Spectral analysis of Al Haouz earthquake and comparison with the design spectrum

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Abstract. Al Haouz earthquake damage highlights the insufficiency of the current normative spectrum. Spectral amplitude comparison against the local records shows that the spectral amplitudes, in certain periods ranges, were greater than RPS 2011 predictions, particularly for the case of medium-height RC buildings. This underestimation of seismic load highlights the necessity to update the design spectrum such that the seismic risk level in Morocco will be better addressed. This revision would render new constructions safer and improve ways of assessing and restoring existing structures. The study is based on the accelerogram of Al Haouz earthquake (Mw = 6.8) and aims to investigate the spectral parameters of the motion with the view of assessing its importance to buildings, according to which comparison was made with Moroccan earthquake laws requirements (RPS 2011). Elastic response spectra were calculated for 5% damping and, additionally, compared with normative spectrum for the different soil categories. The results present large spectral peaks for the period intervals 0.4-0.8 s, typically associated with the medium-height reinforced concrete structures. The result confirms a possible underestimation, by the normative spectrum, of seismic effects for certain range intervals of periods

Keywords : Al Haouz , earthquake ,accelerogram, spectrum

1.Introduction

Morocco is located in a major seismic convergence zone where the Eurasian and African plates diverge [1]. This area is subject to ongoing tectonic activity in the Rif, Middle Atlas, and High Atlas regions [2-4]. The Al Haouz earthquake (Mw = 6.8) on

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September 8, 2023, at 23:11 UTC was one of the most recent strong earthquakes in Morocco, resulting in an estimated 2,900 deaths and thousands of injuries, as well as damage to traditional adobe structures [5] and concrete-reinforced buildings that were not designed to be earthquake-resistant [6] .

The Moroccan Institute of Geophysics [7] publishes the accelerograms of the earthquake, providing us the ability to analyze the ground response using real data. Response spectrum analysis is an important procedure in earthquake engineering because the response spectrum characterises the peak spectral accelerations of oscillators subject to different periods. This establishes a link between the seismic record and the dynamic stresses considered in structural design. Following this earthquake, the National Institute of Geophysics released seismic recordings, providing a unique opportunity to study the characteristics of ground motion and its effects on structures. Response spectrum analysis is a fundamental method in earthquake engineering as it enables recorded seismic motion to be converted into equivalent dynamic stresses for application to structures. It thus provides a direct link between seismology and structural design. The Moroccan seismic codes (RPS 2011) [8] provide standard design spectra in terms of seismic zone and soil type. Although such spectra represent a basic framework for building design and verification, they are obtained through generalized assumptions that do not necessarily take into account the local characteristics of seismic recordings.

In this context, previous studies [9-10] show that the design spectrum may be inadequate for some recordings. Alpyürür & Ulutaş [11] compared Turkish code (TBEC-2018) spectra and site-specific spectra for deepened areas in southwest Turkey, and it was noted that there were significant differences in the periods corresponding to medium-height structures (R+3 to R+5). Moreover, Jalili et al. [12] registered a case whereby the regulatory spectra were underestimated close to fault lines in Iran and thus, suggested the adoption of local correction factors. Further, Gülkan et al. [13] and Cengiz et al. [14] demonstrated that calibrated site spectra have been indicated as the means for achieving better damage prediction in different soil and structural conditions.

In Morocco, although comparative studies remain limited, some of the interpretations of the recent earthquakes in Nador [15-16] have highlighted the divergence between real and normative spectrum, particularly in areas of local amplification [17] . Al Haouz earthquake and the resulting damage highlight the need to assess the relevance and update of the RPS2011.

This study uses the accelerogram of the Al Haouz earthquake to:

- Identify the major spectral characteristics of the recorded signal;
- Compare the results obtained with the elastic spectrum provided by RPS 2011 for different soil classes;
- Discuss the implications of such a comparison on seismic design and vulnerability of local structures.

The overall objective is to make a contribution to the understanding of the adequacy of normative prescriptions relative to the reality of seismic motion experienced, with the perspective of making an input to deliberations on a possible update of the design spectrum in Morocco.

2. Method for spectrum response determination

The seismic response spectrum is determined using the Duhamel integration method [17], based on the exact solution of the differential equation governing the motion of a simple damped oscillator subjected to dynamic excitation. For a mass-spring-damper system with mass m, stiffness k, and damping coefficient c, the equation of relative motion under the action of ground acceleration $\ddot{u}(t)$ is written as [17] :

$$m\ddot{u}(t) + c\dot{u}(t) + ku(t) = -m\ddot{u_g}\ (t) \tag{1}$$

Where:

u(t) = relative displacement of the mass, m = mass, $c=2\zeta m\omega$ = damping coefficient,

$k=m\omega^2$ = stiffness, $\omega=T/2\pi$ = angular frequency.

The solution to this equation can be formulated using Duhamel's integral, which expresses relative displacement as a convolution between ground acceleration and the impulse response function of the system [17].

$$u(t) = -\frac{1}{\omega_d}\int_0^t \ \ddot{u}_g\ (\tau)\ e^{-\xi\omega(t-\tau)}\sin\big(\omega_d(t-\tau)\big)\ d\boldsymbol{\tau} \tag{2}$$

Where $\omega_d = \omega\sqrt{1-\zeta^2}$ damped pulsation,

Evaluating this integral allows us to reconstruct the time response for each period T, and to deduce the maximum values for acceleration [17]:

$$S_a = max|u(t)| \tag{3}$$

Where S_a : The acceleration response spectrum

3.Structure Analysis and spectra design (RPS2011)

The case study is a four-story building with a basement used for parking. The surface area is 46.70 m in length and 38.81 m in width, giving a total area of 1,812.43 m². The underground parking area, with a height of 2.5 m, is designed to accommodate around forty vehicles. The ground floor has a height of 3 m, while the four upper floors each have a ceiling height of 3m. Fig.1 shows 3D modelling of the studied structure, and Fig. 2 illustrates a plan view of the studied building.

According to Moroccan earthquake-resistant building regulations (RPS 2000, revised in 2011), the assessment of seismic action on a structure is based on two essential criteria: seismic zoning and soil type. Zoning determines the maximum ground

acceleration Amax whose reference values are: $Z0$=0.04g, $Z1$=0.07g, $Z2$=0.10g, $Z3$=0.14g, and $Z4$=0.18g g as shown in Fig.3. Furthermore, the regulations distinguish between four types of soil S1, S2, S3, and S4 which directly influence the shape and amplitude of the response spectrum to be used in design.

RPS2011 sets limits for the relative displacement Δe of Class III buildings as follows: $\Delta e \leq 0.010h/K$, where h: the height of the floor in question and K: the behavior coefficient.

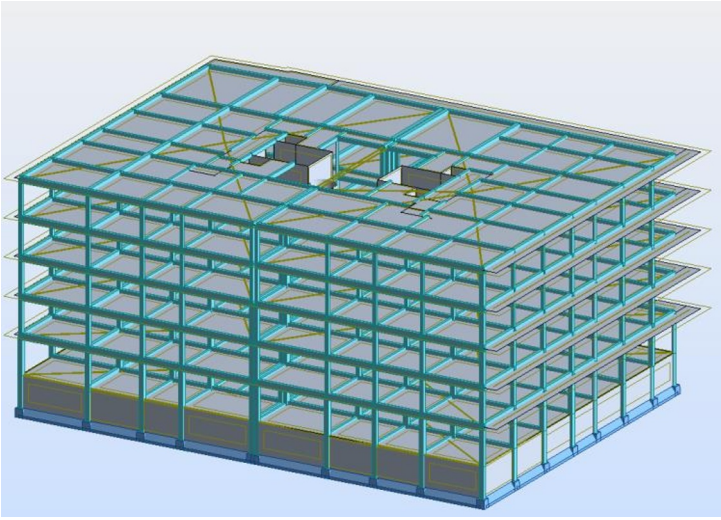

Fig.1. 3D modelling of the studied structure

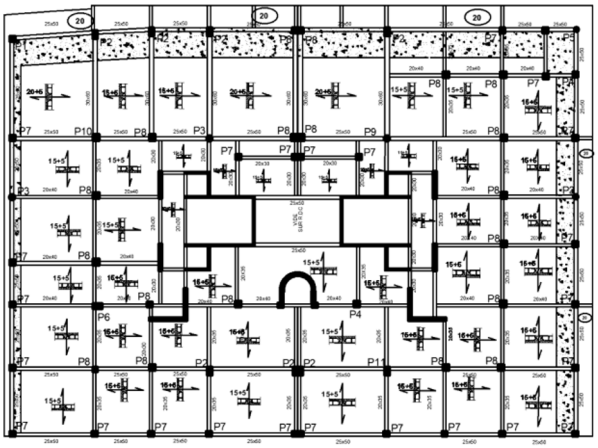

Fig.2. Plan view of the studied building

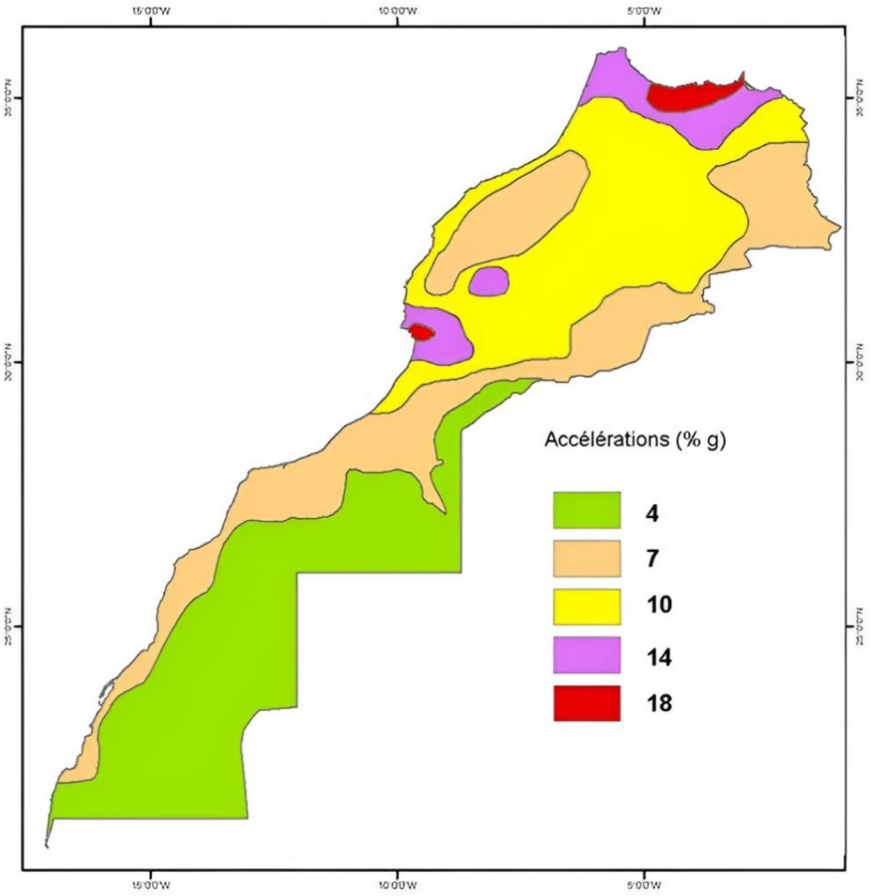

Fig.3. Seismic zoning in Morocco according to RPS2011

4. Results and discussion

4.1. Spectrum response

The acceleration record is the variation of the seismic acceleration over time, as can be seen from Fig.4. It shows a succession of rapid oscillations, characterized by peaks reaching approximately ±0.2 g, reflecting the intensity of the tremors felt during the High Atlas earthquake. The main phase of high acceleration is of rather short duration, thus the major seismic impulse can be identified along with a slow decrease of energy. So this time history gives an idea of the suddenness of the ground shake, however, it does not enable us to forecast the response of different buildings to this excitation. Therefore, the response spectrum will be necessary.

Figure 5 shows the response spectrum obtained from the Duhamel integral with 5% damping, calculated based on the ground acceleration recorded during the Al Haouz earthquake . On this basis, the target design spectrum was constructed.

The response spectrum outlines the possible damage from an earthquake for buildings of different natural periods, 5% being the damping (see Fig.5). It is quite noticeable that the highest spectral acceleration values are found at the short period range (around 0.8 s-1s), thus we can assume that low to medium-rise buildings (R+3 to R+5) were the most impacted. On the other hand, structures that are very rigid (T < 0.2 s) or very flexible (T > 1.5 s) have lower spectral accelerations.

According to Figure 7, the spectrum shows a maximum acceleration of approximately 0.47 g, corresponding to relatively strong seismic excitation. Compared to the reference value of a= 0.10 g defined for zone 2 according to RPS2011, the spectrum shows that the actual intensity of the movement is significantly higher, confirming that Al haouz earthquake produced acceleration levels higher than those specified by the regulations for this seismic zone.

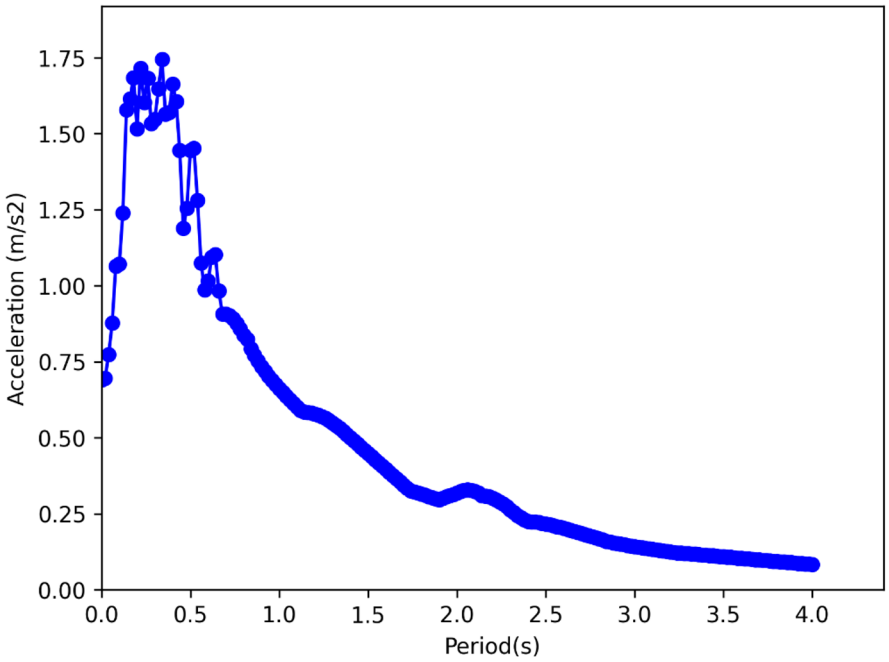

Fig.4. Ground acceleration recorded during the Al Haouz earthquake

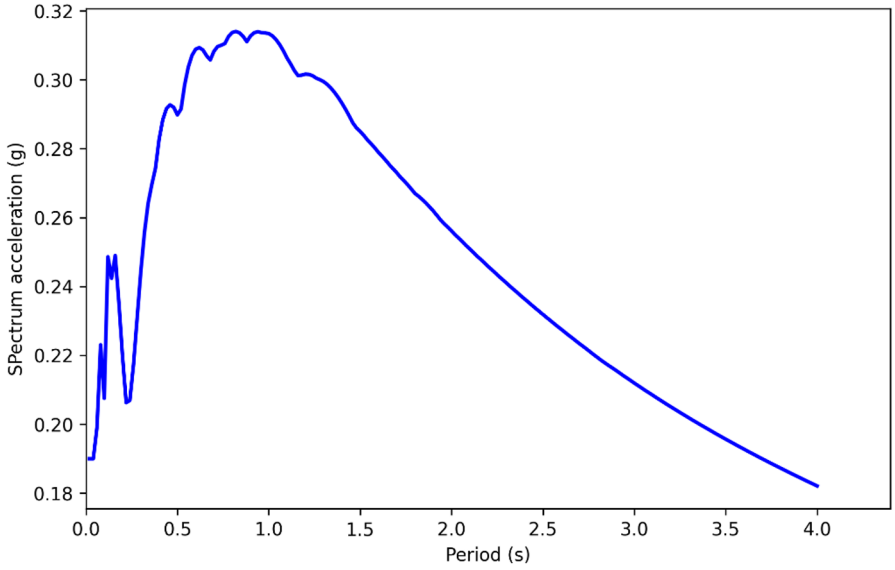

Fig.5. Response spectrum using Duhamel's integral (ξ = 5%)

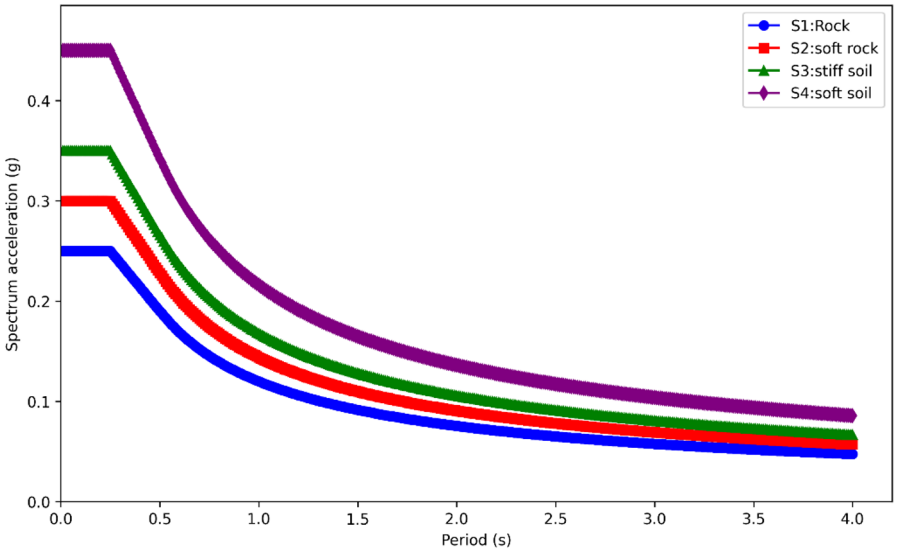

Fig.6. Design Spectrum of the RPS2011

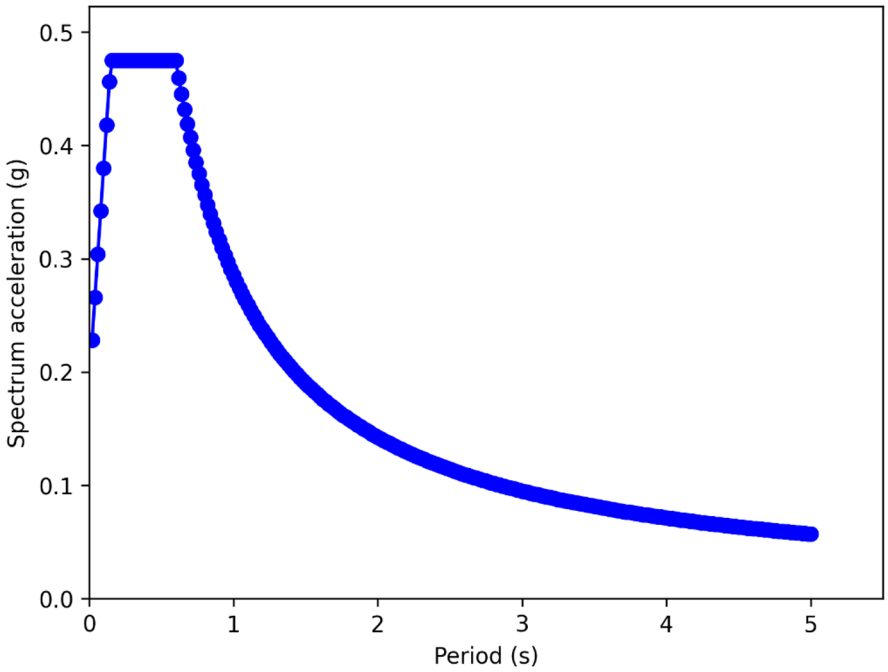

Fig.7. Target Design Spectrum according to RPS2011

Fig.6 shows the normative elastic response spectra of RPS2011 for Zone 2, established with a reference acceleration ag = 0.10 g and considering a damping of 5% . The curves show a maximum response plateau for short periods ($T \leq 0.25$ s), reflecting a strong amplification of spectral acceleration for rigid structures or structures with short natural periods. The ordinate of this plateau varies according to the nature of the soil: it reaches approximately 0.25 g for soil S1 and increases gradually to 0.45 g for soil S4, reflecting the more pronounced amplification effect of loose soils. Beyond T = 0.25 s, the spectral acceleration gradually decreases according to the law defined by RPS2011, indicating that more flexible structures (long periods) are subject to lower dynamic stresses.

The response spectrum achieved from the Al Haouz earthquake and design spectrum based on RPS2011 (Zone 2, ag = 0.10 g) are significantly different depending on the period range (see Fig.5). For short durations ($T < 0.1$ s), the actual spectrum is above the regulatory requirements for soil categories S1, S2 and S3, indicating increased seismic stress compared to the regulations. This difference is even more pronounced in the range 0.4–0.8 s, which includes medium-height R+3 to R+5 reinforced concrete structures. Here, the recorded spectral amplitudes are much greater than the ones specified by RPS2011 and hence suggest underestimation by the latter in this significant range. However, for longer periods ($T > 1.5$–2 s), the design spectra, particularly that of soil S4, are more stringent than the measured response, which demonstrates the conservativeness of the design for tall and slender structures. This

comparison thus indicates the need to include local recordings in seismic hazard estimation for calibrating design spectrum and ensure the protection of Moroccan structures.

4.2. Impact of response spectrum on structural behavior

In Table 1, which is based on the RPS2011 design spectrum, the inter-floor displacements are quite low, and they are well within the limits set by the regulations. For instance, at the top floors (3rd and 4th) the displacements in the X-direction are 0.7 cm, which is less than the allowed 2.14 cm. In contrast, Table 2, derived from the Al Haouz acceleration spectrum exhibits higher inter-story displacements. As a result, at the 3rd and 4th floors the displacements go up to 1.2 cm and 1.3 cm, respectively. While these numbers are still below the limits, they show a considerable escalation of the structural reaction when a local spectrum is employed, that is more accurate to the seismicity of the area. The comparison thus conveys that the RPS2011 normative spectrum is inclined to underrate the displacements slightly relative to the spectral data of Al Haouz earthquake.

Table 3, referring to the total displacements calculated on the basis of the RPS2011 design spectrum, shows a maximum in X and Y of 3.1 cm. These maximums are less than half of the total limit of 7.48 cm, meaning it is still within the scope of acceptable deformations for the structure. In comparison, the data in Table 4, based on the Al Haouz spectrum, point to a total displacements that are greater overall. In numbers, these displacements being 4.7 cm in X and 4.9 cm in Y. While these do not exceed the limit, they indicate that the structure is subjected to greater stresses in the Al Haouz region. Accordingly, it can be concluded that the local spectrum contributes to greater total displacements than those produced under an RPS2011 loading condition.

Table 1 :Displacements inter-floor values using design spectrum (RPS2011)

Story	**Height (m)**	**U X (cm)**		**U Y (cm)**		**Limit displacement (cm)**
		Ux	Uy	Ux	Uy	
Underground	2.50	0.2	0.0	0.0	0.2	1.78
RDC	3	0.4	0.1	0.1	0.4	2.14
1er story	3	0.5	0.1	0.1	0.6	2.14
2ème story	3	0.6	0.1	0	0.6	2.14
3ème story	3	0.7	0.1	0.1	0.7	2.14
4ème story	3	0.7	0.1	0.1	0.6	2.14

Table 2 :Displacements inter-floor values using Al haouz spectral acceleration

Story	**Height (m)**	**U X (cm)**		**U Y (cm)**		**Limit displacement (cm)**
		Ux	Uy	Ux	Uy	
Underground	2.50	0.3	0.0	0.0	0.2	1.78

RDC	3	0.3	0.1	0.1	0.3	2.14
1er story	3	0.6	0.1	0.1	0.7	2.14
2ème story	3	0.8	0.1	0	0.8	2.14
3ème story	3	1.2	0.1	0.1	1.1	2.14
4ème story	3	1.3	0.1	0.1	1.5	2.14

According to RPS2011, the global displacement Δg_{limit} of the building is calculated as shown below:
$\Delta g_{limit} = 0.004H$ where H is the total height of the structure.

Table 3 :Global displacements values using design spectrum (RPS2011)

Seismic direction	Displacement	Global displacement (cm)	Limit displacement (cm)
x	Ux	3.1	7.48
	Uy	0.5	7.48
y	Ux	0.4	7.48
	Uy	3.1	7.48

Table 4 :Global displacements values using Al haouz spectral acceleration

Seismic direction	Displacement	Global displacement (cm)	Limit displacement (cm)
x	Ux	4.7	7.48
	Uy	0.8	7.48
y	Ux	0.5	7.48
	Uy	4.9	7.48

Conclusion

Normative spectrum are a fundamental tool in earthquake-resistant design, providing an essential regulatory framework for building safety. However, in order to ensure their relevance, they must be regularly reviewed and supplemented by analysis of actual seismic records, which allow local specificities of ground motion to be taken into account. In Morocco, as in other regions exposed to significant seismic activity, this comparison highlights a potential underestimation of stresses for certain period ranges, particularly those corresponding to medium-height reinforced concrete structures. This underestimation increases the vulnerability of buildings to earthquakes.

The results of our study confirm this observation: the inter-storey displacements and the overall displacement of the building studied, when assessed using the actual spectrum derived from the Al Haouz earthquake record, are greater than those obtained using the normative spectrum defined by RPS2011. These findings highlight the need to update the design spectrum in order to ensure a better match between regulatory requirements and the reality of seismic risk, thereby strengthening the resilience of Morocco's building stock.

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