The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM)
ISSN: 2602-3199

The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 2023

Volume 26, Pages 677-684

IConTES 2023: International Conference on Technology, Engineering and Science

Influence of the Behaviour Coefficient on the Damage Level of an RC Elevated Tank under Seismic Loading

Ourdia Ider
Mouloud Mammeri University

Hocine Hammoum
Mouloud Mammeri University

Karima Bouzelha
Mouloud Mammeri University

Amar Aliche
Mouloud Mammeri University

Abstract: In Algeria, the seismic design of elevated concrete storage tanks is carried out in accordance with seismic standard, involving a behavior coefficient of the structure. This behaviour coefficient is used to determine the internal forces and to estimate the inelastic deformations undergone by the structure. For the elevated water tank, considered as reverse pendulum structure, this coefficient assumes a constant value (R=2) in the Algerian seismic code. Taking into account a single value, whatever the seismic zone, the site of implantation and the geometric characteristics of the structure, can lead to design errors leading to oversizing, hence an additional cost of the structure. Thus, faced with the need to design resistant structures while minimizing construction costs, it is important to precisely determine the value of this behaviour coefficient to introduce into the evaluation of the structure's response. In this research, the seismic performance of an RC elevated tank is analyzed, using a nonlinear approach based on the Pushover method, initially using the behavior coefficient prescribed by the Algerian seismic code, then secondly using the behavior coefficient approximated by a power-type law, taking into account the seismic zone, the type of soil, the height of the structure and the storage capacity. The results of this study highlight the influence of the value of the behavior coefficient on the seismic performance and the level of damage to an elevated tank.

Keywords: Behavior coefficient, Pushover method, Nonlinear approach, Elevated tank.

Introduction

In civil engineering, structures damage after strong seismic action is an indisputable result that depends on many factors, including the value of the adopted seismic behaviour coefficient. Thus, if the latter is underestimated, the structure is likely to suffer extreme deformation and major damage. On the other hand, if the behaviour coefficient is overestimated, the structure may be over-designed, without significantly reducing the risk of damage it will face during a devastating earthquake. Given the need to design resistant structures while minimising construction costs, it is important to determine precisely the value of the behaviour coefficient to introduce into the calculation of the structure's performance point.

In this research, the influence of the value of the seismic behaviour coefficient on damage is studied, in order to assess the effect of this parameter on the structure performance. The behaviour coefficient is calculated by a power relation proposed in section 1 as a function of the seismic zone and the height of the pedestal, performed by a nonlinear approach. The methodology for evaluating the performance point is defined in procedure B of ATC-40. The spectral displacement S_d of the performance point defined by the intersection between the effective demand spectrum, defining the earthquake, and the capacity curve of the structure gives the value of the maximum displacement of the structure. This is considered to be the major factor conditioning structural damage (Mekki, 2015). Once this displacement S_d is defined, we proceed to classify the RC elevated tank in a damage domain that we propose as a function of the ultimate displacement δ_u extracted from the capacity curve (defined by the passage of the structure from the plastic phase to ruin) and the elastic displacement δ_e (obtained by the bilinear curve).

Evaluation of the Behaviour Coefficient Using a Non-Linear Approach

The evaluation of the behaviour coefficient, noted R, using a non-linear approach was carried out as part of the preparation of Ider's doctoral thesis (Ider, 2023). The results of this research showed that the behaviour coefficient is a function of the height of the pedestal H (Figure 1) and obeys to a power law as follows :

$$R = aH^b$$

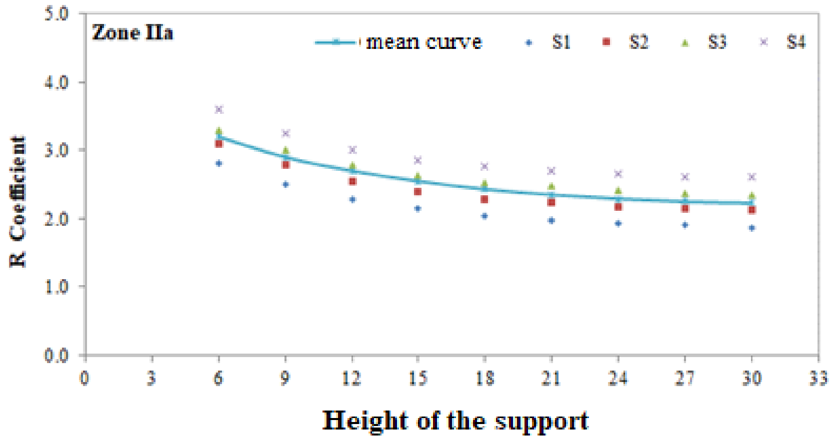


Figure 1. Behaviour coefficient as a function of pedestal height H.

The values of parameters (a) and (b) are obtained as a function of the seismic zone and the the site type. An summary of the results for the behavior coefficient is presented in table 1 for the seismic zone IIa. The results show that the behaviour coefficient takes different values for each height and each site (table 1), contrary to the Algerian Seismic Regulations (RPA,2003) which consider a single value of the behavior coefficient (R=2) whatever the study parameters.

Table 1. Value of the behavior coefficient R as a function of the height of the pedestal H, and site type, in medium seismic zone (IIa)

H(m)	6	9	12	15	18	21	24	27	30
S1 site	2.8	2.5	2.28	2.14	2.05	1.98	1.94	1.9	1.87
S2 site	3.1	2.78	2.55	2.4	2.29	2.23	2.18	2.15	2.12
S3 site	3.3	3	2.78	**2.63**	2.53	2.47	2.42	2.38	2.35
S4 site	3.6	3.25	3.00	2.85	2.76	2.7	2.65	2.62	2.6

Evaluation of Damage Level

In the field of earthquake engineering, the assessment of seismic risk is linked to both the demand (seismic hazard) and the capacity of the structure (performance) (Desprez, 2005; Mekki, 2015). For this, and in order to carry out an assessment of the seismic performance of a structure, through a mechanical analysis, recourse to the concept of damage indicator, which provides information on the extent of degradation that may occur in a structure, is necessary. Several methods for damage evaluation to civil engineering structures have been developed, such as the RISK-UE method, which is a qualitative method widely used in Europe to assess the effects of earthquakes on structures (RISK-UE, 2001). This method links the concept of visual observation of damage to displacements measured at the top of the structure. The RISK-UE method provides a range of criteria for observing and describing damage, classified according to a rating scale from 0 (no damage) to 5 (very significant damage). Based on this classification, we propose six damage domains for RC elevated tanks, as illustrated in Table 2.

Table 2. Proposed damage domains for RC elevated tanks.

Degrees and damage domains	Relations for differents limits spectrals displacements
Green 1 Domain (Negligible Damages)	Sd < 0.4 δe
Green 2 Domain (Minor Damages)	0.4 δe ≤ Sd < 0.8 δe
Orange 1 Domain (Moderate Damages)	0.8 δe ≤ Sd < δe + 0.25 (δu - δe)
Orange 2 Domain (Significant Damages)	δe + 0.25 (δu - δe) ≤ Sd < 0.75 δu
Orange 3Domain (Severe Damages)	0.75 δu ≤ Sd < δu
Red Domain (Complete Structural Collapse)	Sd ≥ δu

δe :Elastic limit displacement
δu : Ultimate limit diplacement

The ultimate displacement δu is extracted from the capacity curve (Figure 2), and is defined by the passage of the structure from the plastic phase to ruin, while the elastic displacement δe is obtained by the bilinear curve.

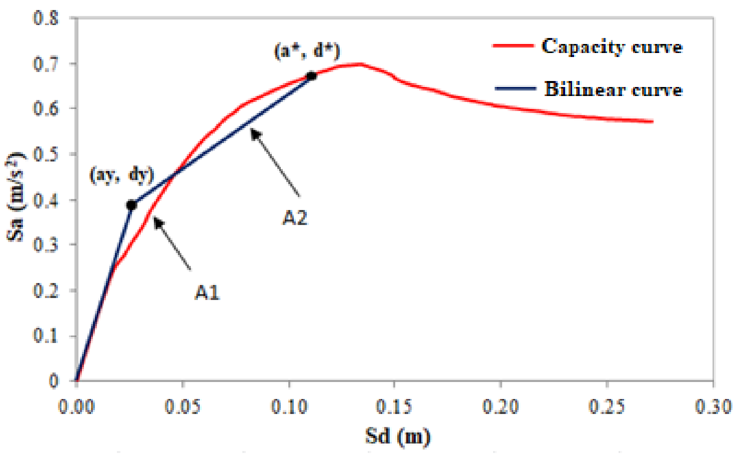


Figure 2. Capacity curve.

Application to the Case Study

To apply the methodology presented above, we consider an RC elevated tank with a capacity of 200 m3, with pedestal height of H=15m. The tank is located in Zone IIa on a soft site (S3). The behaviour coefficient given by the power law is (R = 2.63). A three-dimensional finite element model was developed to simulate the behaviour of the tank under lateral loading of the progressive thrust type, using the ETABS© software.

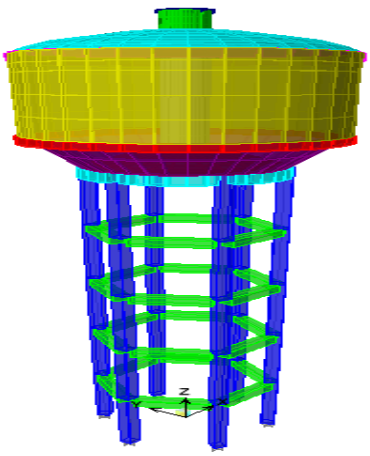


Figure 3. Finite element modeling of the elevated tank.

Evaluation of the Performance Point

Estimation of the Effective Damping of the Structure

To evaluate the right damping of the structure, a series of reduced spectra is developed, varying the damping factor ξ by 5%, 10%, 15%, ..., 29% (Figure 4), as stipulated in ATC40 for type B structures.

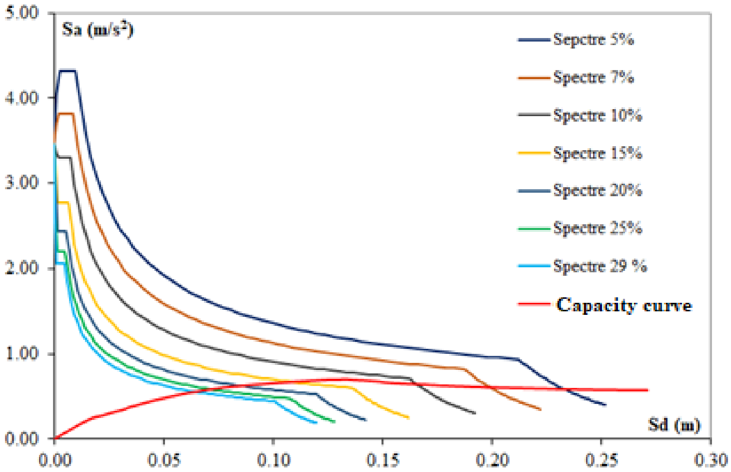


Figure 4. Representation of the family of reduced spectra

In the vicinity of the point with coordinates (a*; d*), defined by the bilinear curve (Figure 2), we choose three points one step apart on either side whose coordinates are defined by (api,dpi).
For each value of (api , dpi), the effective damping ξeff is determined by the following relation according to ATC 40.

$$\xi_{eff} = 5 + \kappa.\xi_0$$

ξ o represents the viscous damping which is a function of the coordinates of the points (api ; dpi) and (ay ; dy)

$$\xi_0 = \frac{63.7\left(a_y d_{pi} - d_y a_{pi}\right)}{a_{pi} d_{pi}}$$

For an elevated tank, classified as type B (public works of national interest or of certain socio-cultural and economic importance), the k factor is taken equal to 0.67 (see ATC 40). For each value of dpi in the series under consideration, we deduce pairs (dpi , ξeff), recorded in the table below (Table 3):

Table 3. Selected displacement values and corresponding damping.

d_{pi}	a_{pi}	ξ_o	k	ξ_{eff}
0.061	0.54	18.970	0.670	17.710
0.069	0.575	18.880	0.670	17.650
0.077	0.605	18.730	0.670	17.549
0.088	0.631	18.540	0.670	17.422
0.101	0.658	18.140	0.670	17.154
0.112	0.677	17.700	0.670	16.859
0.123	0.694	16.820	0.670	16.269

Different spectra are generated from the values of ξeff (Figure 5). The intersection of generated spectra with the vertical projections of the corresponding dpi , gives a set of points with coordinates (dpi , ξeff). By interconnecting these resulting points, we obtain a curve whose intersection with the capacity spectrum defines the structure's performance point, corresponding to the maximum displacement. This performance point represents the intersection of the capacity curve with the actual seismic demand corresponding to the effective damping of the structure ξeff =17.30% obtained by interpolation (Figure 5). The coordinates of the performance point are given in Table 4 and illustrated in Figure 6.

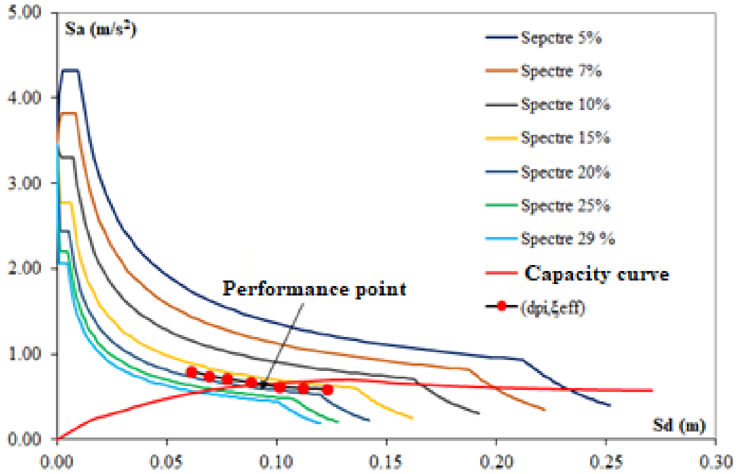


Figure 5. Evaluation of the performance point

Table 4. Coordinates of the performance point

S_d spectral displacement of the performance point	0.099	m
S_a spectral acceleration of the performance point	0.654	m/s^2
Effective damping ξ_{eff}	17.30	%

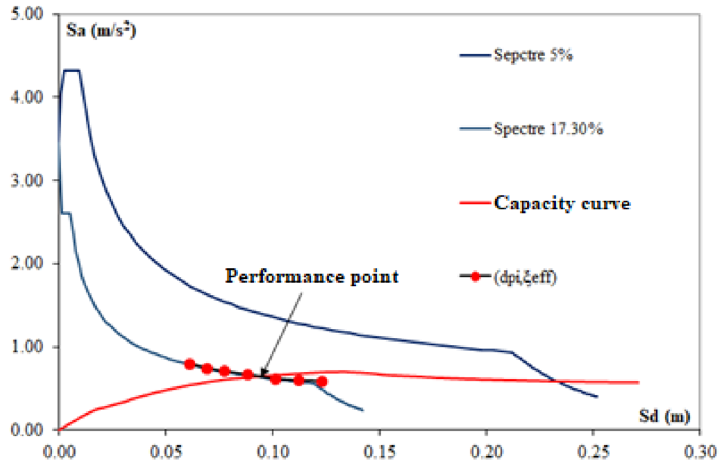
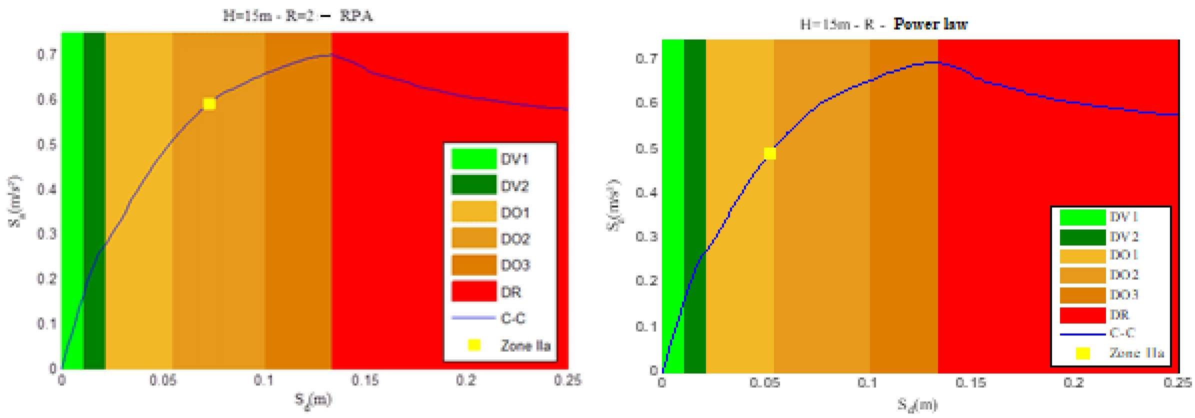


Figure 6. Coordinates of the performance point



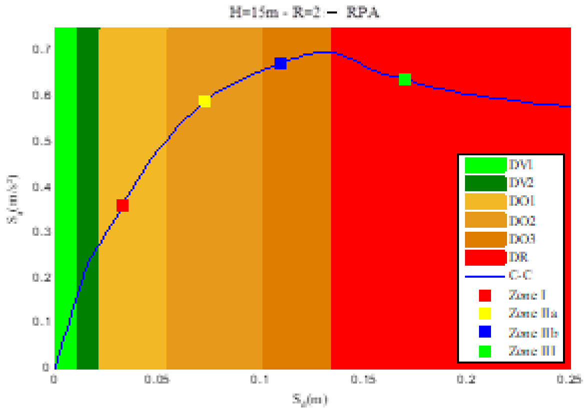
(a) (b)

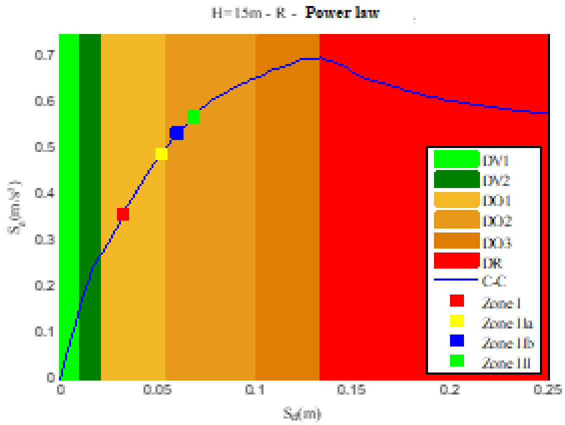
Figure 7. Position of the performance point in the damage domain.

The position of the performance point in the damage domain defined in Table 2 is shown in Figure 7(a) for R=2 (RPA, 2003) and Figure 7(b) for R=2.63from the power law. It should be noted that this performance point is located in the orange 2 domain for R =2 and at the limit of the orange 1 domain for R=2.63. In this case, it can be seen that the RPA overestimates the damage. However, by considering the R power law coefficient, the structure becomes more ductile and works more in the plastic domain, which enables it to reduce the maximum displacement and consequently the damage.

Influence of the Behaviour Coefficient and the Seismic Zone

To assess the influence of the behaviour coefficient R on tank performance, we carried out a two-stage analysis. In the first case, we considered the behaviour coefficient R recommended by the RPA, varying the seismic zone, and in the second case, we considered the behaviour coefficient R evaluated from the proposed power law, also varying the seismic zone. The results are shown in Figures 8 (a) and (b).





(a) (b)

Figure 8. Position of the performance point for different seismic zones

The comparison of the results of the performance point shows that when the behaviour coefficient (R=2) recommended by the Algerian seismic regulations (RPA, 2003) is considered, the structure rapidly penetrates the red domain. Conversely, the results of the value from the of thepower law of the behaviour coefficient R show a significant reduction in the penetration of the elevated tank into the red zone, which is reflected in the correct consideration of the force-displacement pair to which the structure is subjected. In fact, the use of a coefficient R>2 has a direct influence on the ductility of the elevated tank by reducing the range of values of the estimated performance points compared with those resulting from the use of R of the RPA, thus leading to an economical design.

Influence of Pedestal System Height

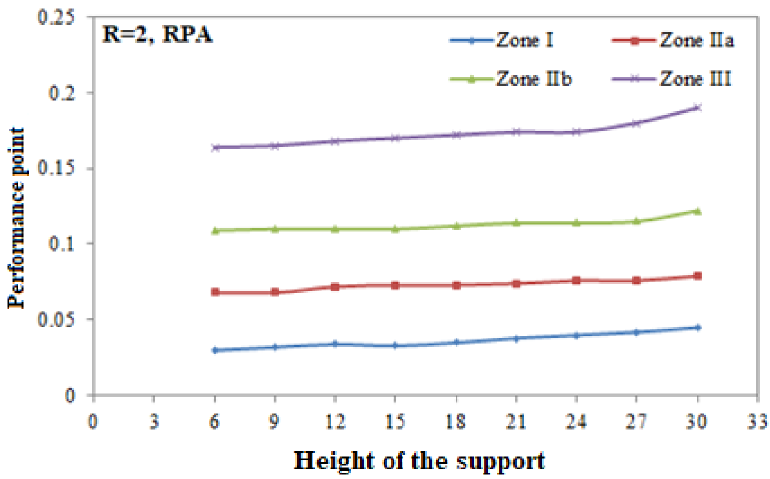


Figure 9. Evolution of the performance point as a function of the height of the pedestal H, for R=2 (RPA)

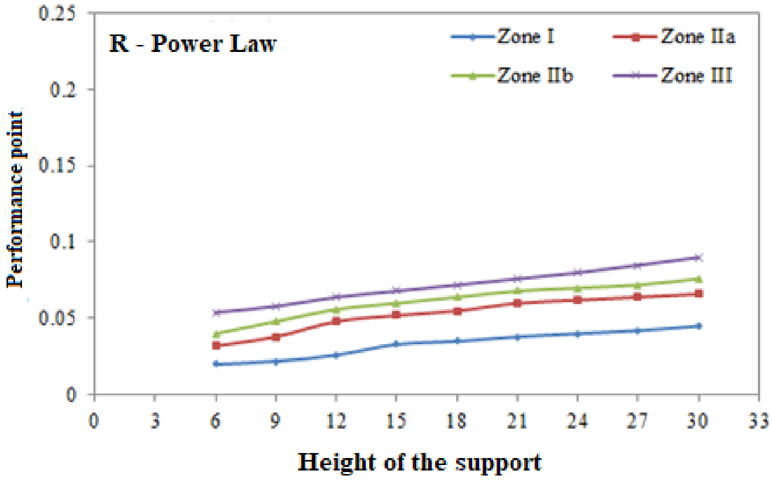


Figure 10. Evolution of the performance point as a function of different pedestal heights H, for R obtained from the power law

A summary of the results obtained for the evolution of the performance point for different seismic zones and different heights of the pedestal is presented in Figures 9 and 10 for the behaviour coefficient R recommended by the RPA (R=2) and the values of the behaviour coefficient R obtained by the power law apraoch, respectively.

It can be seen that whatever the value of the behaviour coefficient R, the spectral displacement of the performance point increases with the height of the tank pedestal sytem. However, we note that this increase is more pronounced for the value of R recommended by the RPA (R=2), and this is very visible in zones of very high seismicity (zone III); this reduces the performance of the tank and causes the structure to enter the failure domain more quickly, moving from zone I to zone III. On the other hand, considering the values of the behaviour coefficient R, obtained from the power law , the structure gains in performance.

The behaviour coefficient R recommended by the RPA has the effect of overestimating the spectral displacement Sd of the performance point and is very easily positioned in safety, given that it adopts the same value whatever the height and whatever the seismic zone. It should also be noted that the various spectral shifts Sd of the performance point obtained for the behaviour coefficient R from the power law are less than those given by the value of (R=2), recommended by the RPA.

Conclusion

The non-linear analysis of the seismic behaviour of an elevated tankis carried out in this study using the "Pushover" method, varying the seismic zone, the location and the height of the pedestal. To calculate the seismic response of the tank, we focused on the value of the behaviour coefficient R. We adopted the value of the R coefficient recommended by Algerian seismic code (R=2) and the R value obtained from the power law.
The results of the spectral displacement of the performance point showed that by considering the value of R=2, the tank rapidly enters the red domain, depending on the seismic zone and the height of the tank pedestal, contrary to the case of the R coefficient obtained from the power law. The latter has a direct influence on the ductility of the tank by reducing the range of performance point values. Using more realistic values of R, its reflects a better performance of the structure, which translates into greater penetration into the plastic zone and therefore better damping of seismic stresses and more controlled displacements, resulting in an economical design.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

Acknowledgements or Notes

* This article was presented as a poster presentation at the International Conference on Technology, Engineering and Science (www.icontes.net) held in Antalya/Turkey on November 16-19, 2023.

References

ATC-40. (1996). *Seismic evaluation and retrofit of concrete buildings* (Volume 1). Applied Technology Council. Retrieved from https://www.atcouncil.org/pdfs/atc40toc.pdf

Desprez, C., Mazars, J., Kotronis, P., & Paultre, P. (2013). Damage model for FRP-confined concrete columns under cyclic loading. *Engineering Structures*, *48*, 519–531.

DTR/B-C 2–48. (2003) .National seismic code for building design and construction (R.P.A 99/ version 2003).

Ider, O. (2023). *Evaluation of the global behavior coefficient R for elevated tanks*. (Doctoral dissertation). Mouloud Mammeri University of Tizi-Ouzou. Algeria.

Mekki, M. (2015). *Approche probabiliste dans la détermination des courbes de vulnérabilité des structures en génie civil* (Doctoral dissertation). Université de Bordeaux; Université des Sciences et de la Technologie d'Oran. Mohamed Boudiaf (Algérie).

RISK-UE. (2003). An advanced approache to earthquake risk scenarios with applications to different European towns.

Author Information

Ider Ourdia
Mouloud Mammeri University
Civil Engineering Department, Mouloud Mammeri University, 15 000 Tizi-Ouzou, Algeria

Hocine Hammoum
Civil Engineering Department, Mouloud Mammeri University, 15 000 Tizi-Ouzou, Algeria

Bouzelha Karima
Civil Engineering Department, Mouloud Mammeri University, 15 000 Tizi-Ouzou, Algeria

Amar Aliche
Mouloud Mammeri University
Civil Engineering Department, Mouloud Mammeri University, 15 000 Tizi-Ouzou, Algeria
Contact e-mail: *amar.aliche@ummto.dz*

To cite this article:

Ider, O., Hammoum, H., Bouzelha, K., & Aliche, A. (2023). Influence of the behavior coefficient on the damage level of an RC elevated tank under seismic loading. *The Eurasia Proceedings of Science, Technology, Engineering & Mathematics (EPSTEM), 26*, 677-684.