SAAD DAHLEB UNIVERSITY - BLIDA

Faculty of Technology
Department of Civil Engineering

MASTER'S THESIS IN CIVIL ENGINEERING

Specialty: Structure

# SEISMIC FRAGILITY CURVES OF SCHOOL BUILDINGS IN ALGERIA: CASE STUDY OF THE GREAT BLIDA

Submitted by:

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## Abstract

The goal of this study is to analyze the seismic behavior of school buildings in the area of Blida.

To achieve this goal, two schools were chosen as case studies representing the two most common structural systems in the area, and then were modeled in SeismoStruct 2018 to launch the following structural analyses: Nonlinear time history Analysis and static pushover analysis.

Using the results from the structural analyses, the seismic fragility and performance of the two case studies were evaluated, and suitable solutions to improve the seismic capacity of the school building in the area were recommended.



**Keywords:** Seismic fragility – school buildings – resilience – vulnerability – retrofitting.



## ملخص العمل

الهدف من هذه الدراسة هو تحليل السلوك الزلزالي للمباني الدراسية في منطقة البليدة.

من أجل تحقيق هذا الهدف، تم اختيار مدرستين كدراسة حالة لتمثيل النظامين الهيكليين الأكثر استعمالاً في المنطقة، قبل تصميمهما بواسطة برنامج SeismoStruct من أجل تطبيق التحليلات الهيكيلية التالية: تحليل لاخطي ديناميكي باستخدام سجل زمني، و الدفع لاخطي المتعاقب.

باستعمال النتائج من التحليلات الهيكلية السابق ذكرها، تم تقييم الهشاشة و الأداء الزلزلين لدراسة الحالة المعتبرة، و اقتراح □رق مناسبة لتحسين الأداء الزلزلي للمباني الدراسية في المنطقة.



**كلمات مفتاحية:** هشاشة زلزالية – المباني المدرسية – المرونة أو الثبات – نقا□ ضعف – تعديل تحديثي.



## Résume

Le but de cette étude est d'analyser le comportement sismique des bâtiments scolaires de la zone de Blida.

Pour atteindre cet objectif, deux écoles ont été choisies comme études de cas représentant les deux systèmes structurels les plus courants dans la région, puis ont été modélisées dans SeismoStruct 2018 pour lancer les analyses structurelles suivantes: Analyse non linéaire de l'historique de temps des structures et analyse statique non linéaire push over.

En utilisant les résultats des analyses structurelles, la fragilité et la performance séismique des deux études de cas ont été évaluées, et des solutions appropriées pour améliorer la capacité sismique du bâtiment scolaire dans la région ont été recommandées.



**Mots clés**: fragilité sismique - bâtiments scolaires - résilience - vulnérabilité - modernisation.

# Acknowledgement

First, I would like to thank God for giving me the strength, knowledge, ability and opportunity to undertake this research study and to persevere and complete it satisfactorily. Without his blessings, this achievement would not have been possible.

I would like to express my sincere gratitude to my supervisor Dr. Rafik Taleb for the continuous support of my study and research especially in these hard times, for his patience, motivation, and guidance that helped shape my thesis the way it is now. It was a great privilege and honor to work and study under his supervision, and I am extremely grateful for what he has offered me.

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IKHLEF Abdelwadoud

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# *Introduction*

Throughout the history, school buildings frequently collapse or suffer heavy damage during earthquakes due to the various distinctive characterizes these buildings possess, causing a huge human and financial loss around the world, and with Algeria being one of the most seismically active areas in the Mediterranean basin, with many destructive earthquakes reported throughout history, striking different regions concentrated in the northern part of the country, it was necessary to study the behavior of school buildings in the area.

During Boumerdes earthquake in 2003, the school buildings of Algeria suffered significant amount of damage, where the shockwave completely destroyed 103 school buildings, and another 753 were seriously damaged in Boumerdes and Algiers.

Fortunately for the citizens of the area, the deadly earthquake occurred after school hours at 19:44, resulting in no fatalities or injuries to occur in school ground, but on the other hand the financial loss was very immense, as it costed the Algerian government 70 million dollars in reconstruction and rehabilitation efforts, not to mention the social loss as children missed good chunk of their school year waiting for repairs effort to complete.

The main objective of this study is to evaluate the seismic fragility of school building in the Great Blida, one of the most seismic zones in Algeria, by executing various performance inspections and developing fragility curves for the case studies chosen in research, in hope of establishing a general understanding of the behavior of school building in Blida during seismic activities in relate to their structural design, and for the evaluation to be used as decision making tool for the future, to implant strategies for reducing seismic vulnerabilities.

## The work plan of the project

Throughout the history, School buildings were always known to have distinct characteristic features that cause them to be more vulnerable to seismic hazards then most other buildings, to investigate this matter, a work plan was chosen to undertake this task in a logical manner, and help ease the study:

- Collecting data on the school building in the area of study such as completion date, structural system, blueprints, and number of students…etc, and despite the field work getting cut short due to Covid-19, the amount of gathered data was enough to complete the project.

- Classifying the school building using the collected data, depend on structural system, seismic code that was followed during the design phase…etc.

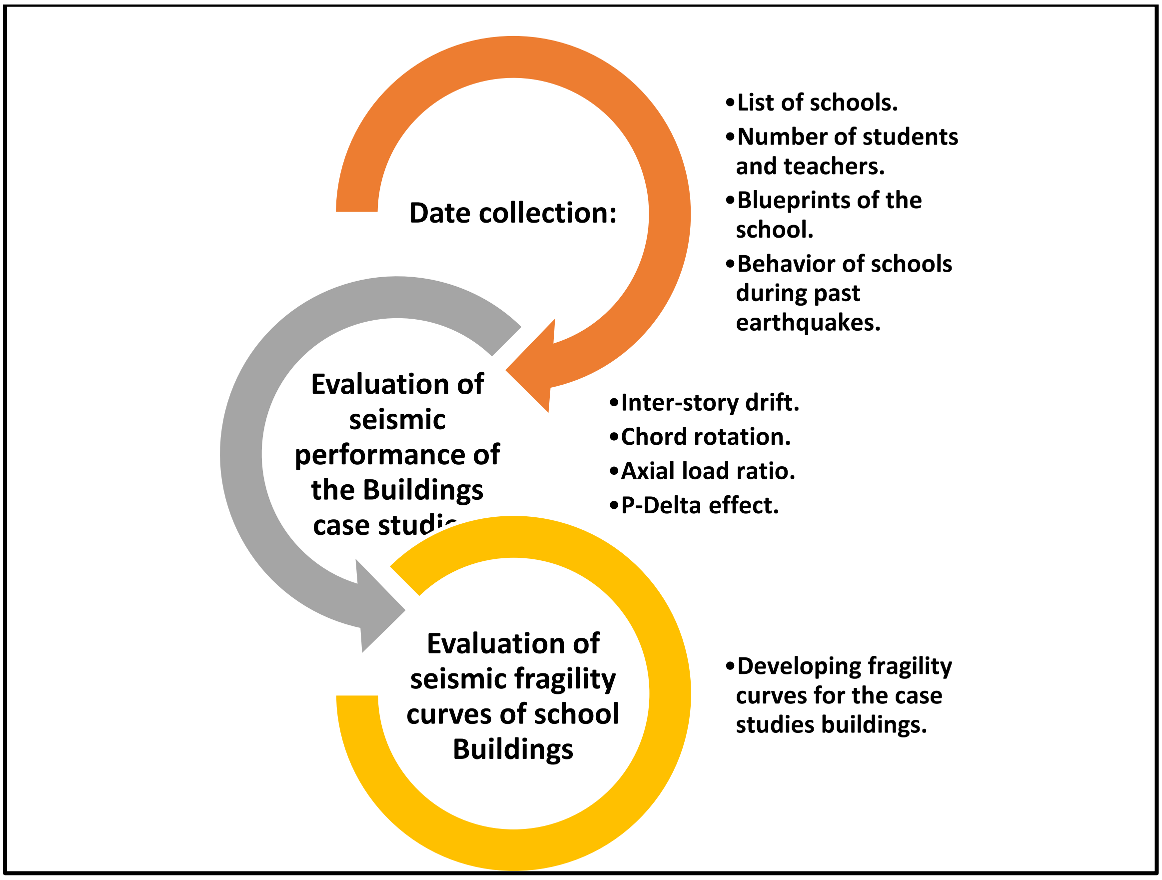
- Studying the seismicity of Algeria, and analyzing the seismic code regulations and the various changes that happened to it throughout the history to get better understanding of the seismic design changes that occurred during the years.

- Exploring earthquake mitigation techniques used for schools around the world, the various methods in retrofitting buildings, its benefits and drawbacks of this techniques, its cost in hope of implanting it in Algeria.

- Analyzing the behavior of school buildings during past earthquakes (mainly Boumerdes earthquake) to conclude the common seismic vulnerabilities that school buildings suffer from.

- Executing various performance inspections on the case studies using Boumerdes earthquake ground motions, to assess what type of damages that could happen such as story drift, chord rotation.

- Finally, evaluating the seismic fragility of the case studies to get better understanding on the various factors that can affect the fragility of building during earthquakes.




### The activities undertaken to realize the study

To undertake these tasks, the following activities were done:

- Visiting the Directorate of Education for the State of Blida to obtain various data about the schools in the area: the name of all the schools in the area, date of construction, number of students and teachers per school, and the address of each school.

- Using the addresses from the first activity, an interactive map in google earth was then created containing all the schools in the area.

- An inspection visit was then conducted to various schools in the four municipalities to determine the structural system of the school buildings, their construction type, the current state of the buildings, and inspecting the surrounding communities.

- Choosing two schools from to be case studies for the research and represent the common structural design of schools in the area.

- Obtaining blueprints and design manual for the two case studies from design offices to model the buildings before performing structural analyses.

# ***Chapter I***

# *Generalities*

## I.1. Introduction

The concept of resilience is routinely used in research in disciplines ranging from environmental research to materials science and engineering, psychology, sociology, and economics.

In the fields of engineering and construction, resilience became an important objective of design because of the range of horrific natural disasters (earthquakes – floods – wars... etc.) that can destroy communities and buildings, and because of that a structure must be resilient in order to stand for decades.

This first chapter will discuss the seismicity of Algeria, the various analysis used in this study, the concept of seismic resilience, and the process of developing fragility function.

## I.2. The seismicity of Algeria

Algeria is one of the most seismically active areas in the Mediterranean basin, with many destructive earthquakes reported throughout history, striking different regions concentrated in the northern part of the country.

This seismicity is related to constant collision between the African and Eurasian plates, and is located along the Tel Atlas f Algeria along the plate boundary zone.

Seismology in Algeria can be divided into two periods in relation to the the implementation of the first seismic station in 1910:

### I.2.1. The macroseismic approach [pre-1910]

All of these studies were based on human perception of shaking along with interpretations of intensity and descriptions of each earthquake's effects and damage.

Isoseismal maps were drawn for each earthquake base on the damage, in relation to the epicenter of the earthquake.

### I.2.2. The instrumental approach [post-1910]

After the implantation of the first seismic station in Algeria, and the introduction of seismographs, that allowed for more accurate recording of the magnitudes and intensities of recent earthquakes in Algeria.

As of today, there are 80 seismic station (Fig I.1) as part of the Algerian Digital Seismic Network, that was created to rapidly defuse the install a rapid alert system to diffuse information to authorities and study the seismicity of Algeria.

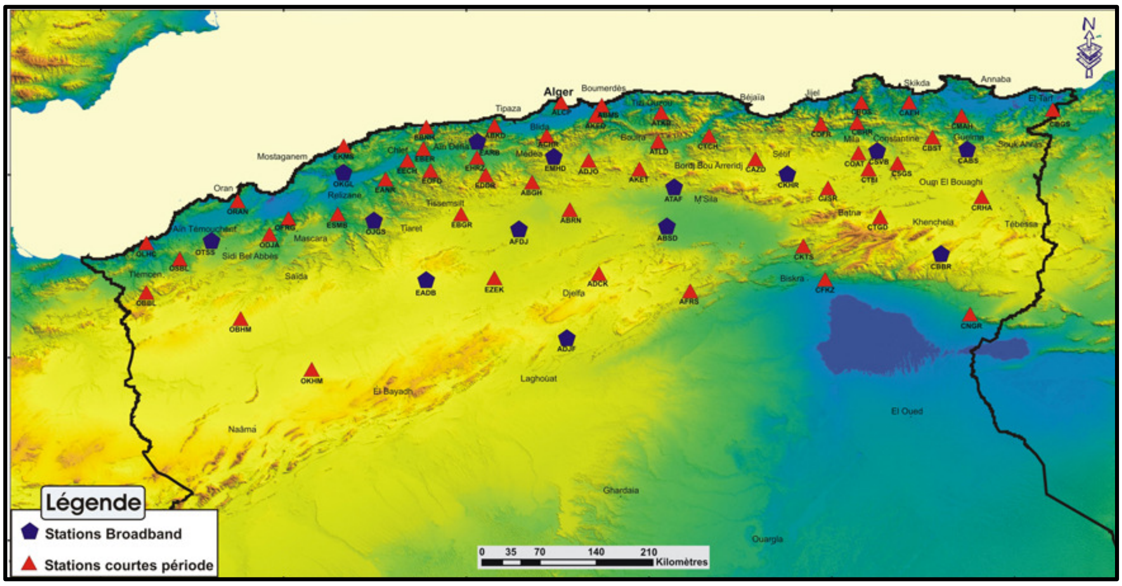



**Figure I.1:** Localization of the seismic stations of Algeria.

In this table are the notable earthquakes recorded in Algerian history with maximum intensity greater than or equal to IV:

**Table I.1:** Historical Earthquakes in Northern Algeria from the Algerian Earthquake Catalog.

| Date | Location | Intensity | Magnitude | Casualties |
|---|---|---|---|---|
| 1365/01/03 | Algiers | X | - | - |
| 1716/02/03 | Algiers | IX | - | 20000 victims |
| 1790/10/09 | Oran | IX-X | - | 2000 deaths |
| 1825/03/02 | Blida | X-XI | - | 7000 deaths |
| 1856/08/22 | Djidjelli | X | - | - |
| 1867/01/02 | Mouzaïa | X-XI | - | 100 deaths and 160 injuries |
| 1869/11/16 | Biskra | IX | - | 30 deaths |
| 1887/11/29 | Mascara | IX-X | - | 20 deaths |
| 1891/01/15 | Gouraya | X | - | 38 deaths |
| 1910/06/24 | Sour el Ghozlane | X | - | 81 deaths |
| 1946/02/12 | Béjaïa | IX | - | 264 deaths and 112 injuries |
| 1954/09/09 | Orléansville | X | 6.7 | 1243 deaths |
| 1980/10/10 | El Asnam | IX | 7.3 | 2633 deaths and 8,369 injuries |
| 1985/10/27 | Constantine | VIII | 5.9 | 10 deaths and 300 injuries |
| 1989/10/29 | Tipasa-Chenoua | VII | 5.9 | 22 deaths |
| 1994/08/18 | Mascara | VII | 5.7 | 171 deaths and 289 injuries |
| 1999/12/22 | Ain Temouchent | VII | 5.7 | 26 deaths |
| 2000/11/10 | Beni Ourtilane | VII | 5.7 | 2 deaths and 50 injuries |
| 2003/05/21 | Zemmouri | X | 6.8 | 2278 deaths and 11,450 injuries |
| 2006/03/20 | Laalam | VII | 5.2 | 4 deaths and 68 injuries |
| 2010/05/14 | Beni Ilmane | VII | 5.2 | 4 deaths and 170 injuries |

(Fig I.3) shows the distribution of earthquakes reported in the CRAAG catalog for seismic events with magnitudes greater than 4.0 concentrated in the north around specific seismogenic areas.

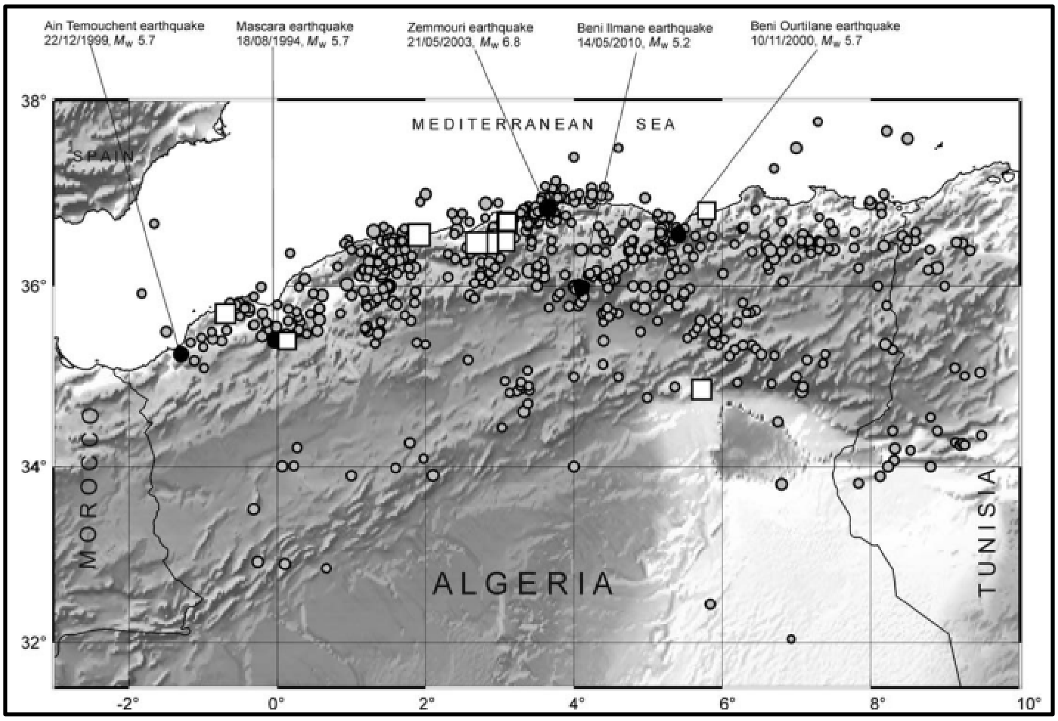



**Figure I.2:** Seismicity of Algeria as reported in GRAAG catalog of earthquakes with M > 4.

## I.3. The evolutions of the Algerian seismic code regulations

### I.3.1. After 1716 Algiers earthquake

The first ever Algerian seismic regulations were implanted by the Dey (Governor of Algiers) after the 1716 Algiers earthquake destroyed 200 houses, killing 20000 innocent people in the process. The imposed measures aimed to fix main pathologies that caused the collapse (the absence of links between walls, the bad construction of masonry, and the absence of anchoring of the floors to the load-bearing walls), by using wood logs to link the walls to each other (Fig I.3) and link the floor to the bearing walls.

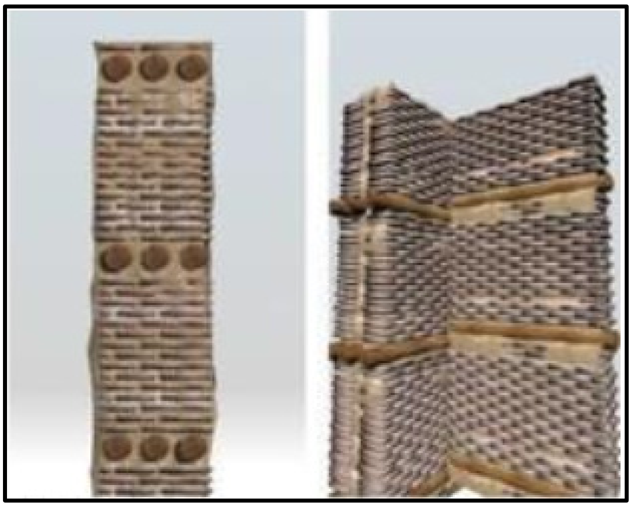


**Figure I.3:** The use of wood logs to link walls together.

### I.3.2. After 1954 El-Asnam earthquake

After El-Asnam earthquake that destroyed 20000 houses, killing 1243 innocent in the process, the French government implanted seismic recommendation for construction called the “AS55), which contained a seismic zone map (Fig I.4), which divided Algeria into two seismic categories: Low seismicity – High seismicity, providing round acceleration level and specifications design for each zone.

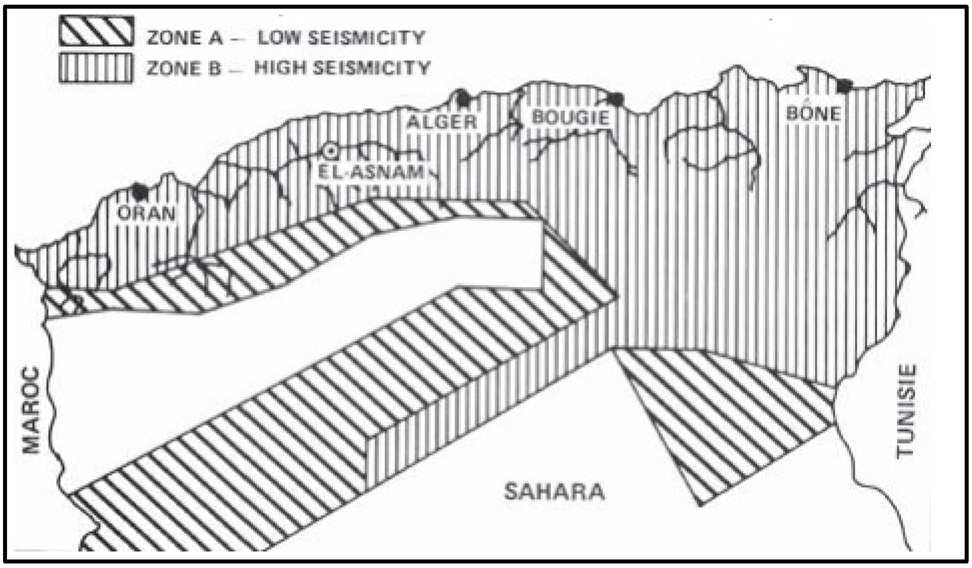



**Figure I.4:** AS55 Algerian seismicity zone map.

### I.3.3. After 1980 El-Asnam earthquake

After the second El-Asnam earthquake that killed 2633 innocent, the Algerian government (now independent from France), implanted the first official seismic code regulations titled RPA81 (Algerian seismic regulation 81), that illustrate the elementary rules of seismic resistant design that weren’t followed by the Algerian population.

It was later revised in 1999 (RPA99) to: modify the equivalent static method, encourage the use of dynamic spectral method, implanting new seismic zone map (Fig I.5) that divide the country into 4 seismic categories, and group the rules in of seismic resistant design in one easy to read and comprehend version.

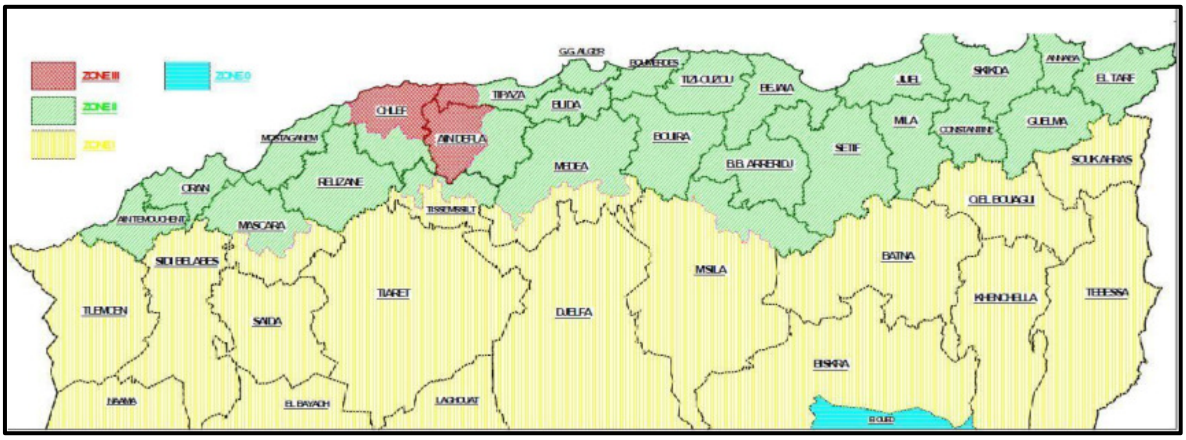


**Figure I.5:** The RPA99 Algerian seismicity zone map.

### I.3.4. After 2003 Boumerdes earthquake

The latest revision of the Algerian seismic code regulations came after the 2003 Boumerdes earthquake that end up killing 2278 innocent people, injuring 11450 person and damaging 44000 houses.

This revision implanted the following clauses: including the affected areas from the earthquake in zone III (high seismicity zone) (Fig I.6), limiting the number of stories for building with reinforced concrete and encouraging the use of shear walls, increasing the value of seismic factor A, restriction on the open spaces at ground level to avoid the soft story problem which destroyed many buildings, and increasing the size of structural members especially columns.

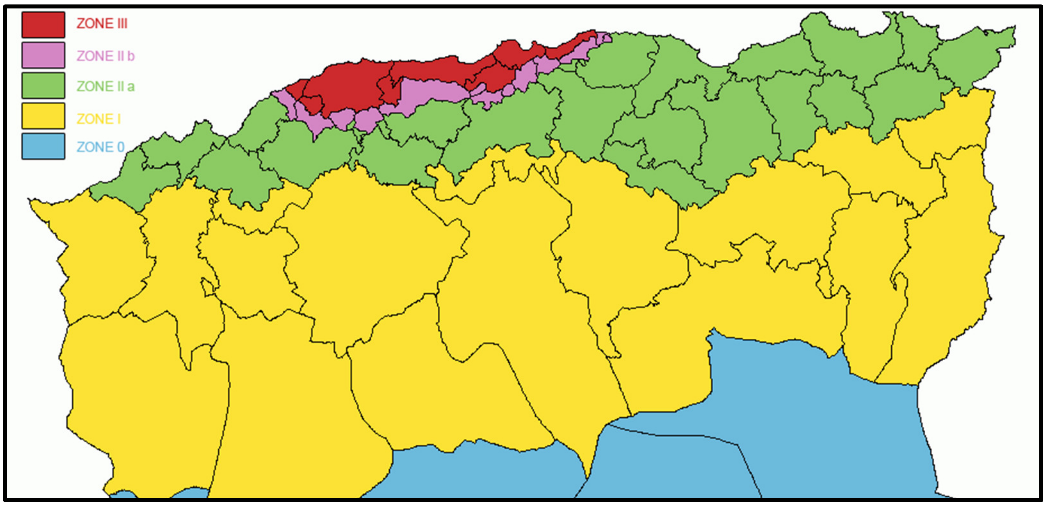



**Figure I.6:** The RPA99v2003 Algerian seismicity zone map.

## I.4. The various types of structural analysis used in this study

During this study, two types of structural analysis were mainly performed using SeismoStruct 2020 to achieve the targeted results:

- Nonlinear dynamic time-history analysis that was used to execute various performance inspections using Boumerdes earthquake's strong ground motions.
- Static pushover analysis that was used to develop seismic fragility curves using the static pushover to fragility software.

### I.4.1. Nonlinear dynamic time-history analysis

A time-history analysis is a step-by-step analysis of the dynamical response of a structure to a specified loading that may vary with time such as seismic loading. The distinction is made between the dynamic and the static analysis on the basis of whether the applied action has enough acceleration in comparison to the structure's natural frequency. If a load is applied sufficiently slowly, the inertia forces (Newton's first law of motion) can be ignored and the analysis can be simplified as static analysis.

A nonlinear analysis is an analysis where a nonlinear relation holds between applied forces and displacements. Nonlinear effects can originate from geometrical nonlinearity's (i.e. large deformations), material nonlinearity's (i.e. elasto-plastic material), and contact. These effects result in a stiffness matrix which is not constant during the load application. This is opposed to the linear static analysis, where the stiffness matrix remained constant. As a result, a different solving strategy is required for the nonlinear analysis and therefore a different solver.

Nonlinear dynamic time-history analysis (Fig I.7) is used to determine the dynamic response of a structure to arbitrary loading.

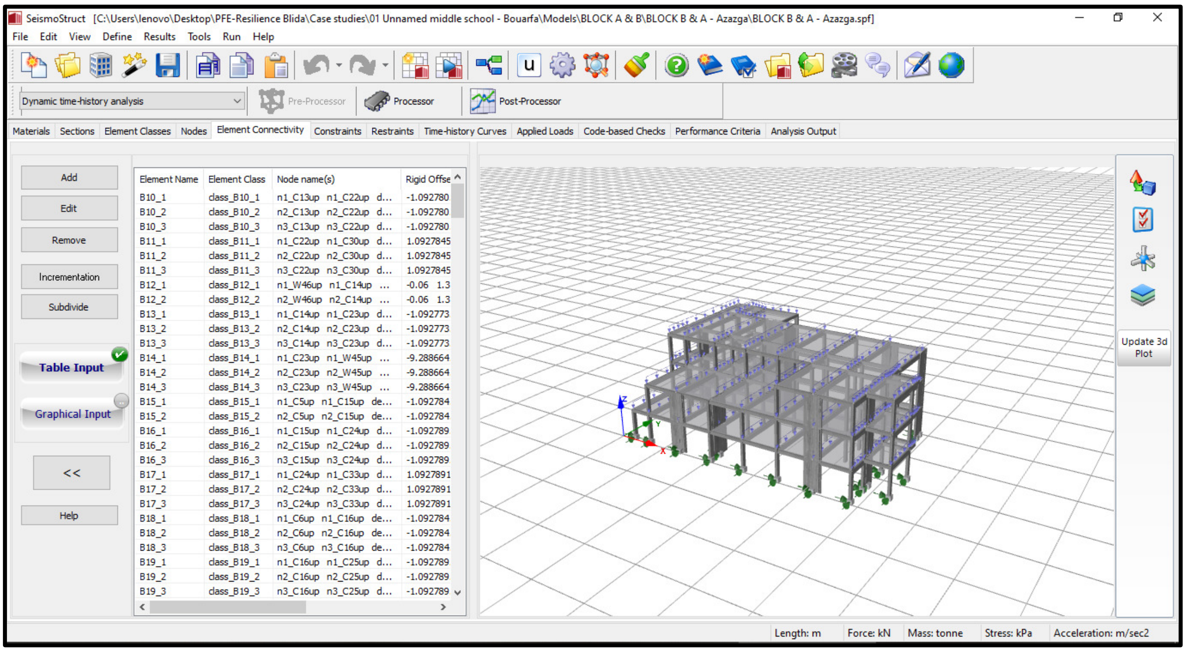



**Figure I.7:** Nonlinear dynamic time-history analysis performed by SeismoStruct.

**The various inspections performed on the building**

Using the results from the nonlinear dynamic time-history analysis, here are the different performance inspections that were looked for, on each building:

- **Story Drift**

In principle, large lateral displacements between stories, or "drift" (Fig I.8), put the entire safety of the building in danger, due to the damage that it can represent to nonstructural elements. Depending on the extent of displacement, partial or total collapse of the building can occur.

According to the actual Algerian seismic regulations RPA99 ver.2003, floor drift should not exceed 1% of the floor height.

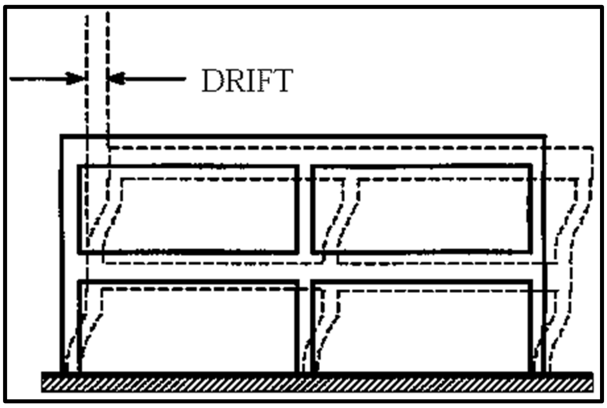



**Figure I.8:** Definition of story drift.

- **Chord rotation**

The chord rotation is defined as the angle between the chord connecting the considered end section of the member to the section at which M = 0 and the tangent to the member axis at the end section (Fig I.9).

Chord rotation demand of certain member shouldn't exceed its capacity to rotate, and that capacity depends on the geometrical and mechanical properties of the considered member as well as on the seismic input, hence the same structural member may develop different capacities as the seismic action changes.

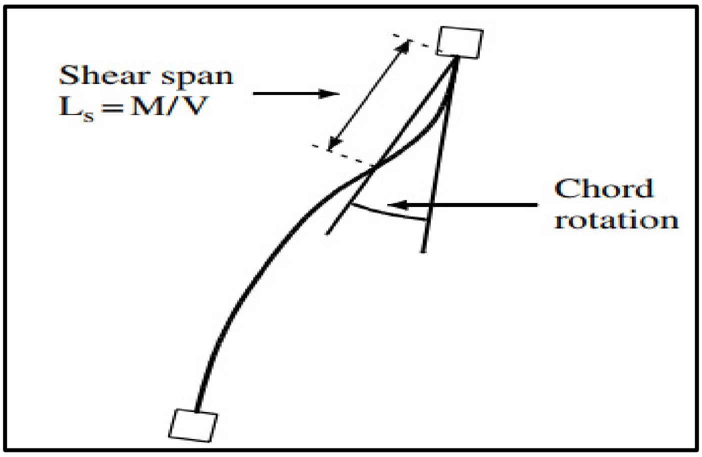



**Figure I.9:** Definition of chord rotation.

- **Axial load ratio**

Due to the influence of compressive axial loads (Fig I.10) on the deformation of reinforced concrete columns, the Algerian seismic regulations introduced an upper limit to said loads in term of "Axial load ratio" under the seismic load combinations.

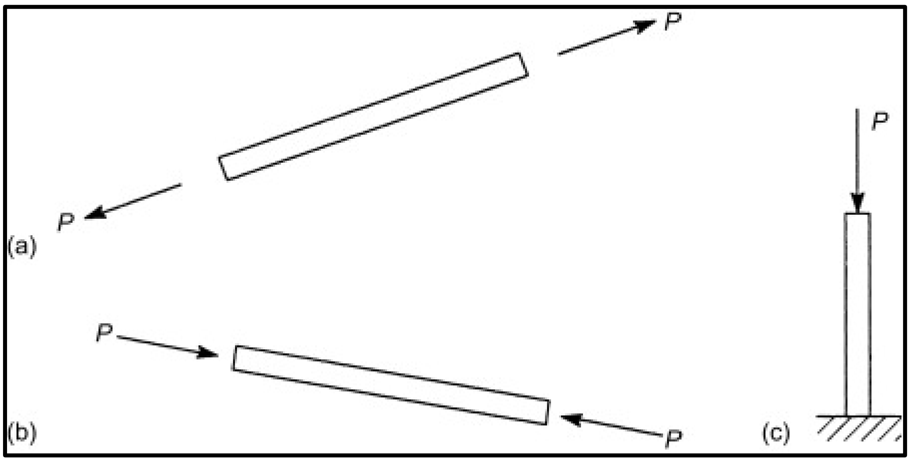



**Figure I.10:** Example of axially loaded members.

- **P-delta effect**

P-Delta effect, one type of geometric nonlinearity, involves the equilibrium compatibility relationships of a structural system loaded about its deflected configuration (the main concern is the application of gravity load).

This condition magnifies story drift and certain mechanical behaviors while reducing deformation capacity as P-delta effects increase lateral flexibility for members under compression, but they can also increase the lateral stiffness for members under tension (Fig I.11).

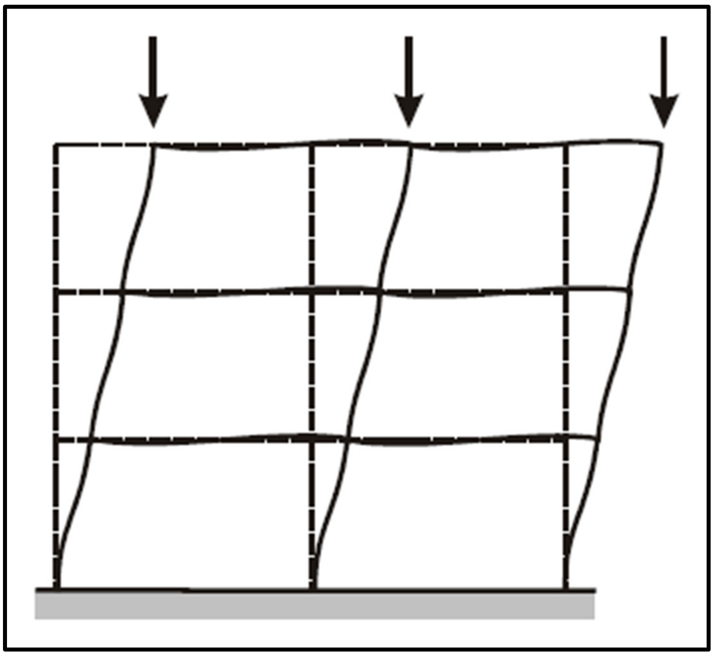


**Figure I.11:** Definition of P-Delta effect.

### I.4.2. Static pushover analysis

Conventional (non-adaptive) pushover analysis is employed in the estimation of the horizontal capacity of structures implying a dynamic response that is not significantly affected by the levels of deformation incurred (i.e. the shape of the horizontal load pattern, which aims at simulating dynamic response, can be assumed as constant)

Static pushover analysis (Fig I.12) is an analysis method where the structure is subjected to both gravity loading and a displacement controlled lateral load pattern which continuously increase by the program until an ultimate condition is reached.

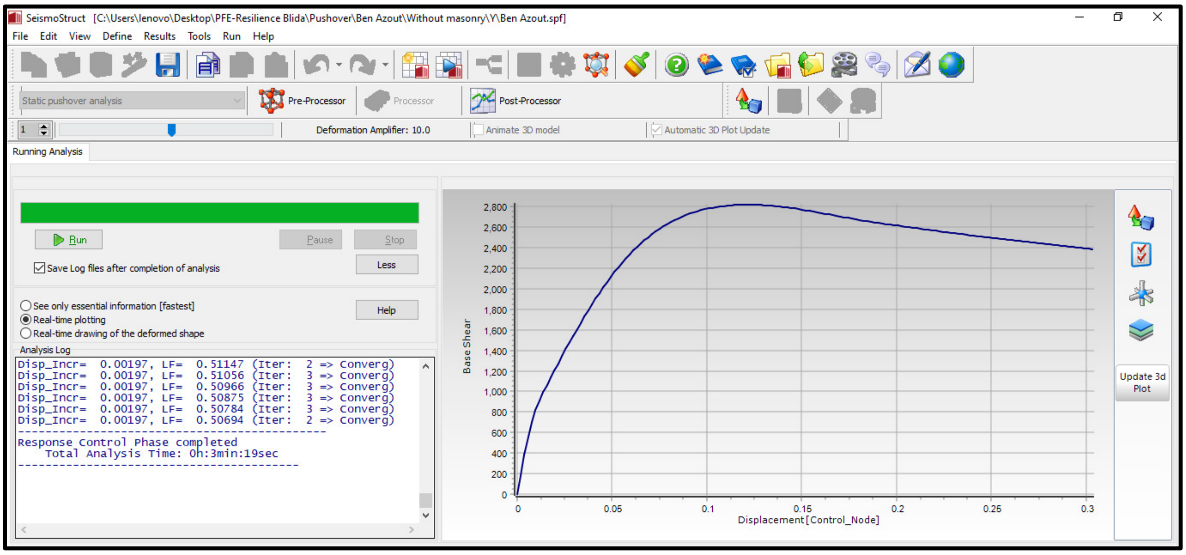



**Figure I.12:** Pushover analysis performed by SeismoStruct.

The target condition chosen in this analysis is the **c**ollapse prevention limit state (Maximum drift = 4%):

- **For 2 story buildings**: target displacement = 4% (7.48) = 30 cm.
- **For 3 story buildings**: target displacement = 4% (11.22) = 45 cm.

The output generates static-pushover curve which plot a strength-based parameter against deflection, which is usually the "Base shear" in relation to the "lateral displacement at the top of the structure".

Conventional pushover analysis features an inherent inability to account for the effects that progressive stiffness degradation, typical in structures subjected to strong earthquake loading, has on the dynamic response characteristics of structures, and thus on the patterns of the equivalent static loads applied during a pushover analysis. Indeed, the fixed nature of the load distribution applied to the structure ignores the potential redistribution of forces during an actual dynamic response, which pushover tries to somehow reproduce.

Consequently, the resulting changes in the modal characteristics of the structure (typically period elongation) and consequent variation in dynamic response amplification are not accounted for, which might introduce non-negligible inaccuracies, particularly in those cases where the influence higher mode is, or becomes, significant

## I.5. Numerical modeling using SeismoStruct 2020

In this study, all the time history and pushover analyses will be carried out using SeismoStruct 2020 (Fig I.13), a fiber element-based program for seismic analysis of framed structures accounting for both material inelasticity and geometric nonlinearity.

SeismoStruct 2020 can perform nine different types of analysis:

- Response spectrum analysis.
- Dynamic and static time-history.
- Conventional and adaptive pushover.
- Incremental dynamic analysis.
- Eigenvalue analysis.
- Non-variable static loading and buckling analysis.

The structural elements (columns, beams, walls) were modeled using SeismoStruct building modeler that features a graphics user interface that caters for a relative straightforward creation of error-free models, even by inexperienced users.

This computer code incorporates both local (beam-column effects) and global (large displacements/rotations effects) sources of geometric nonlinearity as well as the interaction between axial force and transverse deformation of the element.

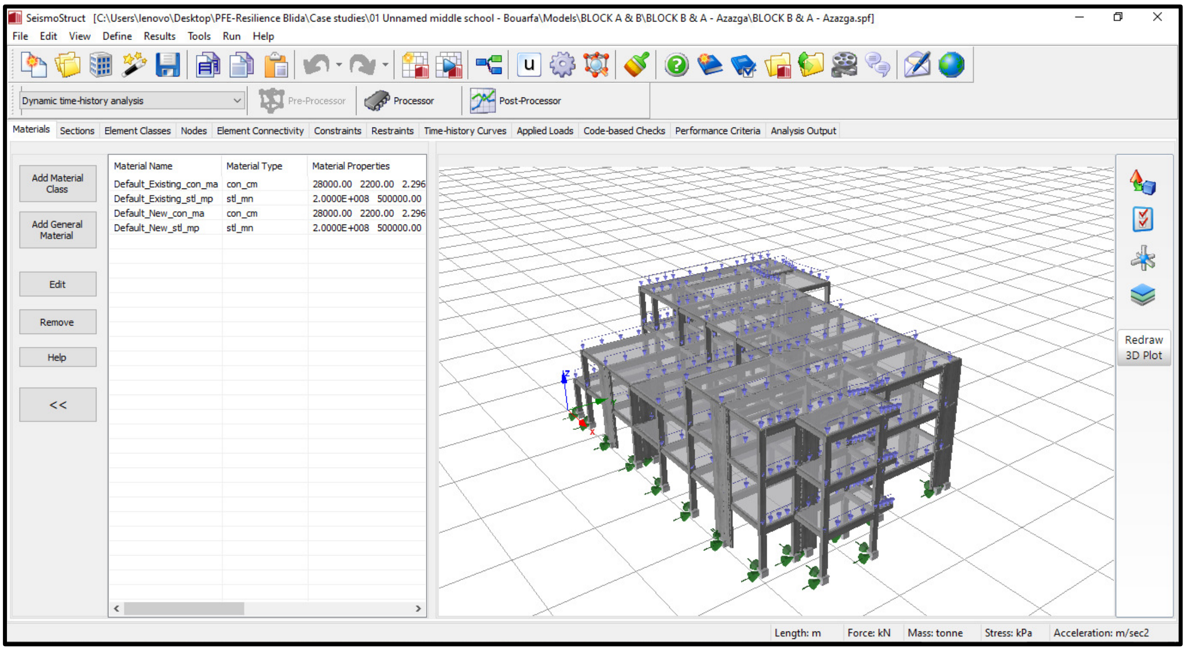



**Figure I.13:** SeismoStruct user interface.

### Materials nonlinearity modelling

Material nonlinearity is associated with the inelastic behavior of a component or system. Inelastic behavior may be characterized by a force-deformation (F-D) relationship, also known as a backbone curve, which measures strength against translational or rotational deformation.

The general F-D relationship indicates that once a structure achieves its yield strength, additional loading will cause response to deviate from the initial tangent stiffness (elastic behavior). Nonlinear response may then increase (hardening) to an ultimate point before degrading (softening) to a residual strength value.

The relationship type used in modelling both concrete and steel rebars is the hysteresis which is useful for characterizing dynamic response under application of a time-history record.

- **Concrete**

In this study, Chang & Mander's [Chang & Mander, 1994] (Fig I.14) concrete model is used to define confined and unconfined concrete, which generates continuous hysteretic stress-strain relationships with slope continuity for confined and unconfined concrete in both compression and tension.

This model puts particular emphasis on the transition of the stress-strain relation upon crack opening and closure, contrary to other similar models that assume sudden crack closure with rapid change in section modulus.

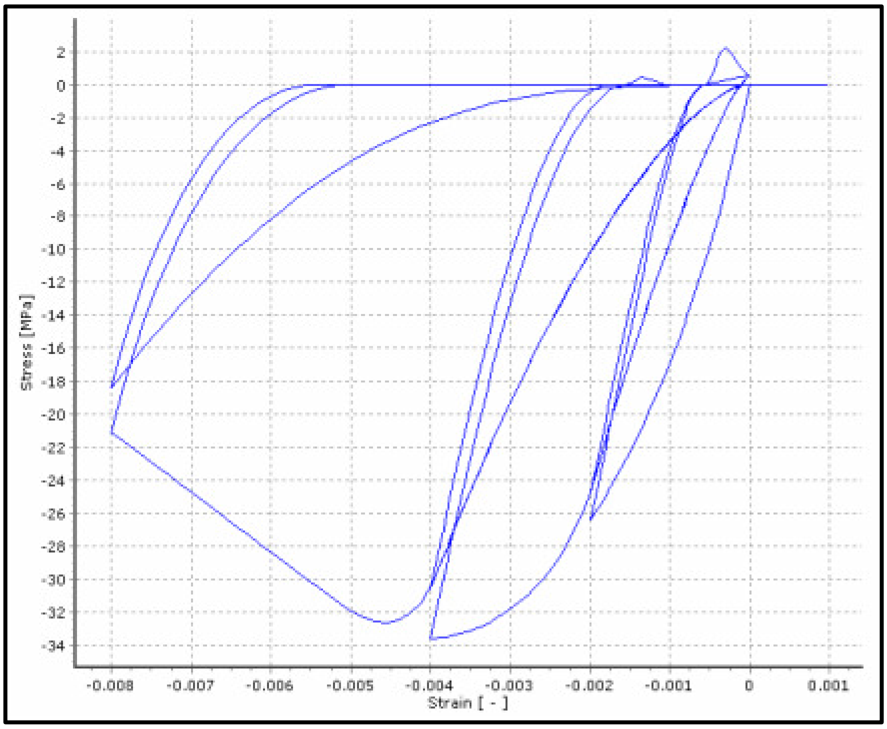
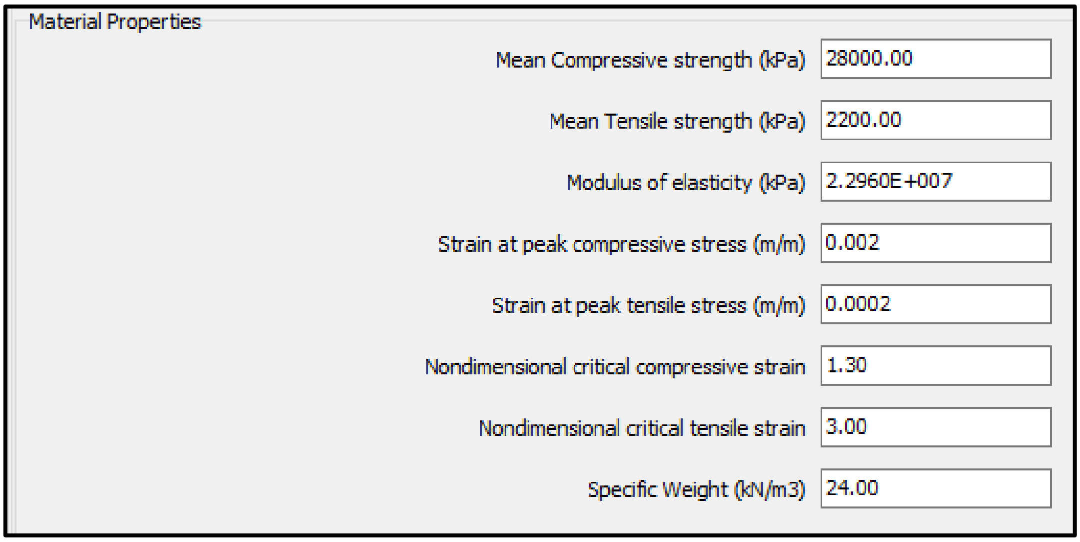



**Figure I.14:** Hysteretic Constitutive Model for Concrete by Chang and Mander.

The model is defined by the following properties (Fig I.15):



Material Properties

| | |
|---|---|
| Mean Compressive strength (kPa) | 28000.00 |
| Mean Tensile strength (kPa) | 2200.00 |
| Modulus of elasticity (kPa) | 2.2960E+007 |
| Strain at peak compressive stress (m/m) | 0.002 |
| Strain at peak tensile stress (m/m) | 0.0002 |
| Nondimensional critical compressive strain | 1.30 |
| Nondimensional critical tensile strain | 3.00 |
| Specific Weight (kN/m3) | 24.00 |

**Figure I.15:** Concrete properties according to Chang and Mander model.

- **Steel rebar**

For steel rebar, Menegotto and Pinto [1973] steel model (Fig I.16) is used to define steel rebar section, which consider the hysteretic behavior with isotropic hardening.

Its employment should be confined to the modelling of reinforced concrete structures, particularly those subjected to complex loading histories, where significant load reversals might occur. This model, initially developed with ribbed reinforcement bars in mind, can also be employed for the modelling of smooth rebars, often found in existing structures.

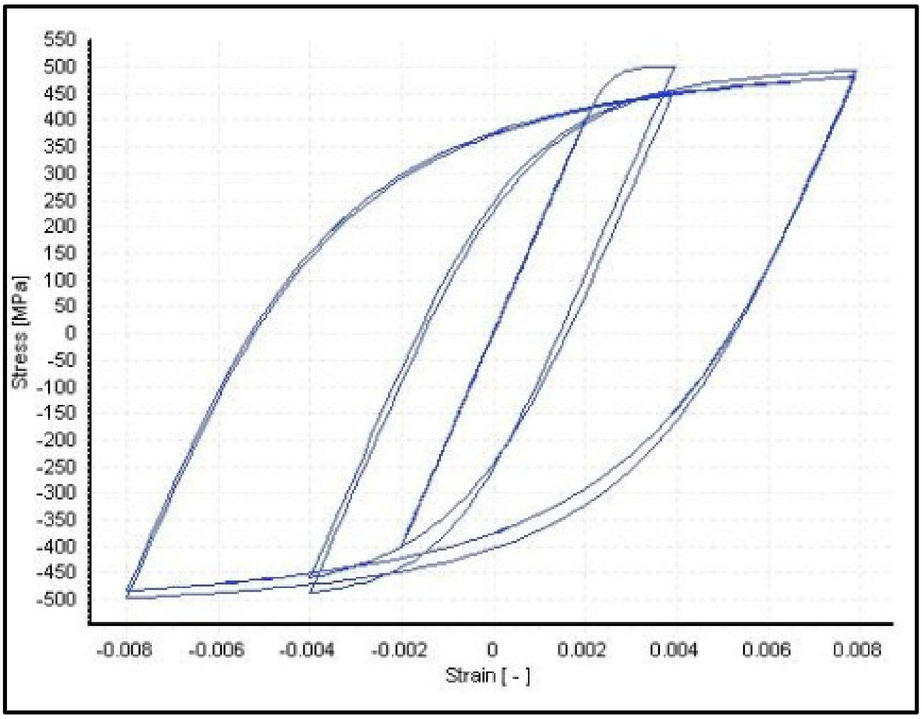



**Figure I.16:** Menegotto-Pinto model for steel sections.

The model is defined by the following properties (Fig I.17):

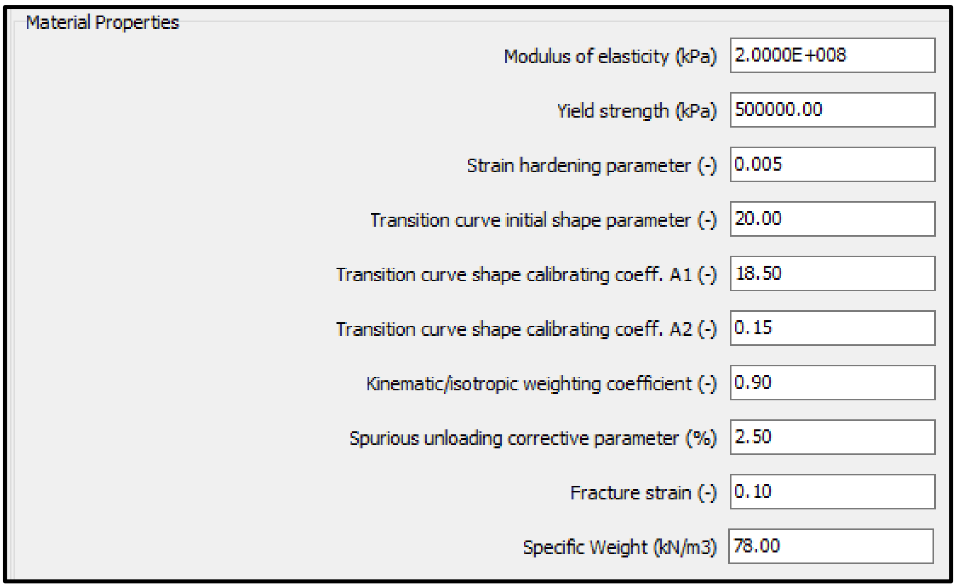



**Figure I.17:** Steel rebar properties according to Menegotto-Pinto model.

- **Inelastic masonry infill technical notes**

A four-node masonry panel element (Fig I.18), developed and initially programmed by Crisafulli [1997], for the modelling of the nonlinear response of infill panels in framed structures. Each panel is represented by six strut members; each diagonal direction features two parallel struts to carry axial loads across two opposite diagonal corners and a third one to carry the shear from the top to the bottom of the panel. This latter strut only acts across the diagonal that is on compression, hence its "activation" depends on the deformation of the panel. The axial load struts use the masonry strut hysteresis model, while the shear strut uses a dedicated bilinear hysteresis rule.

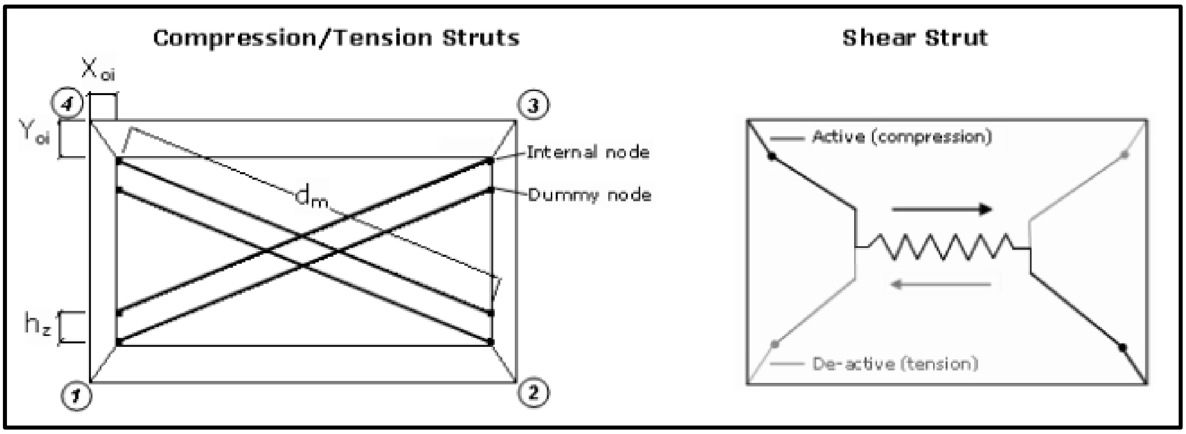



**Figure I.18:** Illustration of both compression/tension struts and shear strut.

The masonry infill in SeismoStruct was modeled using the input properties that are shown in (Fig I.19):

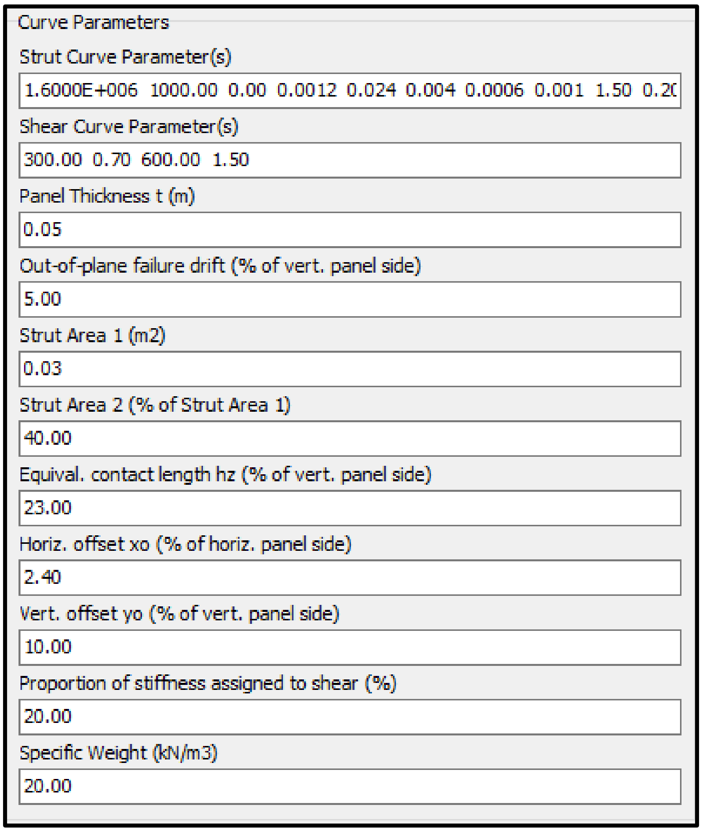



**Figure I.19:** Masonry infill properties for numerical modelling.

To account for effect of the openings; the strut area was reduced thus reducing the infill panels' stiffness.

Several researchers suggest various factors to account for the loss in stiffness, the following factors were chosen for this research:

- The strut area for the infill with "small windows" is estimated at: 70% of the strut area of a complete infill (without openings).
- The strut area for the infill with "large windows" is estimated at: 60% of the strut area of a complete infill (without openings).
- The strut area for the infill with "door" is estimated at: 50% of the strut area of a complete infill (without openings).

## I.6. Definition of seismic resilience

The term of resilience is often used to describe both strength and flexibility, according to Lexico (Oxford's dictionary), the term resilience means: "The capacity to recover quickly from difficulties; toughness **or** the ability of a substance or object to spring back into shape; elasticity".

In the field of civil engineering, Bruneau and Reinhorn [2007] and Cimellaro et al. [2010] defined "Resilience as a function indicating the capability to sustain a level of functionality or performance for a given construction (building, bridge… etc.) over a period defined as the control time that is usually decided by owners, or society".

When talking about seismic activities; the term implies the ability of building to not only withstand normal level stress, but to also adapt to sudden high level of stress bought by earthquakes.

In conclusion, seismic resilience is the ability of building to:

- Absorb the shock of earthquakes when it happens.
- Recover quickly after the shock (re-establishing a normal level of performance).

## I.7. How to evaluate the resilience of a building

At any given time, the resilience of a building can be measured by measuring its performance (the ability to provide a service); looking at the performance of a building as number or percentage, then overtime that number can change, sometimes gradually, sometimes abruptly due to hazardous events such as major earthquakes, floods…etc.

In case of earthquakes for example, a part of the building can fail leading to a reduction in performance, after that, time and resources are needed to restore it to a normal state; the resilience of that building can be evaluated depend on the time and resources needed to get back to that normal level of performance.

Since schools are the main focus of this study, let us consider the school of Ben Azout as example, the performance P(t) of any school can be measured at any time by the number of students it can serve. For this specific school that number is 250 students, let us call this the optimal performance, this performance can range from 250 students (100%) where there's no degradation in service to 0 student (0%) where no service is available. If an earthquake occurred at time $t_0$, destroying serval classrooms, resulting in half the students having no place to study, the performance of this school is immediately reduced from 250 students (100%) to 125 students (50%), as indicated in (Fig I.20), after short delay $t_r$ for preparation, the repairs starts until time $t_1$ when it is completely repaired.

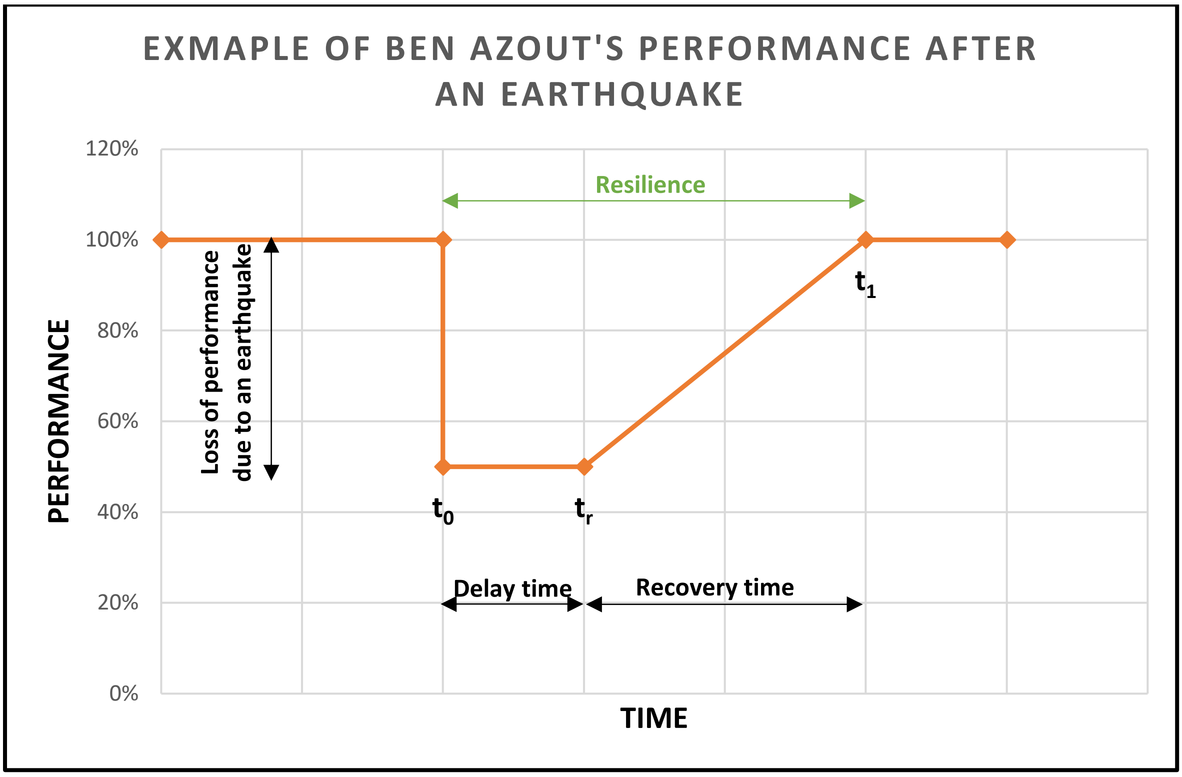



**Figure I.20:** Performance of Ben Azout school after an earthquake.

Hence, the school earthquake loss of resilience R, with respect to that specific earthquake, can be measured by the size of the expected degradation in performance, over time (time to recovery). Mathematically, it can be defined by:

$$\boldsymbol{R} = \int_{t0}^{t1} [\mathbf{100} - \boldsymbol{P}(\boldsymbol{t})]\boldsymbol{dt}$$

Obviously to have the full picture, the performance of school must be measured in light of different set of earthquakes that can happen, and for that to happen the probabilities of various earthquakes to occur have to be included (depend on magnitude and intensity).

Additionally, in some cases the return to 100% pre-earthquake performance is not enough, especially where the seismic resilience was low in the first place, so the aim should be to achieve more than 100% pre-earthquakes level while doing the repairs.

In conclusion: the principal behind measuring seismic resilience of school is to quantify the difference between the ability of a said school to provide services prior to the occurrence of an earthquake and the expected ability of that school to perform after an earthquake.

## I.8. The importance of having good seismic resilience

The main objective of enhancing seismic resilience is to minimize human casualties (be it death or injury), economic loss, and minimizing any reduction in quality of life because of earthquakes, and that can be achieved by enhancing the ability of a building's structural system to perform during and after an earthquake, while also preparing strategies to recover into pre-disaster performance as quick as possible leading to:

- Identifying and designing studies that will ultimately lead to improving seismic resilience.
- Evaluating the relative contribution of different loss-reduction measures to resilience
- Choosing the best measures to achieve the desirable level of seismic resilience with the least cost possible.

## I.9. Developing fragility function

Fragility curves describe the probability of a building reaching or exceeding a specific damage state at a given value of seismic response parameter such as:

- Maximum acceleration
- Velocity displacement
- Spectral acceleration…etc.

The fragility curves (Fig I.21) are established to provide a prediction of potential damage during an earthquake. These curves represent the seismic risk assessment and are used as an indicator to identify the physical damage at peak ground motion (PGA).

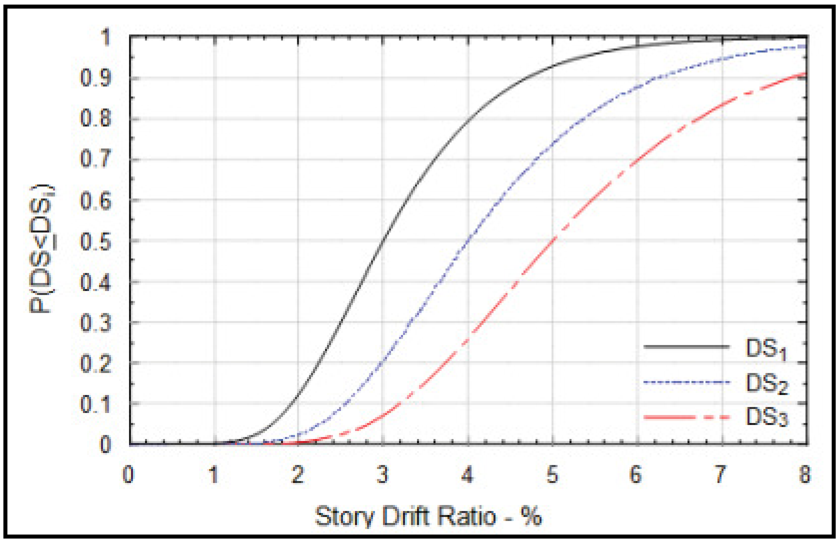



**Figure I.21:** Example family of fragility curves for moment resistent frame beam-column connections.

The development of fragility curves could be performed based on calculation or experimental data from real life earthquake or dynamic tests in laboratories.

The first step in developing fragility curve is to define the failure states limits; according to FEMA356 and ASCE/SEI 41-17 these state limits are defined by two main factors: Drift and damage types.

For concrete buildings there are five limit states which are defined by the inter-story drift and the type of damage that appears on structure members:

**Table I.2:** Structural performance levels and damage for vertical structural elements.

| Limit-state | | Concrete frames | Concrete walls |
|---|---|---|---|
| **Fully operational** | **Description** | The fully operational level is a condition in which it is expected that damage is insignificant and structure does not need any repair measures. Structural elements are prevented from significant yielding and retaining their strength and stiffness properties. All systems important to normal operation are functional. Non-structural components, such as partitions and infills should not be damaged. | |
| | **Damage** | Insignificant damage. | |
| **Immediate occupancy** | **Description** | The Immediate Occupancy after the earthquake is a condition in which it is expected that no building operation is interrupted during and after the design earthquake, with the possible exception of minor importance functions. Structural elements are retaining their strength and stiffness properties. A few hairline cracks may occur in the structure. | |
| | **Damage** | Minor hairline cracking.<br>Limited yielding possible at a few locations.<br>No crushing (strains below 0.003). | Minor hairline cracking of walls, <1/16" wide.<br>Coupling beams experience cracking <1/8" width. |
| | **Drift** | 1% | 0.5% |
| **Life safety** | **Description** | The Life Safety is a condition in which moderate damage to the structure is expected to occur during the design earthquake, although it is likely to be uneconomic to repair. Structural elements are retaining some residual strength and stiffness. Non-structural components are damaged, although partitions and infills have not failed out-of-plane. Moderate permanent drifts are present. | |
| | **Damage** | Extensive damage to beams.<br>Spalling of cover and shear cracking (<1/8"width) for ductile columns.<br>Minor spalling in nonductile columns.<br>Joint cracks <1/8" wide. | Some boundary element stress, including limited buckling of reinforcement.<br>Some sliding at joints.<br>Damage around openings.<br>Some crushing and flexural cracking.<br>Coupling beams: extensive shear and flexural cracks; some crushing, but concrete generally remains in place. |
| | **Drift** | 2% | 1% |
| **Collapse prevention** | **Description** | The Collapse Prevention is a condition in which severe (nonrepairable, in general) damage to the structure is expected during the design earthquake and would probably not survive another earthquake. The structure is heavily damaged with low residual lateral strength and stiffness, although vertical elements are still capable of sustaining vertical loads. Most non-structural components have collapsed and large permanent drifts are present. | |

| | | | |
|---|---|---|---|
| | **Damage** | Extensive cracking and hinge formation in ductile elements.<br>Limited cracking and/or splice failure in some nonductile columns.<br>Severe damage in short columns. | Major flexural and shear cracks and voids.<br>Sliding at joints.<br>Extensive crushing and buckling of reinforcement.<br>Failure around openings.<br>Severe boundary element damage.<br>Coupling beams shattered and virtually disintegrated. |
| | **Drift** | 4% | 2% |
| **Sidesway collapse** | **Description** | Sidesway collapse is the global failure of the system caused by a reduction of the lateral load-bearing capacity due to large horizontal displacements. | |
| | **Damage** | Total collapse of the structure | |

After trying to develop the fragility function according to the methodology of FEMA695, where fragility curves can be visualized through the concept of Incremental dynamic analysis (IDA), in which the structure is subjected to a 44 ground motions that are scaled to an increasing intensity until the building collapse.

The task became impossible due to lack of computing power as each analysis takes large amount of time (8 to 12 hours), so instead of that: the method that was relied on is using "the static pushover to fragility" procedure using SPO2FRAG.

SPO2FRAG (Static pushover to fragility) (Fig I.22) is a MATLAB-coded software tool for estimating structure-specific seismic fragility curves of buildings, using the results of static pushover analysis.

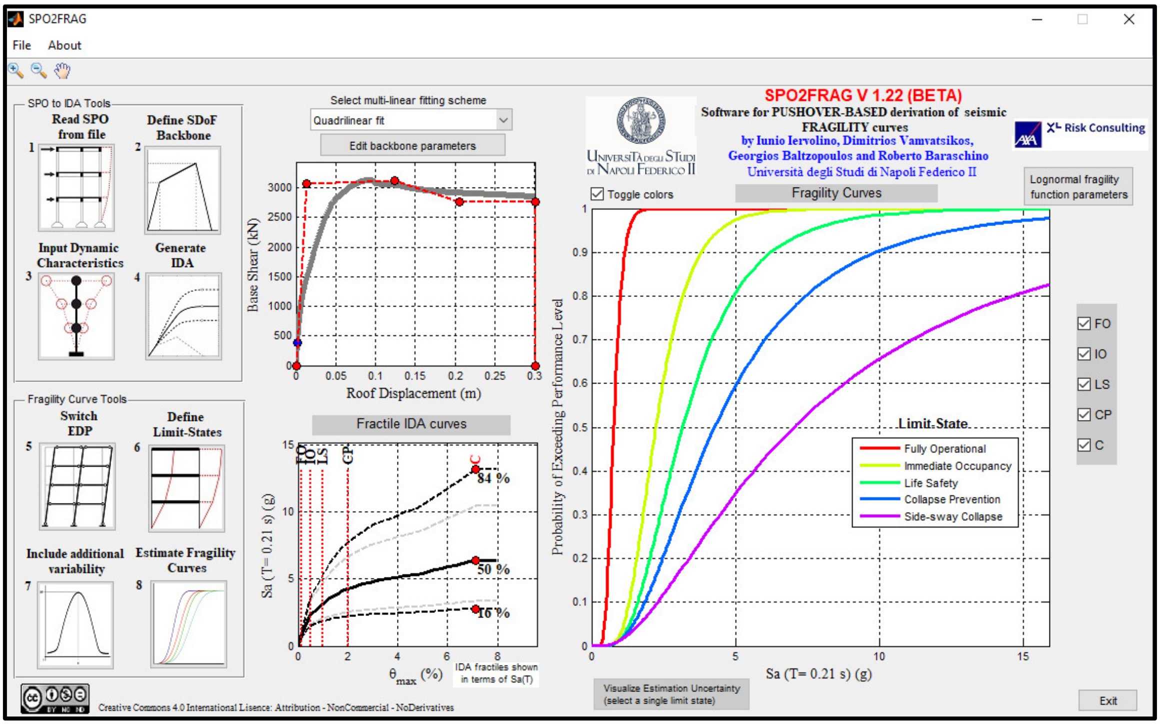



**Figure I.22:** User interface for SPO2FRAG.

The SPO2FRAG tool eschews the need for computationally demanding dynamic analyses by simulating the results of incremental dynamic analysis via the SPO2IDA algorithm (Fig I.23), a procedure which was developed by Vamvatsikos and Cornell [2006] to estimate the seismic demand and capacity of the first-mode dominated structures, by exploiting a connection between the pushover (capacity) curve and IDA results to obtain IDA results that can be used to develop fragility curves for case studies.

Additionally, the fragility curve function can be calculated for multiple limit states using intensity-measure-based analytical approach, by assigning the various damage thresholds.

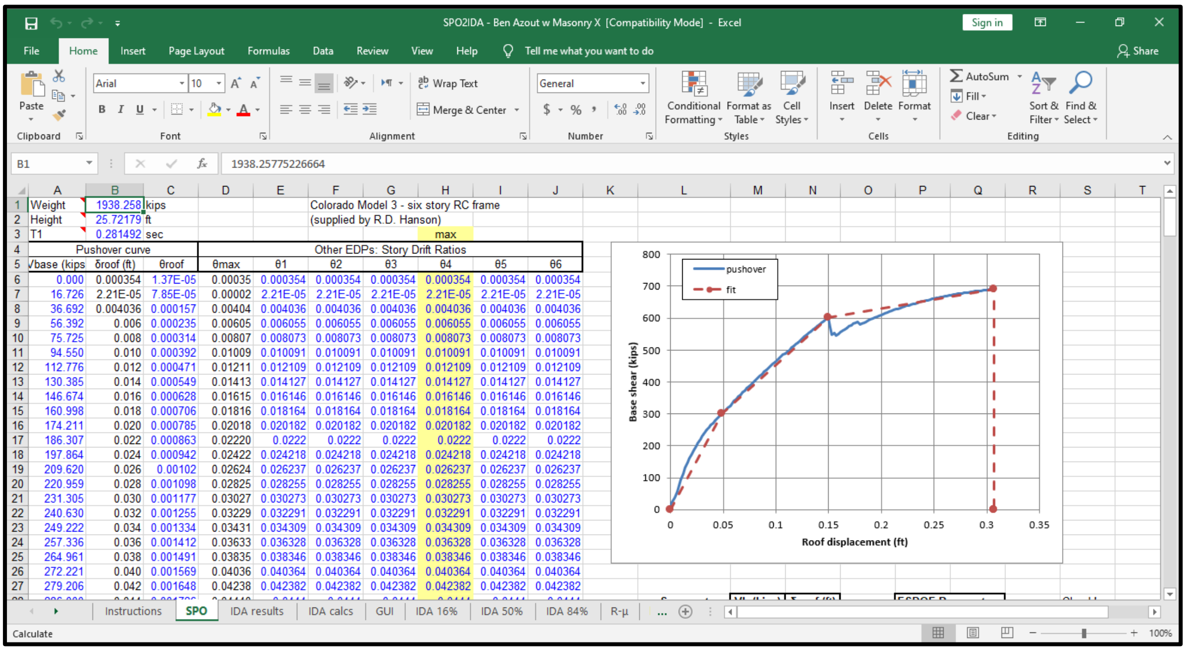



**Figure I.23:** User interface for SPO2IDA.

## I.10. Conclusion

Due the high seismicity of Algeria and the various changes that occurred to the seismic code regulations, the importance of studying the seismic performance of school buildings throughout the history by analyzing the various structural systems used in said buildings became very apparent, to ensure the safety of children during earthquakes and to suggest various methods of reducing earthquake hazards in the future.

# *Chapter II*

## *Seismic Performance of School buildings in Algeria*

## II.1. Introduction

Schools have very important role in modern society both as place when children spend on fourth of their everyday life and safe haven to people after disasters, so this chapter will try to give a wider look at the schools in Algeria:

- The education system in Algeria.
- The importance of schools in today's society.
- The behavior of schools during the last seismic disaster "Boumerdes earthquake".
- The reason why schools are very vulnerable to seismic disasters.
- The scope of the study.
- Description of the schools in the area.
- Earthquake mitigation for school buildings.

## II.2. The education system of Algeria

Education in Algeria is free and compulsory for Algerians from the ages of 6 to 15. Algerian education is still grounded in the French fact-acquisition orientation, and teaching is almost exclusively in the lecture and memorization mode.

The education is structured into 3 categories: Primary education – secondary education – higher education.

Since this study only focuses on the two first categories, higher education will be ignored throughout the thesis.

### II.2.1. Primary education

In Algeria, primary education lasts for 9 years (5 + 4):

- 5 years of primary school.
- 4 years of middle school.

Most pupils are taught in public schools. Pupils take English classes from the 1$^{st}$ grade of middle school. At the end of middle school pupils need to take final test "middle school certificate" to pass into high school.

### II.2.2. Secondary education:

High school in Algeria last for 3 years, where pupils take a general range of subjects, while having to choose a profile in the literature or in science and technology. They will continue their specialization in their 2nd and 3rd year.

At the end of high school, pupils need to pass Baccalaureate exam to access higher education.

## II.3. The importance of schools in today's society

The reason for choosing schools as the main focus of this study is because schools should be considered the most important structure in any society for multiple reasons:

- Schools are the place in which tens of thousands of children spend lot of time everyday, for example: during the Boumerdes earthquake in 2003, more than 103 school building were completely destroyed and approximately 753 other were badly damaged, but fortunately it happened after the school hours (19:44:21 local time), which prevented any human loss to occur in school ground.
  If that earthquake for example happened during school hours, we could be looking at casualties of at least 60 thousand children (average number of students per school is 600 student).
- Quality education and good health and well-being are two of the UN 17 sustainable goals.
- Educations and healthcare are considered the main hubs of health community.
- When a disaster strikes or a conflict erupts, schools are typically closed to provide shelter to displaced people, which make their functionality after disasters very critical for sustainable cities and communities.

## II.4. The behavior of schools during Boumerdes earthquakes

### II.4.1. Overview

During the last seismic disaster Boumerdes earthquake in 2003, the shockwave completely destroyed 103 and seriously damaged another 753 school buildings.

The damage from the earthquake varied in scale from grade 1 all the way to grade 5 (Fig II.1) according to the EMS (Fig II.2) as shown in Table II.1.

**Table II.1:** Damage distribution of the school buildings after Boumerdes earthquake.

| **Level of damage** | **Grade 1** | **Grade 2** | **Grade 3** | **Grade 4** | **Grade 5** | **Total** |
|---|---|---|---|---|---|---|
| **Number of schools** | 490 | 814 | 467 | 286 | 103 | 2160 |
| **Percent of schools** | 22.69% | 37.69% | 21.62% | 13.24% | 4.77% | 100% |

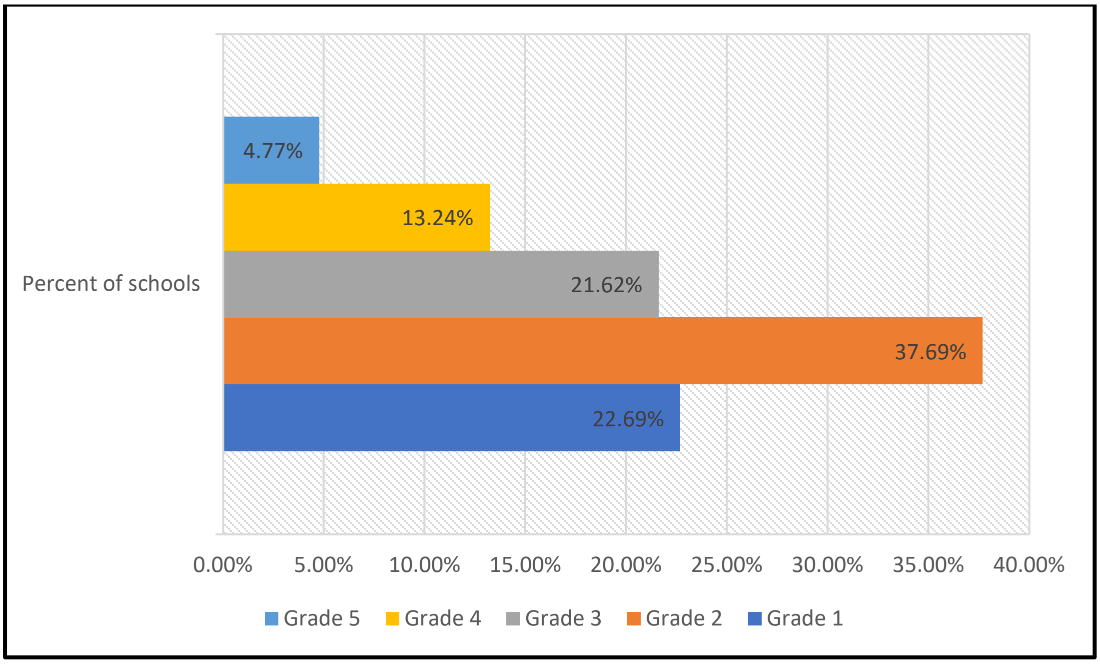



**Figure II.1:** Damage distribution of the school buildings after Boumerdes earthquake.

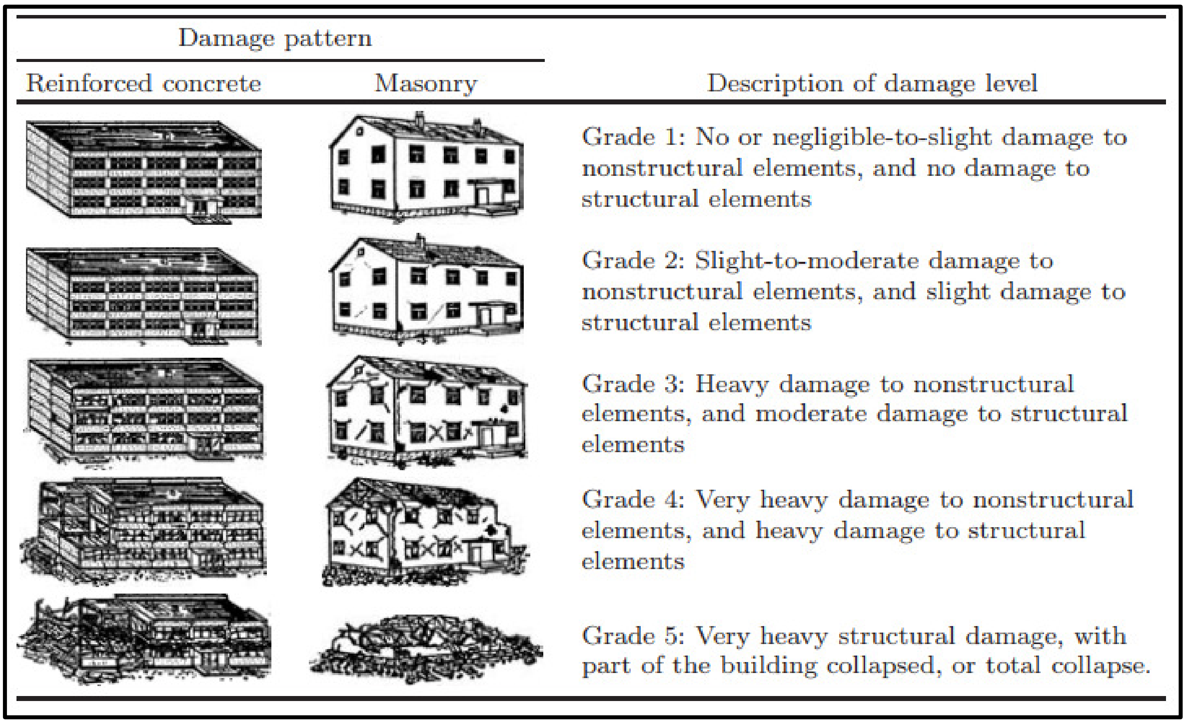



**Figure II.2:** The European macro-seismic classification of damage grades.

### II.4.2. The different types of school damage after Boumerdes earthquake

The combination of poor construction material, poor design choices, poor construction techniques and other factors that are going to be elaborated on in the next subchapter resulted in the following typical damages:

- **Destruction of short columns**

Short column possesses high stiffness that attracts most of the force acting on the multi-story building. Inadequate design of short column to sustain these forces will result in damage and shear failure (Fig II.3). This behavior of the short column under excessive force is called as short column effect and it mostly occur because of the architectural arrangement of windows.

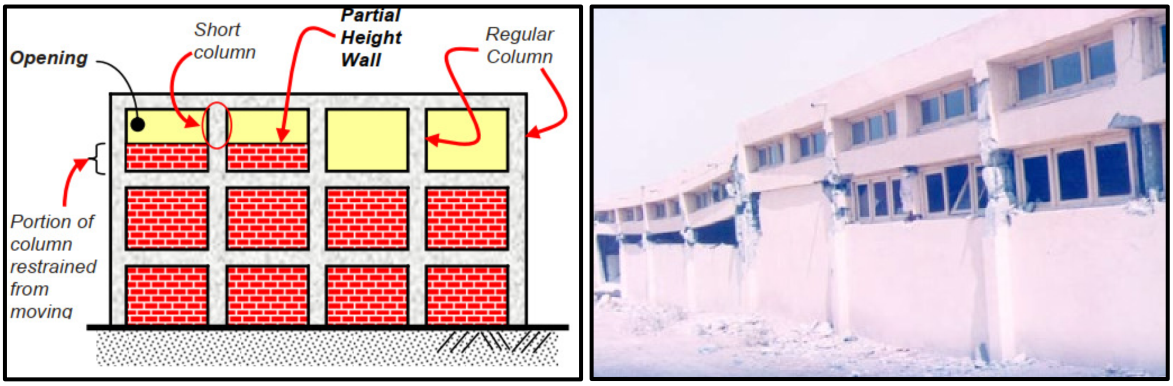



**Figure II.3:** Short columns effect in RC building.

- **Soft-story damage resulting in pancake collapse**

Pancake collapse (Fig II.4) occurs when most or all vertical supporting members "columns" fail and allow floors to collapse on top of each other.

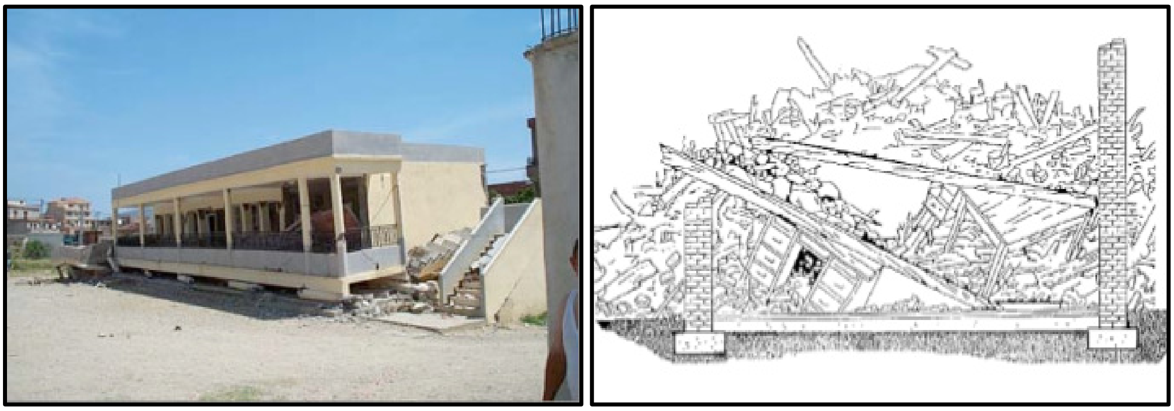


**Figure II.4:** Soft-story effect during Boumerdes earthquake.

- **Destruction of column-beam joints** (Fig II.5)

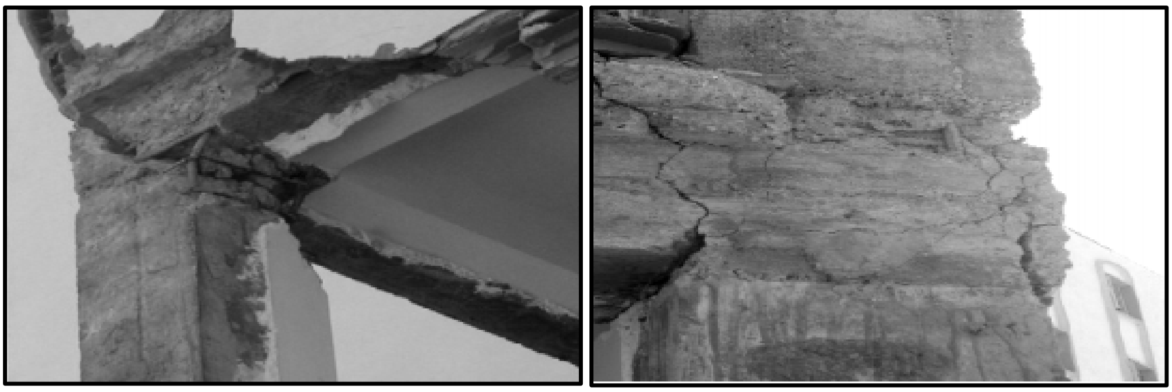


**Figure II.5:** Column-beam joint damage during Boumerdes earthquake.

- **Rupture of stair cases.**
- **Damage in masonry infill** (Fig II.6)

**Figure II.6:** Masonry infill damage during Boumerdes earthquake.

### II.4.3. Recovery cost

According to the ministry of education, the damage on the schools resulted from the earthquake ended up costing the Algerian government 70 million $ (USD) in reconstructions and rehabilitations efforts as showed in Table II.2:

**Table II.2:** Recovery cost of school buildings in Algiers and Boumerdes provinces.

| | Number of schools | | Cost in million $ (usd) | |
|---|---|---|---|---|
| **Type of school** | **Rebuilt** | **Rehabilitated** | **Rebuilt** | **Rehabilitated** |
| **Primary schools** | 100 | 253 | 3.75 | 9.31 |
| **Middle schools** | 12 | 111 | 9 | 18.25 |
| **High schools** | 10 | 58 | 18.75 | 10.5 |
| **Total** | 122 | 422 | 31.5 | 38.06 |
| | | | 69.56 | |

## II.5. What make schools more vulnerable to seismic hazards than other buildings

Schools have multiple characteristics that make them more vulnerable to seismic hazards than other buildings in relate to: General layout, structural system and construction materials, location, lack of supervision and other underlying motives that this subchapter will try to elaborate on:

### II.5.1. General layout

Most schools around the world including Algeria share the same layout of large classrooms with large windows, that while supporting the school's functionality increase its seismic vulnerability greatly.

The need to accommodate the large number of pupils per teacher and to have unobscured line of sight leads to making large classes without the necessary interior support (Fig II.7).

**Figure II.7:** Lack of interior support inside classrooms.

Additionally, having the need to provide cross-ventilation and natural light lead schools to having large windows, that create lot vulnerabilities; Many concrete frame buildings have stiff partial-height masonry walls below the windows, which create "short or captive columns" (Fig II.8) failure above the wall which fail in shear, making it is one of the most common causes of seismic damage according to the earthquakes reports around the world.

**Figure II.8:** Short columns effect in Algerian schools.

Also having large windows in only on side of the room, while having wall on the other which can create unbalance that lead to torsion in some of the buildings.

Finally, having large classrooms and large windows cause the schools building to be one or at most two classrooms large, with classrooms places next to each other with corridor on the side, mixing all of that with the need to pack more classrooms in the available land results in creating irregular layout (Fig II.9), with few if any cross-walls to reduce the span of classroom's long walls; which weaken the buildings that relies on walls for seismic resilience cause the long span of roofs and floors allow the walls to move more which can cause the roof or floor to pull apart and collapse which did happen during the Boumerdes earthquake.

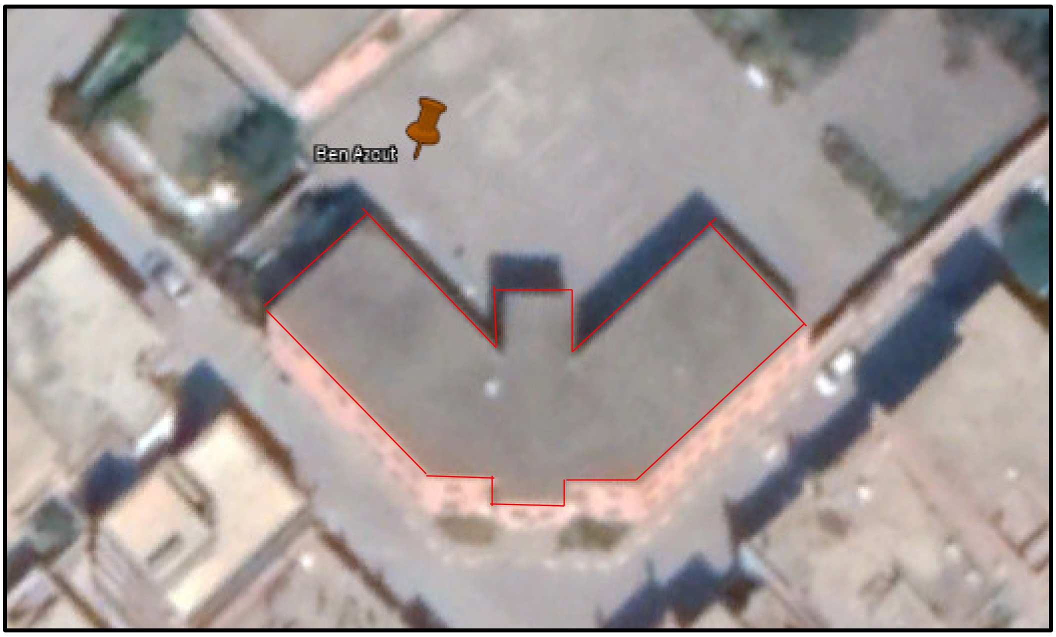


**Figure II.9:** Irregular layout of some schools in Great Blida.

### II.5.2. Structural system and construction materials

Many of the schools in Algeria (especially before Boumerdes earthquake) share the same design; due to jurisdictions using a standard building design for multiple schools (the common L shaped school design for example) (Fig II.10) to reduce cost and improve the efficiency of construction, but on the other hand **if** the standard design have major seismic weakness, then those weakness will appear in the many schools that share or have similar design.


**Figure II.10:** The L shaped design commonly used in Algerian schools.

The quality of construction materials is another important factor in poor seismic resilience, as showed during the Boumerdes earthquake, where many of the collapsed schools had poor quality engineered materials used during construction, and this could be due to multiple reasons:

- Cost pressure for achieving the lowest bid may lead contractor to providing poor quality materials.
- Good quality materials not locally available,
- Lack of materials testing and quality control.

### II.5.3. Location

Due to the restrictions in choice of available areas (Schools are often located in communities near housing), schools can be located on sites vulnerable to seismic hazards (sites that amplify ground motions for example) if the community cannot provide safer site to the authorities.

### II.5.4. Lack of supervision

After the inspection of the collapsed building during the Boumerdes earthquake, the inspectors found most building didn't respect the previous Algerian seismic code due to bad supervision, which resulted in: using poor materials (especially in the concrete), dimensions of reinforcement not conforming to the code or placing it in the wrong way (Fig II.11).

The cost pressure involved in winning the bid to build the school can force contactor to use poor quality materials and low skill workers, in addition to lack of supervision can lead to very problematic results.

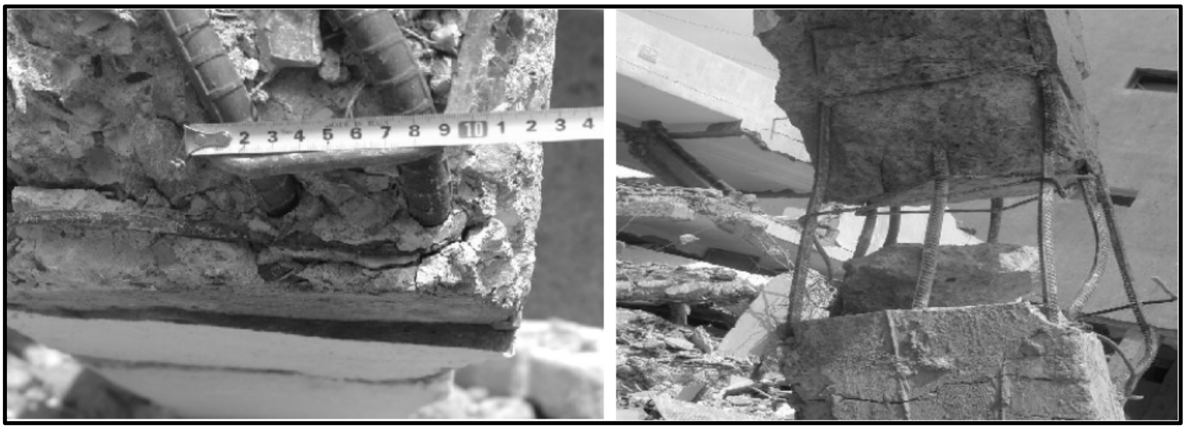


**Figure II.11:** Bad construction practices observed after Boumerdes earthquake.

## II.6. The scope of the study: "The great Blida"

In this study, the focus of the research are the schools located in the four municipalities that were once called the "Great Blida" in the past: "Blida – Bouarfa – Beni mered – Ouled Yaich" (Fig II.12), which are located in the center of Blida Province.

According to the Algerian seismic code (RPA99 v2003), these four municipalities are located in Zone III, which refers to areas with High seismicity (highest evaluation possible in Algeria) which is understandable considering the history of the province with destructive earthquakes during the past two decades, such as the earthquake of March 2$^{nd}$, 1825 with the Intensity of X that resulted in the death of 7000 person, and the earthquake of January 2$^{nd}$, 1867 with the intensity of IX.

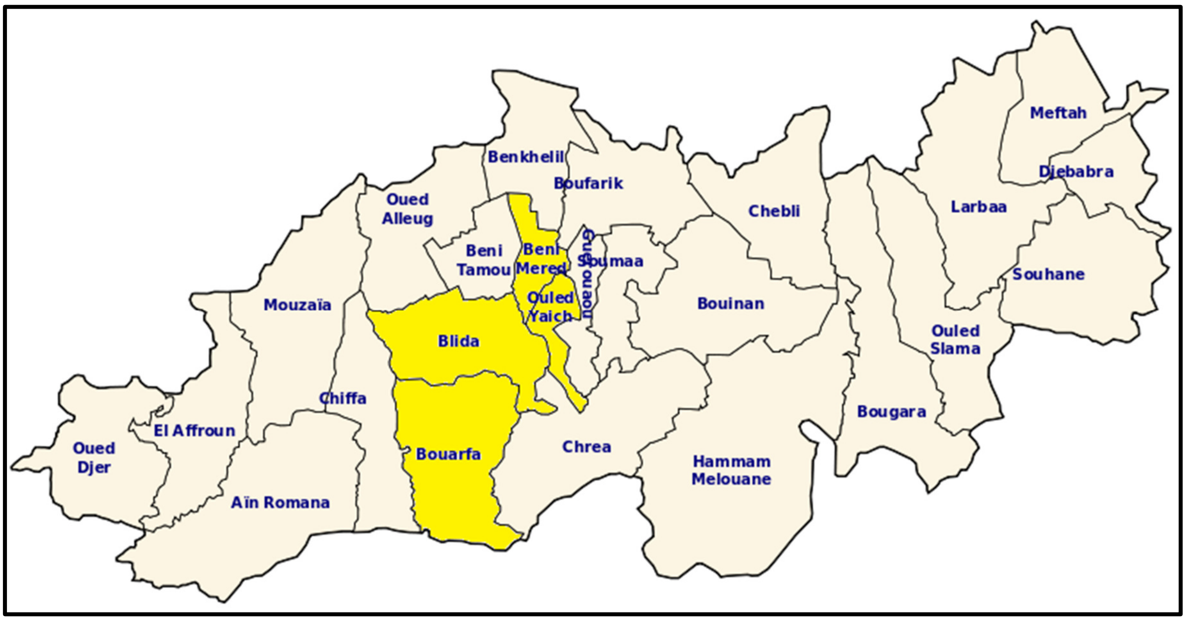



**Figure II.12:** Location of "The great Blida" in the province.

This study concern 155 schools that are distributed over the four municipalities as follows (Fig II.13):

**Table II.3:** Distribution of schools per municipality.

| Municipality | Primary school | Middle school | High school | Total |
|---|---|---|---|---|
| **Blida** | 55 | 19 | 8 | 82 |
| **Ouled Yaich** | 25 | 12 | 3 | 18 |
| **Beni mered** | 10 | 04 | 1 | 15 |
| **Bouarfa** | 12 | 04 | 2 | 40 |
| **Total** | 102 | 39 | 14 | 155 |
| **Percentage** | 65.8% | 25.2 | 09% | 100% |

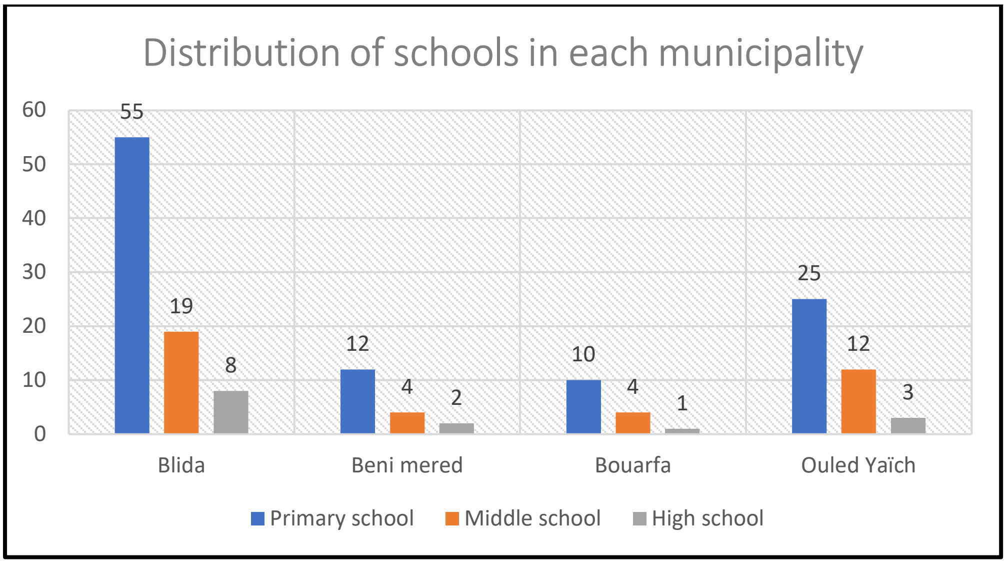



**Figure II.13:** Distribution of schools per municipality.

The schools are located in each municipality as follows (Fig II.14-17):

**Municipality of Blida**

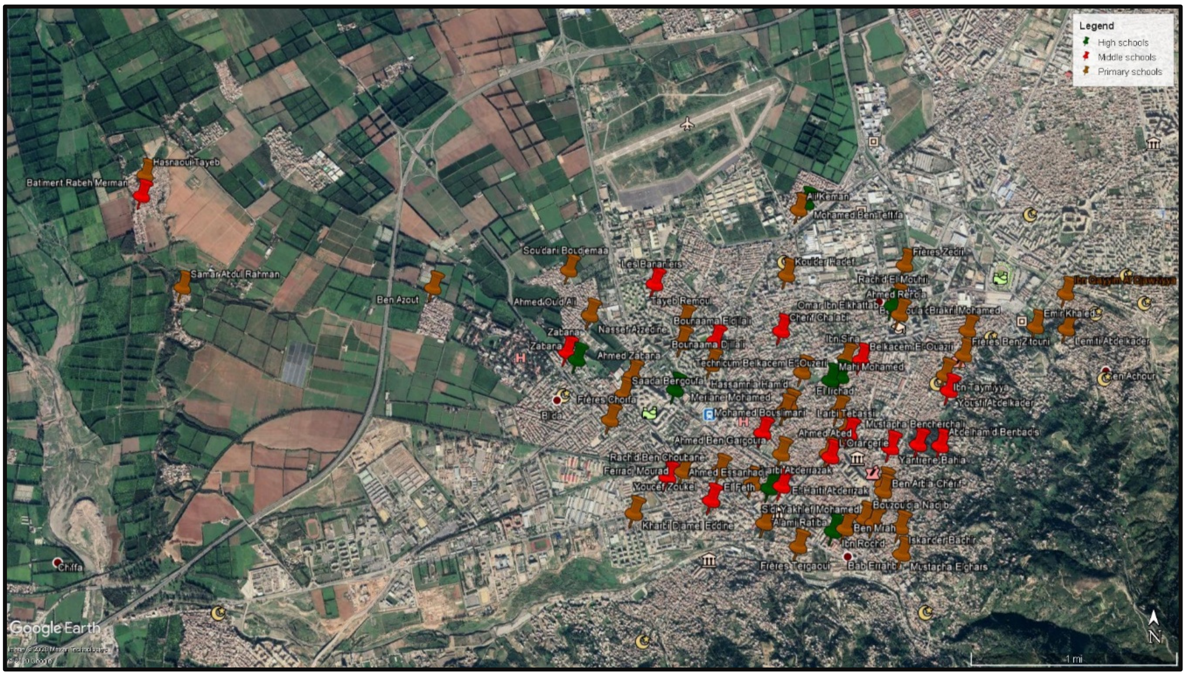



**Figure II.14:** Localization of school buildings in the municipality of Blida.

**Municipality of Ouled Yaich**

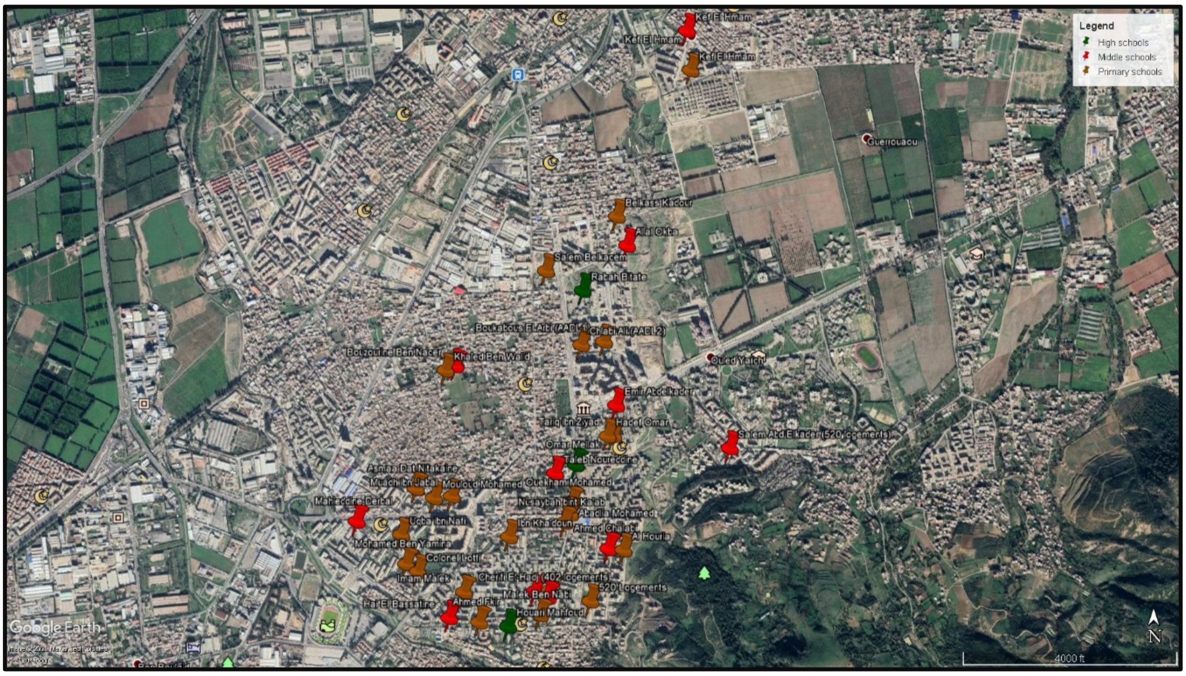



**Figure II.15:** Localization of school buildings in the municipality of Ouled Yaich.

**Municipality of Beni mered**

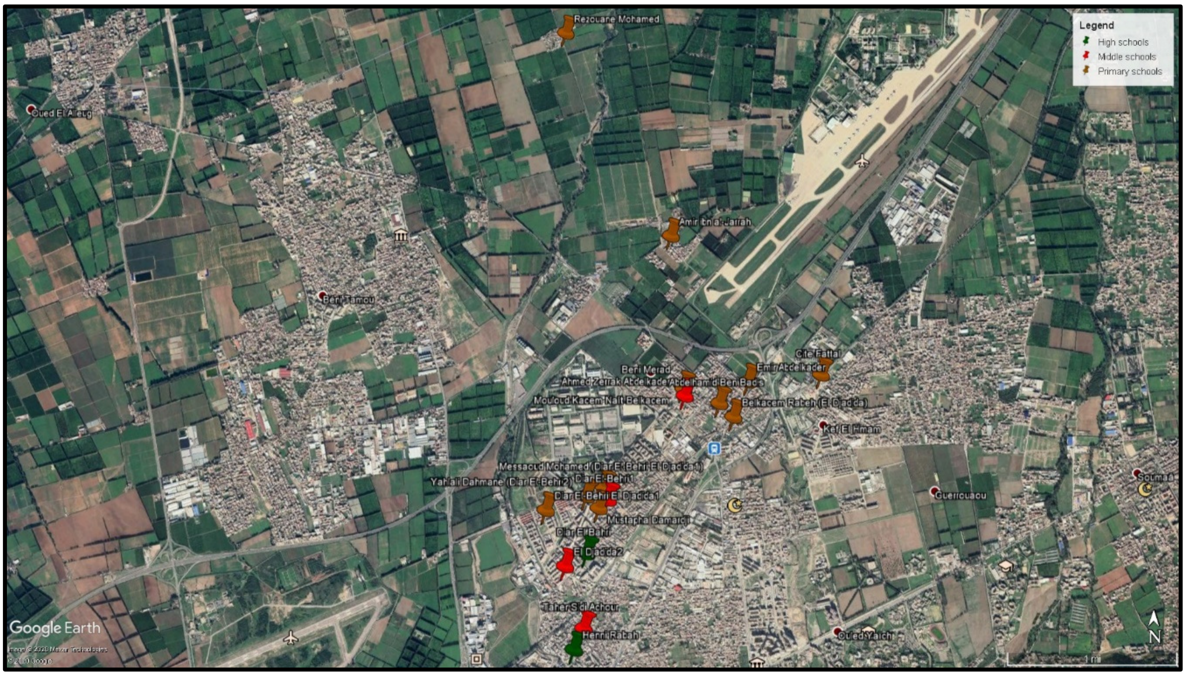



**Figure II.16:** Localization of school buildings in the municipality of Beni Mered.

**Municipality of Bouarfa**


**Figure II.17:** Localization of school buildings in the municipality of Bouarfa.

The reasons for choosing this area to be the focus of the study are:

- **The familiarity of the area:** which make it an easy task to visit the schools and get the various data required to make the study (blueprints – photos – visual evaluation of the schools).
- **The variety of schools in the area:** with the oldest school being built in 1864 and the newer ones still under construction, this area offer big variety of designs and structural systems (masonry – reinforced concrete…etc.).
- **The seismic history of the area:** with the high seismic activities of the area, evaluating the seismic resilience of schools should be a priority in hope that decision makers can implement preventive measures to reduce human loss in the case of future earthquakes.

## II.7. Description of the existing schools in the area

There are 155 school in "Great Blida", they can be classified into three categories depend on their bracing system and the era they were built on:

### II.7.1. Masonry buildings


**Figure II.18:** Ahmed Abed primary school (Masonry building).

This category includes all the building constructed during the colonial era (1830-1962) (Fig II.18); most of the schools from this era suffer of degradation due to aging and lack of maintenance.

This category accounts for 13.5% of the school in Great Blida.

### II.7.2. Reinforced concrete buildings [Moment-resisting frame system]

**Figure II.19:** Ben Azout primary school (Moment-resisting frame system).

We can divide this category into two parts:

**1/ Buildings without seismic resistant design:**

This includes all the schools that were constructed before Asnam earthquake (1962-1983); most of the schools from this era were constructed without any seismic design, due to the government building as many schools as possible to respond the quickly growing population and the rapid spread of education after the independence which resulted in many of the schools lacking any type of quality control.

**2/ Buildings with seismic resistant design:**

This includes all the schools built after the introduction of Algerian seismic code of 1983 (RPA81 v.83); most of the schools from this era (Fig II.19) were constructed under technical supervision, to avoid the main causes of damage in the Asnam earthquake:

- Damages dues to short columns.
- Poor conceptual design.
- Poor structural material.

This category accounts for most of the schools in the area: 71.61% of the schools in Great Blida.

### II.7.3. Reinforced concrete buildings [RC walls bracing system]

**Figure II.20:** A middle school under construction (RC walls system).

This includes all the schools (Fig II.20) built after the introduction of Algerian seismic code of 2003 (RPA99 v.2003); that introduced:

- The use of concrete shear walls.
- Restricting the number of stories for building with reinforced concrete.
- Increasing the size of structural elements.

This category accounts for 14.89% of the school in Great Blida with the number increasing at fast rate.

And here's the overall and specific distribution of schools in "Great Blida" based on their bracing system (Fig II.21-22):

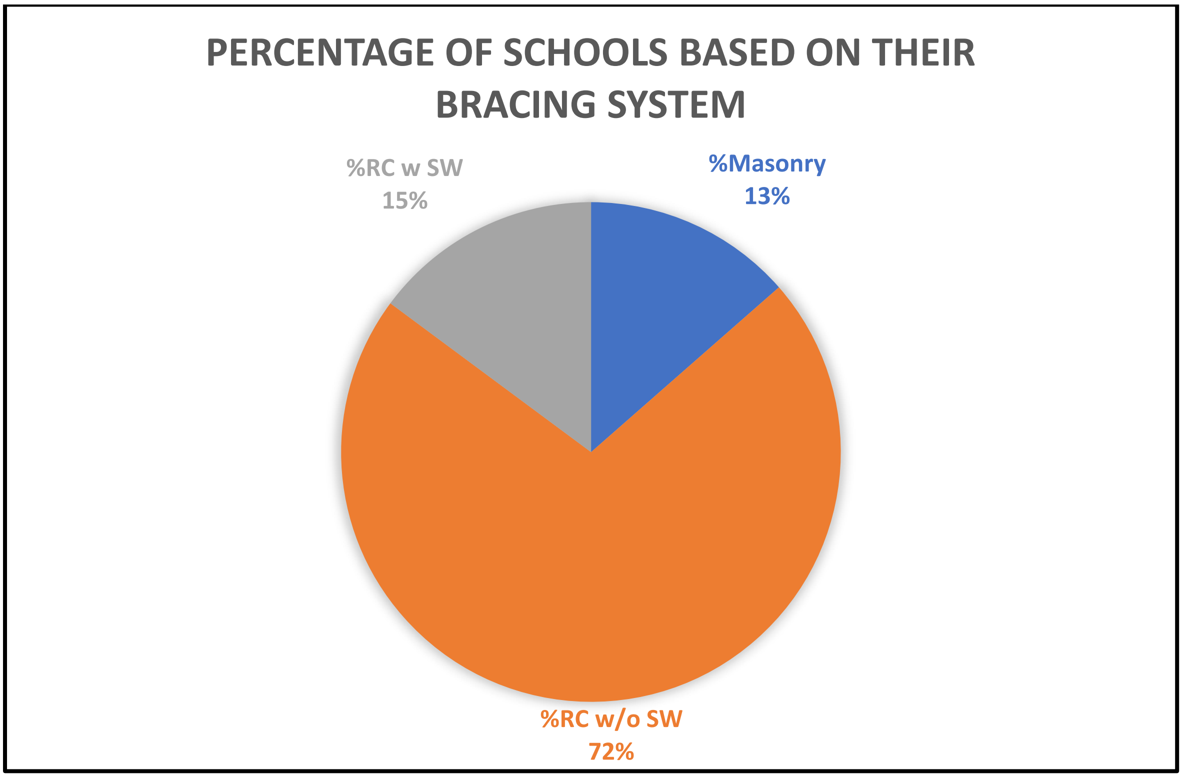



**Figure II.21:** Overall distribution of schools based on their bracing system.

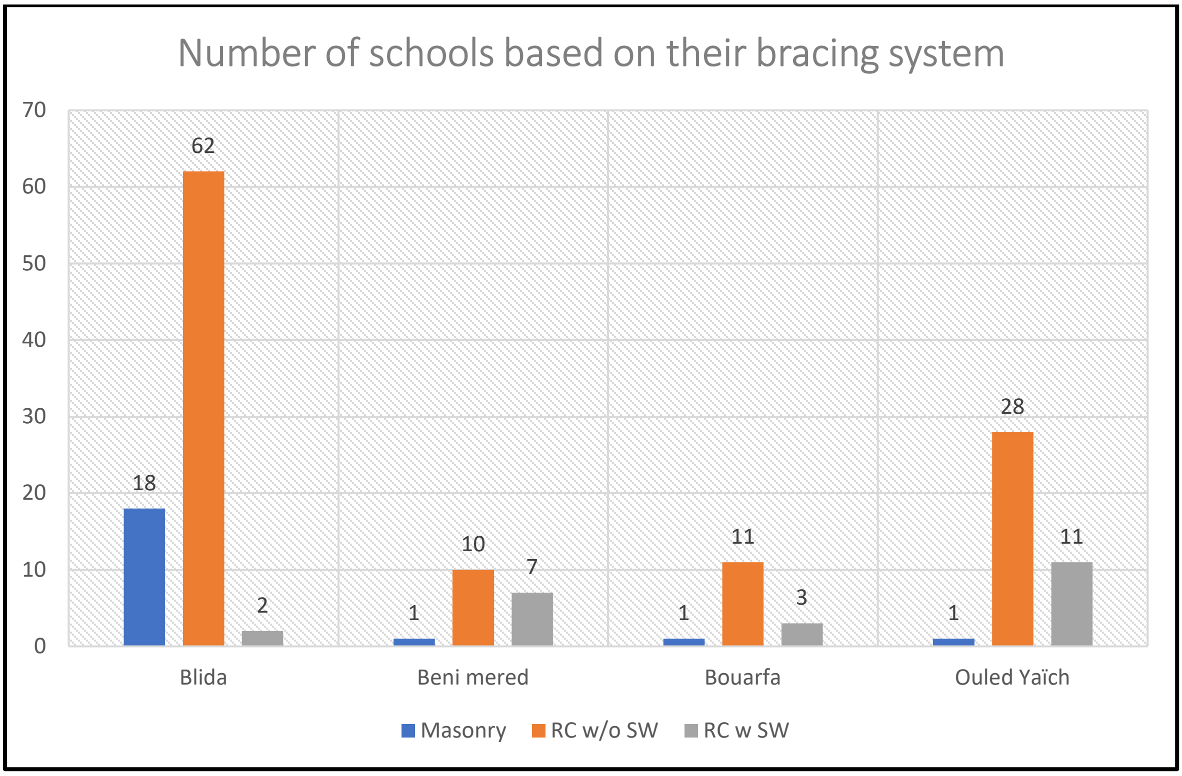



**Figure II.22:** Distribution of schools in each municipality.

## II.8. Distribution of pupils in the schools of the area

Overcrowded classrooms are one of the common problems that face pupils in Algerian schools, especially the primary ones, which is very dangerous problem to have during an earthquake (or any other disaster) because it makes the evacuation process very difficult.

In Great Blida, there were 81890 pupils attending school during the academic year of 2019/2020, distributed in each classroom as shown in (Fig II.23):

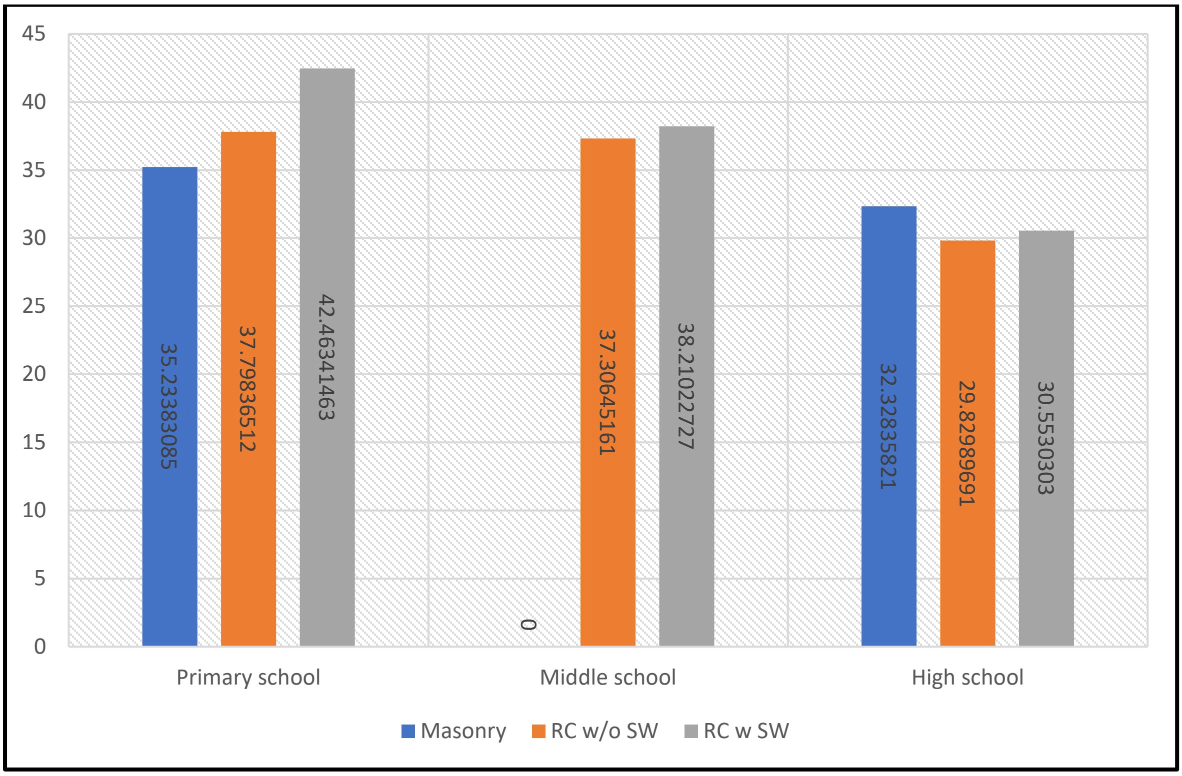



**Figure II.23:** Distribution of students per classroom.

## II.9. Earthquake mitigation for school building

Ensuring the safety of children and student should be a top priority for the local authorities, as children spend most of their day on schools. Therefore, the buildings and facilities of schools must be maintained to keep enough capacity of earthquake resistance, to keep the damage on school building minimal at the time of earthquakes, and to resume the educational activities as soon as possible.

### II.9.1. Definition of earthquake mitigation and the role of civil engineer in it

Earthquake mitigation can be defined as the range of activities design to eliminate or reduce the loss of life, injuries, and property damage during earthquakes. While preventing earthquakes from happening is impossible task, reducing its impact on school buildings should be a top priority.

Earthquake mitigation should be continuous goal in civil engineering around the world, as civil engineers are at the forefront in developing appropriate techniques and designs for managing and mitigating risks by:

- Improving our understanding of seismic activities which results in better forecasting of earthquakes and be prepared making seismicity zone maps and specific design codes that fit zone.
- Improving our understanding of building's behavior during earthquakes, its vulnerabilities to these seismic activities, and the way to reduce said vulnerabilities.
- Aiding the authorities during earthquakes by participating in rescue operations, and restoration and reconstruction works after the disaster ends.

### II.9.2. Earthquake mitigation principals for future school buildings

For new school building, the local authorities should consider the following activities, in collaboration with civil engineers before building new school facilities:

**Selecting an appropriate site**

Choosing an appropriate site (Fig II.24) for schools should be top priority before designing school buildings, as schools ideally should be located in areas that are less prone to earthquakes.

But since that's not always possible, as schools are often located in communities near housing, for new schools being built in areas with seismic risk, the site must be thoroughly analyzed by preforming soil testing, considering landslide potential, and proximity to fault lines.


**Figure II.24:** Geotechnical engineer performing soil tests.

**Selecting a seismic resistant design**

During the design phase, the focus of earthquake mitigation should be on the structural members (columns, beams, shear walls) whose primary function is to support the buildings and resist the sudden seismic loads that could encounter at in any second through appropriate design and construction.

Design choices that create seismic vulnerabilities should be avoided to the extent possible during architectural design phase, such as short columns. When it is not possible to avoid it, this effect should be addressed during the structural design instead.

In some instances, the industry code may not be stringent enough, so performance-based design (Fig II.25) should be targeted, as earthquake-resistant structures are intended to withstand the largest earthquake of a certain probability that is likely to occur at their location. This means the loss of life should be minimized by preventing collapse of the buildings for rare earthquakes while the loss of the functionality should be limited for more frequent ones

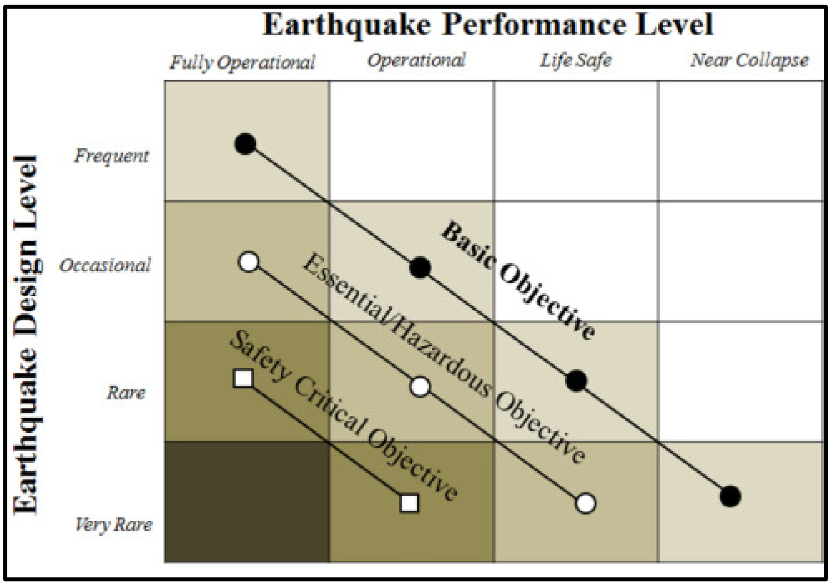



**Figure II.25:** Performance objective for buildings during earthquakes.

**Ensuring comprehensive supervision during the construction phase**

Since the majority of collapsed building during earthquakes in Algeria can be traced back into bad construction practices, a civil engineering supervisor should be present during the construction phase (Fig II.26) to ensure that:

- The quality structural materials (concrete) is up to the standards.
- The contractors are respecting the structural design shown in blueprints, especially the dimensions of structural members, the dimensions of reinforcements and its placement.
- The ability to adapt to sudden situation and propose changes to the structural design if needed.

**Figure II.26:** An engineer instructing a laborer.

### II.9.2. Earthquake mitigation principals in existing school buildings (Retrofitting)

For existing buildings, earthquake mitigation efforts consist of assessing the structure performance to resist seismic activities based on the current seismic regulations. If the assessment found that the structure's performance is not sufficient, retrofitting strategies should be proposed to remedy the problem.

**Definition of retrofitting**

Retrofitting is a technical intervention in structural system to improve its performance (Fig II.27) during seismic disasters, by improving it's:

- **Strength:** that is generated mainly from the structural members: shape, dimensions, numbers, and configuration.
- **Ductility:** that is generated from degree of seismic resistant, material used in construction, good detailing.
- **Earthquake loads:** that is generated from mass of the structure, seismicity of the area.

Retrofitting needs to be tailored for each building separately, as each building has its own purpose and deficiencies, therefore each building needs to be assessed on its own and has unique approach made for it.

When making retrofitting plan, the resulted building should aim to fulfill all the seismic regulations requirements and performance levels to be worth the effort.

**Figure II.27:** Seismic retrofitting of school building in Nepal.

**The factor that influence the decision to perform retrofitting**

Retrofitting is performed when the assessment of a school buildings shows its inability to withstand the seismic activities of the area as described in the seismic code regulations, without suffering unacceptable limit of damage.

The other important factors that influence that decision:

- **Technical aspect**

Sometimes is impossible to perform retrofitting, due to the very poor condition of the building, therefore rebuilding become a must.

- **Cost-benefit of retrofitting**

Retrofitting is only feasible, if the overall cost of the project is less than the cost of building new school, therefore a cost-benefit analysis should be conducted on the school building.

Most studies imply that retrofitting is more economically beneficial than rebuilding schools, but the analysis must include all the factors that can affect the decision in both short and long run.

- **Skilled workmanship**

Retrofitting require a special set of skills that is unique in nature to usual construction techniques, therefore skillful builders should be available to perform the process.

- **Duration of the process**

Since school don't operate during summers, it's best for retrofitting process to only occur during summer break in order to not disturb the school year.

**Retrofitting process**

There are 3 general steps when it comes to retrofitting buildings:

**1- Assessing the current state of the building**

The first step in the retrofitting process is assessing the building looking for vulnerabilities that effect its seismic resistance.

At first, visually by looking at the current state of structural members, looking for any signs of deterioration of materials, any signs of deformation in structural elements such spalling, crack width and pattern (Fig II.28), corrosion…etc., mapping the damage in the process.

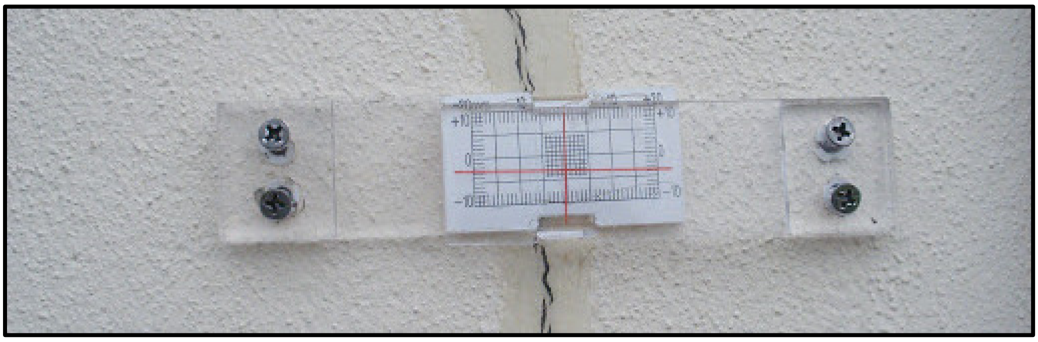


**Figure II.28:** Measuring crack width and pattern.

After that, the engineers must perform structural analysis using non-destructive and semi-destructive tests to assess the current condition of the structural members and give proper evaluation of the current properties of materials. The most common test is the concrete hammer test (Fig II.29) to measure the compressive strength of reinforced concrete.

**Figure II.29:** Measuring the compressive strength of concrete using the concrete hammer test.

Lastly, the result from the structural analysis must be used to model the structure (Fig II.30) and perform detail analysis of the behavior of the structure when subjected to seismic loads, using structural analysis tools such as SeismoStruct. The results from this last assessment are used to design the appropriate retrofitting approach for the building.

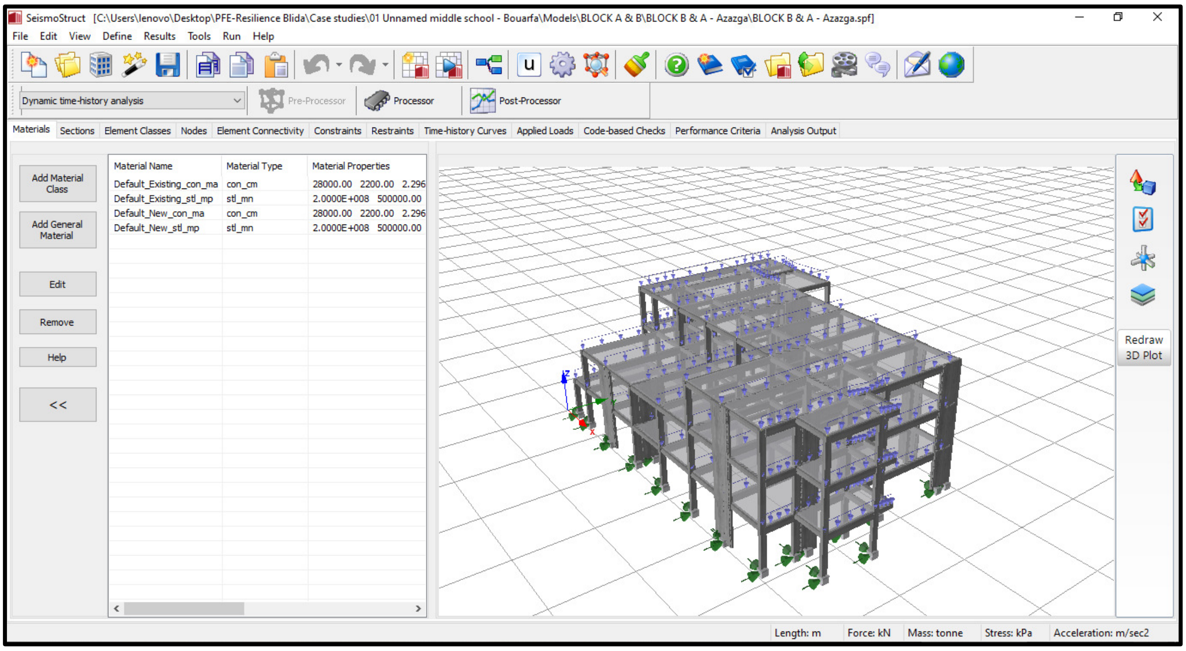



**Figure II.30:** Nonlinear dynamic time-history analysis.

### 2- Designing the appropriate approach

After finishing the detailed analysis of the structure, the next step is choosing an appropriate approach for the retrofitting process, that fulfill the targeted level of performance for the building (for school buildings, the structure must suffer any structural damage due to future earthquakes), and be easy to implant by the workers (the skill of workers must match the techniques used in the retrofitting process).

There are various techniques that are used in retrofitting buildings, and choosing the appropriate one is matter of determining the deficiencies of the building, and choosing the techniques that answers those deficiencies.

Here are some of the most common retrofitting techniques that are used around the globe for retrofitting reinforced concrete buildings:

#### Inserting new structural element

One of the most common techniques that were used after Boumerdes earthquakes is inserting new structural elements such as shear walls (Fig II.31) to existing building. This technique aims to increases the overall stiffness of the structure, while reducing load distribution by adding new structural elements to help carry the seismic load.

The inserted elements should maintain the existing balance of force distribution in the building to avoid torsional effect, therefore the new structural elements should be added in symmetrical fashion. And the connection areas should be very detailed and built with precision to maintain good load paths to transfer inertia forces into the ground.

**Figure II.31:** Retrofitting existing building after Boumerdes earthquake by inserting shear walls.

#### Concrete jacketing of existing structural members

Concrete jacketing is the act of adding a thick layer of reinforced concrete around the existing structural member (columns or beams) (Fig II.32), to improve its flexural strength, ductility and shear strength. It also helps decrease the workload as this method reduce the need of strengthening the foundation.

**Figure II.32:** Examples of column and beam jacketing.

**Decreasing the demand on existing building**

Sometimes the best approach in retrofitting is decreasing the demand on the existing structural elements, and that is by reducing the weight of the building, either by removing the upper levels, changing the purpose of the building, removing heavy equipment…etc.

This approach is usually avoided in retrofitting schools building, because it disturbs the role of the school.

**3- Implanting the chosen approach**

After the appropriate approach is chosen, the construction phase begins under the strict supervision of engineers to ensure the quality of the works.

**The advantage and disadvantage of retrofitting**

Choosing retrofitting approach over rebuilding has its own advantages and disadvantages, here are the main one:

**Advantages**

- Achieving similar performances level to new building with lower cost.
- Producing lower debris than demolishing the school to rebuild it.
- The school buildings can still be partially used during the retrofitting process.
- Saving lot on both human and natural resources.
- Retrofitting is better for the environment, as it cut 12% off carbon emissions and resources, and 11% for human health than building new school buildings.
- Greatly improve the seismic resistance capacity of the building (Fig II.33).

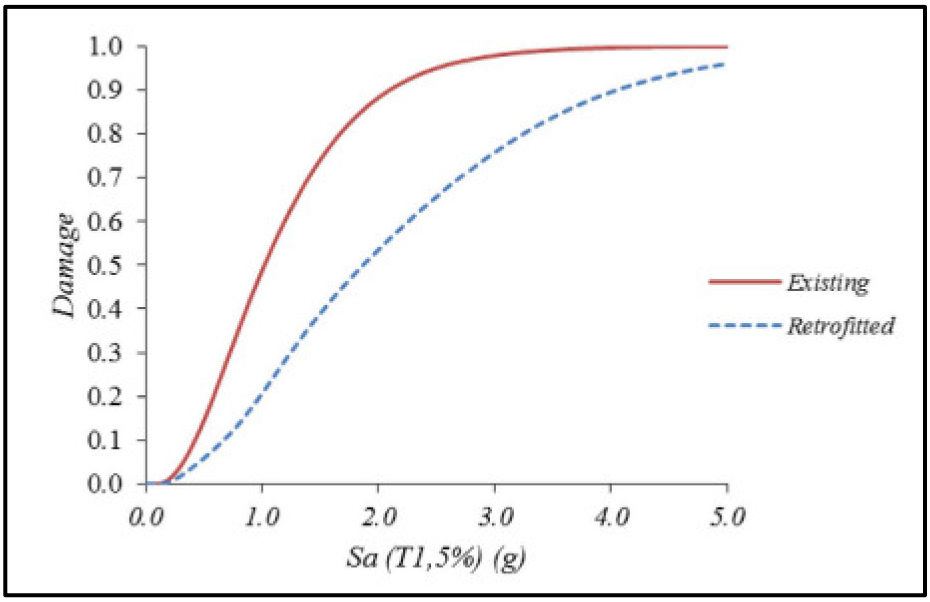



**Figure II.33:** Vulnerability curves for the same Iranian school before and after retrofitting.

**Disadvantages**

- The retrofitting process require skillful workers to perform it.

## II.10. Conclusion

Improving the seismic resilience of school buildings should be always the constant goal for local authorities, to avoid human loss as much as possible in case of earthquakes, and while implanting earthquake mitigation techniques in new building is very important, retrofitting existing school buildings should be the top priority for its many advantages over building new schools, such as producing similar level of seismic performance at lower cost, and the environmental benefits that retrofitting yield.

But for that to happen, the government needs to implant a periodic inspection to assess the seismic vulnerabilities of existing buildings, while training skillful workers that can implant the retrofitting techniques.

# ***Chapter III***

# *Case studies of School Buildings*

## III.1. Introduction

To evaluate the seismic fragility functions of existing schools in Blida, two school building were chosen as case studies to represent the most commonly used types of structural systems for schools in Algeria.:

- **Moment-resisting frame system:** represented by the school of Ben Azout that was built in 2003, right before the Boumerdes earthquake.
- **Reinforced concrete wall system:** represented by a school that is still under construction.

Both schools were modeled numerically in SeismoStruct 2020 software, assuming vertical loads as given in Table III.1, before running the various analysis to develop fragility curves.

**Table III.1:** Vertical loads of the SeismoStruct numerical model.

| Design parameters | Value |
|---|---|
| Dead load of stories | 5.44 kN/m² |
| Dead load of roof | 5.93 kN/m² |
| Live load of stories | 2.5 kN/m² |
| Live load of roof | 1 kN/m² |

## III.2. Case study #1: A middle school (under construction)

### III.2.1. Overview

This middle school is still under construction in the municipality of Bouarfa (Wilaya of Blida).

This school has been designed based on the latest version of the Algerian seismic regulations (RPA99v.2003), using dual bracing system consists of frame and RC shear walls.


**Figure III.1:** Localization of the middle school under construction.

It consists of:

- Two stories building used as administrative bloc (Bloc C) containing: principal office, secretary office & multipurpose offices.

- Two identical three stories building used as educational blocs (Bloc A and B), containing: classrooms, laboratories, multipurpose room, workshops & stores.

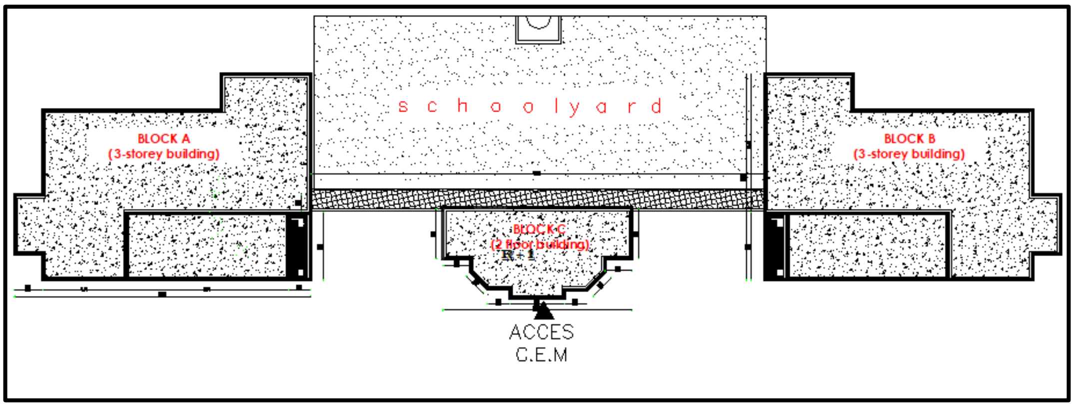



**Figure III.2:** Buildings layout of the middle school.

### III.2.2. Bloc A and B

**Building dimensions**

- **Total building length:** 32.83m.
- **Total building width:** 22.80m.
- **Floor height:** 3.74m.
- **Number of stories:** 3.
- **Total building height:** 11.12m.

**Building blueprints**

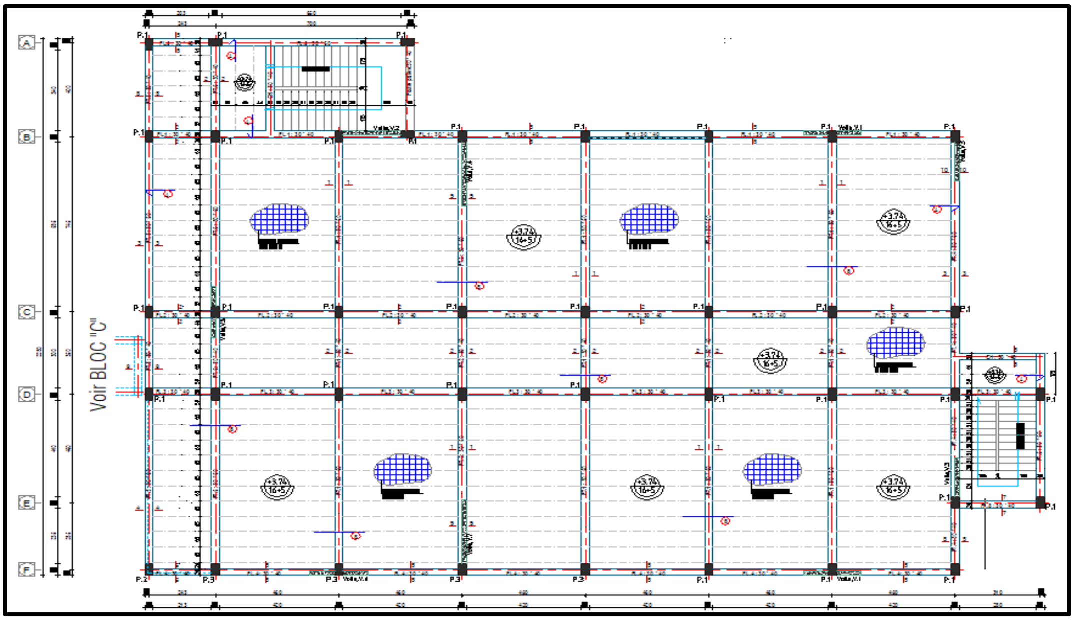



**Figure III.3:** Plan view of the 1st and 2nd floor of bloc A.

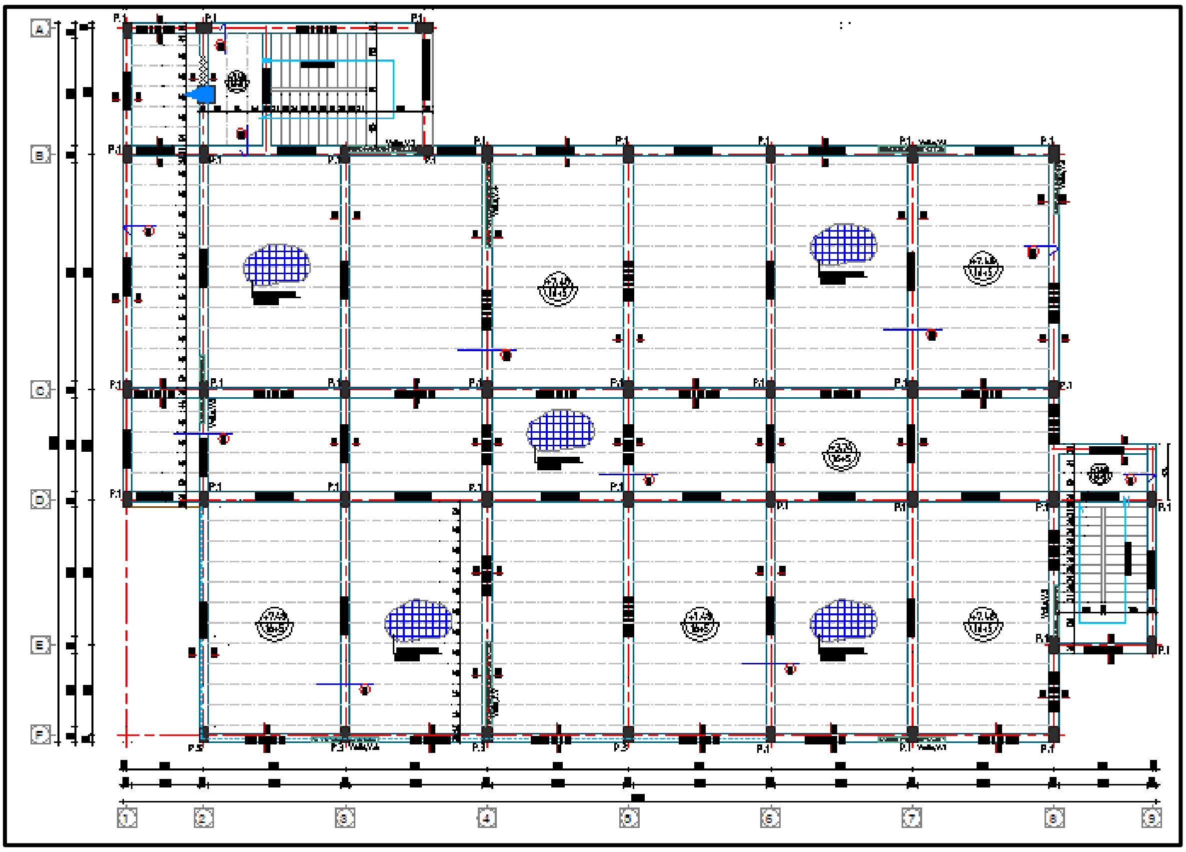



**Figure III.4:** Plan view of the 3rd floor of bloc A.

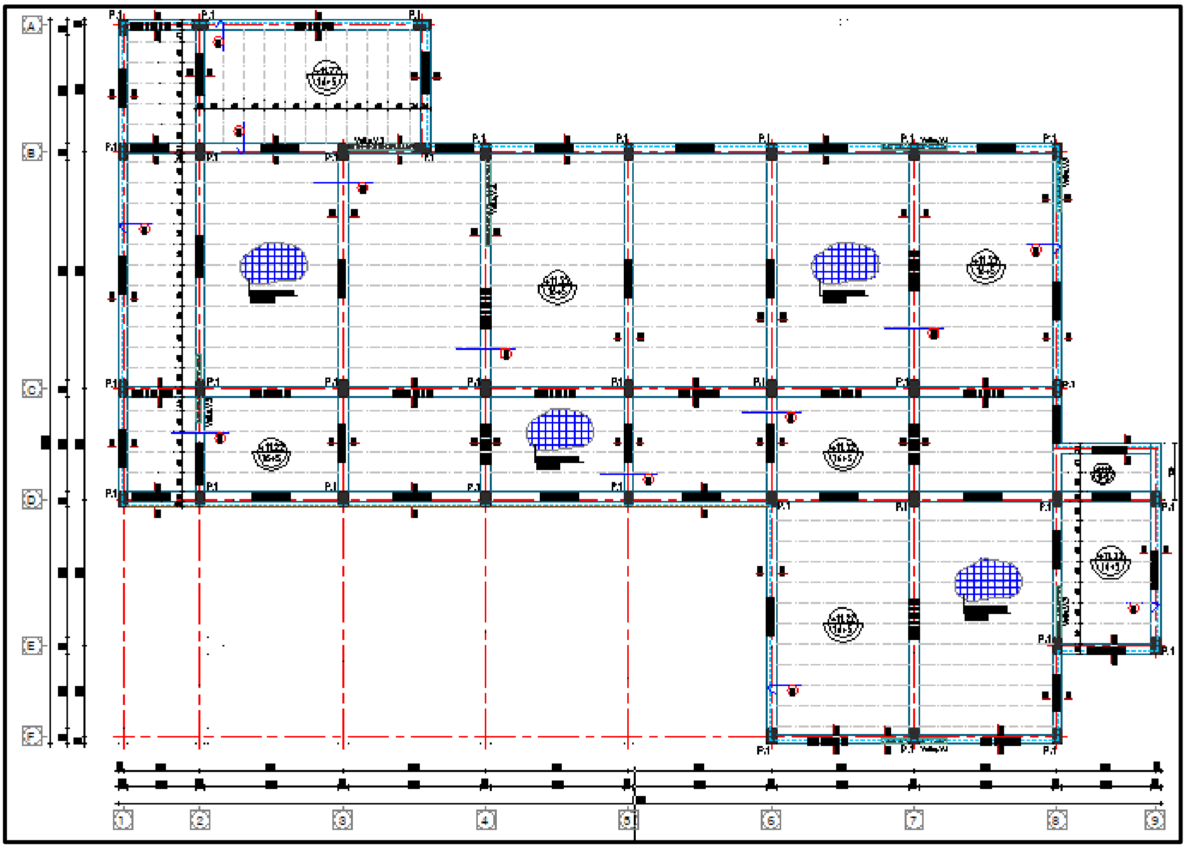
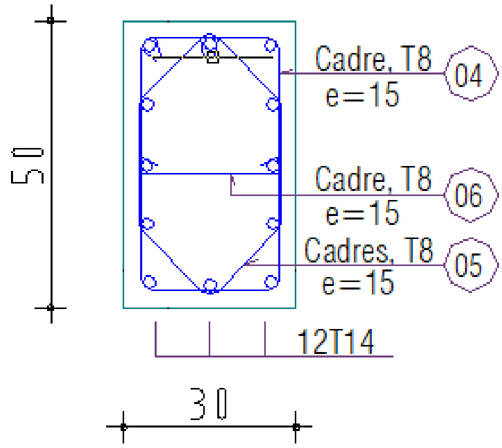
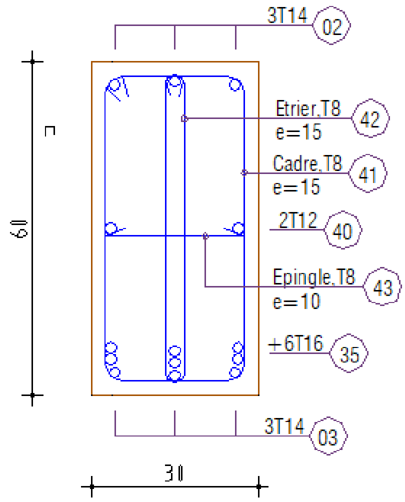
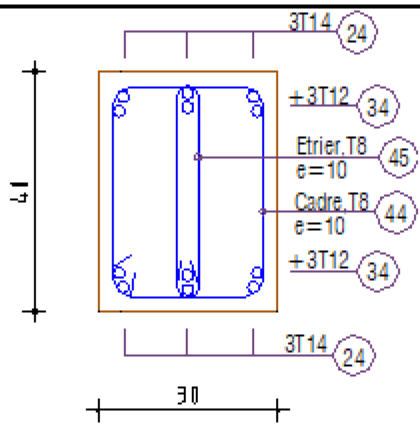


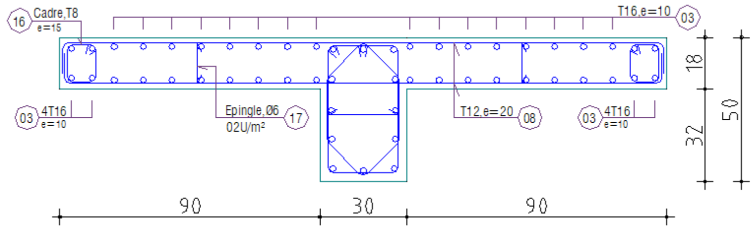
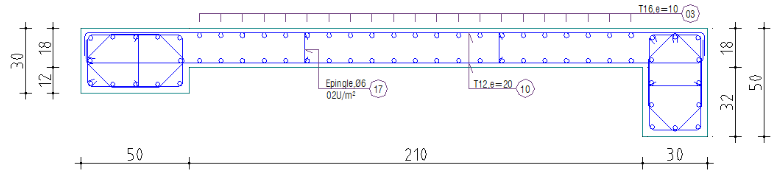
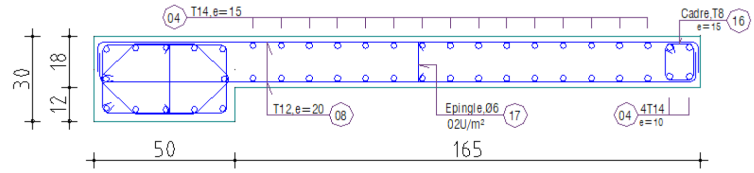
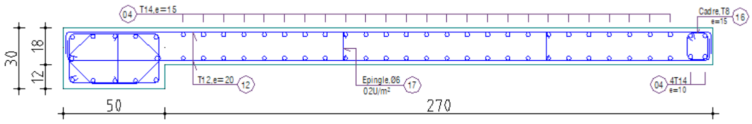
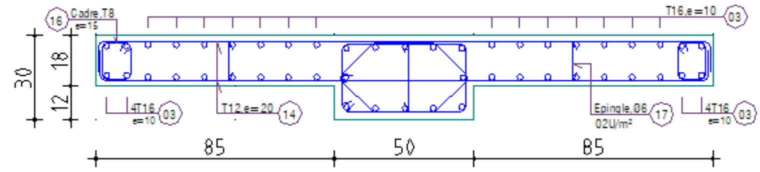

**Figure III.5:** Plan view of the roof of bloc A.

## Detailing of structural elements

Here is the detailing of the structural elements of the building:

**Table III.2:** Detailing of the structural members of bloc A.

| Name | Detailing |
|---|---|
| **Columns** | |
| **Name** | **Detailing** |
| Column #1<br>50*30 |  |
| **Beams** | |
| **Name** | **Detailing** |
| Principal beam<br>60*30 |  |
| Secondary beam<br>40*30 |  |
| **Shear walls** | |
| **Name** | **Detailing** |

| | |
|---|---|
| Shear wall #1 |   |
| Shear wall #2 |   |
| Shear wall #3 |   |
| Shear wall #4 |   |
| Shear wall #5 |   |

**SeismoStruct numerical model**

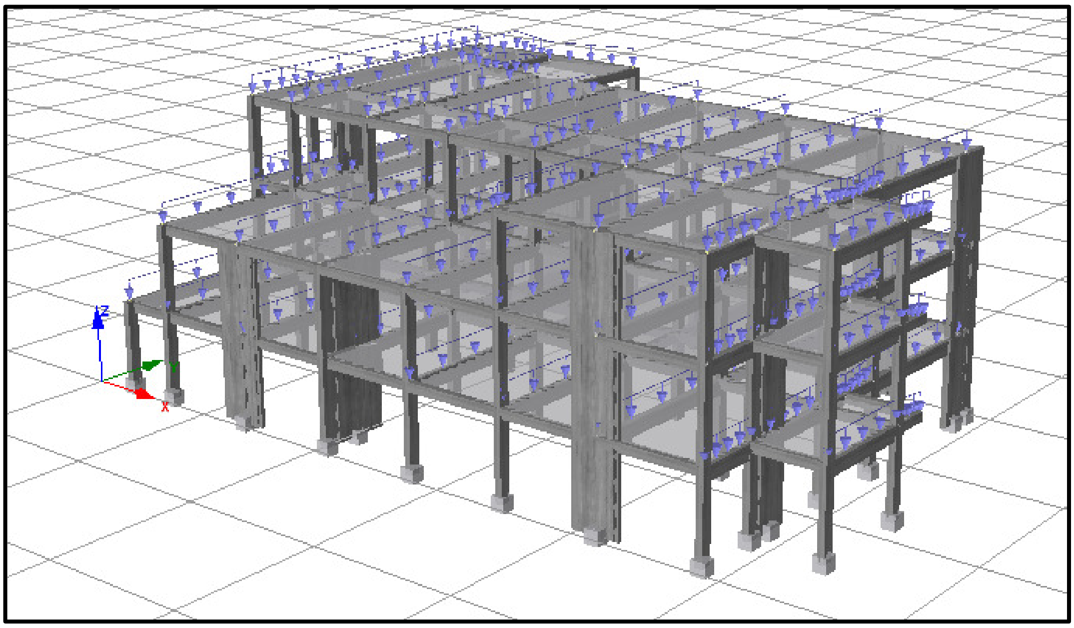


**Figure III.6:** SeismoStruct numerical model of bloc A.

### III.2.3. Bloc C

**Building dimensions**

- **Total building length:** 20.95m.
- **Total building width:** 11.20m.
- **Floor height:** 3.74m.
- **Number of stories:** 2.
- **Total building height:** 7.48m.

**Building blueprints**

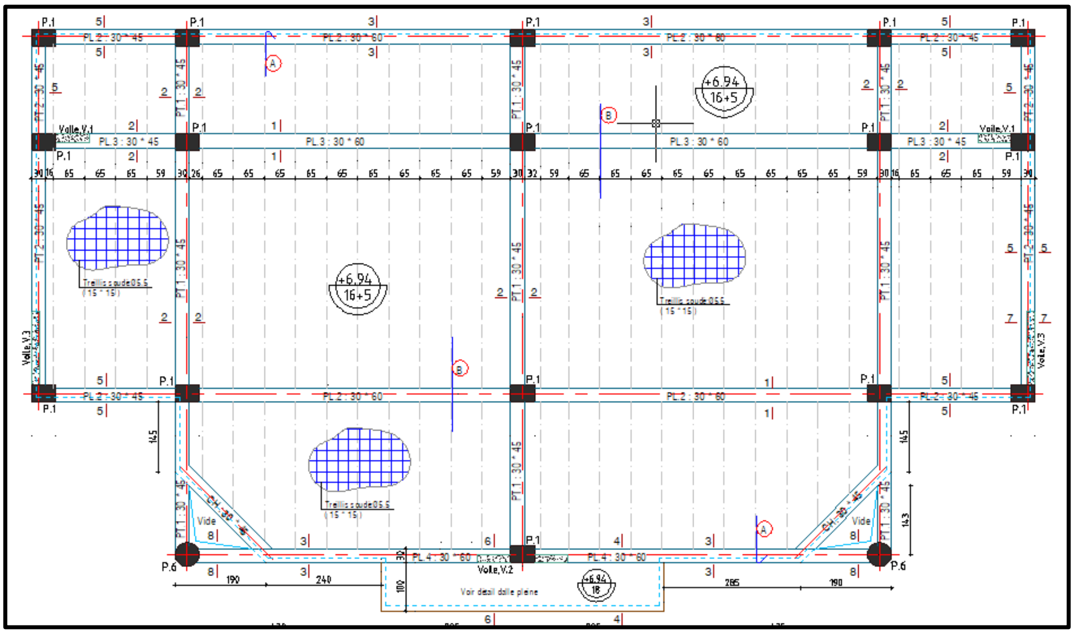



**Figure III.7:** Plan view of bloc C.

**Detailing of structural elements**

Here is the detailing of the structural elements of the building:

**Table III.3:** Detailing of the structural members of bloc C.

<table>
<tr><th colspan="2">Columns</th></tr>
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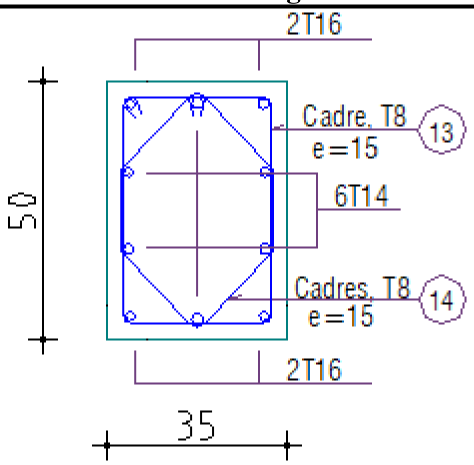
<tr><td>Column #1<br>50*35</td><td>
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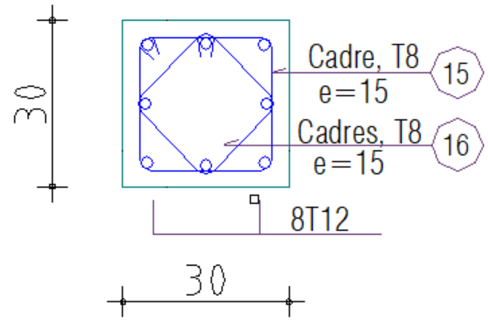
<tr><td>Column #2<br>30*30</td><td>
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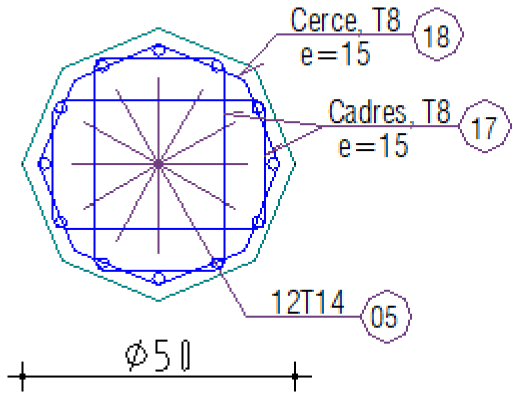
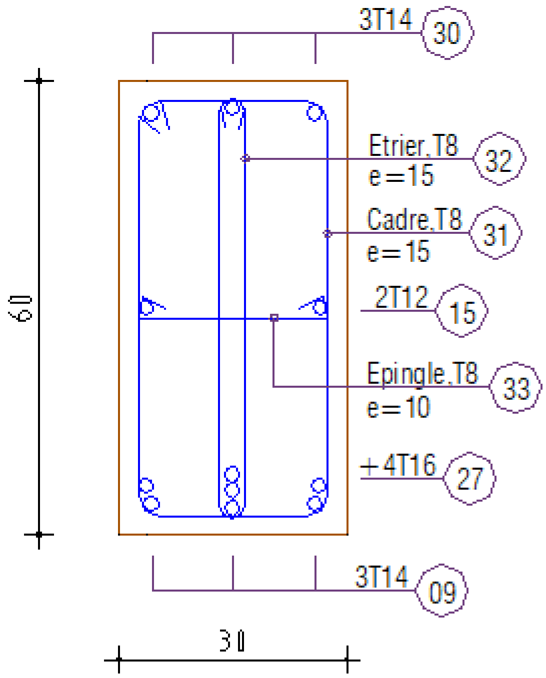
<tr><td>Column #3<br>Ø50</td><td>
</td></tr>
<tr><td colspan="2">Beams</td></tr>
<tr><td>Name</td><td>Detailing</td></tr>
<tr><td>Principal beam<br>60*30</td><td>
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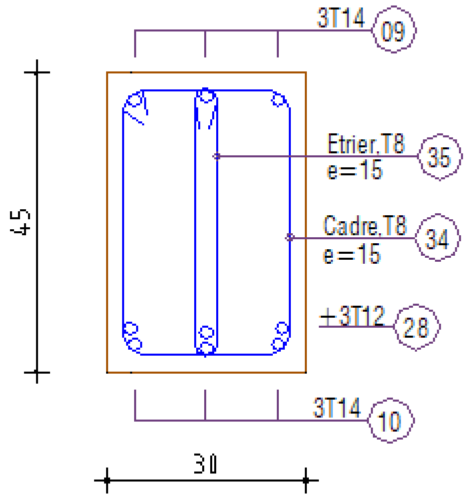
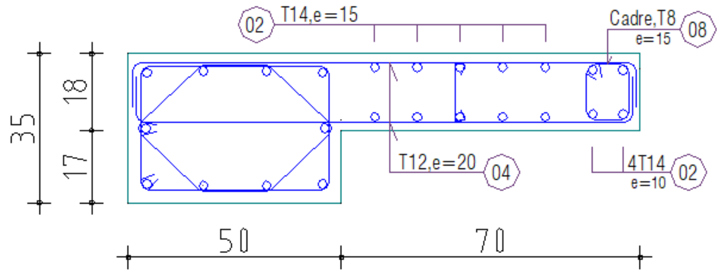
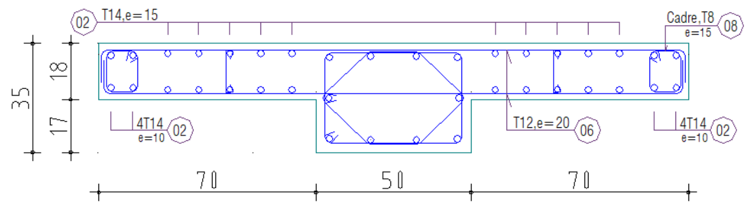
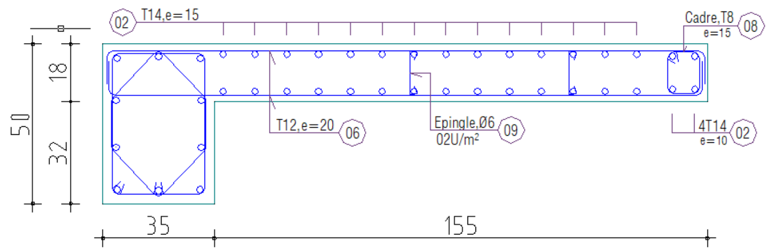
| | |
|---|---|
| Secondary beam 45*30 |  |
| **Shear walls** | |
| **Name** | **Detailing** |
| Shear wall #1 |  |
| Shear wall #2 |  |
| Shear wall #3 |  |

**SeismoStruct numerical model**

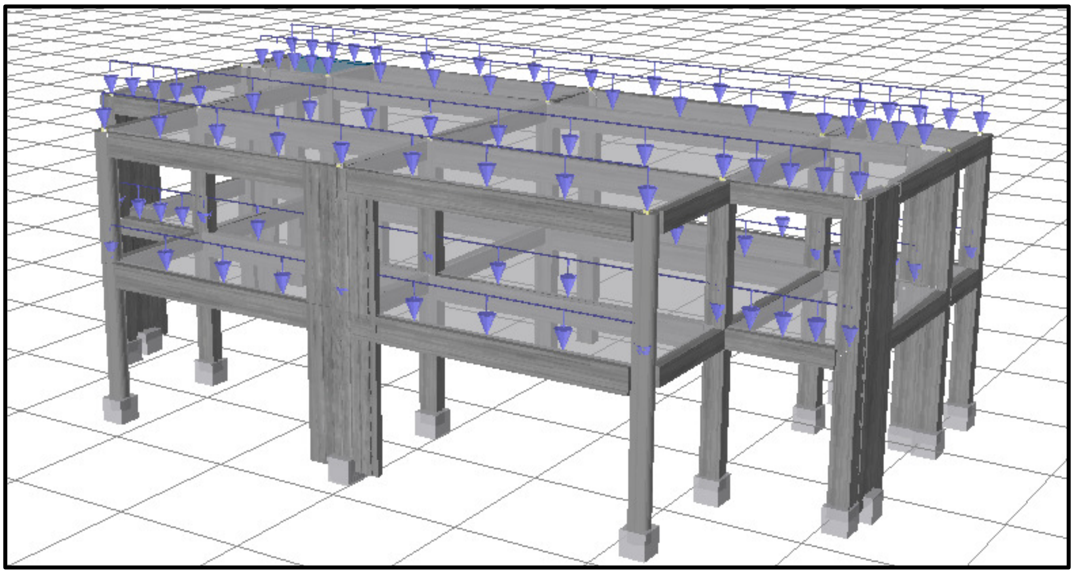


**Figure III.8:** SeismoStruct numerical model of bloc C.

## III.3. Case study #2: Ben Azout primary school

### III.3.1. Overview

**Ben Azout** is primary school located in the municipality of Blida; it opened its doors to student for the first time in 2003.


**Figure III.9:** Localization of Ben Azout primary school.

This school has irregular form and was built according to the previous Algerian seismic regulations (RPA99), using moment-resisting frame bracing system (RC beam/columns) with masonry infills.

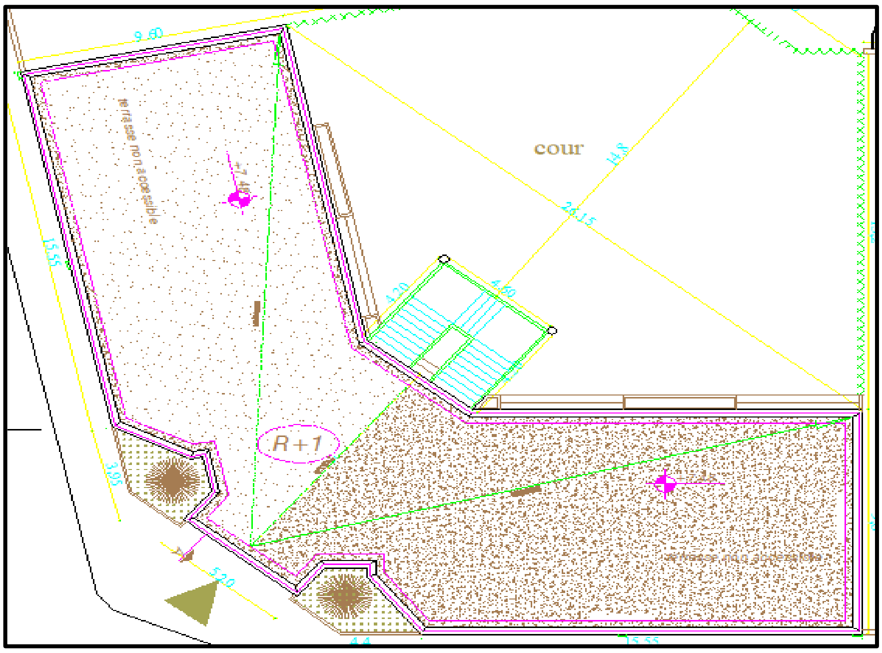



**Figure III.10:** Building layout of Ben Azout primary school.

### III.3.2. Details of the building

**Building dimensions**

- **Floor height:** 3.74m.
- **Number of stories:** 2.
- **Total building height:** 7.48m.

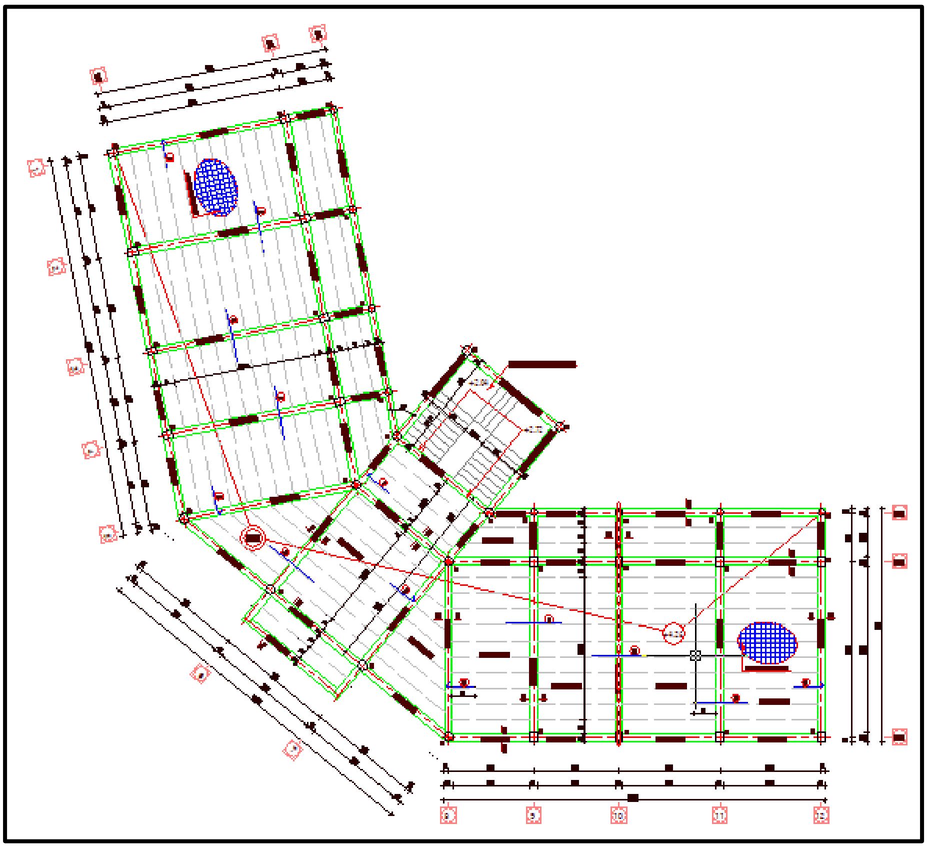


**Figure III.11:** Plan view of the Ben Azout primary school.

### Detailing of structural elements

Here is the detailing of the structural elements of the building:

**Table III.4:** Detailing of the structural members in bloc A.

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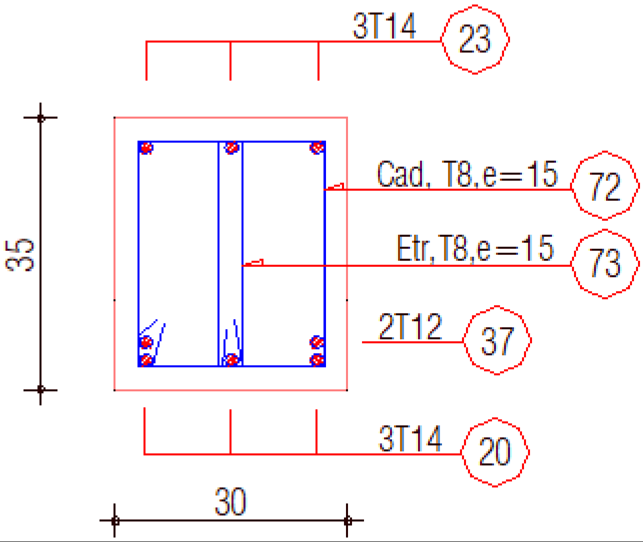
<tr><td>Column #1<br>35*30</td><td>
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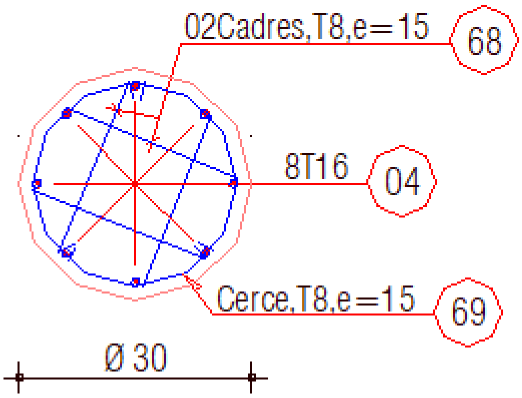
<tr><td>Column #2<br>Ø30</td><td>
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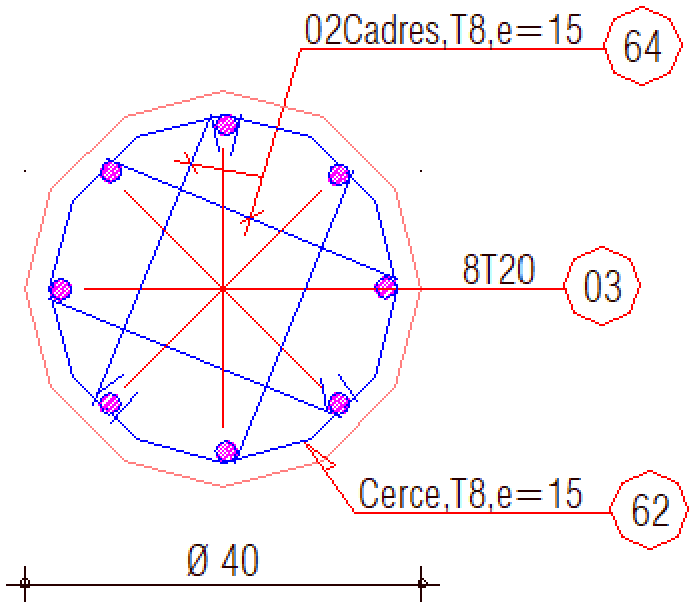
<tr><td>Column #3<br>Ø40</td><td>
</td></tr>
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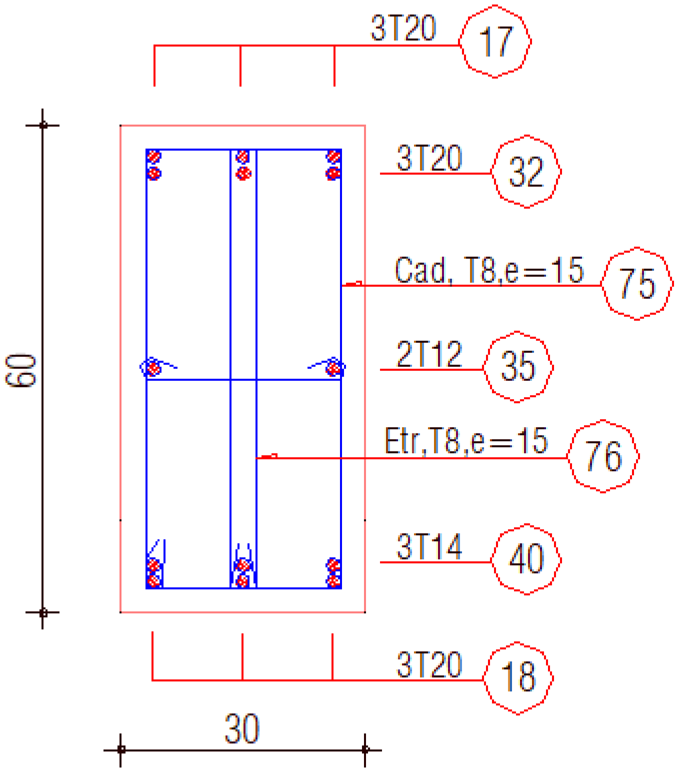
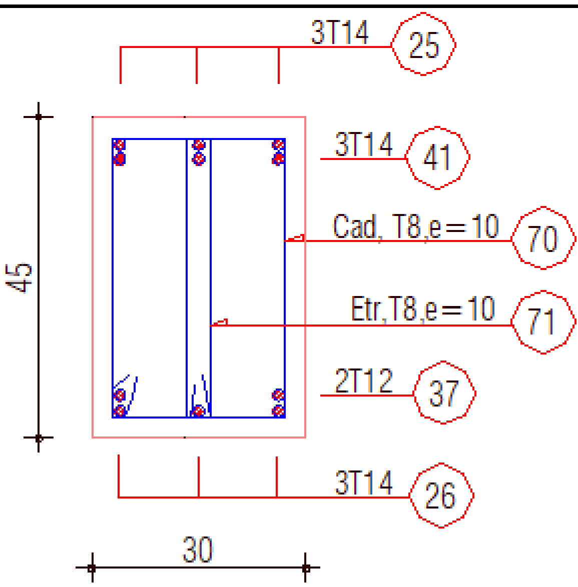
| Beams | |
|---|---|
| **Name** | **Detailing** |
| Principal beam<br>60*30 |   |
| Secondary beam<br>45*30 |   |

**SeismoStruct numerical model**

**Without the masonry infill**

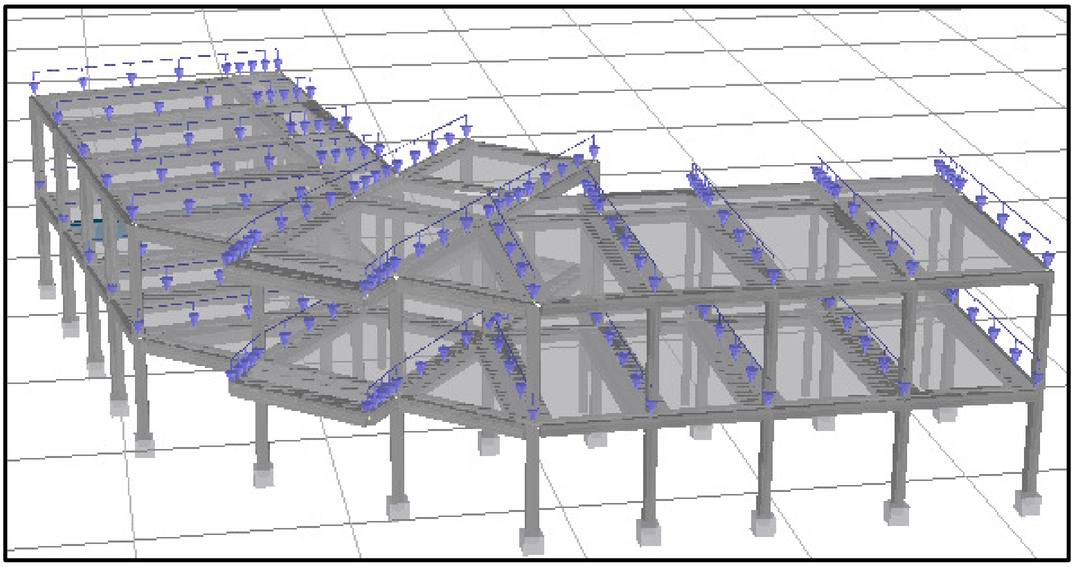


**Figure III.12:** SeismoStruct numerical model of Ben Azout school (without masonry infill).

**With the masonry infill**

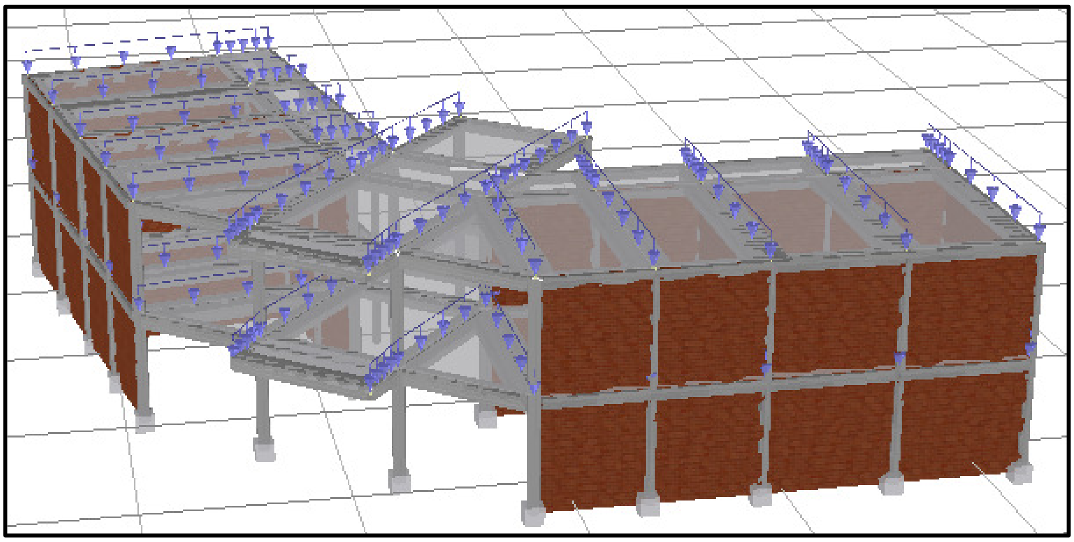


**Figure III.13:** SeismoStruct numerical model of Ben Azout school (with masonry infill).

## III.4. Conclusion

These two schools were chosen to highlight the many differences that school buildings have in the great Blida, from the various structural systems to the different structural elements and layouts, which affect the seismic fragility and performance of buildings in many ways, and need to be evaluated to ensure the safety of children.

# ***Chapter IV***

## *Evaluation of seismic performance of the Buildings case studies*

## IV.1. Introduction

To evaluate the two schools' behavior in past earthquakes, multiple nonlinear dynamic time-history analyses were run using 3 different strong ground motions of the Boumerdes earthquake to perform the various performance inspections mention in the first chapter (I.4.1.). This chapter will discuss the results of the performance inspection.

## IV.2. Case study #1: A middle school (under construction)

### IV.2.1. Bloc A and B

**SeismoStruct numerical model**

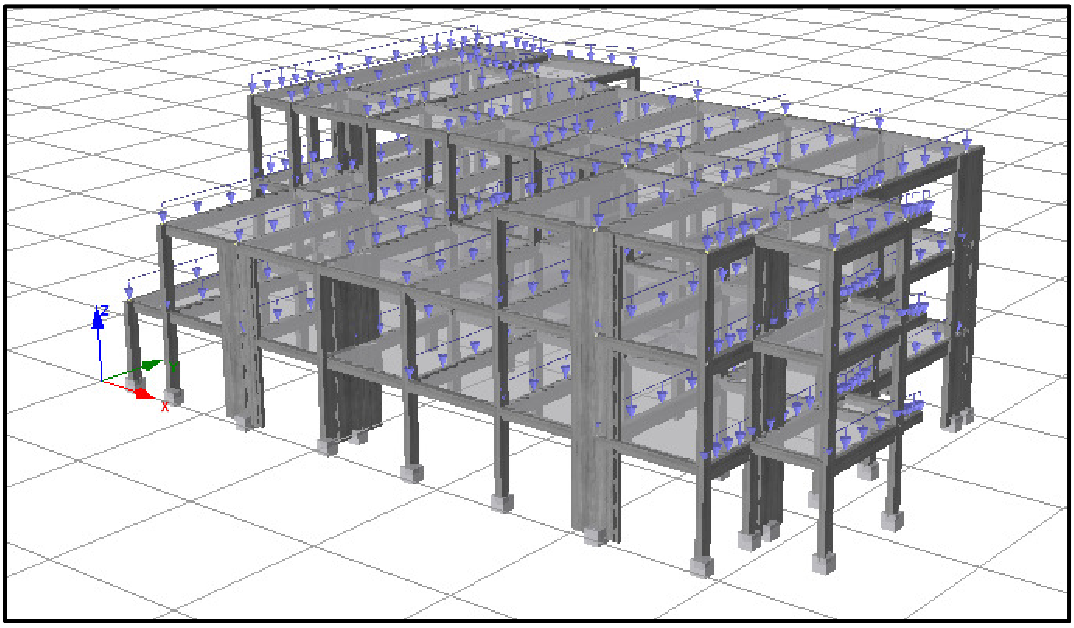


**Figure IV.1:** SeismoStruct numerical model of bloc A.

**Performance check #1: Inter-story drift**

Here are the results from the analysis:

**Table IV.1:** Inter-story drifts for bloc A.

| Strong ground motion #01: Azazga | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Direction** | **X** | | | | **Y** | | | |
| **Floor** | **Roof** | **3rd** | **2nd** | **1st** | **Roof** | **3rd** | **2nd** | **1st** |
| **Displacement (cm)** | 2.9 | 2.4 | 1.9 | 1.5 | 2.1 | 1.8 | 1.6 | 1.4 |
| **Drift (cm)** | | 0.5 | 0.5 | 0.4 | | 0.3 | 0.2 | 0.2 |
| **Strong ground motion #02: Dar El Beïda** | | | | | | | | |
| **Direction** | **X** | | | | **Y** | | | |
| **Floor** | **Roof** | **3rd** | **2nd** | **1st** | **Roof** | **3rd** | **2nd** | **1st** |
| **Displacement (cm)** | 4.4 | 5.1 | 5.7 | 6.1 | -1.7 | -2.1 | -2.5 | -2.7 |
| **Drift (cm)** | | -0.7 | -0.6 | -0.4 | | 0.4 | 0.4 | 0.2 |
| **Strong ground motion #03: Keddara** | | | | | | | | |

| Direction | X | | | | Y | | | |
|---|---|---|---|---|---|---|---|---|
| Floor | Roof | 3rd | 2nd | 1st | Roof | 3rd | 2nd | 1st |
| Displacement (cm) | -2.5 | -1.9 | -1.4 | -1 | 6.9 | 6.6 | 6.3 | 6.1 |
| Drift (cm) | | -0.6 | -0.5 | -0.4 | | 0.3 | 0.3 | 0.2 |
| **Admissible drift = 1% floor height = 3.74 cm** | | | | | | | | |

**Performance check #2: Chord rotation**

Here are the results from the analysis:

**Table IV.2:** Chord rotation results for bloc A.

| Strong ground motion #01: Azazga | | | | | | |
|---|---|---|---|---|---|---|
| **Axis** | **2** | | | **3** | | |
| **Element** | **Beams** | **Columns** | **Shear walls** | **Beams** | **Columns** | **Shear walls** |
| **Peak performance ratio** | 4.62% | 2.44% | 3.44% | 1.02% | 3.2% | 3.11% |
| **Strong ground motion #02: Dar El Beïda** | | | | | | |
| **Axis** | **2** | | | **3** | | |
| **Element** | **Beams** | **Columns** | **Shear walls** | **Beams** | **Columns** | **Shear walls** |
| **Peak performance ratio** | 50.03% | 18.99% | 3.84% | 2.34% | 5.81% | 36.54% |
| **Strong ground motion #03: Keddara** | | | | | | |
| **Axis** | **2** | | | **3** | | |
| **Element** | **Beams** | **Columns** | **Shear walls** | **Beams** | **Columns** | **Shear walls** |
| **Peak performance ratio** | 4.69% | 3.03% | 3.09% | 1.48% | 2.96% | 5.62% |
| **Performance ratio = demand / capacity ≤ 100%** | | | | | | |

**Performance check #3: Axial load ratio**

Here are the results from the analysis:

**Table IV.3:** Axial load ratio results for bloc A.

| | Axial load (kN) | Column section (mm²) | 28-days compressive strength (kPa) | Axial load ratio |
|---|---|---|---|---|
| **Strong ground motion #01** | 587.546 | 150000 | 25 | **0.16** |
| **Strong ground motion #02** | 661.080 | 150000 | 25 | **0.18** |
| **Strong ground motion #03** | 586.568 | 150000 | 25 | **0.16** |
| **Axial load ratio = axial load / (column secion * 28-days compressive strength) ≤ 0.3** | | | | |

**Performance check #4: P-Delta effect**

Here are the results from the analysis:

**Table IV.4:** P-Delta effect results for bloc A.

| | P (kN) | D (mm) | V (kN) | $H_f$ (mm) | θ |
|---|---|---|---|---|---|
| **X-Direction** | | | | | |
| **Strong ground motion #01** | 14090.51 | 4 | 2256.84 | 3740 | **0.67%** |
| **Strong ground motion #02** | 14951.49 | 4 | 2022.99 | 3740 | **0.79%** |
| **Strong ground motion #03** | 14050.16 | 4 | 2286.32 | 3740 | **0.66%** |
| **Y-Direction** | | | | | |
| **Strong ground motion #01** | 14090.51 | 2 | 1926.7 | 3740 | **0.39%** |
| **Strong ground motion #02** | 14951.49 | 2 | 2560.59 | 3740 | **0.31%** |
| **Strong ground motion #03** | 14050.16 | 2 | 2236 | 3740 | **0.34%** |
| $\theta = \frac{P * D}{V * H_f} \leq 10\%$ | | | | | |

### IV.2.2. Bloc C

**SeismoStruct numerical model**

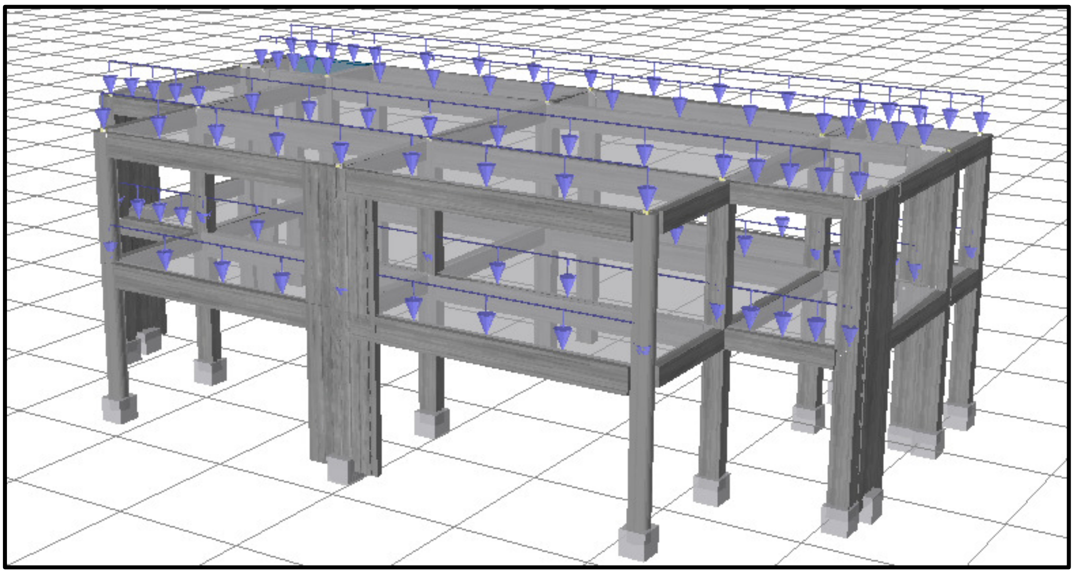


**Figure IV.2:** SeismoStruct numerical model of bloc C.

**Performance check #1: Inter-story drift**

Here are the results from the analysis:

**Table IV.5:** Inter-story drifts for bloc C.

| Strong ground motion #01: Azazga | | | | | | |
|---|---|---|---|---|---|---|
| **Direction** | **X** | | | **Y** | | |
| **Floor** | **Roof** | **2nd** | **1st** | **Roof** | **2nd** | **1st** |
| **Displacement (cm)** | 0.4 | 0.3 | 0.1 | 3 | 2.8 | 2.5 |
| **Drift (cm)** | | 0.1 | 0.2 | | 0.2 | 0.3 |
| **Strong ground motion #02: Dar El Beïda** | | | | | | |
| **Direction** | **X** | | | **Y** | | |
| **Floor** | **Roof** | **2nd** | **1st** | **Roof** | **2nd** | **1st** |
| **Displacement (cm)** | 13.6 | 13.5 | 13.2 | 16.1 | 15.8 | 15.5 |
| **Drift (cm)** | | 0.1 | 0.3 | | 0.3 | 0.3 |
| **Strong ground motion #03: Keddara** | | | | | | |
| **Direction** | **X** | | | **Y** | | |
| **Floor** | **Roof** | **2nd** | **1st** | **Roof** | **2nd** | **1st** |
| **Displacement (cm)** | -1.7 | -1.8 | -2.1 | -5.3 | -5.5 | -5.8 |
| **Drift (cm)** | | 0.1 | 0.3 | | 0.2 | 0.3 |
| **Admissible drift = 1% floor height = 3.74 cm** | | | | | | |

**Performance check #2: Chord rotation**

Here are the results from the analysis:

**Table IV.6:** Chord rotation results for bloc C.

| Strong ground motion #01: Azazga | | | | | | |
|---|---|---|---|---|---|---|
| **Axis** | **2** | | | **3** | | |
| **Element** | **Beams** | **Columns** | **Shear walls** | **Beams** | **Columns** | **Shear walls** |
| **Peak performance ratio** | 2.09% | 0.92% | 0.81% | 1.72% | 0.26% | 0.04% |
| **Strong ground motion #02: Dar El Beïda** | | | | | | |
| **Axis** | **2** | | | **3** | | |
| **Element** | **Beams** | **Columns** | **Shear walls** | **Beams** | **Columns** | **Shear walls** |
| **Peak performance ratio** | 2.35% | 0.99% | 1% | 2.58% | 0.32% | 0.03% |
| **Strong ground motion #03: Keddara** | | | | | | |
| **Axis** | **2** | | | **3** | | |
| **Element** | **Beams** | **Columns** | **Shear walls** | **Beams** | **Columns** | **Shear walls** |
| **Peak performance ratio** | 1.86% | 1.15% | 1.17% | 1.94% | 0.28% | 0.04% |
| **Performance ratio = demand / capacity ≤ 100%** | | | | | | |

**Performance check #3: Axial load ratio**

Here are the results from the analysis:

**Table IV.7:** Axial load ratio results for bloc C.

| | Axial load (kN) | Column section ($mm^2$) | 28-days compressive strength (kPa) | Axial load ratio |
|---|---|---|---|---|
| **Strong ground motion #01** | 509.540 | 175000 | 25 | 0.12 |
| **Strong ground motion #02** | 509.950 | 175000 | 25 | 0.12 |
| **Strong ground motion #03** | 507.930 | 175000 | 25 | 0.12 |
| **Axial load ratio = axial load / (column secion * 28-days compressive strength) ≤ 0.3** | | | | |

**Performance check #4: P-Delta effect**

Here are the results from the analysis:

**Table IV.8:** P-Delta effect results for bloc C.

| | P (kN) | D (mm) | V (kN) | $H_f$ (mm) | θ |
|---|---|---|---|---|---|
| **X-Direction** | | | | | |
| **Strong ground motion #01** | 3947.18 | 2 | 660.37 | 3740 | **0.31%** |
| **Strong ground motion #02** | 3853.45 | 3 | 752.49 | 3740 | **0.41%** |
| **Strong ground motion #03** | 3871.1 | 3 | 882.51 | 3740 | **0.35%** |
| **Y-Direction** | | | | | |
| **Strong ground motion #01** | 3947.18 | 3 | 728.36 | 3740 | **0.43%** |
| **Strong ground motion #02** | 3853.45 | 3 | 872.17 | 3740 | **0.35%** |
| **Strong ground motion #03** | 3871.1 | 3 | 767.11 | 3740 | **0.40%** |
| $\theta = \frac{P * D}{V * H_f} \leq 10\%$ | | | | | |

## IV.3. Case study #2: Ben Azout primary school

### IV.3.1. Without the masonry infill

**SeismoStruct numerical model**

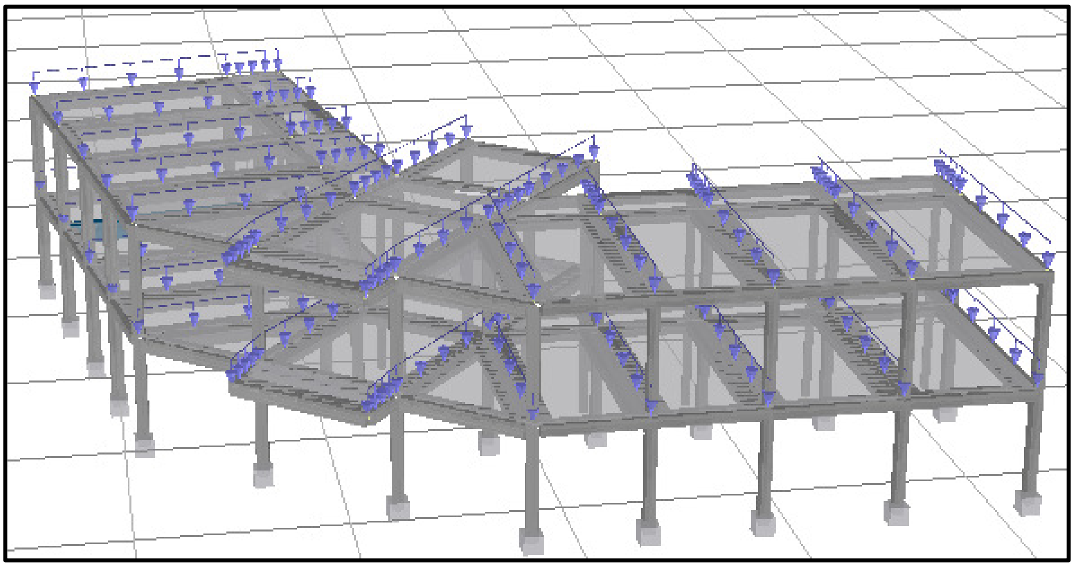


**Figure IV.3:** SeismoStruct numerical model of Ben Azout school (without masonry infill).

**Performance check #1: Inter-story drift**

Here are the results from the analysis:

**Table IV.9:** Inter-story drifts for Ben Azout school (without masonry infill).

| Strong ground motion #01: Azazga | | | | | | |
|---|---|---|---|---|---|---|
| **Direction** | **X** | | | **Y** | | |
| **Floor** | **Roof** | **2nd** | **1st** | **Roof** | **2nd** | **1st** |
| **Displacement (cm)** | 1.5 | -0.7 | -3 | 7.4 | 5.4 | 2.3 |
| **Drift (cm)** | | 2.2 | 2.3 | | 2 | 3.1 |
| **Strong ground motion #02: Dar El Beïda** | | | | | | |
| **Direction** | **X** | | | **Y** | | |
| **Floor** | **Roof** | **2nd** | **1st** | **Roof** | **2nd** | **1st** |
| **Displacement (cm)** | 1.7 | 3.5 | 6 | -4.7 | -3.4 | -1.1 |
| **Drift (cm)** | | -1.8 | -2.5 | | -1.3 | -2.3 |
| **Strong ground motion #03: Keddara** | | | | | | |
| **Direction** | **X** | | | **Y** | | |
| **Floor** | **Roof** | **2nd** | **1st** | **Roof** | **2nd** | **1st** |
| **Displacement (cm)** | 16.4 | 15.2 | 12.5 | 12.9 | 11.4 | 8.9 |
| **Drift (cm)** | | 1.2 | 2.7 | | 1.5 | 2.5 |
| **Admissible drift = 1% floor height = 3.74 cm** | | | | | | |

**Performance check #2: Chord rotation**

Here are the results from the analysis:

**Table IV.10:** Chord rotation results for Ben Azout school (without masonry infill).

| Strong ground motion #01: Azazga | | | | |
|---|---|---|---|---|
| Axis | 2 | | 3 | |
| Element | Beams | Columns | Beams | Columns |
| Peak performance ratio | 263.13% | 61.73% | 12.39% | 47.29% |
| Strong ground motion #02: Dar El Beïda | | | | |
| Axis | 2 | | 3 | |
| Element | Beams | Columns | Beams | Columns |
| Peak performance ratio | 6.8% | 10.65% | 0.83% | 11.16% |
| Axis | 2 | | 3 | |
| Element | Beams | Columns | Beams | Columns |
| Peak performance ratio | 222.52% | 108.33% | 8.34% | 44.42% |
| Performance ratio = demand / capacity ≤ 100% | | | | |

**Performance check #3: Axial load ratio**

Here are the results from the analysis:

**Table IV.11:** Axial load ratio results for Ben Azout school (without masonry infill).

| | Axial load (kN) | Column section ($mm^2$) | 28-days compressive strength (kPa) | Axial load ratio |
|---|---|---|---|---|
| Strong ground motion #01 | 946.470 | 120000 | 25 | 0.32 |
| Strong ground motion #02 | 519.050 | 125664 | 25 | 0.16 |
| Strong ground motion #03 | 890.530 | 120000 | 25 | 0.30 |
| Axial load ratio = axial load / (column secion * 28-days compressive strength) ≤ 0.3 | | | | |

**Performance check #4: P-Delta effect**

Here are the results from the analysis:

**Table IV.12:** P-Delta effect results for Ben Azout school (with masonry infill).

| | P (kN) | D (mm) | V (kN) | $H_f$ (mm) | θ |
|---|---|---|---|---|---|
| **X-Direction** | | | | | |
| **Strong ground motion #01** | 9842.21 | 23 | 1264.92 | 3740 | **4.78%** |
| **Strong ground motion #02** | 8072.69 | 25 | 1415.44 | 3740 | **3.81%** |
| **Strong ground motion #03** | 8758.56 | 27 | 1619.83 | 3740 | **3.9%** |
| **Y-Direction** | | | | | |
| **Strong ground motion #01** | 9842.21 | 31 | 1451.47 | 3740 | **5.62%** |
| **Strong ground motion #02** | 8072.69 | 23 | 1244.35 | 3740 | **3.98%** |
| **Strong ground motion #03** | 8758.56 | 25 | 1401.9 | 3740 | **4.71%** |
| $\theta = \frac{P * D}{V * H_f} \leq 10\%$ | | | | | |

**IV.3.2. With the masonry infill**

**SeismoStruct numerical model**

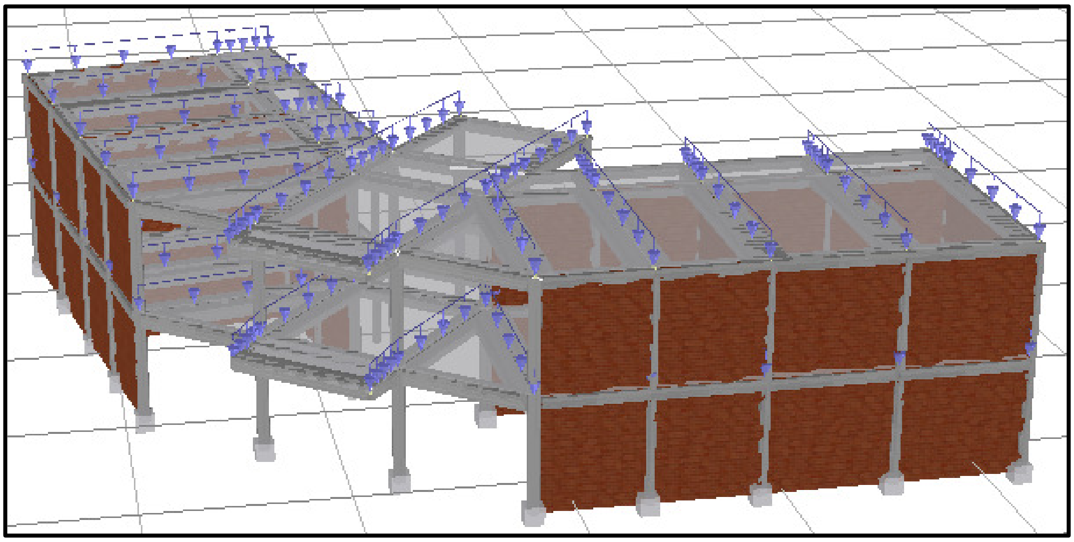


**Figure IV.4:** SeismoStruct numerical model of Ben Azout school (with masonry infill).

**Performance check #1: Inter-story drift**

Here are the results from the analysis:

**Table IV.13:** Inter-story drifts for Ben Azout school (with masonry infill).

| Strong ground motion #01: Azazga | | | | | | |
|---|---|---|---|---|---|---|
| **Direction** | **X** | | | **Y** | | |
| **Floor** | **Roof** | **2nd** | **1st** | **Roof** | **2nd** | **1st** |
| **Displacement (cm)** | -5.6 | -5 | -3.4 | 4.5 | 3.8 | 2.5 |
| **Drift (cm)** | | -0.6 | -1.6 | | 0.7 | 1.3 |
| **Strong ground motion #02: Dar El Beïda** | | | | | | |
| **Direction** | **X** | | | **Y** | | |
| **Floor** | **Roof** | **2nd** | **1st** | **Roof** | **2nd** | **1st** |
| **Displacement (cm)** | -6.5 | -5.9 | -4.4 | -1.5 | -2.2 | -3.4 |
| **Drift (cm)** | | -0.6 | -1.5 | | 0.7 | 1.2 |
| **Admissible drift = 1% floor height = 3.74 cm** | | | | | | |

**Performance check #2: Chord rotation**

Here are the results from the analysis:

**Table IV.14:** Chord rotation results for Ben Azout school (with masonry infill).

| Strong ground motion #01: Azazga | | | | |
|---|---|---|---|---|
| **Axis** | **2** | | **3** | |
| **Element** | Beams | Columns | Beams | Columns |
| **Peak performance ratio** | 63.18% | 27.31% | 2.88% | 39.51% |
| **Strong ground motion #02: Dar El Beïda** | | | | |
| **Axis** | **2** | | **3** | |
| **Element** | Beams | Columns | Beams | Columns |
| **Peak performance ratio** | 13.85% | 7.40% | 1.86% | 37.58% |
| **Performance ratio = demand / capacity ≤ 100%** | | | | |

**Performance check #3: Axial load ratio**

Here are the results from the analysis:

**Table IV.15:** Axial load ratio results for Ben Azout school (with masonry infill).

| | **Axial load (kN)** | **Column section ($mm^2$)** | **28-days compressive strength (kPa)** | **Axial load ratio** |
|---|---|---|---|---|
| **Strong ground motion #01** | 851.810 | 125664 | 25 | 0.27 |
| **Strong ground motion #02** | 584.800 | 120000 | 25 | 0.19 |
| **Axial load ratio = axial load / (column secion * 28-days compressive strength) ≤ 0.3** | | | | |

**Performance check #4: P-Delta effect**

Here are the results from the analysis:

**Table IV.16:** P-Delta effect results for Ben Azout school (with masonry infill).

| | P (kN) | D (mm) | V (kN) | $H_f$ (mm) | θ |
|---|---|---|---|---|---|
| **X-Direction** | | | | | |
| **Strong ground motion #01** | 9341.75 | 16 | 1538.85 | 3740 | **2.59%** |
| **Strong ground motion #02** | 8948.33 | 15 | 1538.69 | 3740 | **2.33%** |
| **Y-Direction** | | | | | |
| **Strong ground motion #01** | 9341.75 | 13 | 1498.16 | 3740 | **2.16%** |
| **Strong ground motion #02** | 8948.33 | 12 | 1377.87 | 3740 | **2.08%** |
| $\theta = \frac{P * D}{V * H_f} \leq 10\%$ | | | | | |

## IV.4. Conclusion

After running the various inspections, the following results were noticed:

- While both schools pass the story drift test, the buildings with shear walls (the school) have significant lower drift value than the school with only frame bracing (Ben Azout) due to shear walls augmenting the stiffness of the building.
- The chord rotations in the old school is significantly bigger than the chord rotations in the structural members of the new school, even exceeding the admissible value in some cases which can cause a member failure that can be very dangerous.
- It was found that the axial load ratio is verified in all instances expect one in Ben Azout model, due to the big emphasis Algerian seismic regulations put on compressive strength of reinforced concrete, even in its older versions of code.
- The P-Delta effect is verified in all inceptions and has very little effect on the two schools, due to the small displacements of the structural member ends.

In conclusion, it was noticed that the new school performs better during earthquakes thanks to the many improvements to the Algerian seismic regulations revision in 2003, after the Boumerdes earthquake.

# *Chapter V*

## *Evaluation of seismic fragility curves of school Buildings*

## V.1. Introduction

The next step in this research is developing fragility curves for the four case studies, by performing static pushover analysis, and then using algorithmic tools to estimate the seismic fragility of buildings as mentioned in chapter I (I.9).

The purpose of developing fragility functions is to reduce damage cost and loss of life during a seismic event. Therefore, fragility curves can be used as a decision-making tool for both pre- and post-earthquake situations. Moreover, these curves may help develop future local code provisions.

## V.2. Static pushover analysis results

Follow the procedure mentioned in chapter 1 (I.4.2), here are the results of the static pushover analysis for the four case studies:

### V.2.1. The middle school – Bloc A and B

**X-Direction**

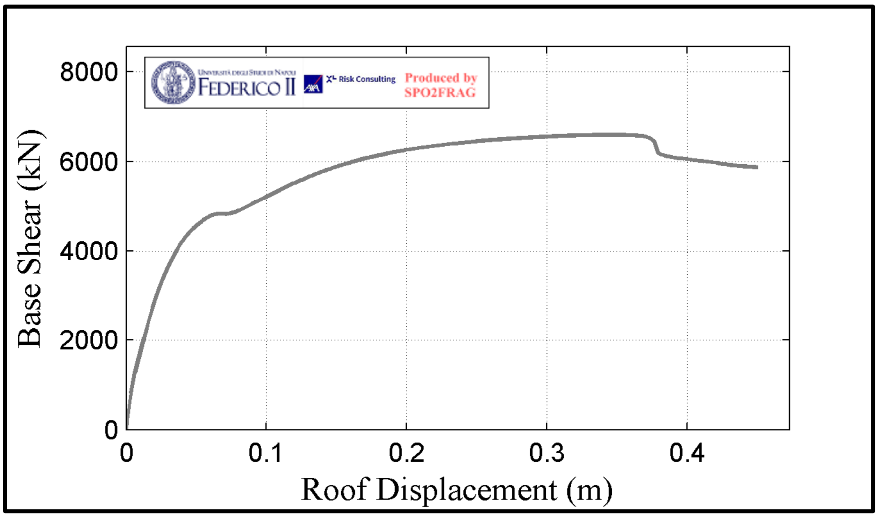



**Figure V.1:** Nonlinear static pushover curve for bloc A in the X-direction.

**Y-Direction**

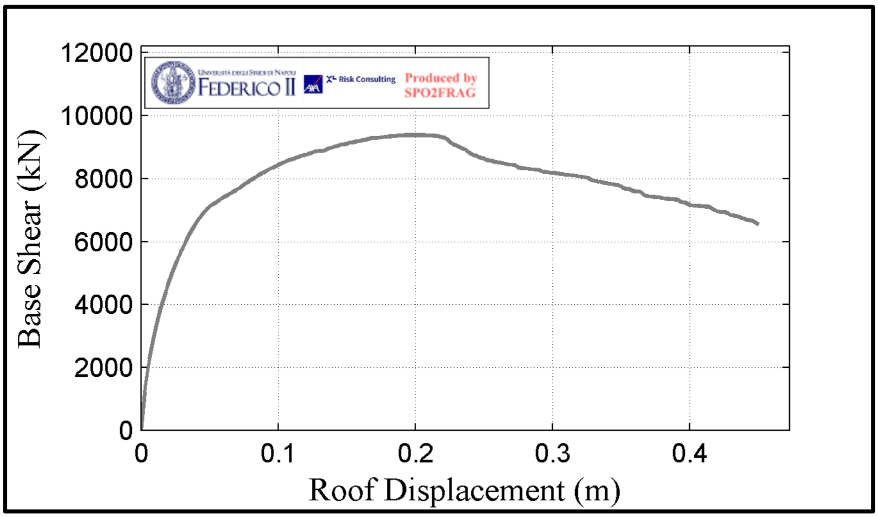



**Figure V.2:** Nonlinear static pushover curve for bloc A in the Y-direction.

### V.2.2. The middle school – Bloc C

**X-Direction**

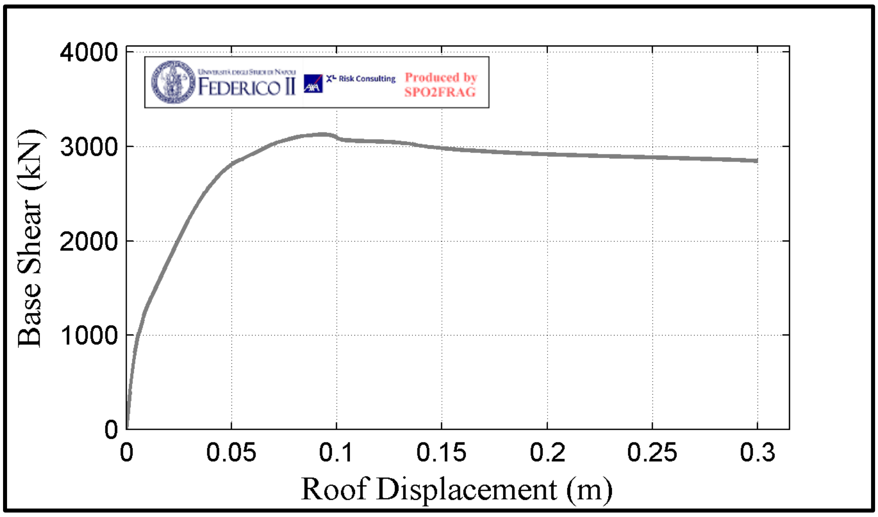



**Figure V.3:** Nonlinear static pushover curve for bloc C in the X-direction.

**Y-Direction**

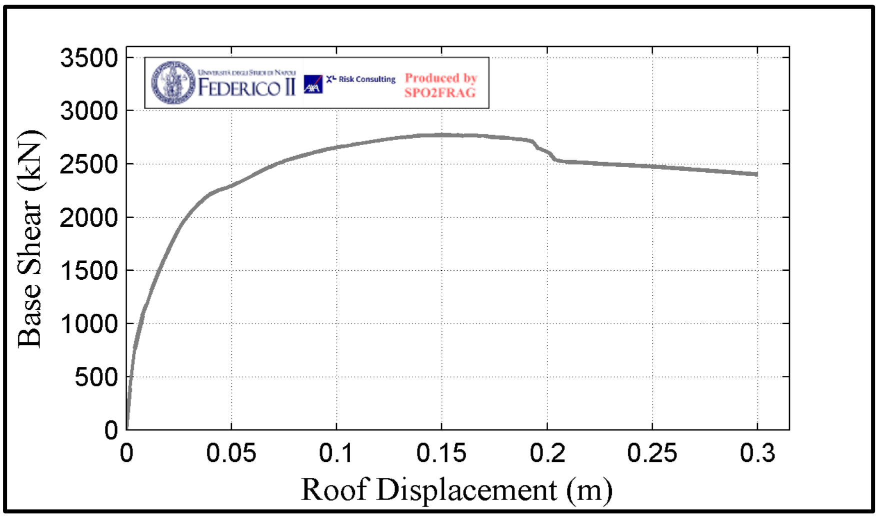



**Figure V.4:** Nonlinear static pushover curve for bloc C in the Y-direction.

### V.2.3. Ben Azout primary school - with masonry infill

**X-Direction**

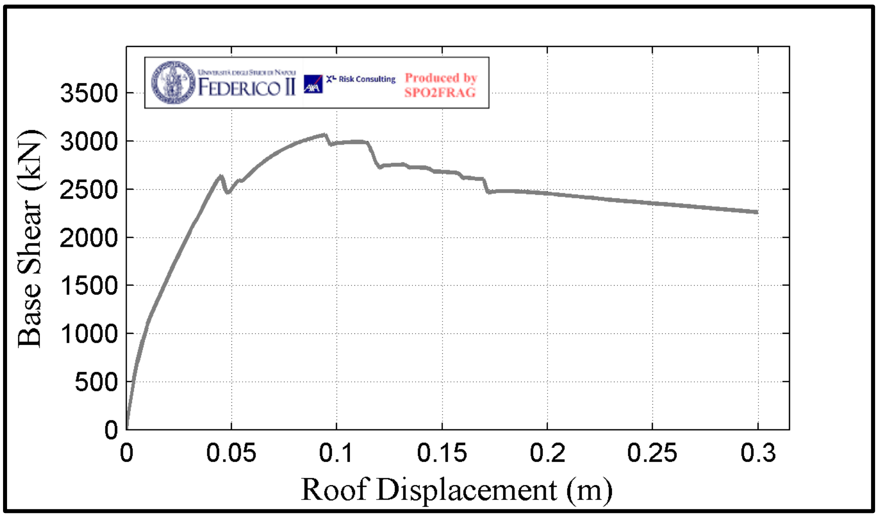



**Figure V.5:** Nonlinear static pushover curve for Ben Azout (with masonry infill) in the X-direction.

**Y-Direction**

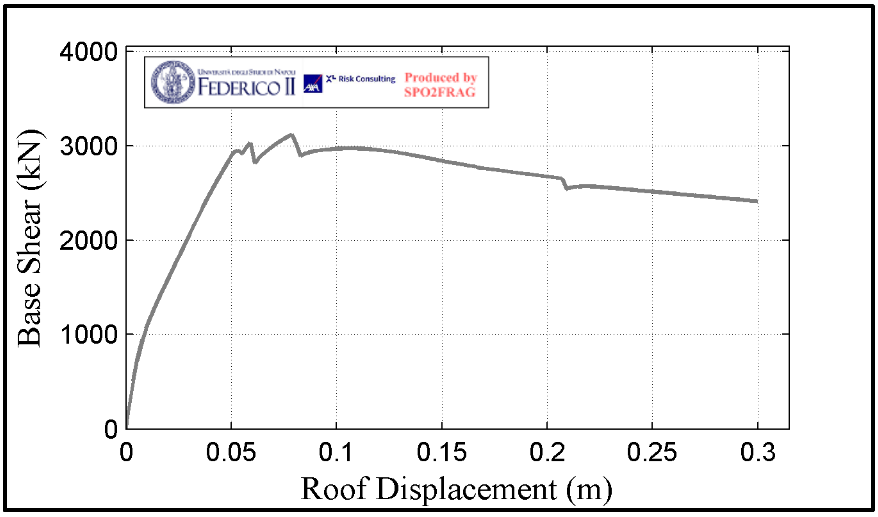



**Figure V.6:** Nonlinear static pushover curve for Ben Azout (with masonry infill) in the Y-direction.

### V.2.4. Ben Azout primary school - without masonry infill

**X-Direction**

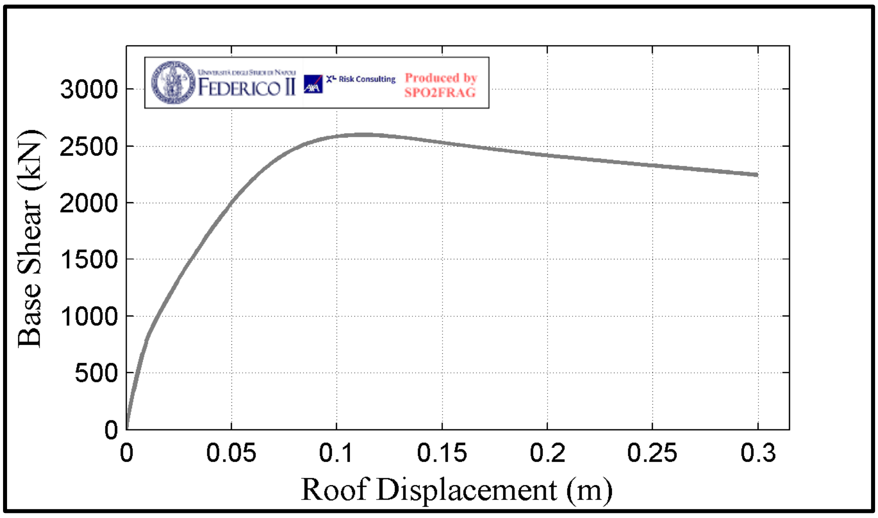



**Figure V.7:** Nonlinear static pushover curve for Ben Azout (without masonry infill) in the X-direction.

**Y-Direction**

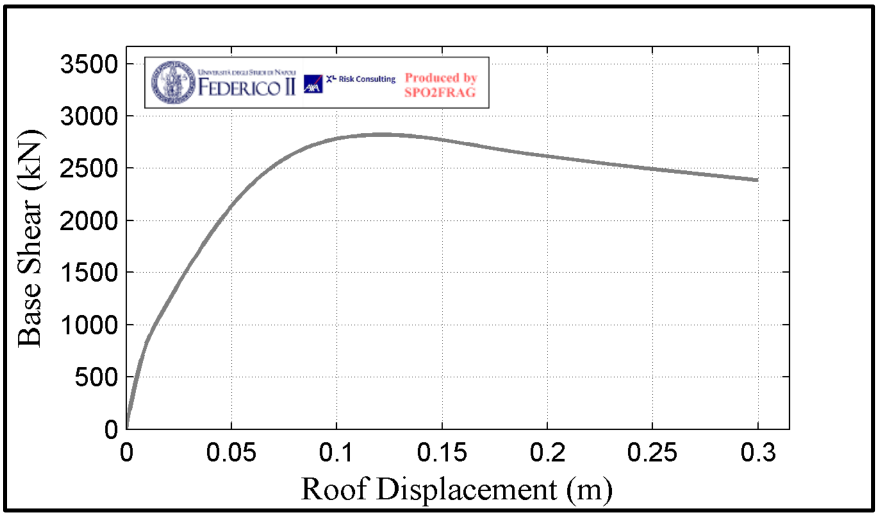



**Figure V.8:** Nonlinear static pushover curve for Ben Azout (without masonry infill) in the Y-direction.

## V.3 Approximate incremental dynamic analysis results

In incremental dynamic analysis (IDA), a large number of nonlinear response history analyses are performed using ground motions, that are increasing in intensity according to predetermined scale, until the structure collapses.

Because this method involves a large number of suitable ground motions pairs to generate a collapse fragility (20 ground motion at the very least), each of which are incrementally scaled to many intensity levels, and for each intensity a nonlinear response analysis must be conducted: the resulting date from this analysis is very comprehensive but comes at the price of high computing power.

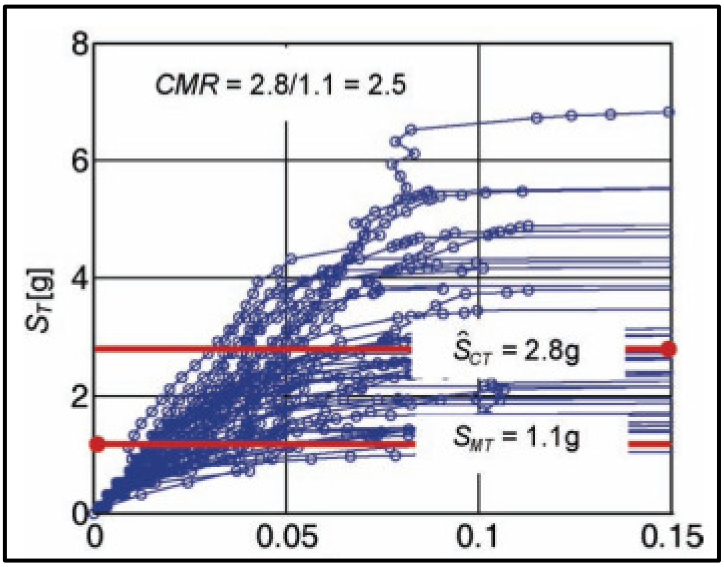



**Figure V.9:** Sample incremental dynamic analysis results.

Due to the demanding nature of the analysis, it is often restricted to research and has gained less popularity among engineers in practical. To overcome these difficulties several nonlinear static (pushover) analysis-based methods have recently been developed by researchers to develop approximate IDA results such as SPO2IDA procedure that was mentioned in chapter 1 (I.9):

### V.3.1. The middle school – Bloc A and B

#### X-Direction

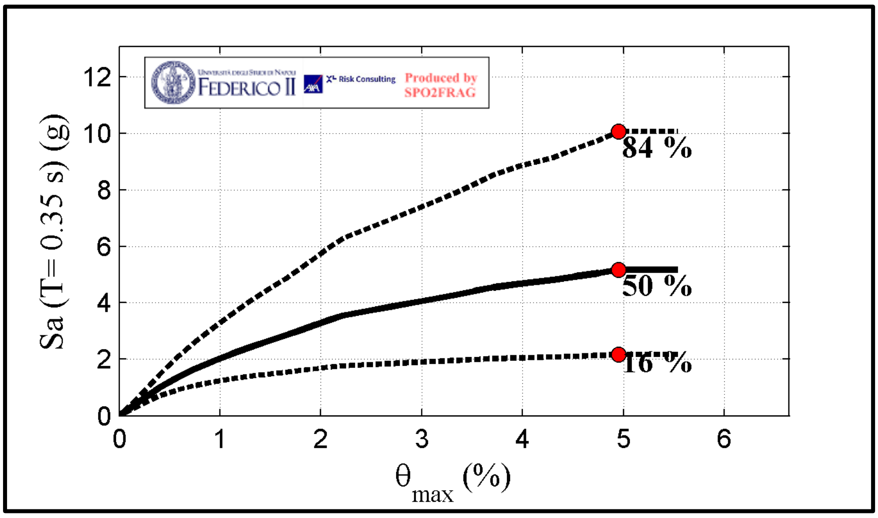



**Figure V.10:** Approximate IDA curve for Bloc A in the X-direction.

**Y-Direction**

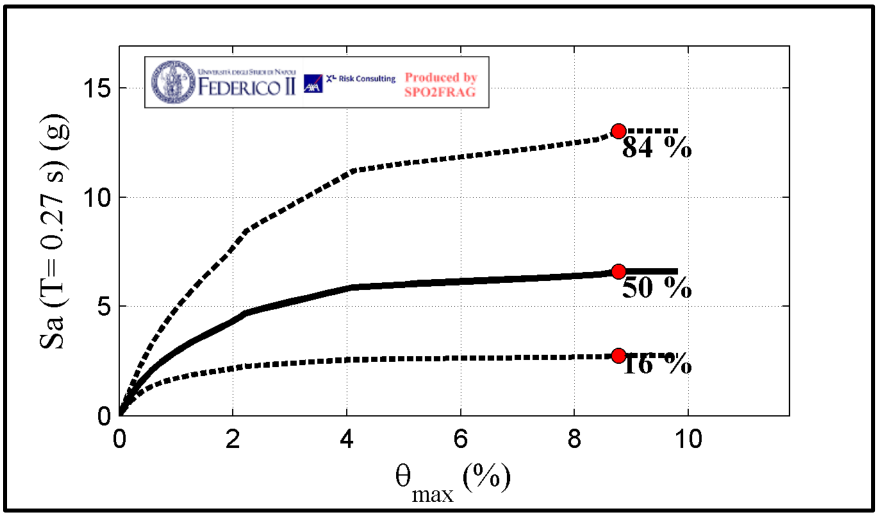



**Figure V.11:** Approximate IDA curve for Bloc A in the Y-direction.

**V.3.2. The middle school – Bloc C**

**X-Direction**

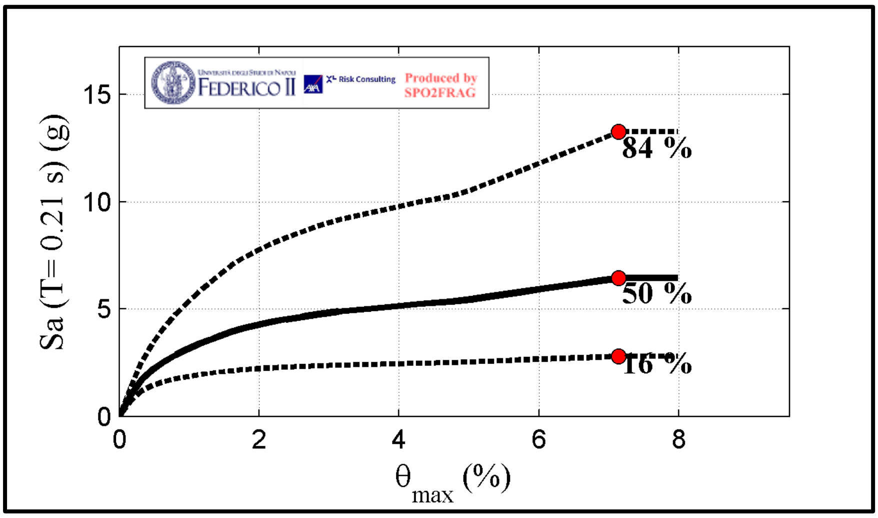



**Figure V.12:** Approximate IDA curve for Bloc C in the X-direction.

**Y-Direction**

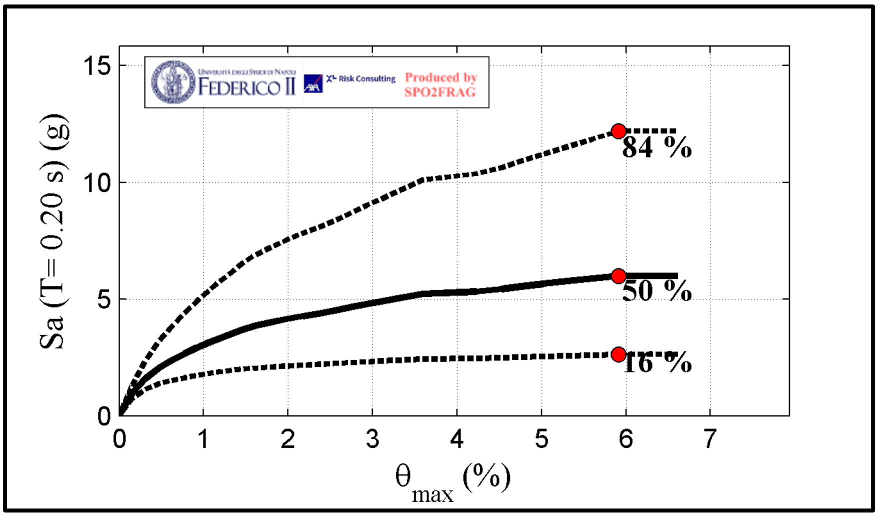



**Figure V.13:** Approximate IDA curve for Bloc C in the Y-direction.

### V.3.3. Ben Azout primary school - with masonry infill

**X-Direction**

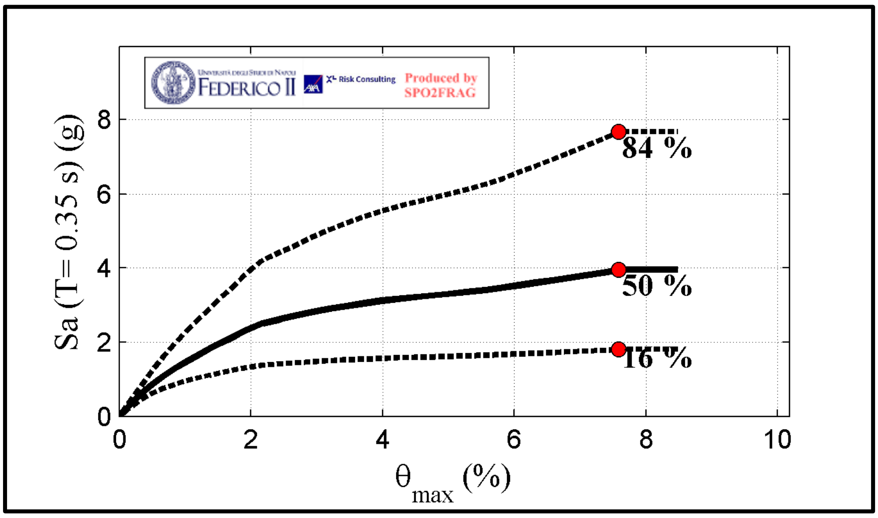



**Figure V.14:** Approximate IDA curve for Ben Azout (with masonry infill) in the X-direction.

**Y-Direction**

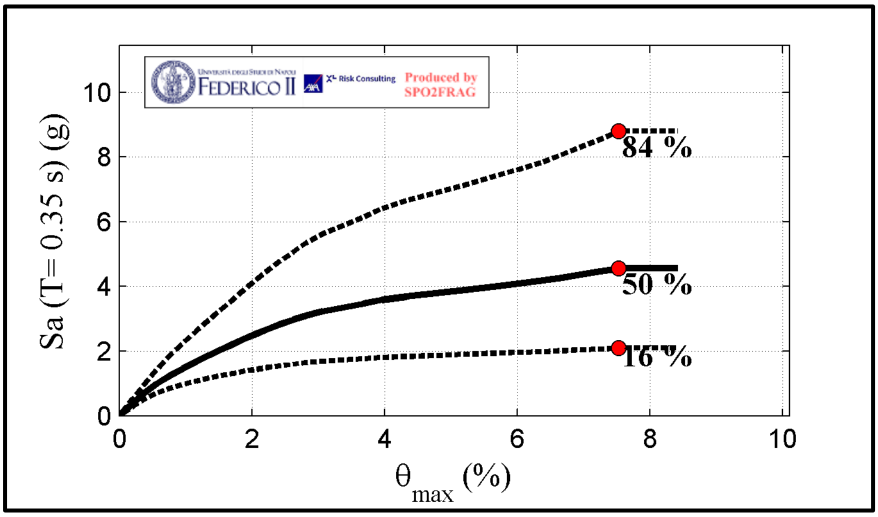



**Figure V.15:** Approximate IDA curve for Ben Azout (with masonry infill) in the Y-direction.

### V.3.4. Ben Azout primary school - without masonry infill

**X-Direction**

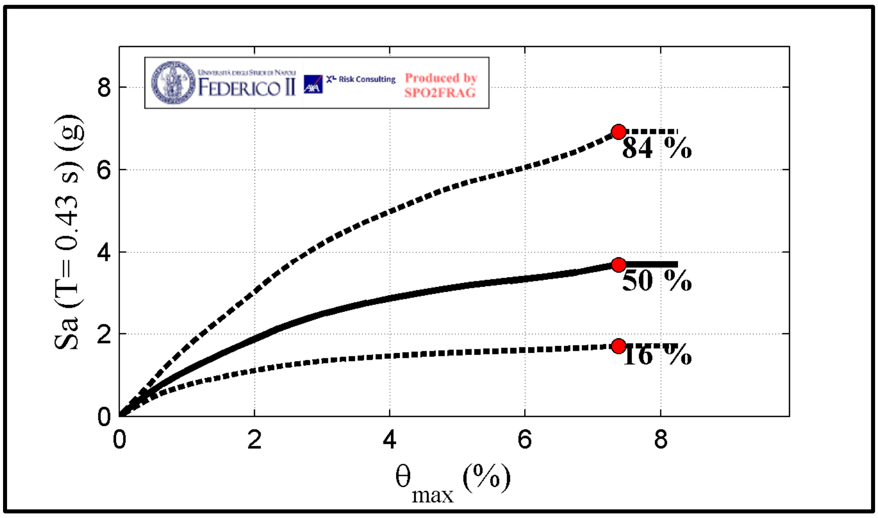



**Figure V.16:** Approximate IDA curve for Ben Azout (without masonry infill) in the X-direction.

**Y-Direction**

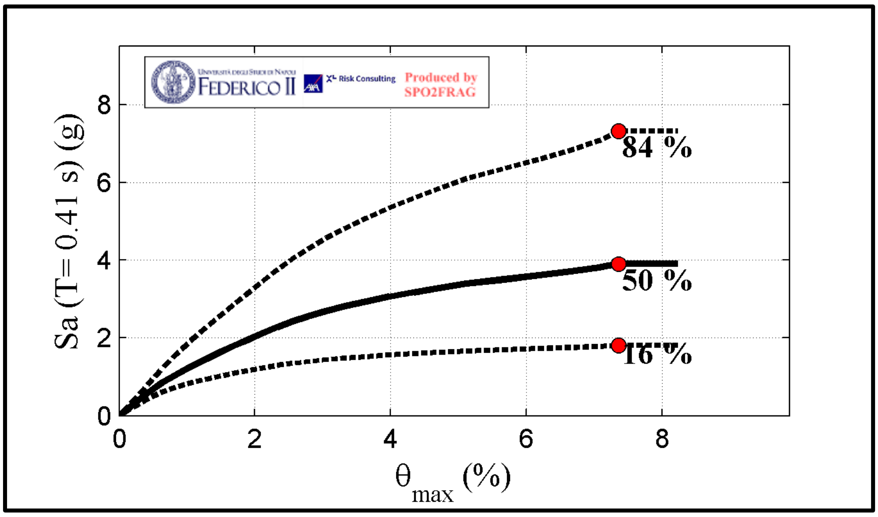



**Figure V.17:** Approximate IDA curve for Ben Azout (without masonry infill) in the Y-direction.

## V.4. The fragility curves obtained from the analysis

Here are the fragility curves of four case studies by using SPO2FRAG software:

### V.4.1. The middle school – Bloc A and B

**X-Direction**

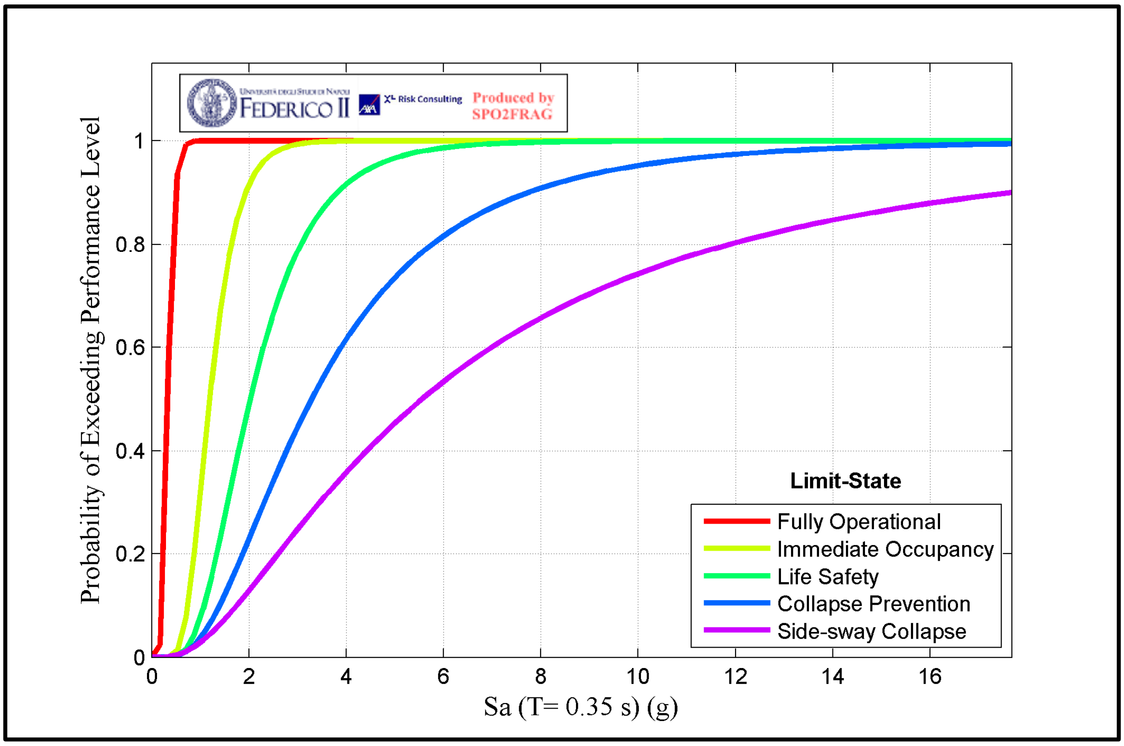



**Figure V.18:** Fragility curve for Bloc A in the X-direction.

**Y-Direction**

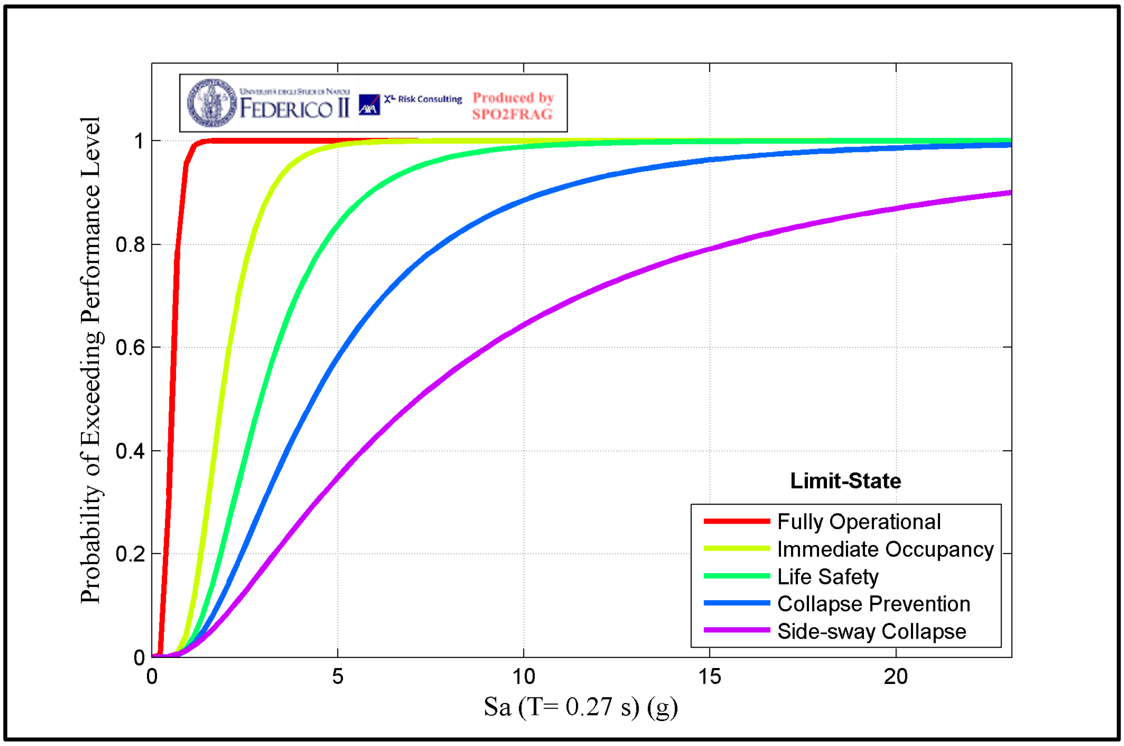



**Figure V.19:** Fragility curve for Bloc A in the Y-direction.

### V.4.2. The middle school – Bloc C

**X-Direction**

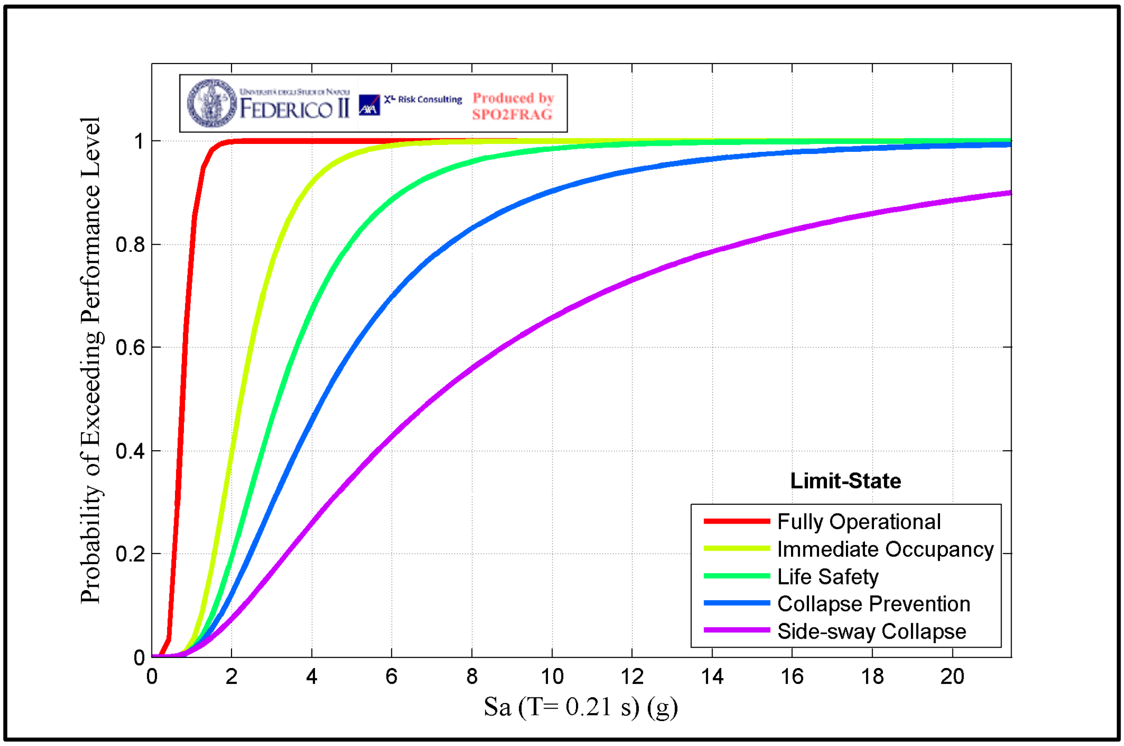



**Figure V.20:** Fragility curve for Bloc C in the X-direction.

**Y-Direction**

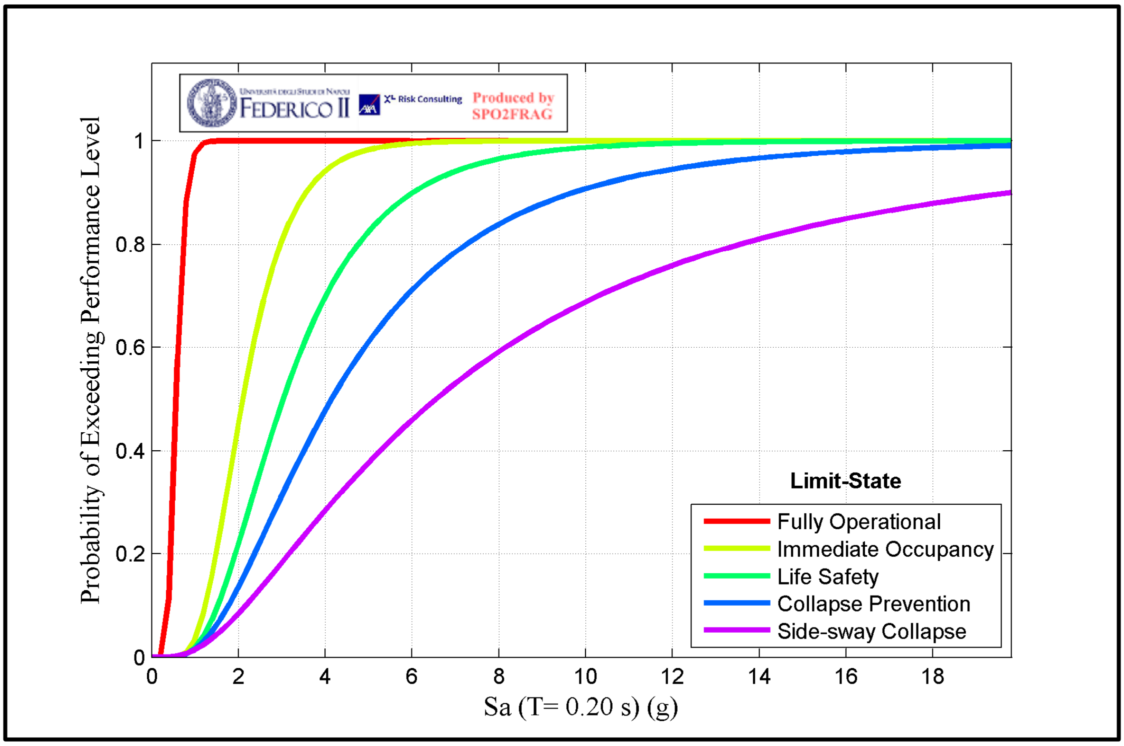



**Figure V.21:** Fragility curve for Bloc C in the Y-direction.

### V.4.3. Ben Azout primary school - with masonry infill

**X-Direction**

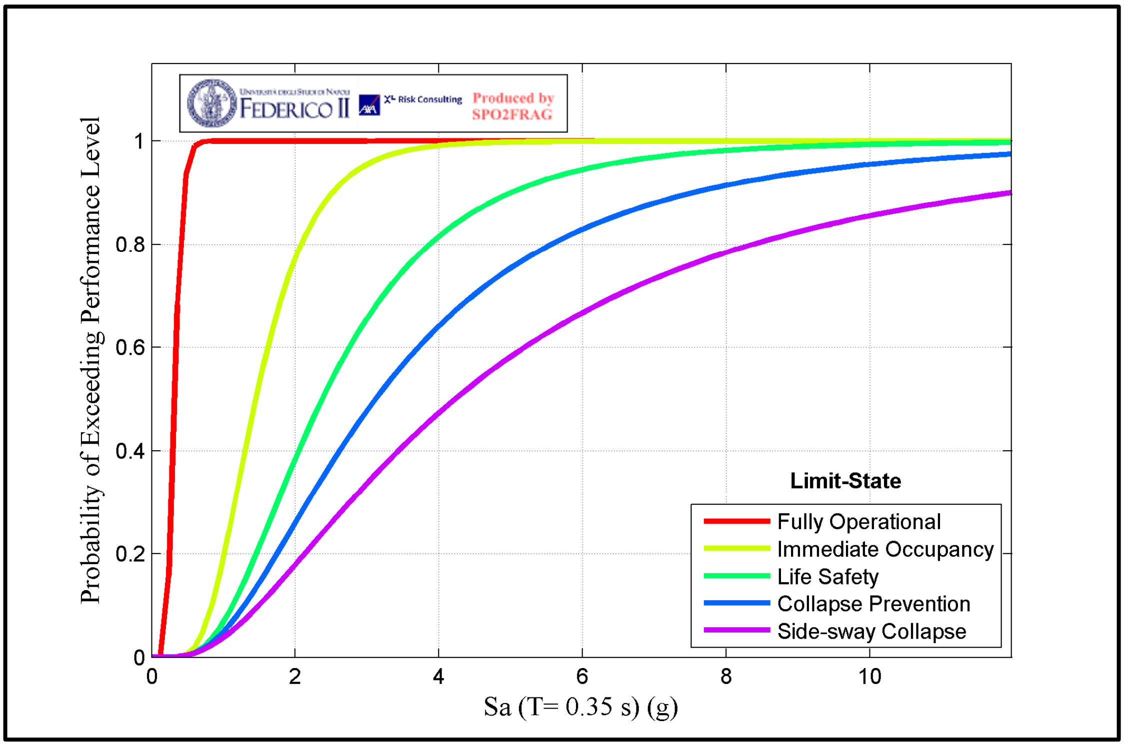



**Figure V.22:** Fragility curve for Ben Azout (with masonry infill) in the X-direction.

**Y-Direction**

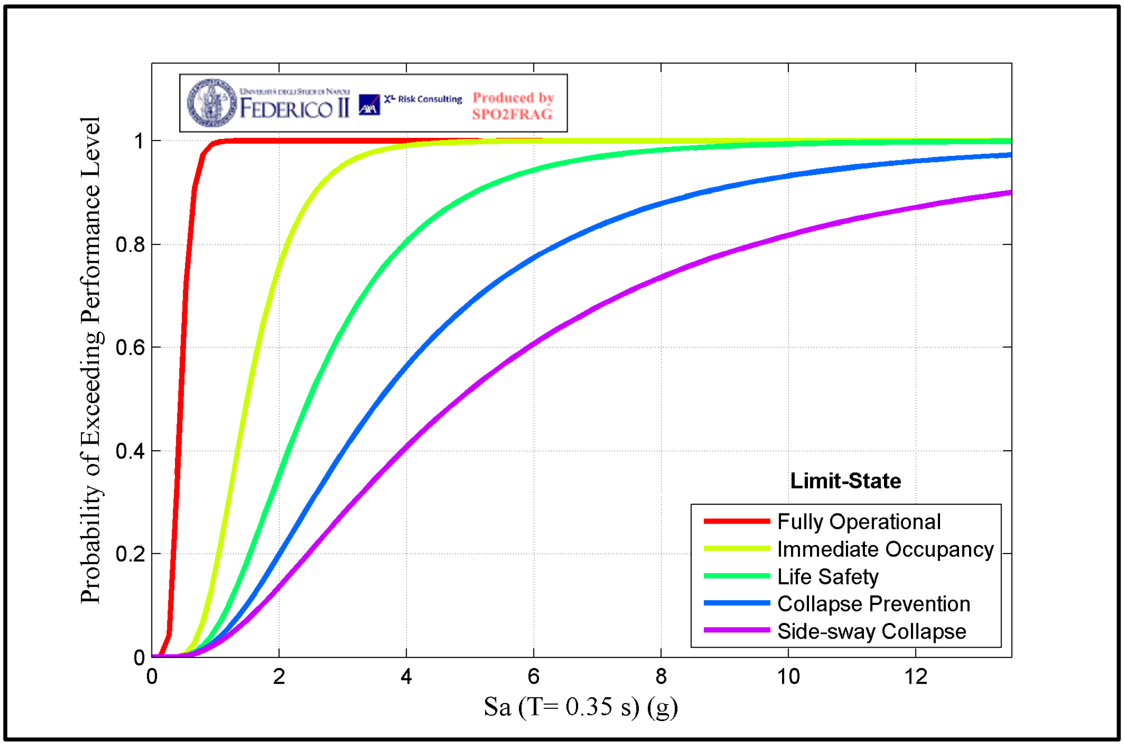



**Figure V.23:** Fragility curve for Ben Azout (with masonry infill) in the Y-direction.

### V.4.4. Ben Azout primary school - without masonry infill

**X-Direction**

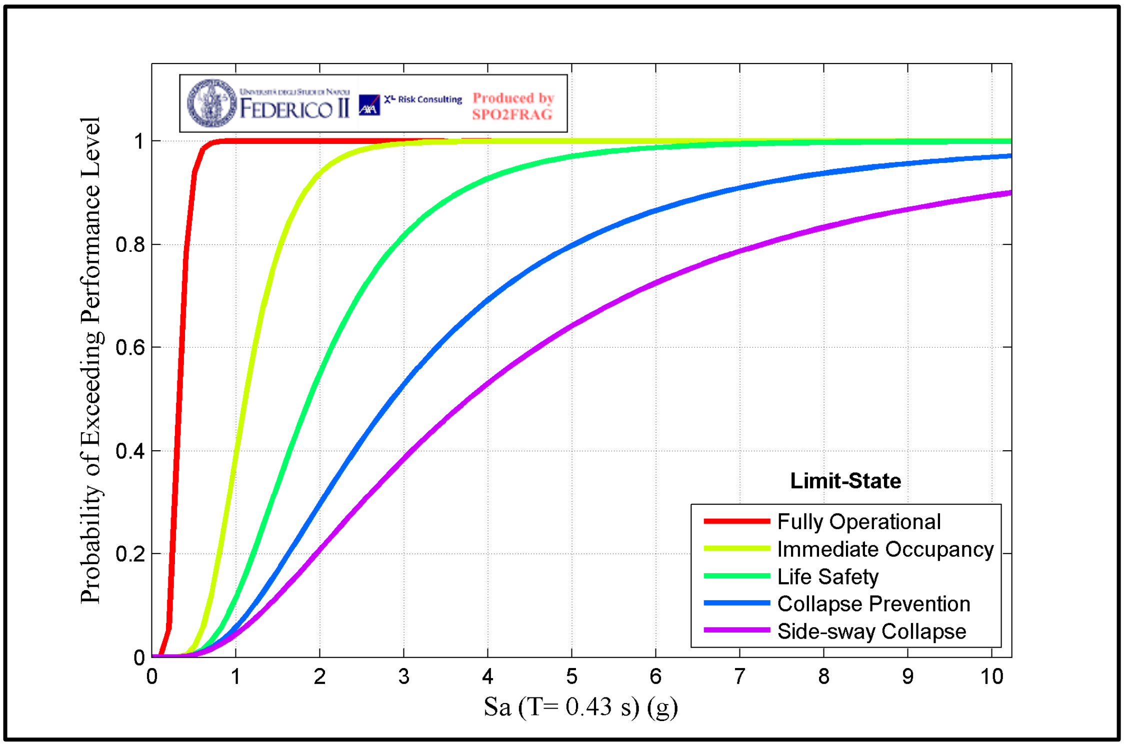



**Figure V.24:** Fragility curve for Ben Azout (without masonry infill) in the X-direction.

**Y-Direction**

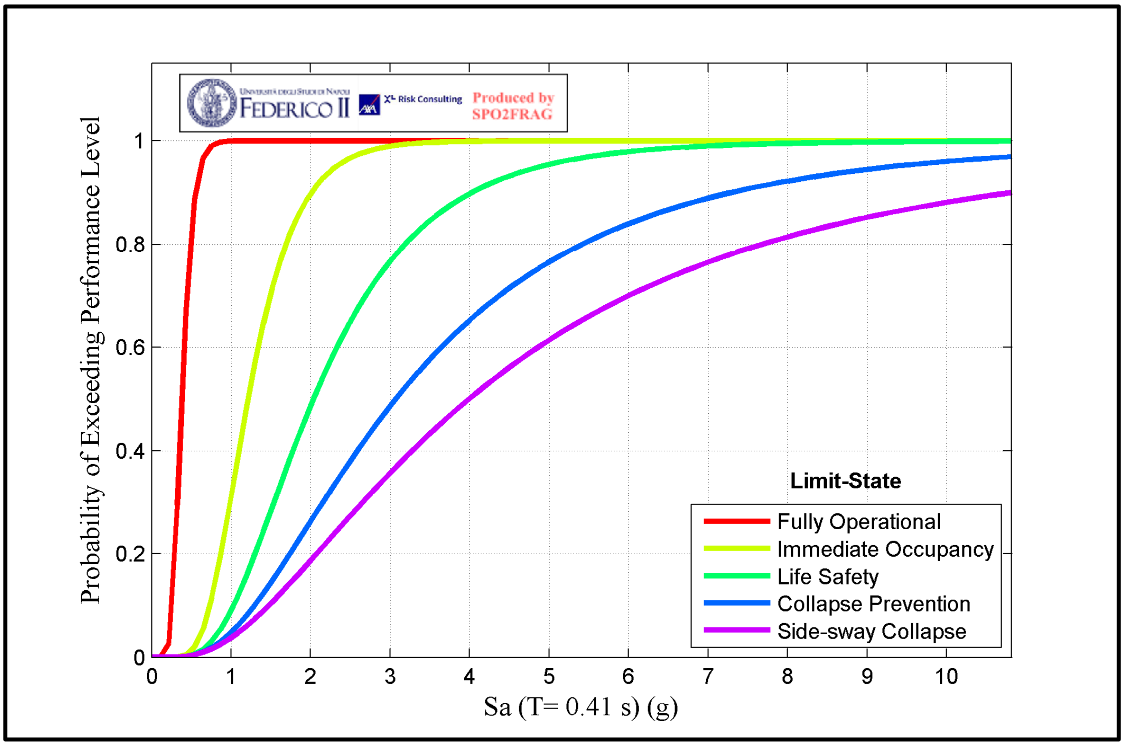



**Figure V.25:** Fragility curve for Ben Azout (without masonry infill) in the Y-direction.

## V.5. The various factors that influence fragility

### V.5.1. The effect of building height:

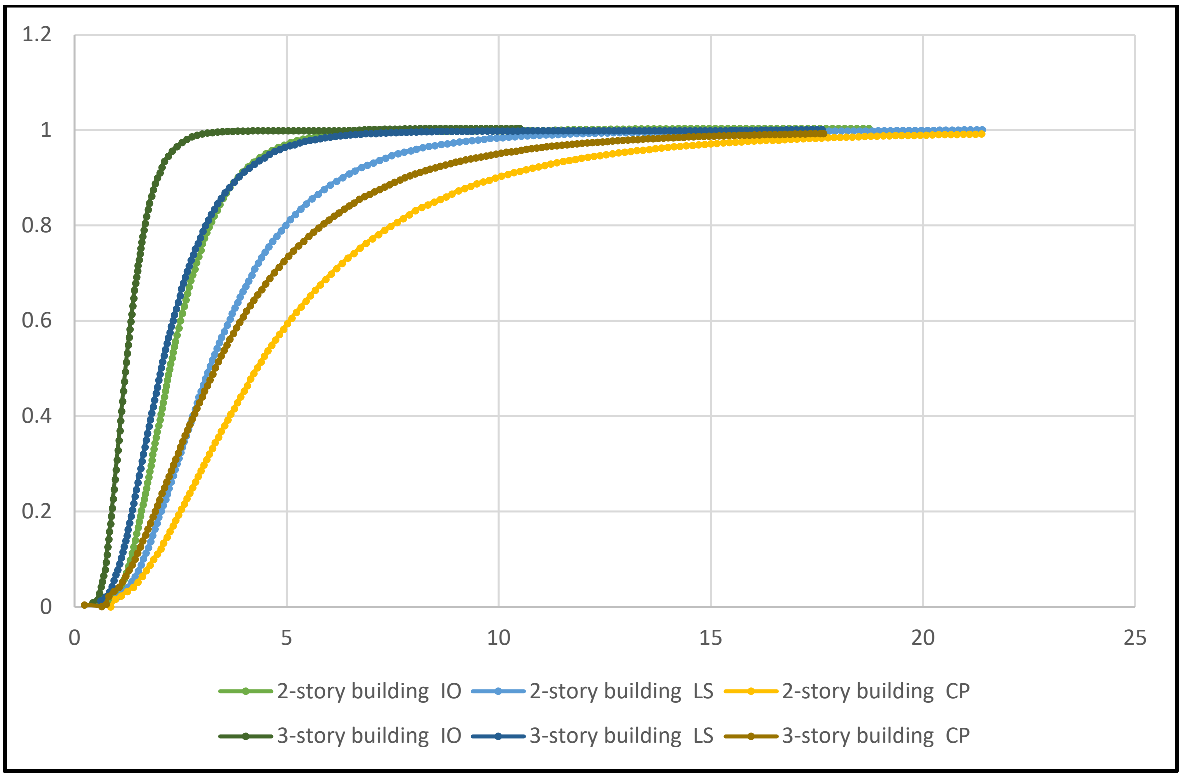



**Figure V.26:** Collapse fragility curves comparison between 2-story and 3-story buildings.

Based on the fragility curves of “Bloc A” (three-story building) and “Bloc C” (two-story building) of the middle school under construction (fig V.26), that share the same bracing system (RC walls), the following conclusions are made:

The two-story building has higher median capacity to withstand earthquake than the three-story building by an increase that range from 83%-88% in IO state to 30%-29% in collapse prevention state, which shows that the as the height of building increases, it’s median capacity to withstand seismic activities decreases due to bigger floor drift capacity.

**Table V.1:** Median capacity comparison between 2-story and 3-story buildings.

| | Median capacity Sa (g) of the [5-95%] confidence interval of the fragility parameter estimators | | |
|---|---|---|---|
| **Performance levels** | **Two-story building (h=7.48m)** | **Three-story building (h=11.22m)** | **Increase in median capacities for the “2 story building”** |
| **Immediate Occupancy** | 1.967g - 2.527g | 1.073g - 1.342g | 83% - 88% |
| **Life Safety** | 2.697g - 3.707g | 1.750g - 2.352g | 54% - 57% |
| **Collapse Prevention** | 3.513g - 5.203g | 2.691g - 4.018g | 30% - 29% |

### V.5.2. The effect of RC walls:

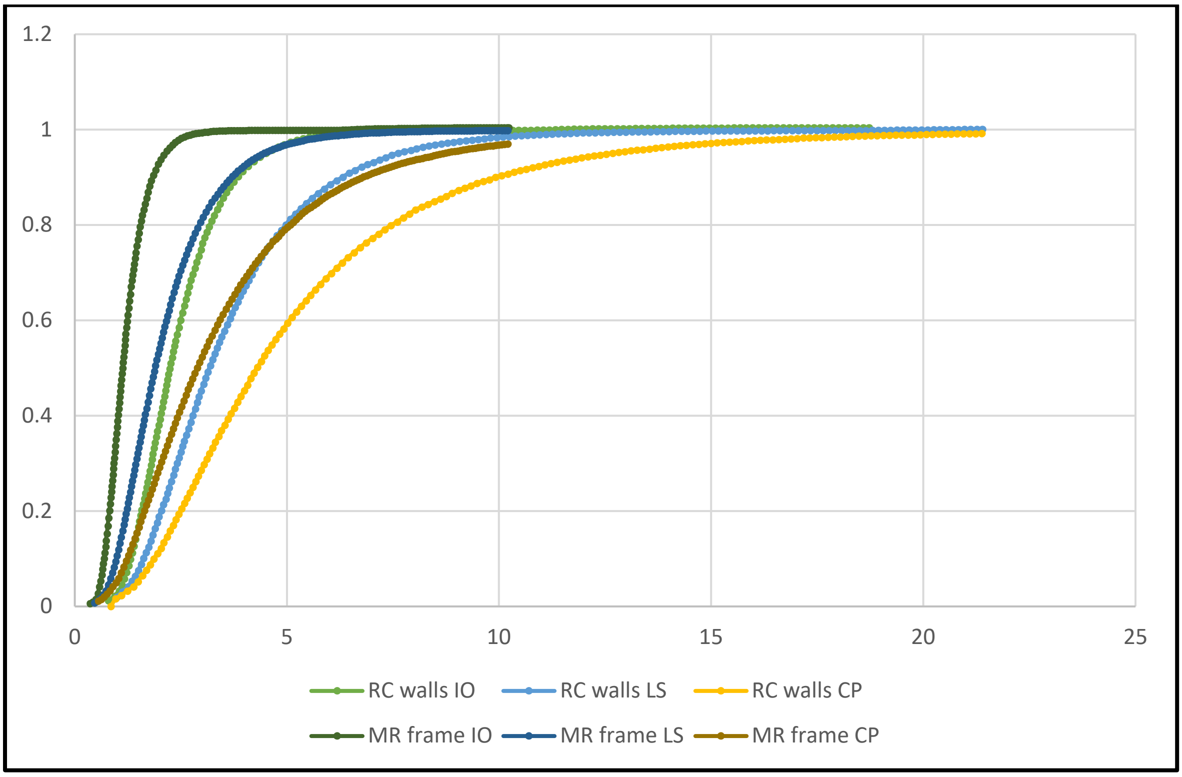



**Figure V.27:** Collapse fragility curves comparison between RC walls and MR frame buildings.

Based on the fragility curves of “Bloc C” from the middle school and “Ben Azout school” model that doesn’t include the masonry infill (fig V.27), two buildings that share the same height but the former include RC walls while the latter doesn’t, the following conclusions are made:

The RC walls structure has very big increase in its capacity to withstand seismic activities than MR frame structure, that it almost reached double the capacity in “Immediate occupancy” state, and this big difference in behavior against seismic activities is due to RC walls increasing the lateral stiffness of building, resulting in limiting its story drifts.

**Table V.2:** Median capacity comparison between RC walls and MR frame buildings.

| | **Median capacity Sa (g) of the [5-95%] confidence interval of the fragility parameter estimators** | | |
|---|---|---|---|
| **Performance levels** | **MR frame** | **RC walls** | **Increase in median capacities for the “RC wall” structure** |
| **Immediate Occupancy** | 0.992g - 1.249g | 1.967g - 2.527g | 98% - 102% |
| **Life Safety** | 1.604g - 2.193g | 2.697g - 3.707g | 68% - 69% |
| **Collapse Prevention** | 2.341g - 3.501g | 3.513g - 5.203g | 50% - 48% |

### V.5.3. The effect of masonry infill

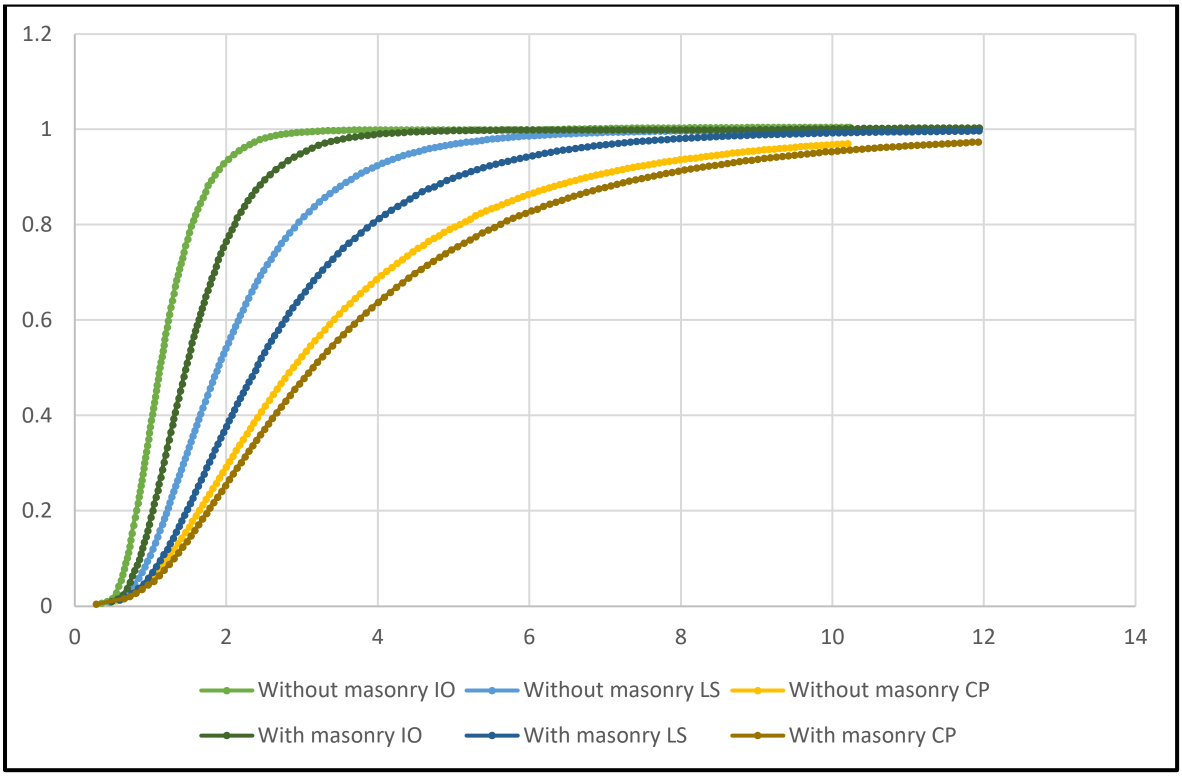



**Figure V.28:** Collapse fragility curves comparison of the same building “with” and “without” masonry infill.

Based on the two fragility curves of "Ben Azout school" in which one model includes the masonry infill effect while the other doesn't (fig V.28), the following conclusions are made:

Masonry infill slightly help the structure have better fragility performance, and that's by dissipating the seismic energy, resulting in failing before the frame, because the walls are weaker, they absorb lower earthquake forces which delay column shear failure.

**Table V.3:** Median capacity comparison of the same building "with" and "without" masonry infill.

| | **Median capacity Sa (g) of the [5-95%] confidence interval of the fragility parameter estimators** | | |
|---|---|---|---|
| **Performance levels** | **Without masonry infill** | **With masonry infill** | **Increase in median capacities for the "MR frame"** |
| **Immediate Occupancy** | 0.992g - 1.249g | 1.276g - 1.650g | 28% - 32% |
| **Life Safety** | 1.604g - 2.193g | 1.995g - 2.828g | 24% - 29% |
| **Collapse Prevention** | 2.341g - 3.501g | 2.535g - 3.835g | 8% - 9% |

## V.6. Conclusion

After developing fragility curves for the case studies, the reason most seismic codes advise the use of "RC walls" in high seismic region became very clear, due the big advantage in performance that shear walls provides by resisting the lateral loads of wind and earthquakes, resulting in almost double the seismic capacity that MR frame provides in lower limit-state.

Building height has straight away effect on fragility, because as the height increases, it results in bigger inter-story drift, that lower the building capacity to withstand large seismic activities.

Good masonry infill slightly improves the fragility of a structure, by absorbing lower earthquake forces, and failing first delaying any damage to the structural members.

These advantages are more apparent in lower limit-states and decreases as intensity goes up.

# ***Conclusion***

## Conclusions and recommendations

The goal of this study is to evaluate the performance and fragility of the school building in the area of Great Blida.

In this study, the evaluation of the fragility function for the two case studies was presented. Two school buildings were chosen from the total of 155 schools to represent the two most common structural systems in Algerian schools: Moment resisting frame and shear walls, in order to obtain.

1- Performance results from the various inspections executed on the two case studies using the strong ground motions from Boumerdes earthquake.
2- Fragility curves for the two case studies using static pushover analysis and the pushover to fragility procedure that uses SPO2IDA.

The main results obtain from the various analyses were:

- School buildings with moment resisting frames built before 2003 are much vulnerable to earthquakes compared to modern school buildings with RC shear walls.
- The great effect of shear walls on the seismic capacity of a building, by providing large strength and stiffness to structure, which significantly reduces lateral sway of the building and thereby reduces damage to structure and its contents.
- The importance of modeling the masonry infill in the various structural analyses, for its effect on the seismic performance and fragility of the building, by absorbing lower earthquake forces protecting the structural members in the process.

This leads us to the importance of establishing comprehensive periodic fragility evaluation for all existing school in Blida, using visual analysis and both “Nondestructive” and “Semi destructive” testing in order to recommend suitable solutions to mitigate earthquake damage, such as retrofitting existing school buildings, that not only improve the seismic capacity of said buildings, but also finically and environmentally better than building new schools.

The second important thing in preventing future schools from having seismic vulnerabilities by adapting to new seismic designs such performance -based, and the strict supervision during the process of constructing building, to avoid business fraud practices that led to thousands of deaths and injuries in past earthquakes, in favor of financial gain.

Unfortunately due to Covid-19 causing quarantine, this study didn’t include an important factor that caused the most damage to buildings during the last earthquake, which is the human aspect and the quality of execution for the design, as many building didn’t respect the previous seismic code, contractors using poor quality materials to be save money, and the poor skilled workers that didn’t follow the instructions (especially in reinforcement), so this study only dealt with design factors.

In the end, this is just a starting point for future research on the subject in order to provide safe and resilient educational services in Algeria schools, that should be continue on, by performing detail analysis to all the existing school buildings in the area, using the incremental dynamic analysis and not just an approximate method, to get comprehensive data that could shape the future of seismic design in Algerian schools.

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