments malfunctioned or damaged in the period of the construction. It’s notable that, the surface settlement of the dam had been continuing and it was still not evident that the settlement had gone into a stable state. The residual excess pore pressure in the core was still high after 11 years from first impounding. Developed excess pore water pressure in the clay core of zoned rockfill dams during the construction period and first stage impounding, may lead to initiation or progression of hydraulic fracturing. The ability to predict the development and dissipation of these pore pressures is important in assessing the performance of such structures. This phenomenon also depended on the arching effect status of the core zone due to difference in stiffness of materials. (Maleki and far, 2004). In present study, the received data from stress and pore water instruments (section 260) analysised to understand the dam’s deformation behavior. Also, the graphs drew just for available data’ instrument. The symbols of instrument’s situation are shown in table 1.

Table 1. Symbol of instrument’s situation

symbol	Situation
U/C	Upstream (in core)
CL	Center of core
D/C	Downstream (in core)
U/Filter	Upstream (in filter)
D/Filter	Downstream (in filter)
U/Shell	Upstream (in shell)
D/Shell	Downstream (in shell)

2- EARTH PRESSURE

The stress in dam body has been measured, using total pressure cells which are installed in the core, downstream filter and downstream shell from the beginning of the embankment (Figure 1.), The total pressure cells in the upstream side of the core and upstream filter malfunctioning and data in these portions were not available.

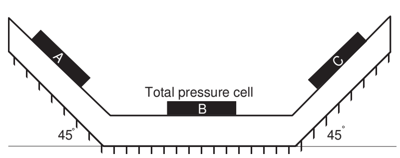

Figure 1. Earth pressure gauges in one cluster

The Stress ratio was defined as a ratio of the actual vertical pressure to the apparent pressure calculated from the embankment weight (γ_H) above the measuring point. The positions of the instrument that was workable are shown in table 2. Variation of the stress ratio (σ_V/γ_H) at respective measuring section (CH. 260) are shown in figures 2 to 4. In these graphs, RWL is the water level behind the dam. The stress ratio in the core was in a range (0.6 -0.7) and that in the filter are (0.7-1.40). This phenomenon caused by arching in the core zone.

Table 2. Situation of instrument in CH. 260

Instrument	Elevation	Situation
2103	230	CL
2104	230	D/C
2105	230	D/Filter
2107	230	D/S
2202	270	CL
2203	270	D/C
2304	310	D/C
2305	310	D/Filter

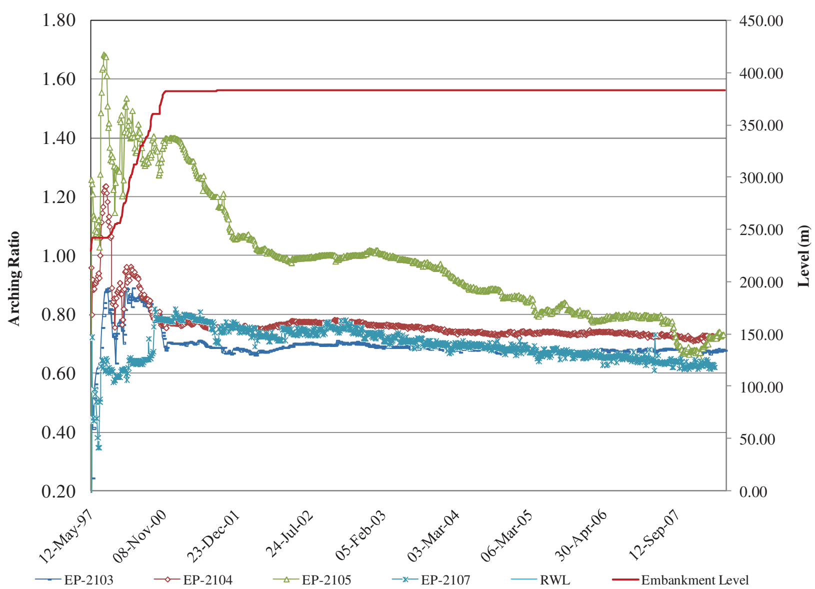

Figure 2. Vertical stress ratio at 230 elevation (CH. 260 m).

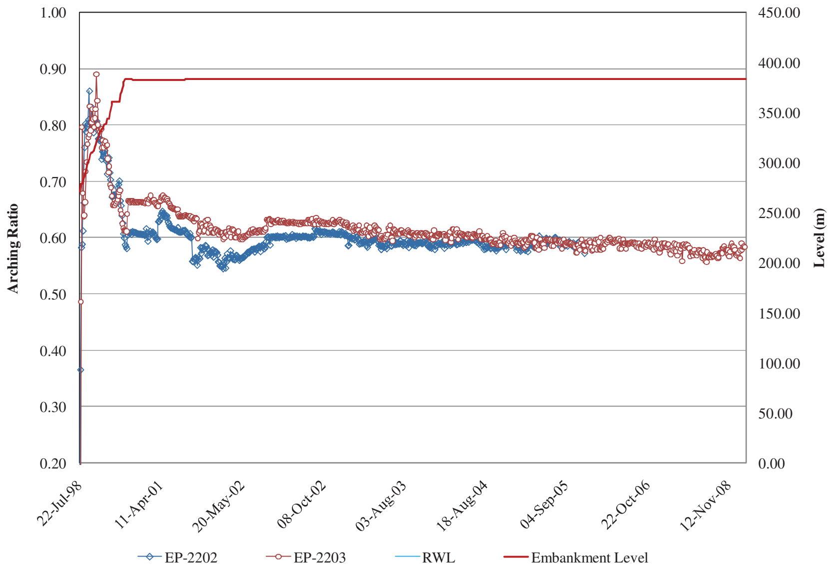

Figure 3. Vertical stress ratio at 270 elevation (CH. 260 m).

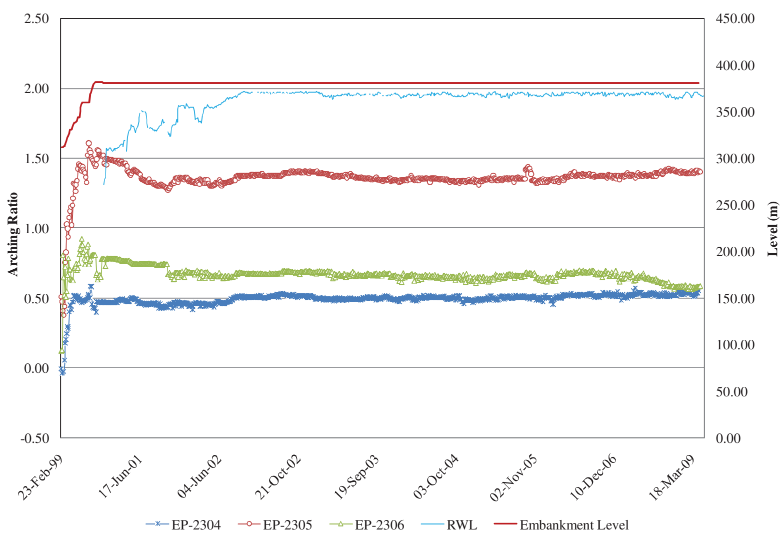

Figure 4. Vertical stress ratio at 310 elevation (CH. 260 m).

Principle stresses in the dam body are calculated from the measurement data of the total pressure cells at the respective measuring points. Variations of the effective stress paths in the core expressed with relationship between $p = (\sigma_1 + \sigma_2)/2$ and $q = (\sigma_1 - \sigma_2)/2$, together with the measured pore pressure (p_u) in this equation $p' = p - p_u$. The values are shown in figure 5 to 7 which indicate a trace of Mohr's stress circle peak. The strength parameters in this failure criterion are soil cohesion and internal friction angle. The values of them are 20 kN/m^2 and 30° respectively. The points above the failure envelope show the yielding condition.

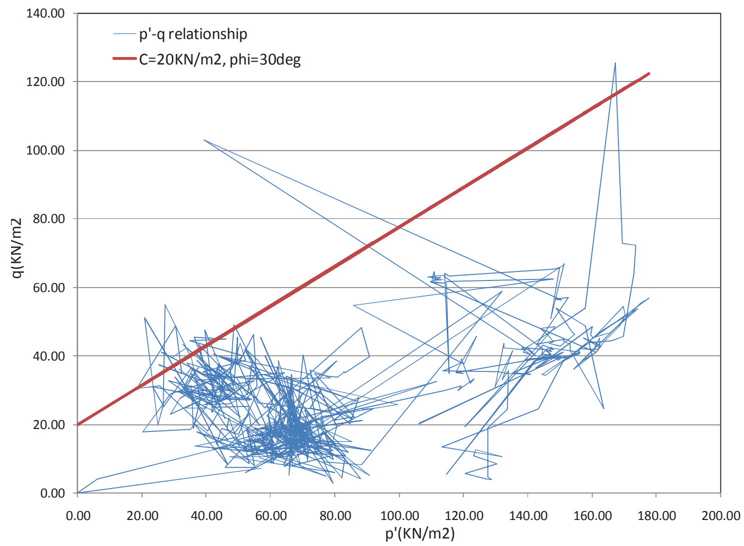

Figure 5. Effective stress path in (p'-q) space (Sec. 260, El. 230, Core CL)

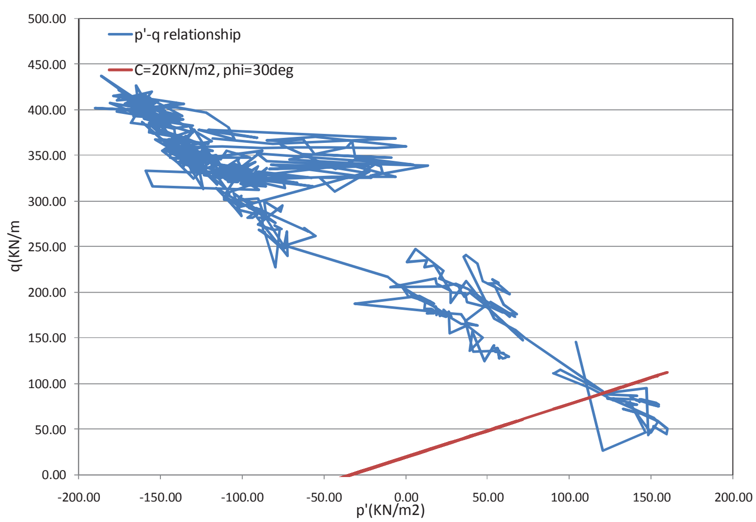

Figure 6. Effective stress path in (p'-q) space (Sec, 260, EL230, Core D/S)

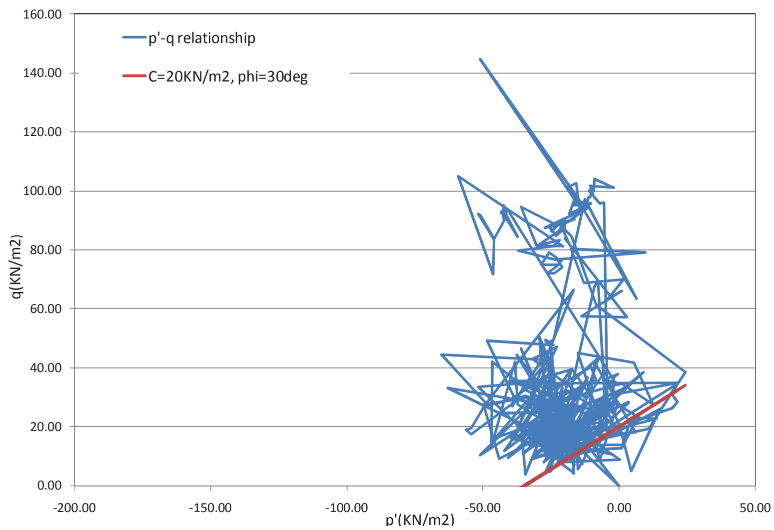

Figure 7. Effective Stress Path in (p'-q) space (Sec. 260, EL270, Core CL)

Deviation of the orientation of the maximum stress from the vertical direction is presented in Figures 8 and 9. These graphs pointed out substantial rotation of the principal stress direction to the upstream in the core, which was indicative of a progressing shear zone and would lead to bulging of the core.

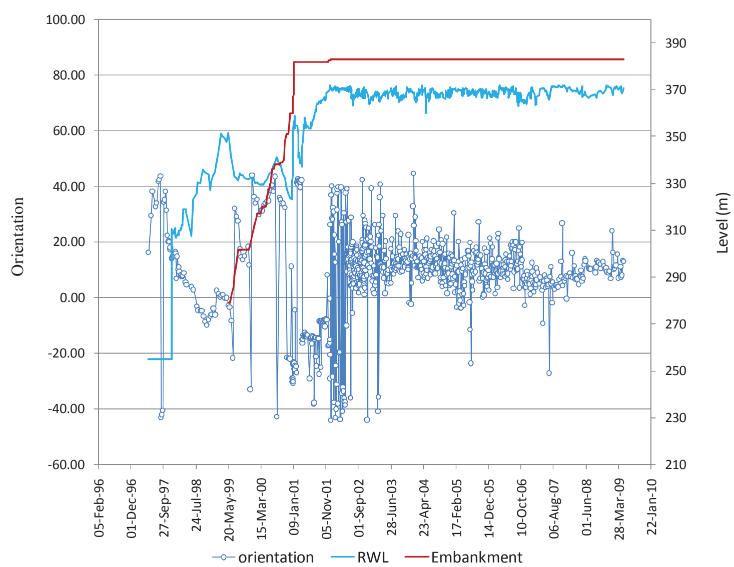

Figure 8. Orientation of principal stress direction (Sec, 260, El. 230)

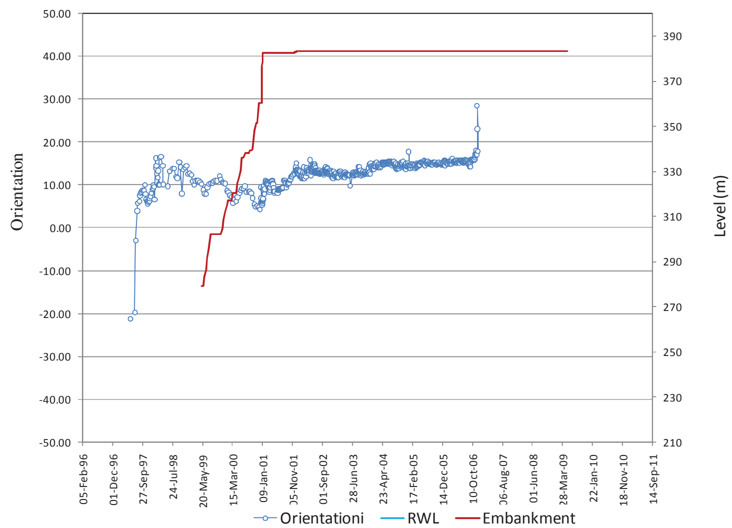

Figure 9. Orientation of principal stress direction (Sec, 260, El. 230)

3. PORE WATER PRESSURE

Pore pressure in the dam body had been measured by using pore pressure gauge installed in the center and downstream side of the core. The pore pressure gauges in the upstream side of the core were malfunctioning data in these portions were not available.

A ratio of the pore pressure to the measured vertical earth pressure (letter M in graphs) and to the principal stress (letter S in the graphs) are shown in figure 10-12. Variation of these values indicates a dissipating process of pore water and air form the core. The level of the pore pressure ratio after 11 years from the embankment completion was high. These had been continuously decreasing since the full impoundment at a slow rate.

The ratio of the pore pressure in the lower portion of the core was still at the high values of 90%. Therefore, the measurement results were simply indicative that the dissipating process of the pore pressure in the core of the MES dam was extremely slow.

Considering that the pore water pressure is an isotropic tension and the main stress is also zero in shear conditions. It can be concluded that the pore water pressure ratios calculated on the principal stresses is closer to reality than base on the total stress.

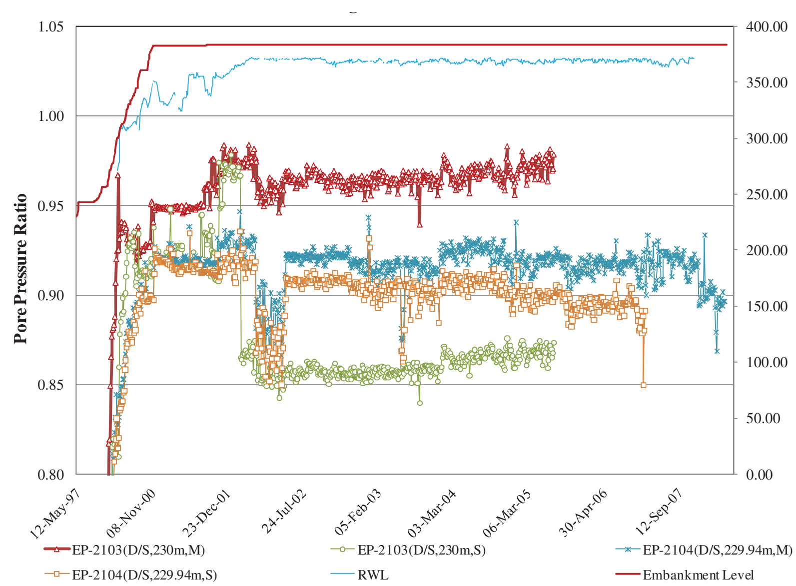

Figure 10. Pore Pressure ratio at 230 elevation (CH 260)

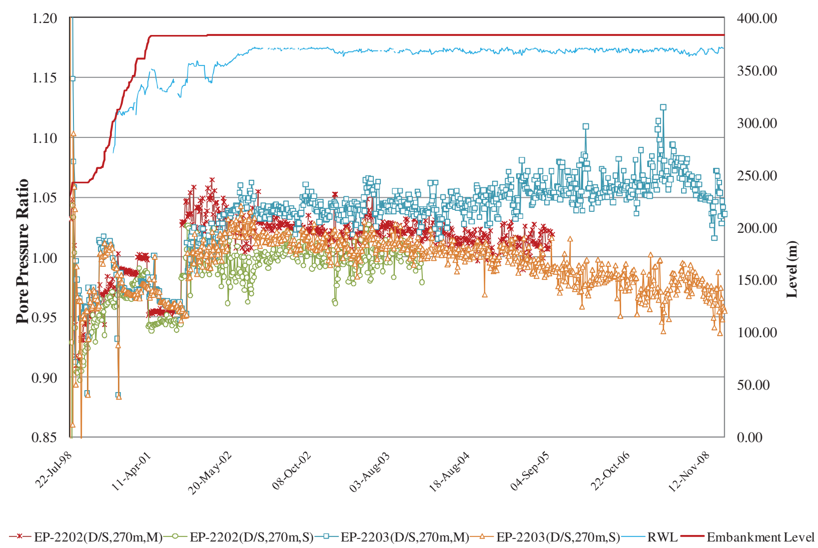

Figure 11. Pore Pressure ratio at 270 elevation (CH 260)

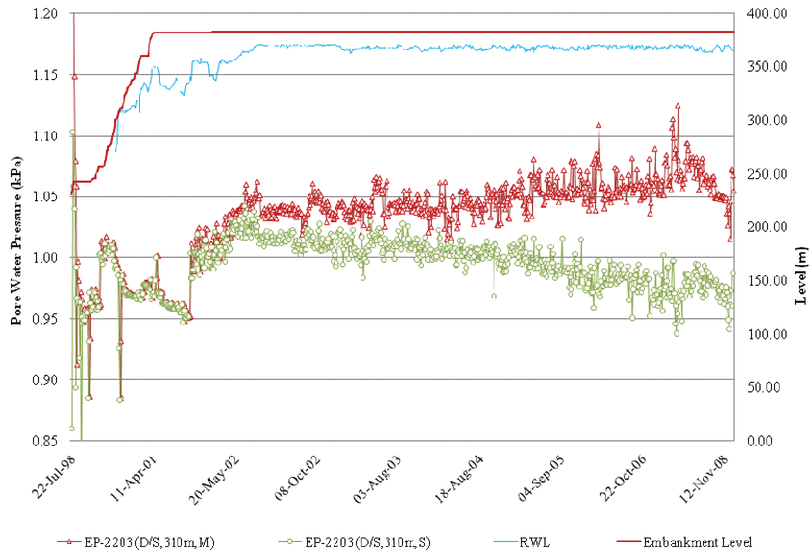

Figure 12. Pore Pressure ratio at 310 elevation (CH 260)

4. EFFECTIVE STRESS

Variation of the effective stress in the middle and downstream part of the core at 280 elevation are shown in figures 13-15. In these graphs, horizontal axis is the distance of the left side to right side of the dam axis and the elevations of abtuments are shown. Effective stress in the CH. 260 had been very little increased after impounding, this mater indicates that the condition is undrained and the progressive of consolidation is very low. Also at 310 elevation in CH260 the effective stress have little increase after impounding (report on monitoring of MS dam behavior, 2014).

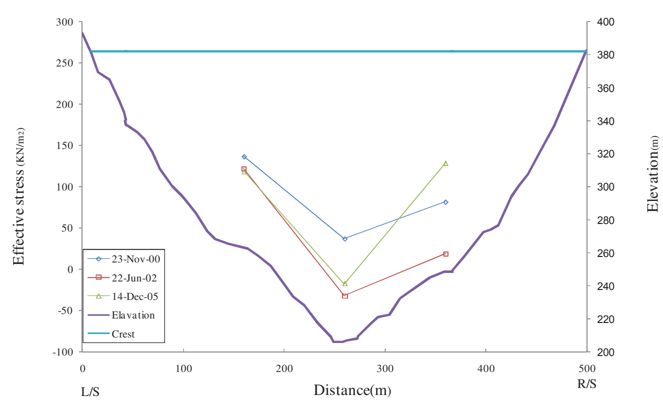

Figure 13. Effective stress in middle part of the core at 280 elevation along the axis' dam

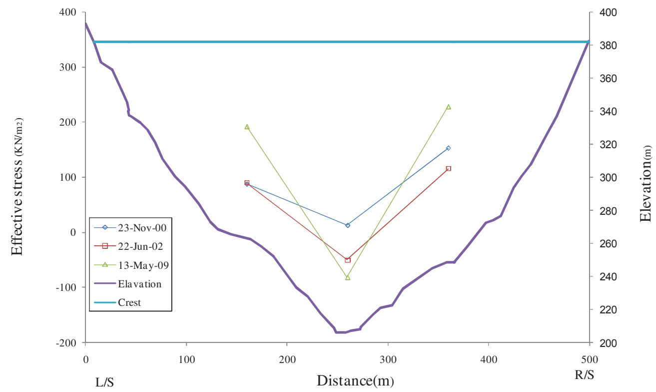

Figure 14. Effective stress in downstream part of the core at 280 elevation along the axis' dam

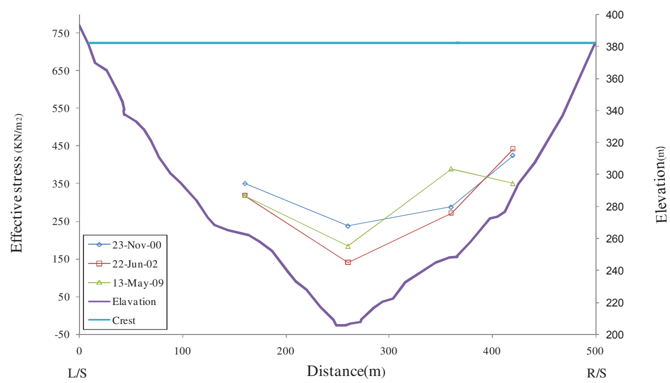

Figure 15. Effective stress in downside of the core at 310 elevation along the axis' dam

5. CONCLUSION

By considering the fact that the surface settlement had been continuing without notable progress of consolidation and Pore pressure ratio for most sections of core is high (over 0.8). Also, the orientation of the stress to upstream was indicative of a progressing shear zone and would lead to bulging of the core.

Bulging of the downstream part of the core is expected to occur at mid-height and below. Such bulging will certainly lead to a deformational response of the adjacent part of the filter and the downstream shell. This is the main reason for developing the lateral deformation in the clay core. It’s notable that the settlement of the foundation not expected, so it’s lead to mobilize the pressure to adjacent part of downstream of core and amplify the deformation this part of dam body.

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