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Effect of Earthquakes on Metal Silos

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Before I start this acknowledgment, I would like first to thank god for keeping me sain and resilient enough to finish this thesis through all the challenges that I faced

I would like to pay my special regards to my most important, I owe more than thanks to my family members which includes my parents DR.Khaled and Faiza and my little brother Imad , for their moral support and encouragement throughout my life. Without their support, it is impossible for me to finish my college and graduate education seamlessly.

I wish to express my deepest gratitude to my master thesis advisor/supervisor Dr.Hacini Slimane , He spends vary much time instructing me how to write a paper, how to search literature and how to collect data and be there for all kind of support

Nevertheless, it is lucky for me to meet some friends who inspirit my effort to overcome these difficulties. These friends are Nadine Massaoudi, Mounir khangaoui .

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General summary

The aim of this study is to see the effect of the earthquakes on the metal silo on multiple perspective due to the constant fear of earthquakes happening all over the world and specially Algeria , while taking the previous damages and the loses into account in order to have a better angle of view on how to deal with it and what to expect in the future The study was conducted by dividing it into two main parts a theoretical and explanatory one and a practical one using the Abaqus software to simulate the earthquake that made us reach the results of what can actually happen if an earthquake hits on different levels, while the silo itself filled with different materials .

Key words: Earthquakes, Metal silo, Algeria, Abaqus , Simulation.

الملخص العام :

الهدف من هذه الدراسة هو معرفة تأثير الزلازل على الصومعة المعدنية من منظور متعدد بسبب الخوف المستمر من الزلازل التي تحدث في جميع أنحاء العالم خاصة الجزائر مع مراعاة الأضرار السابقة والخسائر التي كان علينا أن نجمها للحصول على رؤية أفضل حول كيفية التعامل معها وما يمكن توقعه في المستقبل. لقد أجرينا الدراسة بتقسيمها إلى قسمين رئيسيين ، أحدهما نظري وتوضيحي والآخر عملي باستخدام برنامج Abaqus لمحاكاة الزلزال الذي ساعدنا للوصول إلى نتائج لتوقع ما يمكن أن يحدث بالفعل إذا ضرب زلزال على مستويات مختلفة ، بينما كانت الصومعة نفسها مليئة بمواد مختلفة.

الكلمات المفتاحية: الزلازل ، الصوامع المعدنية ، الجزائر ، اباكوس، المحاكاة.

Résumé général :

Le but de cette étude est de voir les effets de tremblements de terre sur le silo métallique sur de multiples perspectives par peur des conséquences du séisme qui se reproduit constamment dans le monde entier et spécialement en Algérie, tout en tenant compte les dommages et les pertes précédents que nous avons dû subir afin d'obtenir une meilleure perspective sur la façon d'y faire face et à quoi s'attendre à l'avenir.

Notre étude a été menée en deux parties, une, théorique explicative et une autre pratique en utilisant le logiciel Abaqus pour simuler le tremblement de terre qui nous a fait atteindre les résultats de ce qui peut réellement se produire si un séisme frappe à différents niveaux, tandis que le silo lui-même rempli de différents matériaux.

Mots clés : Tremblements de terre, Silo métallique, Algérie, Abaqus, Simulation.

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INTRODUCTION

INDUCTION

Earthquakes has been and always will be one of the engineering biggest dilemma, combined with its effect on the infrastructure and the structure itself it's a challenge as a civil engineer mostly to conduct a study case on its effect and bigger challenge on the anticipating of it.

And this study, aims to see the effect of earthquake on the level of metal silo's, since it's a structure that exists in Algeria and bearing in mind that during the last few period Algeria is facing numerous earthquakes in different regions that's effecting the stability of the things.

In this thesis, there will be many main chapters to analyze, starting form the first one which is the metal silo's itself, its different structure and positioning in the field and to go by the earthquake itself and see why does it happen, under what conditions and most importantly how to analyze an earthquake to surpass its own damage

In this thesis, the software that will be used is Abaqus which will allow to conduct the necessary simulation to see how it'll effect our silo's and what kind of damages to expect when it's happening.

The main aim is to have a live study case of the entire operation and see different silo's in many seismic areas in Algeria but unfortunately that was impossible to happened due to our national restriction because of Covid19.

Yet, enough data was collected from the web to help proceed our studies that will be seen in research present here.

And with all of this data, there will be a use of a real study of a metal silo and Abaqus software for the seismic simulation in order to calculate and get the best results possible for such behaviors.

Basically, this thesis will study how the earthquake will affect the damages done on the metal silo's and see the after effect of it that can lead to a conclusion on what' coming next specially on these times of stress, when earthquakes are happening all over Algeria and the world. As a civil engineer, this thesis will be insightful enough to understand the basics of what's going on at that level.

1. METAL SILO

1. METAL SILO

1.1. Generalities

Traditional storage practices in developing countries cannot guarantee protection against major storage pests of staple food crops like maize, leading to 20-30% grain losses, particularly due to post-harvest insect pests and grain pathogens.

As a result, smallholder farmers end up selling their grain soon after harvest, only to buy it back at an expensive price just a few months after harvest, falling in a poverty trap.

The potential impact on poverty reduction and greater livelihood security will not be realized, however, if farmers are unable to store grains and sell surplus production [9] at attractive prices.

To address this problem, a metal silo was developed as a valid option and proven effective in protecting stored grains from attack by storage insect pests.[9]

A metal silo is a cylindrical structure, constructed from a galvanized iron sheet and hermetically sealed, killing any insect pests that may be present.[10] The impact of metal silo technology in Africa, Asia and Latin America includes, improving food security, empowering smallholder farmers, enhancing income opportunities and job creation, and safeguarding the agro-ecosystems [11].

The metal silo can be fabricated in different sizes, 100 kg-3000 kg holding capacity by trained local artisans, with the corresponding prices of \$35 to \$375.[9] The use of metal silo, therefore, should be encouraged in order to prevent storage losses and enhance food security in developing countries.

1.2. Metal silo types

Metal silos aren't all built alike, especially when they are custom fabricated. But there are three main types of metal silos that are typically used in industrial settings. Knowing the difference between them — not only in terms of configurations but also applications — can be helpful to anyone who's setting out to source metal silos [12].

1.2.1. Flat-Bottom Metal Silos

Metal silos with flat bottoms are used to store materials for extended periods of time. Most often, they store grain, meaning that you'll find them at breweries, feed mills, flour mills, and port facilities, for example [12].



Figure 1: Flat-Bottom Metal Silos

While welded construction is available, flat-bottom metal silos are usually built using carbon steel body sheets that are bolted onto a frame made of structural steel stiffeners. All this metal is usually hot-dipped galvanized to protect it from the elements [12].

Important accessories for these large metal silos include wind rings, which stiffen flat-bottom metal silos for wind loading and bolster their structural stability [12] during filling and discharge, as well as industrial access equipment. The latter can include spiral stairs that wind around the silo (if it is big enough) and caged ladders to provide access to the inspection door at the top [12].

By equipping a flat-bottom silo with a sweep auger, the material at the bottom can be unloaded first according to the “first in, first out” principle [12]. A sweep auger will also provide controlled flow for a diverse range of stored materials, which means that a flat-bottom silo can be adapted to store diverse materials [12] over the years — rather than having to engineer a silo for a specific product’s physical properties, as with conical-bottom metal silos.

1.2.2. Conical-Bottom Metal Silos

Also known as “cone bottom silos,” conical-bottom metal silos are also used to store a wide variety of materials, including grain, sand and salt for winter road maintenance, and powder. But they are typically used for temporary storage as they often hold smaller quantities than flat-bottom silos and can be raised on structural steel supports to [12] permit access underneath, making loading materials for transport easier.

Much like flat-bottom silos, conical-bottom metal silos can be fabricated using sheets bolted to structural steel frames [12]. But they are also often made using welded construction, which lasts longer and produces a structure that is less likely to interfere with material flow [12].



Figure 2: Conical-Bottom Metal Silos

The conical hopper attached to the bottom of these silos allows for an easy, metered unloading, provided the material in the silo corresponds to the silo design [12]. Metal silos with conical bottoms must be precisely engineered for the material they are meant to store if flow is to be properly controlled [12].

Conical-bottom metal silos can be galvanized or painted to resist corrosion.

1.2.3. Horizontal Metal Silos

Like conical-bottom silos, horizontal metal silos are best suited for short-term storage. They are often used to aggregate metal chips, cement, lime, ash, and other waste particulates collected by air filtration systems [12].

Horizontal metal silos are almost always made using welded construction and finished with durable paint [12]. Coming in a wide variety of sizes, they can be designed to meet any planning or space restrictions, including those for interior spaces.

When installed inside a plant, horizontal metal silos are typically lifted off the ground on structural steel platforms to preserve floor space [12]. This also makes discharge convenient since gravity will do the work of pulling the stored material out of the silo via a chute or hopper [12].

Raised horizontal metal silos are accessed via stairs, ladders, or a combination of these two types of industrial access equipment, depending on the design.

1.3. Calculation and design of the metal silos and tanks

1.3.1 Algorithm of calculations:

Table 01: Algorithm of calculations

Step of analysis	Number of Eurocode	Comments
1	EN 1990	General information on reliability of structures
2	EN 1991-1, EN 1991-4	Loads and actions
3	EN 1993-3-2, EN 1993-4-1, EN 1993-4-2	Specific requirements for chimneys, silos and tanks
4	EN 1993-1-6	Calculation of shell structures
5	other	Calculation of other parts of structures

1.3.2. Reliability of structures:

Scope of EN 1991-4 actions on structures: silos and tanks

(I)P This part provides general principles and actions for the structural design of silos for the storage of particulate solids and tanks for the storage of fluids and shall be used in conjunction with EN 1990, other parts of EN 1991 and EN 1992[14] to EN 1999.

This part includes some provisions for actions on silo and tank structures that are not only associated with the stored solids or liquids (e.g. the effects of thermal differentials, aspects of the differential settlements of batteries of

The following geometrical limitations apply to the design rules for silos:

- The silo cross-section shapes are limited to those shown in Figure 1. Id, though minor variations may be accepted provided the structural consequences of the resulting changes in pressure are considered;

The following dimensional limitations apply:

$h-b./, d-c.<10$

-, $h-b.<100m$

-, $d-c.<60m$.

The transition lies in a single horizontal plane (see 1.1a);

The silo does not contain an internal structure such as a cone or pyramid with its apex uppermost, cross-beams, etc. [15]. However, a rectangular silo may contain internal ties [16].

The following limitations on the stored solids apply to the design rules for silos:

- Each silo is designed for a defined range of particulate solids properties;
- The stored solid is free-flowing, or the stored solid can be guaranteed to now freely within the silo container as designed (see 1.5.12 and Annex C);
- The maximum particle diameter of the stored solid is not greater than 0,03dc

NOTE: When particles are large compared to the silo wall thickness, account should be taken of the effects of single particles applying local forces on the wall [17].

8. EN 1991-4:2006 (E)

The following limitations on the filling and discharge managements apply to the design rules for silos:

- Filling involves only negligible inertia effects and impact loads
- Where discharge devices are used (for example feeders or internal flow tubes) solids flow is smooth and central

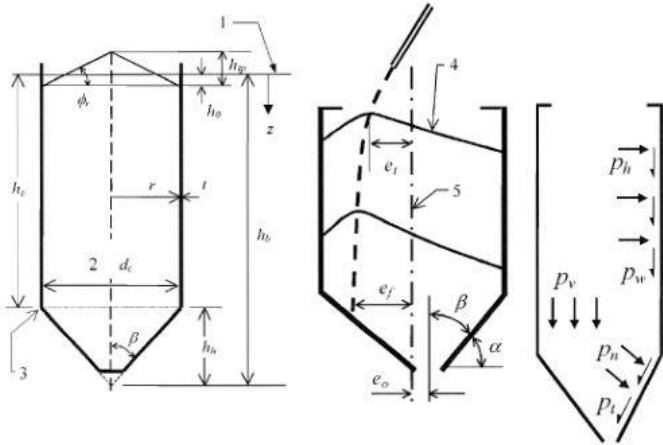
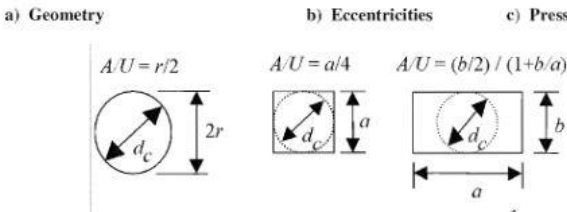


Figure 3 : Silo forms showing dimensions and pressure notation



Key:

- Equivalent surface
- Inside dimension
- Transition
- Surface profile for full condition
- Silo center line

1.3.3. Normative references:

This European Standard incorporates, by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text and the publications are listed hereafter [21]. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment [22] or revision. For undated references the latest edition of the publication applies (including amendments).

ISO 3898: 1997 Basis of design for structures: Notation. General symbols

NOTE: The following European Standards which are published or in preparation are cited at the appropriate places in the text:

- **1.3.4. Characteristics of analyzed structures:**

Table 02: Characteristics of analyzed structures

Structure	Consequence class	Thickness [mm]	Grade of steel	FEM shell elements
Chimney in an electric power station	CC2	10–20	1.4401 stainless steel	Four-nodes
Silo constructed from flat sheets	CC2	6–12	S355	Four-nodes
Tank for storage of ammonia water	CC3	6	1.4301 stainless steel	Four-nodes

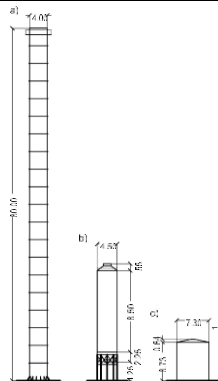


Figure 4: Schemes of analyzed structures: a) chimney, b) silo, c)

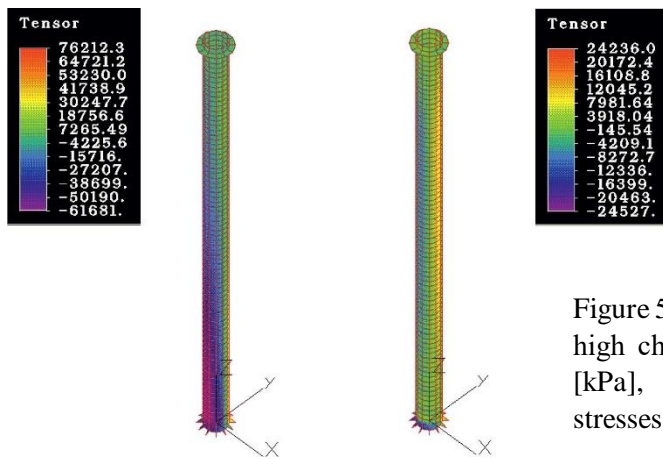


Figure 5: Example design results for the chimney 80m high chimney for the pressure of wind velocity: σ [kPa], meridional stresses (left), circumferential stresses (right), LA analysis, (Algor [22])

1.3.5. Results FEM for chimney:

Table 03: Results FEM for chimney:

Limit state (condition)	Check
LS1 (1)	$0.220 < 1.0$
LS3 (2)	$0.760 < 1.0$

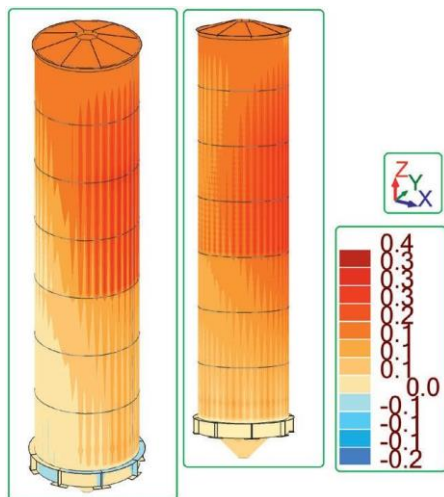


Figure 7 : Silo for wheat, FEM results, displacements u_s (left), general displacements (right) [cm], LA analysis, (Robot [23])

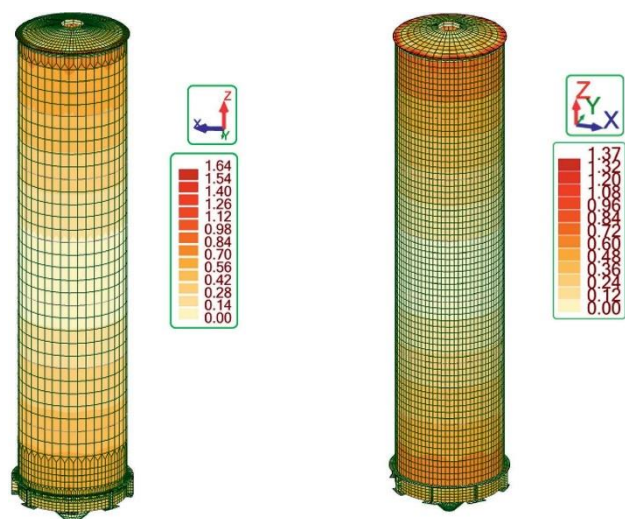


Figure 6 : Comparison of results from LA analysis (left) and GMNA analysis (right); dead weight, σ [MPa]

1.3.6. Results FEM for silo:

Table 04: Results FEM for silo:

Limit state (condition)	Check
LS1 (1)	0.277 < 1.0
LS3 (2)	0.907 < 1.0

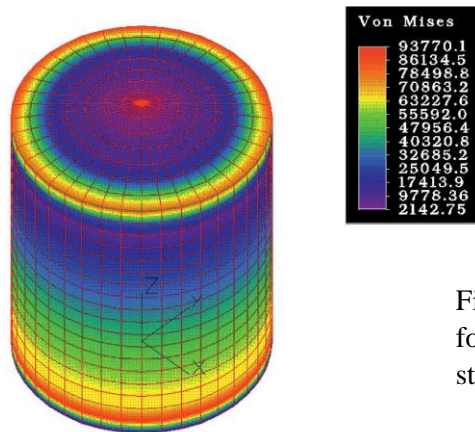


Fig. 8. Results of calculations (Algor [22]) for the most disadvantageous equivalent stress, LA analysis, [kPa]

SVIEW 4.16 Fileczki LC 1/ 1 Vu= 7 Lo= 45 Lu= 45 R= 0

1.3.7. Results FEM for tank:

Table 05: Results FEM for tank:

Limit state (condition)	Check
LS1 (1)	0.723 < 1.0
LS3 (2)	0.095 < 1.0

Safety factors:

- For ammonia water $\gamma = 1.40$,
- Other live loads $\gamma = 1.50$,
- For dead weight = 1.35, $\gamma = 1.10$, $\gamma = 1.25$, $\gamma = 1.05$, $k_{Fi} = 1.10$ (factor for actions for RC3).

1.3.7. Summary

The metal silo is a necessity in the modern world, they are considered as a big construction that can hold a huge amount of materials needed, that's why preserving them the right way and protecting them and protect ourselves also is a must, and so everyone needs to be ready in case of an earthquake to avoid all damages.

2. EARTHQUAKE

2. EARTHQUAKES

2.1. Generalities

- Earthquakes represent the vibration of Earth because of movements on faults.
- The focus is the point on the fault surface where motion begins.
- The epicenter is the point on Earth's surface directly above the focus.

An **earthquake** occurs when Earth's surface shakes because of the release of seismic energy following the rapid movement of large blocks of the crust along a fault. **Faults** are breaks in the crust that may be hundreds of kilometers long and extend downward 10 to 20 km (6-12 miles) into the crust [36]. The 1,200 km (750 miles) long San Andreas Fault that separates the North American and Pacific Plates in California is the most active fault system in the contiguous [36] U.S. The Izmit earthquake occurred on the North Anatolian Fault, a fault that is of similar length and sense of movement as the San Andreas Fault [36]. Unraveling the movement history of large faults that produce devastating but infrequent earthquakes can help predict the potential threat from similar faults elsewhere [36].

The point on the fault surface where movement begins, the earthquake source, is termed the **focus**. **Seismic waves** radiate outward from the focus [36]. Earthquake foci (plural of focus) occur at a range of depths. The majority of earthquakes occur at shallow depths that range from the surface down to 70 km (44 miles) [36]. Less frequent intermediate (70-300 km; 44-188 miles) and deep (300-700 km; 188-438 miles) earthquakes are generally associated with subduction zones where plates [36] descend into the mantle. Damage is greatest from shallow earthquakes because the seismic waves travel a shorter distance before reaching the surface.

The **earthquake effects**, the type of damage associated with earthquakes, include changes in the natural environment such as landslides but most attention is focused [36] on seismic waves are captured by a recorder known as a seismograph. The relative arrival times of different types of seismic waves is used to determine the distance of the

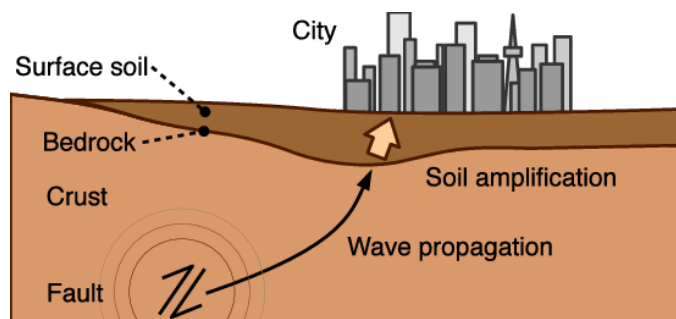


Figure 9: Physics-Based Urban Earthquake Simulation Enhanced by 10.7 BlnDOF \times 30 K Time-Step Unstructured FE Non-Linear Seismic Wave Simulation

seismograph station from the origin of the earthquake [36]. Three or more records can be used to pinpoint the earthquake's

2.2. Faults and Earthquakes

- Earthquakes represent the vibration of Earth because of movements on faults.
- Faults can be identified by the offset of rock layers on either side of the fault surface.
- Normal and reverse faults are types of dip-slip faults.
- Left-slip and right-slip faults are types of strike-slip faults.[36]
- Past fault movement has brought together rocks that used to be farther apart;
- Earthquakes on the fault have left surface evidence, such as surface ruptures or fault scarps (cliffs made by earthquakes);
- Earthquakes recorded by seismographic networks are mapped and indicate the location of a fault.

An earthquake occurs when Earth shakes because of the release of seismic energy following the rapid movement of large blocks of the crust along a fault [36]. A **fault** is a fracture in the crust, Faults may be hundreds of kilometers in length but only part of longer faults typically break during an earthquake [36] Fault segments that have not experienced a recent earthquake are termed **seismic gaps** and are considered potential sites for future events [36]. The Izmit earthquake occurred in a 150 km (94 mile) long gap at the western end of the North Anatolian Fault.[36]

Two adjacent fault segments to the east and west broke during large earthquakes in 1963 and 1967. Eleven earthquakes of magnitude 6.7 [36] or greater occurred along segments of the fault over the previous 60 years [36]. Even though scientists can identify potential seismic gaps, the faults may not cooperate to generate an earthquake [36]. Earthquake specialists predicted an earthquake would strike the region around the small California town of Parkfield before the end of 1993 but the quake still hasn't [36] shown up, despite the fact that there are millions of dollars' worth of instruments in the ground waiting for the big day to arrive [36].

Even the largest earthquakes require relatively small fault movements because such large volumes of rock are involved [36]. Offsets on faults for the largest of earthquakes are less than 10 meters, and typically **less than 5 meters per quake** [36]. The accumulated movement from

hundreds of thousands of earthquakes over millions of years results in the formation of mountains in association with plate boundaries [36].

2.2.1. Faults of earthquakes

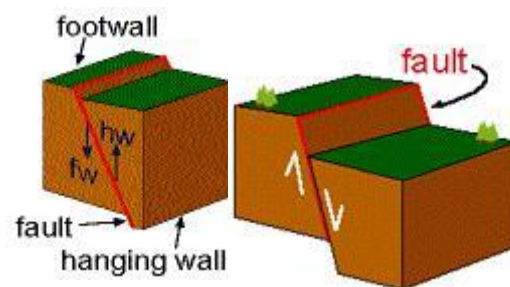
Surface features that have been broken and offset by the movement of faults are used to determine how fast the faults move and thus how often earthquakes are likely to occur. For example, a streambed that crosses the San Andreas fault near Los Angeles is now offset 83 meters (91 yards) from its original course. The sediments in the abandoned streambed are about 2,500 years old. If the movement on the San Andreas has cut off that streambed within the last 2,500 years, then the average slip rate on the fault is 33 millimeters (1.3 inches) per year.

This does not mean the fault slips 33 millimeters each year. Rather, it stores up 33 millimeters of slip each year to be released in infrequent earthquakes. The last earthquake offset the streambed another 5 meters (16 feet). Assuming that all earthquakes have 5 meters (5000 millimeters) of slip, there will be earthquakes on average every 150 years: 5000 millimeters divided by 33 millimeters per year equals 150 years. This does not mean the earthquakes will be exactly 150 years apart. While the San Andreas fault has averaged 150 years between events, earthquakes have occurred as few as 45 years and as many as 300 years apart.

2.2.2. Fault Classification:

Faults are distinguished as dip-slip or strike-slip faults. Two types of **dip-slip faults** are identified on the basis of the relative motion of rocks across an inclined fault surface (Fig. 10).

Figure 10. Top: The hanging wall (hw) lies above an inclined fault; the footwall (fw) lies below the fault. Bottom: Normal fault.



The block of rocks above a fault is termed the **hanging wall**; the **footwall** lies below the fault [37]. Miners working in shafts that crossed faults were able to hang their lanterns from the

hanging wall while their feet remained below the fault in the footwall [36]. Inclined faults can be identified by the offset of rock layers on either side of the fault surface [36]. The hanging wall moves down relative to the footwall in a **normal fault**. In contrast, the hanging wall moves up relative to the footwall in a **reverse fault** [38]. Movement on a dip-slip fault often results in a break or offset at the land surface. This break in slope is known as a **fault scarp** (Fig 11) [39].



Figure 118: Fault scarp formed during the Hogben Lake earthquake, Montana, 1959. Person in foreground is approximately 2 meters tall. Surface at bottom of slope was at same elevation as upper surface prior to movement on the normal fault.

Two types of **strike-slip faults**, left-slip and right-slip faults, are identified on the basis of the motion on vertical fault surfaces [36]. An observer, standing on one side of the fault, sees objects on the other side of the fault move to the right for a **right-slip fault** or to the left for a **left-slip fault** [36]. The 1,200 km long **San Andreas Fault**, California, is a famous example of a right-slip fault. Areas of frequent earthquake activity are laced with faults. Maps of California show that several faults make up the San Andreas Fault system [40]. The North Anatolian Fault that broke during the Izmit earthquake is also a right-slip fault (Fig. 8) and is of similar length as the San Andreas fault [36].

2.2.3. Faults and Plate Boundaries:

Earthquake distribution is far from random. Earthquakes occur on active faults and active faults are preferentially located along plate boundaries (Fig. 12) [36]. Although, both dip-slip and strike-slip faults are associated with all types of plate boundary, each type of boundary is characterized by a specific fault style [41]. Strike-slip faults are common at transform plate boundaries

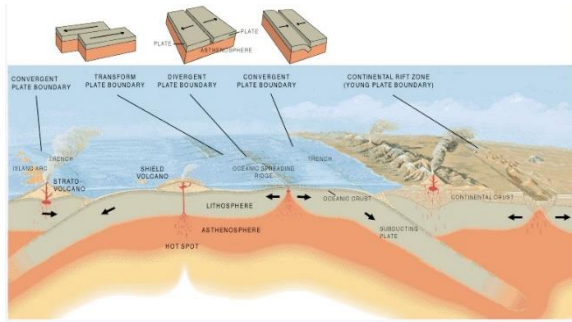


Figure 9: Faults | Earth 520: Plate Tectonics and People: Foundation

2.3. Seismic Waves

- Seismic waves can be divided into surface waves that travel on Earth's surface and body waves that travel through Earth.
- Body waves are further divided into S waves and P waves.
- Seismic waves are recorded on a seismogram at a seismograph station.
- The distance of an earthquake epicenter from a seismograph station is determined by the difference in the arrival times of P and S waves at a seismograph station [44].
- Earthquake magnitude is calculated using the amplitude (height) of the S wave recorded on a seismogram [45].

Seismic waves represent the energy released from the earthquake focus [46]. There are two types of seismic waves:

- **Surface waves** travel on Earth's surface and cause much of the destruction associated with earthquakes. Undulations of the land surface during an earthquake are a representation of surface waves (Fig. 13) [48]. Surface waves may result in vertical motions (**Rayleigh waves**), much like waves

traveling through water, or sideways motions (**Love waves**) with no vertical component of movement.

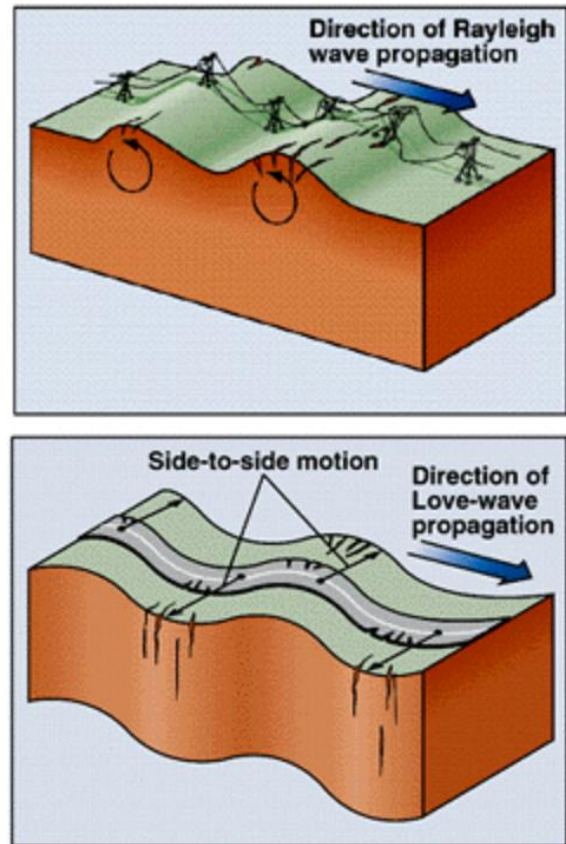


Figure 13: Rayleigh (top) and Love waves (bottom) are surface waves with contrasting motion directions generated during an earthquake.

- **Body waves** travel through Earth's interior. These are further subdivided into **P** (primary) waves and **S** (secondary or shear) waves based upon their vibration direction and velocity. Variations in seismic wave velocity are used to infer the properties of Earth's interior **waves** vibrate parallel to their travel direction in the same way a vibration passes along a slinky toy (Fig. 11). P waves travel at speeds of 4 to 6 km per second (2.5-4 miles per second) in the uppermost part of the crust. **S waves** vibrate perpendicular to their travel direction, like the wave that passes along a rope when it is given a sharp jerk (Fig. 13). S wave velocity is 3 to 4 km per second (2-2.5 miles per second) in the shallow crust.

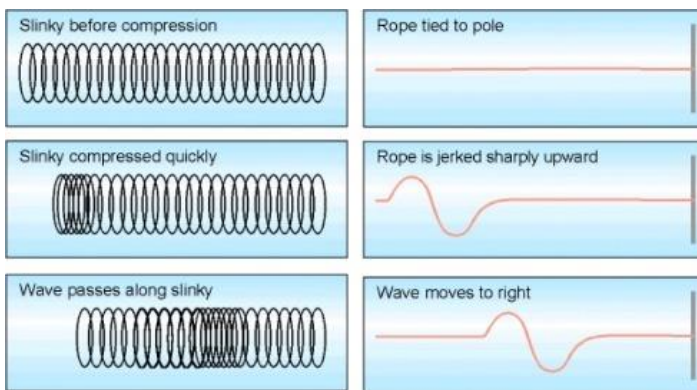


Figure 10: seismogram

The velocity of seismic waves is lower in loose, unconsolidated materials (sand, partially melted rock) and higher in solid materials (rock) [50].

Both P and S waves are generated at an earthquake focus as a result of movement on a fault [51]. P waves will arrive at a recording station (**seismograph station**) first because of their greater velocity [52]. Surface waves are the last to arrive because P and S waves travel a more direct route through the earth (Fig. 15) [53].

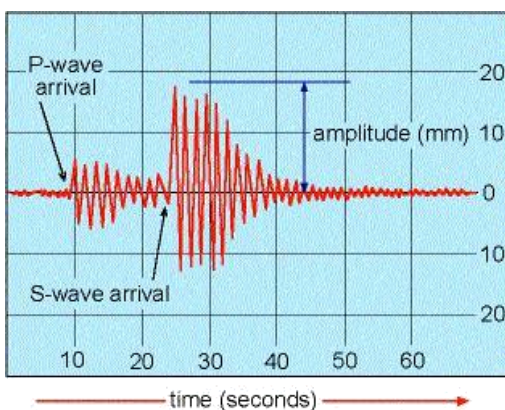


Figure 11: Contrasting travel paths for surface waves and body waves following an earthquake.

The record of an earthquake at a seismograph station is a **seismogram** (Fig. 16) [54]. The principal elements of a seismogram that interest seismologists (scientists who study earthquakes) are the relative size of the recorded waves and the difference in time that the first P and S waves were recorded. The amplitude of the recorded wave is proportional to the magnitude of shaking associated with the earthquake but shaking may vary with the character of the material [55] underlying the seismograph station. Loose, unconsolidated materials (e.g., mud, sediment) may exaggerate the shaking whereas solid bedrock may result in smaller vibrations.

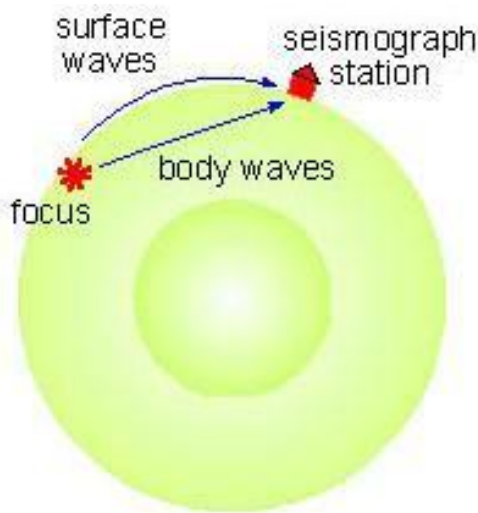


Figure 1612: An idealized seismogram illustrating the sequential arrival of seismic waves. Determination of the distance from an epicenter require calculating the difference in arrival time of P and S waves (~14 seconds). Earthquake magnitude is related to the ample

The difference in arrival time between P and S waves on a seismogram can be used to determine the distance of the station from the earthquake source and the amplitude [56] (height) of the S wave recorded at the station can be used to determine earthquake magnitude (see Measurement of Earthquakes)[57].

The time interval between the recorded arrival of P and S waves increases the further the seismograph station is located from the epicenter [58]. Seismologists match the time difference with standard curves (Fig. 17) to determine distance from the earthquake.

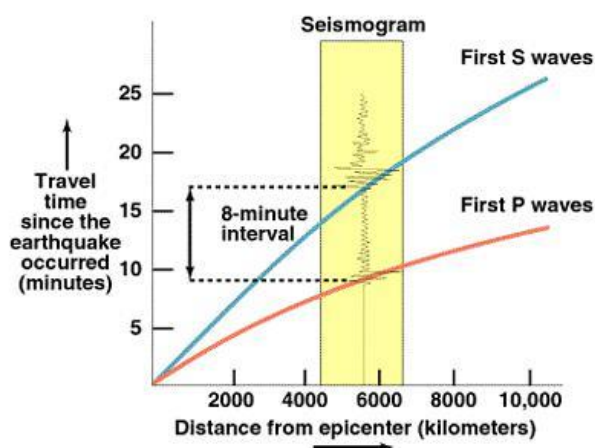


Figure 17: Graph of distance from the epicenter and time for seismic waves to reach seismograph station. The time interval between the arrival of P and S waves increases with increasing distance from the epicenter.

Data at a single seismograph station are insufficient to pin-point the earthquake epicenter because a seismogram yields only the distance from the earthquake source. [60] The epicenter could be located anywhere along a circular arc of the calculated distance from the seismograph station [61]. Seismologists must use data from multiple recording stations to learn the location of the event. The common intersection point for several circles plotted relative to different stations represents the point on the surface above the earthquake source

2.4. Effects of Earthquakes

- A major earthquake under a heavily populated area in the U.S. could result in thousands of deaths.
- Several effects of earthquakes could result in extensive damages.
- Ground shaking can collapse buildings.
- Uplift may raise or lower large areas of Earth's surface.
- Liquefaction in water-saturated sediment can result in the collapse and subsidence of the ground surface [63].
- Landslides are a potential hazard on steep slopes in seismic zones.
- Tsunamis, giant sea waves, are dangerous to coastal communities, especially around the Pacific Ocean.

A magnitude 6.7 earthquake struck the Northridge suburb of Los Angeles on January 17, 1994. The earthquake resulted in the deaths of 57 people and injured over 9,000 more [65]. There are about 150 earthquakes of this magnitude worldwide each year but this was the first time a quake of this size occurred in a heavily developed area of the U.S. An earthquake of similar size killed over 50,000 people in Iran in 1993.

The Elysian Park fault was recently discovered below downtown Los Angeles and may produce substantial future earthquakes [66]. Movement on the 55 km (35 miles) long fault could result in up to 5,000 deaths, leave 750,000 homeless, and cause \$100 billion in damages in Los Angeles. A comparable earthquake in Kobe, Japan (exactly one year after the Northridge quake), killed over 6,000 people.

The images in the following figures show damage from the largest recorded U.S. earthquake (Alaska, 1964) and illustrate the effects of earthquakes. All images taken from USGS National Earthquake Information Center (NEIC) [67].

Sudden changes on or near the earth's surface result from earthquakes and may include:

Ground Shaking: Rapid horizontal movements associated with earthquakes may shift homes off their foundations and cause tall buildings to collapse or "pancake" as floors collapse down onto one another. Shaking is exaggerated in areas where the underlying sediment is weak or saturated with water (Figs. 18, 19) [69].



Figure 13: Part of a railroad bridge over the Copper River was shaken loose by the 1964 Anchorage earthquake. Image courtesy of USGS

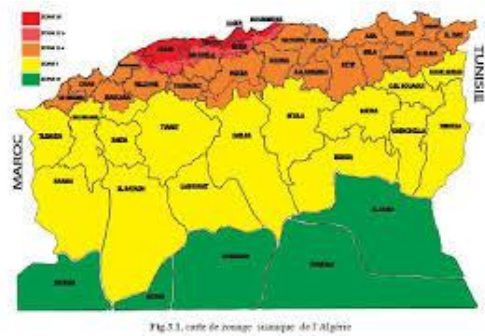


Figure 14: This map shows in color those parts of the contiguous States of Algeria that risks Earthquakes happening by RPA2003

Fault Rupture and Uplift: Break of the ground surface by the fault plane may form a step in the surface known as a fault scarp (Fig. 11) [70]. Large sections of Earth's surface may change elevation as a result of uplift on an earthquake fault (Fig. 19). Mountains east of Los Angeles were uplifted 0.3 meters (1 foot) by the 1994 Northridge earthquake.

Liquefaction: Liquefaction occurs when water-saturated sediment is reorganized because of violent shaking. The sediment collapses, expelling the water, and causing the ground surface to subside.

Landslides: Earthquakes are often associated with mountains formed along convergent plate boundaries [72]. The steep slopes present in these environments are prone to landslides when shaken (Fig. 20). Landslides are common following earthquakes. The Pacific Tsunami Warning System (PTWS) is a network of stations that attempt to identify potentially damaging tsunamis from earthquakes in or around the Pacific [73] Ocean. The PTWS issues warnings or watches that predict tsunami arrival times for coastal areas.



Figure 15: Top: uplifting floor

2.5. Measurement of Earthquakes

- There are three methods used for measuring earthquakes.
- The Modified Mercalli scale measures intensity and is often used to rank the cultural effects of historical earthquakes.
- Mercalli scale values vary with distance from epicenter, building materials used, and population density [75].
- The Richter scale is the most well-known and measures earthquake magnitude using the amplitude (height) of the S wave recorded on a seismogram.
- Each division in the Richter scale represents a 10-fold increase in amplitude and an approximate 30-times increase in energy released [75].
- The moment-magnitude scale has recently found favor as a method that more accurately measures energy release on large faults [76].

There are three principal methods of measuring the effects of earthquakes.

- Modified Mercalli scale is used to measure damage and human perception of an earthquake.

- Richter scale is the most familiar and measures the size of the seismic waves recorded at a seismogram [77].
- Moment-magnitude scale has replaced the Richter scale in popularity among geophysicists because it gives a more accurate interpretation of the amount of energy released [78] by an earthquake.

Modified Mercalli Scale:

The Mercalli scale measures earthquake intensity: the level of destruction of the earthquake (higher values) and the effect of the event on people (lower values). The scale ranks intensity from I to XII (1-12) using Roman numerals. The table below summarizes the characteristics of the Mercalli scale.

Index Effects of Earthquake on People and Structures

- I. Not felt by people.
- II. Felt by people at rest on upper floors of buildings.
- III. May be felt by people indoors. Vibrations similar to the passing of a truck.
- IV. Felt indoors by many, outdoors by few. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building.
- V. Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned.
- VI. Felt by all; many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
- VII. Slight to moderate damage in ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
- VIII. Slight damage in buildings designed to withstand earthquakes; heavy damage in poorly constructed structures. Chimneys, columns, walls may fall.

- IX. Considerable damage in specially designed structures. Damage great in substantial buildings, partial collapse. Buildings shifted off foundations.
 - X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations.
 - XI. Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.
 - XII. Total damage, objects thrown into air.
-

2.6. Distribution of Earthquakes

- Earthquakes are most frequent along plate boundaries.
- The largest earthquakes are associated with convergent plate boundaries.
- Oceanic ridges are characterized by shallow earthquakes.
- Deep earthquakes (to depths of ~700 km) occur within subduction zones along convergent plate boundaries.
- The most devastating earthquakes are typically shallow earthquakes (0-33 km depth).
- Alaska has the largest U.S. earthquakes but California has the most damages because of a larger population.
- Some large historical earthquakes have been identified in the eastern U.S., in particular a swarm of three major quakes which occurred at New Madrid, Missouri, 1811-1812 [88].

2.6.1. Occurrence of earthquakes

Earthquakes occur at many sites around the world but seismicity is concentrated in specific locations. A map of the Pacific Ocean basin showing the location of large earthquakes over a 20-year period (1975-1995) is presented below [89]. Compare the map with a map of plate boundaries for the same area (Fig. 21).



Figure 16 : Top Distribution of earthquake focal depths around the Pacific Ocean.

Earthquake distributions have several characteristics:

- There is a strong correlation between earthquake foci and plate boundaries (Fig. 21). Swarms of earthquakes resulting from collisions of continental plates form a belt across central Asia, through the Middle East and southern Europe.
- Continental interiors that are far removed from plate boundaries (e.g., Canada) have few earthquakes.
- A belt of shallow earthquakes can be traced along the global oceanic ridge system from the center of the Atlantic Ocean, through the Indian Ocean, around the southern [90] Pacific Ocean, and into the East Pacific.
- Earthquakes are present under hot spots such as the Hawaiian Islands in the central Pacific Ocean.
- The largest earthquakes are associated with convergent plate boundaries (Fig. 22) [91].

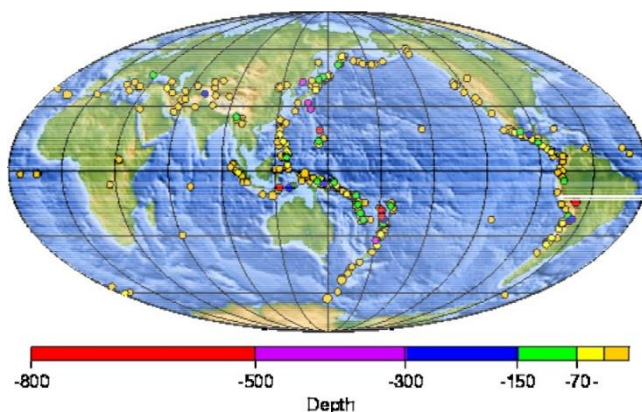


Figure 22: Locations and focal depths of earthquakes of magnitude 7 and greater from 1975-1998. Colors correspond to focal depths

2.6.2. variation of focal depth with location

Epicenter locations on the maps above are colored based upon the depths of the earthquake foci. Several patterns are obvious from the map:

- Deep earthquakes (focal depth >300 km) are present in association with subduction zones along convergent plate boundaries such as western South America (Nazca/South American Plates), southern Alaska (Pacific/North American Plates), and the southwest Pacific (Pacific/Australian Plates).

2.6.3. where are the most active area in Algeria for earthquakes

Algeria has experienced many destructive earthquakes during the last few centuries (e.g., Ayad and Boozehound, 2015). The city of El Asnam (formerly Orléanville, today Chlef) was severely damaged in 1954 and 1980 by magnitude 6.7 and 7.3 earthquakes, respectively. On October 10, 1989, a magnitude 5.9 earthquake struck the Mont Chenoua-Tipasa coastal area approximately 150 km west of Zemmouri, which is where the May 21, 2003 earthquake occurred (Mw6.8). Many other large historical and instrumental earthquakes have severely damaged the coastal cities of Algeria over the last few centuries (i.e., around Algiers, Oran, Mascara, Djidjelli, Constantine and Bejaia). These earthquakes suggest active deformation of the margin in conjunction with the clear offshore extent of active coastal faults. According to several studies, the main active geological structures around El Asnam, Algiers, Zemmouri and Boumerdès have experienced several disastrous earthquakes. Many other earthquakes have occurred in and around the Chlef and Mitidja Basins, underlining the seismic activity in the area. In this chapter, it is highlighted that the main characteristics of the two largest earthquakes that have occurred in Algeria in the modern period: the El Asnam earthquakes of September 9 (Mw6.7) and October 10 1980 (Mw7.3), and the Zemmouri-Boumerdès earthquake of May 21, 2003, (Mw6.8).

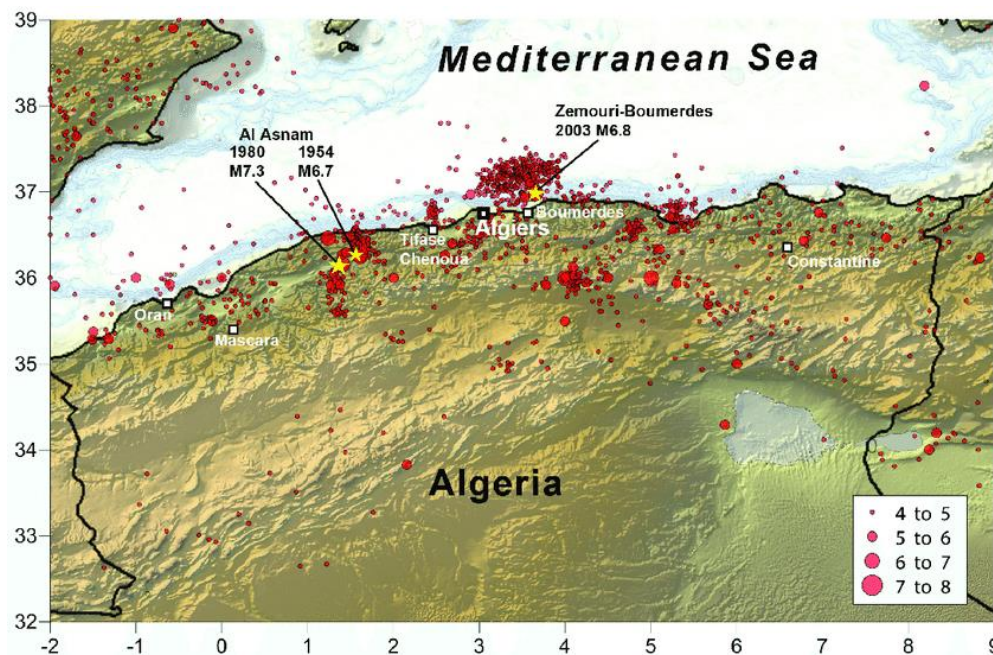


Figure 17 : Seismicity ($M \geq 4.0$) of Algeria for 1910-2016. Seismic data were taken from the ISC database. The yellow stars represent the three major earthquakes discussed in this study. The topography and bathymetry data were extracted from the Shuttle Radar Topography.

2.6.4. Richter Scale

The Richter scale measures earthquake magnitude, the amplitude of seismic waves recorded on a seismograph following an earthquake. (See the Virtual Earthquake exercise on page 11).

$$M_b = \log_{10}(A/T) + Q$$

Formula to determine magnitude from body waves (M_b) where A is the amplitude of ground motion (microns); T is time taken for motion (seconds); and Q is a correction for distance from the epicenter and the focal depth (kilometers).

Charles Richter developed the scale in the 1930s to measure shallow earthquakes in California. These early measurements of magnitude (M_L - local magnitude) simply relied on using two factors (the difference in P- and S-wave arrival times and S-wave amplitude). The measured earthquakes were less than 600 km (375 miles) from the seismograph stations and occurred at similar depths in the crust.

More complex formulae to determine magnitude from seismic body waves or surface waves were developed as the number of seismograph stations increased and it was recognized that earthquakes occurred at a range of depths [106].	Magnitude	Ground Motion	Energy
	1	29	1
	2	10	30
	3	100	900
	4	1,000	27,000
	5	10,000	810,000
	6	100,000	24,300,000
The Richter scale is logarithmic, each division represents a 10-fold increase in the ground motion associated	7	1,000,000	729,000,000
	8	10,000,000	21,870,000,000

with the earthquake, and ~30-times increase in energy [107] released. For example, a magnitude 7 earthquake has ten times as much ground motion (and releases over 30-times the energy) as a magnitude 6, 100 times as much motion (900 times the energy) as a magnitude 5, 1,000 times the motion of a magnitude 4, etc. [108]

Unlike the Mercalli scale, the Richter scale does not have a maximum value; it is open-ended.[109] The largest earthquakes measured with the Richter scale have magnitudes between 8 and 9. It is probable that rocks in Earth's crust are unable to withstand stresses necessary to generate earthquakes of magnitude 9 or more.

The terminology used to describe earthquakes is dependent upon their magnitude.

Description	Magnitude	Equivalent Intensity	Number per Year
Great	8+	XI-XII	1
Major	7-7.9	IX-X	18
Strong	6-6.9	VII-VIII	120
Moderate	5-5.9	VI-VII	800

Moment-Magnitude Scale:

The moment-magnitude (M_w) scale measures the energy released by the earthquake more accurately than the Richter scale.[110] The amount of energy released is related to rock properties such

$$M_w = 2/3 \log_{10}(M_0) - 10.7$$

Formula to determine magnitude where $M_0 = mSd$, where m is shear strength of the faulted rock, S is the area of the fault, and d is fault displacement.

as the rock rigidity, area of the fault surface and amount of movement on the fault.[111] It provides the most accurate means of comparison of large earthquakes.

2.7. Earthquake Prediction

2.7.1 where and how big

Answers to the Where? and How big? questions are already known in regions of frequent seismic activity. The answers to these questions depend on an understanding of the earthquake mechanism. As discussed, the fact that earthquakes occur on faults. Many active faults have already been discovered but some questions remain about the potential size of earthquakes on faults that have no associated historical earthquakes. For such faults, scientists attempt to estimate future earthquake magnitudes from fault size. Earthquake magnitude is directly related

to fault length - the longer the fault the bigger the earthquake (Fig. 25). The 1906 San Francisco earthquake (M_w 7.7) [117] was caused by rupture of 400 km (250 miles) of the San Andreas Fault and shaking lasted for nearly two minutes. In contrast the magnitude 6.7 [118] Northridge earthquake was caused by displacement on a 14 km (9 miles) long fault segment and the duration of shaking was just 7 seconds.[119]

2.7.2. When?

Displacement on faults is related to crustal deformation associated with plate tectonics and is concentrated in relatively narrow zones along plate margins. Stresses build up in rocks where plates interact. Faults exhibit movement when stresses reach sufficient levels [120]. Rocks adjacent to the fault may be deformed prior to fault movement. Stresses cause deformation of rocks (**strain**) and geologists can measure the accumulation of strain in deforming rocks in an effort to predict the timing of future earthquakes.

Strain can be measured in the vicinity of active faults using a variety of instruments including creepmeters, strain meters, and satellite positioning systems.[121] **Creepmeters** survey displacement between two points on opposite sides of a fault. As strain increases the distance between points increases.[122] **Strain meters** measure the distortion of the originally circular profile of cylindrical boreholes as a result of deformation. Boreholes are distorted to an increasingly elliptical shape in section as strain accumulates. Satellites of the **Global Positioning System** (GPS) can be used to continually monitor the location of receivers on the ground on either side of a fault.[123] Distances between stations distributed over an area of hundreds of square kilometers can be determined to within a few centimeters [124]. Monitoring of stations over months or years reveals changes in the relative positions of receivers related to the buildup of strain along the fault [124].

Scientists can establish an average recurrence interval - the time between earthquakes of similar magnitude - for individual faults by determining the ages of offset [125] layers of rocks and/or sediment. Analysis of how much time has elapsed since the last earthquake and the amount of energy that was released (magnitude) help reveal which faults may be storing up sufficient strain for earthquakes in the relatively near future.[126]

2.7.3. Probability Theory

Researchers have used statistical methods to predict the **probability** of future damaging earthquakes on particular faults with sufficient record of seismicity. Faults with a high probability of an earthquake exhibit a lot of stored strain and a long-time interval without fault movement.

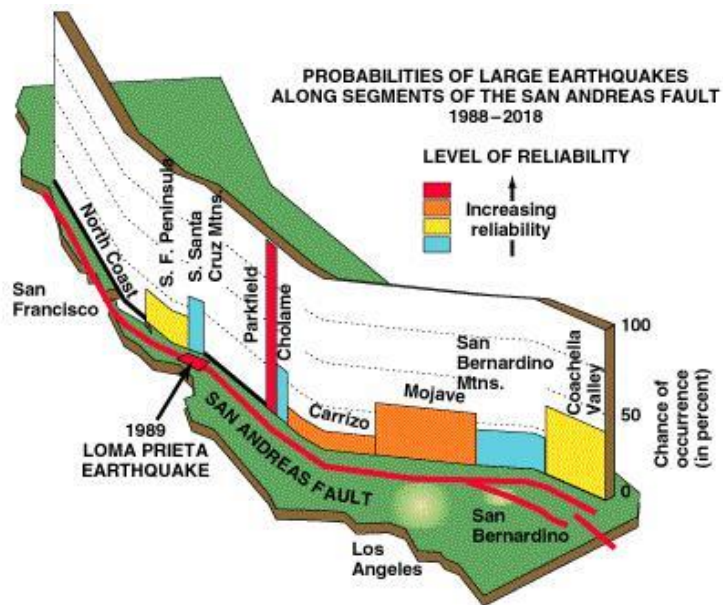


Figure 18: The probability of fault movement varies along the San Andreas Fault. Segments along the southern half of the fault system are most likely to break, especially at Parkfield.

2.8. Summary

An Earthquake is something that happens suddenly. The occurrence can be anticipated but it can happen at any moment anywhere, That's why being well prepared for it is a need.

History has showed the damages and effects that it can leave in their infrastructure or human damages so the engineer must be set and ready to face that with materials needed.

3. ABAQUS PRESENTATION

3. ABAQUS PRESENTATION

3.1. Generalities

Abaqus/CAE, or "Complete **Abaqus** Environment" (a backronym with a root in Computer-Aided Engineering). It is a **software** application **used** for both the modeling and analysis of mechanical components and assemblies (pre-processing) and visualizing the finite element [136] analysis result, and mainly utilized during the entire project and relying on it to process the results and simulate the scenes

It's also a software suite for finite element analysis and computer-aided engineering, originally released in 1978 [137]. The name and logo of this software are based on the abacus calculation tool [138]. The Abaqus product suite consists of five core software products: Abaqus/CAE, or "Complete Abaqus Environment.

3.2. Finite element method:

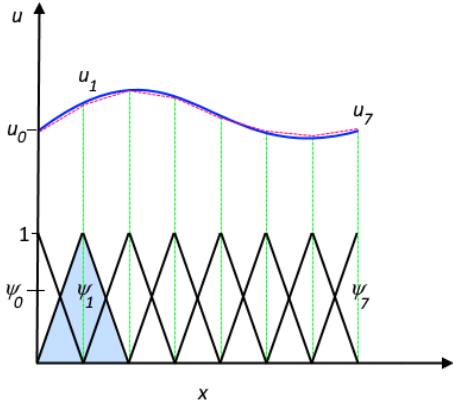
The description of the laws of physics for space- and time-dependent problems are usually expressed in terms of *partial differential equations* (PDEs). For the vast majority of geometries and problems, these PDEs cannot be solved with analytical methods [132]. Instead, an approximation of the equations can be constructed, typically based upon different types of *discretization's*. [132] These discretization methods approximate the PDEs with *numerical model equations*, which can be solved using numerical methods. [132] The solution to the numerical model equations are, in turn, an approximation of the real solution to the PDEs. The *finite element method* (FEM) is used to compute such approximations. [132]

Take, for example, a function u that may be the dependent variable in a PDE (i.e., temperature, electric potential, pressure, etc.) The function u can be approximated by a function u_h using linear combinations of basic functions according to the following expressions:

$$(1) \quad u \approx u_h \quad \text{And} \quad (2) \quad u_h = \sum_i u_i \psi_i$$

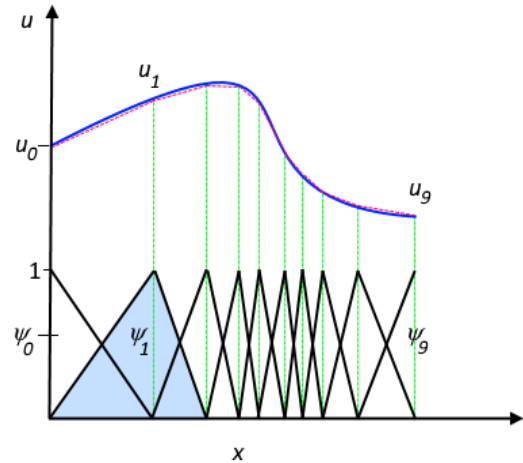
Here, ψ_i denotes the basic functions and u_i denotes the coefficients of the functions that approximate u with u_h . The figure below illustrates this principle for a 1D problem. u could, for

instance, represent the temperature along the length (x) of a rod that is not uniformly heated. Here, the linear basis functions have a value of 1 at their respective nodes and 0 at other nodes. In this case, there are seven elements along the portion of the x -axis, where the function u is defined (i.e., the length of the rod).[134]



The function u (solid blue line) is approximated with u_h (dashed red line), which is a linear combination of linear basis functions (i_n is represented by the solid black lines). The coefficients are denoted by u_0 through u_7 .

One of the benefits of using the finite element method is that it offers great freedom in the selection of discretization, both in the elements that may be used [135] to discretize space and the basic functions. In the figure above, for example, the elements are uniformly distributed over the x -axis, although this does not have to be the case. Smaller elements in a region where the gradient of u is large could also have been applied, as highlighted below.



The function u (solid blue line) is approximated with u_h (dashed red line), which is a linear combination of linear basis functions (i_n is represented by the solid black lines). The coefficients are denoted by u_0 through u_7 .

Both of these figures show that the selected linear basis functions include very limited support (nonzero only over a narrow interval) and overlap along the x -axis. Depending on the problem at hand, other functions may be chosen instead of linear functions.

Looking back at the history of FEM, the usefulness of the method was first recognized at the start of the 1940s by Richard Courant, a German-American mathematician.[133] While Courant recognized its application to a range of problems, it took several decades before the approach was applied generally in fields outside of structural mechanics, becoming what it is today.

3.3. Presentation of the calculus cod of ABAQUS

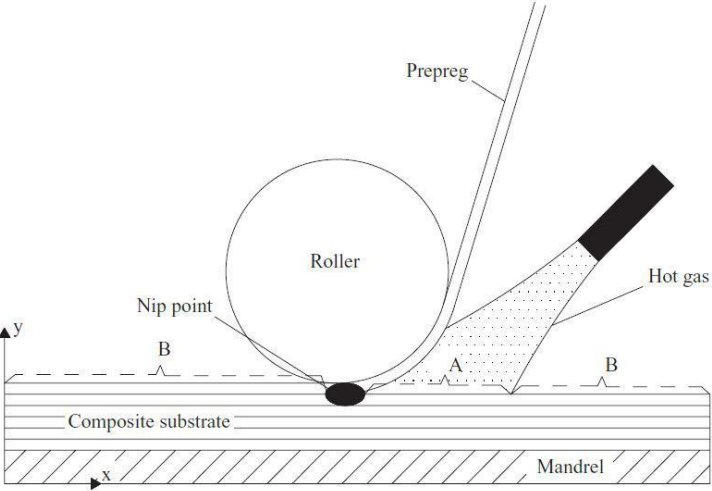
3.3.1. ABAQUS/Standard

ABAQUS has two structural analysis types - Standard and Explicit. The ABAQUS/Standard is more efficient for solving smooth nonlinear problems; on the other hand, ABAQUS/Explicit is the choice for a wave propagation analysis. For this simulation, the nature of process modelling is of a smooth nonlinear characteristic. Moreover, there is no stress wave study necessary in this simulation. Therefore, a standard (Implicit) analysis is considered in ABAQUS for this thesis work.

3.3.3. Simulation Strategies

3.3.3.1. Non - Linear Analysis

Figure 25 : The schematic diagram of the modelling of the thermoplastic composite prepreg lay-up process (A - Boundary impacted by heat, B - Boundary under natural convection). [49]



A nonlinear structural analysis is used when the structure’s stiffness changes during loading. The in - situ process simulation consists of non - linear material behavior, therefore it is mandatory to choose use a non - linear analysis for this simulation to obtain converged results [143]. The behavior of the thermoplastic composite is presented in section A sample simulation test with linear type analysis was performed, which resulted in erroneous displacements and errors during the simulation as expected. [144]

3.3.4. Numerical Modelling: Methodology

3.3.3.3. Modelling Space - 3D

Previous studies have all been performed using 2D modelling of the tape placement, except for one research work by Chinrest, performed using three-dimensional.

X. Plane comprising of the length of the tape and through the thickness of the laminate

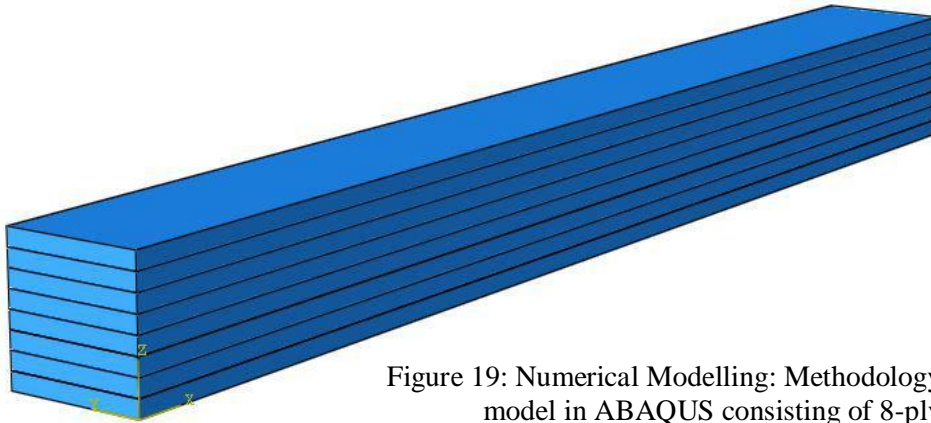


Figure 19: Numerical Modelling: Methodology: The 3D laminate model in ABAQUS consisting of 8-ply laminate.

(3D) modelling [2]. Though the computational time is considerably less for a 2D case, ABAQUS allows us to model the tape placement in 3D thereby allowing us to simulate the effects across the tape width. Initially, the tape parts were modelled as shells in ABAQUS, however, transient temperature loads could not be applied to shell elements. The placement of one layer over another was not realistic as the planar parts coincided in space without an offset prepreg thickness. This meant that results through the thickness could not be estimated and visualized. Additionally, the thermal interactions between the tape surfaces could not be prescribed for shell parts. Several errors emerged when the simulation was performed using a shell part model, therefore the modelling of the tape part was selected as a 3D solid part, as shown in Figure 26. In this approach, there is also the possibility to visualize the tape deformations while processing and adapt the processing parameters accordingly [146]. A 3D model simulation would involve an increase in the nodal degrees of freedom and subsequent increased computational time. Therefore, in order to compute the results faster, a mesh convergence study is necessary to determine the optimum mesh size.

3.4. Presentations of the finite elements calculation code ABAQUS

3.4.1. ABAQUS / Standard: Implicit algorithm

- General code of finite element analysis (spatial discretization)
- Resolution based on Newton-Raphson algorithm and Risk method. Linear and non-linear problems.
- 1D, 2D, 3D and Axisymmetric geometry.
- Numerous analysis procedures in the time and frequency domain.

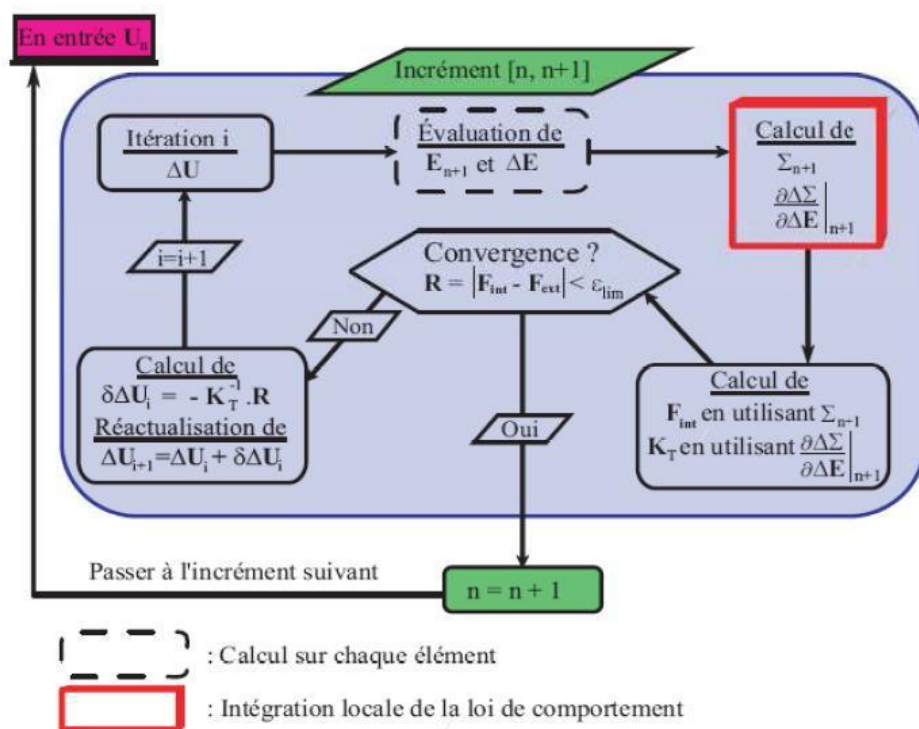


Figure 20: Flowchart of implicit scheme resolution.

3.4.2. ABAQUS / Explicit: explicit "Dynamic" algorithm

- Nonlinear analysis (spatial and temporal discretization)
- Transient and dynamic problem of structures
- Resolution based on the explicit method of time integration

But possibility of quasi-static analyzes where there is an important nonlinear behavior.

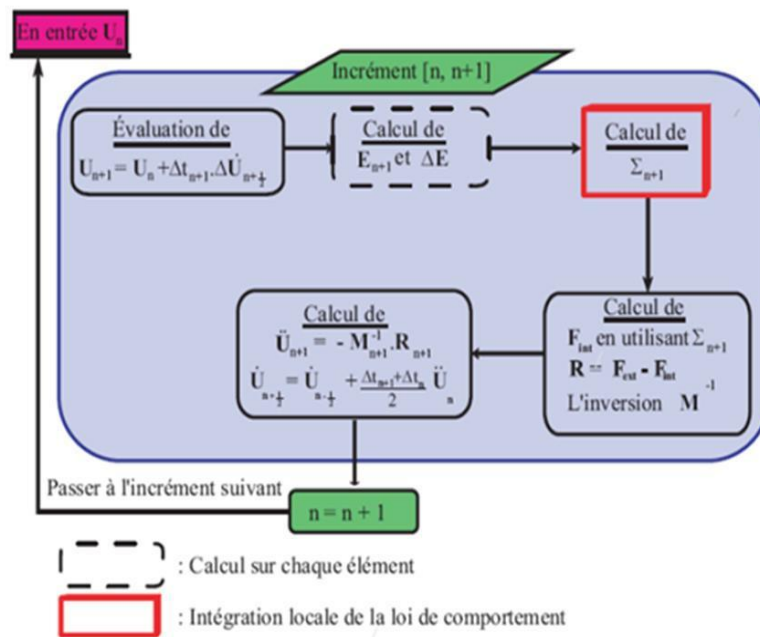


Figure 21: Explicit schema resolution flowchart.

3.5. Presentation of the different types of Abaqus elements

The ABAQUS calculation code has a multitude of element types that differ in their interpolation, symmetry and physical properties. Thus, the code proposes elements with 3D dimensions, with 2D dimensions of the linear elements (1D) and the connectors.

The choice between these different dimensionalities depends on the mastery of the problem to simulate.

This makes it possible to take account of geometry symmetries, loadings, boundary conditions and material properties. [05]

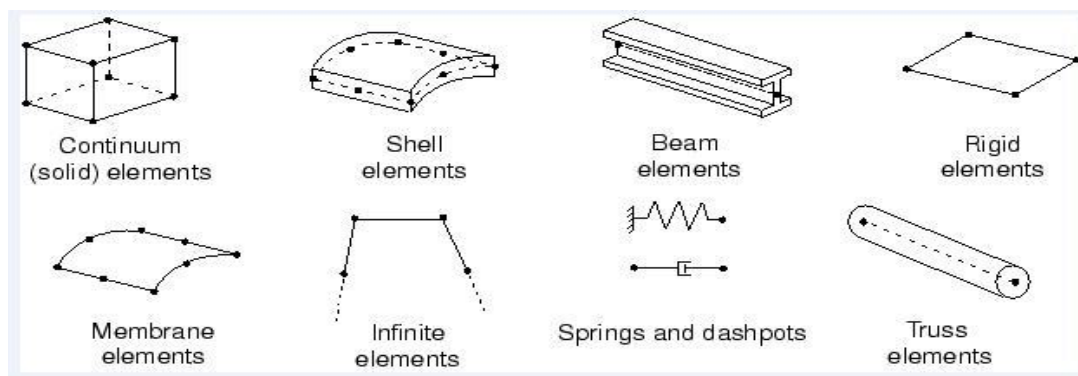


Figure 22: Different types of elements available in the Abaqus library.

3.6. The systems of units using the ABAQUS software

Before starting to define a model, you have to choose the system of units you will use. ABAQUS does not have an integrated system of units.[156] All input data should be specified in consistent units in the results that follow the unit system and base on SI (mm).

MASS	LENGTH	TIME	FORCE	STRESS	ENERGY	Steel Density	Steel Modulus	G - Gravity Constant
kg	m	s	N	Pa	Joule	7.83E+03	2.07E+11	9.81
kg	mm	ms	kN	Gpa	kN-mm	7.83E-06	2.07E+02	9.81E-03
g	cm	s	dyne	dyne/cm ²	erg	7.83E+00	2.07E+12	9.81E+02
g	cm	us	1e7N	Mbar	1e7 N-cm	7.83E+00	2.07E+00	9.81E-10
g	mm	s	1e-6N	Pa	1e-9 J	7.83E-03	2.07E+11	9.81E+03
g	mm	ms	N	Mpa	N-mm	7.83E-03	2.07E+05	9.81E-03
ton	mm	s	N	Mpa	N-mm	7.83E-09	2.07E+05	9.81E+03
lbf-s ² /in	in	s	lbf	psi	lbf-in	7.33E-04	3.00E+07	3.86E+02
slug	ft	s	lbf	psi	lbf-ft	1.52E+01	4.32E+09	32.2

Table 06: units in ABAQUS. [03]

What is a module?

Abaqus/CAE is divided into functional units called modules. Each module contains only those tools that are relevant to a specific portion of the modeling task. For example, the Mesh module contains only the tools needed to create finite element meshes, while the Job module contains only the tools used to create, edit, submit, and monitor analysis jobs. Abaqus/Viewer is a subset of Abaqus/CAE that contains only the Visualization module.

4. MODELING

4. MODELING

4.1. Introduction:

On this part, there was made a Flat-Bottom Metal Silo typed of 5m Width and 30m Hight after that filling the metal silo with Fine Aggregate that is consisted of the following characteristics (Density: 1200 kg/m³, Young's Modulus: 3E7 Pascal, Poisson's Ratio: 0.2, Mohr Coulomb Plasticity: Friction Angle = 33, Dilation Angle = 25).

The earthquake that will be used is Boumerdes one, but it couldn't be realized due to lack of data and resources (Acceleration tables) so instead, there was used two other ones which are:

- Valley, California Earthquake on 03 Jun 2020 with 5.5 magnitude at 18:32:11.140 PDT, Coordinates: 35.6148, -117.4282, Depth: 8.4 km.
- Indio's, Puerto Rico Earthquake on 07 Jan 2020 with 6.4 magnitude at 8:24:26.56 UTC, Coordinates: 17.916, -66.813, Depth: 10.0 km Searles.

These characteristics were applied on the Abaqus software to simulate our results and compare between them to see how it'll effect the silo in the normal case.

4.2. Modeling the silo

When Abaqus is launched, a window will pop-up asking to choose one from three options, Creating a new model database:

1. With standard/Explicit model.
2. With CFD model.
3. With Electromagnetic model.

After choosing the first option, it will be possible to start modeling and creating a Part by "Create part" on the Toolbox, a window will pop-up asking to name the part, choosing a modeling space "3D,2D planar, Axisymmetric", the type of the part and base features.

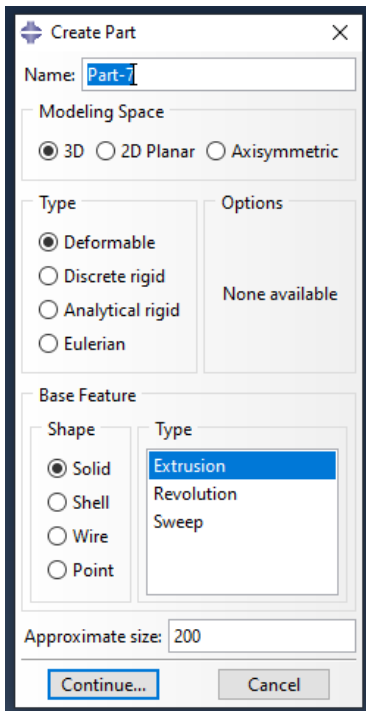


Figure 30: Create Part window.

Starting with naming the part select 3D for modeling space, until choosing the type which is Deformable and keeping the base features as show on the Figure 30, after clicking continue a sketching space will be shown on the canvas drawing area with new tools to draw our Silo. As the Figure 31 below:

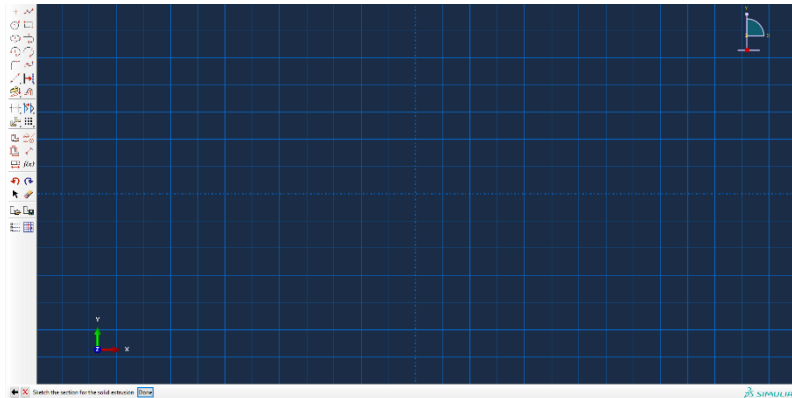


Figure 31: Sketching Canvas.

Once the sketching is completed, and the OK is clicked, the part on the Viewport will be shown like this:

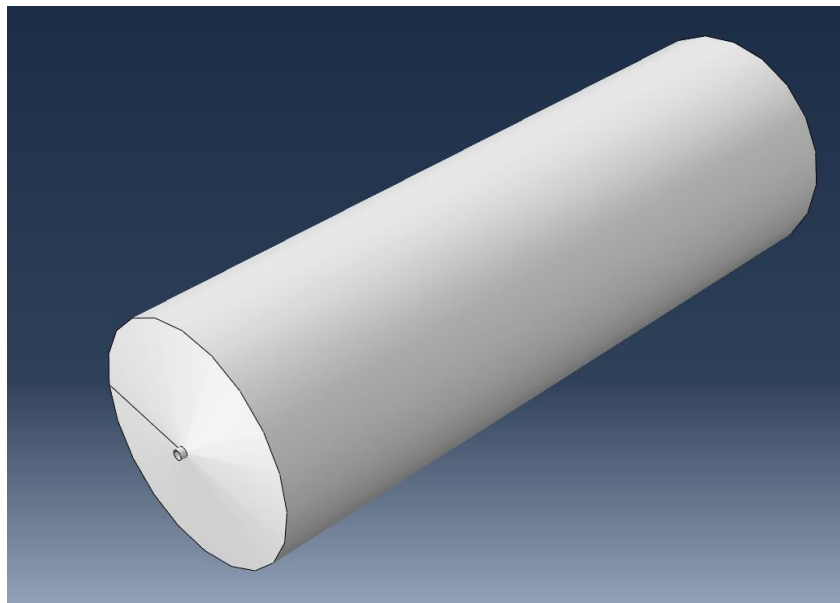


Figure 32: final result of sketching on Viewport.

After getting this shape, the user has to create section and material definitions and assign them to regions of parts. Starting by creating a Material in Property, and the Material is Metal and Concrete by Defining their characteristics after it, clicking OK and pass to Creating sections. To defernite metal from fine aggregate.

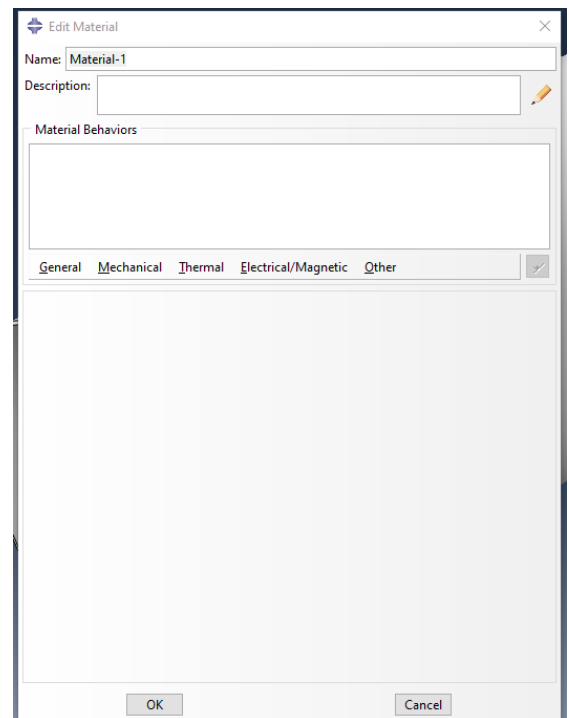


Figure 33: Creating Material Window.

After that, the user goes to “Section manager “to create the sections metal and fine aggregate to sperate the model from metal parts to aggregate parts, then selects each part with its section.

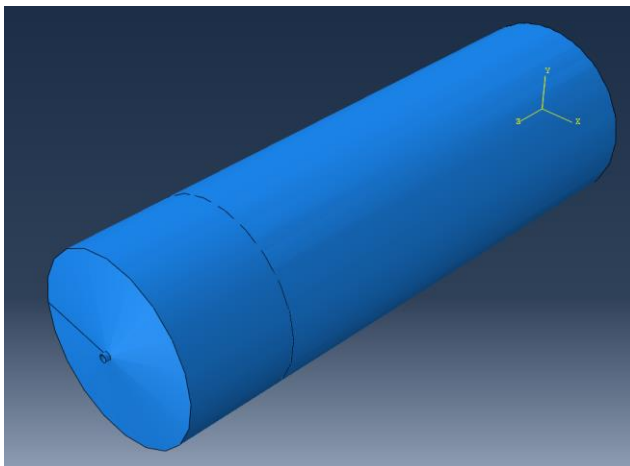


Figure 34: Final silo module.

Now, passing to assemble the parts together in order to have the complete Silo module, the user clicks on Create instance on the assembly toolbox and adds all the parts that needed to be assembled to get the final module ready to do experiments on.

The next step is to Mesh this Module to Create a finite element mesh, the results of mesh will be shown on the Figure 35 below:

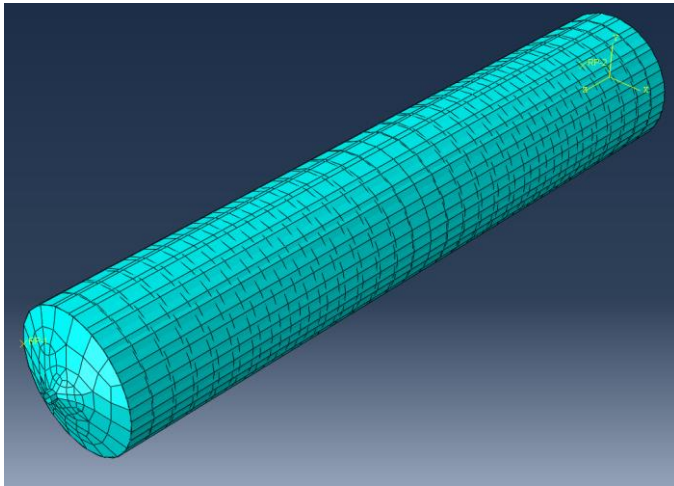


Figure 35: Final Silo Module Meshed.

Now it's time to add loads, boundary conditions, and fields and the Earthquakes, after adding all loads and BCs and our earthquake, the result will be:

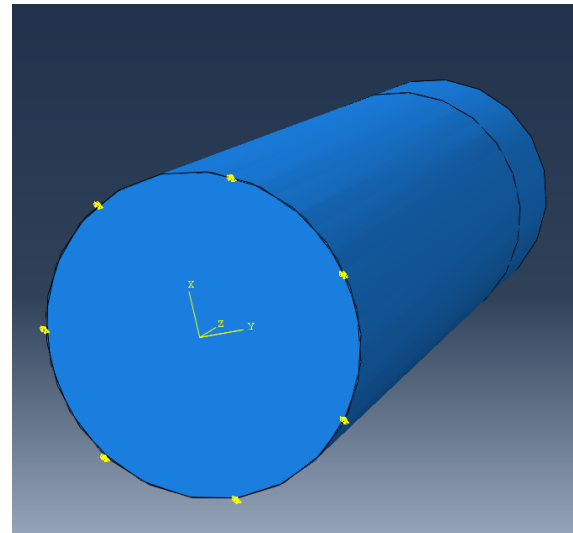


Figure 36: Silo module with BCs, loads and earthquake

Now after finishing everything, the user goes to analysis then clicks on job and creates one, by the right click on the created job the user can select Submit and waits Abaqus to finish the simulation.

It might take few minutes to finish the simulation, when the simulation ends "Completed" will be writing next to the job name as shown on the Figure 37 and with this modeling and simulation are finished successfully.

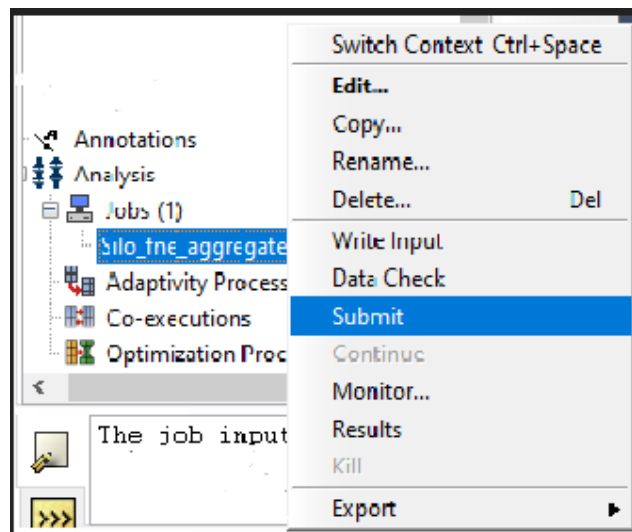


Figure 37: Submitting job on Abaqus.

4.3. Simulation Results

After finishing the simulation, the user can go to results on Abaqus to see what s/he accomplished in this work, there was 6 simulations with different magnitude of the earthquakes and with concrete load and empty silo.

The Earthquakes that were used in this Simulation:

1. Valley, California Earthquake on 03 Jun 2020 with 5.5 magnitude at 18:32:11.140 PDT, Coordinates: 35.6148, -117.4282, Depth: 8.4 km.
2. Indio's, Puerto Rico Earthquake on 07 Jan 2020 with 6.4 magnitude at 8:24:26.56 UTC, Coordinates: 17.916, -66.813, Depth: 10.0 km Searles.

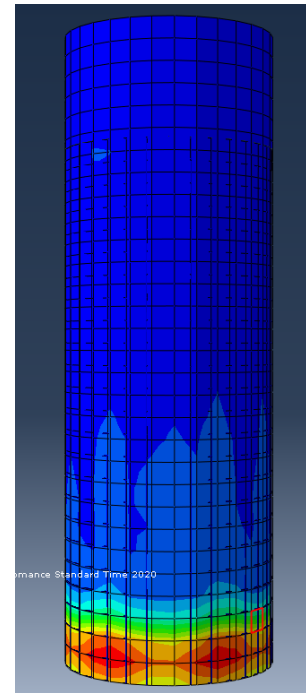


Figure 38: Deformed Shape of silo after the simulation with 6.4 magnitude.

The two earthquakes were used in full of Fine Aggregate Silo:

Materials used for this simulation:

- Metal:
 - Mass density of 7800kg/m³.
 - Young's Modulus: 200E9 Pascal.
 - Poisson's Ratio: 0.27.
 - Damping: Alpha = 0.6634, Beta = 0.03768
- Fine Aggregate:
 - Density: 1200 kg/m³.
 - Young's Modulus: 3E7 Pascal.
 - Poisson's Ratio: 0.2
 - Mohr Coulomb Plasticity:
Friction Angle = 33, Dilation Angle = 25.

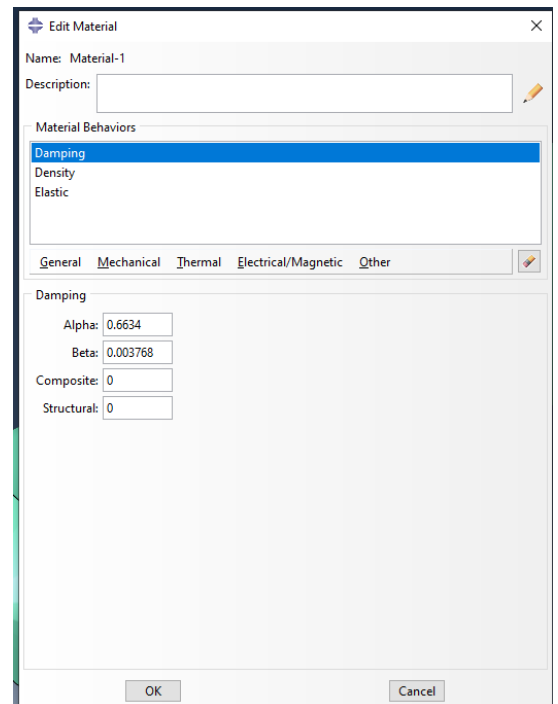


Figure 39: Creating Metal Material on Abaqus

- Silo Dimensions:
 - Width: $D = 10$ m.
 - Hight: $H = 30$ m.

1. The analysis on the first earthquake:

After applying the earthquake on our Silo module with 5.5 Magnitud, the following results will be shown:

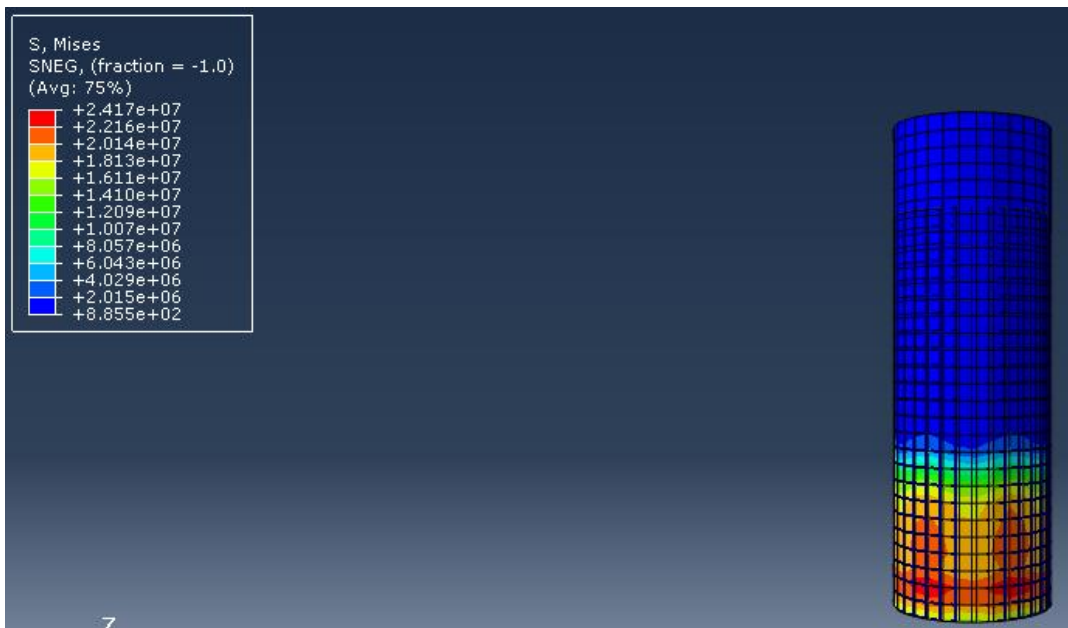


Figure 40: Deformation shape of the silo on 5.5 Magnitude

As seen, the earthquake did some serious damage on the bottom of the silo that may lead to a parament deformation or even worse like cracking on the bottom of the silo.

The displacement results:

In this graph we can see the displacement of the corbs that indicates that it had small shock effect and then it upgraded to a big sock to the structure that made the corbs in drop , peak waveson the top of the sillo

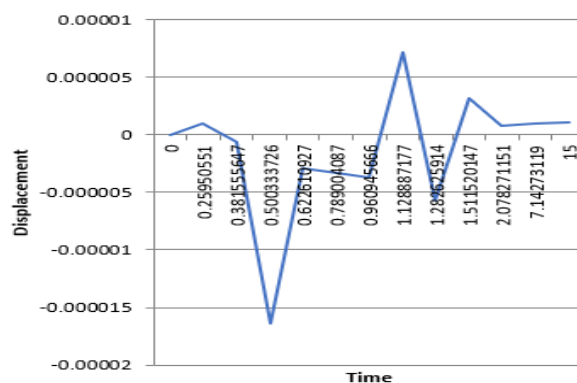


Figure 41: Displacement graph on top of the silo

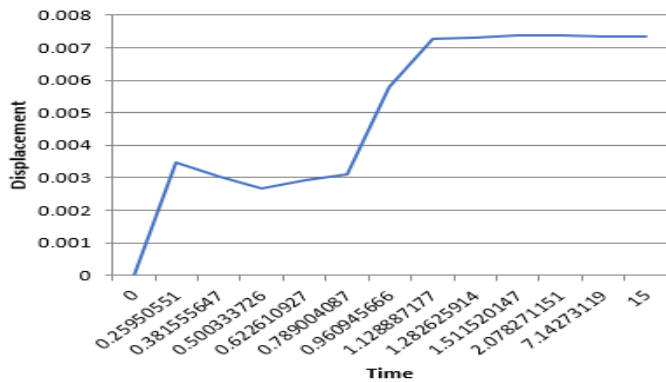


Figure 42: displacement graph on the bottom of the silo

As seen in this graph the displacement in the bottom of the silo was radically from the start point to the stable part after 20 sec's we can notice where the damage occurred the most

As seen, displacements from bottom to top and this is common in any kind of construction metallic or from concrete. In addition, the silo got permanent Damage from reading both displacements graphs.

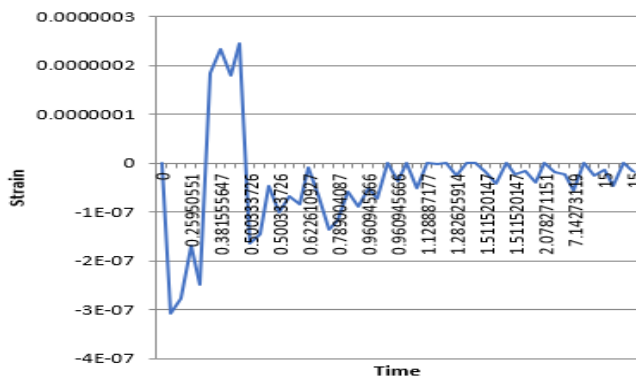


Figure 43: Strain graph on top of the silo

In the strain graph on the top of silo we can the earthquake effect on structure in the waves presented in the Fig 43 that indicates time/movement on the top.

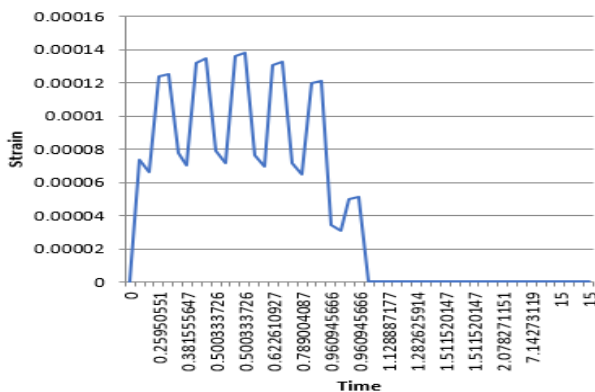


Figure 44: Strain graph on the bottom of the silo

In the strain graph on the Bottom of silo we can the earthquake effect on its structure in the waves presented in the Fig 44 that indicates time/movement on the top.

And now to the Stress graphs:

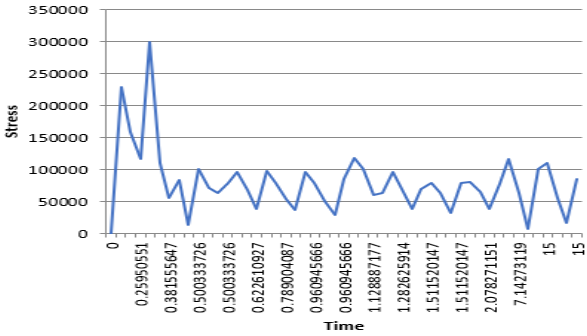


Figure 45: Stress graph on the top of the silo.

For this graph it measures the stress on the top of the silo to see the effect on it by time we can see that in the first few second the peak happened because of the hit of the earthquake waves that led to that specter.

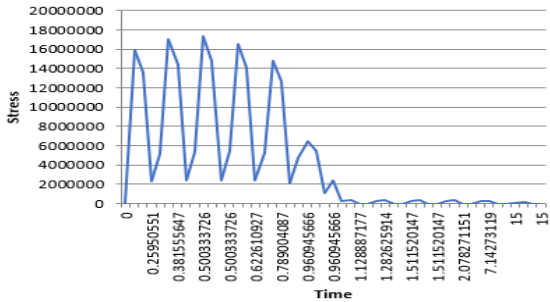


Figure 46: Stress graph on the bottom of the Silo.

This graph part showcase the stress on the bottom, it's noticeable that the curbs are waving up's and downs that means that more damage happened on the bottom level of the silo then the upper one.

From the graphs shown before in the previous figures, it is shown that there is a parament deformation on the silo after the earthquake that made it moves with 7 cm from its original place, which is a lot this can make the silo unstable and unusable and because of it and there isn't a strong possibility that it will survive any further earthquakes.

2. The analysis of the second earthquake:

After applying the earthquake on our Silo module with 5.5 Magnitude, the following results will be shown:

From the Figure 47, it is showed that the results are different from the first simulation after changing the Magnitude of the earthquake. In addition, the deformations are worse then the first one, and this will give different much worsor graphs then before.

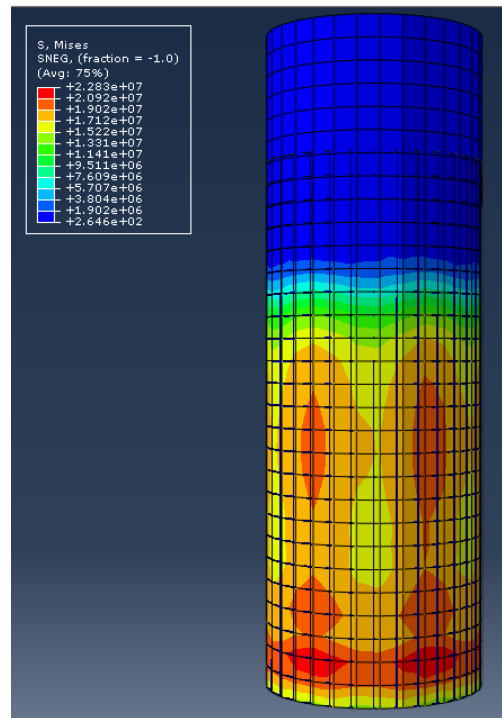
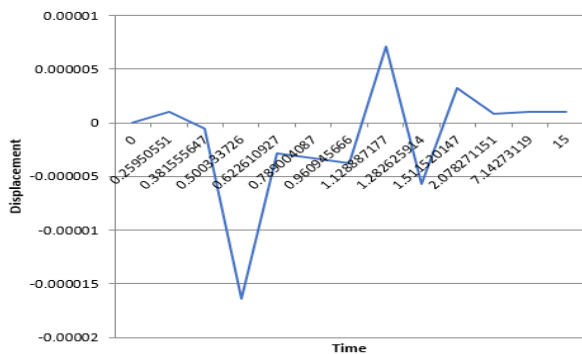


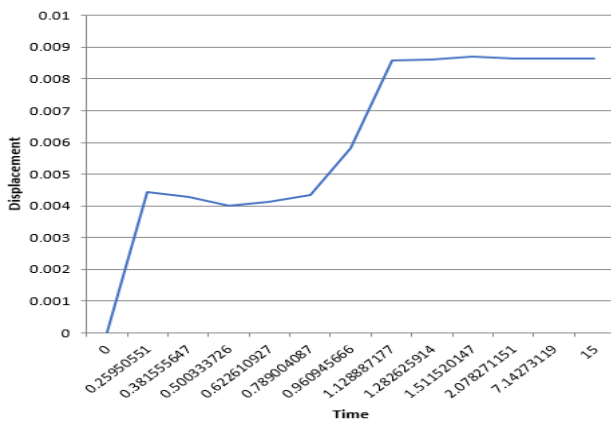
Figure 47: Deformation shape of the silo on 6.4 magnitude earthquake.

Displacement graphs:



On this displacement graph, on the top of the silo's there's a slight change and then a burst of displacement that damaged the silo on Fig 48.

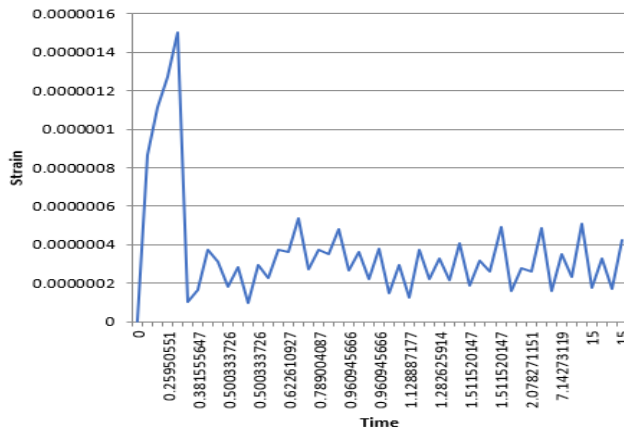
Figure 48: Displacement graph on the top of the Silo.



On this displacement graph on the bottom we can see the stability of the movement with time Fig 49.

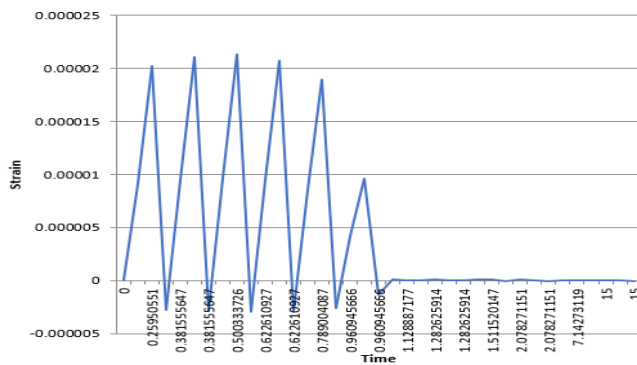
Figure 49: Displacement graph on the bottom of the Silo.

Strain graphs:



For the strain graph here, the pike of the graph happened in the very first moments then it drops based on the earthquake happened on the top of the silo.

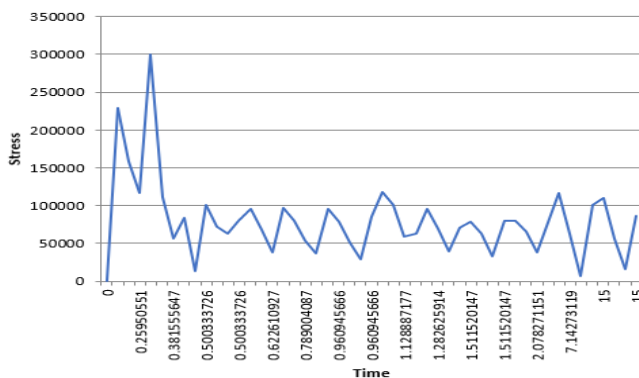
Figure 50: Strain graph on top of the Silo.



This strain graph has demonstrated the change in the movement by time, on the bottom of the silo.

Figure 51: Strain graph on the bottom of the Silo.

Stress graphs:



This graph is showing the effect on the top of the silo when it comes to stress, it is less impactful than in bottom

Figure 52: Stress graph on the top of the Silo.

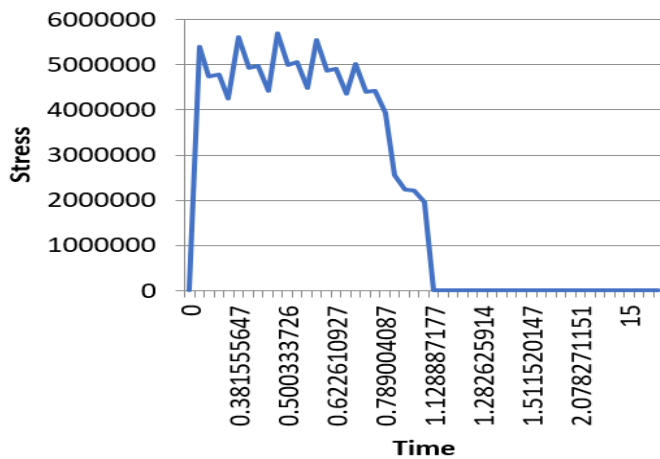


Figure 53: Stress graph on the bottom of the Silo.

From the graphs, it is noticed that there is a permanent deformation on the silo after the earthquake that made it moves with 9 cm from its original place, and now the silo is completely unstable and unusable and it can't survive anything anymore, with 9 cm displacement it's impossible to be useable again and it has to be removed.

3. Comparison Between the two earthquakes:

As seen from the Figure 54, applying different Magnitudes of the earthquakes on the simulation will give different results. The first simulation max displacement was 7 cm, and the second one almost 9 cm, this difference may look small, but it's a lot and it can tell if the silo will survive or not. As a conclusion, the stronger the earthquake is the higher displacement numbers.

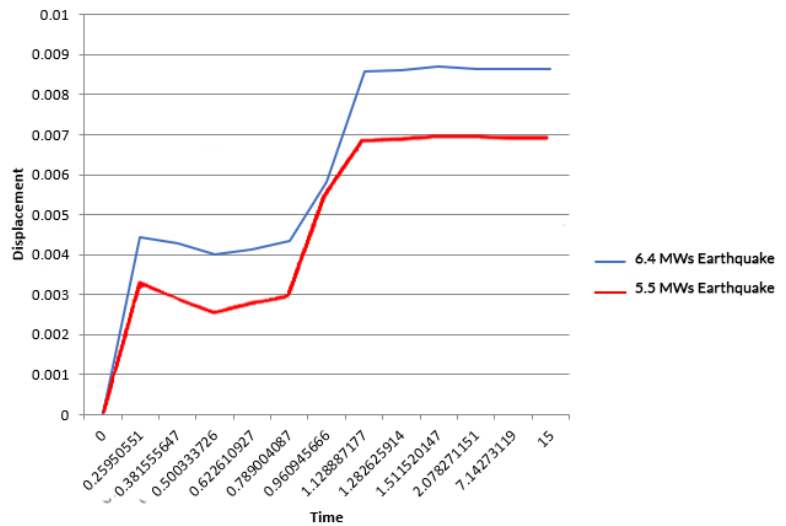


Figure 54: Displacement on the bottom of the Silo.

4.4. Conclusion

Doing this study and research while going through different phases starting from discovering the different types and aspects of silo's and focusing on metal ones, yet seeing the effect of

earthquakes on it was needed.

The engineering part in this study was made by simulating the entire operation using a software titled Simulate Abaqus CAE, that made us have a closer look up to the results shown in our thesis.

It is understood that the earthquakes have a massive damage on the metal silo and it doesn't resist it much, even the best quality and structured studies to realize it.

After multiple analysis on our module the results show the damage done on the metal silo made us conclude that it's unrepairable after an earthquake, especially if the magnitude of the earthquakes exceeds 5.0 Mews, and can also results to instability failure at the base boundary condition which is known as "elephant's foot buckling", due to its characteristic shape. This form of buckle occurs under high internal pressure accompanied by axial forces in the shell structure

Analyses indicate that design and construction quality of elevated silos determine the seismic performance.

As a recommendation on the minimize the damages done, it is noticed that putting small dimensions of silos on the seismic area's should be done and there is a possibility of having bigger dimensions on the none seismic area's to prevent the spoilages, and also to improve the seismic performance and resistance of it.

In the silos under study, the failure is due to the eccentric discharge of its stored solid (funneling). In general, to avoid this kind of instability it is necessary, in the design phase, to characterize, in the best possible way, the pressure distribution caused by eccentric solids flow ,The new rules of the European Standard EN 1991-4 that defines the "Actions in Silos and Tanks "give a new improved description of asymmetrical pressures and it is now possible to perform relatively realistic calculations for this event. In this study it is pointed out that, for the old silos not designed with the new rules, a possible reinforcement of the silo shell can be considered as a possible preventive measure for reducing the risk of failure for the silo. In the specific case addressed by this paper, a steel cage on the silo shell was designed to reduce the stress on the shell due tunneling condition and an increasing of silo resistance to the instability was achieved.

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