GREEN ROOF RETROFITTING IN ALGERIA BETWEEN SUSTAINABILITY AND SEISMIC VULNERABILITY

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Abstract: *Installing green roofs in urban areas is a sustainable practice towards the ecological transition, they offer many advantages with regards to reducing energy consumption, mitigating the urban heat island effect, managing runoff ...etc. In order to propagate this technique, green roofs have to be installed on the top of existing buildings, which can increase their vulnerability during seismic events. The present paper aims to evaluate the impact of green roof retrofitting on the seismic performance of a collective housing in Algeria. To this end, the finite element method was adopted to investigate the seismic-related parameters according to the Algerian seismic regulations. The studied reinforced concrete building is located in the district of Constantine (northern east of Algeria). It was found that the presence of concrete walls, recommended by the Algerian seismic regulations, increases the rigidity of the building, which reflects positively on the building's natural period and displacements. As for the stress-related parameters, the reduced normal force does not increase much; however, a significant increase in the shear forces at the base due to green roof implementation was observed. It was also found that adding a green roof contributes more to the stabilizing moment than to the overturning one during an earthquake event. Hence, in the studied context, the presence of load-bearing concrete walls offers certain positive effects on green roof installation with regard to the seismic performance. Nevertheless, a thorough seismic investigation should be performed before installing green roofs on the top of existing collective housing in Algeria.*

Keywords: *green roof, seismic performance, finite element, ecological transition.*

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Introduction

Climate change effects raise concerns about improving and protecting the environment, especially in urban areas. Innovative eco-friendly practices, like green roofs [1-3], are a key tool towards achieving an ecologically functional land cover in cities. As a planning strategy to face the climate challenges in urban centers by improving the environment quality, green roofs implementation is an important green technology that hosts vegetation in a specially designed substrate [4,5]. The history of green roofs in many cultures goes back thousands of years ago [6]. However, the appearance of the modern concept of green roofs took place in the 20th century, adopted in construction in Germany, and then in Northern Europe, North America, and other Asian countries [7]. Over the past decades, extensive green roofs have been considered as a valuable tool for sustainable development [8]. The environmental and economic benefits due to the thermal regulation capacity of green roofs have resulted in accelerating research and practice of this technique [8,9]. Green roofs offer other advantages for sustainable buildings and cities, including: improving air quality, mitigating the urban heat island effect, managing stormwater (by retaining and then slowly releasing rainwater), preserving the ecological environment, improving sound insulation ... etc. [10-13].

In the Mediterranean region, green roofs are considered as a useful technique for sustainable urban stormwater management, as they compensate for man-made impervious surfaces by absorbing a certain amount of rainwater and slowly releasing the rest into the evacuation systems [14]. In summer, in the

Mediterranean region, green roofs improve energy efficiency and mitigate the urban heat island effect, which consequently reduces the environmental impacts [15]. Weather and vegetation types control the performance of green roofs [16]. The installation of green roofs is gaining more popularity for microclimate regulation, as they are closely associated with climate and the environment [17]. For the specific climatic conditions in the Mediterranean region, the installation of green roofs is a complicated operation as it faces many challenges, such as selecting appropriate vegetation, and designing for climate change [18]. Therefore, plant breeding and improved growing substrates are crucial in future green roof research [19]. The presence of grass on the roofs of buildings could potentiate the effect of trees and shrubs. On the other hand, species with greater sizes and biomass perform better in reducing water runoff, compared to species with smaller sizes and lower biomass [20, 21]. In order to promote biodiversity, green roofs should include different types of substrates, which allows for the creation of multiple microhabitats, which can eventually support a larger diversity of species than if they were uniform [22].

Algeria, like other northern African and Mediterranean countries, is facing many environmental challenges, such as desertification, drought, biodiversity loss, air and water pollution …etc. [23]. Although the installation of green roofs in Algeria is not yet widespread, there is a growing interest in this green practice in the country. The work of [24] reports that the implementation of green roofs and facades could transform the Saharan cities in the southern part of the country into an ecological urban environment. In another study carried out in the town of Jijel, in the northern east of Algeria, the results show that green roofs can be an efficient technique for improving the thermal performance of the surrounding microclimate, and also the energy performance of buildings in urban areas [25].

Green roofs offer great advantages when it comes to reducing urban heat island, regulating runoff, and enhancing the overall life quality...etc. However, in order to propagate its use, green roofs have to be installed on existing buildings, which raises concerns about its impact on the building structure. In regions where earthquakes are frequent, the vulnerability of a building when adding a green roof on the top is crucial. In literature, few authors have worked on the seismic behavior of buildings with green roofs [26-31]. However, in the seismic context of Algeria, and the Algerian seismic regulations, the impact of green roof retrofitting on the seismic performance of buildings was not tackled yet.

The present paper shed light for the first time on the seismic impact of green roofs retrofitting on collective housing according to the Algerian seismic regulations.

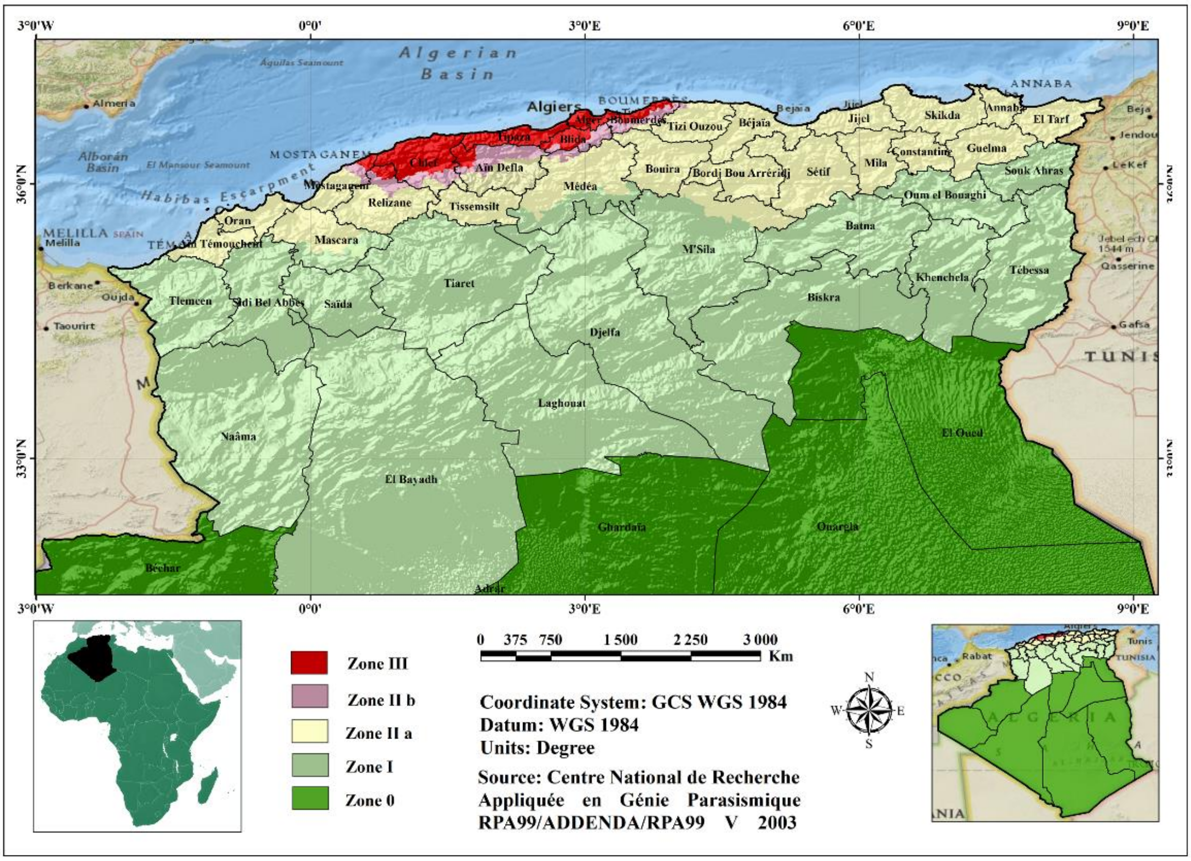
Materials and Methods

Brief introduction into the Algerian seismic regulations

Algerian seismic regulations [32] have evolved through the years, the actual seismic regulations: RPA 99 V2003 is considered the fifth regulation after RPA 81, RPA81 V1983, RPA 88, and RPA 99. The development of the Algerian seismic regulations took into account the progress in the research field, and the lessons learned from earthquakes in Algeria, such as those of Oued Djer (October 1988), Tipaza (October 1989), Mascara (August 1994), and abroad, such as Spitak / Armenia (1988), Sanjan / Iran (1990), Loma Priéta / California (1989), Northridge/California (1994), Kobe/Japan (1995), and Izmit/Turkey (1999). According to [32], the Algerian territory is divided into five (05) zones of increasing seismicity (Fig.1).

Zone O: negligible seismicity.
Zone I: low seismicity.
Zone IIa and IIb: average seismicity.
Zone III: high seismicity.

The Algerian seismic regulations [32] classify buildings according to their importance into four (04) groups, The minimum level of seismic protection granted to a structure depends on its destination and its importance with regard to the protection objectives. The classification aims to protect people, then economic goods and cultural aspects of the community.



Coordinate System: GCS WGS 1984
Datum: WGS 1984
Units: Degree

Source: Centre National de Recherche Appliquée en Génie Parasismique RPA99/ADDENDA/RPA99 V 2003

Fig. 1. *Seismic zones in Algeria [32]*

Group 1A: Buildings of vital importance.

Group 1B: Buildings of major importance.

Group 2: Common buildings or of a medium importance.

Group 3: Buildings of minor importance.

Accordingly, the Algerian seismic regulations give the following zone acceleration coefficients (Table 1).

Table 1. Zone acceleration coefficient [32]

	Zone			
Importance	I	IIa	IIb	III
1A	0.15	0.25	0.30	0.40
1B	0.12	0.20	0.25	0.30
2	0.10	0.15	0.20	0.25
3	0.07	0.10	0.14	0.18

As for the construction sites, the Algerian seismic regulations [32] classify them into four (04) categories based on the mechanical properties of the soil which constitute them.

Category S1 (rocky site): rock or other geological formation characterized by an average shear wave speed (VS) ≥ 800 m/s.

Category S2 (firm site): deposits of very dense sand and gravel and/or overconsolidated clay 10 to 20m thick with VS ≥ 400 m/s below 10m depth.

Category S3 (loose site): thick deposits of moderately dense sand and gravel or moderately stiff clay with VS ≥ 200 m/s below 10m depth.

Category S4 (very loose site):

- deposits of loose sand with or without the presence of layers of soft clay with VS < 200 m/s in the first 20 meters.
- soft to moderately stiff clay deposits with VS < 200 m/s in the first 20 meters.

The analyzed model

In order to assess the impact of green roofs on the seismic performance of collective housing in Algeria, a typical building is chosen as shown in Figure 2. This building is located in the district of Constantine (northern east of Algeria), which falls under the IIa seismic zone. The IIa zone was chosen because it covers a large zone in the northern part of Algeria extended from the east to the west, and known for its important population density. The building importance is classified according to the Algerian seismic regulations in group 2 (common buildings or of medium importance); this category contains buildings for collective housing or office use in which the height does not exceed 48m, other buildings that can accommodate a maximum of 300 people simultaneously, such as office buildings, industrial buildings …etc., and public parking lots. The chosen collective housing is built on a loose site (site of category S3 [32]).

The analyzed building is composed of six floors, each floor is composed of 4 apartments that share one staircase. The overall area of each floor is about 356m^2. The height of each floor is 3.06m, thus, the total height of the building is 18.36m. The cross section of columns varies between 1600 and 1800cm^2. As for the roof, it is inaccessible with a waterproof isolation covered by river gravel.

Fig. 2. *Picture of the analyzed collective housings*

The structural system consists of concrete load-bearing walls (15cm thick) and reinforced concrete (RC) frames. According to the Algerian seismic regulations [32], RC framed buildings with rigid masonry walls (rigid masonry walls are the common separation walls in Algerian buildings) must not exceed five (05) levels or seventeen (17) meters in seismic zone I, four (04) levels or fourteen (14) meters in zone IIa, three (03) levels or eleven (11) meters in zone IIb and two (02) levels or eight (08) meters in zone III. If the aforementioned heights are exceeded, buildings must include concrete load-bearing walls.

The bracing system consists only of concrete load-bearing walls, since in the studied model, the concrete load-bearing walls absorb more than 20% of the forces due to vertical loads [32]. As for the floor, it is made of a hollow block slab that transfers the vertical loads in the X direction. This later is assumed to be fully rigid, i.e., it transfers all the lateral loads to the bearing walls. Regarding the weight of the floors, it was calculated accounting for the hollow block slab and the materials used in floor covering, a value of 5.25 KN/m^2 is adopted for the studied case. In the present study, the compressive strength of the concrete is 25 MPa.

Since the building's roof is already equipped with water-proof isolation covered by river gravel, and the drainage system is already in place, the green roof is considered to be installed directly on the building, as demonstrated in Figure 3. The soil depth varied between 10cm (shallow green roof) and 50cm (deep green roof). The weight of the green roof is calculated using the saturated soil density (19 KN/m^3) and accounting for the weight of the plants as (0.45 KN/m^2). As for the live load, it is considered as maintenance load of 1 KN/m^2.

The building was modeled using the finite element code Robot structural analysis (Fig.4). A modal analysis was performed first, followed by a seismic analysis according to the Algerian seismic regulations. For the generation of finite elements, the nodes are generated at the intersection of vertical/horizontal bars. The tolerance of structure model generation for the analyzed model is 0.1mm. Regarding load-bearing walls, for the mesh generation, an element size of 0.5m was adopted. In this study, only the seismic performance-related parameters were analyzed.

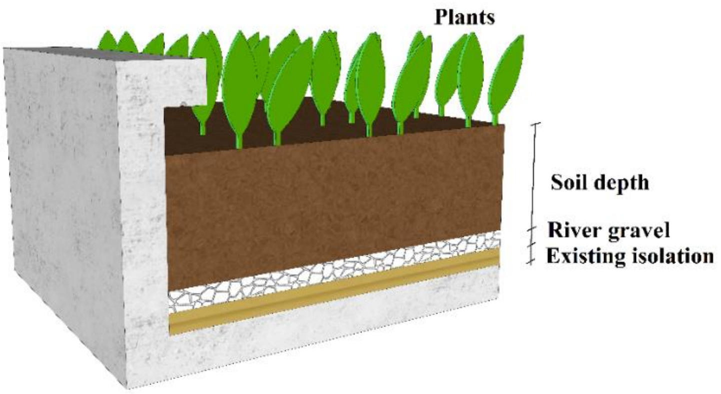


Fig. 3. *Schematic illustration of the green roof*

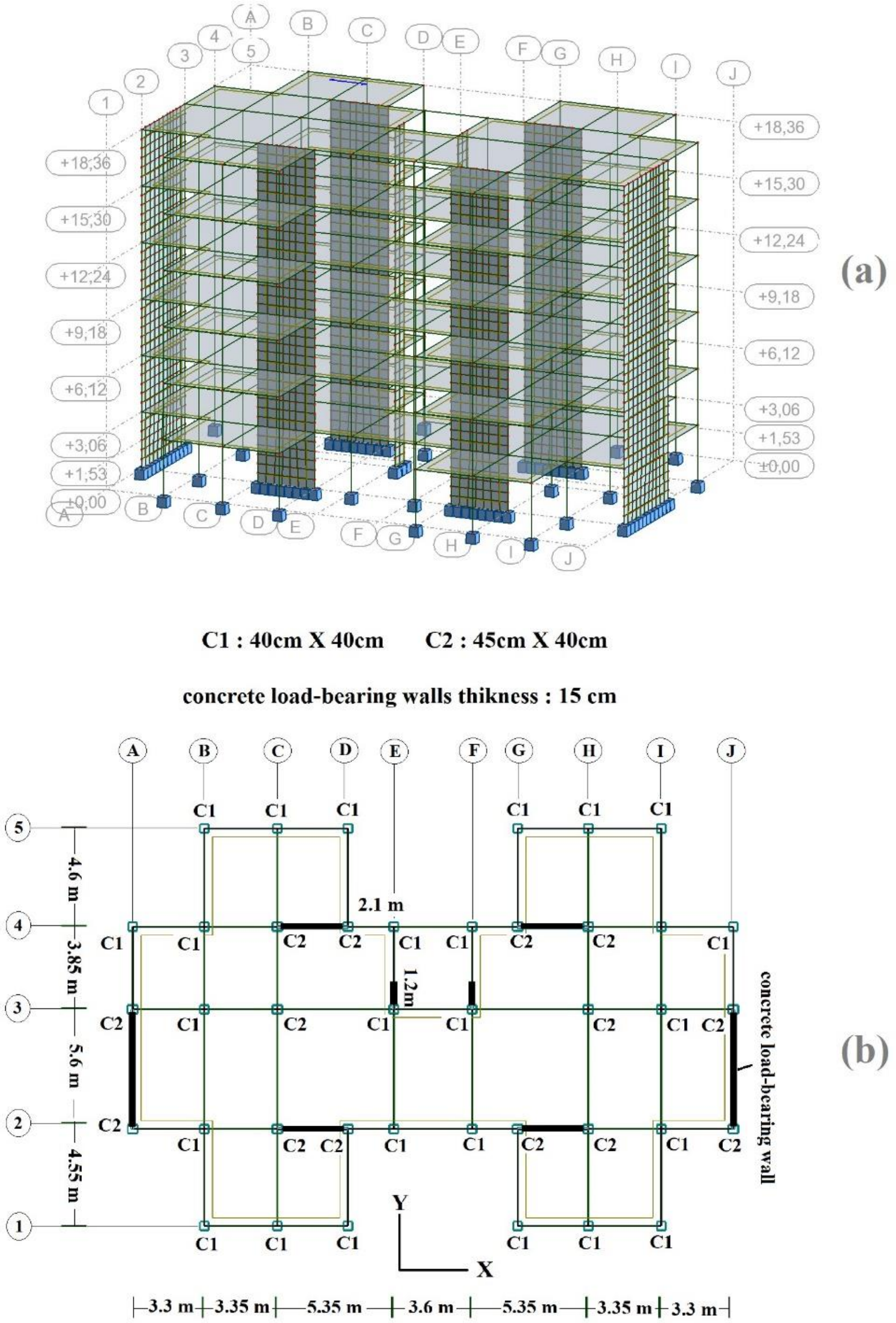


Fig. 4. *The 3D (a) and the building plan (b) of the analyzed numerical model*

Results and Discussion

In the present paper, the seismic performance of a collective housing with green roof retrofitting in Algeria is investigated according to the Algerian seismic regulations [32]. In order to assess the impact of green roofs on the seismic performance of this building, the natural period of the building, reduced normal forces in columns, peak storey drift, relative displacement, shear forces at the base, and overturning moment are investigated.

Effect of the green roof on the natural period of the building

It is meant by the natural period of a building, the time taken by it to undergo one complete cycle of oscillation. The value of the fundamental period (T) of the structure can be estimated from empirical formulas or calculated by analytical or numerical methods. The empirical formulas to use are as follows [32]:

$$T = Ct.hn^{3/4}\ , \tag{1}$$

h_n: height measured in meters from the base of the structure to the last level (n).
C_t: coefficient, function of the bracing system, type of separation walls. In this case study: "Bracing provided partially or totally by concrete load bearing walls, triangulated blocks and masonry walls" Ct = 0.05.
And:

$$T = \frac{0.09\ hn}{\sqrt{L}}\ , \tag{2}$$

where L is the dimension of the building measured at its base following the considered calculation direction. In this case, it is appropriate to retain, in each direction considered, the smaller of the two values given, respectively, by formulas (1) and (2).

In the present study, the soil depth of the green roof is varied from zero (building without green roof) to fifty centimeters (building with deep green roof), the period of building varies as plotted in Figure 5.

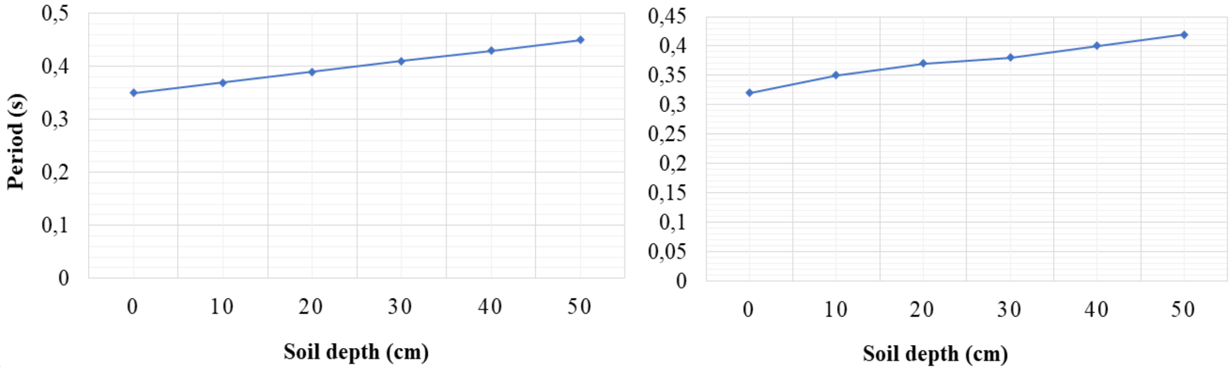


Fig. 5. *Analytical period of the structure in X direction (left side), and Y direction (right side)*

As plotted in Figure 5, the analytical period increases with the increase of the depth of the green roof in both X and Y directions (see Figure 4 for X and Y axes). As for the fundamental period calculated using formulas (1) and (2), they are 0.31s in the X direction and 0.38s in the Y direction.

For the X direction, the analytical period is greater than the fundamental one (0.31s) for all green roof depths, however, in the Y direction, the analytical period is less than the fundamental one (0.38s) for green roof depth less than 30cm and greater for green roof depths 40 and 50cm.

The tolerated analytical period should be less than 1.3 times the fundamental one [32]. In this case, less than 0.40s in the X direction, and 0.49s in the Y direction. For the present study, the periods in the building with 30, 40, and 50cm green roof depth in the X direction offered a greater period than that tolerated by the Algerian seismic regulations. Thus, for all the other configurations, the building periods obey the Algerian seismic regulations. This can be explained by the fact that the presence of load-bearing walls in the building contributes to a more rigid behavior of this later.

Effect of the green roof on peak storey drift

Adding more weight on the top of an existing building will logically cause the maximum storey drift to increase during an earthquake event. Thus, when adding a green roof to an existing building, it is important to make sure that the maximum storey drift at the top is not high enough to collide with the adjacent building.

In the present study, the maximum storey drift with respect to the green roof soil depth is analyzed as shown in Figure 6.

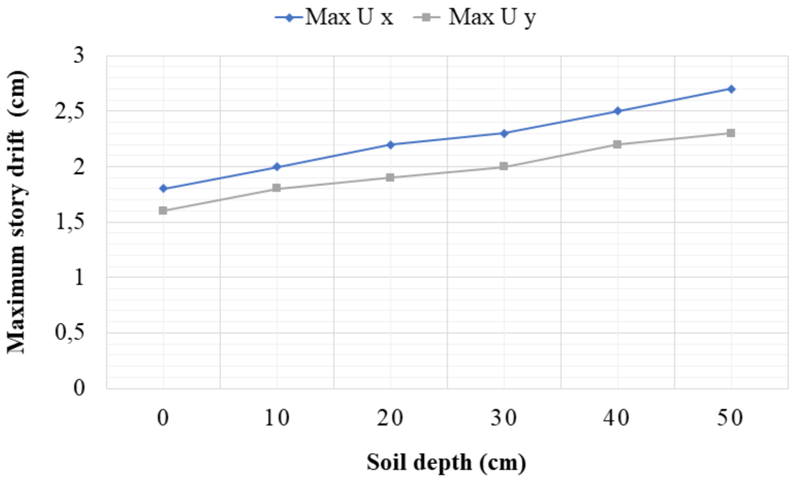


Fig. 6. *Variation of the maximum top storey drift with respect to the green roof soil depth in X and Y directions*

It is noticeable for both directions that the peak storey displacement increases with the increase of soil depth. In the X direction, the increase of top storey maximum displacement (Max Ux) between the building without green roof and the one with 50cm green roof is 0.9cm, and for the Y direction (Max Uy) it is 0.7cm. This increase is not very substantial due the presence of load-bearing walls.

Effect of the green roof on relative storey displacement

By definition, the relative displacement at level “k” with respect to level “k-1” is equal to:

$$\Delta_k = \delta_k - \delta_{k-1} \quad . \qquad (3)$$

The lateral relative displacements of a storey relative to the storey adjacent to it, must not exceed 1.0% of the height of the storey unless it can be proven that a larger relative displacement can be tolerated [32].

In the present study, the relative displacement for each storey increases with the increase of the green roof's soil depth. The tolerated relative displacement should be less than 1% of storey height, thus less than 3.06cm, which is the case for all green roof soil depths (Fig.7).

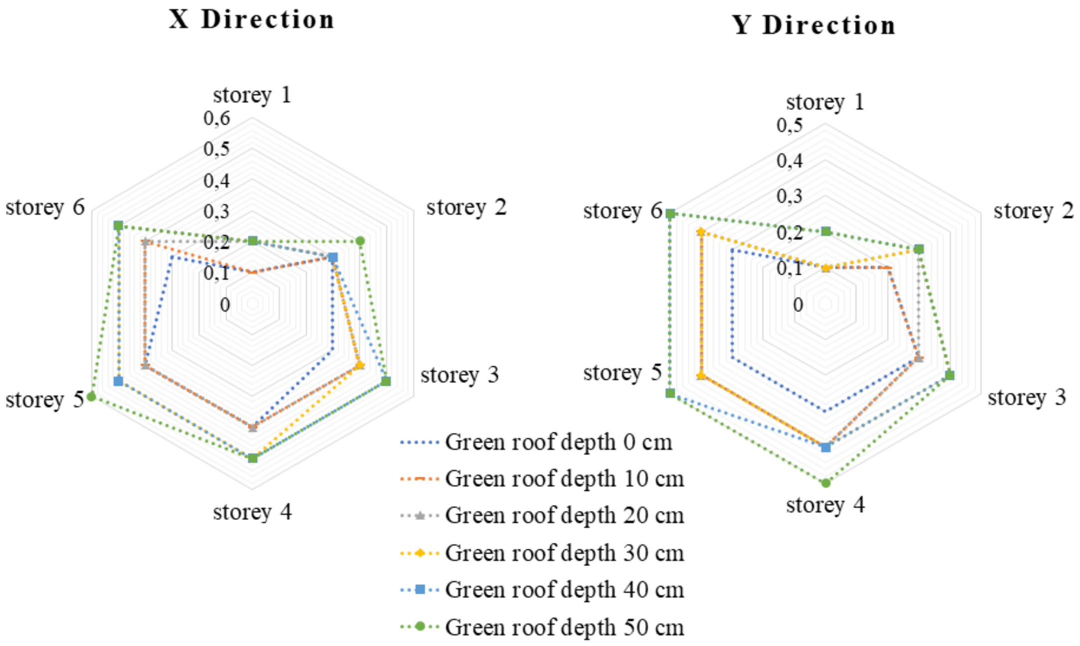


Fig. 7. *Variation of relative storey displacement (cm) with respect to the green roof soil depth in X and Y directions*

Effect of the green roof on reduced normal force

The reduced normal force is restricted in order to avoid or limit the risk of brittle failure under overall stresses due to the earthquake. The threshold for the reduced normal force in columns is 0.3. This later is calculated using the formula [32]:

$$\nu = \frac{Nd}{Bc.fcj}\ , \tag{4}$$

where *Nd* indicates the normal force applied on a column section of concrete during the event of an earthquake; *Bc* is the area of the column; *fcj* is the compression strength of the concrete (25 MPa).

As plotted in Figure 8, it is clear that the reduced normal force increases with the increase of green roof depth, however, for all soil depths, the reduced normal force is less than the threshold recommended by the Algerian seismic regulations.

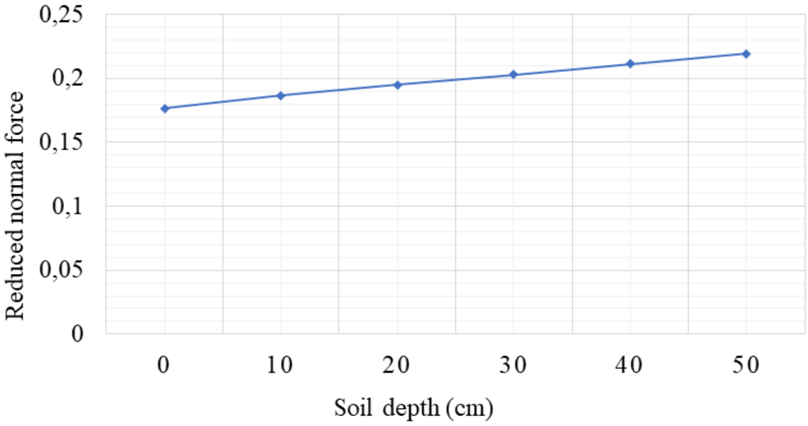


Fig. 8. *Variation of reduced normal force with respect to green roof soil depth*

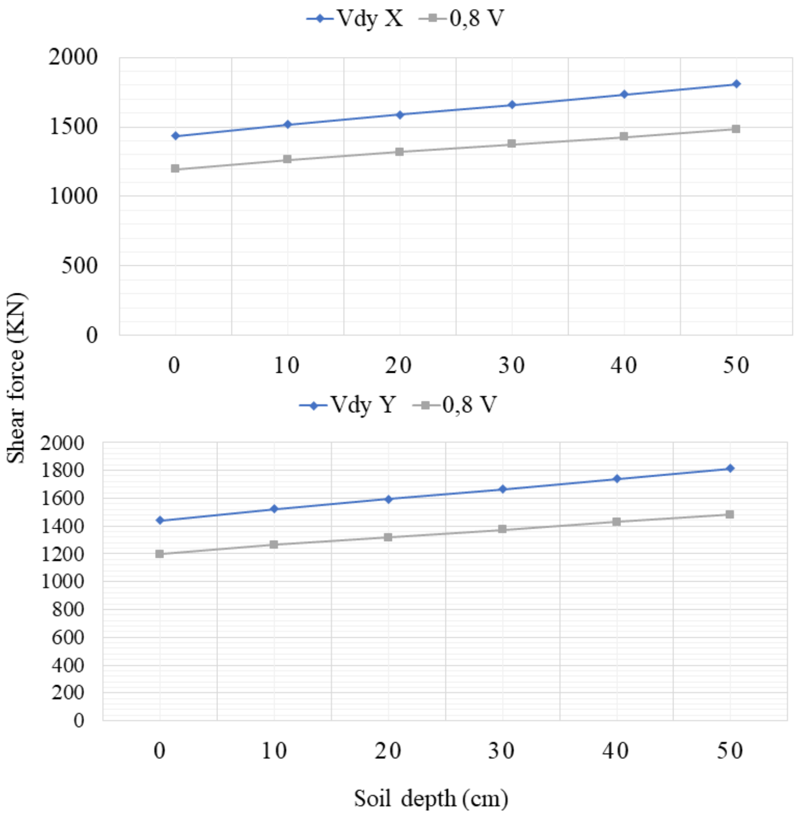


Fig. 9. *Variation of shear forces at the base with respect to green roof soil depth in X direction, and Y direction compared to 0.8 V*

Effect of the green roof on shear forces at the base

At the base of the structure, the resultant of the seismic forces (Vt) calculated by combining the model values must not be less than 80% of the resultant of the seismic forces given by the equivalent static method (V), for a value of the fundamental period specified by the appropriate empirical formula [32].

If Vt < 0.80 V, it will be necessary to increase all the parameters of the response (forces, displacements, moments...etc.) in the ratio 0.8 (V/Vt) [32]. Figure 9 shows the variation of shear forces at the base with respect to green roof soil depth in X and Y directions.

The total seismic force V, applied to the base of the structure, must be calculated successively in two orthogonal horizontal directions according to the formula [32]:

$$V = \frac{A.D.Q.W}{R}\ , \tag{5}$$

A: zone acceleration coefficient,
D: average dynamic amplification factor,
Q: quality factor,
W: total weight of the structure,
R: coefficient of the global behavior of the structure.

As shown in Figure 9, the shear forces at the base increase with the increase of soil depth. In both X, and Y directions, the shear forces for a building with the deepest green roof (50cm) are around 125% of that without a green roof, which represents a significant increase in the shear forces due to green roof implementation.

Effect of the green roof on overturning moment

The overturning moment caused by an earthquake is an important parameter that must be included in seismic performance analysis. When it comes to green roofs, the weight of this later participates in both overturning moment and stabilizing moment. As shown in Figure 10, the stabilizing moment is much greater than the overturning one. Also, both overturning and stabilizing moments increase with the increase of green roof soil depth, however, the increase in the stabilizing moment is much significant, thus, adding a green roof contributes more to the stabilizing moment than to the overturning one.

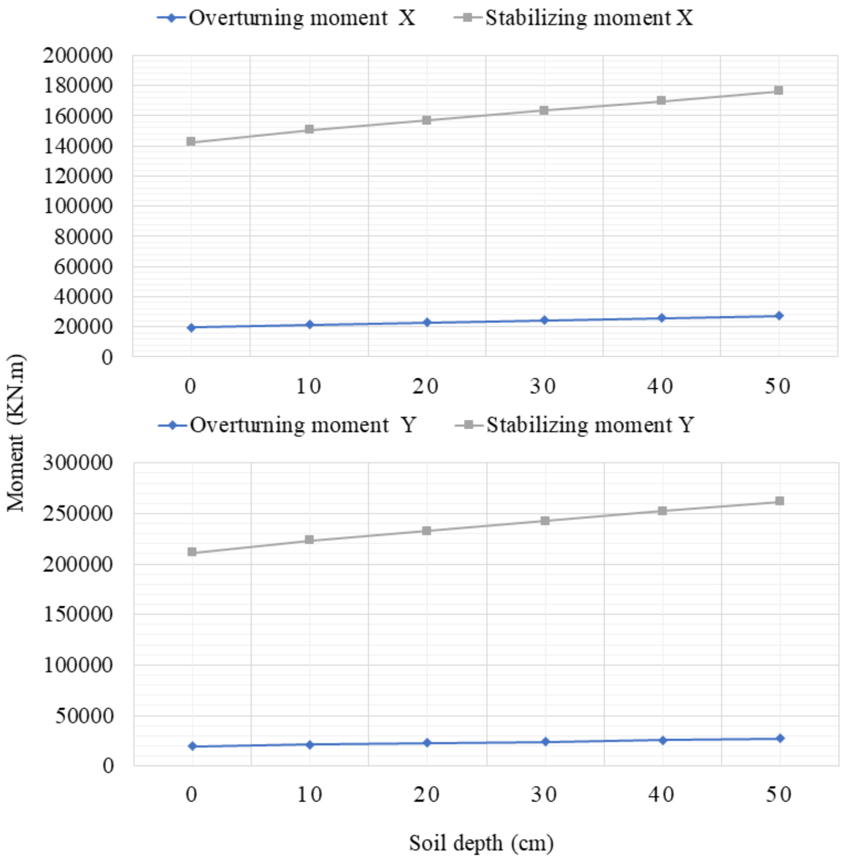


Fig. 10. *Variation of overturning and stabilizing moment in X and Y directions*

Conclusion

Green roofs offer many advantages with regards to reducing energy consumption, mitigating the urban heat island effect, improving air pollution, managing runoff, increasing sound insulation, and preserving the ecological environment. All these qualities make green roofs a very sustainable technique for the ecological transition. However, in order to propagate this technique, green roofs have to be installed on the top of existing buildings, which can increase their vulnerability during seismic events. In this research, the seismic performance of collective housing with green roof retrofitting in Algeria is investigated according to the Algerian seismic regulations.

It was found that the presence of load-bearing concrete walls, recommended by the Algerian seismic regulations, has a certain positive effect on green roof installation with regard to the seismic performance. The presence of these walls increases the rigidity of the building which reflects positively on the building natural period and displacements, thus, even with the loads generated by the green roof installation, most of the displacement-related parameters remained obeyed to the Algerian seismic regulations.

As for the stress-related parameters, the reduced normal stress does not increase much, however, the shear forces at the base for the building with a deep green roof are around 125% of that without a green roof, which represents a significant increase in the shear forces due to green roof implementation.

Both overturning and stabilizing moments increase with the increase of green roof soil depth, however, the increase in the stabilizing moment is much significant, thus, adding a green roof contributes more to the resisting moment than to the overturning one.

In the studied context, the presence of load-bearing concrete walls offers certain positive effects on green roof installation with regard to seismic performance. Nevertheless, a thorough seismic investigation should be performed before installing green roofs on the top of existing collective housing in Algeria.

Conflict of Interest

The authors declare no conflicts of interest.

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