DOI:10.22337/2587-9618-2025-21-4-102-113

NEW ALTERNATIVE APPROACH FOR THE ALGERIAN SEISMIC DESIGN CODE (RPA) OF RC BUILDING WITH SOFT FIRST STORY

Hamou Kada, Kheir Eddine Ramdane, Mabrouk Hamane
University of Science and Technology of Oran, Oran, ALGERIA

Abstract - Soft first story buildings, including Reinforced concrete frameworks, are particularly vulnerable during severe earthquakes, making them a critical concern in densely populated cities where such buildings are necessary. The Boumerdes earthquake stands out as one of Algeria's most devastating natural disasters in recent history due to the significant loss of buildings and lives. A notable observation from this earthquake was the collapse of many homes that had open retail spaces or parking areas on their first floors. Several factors contributed to the collapse of these soft first story buildings:

1. Insufficient Transversal Reinforcement: There was a lack of adequate transverse reinforcement in terms considering both of quantity and detailing.
2. More Flexible or Weaker First Story: The first story of these buildings was often more flexible or weaker compared to upper stories.
3. Absence of Shear Walls: The absence of shear walls compromised the lateral load resistance of buildings, especially those with open spaces on the first floor.

Due to the vulnerabilities highlighted by the Boumerdes earthquake, it is imperative to revise and strengthen the Algerian Earthquake-Resistant Design Code (RPA) It is vital to implement stricter guidelines, particularly regarding the construction of soft first-story buildings. These revisions should focus on improving the structural integrity and seismic resilience of such buildings to reduce future risks during earthquakes. By updating the seismic code with rigorous standards for the construction of soft first-story buildings, Algeria can enhance building safety and reduce the potential for catastrophic damage and loss of life in future seismic events.

The objective of this analytical study is to propose amendments to the Algerian seismic code to mitigate the collapse of soft first-story buildings during earthquakes. The study uses the energy constant law as its analytical framework.

In this research, the buildings of interest were modeled using the SAP2000 software. The Pushover analysis method was employed to analyze the seismic behavior of these structures.

Keywords: Soft story collapse, Algerian seismic design code (RPA), stiffness, story shear, drift, displacement, shear wall, natural time period, Pushover Analysis

НОВЫЙ АЛЬТЕРНАТИВНЫЙ ПОДХОД К ПРОЕКТИРОВАНИЮ СЕЙСМОСТОЙКИХ ЖЕЛЕЗОБЕТОННЫХ ЗДАНИЙ С ГИБКИМ ПЕРВЫМ ЭТАЖОМ ДЛЯ СТРОИТЕЛЬНЫХ НОРМ АЛЖИРА (RPA)

Хаму Када, Хейр Эддин Рамдан, Мабрук Хаман
Университет науки и технологии Орана, г. Оран, АЛЖИР

Аннотация. Здания с гибким первым этажом, включая выполненные в железобетонном каркасе, уязвимы при сильных землетрясениях. Обеспечение их сейсмостойкости является критически важной проблемой в густонаселенных городах, где в таких зданиях существует необходимость. Землетрясение в Бумерде является одним из самых разрушительных стихийных бедствий в новейшей истории Алжира из-за значительных разрушений зданий и числа пострадавших. В результате этого землетрясения было отмечено обрушение многих домов, на первых этажах которых находились открытые торговые площади

или парковочные зоны. Обрушению зданий с гибким первым этажом способствовали несколько факторов:
1. Недостаточное поперечное армирование: как с точки зрения расчетных, так и конструктивных требований было недостаточное количество поперечной арматуры.
2. Более гибкий или более слабый первый этаж: первый этаж этих зданий часто был более гибким или более слабым по сравнению с верхними этажами.
3. Отсутствие диафрагм жесткости: отсутствие диафрагм жесткости снижало сопротивление зданий горизонтальным нагрузкам, особенно для зданий с открытыми пространствами на первом этаже.
В связи с уязвимостями, выявленными в результате землетрясения в Бумерде, необходимо пересмотреть и усилить алжирский кодекс сейсмостойкого проектирования (RPA). Крайне важно внедрить более строгие правила, особенно в отношении строительства зданий с гибким первым этажом. Эти изменения должны быть направлены на улучшение структурной целостности и сейсмостойкости таких зданий, чтобы снизить риски в случае землетрясений в будущем. Обновление кодекса сейсмостойкого строительства, включение в него строгих требований для строительства зданий с гибким первым этажом, позволить повысить безопасность зданий и снизить вероятность катастрофических повреждений и гибели людей в случае землетрясений в Алжире в будущем.
Целью данного аналитического исследования является разработка предложений по актуализации положений алжирского кодекса сейсмостойкого строительства с целью предотвращения обрушения зданий с гибким первым этажом во время землетрясений. Аналитическое исследование базируется на использовании закона сохранения энергии.
В данном исследовании рассматриваемые здания были смоделированы с помощью программного обеспечения SAP2000. Для анализа сейсмостойкости конструкций был использован нелинейный статический расчет (Pushover-анализ).

Ключевые слова: обрушение гибких этажей, алжирский кодекс сейсмостойкого строительства (RPA), жесткость, сдвиг этажа, смещение, перемещение, диафрагма жесткости, период собственных колебаний, Pushover-анализ

1. INTRODUCTION

On May 21, 2003, a magnitude 6.8 earthquake hit the Zemmouri region, located approximately 70 kilometers east of Algiers. With a focal depth of roughly 10 km, it was the strongest earthquake in Algeria since 1980, causing widespread destruction. Over 2,200 people lost their lives and more than 11,000 were injured, largely due to the collapse of residential and public buildings. This disaster revealed critical shortcomings in seismic design and highlighted the need to update and enforce Algeria's building codes.
The main structural issues observed in reinforced concrete (RC) buildings are summarized below:
1. Soft First Story Effects: This occurs when the ground floor is less stiff compared to the upper floors, making it more susceptible to collapse during an earthquake.
2. Short Column Effects: Short columns experience higher shear forces, which can lead to failure if not properly designed.
3. Use of Weak and Slender Columns Poorly Reinforced (Generally Unconfined): Columns that are not adequately reinforced or are too slender can buckle and fail under load.
4. Poor Detailing of Structural Joints: Improperly designed connections between beams and columns can weaken the overall structure.
5. Inadequate Transverse Reinforcing Steel Detailing (Tie Spacing and 90-Degree Hook): Insufficient detailing of ties (spacing and hooks) can lead to poor confinement and shear resistance.
6. Poor Material Quality and Unsound Construction Practices: The use of substandard materials and inadequate construction methods can significantly compromise the strength and durability of a structure.
7. Neglect of Lateral Loads in Design: Failure to account for lateral forces, including seismic and wind actions, may result in inadequate structural performance and potential collapse under dynamic loading.

8. Inappropriate Anchoring of Beam and Slab Reinforcement: Improper anchoring can lead to weak connections and potential failure points.
9. Use of Irregular Building Configurations with Discontinuities in Mass, Strength, Stiffness and Ductility: Irregularities in the building's design can create stress concentrations and weak points.
10. Use of Weak Materials for Facades: Weak facade materials can fail and contribute to overall structural failure.
11. Use of Stiff Spandrel Masonry Walls Resulted in Short Captive Columns that Increased the Shear Demand Beyond the Shear Capacity Supplied: Stiff walls can create captive columns that are subjected to higher shear forces than they can handle, leading to failure.

These issues highlight the importance of proper design, detailing, material selection, and construction practices to ensure structural safety and resilience of RC buildings.

The field investigation revealed that the collapse of soft first-story buildings was notably prevalent during the Boumerdes earthquake, as illustrated in Figure 1.

This category of damage was even more severe during the 1995 Kobe Earthquake is shown in figure 2 and table 1. Therefore, the, the Japanese Seismic Design Guidelines recommended a design procedure to prevent the column side-sway mechanism, or soft first-story collapse [1, 2-3].

Such structural deficiencies primarily result from sudden variations in stiffness, strength, or ductility, combined with the lack of shear walls in the lower stories. Their detrimental impact is amplified by poor mass distribution within the structure.

Consequently, multistory reinforced concrete commercial and residential buildings with insufficient or absent lateral resistance at the first story represent one of the most vulnerable structural types.

his study introduces a procedure for determining the failure modes of buildings exhibiting a soft first story, derived from the failure mechanisms of columns and walls at that level. Subsequently, a strength amplification factor, denoted as α, is formulated according to the energy conservation principle to represent the additional capacity required at the soft story for its ductility factor to be equivalent to that of a total collapse mechanism [6, 8–9].

Figure 1. Soft first story collapses during Boumerdes Earthquake, Algeria 2003. [1-4]

Figure 2. Chuo-ku, Kumamoto city, Japan [5]

Table 1. Damage observation in chuo-ku Earthquake [5]

Damage Type	Soft story Failure	Shear damage to columns	Ground deformation	Moderate to severe damage	minor to moderate damage	Total
Number of buildings	8	4	3	4	3	22

2. METHODS

Following the damage caused by the presence of flexible floors in buildings during the 1995 Kobe earthquake, Japanese researchers highlighted the need to improve seismic design codes to address this phenomenon.

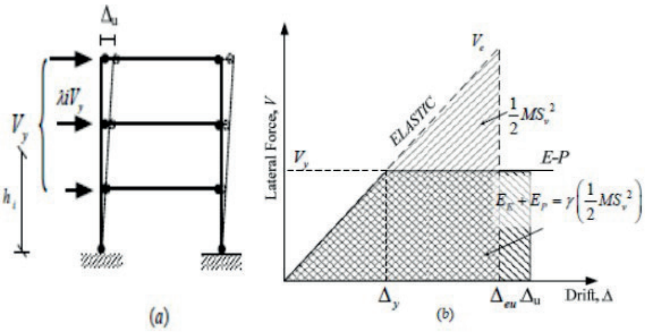


Figure 3. Energy method concept

Figure 3 illustrates the idealized load–deformation (E–P) behavior of the system. The work–energy relationship for this system can be formulated as:

$$(E_e + E_p) = \gamma.\,(\tfrac{1}{2}.\,M.\,S_v^2) = \tfrac{1}{2}\gamma.M.\,(\tfrac{T}{2\pi}.Sa.\,g)^2 \quad (1)$$

E_e: Elastic Energy behavior. E_p: Plastic Energy behavior. S_v: Pseudo-velocity. S_a: Pseudo-acceleration.

The work-energy equation can be written as follows:

$$\frac{1}{2}\left(\frac{W}{g}\right).\left(\frac{T}{2.\pi}.\frac{V_y}{W}.g\right)^2 + V_y.\left(\sum_{i=1}^{N}\lambda_i.h_i\right).\theta_p = \frac{1}{2}.\gamma.\left(\frac{W}{g}\right).\left(\frac{T}{2\pi}.S_a.g\right)^2 \quad (2)$$

Figure 4 illustrates the relationship between strength and deformation for a single-degree-of-freedom system.

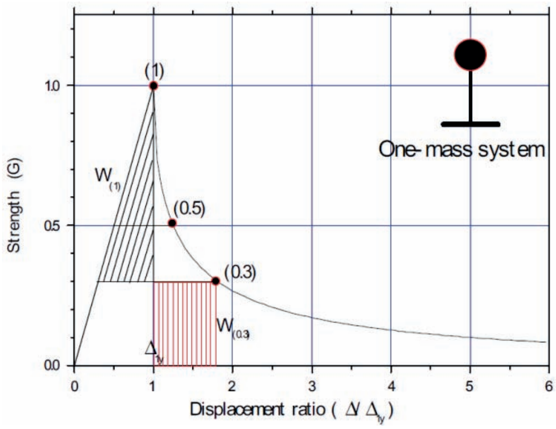


Figure 4. Energy constant law [2][8]

Figure 4 illustrates the idealized indices DS′ (first soft-story index) and DS (collapse index). Assuming an elasto-plastic model with identical base stiffness for both buildings, the ratio DS′/DS satisfying μ = μ′ is given by Equation (3).

$$\alpha_p = D_s'/D_s \quad (3)$$

The total stiffness of the collapse system is considered equal to that of the soft-story building [7], as shown in Figure 3. The relationship is defined by Equation (4):

$$\frac{\theta_y'}{\theta_y} = \frac{D_s'}{D_s} \quad (4)$$

Pushover Analysis

The buildings under investigation were modeled using the SAP2000 software, and the Pushover analysis method was applied. The structures were subjected to incremental loading distributed along their height, and the resulting inelastic load-displacement curve was obtained by controlling top displacement of the structure, as illustrated in Figure 5. [10-13]

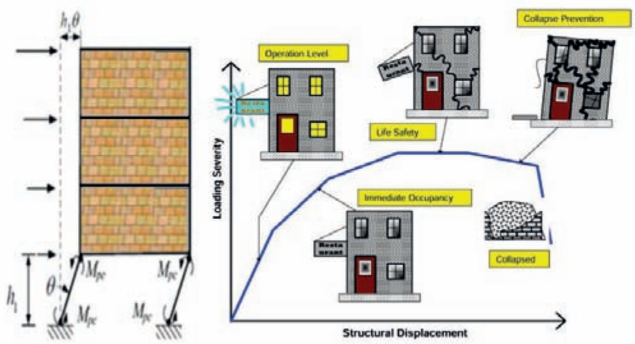


Figure 5. Different loading steps structural response levels [14][15]

Case Study

Three reinforced concrete buildings—G+5 (Case N1), G+7 (Case N2), and G+12 (Case N3)—with varying first-story heights are analyzed to assess the impact of the soft-story configuration on the structure's nonlinear seismic response.

Data

The dimensions and reinforcement of the structural elements (beams, columns, etc.) used in our case study are presented in Figure 6.

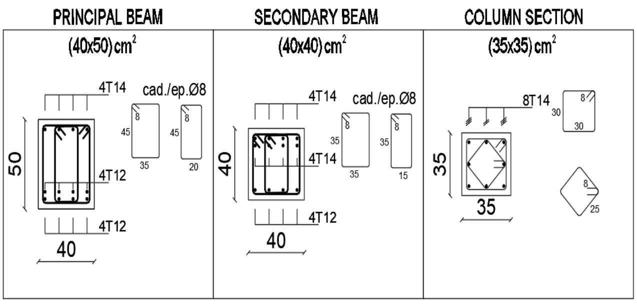


Figure 6. beams and column reinforcement

Lateral loads Distribution

The loads are distributed in a triangular form, expressed by the following equation:

$$Q_i = V_h . W_i . h_i^2 / \sum wi . h_i^2 \quad (5)$$

Table 2. Load cases

Name	Dead	Live	Eqx	Eqy	PSHx	PSHy
Type	Linear static	Linear static	Linear static	Linear static	Lateral Load	Lateral Load

Model Analysis:

The numerical model developed using the software is shown in Figure 7.

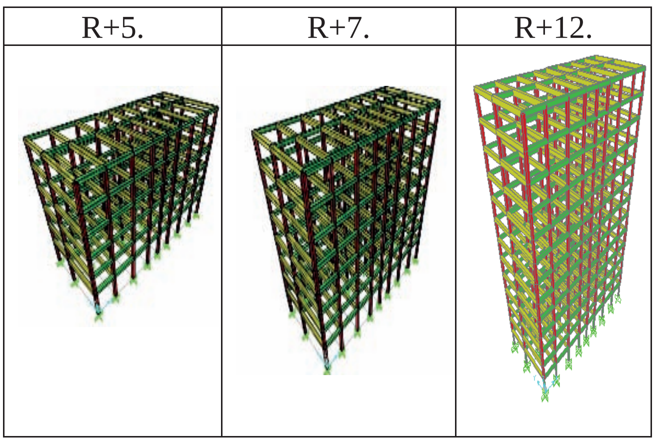


Figure 7. Building model in SAP2000 [11,12]

The fragility curve was obtained from the analysis of the numerical model, as illustrated in Figure 8.

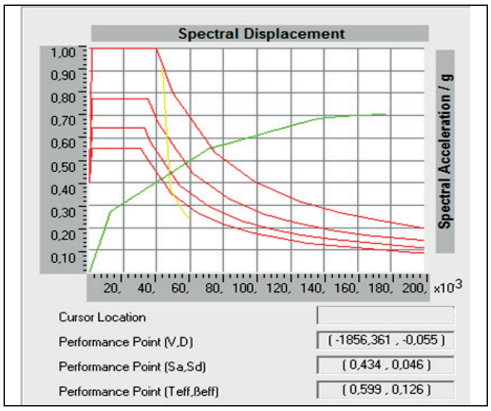
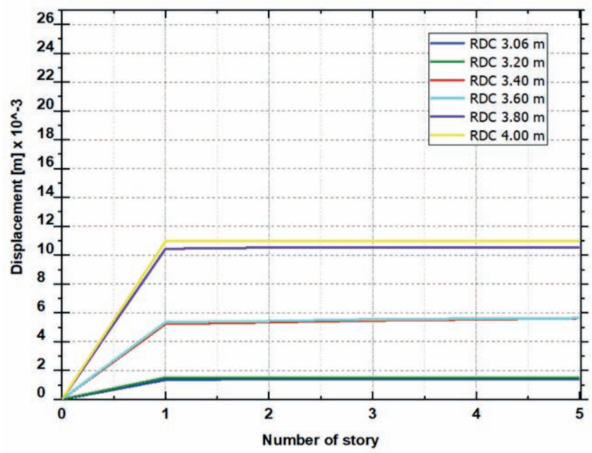


Figure 8. Pushover curve for R+5 building

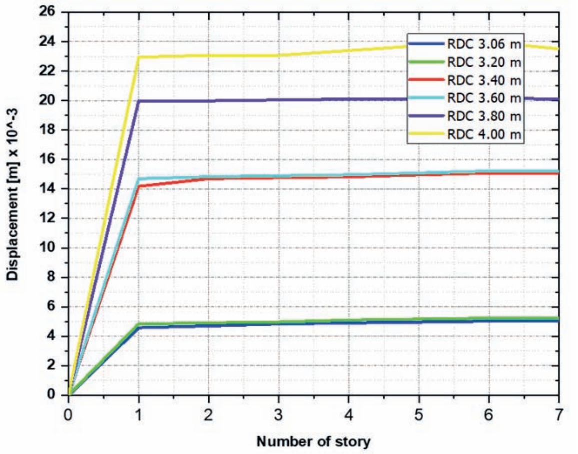
The performance point is defined by the structure's capacity to respond to applied forces and sustain stability under those forces, identified at the intersection of the base shear and displacement.[13][14][15][16].

The R+7 building with a 4 m ground-floor height exhibits more significant damage, demonstrating that the severity of damage is directly affected by the first-story height: the taller the first story, the greater the damage.

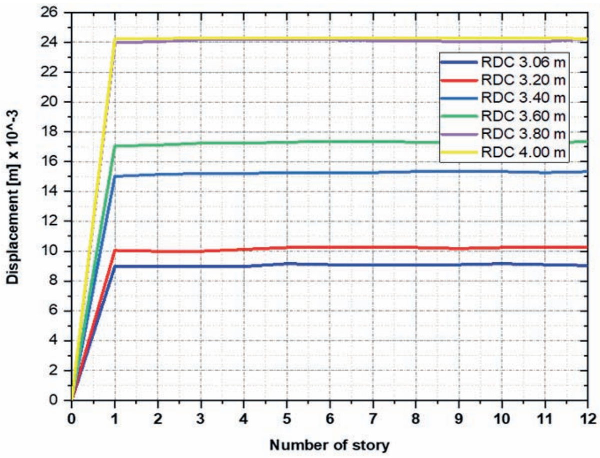
It is reported that the damage plastic hinges are concentrated at the first story (ground floor), highlighting the structural weakness of this level in all three models.



Ground Floor+5



Ground Floor+7



Ground Floor+12

Figure 9. Inter-story displacement

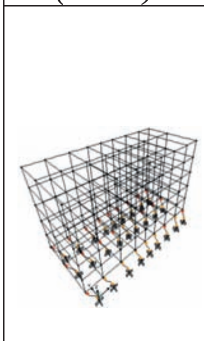
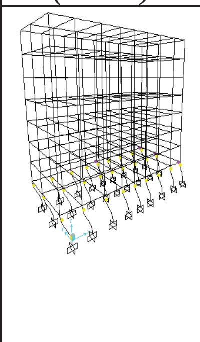
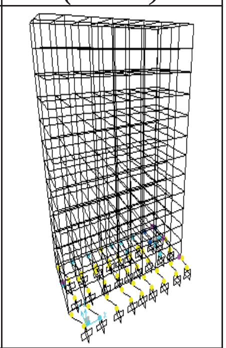
GF+5. (h=4m)	*GF+7. (h=4m)*	*GF+12. (h=4m)*
		

Figure 10. Development of plastic hinges

The difference in top displacement demand between structures with and without a soft story increases by a factor of 4 under low seismicity, 12 under moderate seismicity, and up to 32 under high seismicity.

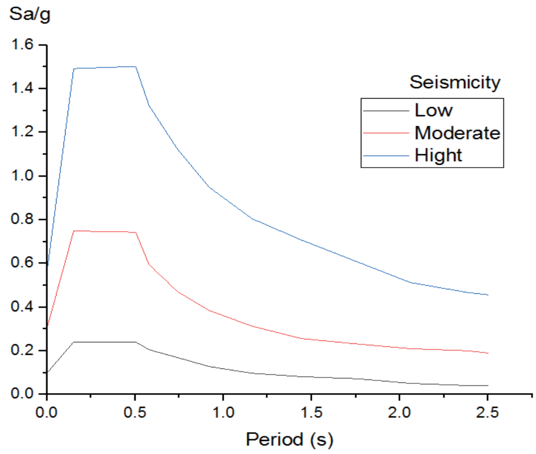


Figure11. Seismicity level

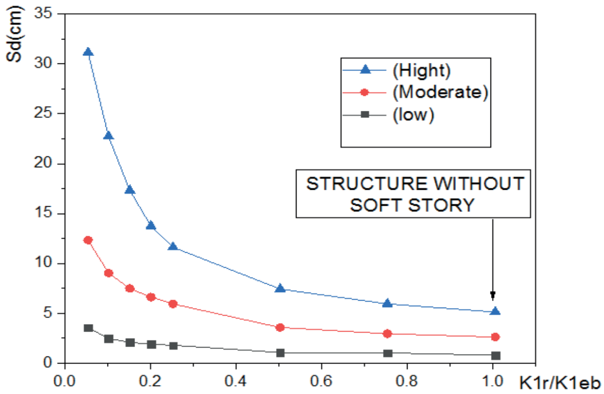


Figure 12. Lateral stiffness displacement in the story

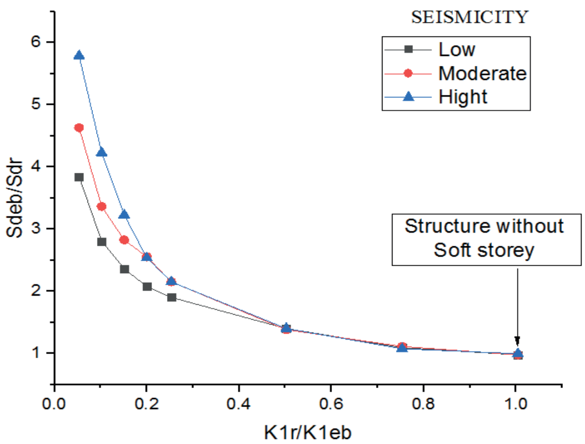


Figure 13. Lateral stiffness by increment request in the story

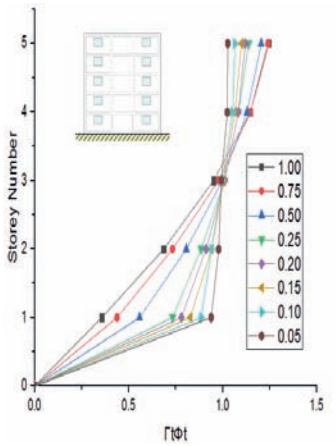


Figure 14. *Lateral stiffness of regular stories*

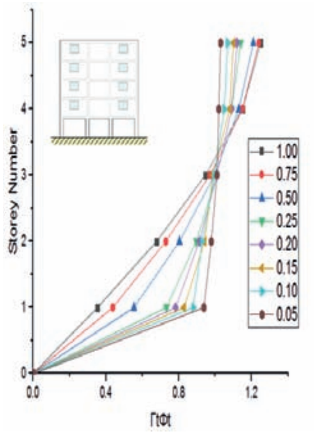


Figure 15. Lateral stiffness in the irregular story

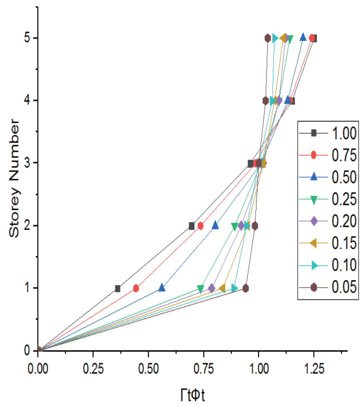


Figure 16. Lateral stiffness soft-unsoft story building

At the soft-story level, displacement can reach up to 25% of the building's total roof drift. However, in structures characterized by a pronounced soft-story mechanism, the first-story displacement may rise dramatically, reaching 80–90% of the total top displacement. For an equivalent seismic demand, the displacement at the first story of a soft-story building can increase by a factor of two to three compared to a regular structure. This demonstrates the considerable sensitivity of soft-story configurations to lateral deformations.

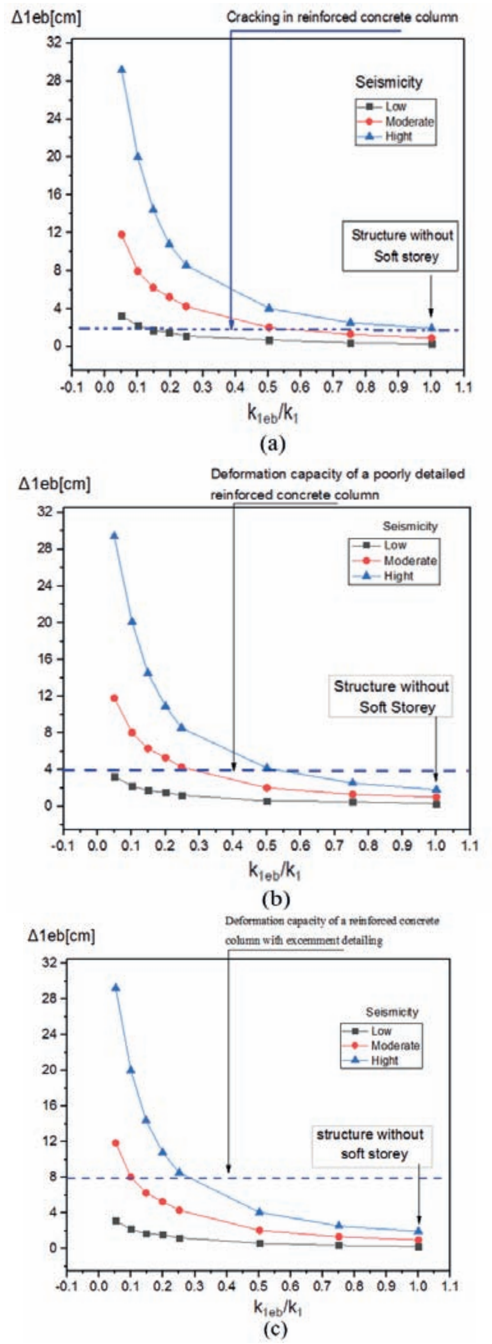


Figure 17. Lateral stiffness with reinforced concrete column

The appearance value of a crack (Δ_{1eb}) in a reinforced concrete column, shown in blue, is lower for regular buildings (without a soft story) compared to non-regular soft story building.

From the observation How can we define the displacement interval between a flexible-floor building (non-regular) and a non-flexible floor building (regular)?

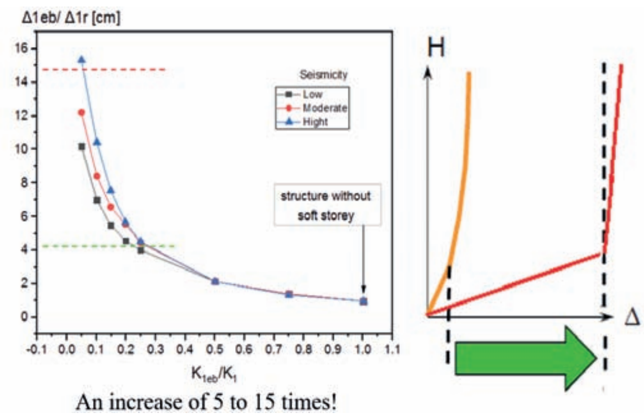


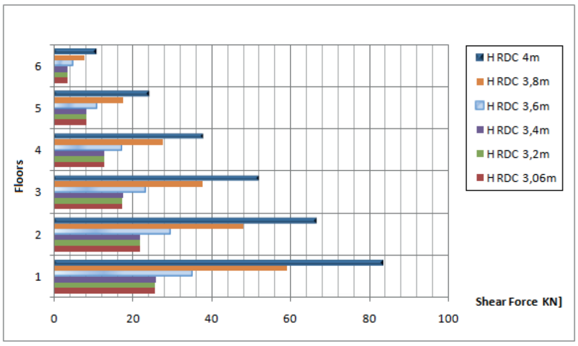
Figure 18. First floor lateral displacement demand

Researchers have determined that conducting studies for analysis and comparison is essential to accurately quantify this issue.

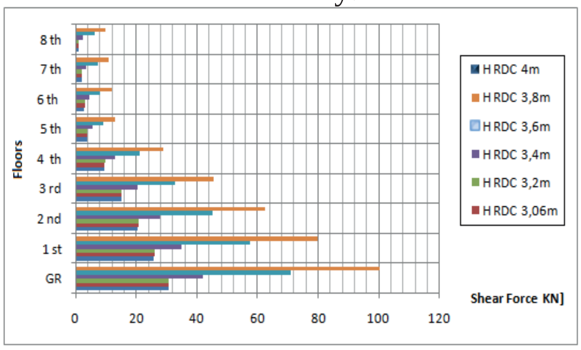
Figure 18 illustrates the variation of shear forces across different levels as a function of the ground-floor height.

Shear force demands on ground story columns are much higher in buildings with a first soft storey.

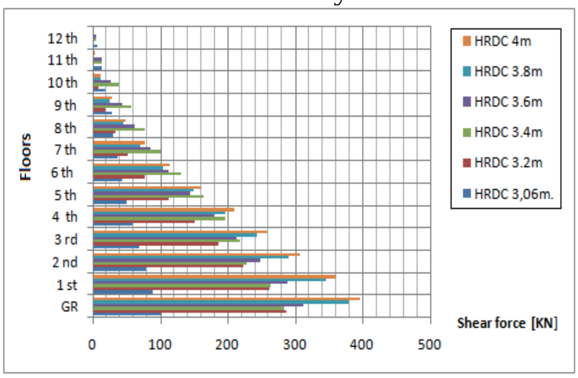
The characteristic factor Ds′ tends to rise as building height increases. For a given structure, the difference in this factor across various seismic codes is around 5%.



R+5 story.



R+7 story.



R+12 story.

Figure 19. Comparison of base shear for R+5, R+7 and R+12 storied buildings for different height Ground Floor

Table 3. Structural characteristic factor Ds'

Code	R+5	R+7	R+12
Japanese	0.5	0.55	0.65
Euro	0.55	0.65	0.7
RPA	0.6	0.7	0.75-0.8

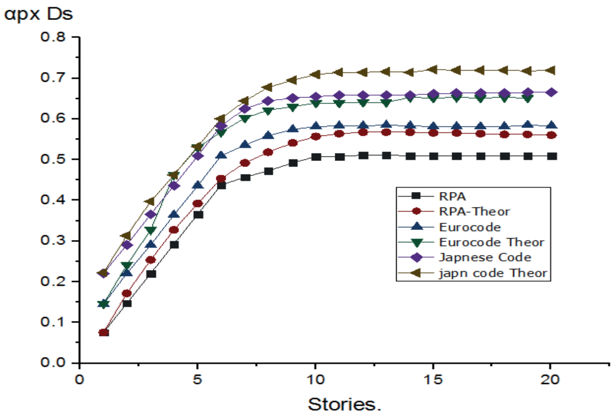


Figure 19. Structural characteristic factor for buildings with 5, 7, and 12 stories

4. CONCLUSION

The May 2003 Boumerdès earthquake caused significant damage, much of which experts found could have been prevented. This prompted authorities to devise comprehensive prevention plans, especially in major cities like Algiers, Oran, and Constantine, where earthquake risks are high. The adage 'prevention is better than cure' highlights this need.

- Minor damages were observed in the structural elements, particularly on the first soft story. This is attributed to the discontinuity of the frame's mass, as well as its strength, stiffness, and ductility.
- Nonlinear analyses revealed a required lateral load factor (αp×Ds) of 0.50 for 6-story buildings, increasing to 0.55 for 10 stories and 0.60 for 14 or more, according to the Japanese code. For the Eurocode, the factors are 0.60, 0.65, and 0.70; for the RPA code, they are 0.65, 0.70, and 0.75, respectively.
- The nonlinear analysis yields a required lateral load factor of 0.50 for 6-story buildings, increasing to 0.55 for 10 stories and 0.60 for 14 or more. In comparison, the Eurocode specifies 0.60, 0.65, and 0.70, while the RPA code specifies 0.65, 0.70, and 0.75.
- Eurocode 8 and the Japanese code permit larger relative drift displacements than the RPA 99 code (2003 version), due to the higher local ductility levels specified in these codes.
- The RPA code specifies a behavior coefficient RRR that indicates the capacity of dissipative structural systems to endure seismic actions in the inelastic domain (see Table 4.3, Chapter IV, p. 39). This coefficient requires that lateral rigidity does not exceed 70% of the rigidity of the story above (Appendix 1, p. 111). However, the code lacks details on how to obtain this coefficient or its applicability to existing buildings versus new designs with a soft first story.
- Calculating earthquake forces for reinforced concrete (RC) buildings with an open ground floor often underestimates the design forces and moments for ground floor columns. Analyses show that base shear can exceed twice the amount predicted by the equivalent force method, whether or not infill is present. Since the response spectrum method is rarely used in practice, it is advisable to double the design shear and moment from the static method to ensure ground floor column safety.
- Buildings with open ground floors are particularly vulnerable to seismic actions, especially in developing countries where this construction type is common. The results of this study demonstrate that such buildings should not be treated as conventional reinforced concrete (RC) structures. The sway analysis reveals that columns at the open ground floor level require approximately 75% greater drift capacity than that estimated by the equivalent static method. To accommodate these high ductility demands, special reinforcement detailing—designed in accordance with moment-resisting frame principles—is essential.

A deeper understanding of this phenomenon is crucial, as it should be identified as a localized issue before it progresses into a broader structural problem.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support of their university and the invaluable guidance and encouragement provided by their supervisor and co-supervisor throughout this research and the preparation of the manuscript.

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Hamou Kada – Ph.D, candidate in Civil, Department civil Engineer, Faculty of Architecture and Civil Engineering, University of Sciences and Technology of Oran, El Mnaouar, BP 1505, Bir El Djir 31000, Oran, Algeria. E-mail: hamoukada@gmail.com

Kheir Eddine Ramdane – Professor, Faculty of Architecture and Civil Engineering, University of Sciences and Technology of Oran, El Mnaouar, BP 1505, Bir El Djir 31000, Oran, Algeria. E-mail: eddine_r@yahoo.fr

Mabrouk Hamane – Professor, Faculty of Architecture and Civil Engineering, University of Sciences and Technology of Oran, El Mnaouar, BP 1505, Bir El Djir 31000, Oran, Algeria. E-mail: mebrouk.hamane@univ-usto.dz

Хаму Када – кандидат технических наук, факультета архитектуры и гражданского строительства, Университет науки и технологии Орана, Эль-Мнауар, BP 1505, Бир-эль-Джир, 31000, Оран, Алжир. E-mail: hamoukada@gmail.com

Хейр Эддин Рамдан – профессор, факультета архитектуры и гражданского строительства, Университет науки и технологии Орана, Эль-Мнауар, BP 1505, Бир-эль-Джир, 31000, Оран, Алжир. E-mail: eddine_r@yahoo.fr

Мабрук Хаман – профессор, факультета архитектуры и гражданского строительства, Университет науки и технологии Орана, Эль-Мнауар, BP 1505, Бир-эль-Джир, 31000, Оран, Алжир. E-mail: mebrouk.hamane@univ-usto.dz