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**Modeling concrete beam repaired using
Two composite materials**

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Dedications

To my father's soul,

To my dear mother

*To my brothers **ABDALLAH AND YAHYA***

To all my family,

(BENKENNINE, HAMAD)

To all my friends

MERIEM, AMEL

To all those who are dear to me

I dedicate this modest work.

ABSTRACT

The load capacity of concrete structures is affected by the cracking behavior of concrete. Since the tensile strength of concrete is much lower than its compressive strength (approximately 10 times), concrete belongs to the group of brittle materials but it is not perfectly brittle. Concrete is considered to be a quasi-brittle material, and therefore, In this work the analysis of failure and crack development in beams made of concrete is presented. The present work, which is numerical in nature, since the code compute ABAQUS was used to discretize the model using MEF method. It aims at understanding the behavior of cracked concrete beams reinforced by different composite materials. Several variants of Patch reinforcement have been analysed, in addition to failure parameters of the structure's behavior such as Von Mises stress, and stress intensity factor.

Key words: concrete beam, crack, composite materials, stress intensity factor, Von Mises stress,.abaqus

RÉSUMÉ

La résistance des structures en béton est affectée par le comportement de fissuration du béton. Étant donné que la résistance à la traction du béton est beaucoup plus faible que sa résistance à la compression (environ 10 fois), le béton appartient au groupe quasi-fragile dont le comportement peut être influé par plusieurs constituants qui interviennent dans sa composition, ainsi qu'a plusieurs paramètres externes. Dans ce travail, l'analyse de la rupture et du développement des fissures dans les poutres en béton est effectuée, en utilisant la MEF grâce au logiciel ABAQUS, il vise à comprendre le comportement des poutres en béton fissurées renforcées par différents matériaux composites, en plus des paramètres du comportement en rupture de la structure tels que la contrainte de Von Mises et le facteur d'intensité de la contrainte.

Mots clés : poutre en béton, fissure, matériaux composites, facteur d'intensité des contraintes, contrainte de Von Mises.abaqus

المخلص

تتأثر سعة حمل الهياكل الخرسانية بسلوك تكسير الخرسانة. نظرًا لأن قوة الشد للخرسانة أقل بكثير من قوتها الانضغاطية (حوالي 10 مرات)، فإن الخرسانة تنتمي إلى مجموعة المواد الهشة ولكنها ليست هشة تمامًا. تعتبر الخرسانة مادة شبه هشة، وبالتالي، يتم تقديم تحليل الفشل وتطور الصدع، في هذا العمل بطبيعته، حيث أن البرنامج الرقمي تم استخدامه لمحاكاة النموذج الحقيقي باستخدام طريقة العناصر المحدودة. يهدف إلى فهم سلوك شعاع خرساني المتصدعة المدعومة بمواد مركبة مختلفة. تم تحليل العديد من المتغيرات من تعزيز التصحيح، بالإضافة إلى معلمات الفشل لسلوك الهيكل مثل إجهاد فون ميسيس، وعامل شدة الإجهاد.

الكلمات الرئيسية: شعاع خرساني، صدع، مواد مركبة، عامل شدة الإجهاد، إجهاد فون ميسيس

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GENERAL INTRODUCTION

GENERAL INTRODUCTION

Nowadays, several materials are used in civil engineering projects, concrete is one of them. In fact, thanks to its excellent performance, especially its high compressive strength and versatility of use, concrete is omnipresent in buildings bridges, pavements, dams and more. To compensate for its low tensile strength concrete is combined with steel to form reinforced concrete in order to work better together. This combination of concrete and steel goes back a very long way, since as early as as far back as 1870, English contractors Alexander Payne and Thaddeus Hyatt tried to place reinforcement in concrete, but were disavowed by contradictions and a few misfortunes. As for the Americans, they waited another 10 years to learn of its existence, thanks to the research work of William E. Ward and Ernest Leslie Ransome, who shed light on the metal reinforcement of concrete. From then on, reinforced concrete gradually spread throughout the world, and is now an indispensable part of today's construction.

All attempts to replace concrete with another material have ended in failure because of the cost. concrete, whose constituents are commonplace, defies all competition. The builder must therefore come to terms with its imperfections, and seek to mitigate them through additions that modify its characteristics. Reinforced concrete responds to this need, because the reinforcement gives concrete the tensile strength it lacks. However, even when reinforced, concrete remains very fragile, as the reinforcement cannot prevent cracking; at most, with the right constructive measures, they can distribute cracks to prevent overly wide fractures in the tensioned concrete.

From the 19th century until a few decades ago, numerous problems occurred in reinforced concrete structures. Examples include heavy road traffic, pathologies due to overloading, design errors, fatigue under cyclic loading. Faced with this situation, techniques for repair and reinforcement by bonding steel sheets and composite plates have been developed. Today, adhesive bonding of composite materials is one of the most rehabilitation methods in this rapidly expanding market.

External reinforcement, while offering considerable advantages (e.g. increased strength of the reinforced element), it does have its limitations. Major drawbacks include composite disbonding and concrete cover failure during shear reinforcement of concrete beam using externally bonded composite limit this method, prompting users to opt for a new technique: internal strengthening. This type of reinforcement, in addition to offering virtually the same advantages of external

bonding, it also dispenses with the aforementioned problems. Although this technique is new and less widespread than the first, it augurs well for the future, and offers a preferable alternative.


External reinforcement of concrete structures is a technique commonly used to rehabilitate or increase the strength of reinforced concrete structures. The causes that leading to structural reinforcement are as numerous as the number of structures themselves, and each case must be considered on its own merits. The most frequent are:

Increased loads on the structure, defects in the design or execution renovation of older structures, changes in the shape of structures, damage to the structure, the need to improve in-service conditions, etc. There are various replacement methods, such as:

replacement of degraded materials, addition of new materials, use of higher-performance materials, increasing the structural cross-section by adding new materials, improving structures by external prestressing, improving the structure of buildings using shock-absorbing devices, bonding of prefabricated elements. While the use of steel as an active or passive reinforcement has its advantages, it also presents disadvantages, such as corrosion and high weight, which prompted engineers to take further in their research, leading to a solution that favours the use of composite materials for the reinforcement of reinforced concrete structures to the detriment of steel. Compared with other strengthening techniques, FRPs offer a number of advantages: light weight, high strength, the possibility and ease complex shapes with a minimum of operations, easy adaptation to any structural cross-section, making them very easy to install thanks to their low weight, high tensile strength and low corrodibility. Internal reinforcement, with both steels and composites, is a new technique

Objective and broad outlines of the research project

The aim of this research project is to use a finite element calculation code to study the behavior of a reinforced concrete beam, strengthened in shear by FRP (Fiber Reinforced Polymer) composite materials. The question of the reliability of reinforcement of beams with FRP frames is a relevant topic, In an attempt to answer this question,



The dissertation is divided into three main chapters:

- The first chapter presents definitions and the importance of the use of Composite materials to reinforce concrete structures, which increase their durability and strength.
- Chapter 2: consists of a bibliographical search of existing models for predicting the behavior existing models for predicting the behaviour laws and failure loads of cracked concrete beams, reinforced with composite materials.
- Chapter 3: presents the numerical modelling programme using the finite element method and ABAQUS software. The first part of this chapter includes the modelling of an unreinforced concrete reference beam. subjected to flexion loading, and then to tensile loading.
- Chapter 4: IS the analysis of results done using finite element code compute ABAQUS, and their interpretations.

The choice of the various mechanical and geometric characteristics is made in an academic manner with the aim of producing the appropriate failure mechanisms.

Finally, a conclusion to the present study and recommendations for future work are presented at the end of the dissertation.

Chapter 1

COMPOSITES MATERIALS

1 introduction

Composites are increasingly being used to repair structures built with other materials. Target applications include bridge beams, bridge decks, parking garages and pipelines, including underground systems.

Some of the typical composite materials most commonly used in industry and engineering are as follows:

- Reinforced concrete and masonry.
- Composite wood, such as plywood.
- Reinforced plastics, such as fibre-reinforced polymer or glass fibre.
- Ceramic matrix composites (ceramic-metal composite matrices).

2 Definition of composite materials

Composite materials can be defined as the outcome of an association and combination between two materials of distinguished nature, in which such composition provides more potent features than the two separated materials from each other's.

In general, it is done through two stages

- continuous phase named the matrix,
- discontinuous phase recognized as reinforcement or reinforcing material.

Though, to shape it by other characteristics, perceptively shock resistance, UV resistance, and fire resistance, fillers are commonly supplemented. These fillers are with fragmentary elements form or powders or liquids [1].

2.1 composite materials"FRP

Amongst the several kinds of composite materials, there are the fiber reinforced polymer "FRP". Overall, it is notably unlike other types a reinforcement of the fibrous type and a thermosetting matrix. The composition of this type of composite material relies on the fiber content and the direction. FRPs are anisotropic with linear elastic performance up to failure [1].

The benefits of FRP are:

- + low density;
- + directional mechanical features;
- + great corrosion resistance
- + very good fatigue resistance;
- + flexibility that helps its usage.

The hindrances are:

- strong anisotropy;
- A brittle fracture;
- high cost than steel (Luyckx, 1999).

FRP" type of composite materials are categorized into three classifications:

1. Polymer Glass Fibre Reinforced Polymer (GFRP): "GFRP".
2. Polymer Carbon Fibre Reinforced Polymer (CFRP)
3. Polymer Aramid Fibre Reinforced Polymer: "AFRP".

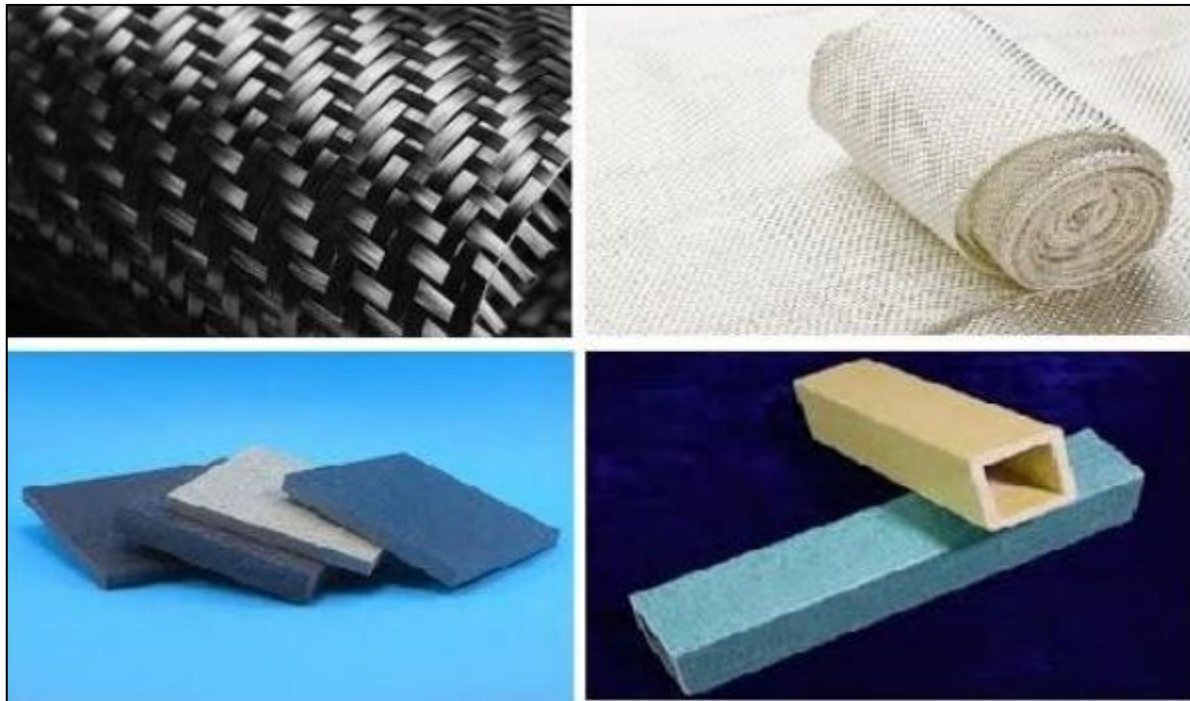


Figure 1: Fiber reinforced polymer composites "FRP".

Table I-1: Comparison between the three types of "FRP" composites (Teng *et al.*, 2002).

Unidirectional composite materials	Fiber content (%/kg)	Density (kg / m ³)	Longitudinal modulus of elasticity (GPa)	Tensile strength (MPa)
Fiberglass / Polyester (laminated FRP)	50-80	1600-2000	20-55	400-1800
Carbon / epoxy (CFRP laminated)	65-75	1600-1900	120-250	1200-2250
Aramid / epoxy (PRFA laminated)	60-70	1050-1250	40-125	1000-1800

2.2 The fibers .

The sorts of used fibers in FRP are long fibers or continuous fibers. Contrary to those that are implemented in the spraying process for boat building and the used fibers in reinforced cementitious materials with 10 to 50 mm in length. These continuous fibers are applied at high amounts varying from 20 to 60% of the volume of the polymer resin, Therefore, the name fiber reinforced polymer (FRP) [1].

2.2.1 Carbon fibers.

Carbon fibers are considered by a very high modulus of elasticity and represented by an order of 200 to 800 GPa. They have an extreme elongation which can wait until 2,5 %.

The returns of carbon fibers are:

- + Zero water absorption;
- + A resistance to several chemical solutions;
- + A well endurance to fatigue.

Carbon fiber has some limits as followed:

- An electrical conductivity that may lead to galvanic corrosion once in contact with steel;
- A poor performance to impact and abrasion, particularly those of the laminated sort.

Based on the carbon content, carbon fibers are classified into three types:

1. HR "high strength" fibers;
2. HM "high modulus" fibers;
3. THM "very high modulus" or intermediate fibers [1]. (1).

2.2.2 Glass fibers

The glass fibers are less expensive fibers in comparison with other sorts, they exemplify the most implemented material for the composites. They are fundamentally made of sand (silica) and

additives (alumina, carbonate of lime, magnesia, boron oxide). Their modulus of elasticity is about 70 to 85 GPa and their extreme elongation diverges from 2 to 5% according to their quality, though the main weaknesses of glass fibers are: [1].

- + Relaxation;
- + Sensitivity to humidity.

There are three kinds of fibers

1. E: for composites, large diffusions and common applications;
2. R: for high performance composites;
3. D: for printed circuit board manufacturing (dielectric properties) [1].

2.2.3 Aramid fibers

Aramid fibers contains aromatic polyamide molecules. At first, they were established and originated to DuPont in 1965 and presented by name Kevlar. Many qualities mark this type of fiber as being the first preference choice for FRP parts in civil engineering usage, for instance:

- The high cost compared to glass fibers,
- The trouble of handling,
- High moisture absorption, that may achieve 6% by weight.

Nevertheless, their benefits entail a tremendously high toughness. For this matter their use in many industrial products is large as bare fabric or as supports for FRP composites that necessitate energy absorption. For illustration, aramid fibers have been detected in bulletproof vests (helmets), construction helmets and attenuators or in the automotive sector (Bank, 2006).

Aramid fibers compromises a modulus of elasticity going from 70 to 200 GPa and an extreme elongation varying from 1.5 to 5% based on the quality [1].

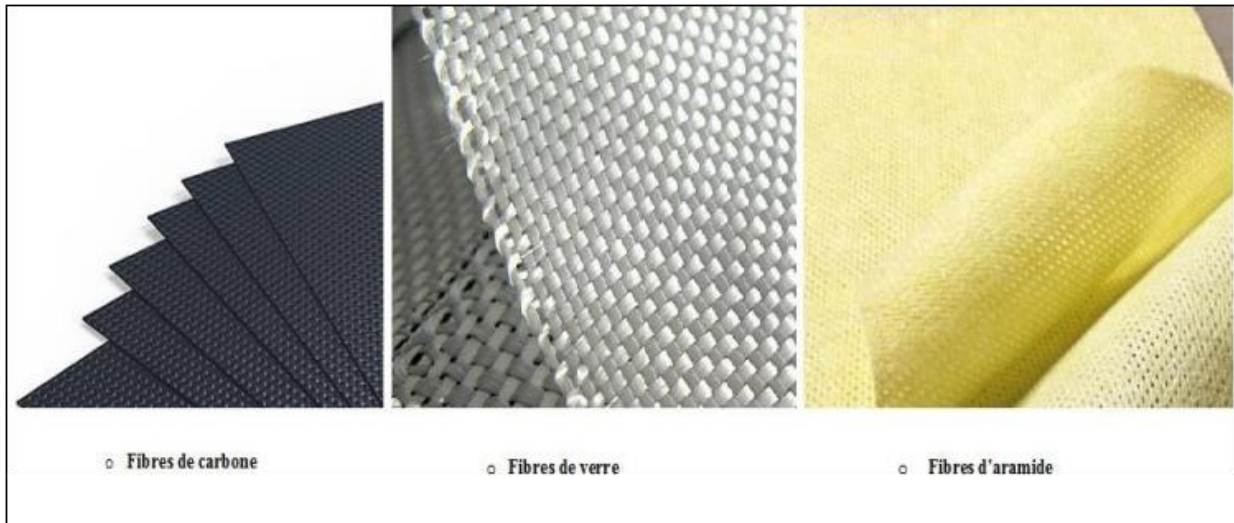


Figure I-2: The three types of fibers for "FRP".

Tableau I-2: characteristics average of fibers [1].

Fibers	filament Diameter (μm)	Volumic Mass (kg.m^{-3})	longitudinal Modulus of elasticity (MPa)	Modulus of Shear (MPa)	Ratio of Poisson	Break stress (traction) MPa	Allongement at break %	Coefficient of thermal dilatation $^{\circ}\text{C}^{-1}$
	d	Mv	E	G	k	Cr	A	α
glass E	16	2 600	74 000	30 000	0.25	2 500	3.5	$0,5 \times 10^{-5}$
glass R	10	2 500	86 000	-	0.2	3 200	4	$0,3 \times 10^{-5}$
Carbon HM	6.5	1 800	390 000	20 000	0.35	2 500	0.6	$0,08 \times 10^{-5}$
Carbon HR	07	1 750	230 000	50 000	0.3	3 200	1.3	$0,02 \times 10^{-5}$
Kevlar 49	12	1 450	130 000	12 000	0.4	2 900	2.3	$-0,2 \times 10^{-5}$

2.4 Matrix

The term polymer is designates a material containing a set of molecules, named macromolecules. These macromolecules involve f repeating units or chains where atoms are stacked together by covalent bonds. The word polymer resin or simply resin is common in the composites industry in order to indicate to the primary polymer component in the non-fibrous part of the FRP material. This non-fibrous portion is also determined as the matrix.

The matrices permit the fibers to be attached together and diffuse stress to the fibers. It may also resist shear forces and transverse or compressive forces. The matrix separates the fibers for the sake of their preservation or protection from moisture, oxidation and chemical attack.

Two main groups of polymers can be identified:

1. Thermoset polymers (TD) for example polyester, vinylester, epoxy and phenolic;
2. Thermoplastic polymers (TP).

They are distinguished from each other by the way the molecular chains are connected when the polymer is in its solid form. Thermoset polymers have a molecular structure joined together to form a continuous three-dimensional network by strongly bonded atoms, a thermoset polymer structure cannot be heated and softened and then transformed into another form it is irreversible.

Thermoplastic polymers contain molecular chains attached together by weak forces. This influences their mechanical and physical properties via cross-linking. This polymer does not set, but rests plastic, then molecular chains can "flow". Thus, once the solid polymer is heated, it can be returned to a different shape throughout cooling consequently it is reversible. [1].

3. Properties of Composite Materials

A fiber-reinforced plastic (FRP) comprises two or more different combined component on a macroscopic scale to make a product with qualities that overcome those of their individual components. A FRP is a mixture of high strength fibers (glass, carbon and aramid fibers are the most commonly used) in a matrix (polyester, vinylester, epoxy or other). The fabricating material is heterogeneous and anisotropic. The fibers brings the mechanical strength whereas the matrix fixes the fibers, keeps them and transfers the loads to the fibers by shear.

FRP sheets are laminates containing many of layers named plies. A ply is a layer of fibers or woven fibers, infused and filled in a matrix. Once the plies are fixed on top of each other in a position of placements based on the wanted mechanical properties, the product is termed a laminate.

FRPs are mass-produced in numerous forms, like thin sheets, bars or profiles. These different products are adequate for a precised use in the engineering domaine. The most significant quality of FRP is its elevated strength-to-weight ratio. Indeed, It he production of FRP is easy and possible with a tensile strength bigger than that of steel, with a corresponding mass minus than 10% of steel.(2)

4. methods of manufacturing FRP

In the whole, it exists more than fifteen methods for the production of composite materials destined to different utilities. In other word, for the industrial applied methods for the civil engineering sector there are three main ways and means, braiding, the pultrusion manufacturing method, and filament winding. [1].

4.1 Pultrusion .

This procedure is meant for molding continuous lengths or constant or closely constant profiles. It involves pulling reinforcing materials like fibers, rows and mats over a bath of thermosetting resin, by means of guide plates and through a heated die. This die typically has a pointy shape to attain both compaction and curing of the FRP after moving via the continuous pull device, the profiles are cut to the wanted length with a saw [1].

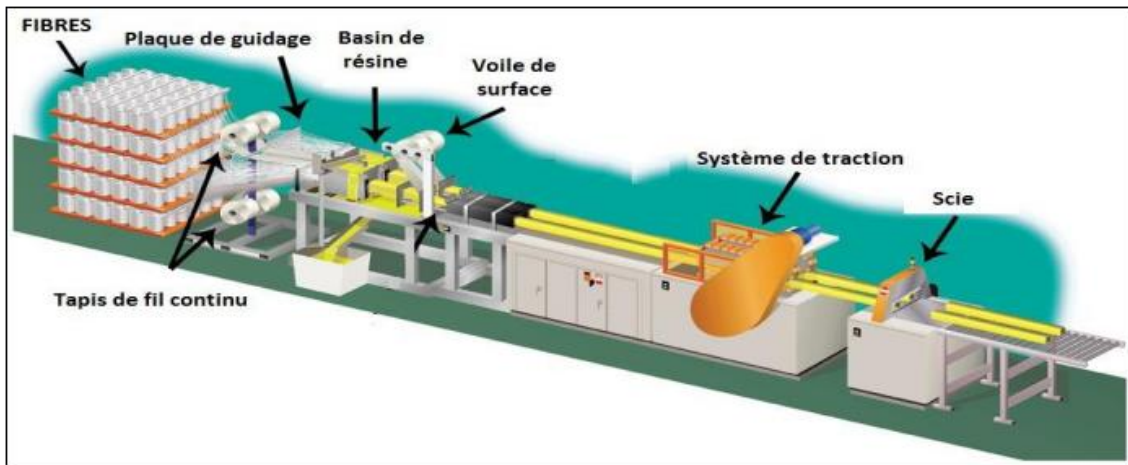


Figure I-3: Pultrusion manufacturing methods.

4.2 Filament winding

Basically, Filament winding is supported by means of a rotating mandrel in the surrounding where an permeated tape is enclosed by resin. The tape is then distributed over an oven to have a tough hollow structure. [1].

This manner can be applied to create circular, elliptical, oval and square tubes, also flat laminates by regulating the winding factors. This practice permits the angle of the fibers to be reformed between 0° (Longitudinal or polar winding) and 90° [1].

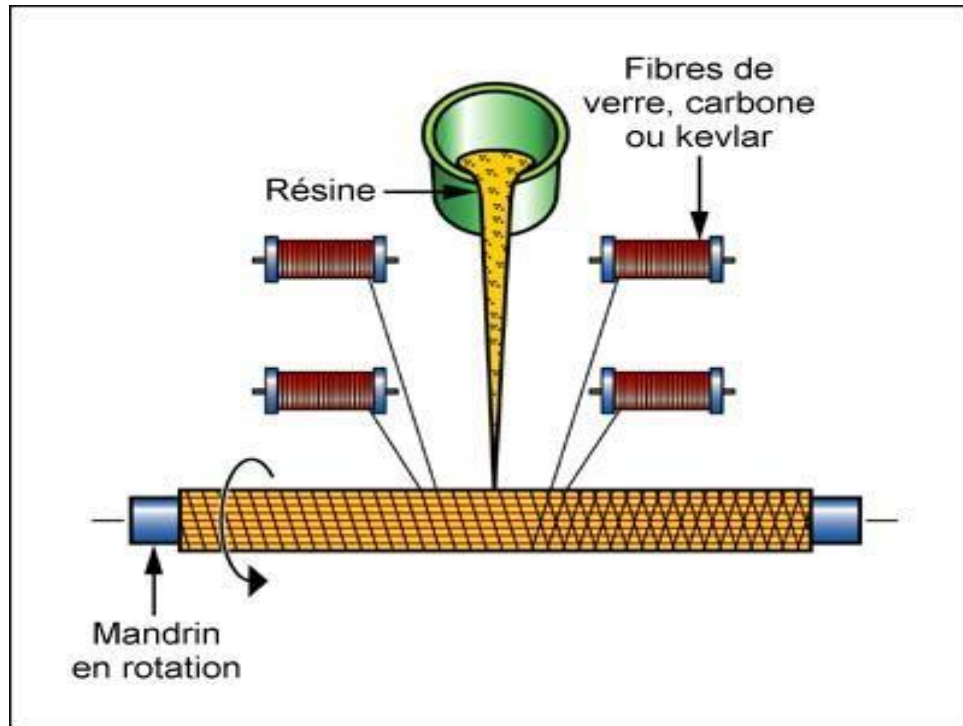


Figure I-4 : Filament winding manufacturing methods.

4.3 Braiding

This procedure can be regarded as the oldest famous textile technologies. It implicates the interweaving of two or more yarns to shape an incorporated structure. In comparison with other techniques, braided FRPs provides significant effect and abrasion resistance in line for the braided yarns. Moreover, they bring to some extent a pure in-plane stiffness and strength. This stiffness is completed by the curvature of the fibers and the low fiber content [1].

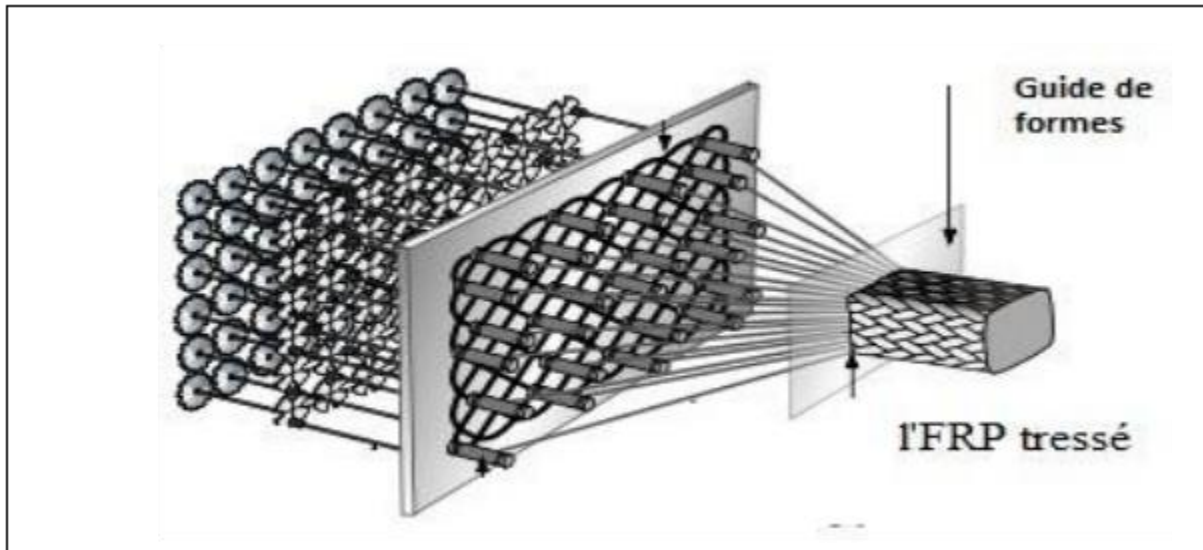


Figure I.5: Manufacturing methods by braiding.

5. Application of composites in civil engineering construction

5.1 Use of FRP bars in the fabrication of reinforced concrete beams [2].

The fabrication of composite bars as a substitution for conventional steel reinforcing bars started in the mid-1980s. Carbon and aramid fibers were specifically used in Japan, whereas in Europe glass and aramid fibers were fabricated. In the United States, aramid bars were frequently used. The bars can be implemented in floor slabs, bridge decks, pre-stressed concrete beams, retaining walls, and geotechnical anchors.

The duration and performance of these materials over corrosion permit them to be practiced in a large diversity of solicitations. The corrosion of the bars triggered by the infiltration of water in the cracks ma make a loss of resistance that can be regarded as very significant in particular cases. Highway flyovers are too influenced by this issue. The de-icing salts that are often done and the repetitive freeze-thaw cycles exemplify the focal reasons of the present degradation of reinforced tangible structures, if it is pre-stressed or not. In Sherbrooke, Canada, the Joffre Bridge was lately reconstructed and a fragment of the slab covers composite materials [LAP 99]. Now, a mesh prepared of carbon fiber was designed to substitute the steel that was discovered in the higher portion of the slab. By putting

composites in position in connection with the de-icing salts, the deterioration degree of this segment is restricted.

The tensile strength altitudes of composite bars are too and far bigger and surpass those of conventional steel (aramid: 2400-3100 MPa, carbon: 2400-5700 MPa, glass: 3300-4500 MPa). In the item of steel, the strength can attain 1860 MPa[2].

6. Rehabilitation of structures using FRP

Once Algeria's independence, a many remarkable constructions were established. So far, several among them are oncoming their finale useful life. This upsets both buildings and strengthened tangible bridges. The deterioration of these constructions is augmented by chemical effects, mechanical shocks and the sustained increase of the use loads. Thus, a lot of these bridges prerequisite to be reconstructed. Though, the budgetary restrictions obliged by our government embolden us to catch further economical and durable elucidations. Composite materials may provide an operative method regardless of the restricted amount of practical illustrations[2].

Structural engineers firstly applied steel plates for structural strengthening. The central clue that directed the scheme of reinforced structures was placed headfirst by L'HERMITE. The early use of steel plates fixed to the tensioned surface to rise the flexural power of reinforced concrete bridge beams existed in 1964 in South Africa.

The primary practices of FRP remained commonly in the aerospace, mechanical engineering, public transport and high-performance sports equipment businesses. In the end of 1960s, studies emerged regarding the application of glass fiber FRP bar as a replacement for steel reinforcement at Rutgers University in New Jersey

Carbon or glass based FRP plates existed firstly as corrosion protection. They permit the elimination of the issue related to length limitations, as they are adequate to any size. Besides, they have confirmed being too operational in rising the circuitous and shear resistance once fused in the shape of plates on the external surfaces of strengthened existing elements. Hence, many supports have been supported out on beams, walls, slabs and on reinforced concrete columns (see figure 1.7).

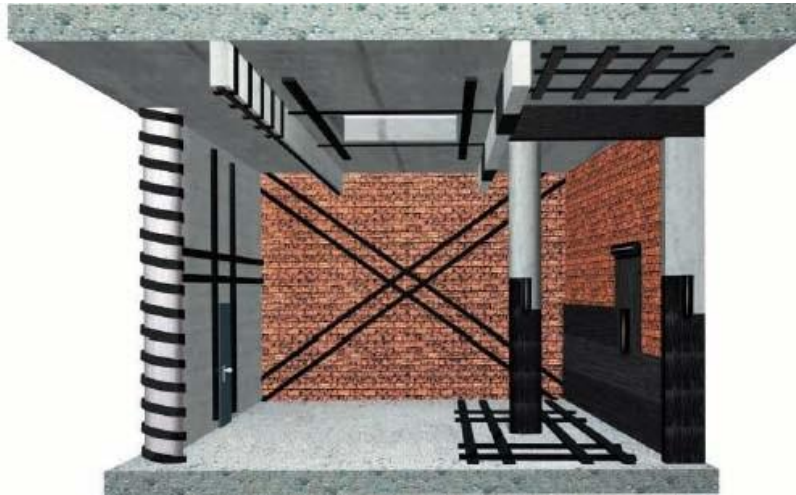


Figure. 1.6 Structural elements t reinforcing composite materials

The principal application of composite materials was related to Switzerland in 1991 that was intended for the restoration of the Kattenbusch Bridge in Germany. This bridge was made of an unceasing box girder over 11 spans. The influence of temperature gradients led to premature cracking at some joints. Reinforcement with fiberglass plates was used (see Figure 1.6).

The custom of composite materials for restoration and reinforcement is a suitable way out supporting a standby as operational as steel. Furthermore, Table 1.3 displays the gains of composites over steel.

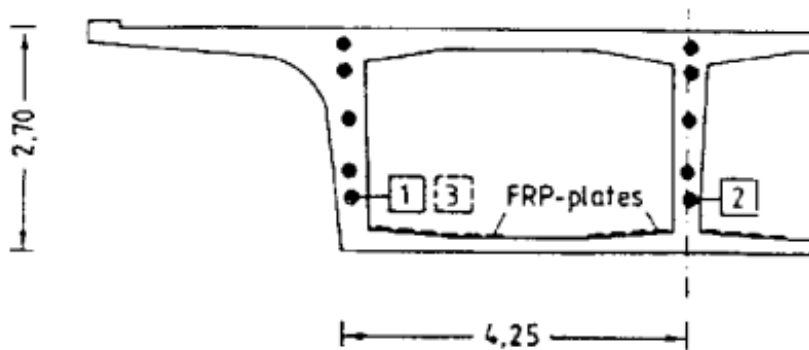


Tableau I-3 Comparison between steel and composite plates [LAP 99].

Criteria	With composites	With steels
Proper weight	Low	high
Tensile resistance	very high	high low or limited
Thickness	too low	difficult, rigid all directions complex adequate
Corrosion	none illimited easy, flexible	
Plate length handlings	easy longitudinal direction	low high
Overlapping (Joints)	remarkable high	hoisting and tying devices
Fatigue behavior Material cost	low	
Facilities cost	no equipement	
Application		

6.1 Wall rehabilitation

Just a little circumstance of practice of composite materials for wall support have been issued. The best acknowledged of these is for a six-story apartment building related to Zurich, Switzerland [LAP 99]. In the meantime, the structure was made in 1930 and rehabilitated to an office structure with certain modifications in its horizontal resistance arrangement, the organizational system was re-tested and controlled. Amongst these deviations, unreinforced masonry walls envisioned for seismic tons were omitted, and those enduring were necessary to proceed a considerably larger load. [2].

The practice of composite materials showed to be right valuable. X-shaped carbon fiber plates were attached to all of the grounds (see Figure 1.4). An anchoring structure with steel rods was implemented to enhance the connection between the fibers and the wall. By the composites, the ductility of the wall was amplified at somewhat little cost and in a precise short time mechanism.



Figure 1.7. Rehabilitation of a masonry wall (Switzerland) [NET 03].

6.2 Slab Rehabilitation

The practice of strip composites can also recover the flexural power of secure tangible slabs. Their refinement and elasticity demonstrate being effective, renovation or strengthening can be completed in a precise little time, with very slight inconvenience and limited working space.

In Algeria, there is just a unique situation of slab reinforcement, realized at the LPA plant in Boudouaou near Boumerdes in 2001[2].



Figure 1.7. Rehabilitation of a masonry slab

6.3. Rehabilitation of columns

The pillars that constitute an exposed structures (bridges, parking lots) are too influenced by ecological circumstances. The existing cover is almost fractured by freeze-thaw phases, not to cite the association of de-icing elements that quicken the procedure.

Stirrups and horizontal bars are not safe and erosion hints to damage the power and strength of the steel. Several restoration methods actually occur to fix fissures in columns. Most regularly, the fractured existing layer is detached and exchanged by a mortar and the renovation ends there. Though, these methods do not remove the effect of water infiltration within the walls to keep longer the reinforcements. [2].

The reinforcement technique, addressed to reinforced concrete columns, involves covering these columns with FRP sheets. The fibers are positioned in the circumferential orientation (see Figure 1.8). This covering generates a tangible confinement aspect that rises the column's resistance toward compression and shear at once. Additionally, to reinstating a supplementary volume to the structure, the column is at the moment secure from faster corrosion over tidal area. This way can also be done to upturn the resistance of some constructions which is situated in very active seismic regions. Structures that no longer fit present building codes can reclaim enriched strength and ductility by the application of composite sheets.



Figure 1.8. Containment of bridge columns by composite materials

6.4. Reinforcement of beams

The consolidation of beams with composite materials has advanced in the last epoch, as an answer to reflected issues with the application of steel plate. Flexural consolidation can be attained with FRPs by connecting the strips to the bottom surface of the beam. A shear reinforcement can be delivered by sticking the strips on the cheeks of these identical beams. In Algeria, the first time of application of these products was the strengthening of the reinforced concrete consoles of the stadium of the town of Tlemcen 1999 [SIK 03]. From the time of this reparation, many other examples of consumption of composite are itemized (Hydra bridge, Oued Larbaâ bridge, El Harrach White Bridge, etc.). The incident of the White Bridge, located in El Harrach, Algiers, witnesses one of the first concrete samples of the significant usage of composites for the strengthening bridges in Algeria [2].



a)



b)

Figure I.9. Rehabilitation of El Harrach White, Algiers (photo CTC\Est)

a) Flexural strengthening b) Shear strengthening

7.Strengthening with FRP composite materials

Composite materials were initially established for the aerospace and aviation productions. Because of the high requests for more effective structure materials, composite materials were presented into the construction manufacturing. The composite reinforcement method was firstly by MEIER in 1991 on existent structures in Switzerland (Foo et al., 2001). MEIER and his group applied his technique for the consolidation of a beam of the IBACH BRIDGE with a total dimension of 228 meters [1].

Numerous academics have funded the improvement of this technique as Kachlakev and McCurry 2000, Parvin and Granata 2000, Teng et al. 2002, Alampalli et al. 2002, Nassif and Najm 2003, Hag-elsafi et al. 2003, Hwang and Yun. Their researches illustrated the effect of this method in strengthening concrete components (Benzaid et al., 2010).

The composite strengthening technique exemplifies a favorable substitute to other reinforcement systems. This could be possible throughout its numerous gainful features counting:

- ✓ A very high strength to weight ratio.
- ✓ The flexibility of composite materials that provides the adaptation to diverse forms.
- ✓ Absence of corrosion.
- ✓ High resistance, particularly to traction.

7.1 Reinforcement using bonded composite materials (EBR Technique)

In 1998 Komlan et al categorized the composite material reinforcement systems into three classes:

Firstly, it was the one of Meier's (Meier *et al.*, 1993) that comprises attachment with an epoxy resin a flat or a number of them with room temperature curing.

The second technique, that of Hamelin, changes from the first by using glue as being the thermosetting sort in which the curing is made by heat and pressure. This way is known by the reinforcement of Hamelin by applying a fabric with the position of the plates in composite.

The third proposed method by the company SOFICAR and the Laboratoire Central of bridge) is alike the second excluding the curing which is prepared at room temperature[1].

All three systems contain gluing to the superficial of the concrete at the place of the stretched fragment of the plates or fabrics done by fiber reinforced polymers "FRP via an epoxy glue. The system of the strengthening is complete after the provision of the surface to be fused which consists in removing the fragile parts to ensure a uniform surface for a good adhesion between the resin and the concrete. This support technique is recognized as (Externally Bonded Reinforcement) EBR see Figure I-6 and Figure I-7

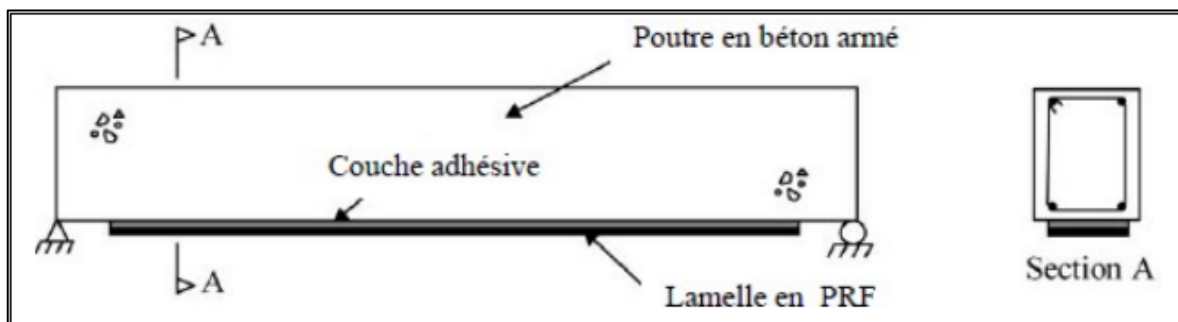


Figure I-10: EBR reinforcement technique (Teng *et al.*, 2002).



Figure I-11: Several uses of the EBR reinforcement technique (Teng *et al.*, 2002).

8. NSM (Near Surface Mounted) reinforcement technique [1].

Lately, FRP strengthening has been the attention of numerous studies in which I was based on the enhancement and the comprehension of the EBR technique. Though, other investigations have suggested a new method termed NSM (Near Surface Mounted). Demonstrating a favorable modernization in the arena of strengthening of reinforced concrete constructions. The scientists proposed it as a substitute to the previous one. Originally, this method was stimulated by a related ancient technique. In fact, it was spread in Europe, exactly in Sweden in the beginning of 1950s. A method that was realized for the strengthening of a reinforced concrete bridge. Engineers plowed channels in the concrete where steel bars were positioned and then packed the grooves with cement mortar. In fact, the NSM method is like the preceding one excepting that the steel bars are substituted by "FRP" rods or flats, and epoxy grape as a replacement for of cement mortar. [2].

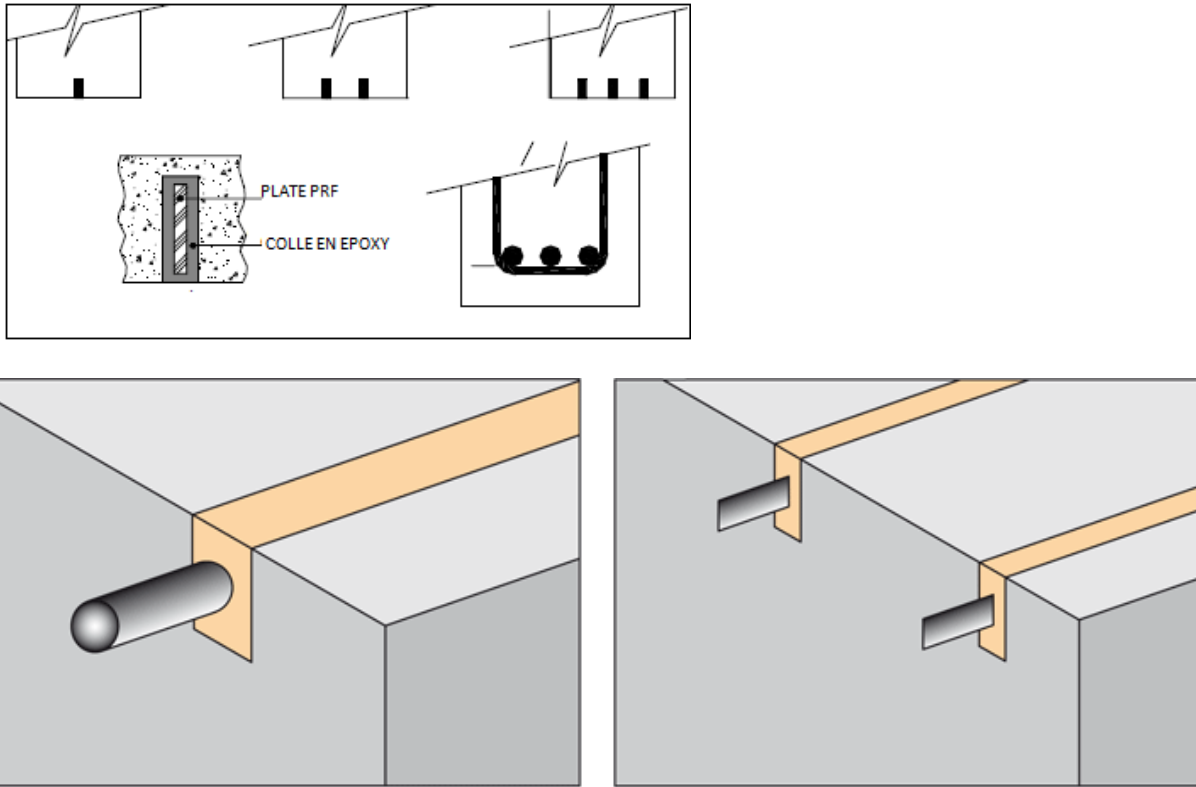


Figure I-12: NSM reinforcement technique.

8.1 SNSM (Saide Near Surface Mounted) reinforcement technique.

In the preceding five years, investigators as (Sharaky *et al.*, 2014), (Bilotta *et al.*, 2015), have established a new practice named SNSM (Side Near surface mounted). This is analogous to NSM excluding the location of the positioned reinforcements which is at the lateral facets than in the bottom of the beam. [1].

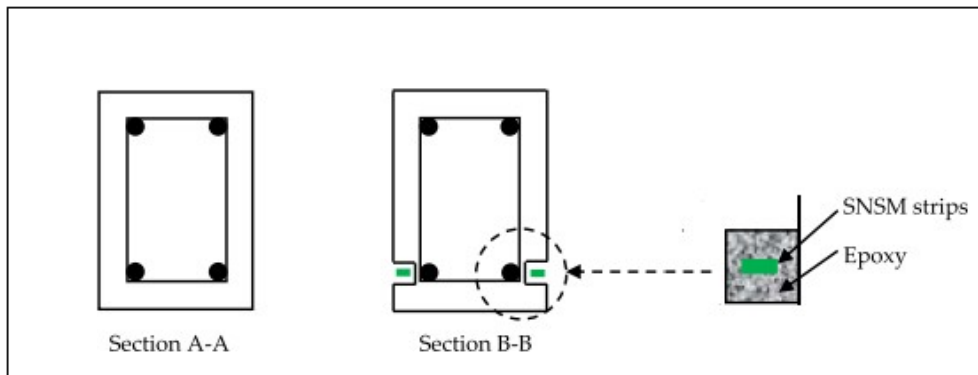


Figure I-13: SNSM reinforcement technique.

9.conclusion

The concrete structures that are exposed to earthquakes or extreme weather conditions are the most vulnerable structures, hence the vital need for their repair. This is especially important for the non-reinforced structures (concrete and brick masonry), which are the areas that undergo more stress. Since they constitute a very promising field, cement matrix materials reinforced with composite materials have been widely studied over the last two decades.

Chapter 2

PLASTICITY AND FAILURE BEHAVIOR

1. Introduction

In the world of concrete failure, the cause of the problem is not often visible, rather it is just a symptom of the real cause. Before any external faults show, stresses build up, internal chemical reactions may take place and unknown costs are already needed to repair the concealed failure. By the time it is visible, it could all be too late.

Each failure requires unique testing, product selection and application to restore the structure to its original state. Major failures used usually triggered by an external force, which then results in a domino effect of failures from imperfections in the concrete or flaws in the reinforcement. Bluey offers a wide range of products for concrete repairs, testing equipment as well as installation teams to restore a wide range of all concrete failures. Mechanical fracture is one of the most common concrete failures that we frequently repair. Most mechanical failures occur because of physical impacts such as collisions. Vibrations, overloading and other movements can also result in cracking and loss of entire concrete sections.

2. Elasticity

In physics, elasticity is the property of a solid material to return to its original shape after being deformed. Elastic deformation is a reversible deformation. A solid material deforms when forces are applied to it. An elastic material returns to its original shape and size when these forces are no longer applied, up to a certain limit of the value of these forces[3].

Phenomenologically, the instantaneous, reversible elastic behavior is easily described by the following diagram, which shows the evolution of the parameters time, stress and strain. [4].

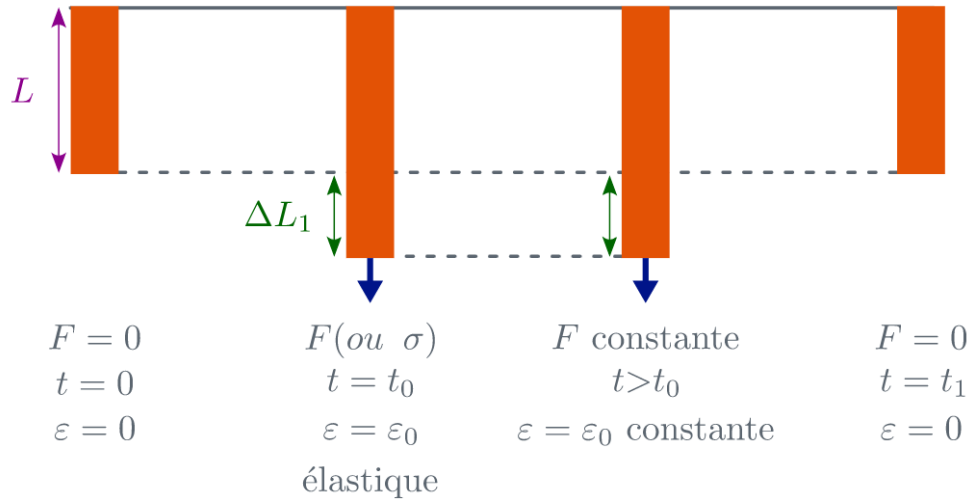


Figure 2.1 The phenomenology of elasticity

Elasticity can be linear, governed by Hooke's law characteristic of all metals, or non-linear in the case of elastomers in particular or in the particular case of hyperelasticity. It can be isotropic in the general case of metals or polycrystalline alloys or anisotropic, emblematically for single crystals but also for textured polycrystals. Finally, the elasticity can have an enthalpic character in the case of crystallized bodies or entropic, for polymers for example. Crystallized solids present a well-established long-range order in relation to their crystalline structure. Elastic deformation results in a collective displacement of the atoms from their equilibrium position which is not likely to generate additional structural order. In other words, the system does not undergo any variation of entropy, it is on the contrary the internal energy which increases with the deformation. We know that the elastic deformation capacity of metals is generally very low, of the order of 1% maximum, even if the displacements can be important. This is precisely the case of a metal rod elastically deformed in bending. To be convinced of the enthalpic character of the deformation, it is enough to appreciate the quantity of energy restored when the bending is released: it can be considerable. On the contrary, in the case of polymers, elastic deformation leads to an increase in structural order generated by an arrangement of macromolecular chains. Thermodynamically, this results in a decrease of entropy. The amount of energy released when the effort required to deform an elastic of 1% is negligible. Note that this elastic is also reversibly

deformable by a few hundred percent. In this ultimate case, a part of entropic elasticity must of course be considered in order to accurately describe the behavior of the elastomer.

When the restitution of elastic energy is not instantaneous, we speak of viscoelasticity (see next figure). This very specific behavior must be distinguished from creep which is a phenomenon operating at high temperature, typically above half the melting temperature of the material considered, expressed in Kelvin. [4].

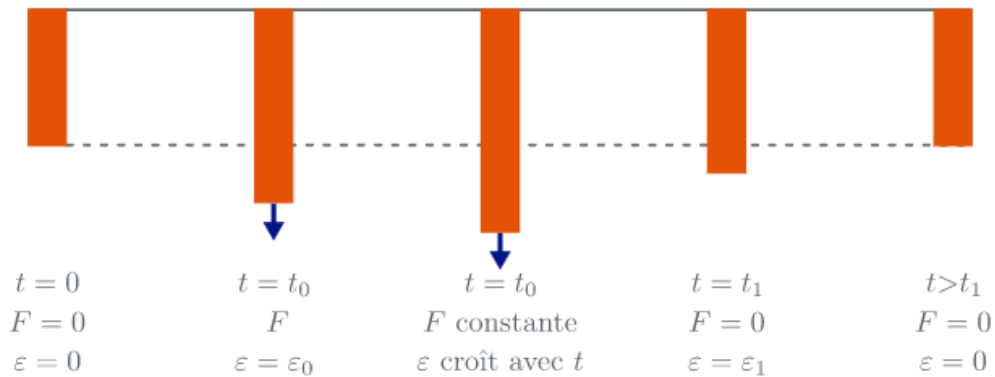


Figure 2.2 The phenomenology of viscoelasticity

2.2. The linear and non linear elasticity

The materials present, below a certain loading threshold, a quasi-reversible elastic behavior characterized by a volumetric density of elastic potential $\pi(\varepsilon)$ which is identified in isothermal regime $T = T_0$ with their volumetric density of free energy (ε). To the deformation increment $d\varepsilon$ corresponds the state of constraint such that:

$$\sigma = \partial \pi / \partial \varepsilon = \partial F / \partial \varepsilon \quad T = \partial E / \partial \varepsilon - T_0 \partial S / \partial \varepsilon$$

This expression shows that the origin of elasticity is twofold: one contribution comes from the internal energy variation associated with deformation, the other comes from the entropy. According to the classes of materials these two contributions can be of very different orders of magnitude.

For very deformable materials such as elastomers, the conformations of the molecular chains can be considerably modified by the deformations almost without variation of the interatomic distances

and the entropy term, responsible for the high rubbery elasticity, becomes preponderant. The resulting deformations are important and the 'elastic' behavior is nonlinear due to the evolution of resistance to the change of macromolecule configuration, entanglement, stretching, alignment. The stress increases well with the deformation since the entropy decreases, the internal structure of the material passes initially from a disordered to an ordered arrangement of macromolecular chains.

The variation of internal energy is prevalent for crystalline materials for which slight variations of interatomic distances associated with deformation lead to considerable variations of the cohesive energy while the entropy is almost not modified [5].

- **Linear elasticity**

Above their threshold of plastic flow (ductile materials) or of rupture (brittle materials), crystalline materials show a linear elastic response. It is therefore translated by a proportional relationship between the tensors σ and ε . In this case the potentials $\pi(\varepsilon) = f(\varepsilon)$ and $\omega(\sigma) = \Phi(\sigma)$ are equal (Cf. Fig. 3.3) and the volumetric density of stored elastic energy is expressed as

$$\pi(\varepsilon) = f = \frac{1}{2} \frac{dw}{dv} = 1/2 \text{Tr}(\sigma\varepsilon)$$

f reduces to a homogeneous function of degree 2 of the components of ε but also of σ . It is a positive definite quadratic form; Euler's theorem on homogeneous functions leads to the relation (5)

$$f = \frac{1}{2} \text{Tr}(\varepsilon\sigma) = \frac{1}{2} \text{Tr} \left(\frac{\varepsilon \partial f}{\partial \varepsilon} \right) = \frac{1}{2} \text{Tr} \left(\frac{\sigma \partial f}{\partial \sigma} \right)$$

- **Isotropic linear elasticity**

Most materials are elaborated in polycrystalline form. As in continuum mechanics, we are only interested in material particles whose dimensions are larger than those of the microcrystals, The macroscopic isotropy of the material generally results from an average of the anisotropic properties of the numerous microcrystals constituting the particle and the elastic mechanical properties do not depend on the orientation within the material, contrary to the case of single crystals or composites.

Subjected to a stress field low enough to keep these materials below their plasticity threshold, the coefficients of the stress-strain relation in the linear elastic regime, the elastic moduli of these materials, are constants independent of the amplitude of the applied stress.

The free energy of an isotropic material, being a homogeneous function of degree 2 of the components of ε or σ , is a scalar invariant by change of reference. f can therefore only be derived from quadratic invariants $\{\text{Tr}^2(\varepsilon), \text{Tr}(\varepsilon)\}$ or $\{\text{Tr}^2(\sigma), \text{Tr}(\sigma)\}$:

$$m^e \text{Tr}^2(\varepsilon) + m^e \text{Tr}(\varepsilon^2) = F = m^\sigma \text{Tr}^2(\sigma) + m^\sigma \text{Tr}(\sigma^2)$$

$m^e \varepsilon, m^e \varepsilon^2$ and $\{m^\sigma, m^\sigma\}$ constituting couples of two independent modules characterizing the isotropic 'elastic' behavior.

These couples are not independent and it is possible to define them as a pair of independent moduli. These couples are not independent and it is possible to express the moduli of one couple in terms of those of the other. Also, by combination, it is possible to define other pairs of modules.

Isotropic materials are characterized by 2 independent elastic modules [5].

2.3 The Elastic moduli

Young's modulus and Poisson's ratio

Around 1800 Young, a doctor by training, became interested in the elasticity of horn. By performing uniaxial tensile tests, he found that the strain ε measured along the tensile axis is proportional to the applied stress σ . He defines the proportionality coefficient $E = \sigma / \varepsilon$. (5)

Poisson completes the analysis by noting that the elongation in the direction of the tensile axis

is accompanied by a proportionally smaller shortening in the perpendicular directions. He positively defines the proportionality coefficient $\eta = - \varepsilon_{\perp} / \varepsilon_{\parallel}$

-The Young's Modulus E has the dimension of a stress and is generally measured in GPa (see Appendix A.4). It represents the stress that would have to be applied to obtain a uniform

deformation, i.e., doubling the initial length. No material responds linearly to such a constraint, most of them have yielded long before.

-The Poisson's ratio η is a dimensionless number in the range $\{0, 1\}$. With the exception of elastomers such as rubber whose Poisson's ratio $\eta > 1$, most continuous isotropic materials have a Poisson's ratio in the range $\{0, 25 - 0, 35\}$.

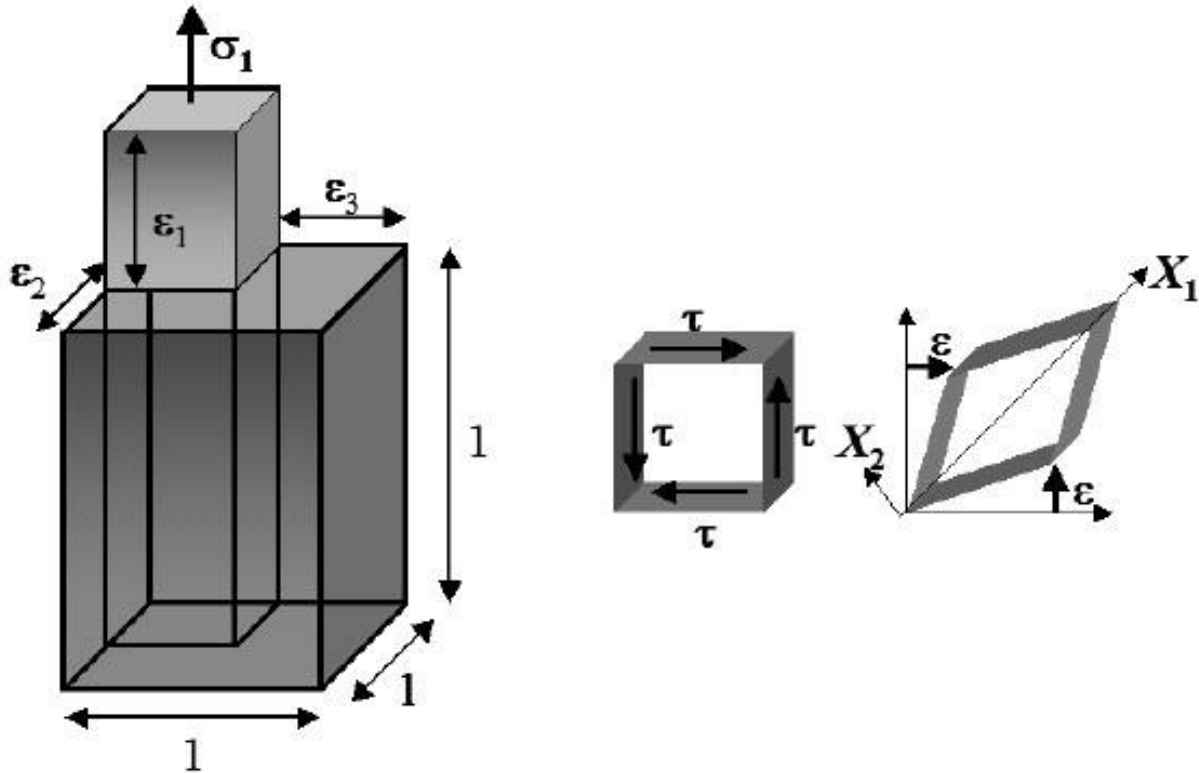


Figure. 2.3 - Modules: Young, Poisson, Coulomb

NB: Structurally complex materials can have Poisson's ratios greater than 0.5.

2.4 Elasticity limit

The elastic limit (or proportionality) is the stress above which irreversible deformations appear. The point corresponding to Re figure (2.3) characterized by a clear change in the load curve $(F, \Delta l)$ is difficult to locate.(6)

If we load from O through A to B, then we unload to B figure (2.4) when we load from C, we will have a new, sharper yield point B σ . (increase or decrease) in the magnitude of the strain. There is then (hardening or softening) of the material. (6)

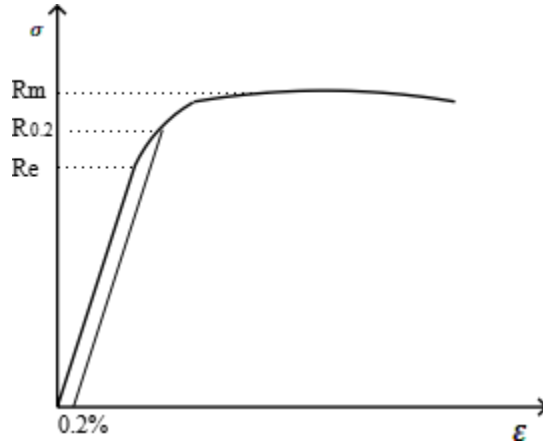


Figure (2.4): Repensing curve (stress - strain)

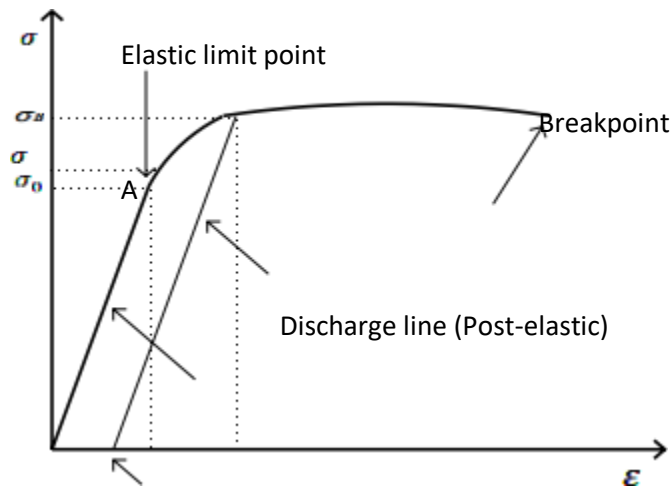


Figure (2.5): Elasticity limit

3. PLASTICITY

When a material is stressed to failure, tests show that the failure stress σ_R is a variable that fluctuates widely, even exceeding a decade for some materials, and that the mode of failure depends on the nature of the material and that the mode of failure depends on the nature of the material.

Thus, in the case of materials now described as brittle, failure may occur suddenly, almost without prior deformation, whereas in the case of materials now described as ductile, it only occurs after a period of great permanent deformation. We now know that brittle materials fracture abruptly above a certain tension, while ductile materials flow plastically before fracturing in shear. While fracture is always the ultimate stage in structural failure, in the case of ductile materials it is preceded by plasticization

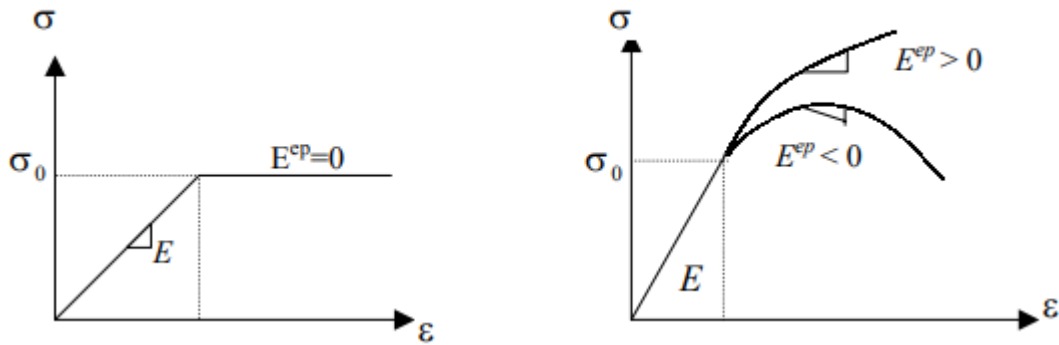
3.1Plastics behavior

Plasticity refers to a material's ability to undergo permanent and irreversible deformation before breaking. At the microscopic level, plastic deformation is seen in the deformation of metallurgical grains. This in turn is induced crystallographically by significant shearing of crystalline planes. It should be noted that not all crystalline materials exhibit this specific property, which in particular enables them to accommodate the mechanical stresses imposed without the material undergoing crippling fracture. Typically, crystalline materials capable of plastic deformation are metals and metal alloys containing dislocations. Ceramics, on the other hand, exhibit only elastic behavior, breaking without residual deformation. It is therefore dislocations, linear crystalline defects formed during the solidification phase of metals and alloys, which convey plastic deformation. The line length of dislocations present in 1cm³ of copper reaches 10⁶cm, which translates into a density of 10⁶cm⁻². As they move, dislocations produce a definitive change in the crystal's shape. Once the material has been processed, dislocations can multiply or recombine. [4].

3.2 Modeling elasto-plastic behavior

The actual behavior is modeled either by the perfect elasto-plastic curve (with no Baushinger effect, Fig. (2.5.a), or by the curve with strain-hardening (linear or non-linear) and therefore a tangent elasto-plastic modulus (figure (2.5.b)). The latter case is more general:

So if $E_{ep} = 0$, it's the case of perfect elasto-plasticity, if $E_{ep} > 0$ it's hardening (positive strain-hardening) and if $E_{ep} < 0$ it's softening (negative strain-hardening). [6].



A). Perfect elasto-plasticity

B) Elasto-plasticity with strain-hardening

Figure (2.6): Modeling elasto-plastic behavior

3.3 General information about Plasticity criteria

These criteria express that the plastic regime is achieved for states verifying relation $f(\sigma) = 0$ regardless of the orientation of the frame of reference in which the stresses are applied, relative to any with respect to any material reference frame. The equation for the plasticity surface can therefore be expressed as a function of the three principal stresses [7]

$\sigma_1, \sigma_2, \sigma_3 :$

for ductile metals, experience shows that the addition of a hydrostatic stress state condition does not alter the plastic flow conditions for the usual hydrostatic stress levels. We can therefore only the deviatoric part of the stress tensor can be taken into account. $s = \sigma - \frac{1}{3}I$ in the expression of the load function, and re-express the criterion as :

$$f(J_2, J_3) = 0$$

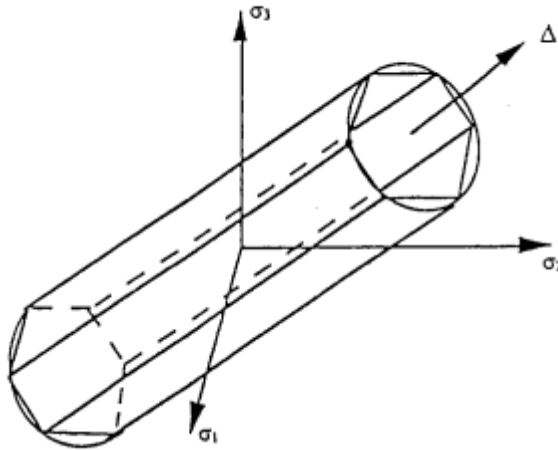


Figure 2.7 Representation of an isotropic plasticity criterion in Haigh-Westergaard space, for a material insensitive to hydrostatic loading

- **Tresca criterion (1864)**

The first criterion still in use today for metallic materials was proposed by Tresca in 1864. This criterion states that the elastic limit is reached when the maximum shear stress reaches a critical value k . The plasticity surface is therefore determined by : (7)

$$\text{MAX} \left(\frac{1}{2} \sigma_1 - \sigma_2; \frac{1}{2} \sigma_2 - \sigma_3; \frac{1}{2} \sigma_3 - \sigma_1 \right) - k = 0$$

The constant k is a measure of the elastic limit in shear; it can also be determined by a uniaxial tensile test, for which the elastic limit σ_g is equal to $2k$. This criterion corresponds to an isotropic material insensitive to hydrostatic pressure, it can be expressed as a function of the invariants J_2 and J_3 , as :

$$f(J_2, J_3) = 4J_2^3 - 27J_3^2 - 36kJ_2^2 + 96k^4J_2 - 69k^6 = 0$$

Its representation in Haigh-Westergaard space corresponds to a right circular cylinder with axis $\hat{\Delta}$ and a regular hexagon base in the deviating plane.

- **Von Mises criterion (1913)**

The Von Mises (1913) criterion assumes that the charge function depends only on the invariant J_2 . The plasticity surface is expressed in the form : [7]

$$f(J_2) = J_2 - k^2 = 0$$

The constant k is a measure of the elastic limit in shear; it is also related to the elastic limit in uniaxial Tension/compression σ_0 By the relation $\sigma_0 = \sqrt{3} k$ Its representation in HaighWestergaard space corresponds to a cylinder of σ_0 with a circular base of radius k , [t in the deviatory plane (Figure I-2). Using the developed expression of J_2 , σ_0 can also represent the plasticity surface by the equations

$$(\sigma_1 - \sigma_2)^2 - (\sigma_2 - \sigma_3)^2 - (\sigma_3 - \sigma_1)^2 - 6K^2 = 0$$

In the principal stress axes or in any axes, respectively.

This criterion can be interpreted as meaning that either the elastic shear energy reaches a critical value, or that the shear stress on the octahedral shear stress on octahedral planes, of equation $x_1 \pm x_2 \pm x_3 = 0$ in the main stress axes, reaches a critical value.

- **Drucker criterion (.1949)**

An isotropic criterion whose trace in the deviation plane lies between the Tresca hexagon and the Von Mises circle was proposed by Drucker. 1949. It involves a combination of the invariants J_2 and J_3 , which is expressed as: [7]

$$f(J_1, J_2) = (3j_2)^2 \left(1 - C \left(\frac{j_3^2}{J_2^3} \right) \right) = \left(1 - \frac{4C}{27} \right) \sigma_0^6 = 0$$

where σ_0 designates the elastic limit in uniaxial or equibiaxial tension/compression. equibiaxial. The surface convexity condition is verified for $c < 9/4$. Figure shows the plasticity surfaces in the deviatorial plane, satisfying the three previous criteria

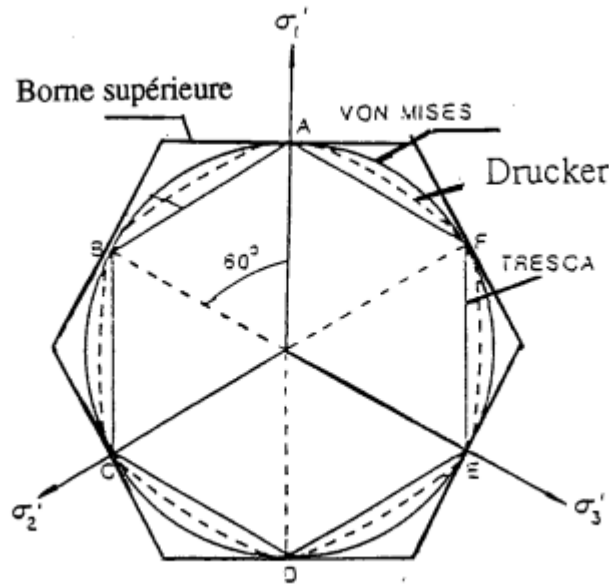


Figure 2.8 Representation in the deviation plane of the plasticity surface corresponding to the criteria of Von Mises, Tresca and Tresca and Drucker criteria

3.4 generality of orthotropic plasticity criteria

Orthotropy is a special case of anisotropy, where the material has three orthogonal planes of symmetry. If we assume a priori a quadratic extension of the Von Mises criterion, which involves an isotropic expression of the form $\mathbf{s}:\mathbf{B}:\mathbf{s}$, (b being a 4th-order tensor) the 81 components of B are reduced by symmetry, to 21 independent coefficients in the general case of anisotropy, and to 15 independent coefficients if we consider independence from hydrostatic loading. The special case of orthotropy finally leads to 6 independent coefficients. We then obtain Hill's (1948) quadratic criterion, whose main limitation is its quadratic form. A much more general formulation has been proposed by Boehler (1982) [7]

4 Concrete Damage Plasticity Model

The concrete damage plasticity (CDP) model in Abaqus is used to create the constitutive model for pre-fabricated slab. The CDP model is commonly used to represent the behaviour of quasi-brittle materials such as concrete, rock, and masonry. It is based on the basic concept presented by [Lubliner *et al.*, 1989] and the improvements proposed by [Lee and Fenves, 1998]. In the sense

that it does not monitor individual macro fractures, the concrete damage plasticity model in ABAQUS is a smeared crack model. The finite element constitutive model's calculations are done separately at each integration point, and the existence of cracks enters the calculations by changing the stress and material stiffness associated with the integration point. This model suggests that the behaviour of concrete under uniaxial compression and tension is governed by damaged plasticity, with compressive crushing and tensile cracking as the primary failure modes. The stress-strain relationship in uniaxial tension is considered to be linear until the failure stress, σ_t^0 , which corresponds to the beginning of macrocracking, is reached. This is frequently followed by softening, which results in strain localisation. In uniaxial compression, it is also presumed that the reaction is linear until the first yield stress, σ_c^0 , after which a plastic regime, often characterised by strain hardening to the ultimate stress, σ_{cu} , and then softening, takes over. CDP is premised on the idea that uniaxial stress-strain relations can be automatically converted into stress-equivalent plastic strain curves using user-supplied inelastic strain data. The present condition of the yield surface, which is utilised to assess multiaxial load scenarios, is then determined by computing the effective tensile and compressive cohesion stresses. [8]

4.1 Defining Yield Surface

A yield surface is a surface in the stress space that encloses the elastic region's volume. This indicates that the stress state within the surface is elastic, but stress levels on the surface have hit the yield point and are now plastic. Further deformation keeps the stress state on the surface, as states outside the surface aren't allowed in rate-independent plasticity. There are several formulas of yield surface criteria, and the Drucker-Prager yield criterion is utilised in ABAQUS for concrete since it allows for failure to be determined both by normal and shear stress. It is a pressure-dependent criteria based on the hydrostatic pressure, p , and the Mises equivalent stress, q , which are both stress invariants of the effective stress tensor. Input parameter κ_c is used to determine the shape of the yield surface. For any given value of the pressure invariant, p , such that the maximum primary stress is negative, $\hat{\sigma}_{max} < 0$, κ_c is the ratio of the second stress invariant on the tensile meridian to that on the compressive meridian at initial yield. κ_c has a range of 0.5 to 1. As a result, if $\kappa_c = 0.5$, the Rankine yield surface is established, and if $\kappa_c = 1$, the von-Mises yield surface is established. $\kappa_c = 2/3$, the default value in ABAQUS is used and it distorts yield surface in the deviatoric plane using Mohr-Coulomb criterion. [7]

4.2 Yield Function in Abaqus

In ABAQUS, Fenvé’s adaptation of Lubliner’s yield function is utilised to account for the differing evolution of strength under tension and compression.

$$F = \frac{1}{1 - \alpha} \left(\bar{q} - 3\alpha\bar{p} + \beta(\epsilon^{pl}) \langle \hat{\sigma}_{max} \rangle - \gamma \langle -\hat{\sigma}_{max} \rangle \right) - \hat{\sigma}_c(\epsilon_c^{pl}) = 0$$

where,

$$\alpha = \frac{(\sigma_{b0}/\sigma_{c0}-1)}{2(\sigma_{b0}/\sigma_{c0}+1)} \text{ for } 0 \leq \alpha \leq 0.5$$

$$\beta = \frac{\bar{\sigma}_c(\epsilon_c^{pl})}{\bar{\sigma}_t(\epsilon_t^{pl})} (1 - \alpha) - (1 + \alpha)$$

$$\gamma = \frac{3(1-K_c)}{2K_c-1}$$

σ_{max} denotes the maximum principal effective stress, and σ_{b0}/σ_{c0} denotes the userspecified ratio of the equibiaxial compressive yield stress to the starting uniaxial compressive yield stress. σ_{b0}/σ_{c0} increases compressive stress owing to effective confinement. [7]

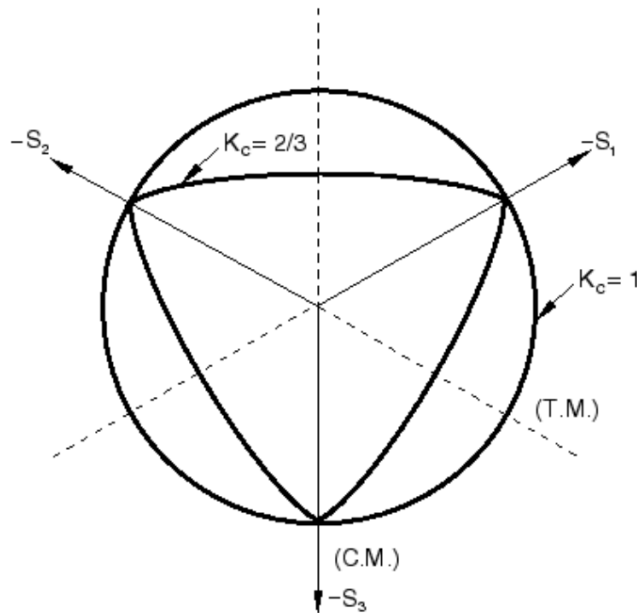


Figure 2.9: “Yield surfaces in the deviatoric plane, corresponding to different values of Kc”.

“C.M.: compressive meridian and T.M.: tensile meridian

σ_{max} may be calculated from the maximum of the experimental range, which includes a uniaxial compression test and a biaxial compression test. Its default value is 1.16 which is suitable for

normal strength concrete only. It is altered for compressive high-strength concrete based on an experimental investigation of equal biaxial-to-uniaxial compressive strength ratios [Dong *et al.*, 2016] and a value of 1.2 is used.

5 Stress Intensity Factor (SIF)

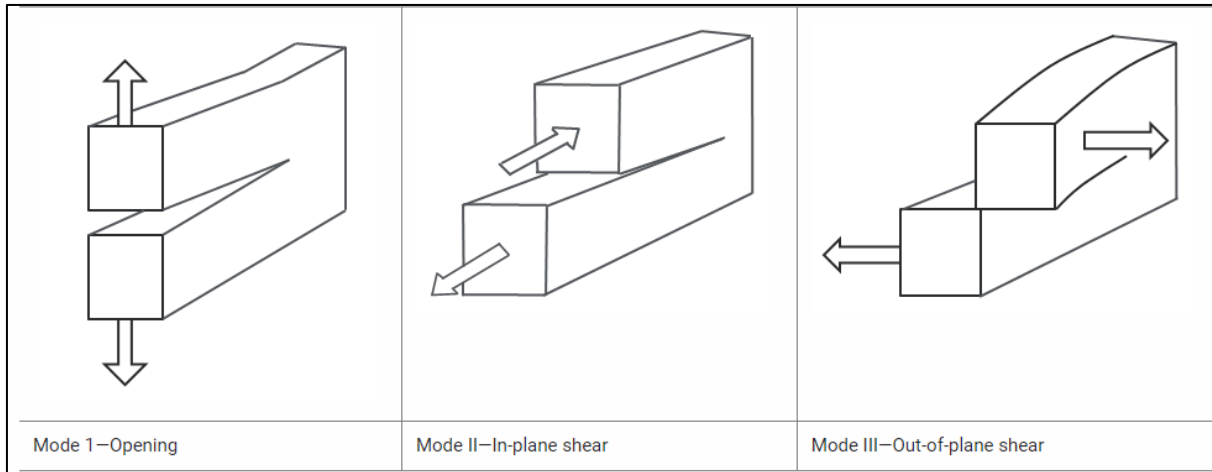
The stress intensity factor (SIF) measure predicts the stress state near a crack tip or crack front caused by a load or residual stress. You can create a SIF measure after defining a crack idealization. You can evaluate the value of the SIF measure in a static analysis to predict the growth of a crack under specific loading conditions.

In case the mesh near the tip of the crack is too coarse you can refine it using the configuration option sim_sif_measure_size_factor

SIF measures are calculated for static analyses with small deformations and for models with linear elastic materials only.

After you select stress intensity factor as the quantity, you need to specify the following information on the Measure Definition dialog box

- **Component**—Different modes of SIF measures that depend on the method by which force is applied to the crack. The following modes are available:
- **Mode I (Opening)**—The crack surfaces move directly apart due to a tensile stress that is normal to the plane of the crack.
- **Mode II (Sliding)**—The crack surfaces move apart due to in-plane shear. The crack surfaces slide over one another in a direction that is perpendicular to the leading edge of the crack.
- **Mode III (Tearing)**—The crack surfaces move apart due to out-of-plane shear. This option is available only for 3D models



A term K , called the *stress intensity factor*, can be defined in the form:

$$K = \sigma\sqrt{\pi a}$$

5. Defining behaviour of concrete under tension

The tensile strength (f_t) of high strength concrete is given by

$$f_t = 0,301(FCM)^{0,67}$$

To define crack opening behaviour in tension, empirical equations proposed by [Hordijk, 1991] were used. Yield Stress-crack opening displacement relation:

$$\frac{\sigma_t}{f_t} = \left[1 + \left(c_1 \frac{w_t}{w_{cr}} \right)^3 \right] e^{-\left(c_2 \frac{w_t}{w_{cr}} \right)} - \frac{w_t}{w_{cr}} \left(1 + c_1^3 \right) e^{-c_2}$$

Relation for fracture energy:

$$G_F = f_t w_{cr} \left[\frac{1}{c_2} \left\{ 1 + 6 \left(\frac{c_1}{c_2} \right)^3 \right\} - \left\{ \frac{1}{c_2} + c_1^3 \left(\frac{1}{c_2} + \frac{3}{c_2^2} + \frac{6}{c_2^3} + \frac{6}{c_2^4} \right) + \frac{1}{2} \left(1 + c_1^3 \right) \right\} e^{-c_2} \right]$$

where f_t is concrete uniaxial tensile strength; σ_t is yield stress; w_t is crack opening

displacement; $w_{cr} = 25$ mm is crack opening displacement at complete loss of tensile strength; G_F is fracture energy; $c_1 = 3.0$ and $c_2 = 6.93$ are constants which are determined by tensile tests of concrete. Damage parameter (d_t) is given by:

$$d_t = 1 - \frac{\sigma_t}{F_T}$$

Compression hardening and Tensile stiffening data used is given in Table 4.5 and 4.6

Crack width	Stress	Damage factor
0	2,7	0
0,01	1,757814939	0,34895743
0,02	1,186052536	0,560721283
0,03	0,853477568	0,683897197
0,04	0,660422324	0,755399139
0,05	0,541654256	0,799387313
0,06	0,458952891	0,830017448
0,07	0,392258654	0,854719017
0,08	0,332443944	0,876872613
0,09	0,276290529	0,897670175
0,1	0,223358721	0,917274548
0,11	0,174219008	0,935474442
0,12	0,129564254	0,952013239
0,13	0,089841765	0,966725272
0,14	0,055163659	0,979569015

6 Conclusion

Knowing the behaviour of concrete structure is a very important step we must do to guaranty it's stability that is why Several parameters must be studied in order to developpe an accurate model, and thus to predict what really happens in reality.

Chapter 3

CODE COMPUT ABAQUS

1 Introduction

In this part, the study of numerical modeling was carried out with the method of finite elements using the software Abaqus. The objective of this study is to analyse the behaviour of the continuous reinforced concrete beams strengthened by composite materials

2 Finite element method

The finite element method (FEM) is widely applied in structural design, with reliable results. FEM is used to discretely solve a partial differential equation (or PDE) for which a "sufficiently" reliable approximate solution is sought. Generally speaking, this PDE concerns an approximation function (x) , defined on a domain $fn(x)$. It includes boundary conditions to ensure the existence and uniqueness of a solution.

Except in special cases, discretization involves redefining and approximating the geometry, so we consider the problem posed on the geometry approximated by a piecewise polygonal or polyhedral domain. Once the geometry has been approximated, a space must be chosen to approximate the solution to the problem. In FEM, this space is defined using the domain mesh (which also explains why it is necessary to approximate the geometry). The domain mesh is used to define a partition of the domain, the blocks of which are the finite elements (Figure 2-1). A finite element is given by an elementary cell and basic functions of the approximation space whose support is the element, and defined in such a way as to be interpolative.

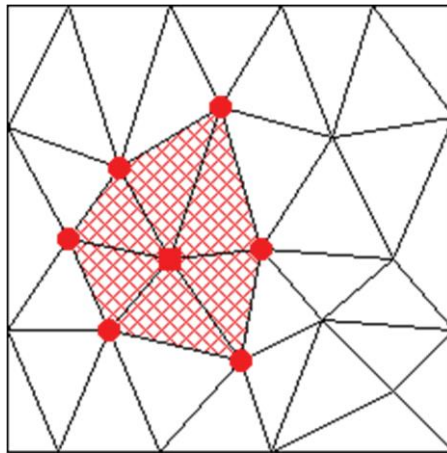


Figure 3-1: Finite element discretization

3. Abaqus software

In the modeling of the structure by the finite elements method, there are currently several commercial software's: ABAQUS, ANSYS... The software of finite elements ideal had been defined as software that would enable a rapid modelling and easy to a problem, ranging from simple to complex. It is important to indicate that the user has an innovative idea of what could be doing, in particular about choice of mesh size and elements type that should be adapted to the problem: the software does not cover everything for the users, in their turn, must always expect the approximate solutions.

In this part, the software Abaqus was used to model the RC beams strengthened by composite materials.

The software is Created in 1978, ABAQUS is a finite element code used to simulate the physical response of structures subjected to loading, temperature, impact or other external conditions. The software Abaqus is composed of two sub-products: Abaqus/Standard and Abaqus/explicit. The benefits of Abaqus are timeliness of pre-treatment, the possibility of distributing the areal elements or bars as some embedded elements in the solid elements of concrete.

ABAQUS is a finite element software package developed by DASSAULT. It comprises three products: ABAQUS/Standard, ABAQUS/Explicit and ABAQUS/CAE: ABAQUS/Standard, ABAQUS/Explicit and ABAQUS/CAE. The ABAQUS software range is particularly renowned for its technology, quality and reliability. It has become an integral part of the design processes of world-renowned companies in all industrial sectors. ABAQUS offers the best solutions for linear, non-linear, explicit and dynamic problems. The software provides an unrivalled environment for finite element analysis, offering a large number of alternatives to operations involving multiple suppliers and products.

- ✓ - The Abaqus/Standard solver is dedicated to static, linear dynamics, thermal thermal analyses and certain multiphysics couplings. It uses an implicit strategy implicit strategy with an iterative resolution path of the equations to be solved, it approaches the solution through successive cycles of equilibrium.

- ✓ The Abaqus/Explicit solver is dedicated to short transient crash and quasi-static dynamic analyses, as well as to certain multi physical couplings. It uses an explicit nonlinear dynamic formulation and determines the solution by explicitly advancing the model's smallest increment time without iteration.

3.1Abaqus/Standard

➤ **Implicit scheme**

The principle of this scheme consists in solving the equilibrium equation at time $t + \Delta t$ from the data set of the system state at time t and the system state at time $t + \Delta t$ where

$u_{t+\Delta t}$ is unknown in the equation to be solved:

$$u_{t+\Delta t} = u_t + \Delta t \dot{u}_{t+\Delta t} + \Delta t^2 \ddot{u}_{t+\Delta t} + \Delta t^3 \dddot{u}_{t+\Delta t} + \theta(\Delta t^4 \dots \ddot{u}_{t+\Delta t})$$

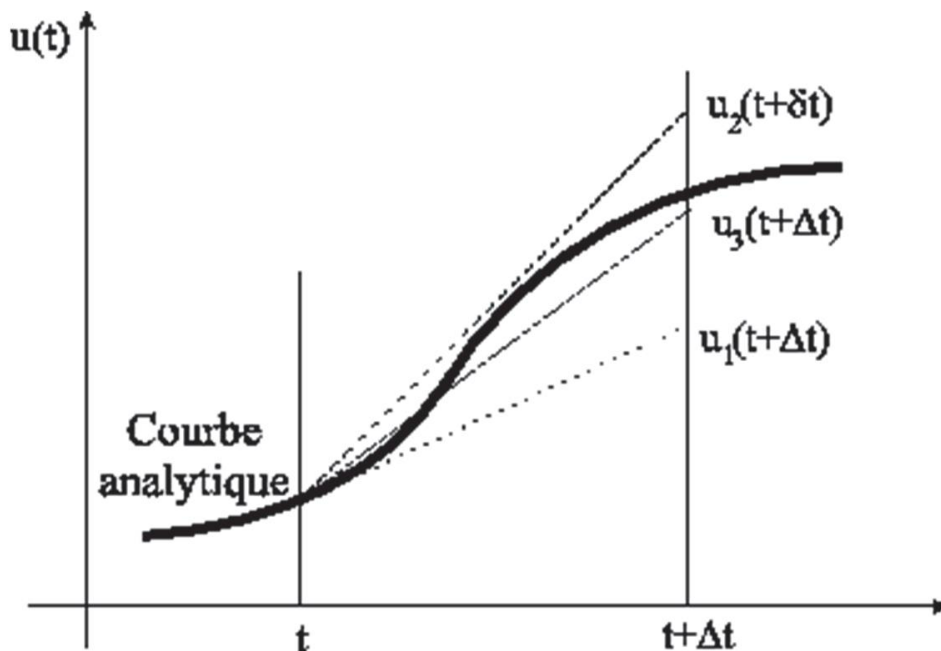


Figure 3.2: Illustration of the implicit integration scheme over time

The value nodal value $u_{t+\Delta t}$ is calculated from the value u_t and its derivatives in $t + \Delta t$. One of the major advantages

of this type of resolution is that the scheme is unconditionally stable. convergence is not subject to numerical restrictions. However, convergence can take a long time, implying long computation times for complicated problems.

➤ **Abaqus/Standard (Implicit)**

In Abaqus/Standard, Newton's method is used to solve non-linear problems. The basic formalism of this method is as follows:

Consider that after i iterations over the time increment, the approximate solution is u_i . The

difference between the exact solution and the solution after i iterations is C_{i+1} . The exact solution is given by : $u = u_i + C_{i+1}$

Symbolically writing the principle of virtual work by an implicit equation gives :

$$F(u) = 0$$

This corresponds to equilibrium with respect to the nodal variable under consideration. This implicit equation can be developed as a Taylor series in u_i , giving :

$$F(u_i) + \frac{\partial F}{\partial u}(u_i)C_{i+1} + \frac{\partial^2 F}{\partial u^2}(u_i)C_{i+1}^2 + \dots = 0$$

If the approximation u_i is close to the solution, then C_{i+1} is small and equation (2-5) can be

reduced to its first two terms, giving:

$$\frac{\partial F}{\partial u}(u_i)C_{i+1} = -F(u_i)$$

This equation (2-6) can be used to determine C_{i+1} to calculate the following approximation u_{i+1}

by: $u_{i+1} = u_i + C_{i+1}$

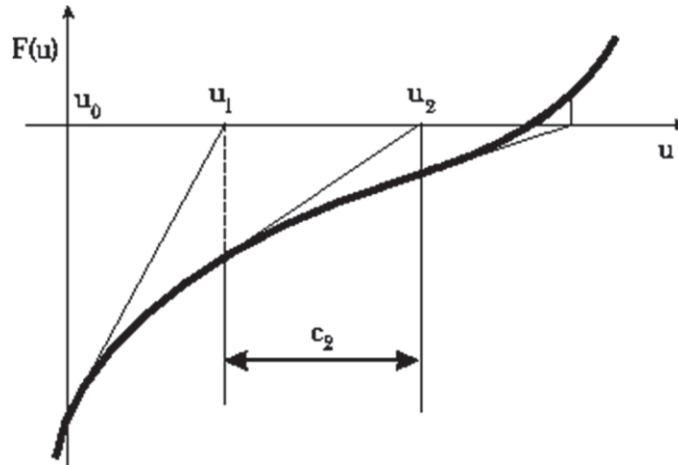


Figure 3-3: Illustration of Newton's method

Figure 2-3 illustrates Newton's method, the aim of which is to determine u such that $F(u) = 0$. On this figure, we can see that the nodal value of the next increment uses the Jacobian matrix as a slope, starting from the current value. The convergence of this method is quadratic, and therefore fast.

However, the Jacobian matrix ($\frac{df}{du}(u)$) may present existence and singularity problems. singularity. In which case, equation (2_5) is not solvable

➤ **Problem types suitable for ABAQUS/Standard :**

Problems suitable for Abaqus/Standard are low-speed static or dynamic problems which require highly accurate stress solutions.

Abaqus/Explicit

➤ **Explicit scheme**

The principle of this scheme is to solve the equilibrium equation for an instant $t + \Delta t$ from the data for time t . This diagram allows us to determine the $u_{t+\Delta t}$ nodal variables according to their values at the start of the t time increment.

$$u_{t+\Delta t} = u_t + \Delta t \dot{u}_t + \Delta t^2 \ddot{u}_t + \Delta t^3 \dddot{u}_t + \theta (\Delta t^4 \ddot{\ddot{u}}_t)$$

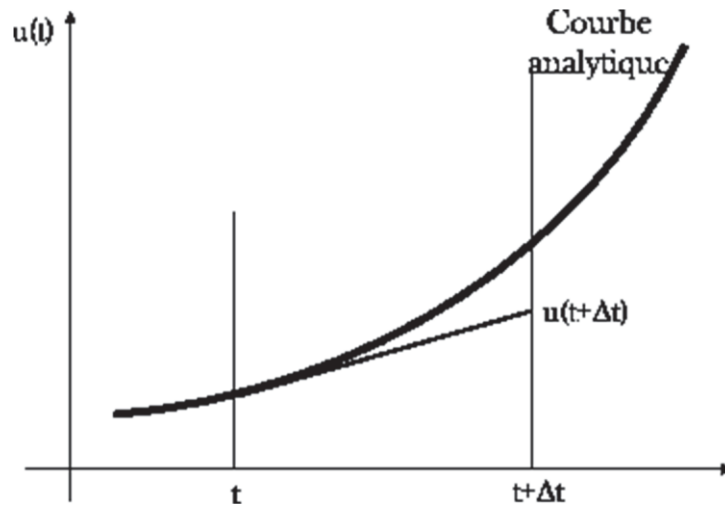


Figure 3-4 : Illustration of explicit time integration scheme

Figure 3-4 illustrates the explicit integration scheme over time, where the solution at time t at time $t + \Delta t$ is a function only of the nodal values and its derivatives at time t , as shown by the following system:

$$\begin{aligned}
 u_{t+\Delta t} &= u_t + \Delta t \dot{u}_t + \Delta t^2 \ddot{u}_t + \Delta t^3 \dddot{u}_t + \dots \\
 \dot{u}_t &= f^1(u_t) \\
 \ddot{u}_t &= f^2(u_t) \\
 &\dots
 \end{aligned}$$

This method of solving cannot accept time increments that are too large. divergent calculations. Convergence is only assured if the time increment Δt is less than a critical increment Δt_c . So, in this method, the size of the increments must be sufficiently small.

Abaqus/Explicit

The explicit version is fully vectorized for use with multi-processor supercomputers. Although the analysis is dynamic, it can be used with a few precautions to perform quasi-static analyses. The explicit scheme implemented within Abaqus leads to lower computation times than the implicit Abaqus/Standard scheme. The explicit algorithm ensures a certain robustness, and is more efficient

in achieving a complete calculation than Abaqus/Standard. This code also offers good contact resolution, which is another advantage for process simulation.

The calculation procedure in Abaqus/Explicite is carried out by explicitly moving forward in time and considering the system as dynamic. Time is considered as virtual time in the case of a quasi-static problem, or as real time in the case of a dynamic problem. Newton's equation is used in all calculation procedures: $M\ddot{U} = F - I$

Where \ddot{u} is the nodal acceleration vector, and M is the nodal mass matrix. F is the vector of applied loads and I is the vector of internal forces.

in general, Abaqus/Explicite uses the algorithm that can be expressed by the following steps:

For each increment Δt of time t, with external forces F(t) and internal forces I(t), it is possible to calculate nodal accelerations:

$$u = M^{-1}(F(T) - I(T))$$

By integrating this equation twice using the central finite difference method, we obtain the nodal displacement vector:

$$\begin{aligned} \dot{u}\left(t + \frac{\Delta t}{2}\right) &= \dot{u}\left(t - \frac{\Delta t}{2}\right) + \frac{\Delta t(t+\Delta t) + \Delta t(t)}{2} \ddot{u}(t) \\ u(t + \Delta t) &= u(t) + \Delta t \dot{u}\left(t + \frac{\Delta t}{2}\right) \end{aligned}$$

Where \dot{u} is the velocity vector, u is the nodal displacement vector. These equations are illustrated in Figure 2-5:

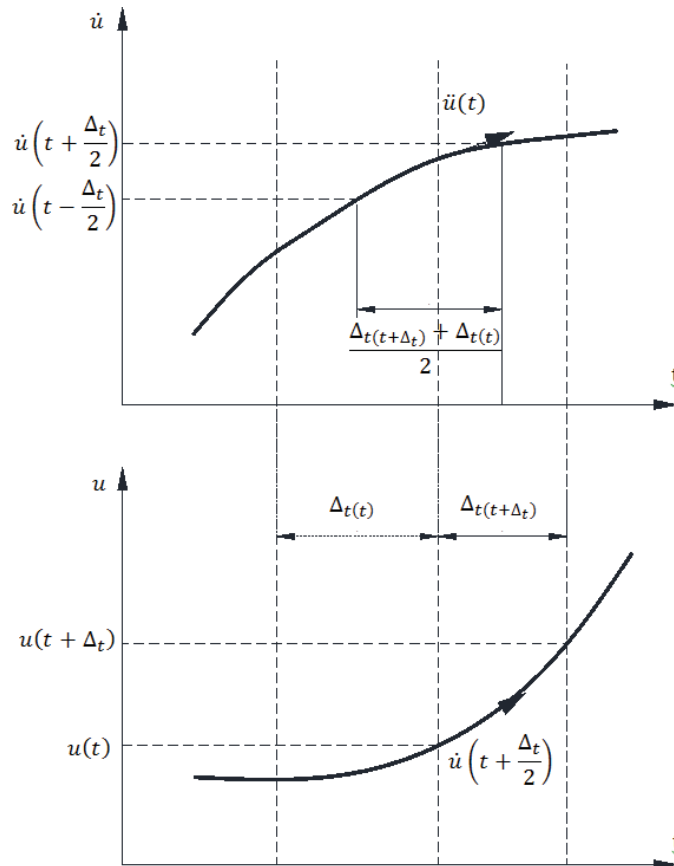


Figure 3-5: Illustration of the central difference operation

The next step is to calculate the strain increment $d\epsilon$ at element level, knowing the strain rate $\dot{\epsilon}$, the stresses at the elements are calculated using using the material's constructive law:

$$\sigma(t + \Delta_t) = f(\sigma(t), d\epsilon)$$

The next cycle is calculated with the new internal nodal force vectors $I(t + \Delta t)$.

and the processes are then repeated to completion.

Thus, the explicit procedure requires neither iteration nor tangent stiffness matrix. The explicit procedure integrates time using many small-time increments. However, the operator is

conditionally stable. The limit of stability for this operator is given in terms of the system's largest eigenvalue by :

$$\Delta_t \leq \frac{2}{\omega_{max}}$$

As the value m_{max} is not easy to determine for a given system, Abaqus/Explicit uses a conservative estimate of Δt_{stable} . An estimate of the smallest eigenvalue of the system can be obtained by determining the maximum mode of the mesh elements. Thus, the time increment allowing stability is given by:

$$\Delta t_{stable} \leq \min \left(\frac{L_e}{C_d} \right)$$

Where L_e is the characteristic length of the smallest element of the mesh and C_d is the speed of wave propagation in the material. propagation velocity in the material. This velocity is given by :

$$C_d = \sqrt{\frac{\lambda + 2\mu}{\rho}}$$

For each new analysis increment, Abaqus/Explicit automatically calculates Δt_{stable} and uses this increment step throughout the analysis. The user can enter a value for the time increment provided that it is smaller than Δt_{stable} calculated by Abaqus/Explicit.

- Problem types suitable for ABAQUS/Explicit :

The dynamic explicit method in the first place is created to analyse the dynamic event at speed, which takes a long time to solve for the implicit method (such as ABAQUS/Standard). When the load is applied rapidly, the behaviour of the structure changes very quickly. Since the stress waves are associated with the highest frequencies in the system, obtaining an accurate solution requires many small time increments.

- Complex contact system :

Contact conditions are more easily formulated with the explicit method than with the implicit method. As a result, the explicit method has the ability to analyse impact problems that contain interaction between many entities.

- Complex post-burn problem:.

ABAQUS/Explicit can quickly resolve unstable post-flaming problems. In some cases, the stiffness of the structure changes rigorously when loading is applied to the system. Post-buckling behaviour often includes the effect of contact interaction.

- Highly non-linear problems:

For many reasons, ABAQUS/Explicit is often effective for analysing systems that are essentially static systems. Among them, the quasi-static problem that translates complex contact is a favoured case for applying the explicit method. In this type of problem, we consider large and rapid deformation.

- Materials with degradation and fracture:

Degradation and breakage of the material often reflect the difficulty of convergence of the problem when using the implicit calculation method. However, ABAQUS/Explicit handles this problem very well. An example of degradation: the reinforced concrete structure with concrete failure taken into account where the "tension-stiffening" parameter can imply a negative value of the system stiffness. An example of material failure is the ductile failure of a metal element, where stiffness decreases until it reaches a zero value, at which point the failed elements are removed from the model entirely.

4 Getting started with ABAQUS

4.1 Description of ABAQUS capabilities

ABAQUS is a solver (Standard, Explicit, Implicit, etc.) which solves a problem described by an (input) file or data file with extension (.inp) and writes the solution to an (output) file or results file with extension (.odb).

A numerical simulation can be run by creating your own input file using a text editor and knowing the various key words, or by using the ABAQUS CAE graphical interface.

ABAQUS covers almost all areas of physics and all types of problem.

4.2 The units

ABAQUS has no built-in system of units. All data must be specified in a compliant system of units[11]

TABLE : the units

Length	Metres	mm
Force	Newton	Newton
Pressure/stress	Pascal	MPa
Density	Kg/m ³	Tons/mm ³
Mass	Kg	Tons
temperature	Kelvin	Kelvin

4.3 The modules

ABAQUS is structured in several modules, and we will describe all the steps to be followed to integrate the characteristics required for our modelling.(12)

We will proceed by configuring each software module in the following order:

- ❖ Part
- ❖ Property
- ❖ Assembly
- ❖ Step
- ❖ Interaction
- ❖ Load
- ❖ Mesh
- ❖ Job

✓ **the part module**

This module can be used to model parts by revolution or extrusion. It can also be used to create and edit geometries and entities (points, lines and reference planes). These entities include both deformable and rigid parts. To create them, use the create icon. Once you have accessed this module, you can select the appropriate (13)

- the modelling space: 3D / 2D Planar/ Axisymmetric
- type of entity to generate: deformable/Discrete rigid/Analytical rigid/Eulerian
- entity shape: Solid/Shell/Wire/Sweep

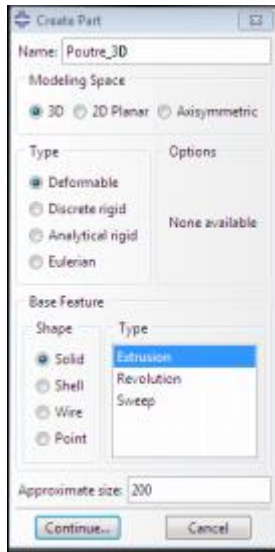


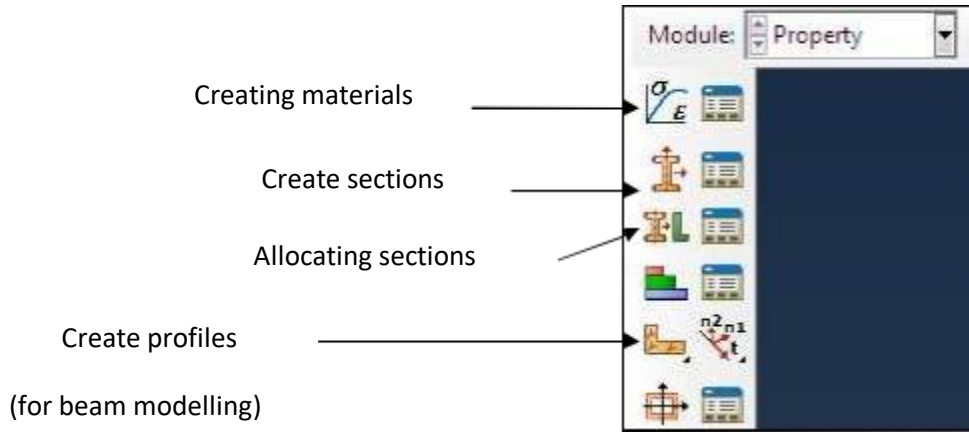
Figure 3.6: part module

creating a part:



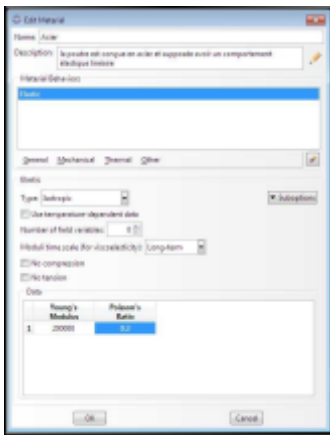
- name the part
- Solid, shell or beam
- define the type of part creation
- Define approximate size
- ✓ **the property module**

The PROPERTY module is used to define the properties of the material(s) of the deformable parts that make up the model, as well as the mass of the rigid bodies if necessary. In this module, depending on the case being studied, you may need to define elastic and/or plastic (or other) properties. To do this, simply click on the icon (Create a material) (Fig.1.8). It is preferable to give a specific name to each of the materials, so that a database can be created specific to the project. We then define: the elastic properties via Mechanical/ Elasticity/Elastic (Young's modulus and Poisson's ratio for an isotropic material, for example) and the plastic properties via Mechanical/Plasticity/Plastic. In this module we also create the material section and the assignment to all the parts of the part or mechanism being studied (Fig.1.8). (13)

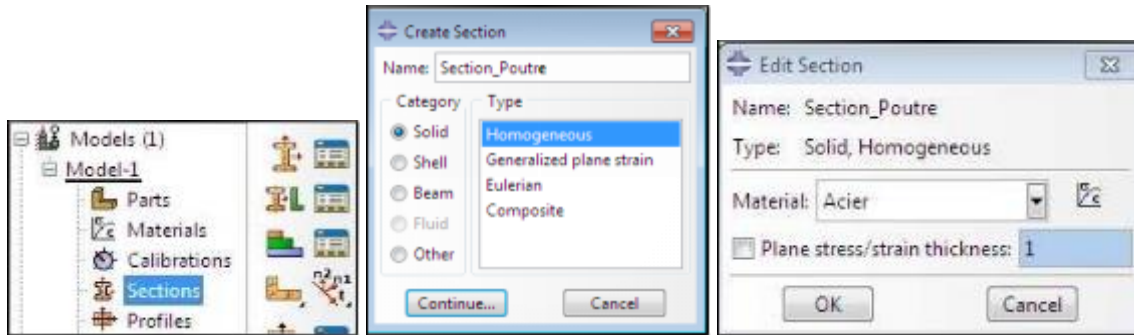


Creating a material 

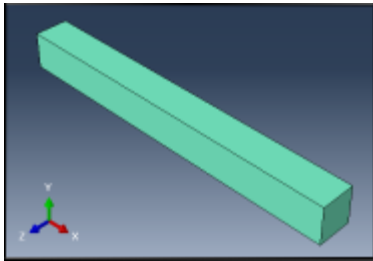
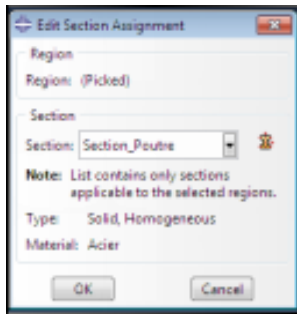
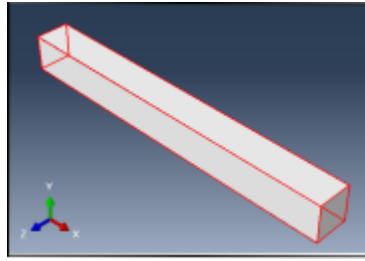
- Definition of the material and its properties



- Definition and assignment of section properties

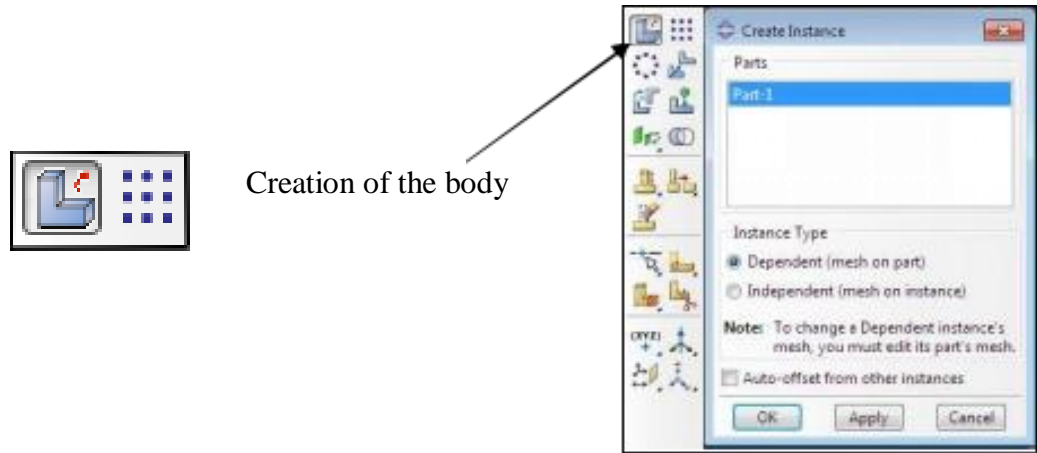


- Assigning the section to the structure



✓ THE ASSEMBLY MODULES

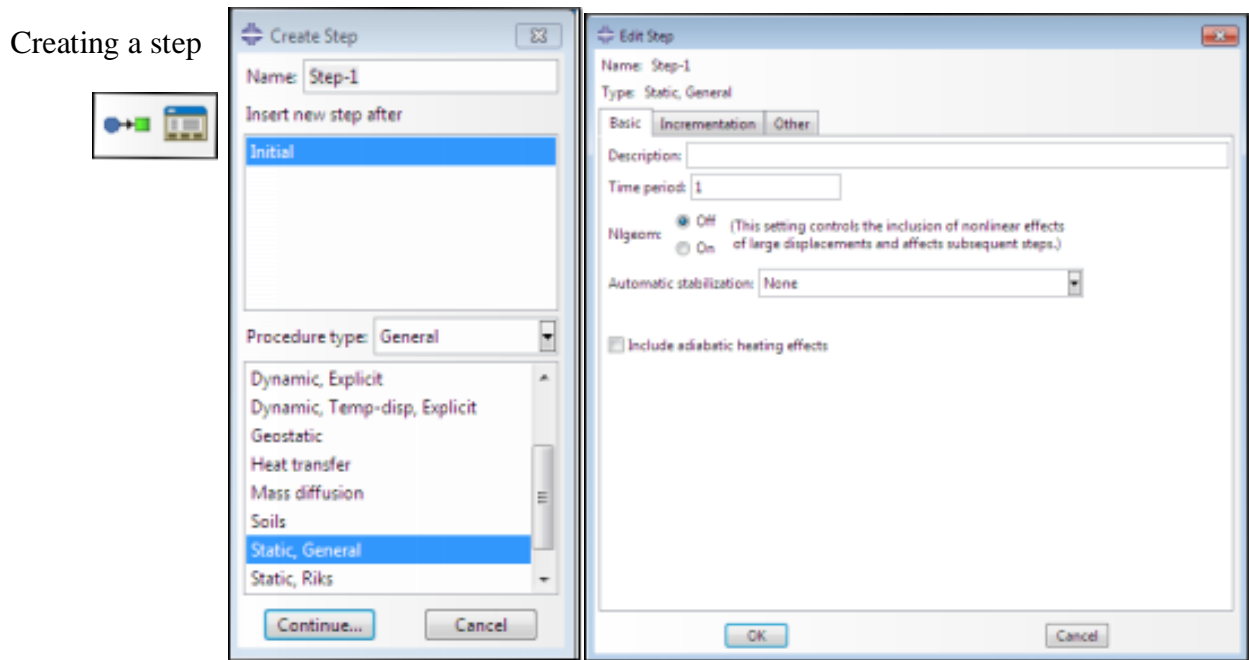
This module is used to create an instance from entities already defined in the Part module. These instances will be the ones you subsequently manipulate in the model. In general, use the icon at the top left to create an instance by selecting all the elements created in Part. In some cases, these instances can also be moved as a whole to reposition them in space. The ASSEMBLY module is used to assemble the various parts created in a project. This step is necessary even if the project consists of a single part[13]



Creation of the body

✓ **STEP module**

The STEP module is used to perform the calculation steps. Depending on the case, an analysis may comprise one or more Steps. For example, a Static, General mode (Fig.1.20) can be chosen, as in the case of a static analysis. Or Dynamic explicit in the case of crash or impact studies. [13]



Creating a step

✓ **5 Interaction module**

This module makes it possible to specify all the interactions between the different parts and regions of the model, whether mechanical, thermal or other. This module is only mandatory if several instances are in contact. [13]

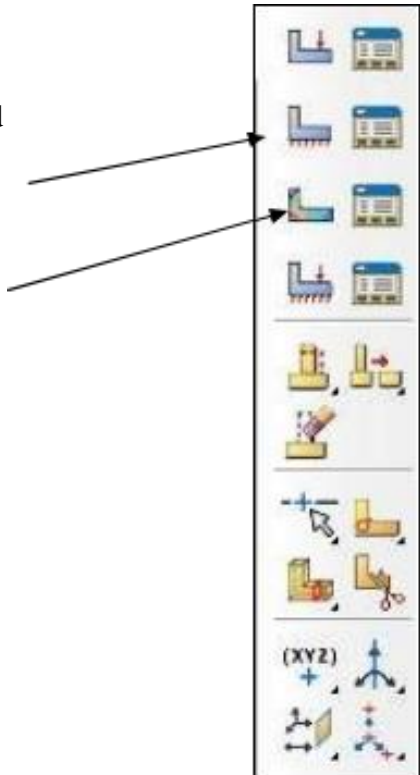
✓ **6 LOAD module**

This module is used to define the stresses experienced by the part or system being studied. The type of stress applied to the part or system is therefore defined. This module is used to specify all the loads and boundary conditions of the problem being studied. The loads and boundary conditions depend on the Steps, so for example a force applied in Step 1 may be inactive in Step 2[13]

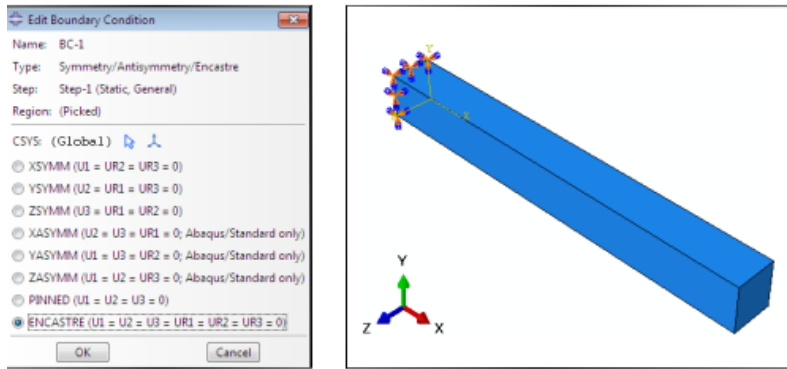
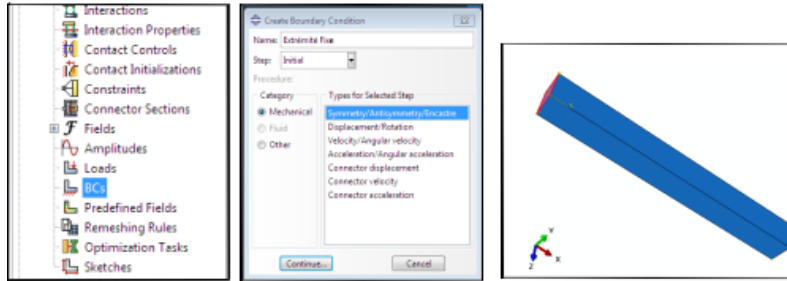
Creating a load



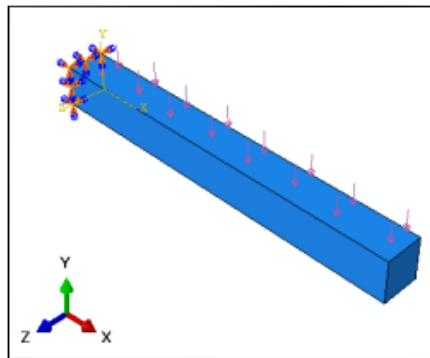
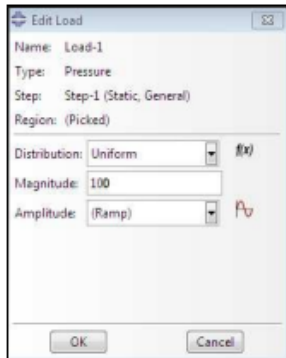
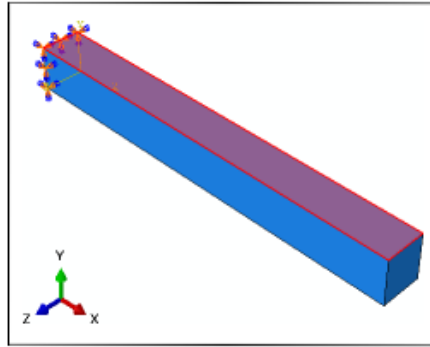
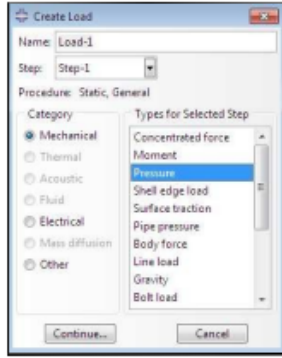
Load: Create a load
BC: Create a boundary condition



Application of boundary conditions to the beam

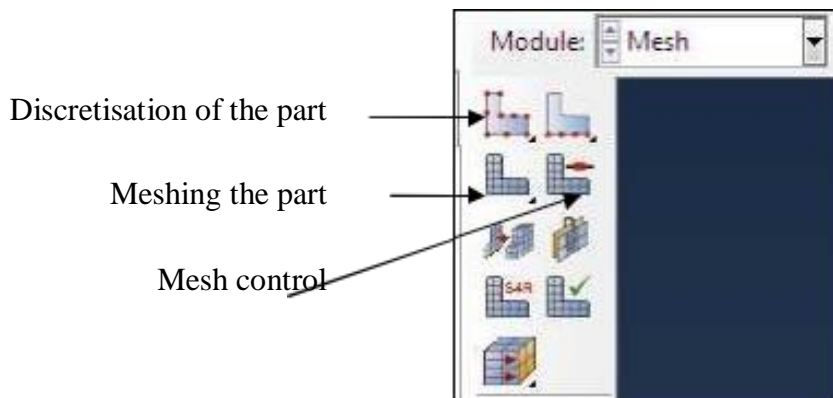


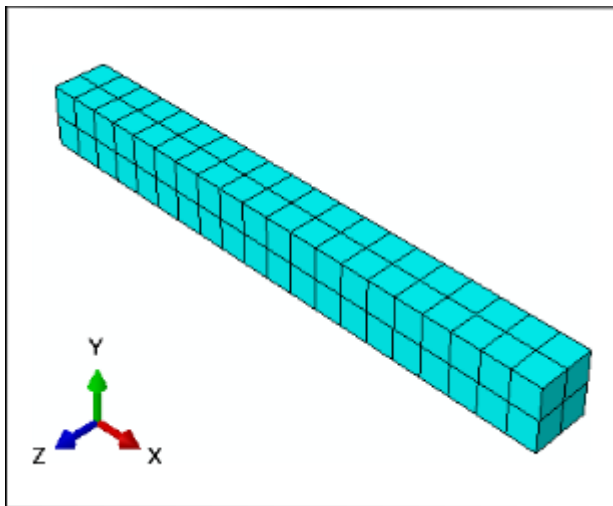
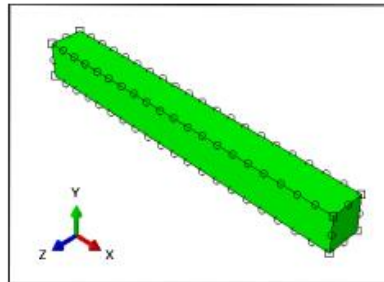
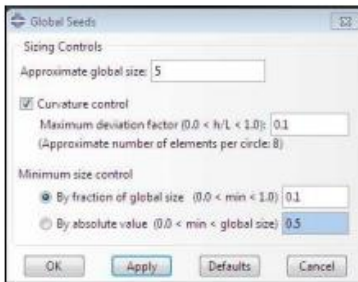
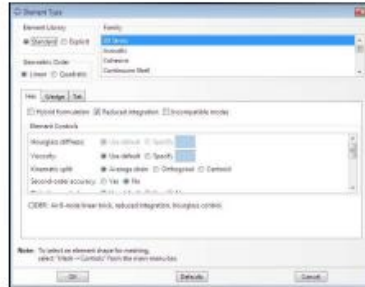
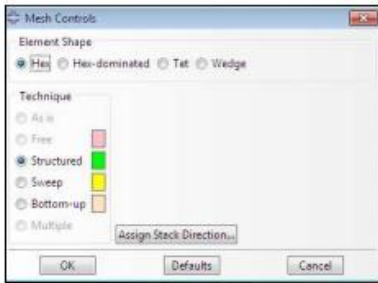
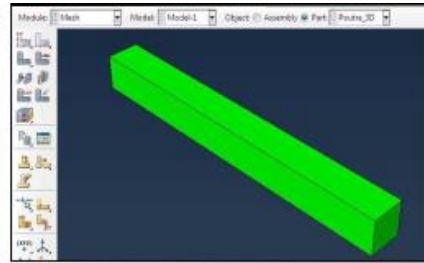
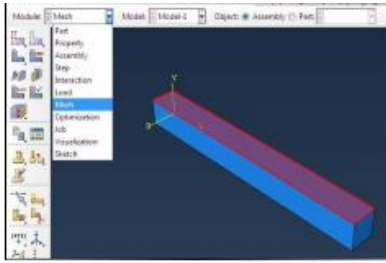
Applying the load to the beam



✓ **MESH module**

The MESH module is used to create the part mesh. It contains all the tools required to generate the finished element mesh on an assembly. It is not necessary for the mesh to be regular; in fact, the mesh can be tightened near points of interest (for example, at points where it is thought that the solution will vary considerably, although care must be taken to ensure that the elements are only slightly distorted (close to a regular polygon). The tighter the mesh, the more accurate the solution obtained using the finite element method. There are several classic elements for meshing our part (hexahedron, tetrahedron, etc.). [13]

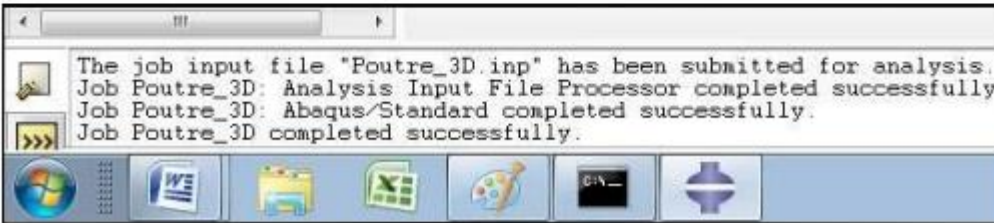
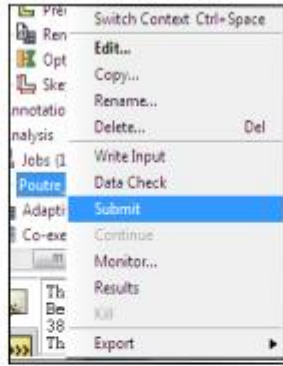
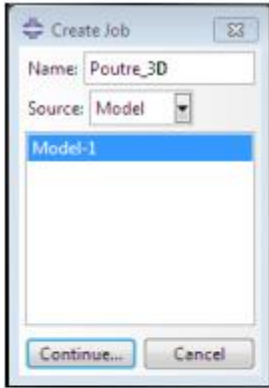




✓ **JOB module**

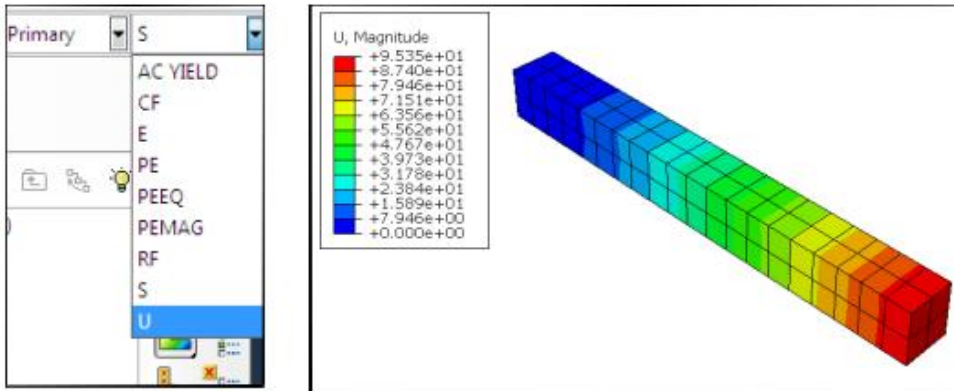
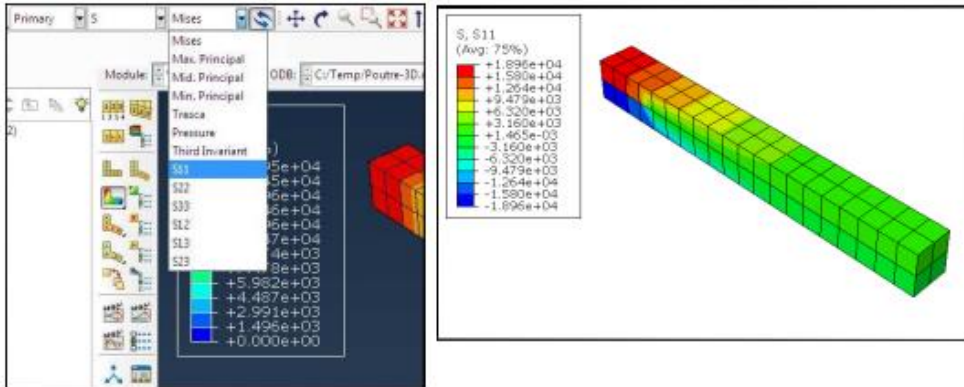
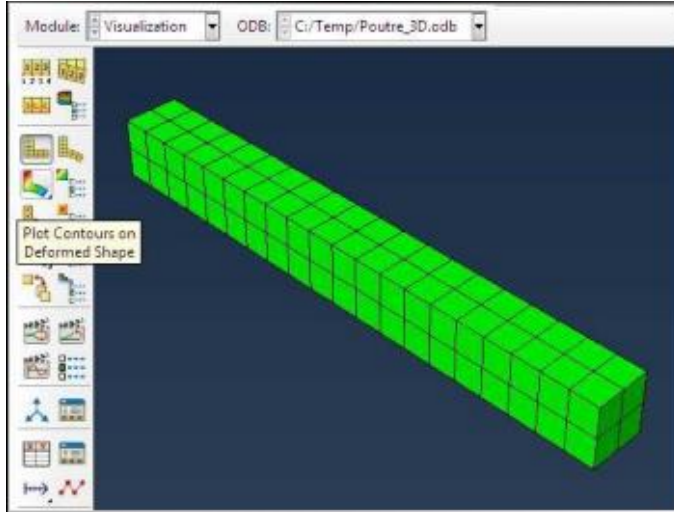
The JOB module is used to launch the calculation. This calculates the stresses, strains and displacements of the part or system under study. [13]

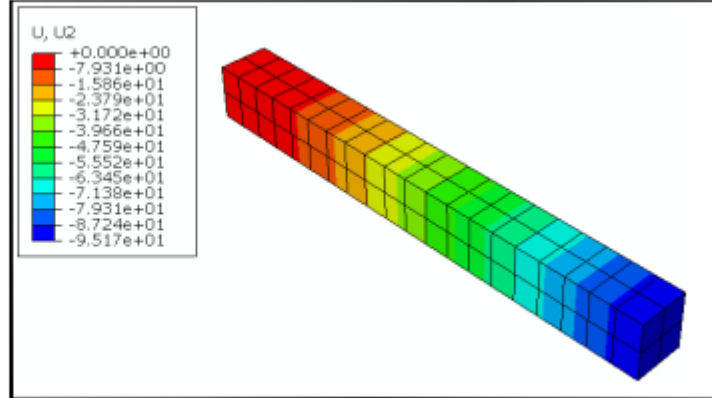
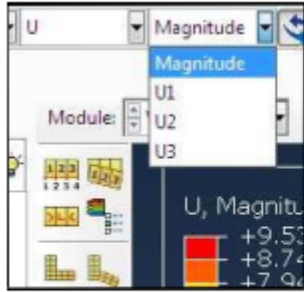
Job creation 



✓ **VISUALIZAION** module

The VISUALIZATION module is used to display the results of previously run calculations. [13]





Chapter 4

Results and analyses

Introduction

Plastic analysis has been used traditionally to assess the collapse behavior of structures on the basis of yielding of cross sections under proportionally increasing loading. However, there are some circumstances under which the traditional methods of plastic analysis cannot be applied.

For example, there are materials that may not be able to sustain plastic moment throughout the loading history because of lack of ductility in the materials [14]

In the late 1940s A. L. L. Baker published several papers on the plastic behaviour of concrete. Research at Imperial College indicated that reinforced concrete was not too brittle for plastic analysis and in 1956 A. L. L. Baker's book⁷ was published, and gave recommendations for the plastic hinge design of reinforced concrete beams.

In our work we analysed the behaviour of concrete beam throughout the study of plastic, and fracture parameters such as Von Mises stress Displacement and Stress intensity factor, using Finite Element method implemented in the code calcul abaqus, for different loads, crack sizes, and different Composite materials used to repair the cracked beam.

Our geometrical model consists of a rectangular concrete beam discretized using abaqus

Table : geometries and dimensions

Dimensions	L(MM)	B(mm)	T(mm)
BEAM	3000	200	300

Table : Material Properties

	YOUG's moduluS	Poisson's ration
BEAM	30 GPA	0.18
ADHISIVE	2 GPA	0.35

2. Von Mises stress

One can note that von mises stress is at maximum towards the fixed end of the beam, and the value is 1.32×10^8 Pa. This is less than the yield point value of mild steel. In comprehensive consideration, the maximum von-mises stress on the frame is 128.1MPa, which appears in the attachment of the sixth beams and the main longitudinal beams.

So the design is safe. In short an engineer's duty is to keep the maximum value of von mises stress induced in the material less than its strength.

3. Von Mises stress calculation

Von Mises stress theory, which can be expressed in the formula $N = \sigma_y / \sigma'$, is suitable for computing the safety factor against failure. It is a theoretical measure of stress used to estimate yield failure criteria in ductile materials and is also popular in fatigue strength calculations (where it is signed positive or negative according to the dominant Principal stress), whilst Principal stress is a more "real" and directly measurable stress.

4 Analysis of FEA results

Firstly, verify if yielding is not present (or acceptable). If your model yields, check if plastic strains are acceptable. Verify if you have stability issues (i.e. with buckling analysis). Don't forget to verify if model deformations are sufficiently small.

The following **figures** are showing Von Misses Stress results for a concrete beam, under Tensil loads, for tensile values 50 MPa, and 100 MPa. Note that S,Mises for 100MPa is two times higher than S,Mises for 50 MPa

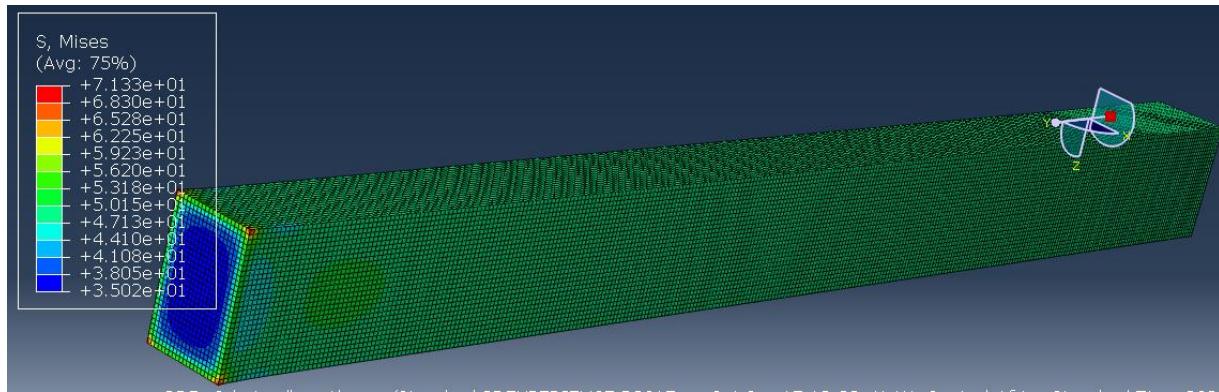


Figure 4.1: Von Mises Stress-load plot for concrete beam under tensile load (50 MPa)

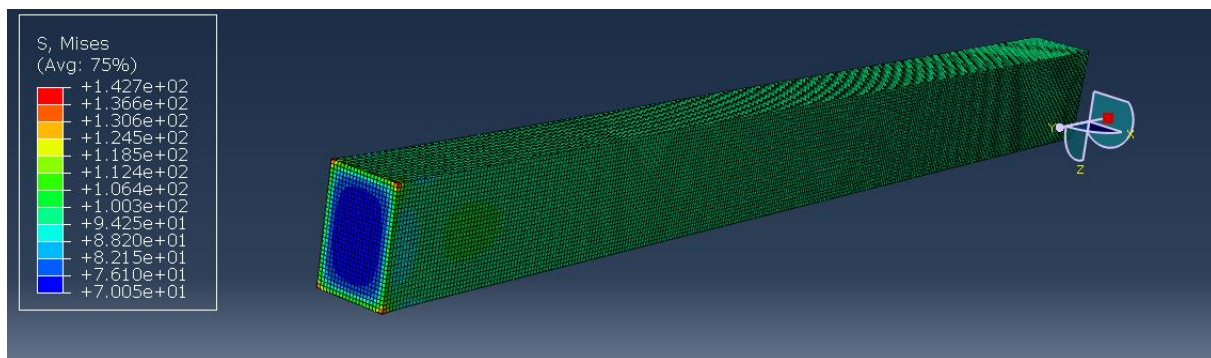
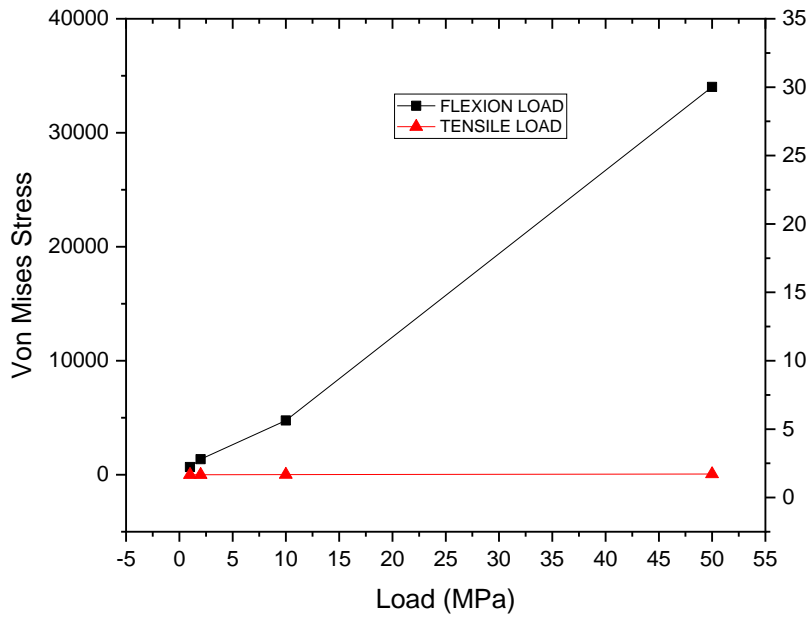


Figure 4.2 : Von Mises Stress-load plot for concrete beam under tensile load (100 MPa)

The following two **figures alfa and beta** show respectively the variation of Von Misses stress , and variation of displacement under tensile load, and flexion Load, it is noticeable that flexion has a higher impact on Von Misses values for both plots, which may indicate that flexion loads is significantly more affecting the concrete beam structure than tensile loads, however it does not mean that tensile load is to be neglected.



1.

Figure 4.3: Von Misses stress-Load plot for concrete beam

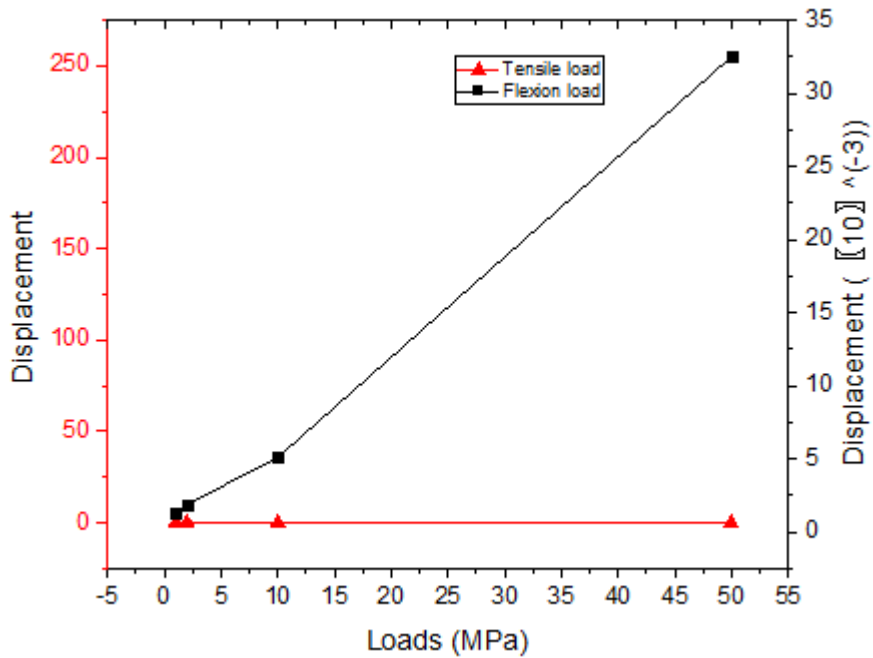


Figure 4.4: Displacement-Load plot for concrete beam

In the design of reinforced concrete members, the tensile strength of the concrete is generally ignored. However, the tensile strength of concrete still has significance in terms of durability and serviceability. For example, the propagation and control of cracks are highly related to the tensile strength of concrete. Ignorance towards the tensile strength of concrete may lead to the problems of serviceability and durability and it makes tensile strength an important parameter of design. [Wen-Cheng Liao, et al. « An Innovative Test Method for Tensile Strength of Concrete by Applying the Strut-and-Tie Methodology » journal Materials Basel]

5. Tensile Strength Of Concrete

The tensile strength of concrete is its capacity to resist cracking or breaking under tension. Although concrete is rarely loaded under pure pressure in a structure, determining the tensile strength is necessary to understand the extent of the possible damage. Breaking and cracking arise when tensile forces surpass the tensile strength.

Compared to the ultra-high performance concrete, traditional concrete has relatively high compressive strength compared to tensile strength, which is significantly lower. This indicates that any concrete structure that may undergo tensile stress must first be reinforced with high tensile strength materials like steel. The knowledge about the tensile strength of concrete is increasingly getting vast due to its significance in managing potential cracking.

Studies indicate that traditional concrete's tensile strength varies between 300 and 700 psi, i.e., around 2 to 5 MPa. This means, on average, the tension averages about 10% of the compressive strength. [15/]

6. CRACKED BEAM

In our work we modeled different sizes of cracks existing in the beam, in order to analyse it's behaviour and failure

Crack's dimensions : Length of 100mm, Width of 2mm, and depth of 30mm

Plastic behaviour of concrete (cracking behaviour)

The major processes that influence and constitute the plastic cracking behaviour of concrete include bleeding, evaporation, settlement, shrinkage, and capillary pressure. These underlying processes mainly occur during the plastic phase of concrete, during which time concrete has considerable rheological properties. [16]

- Plastic cracking refers to cracks that occur in the fresh or plastic state of concrete before it solidifies. The exact point in time where the plastic state of concrete ends is uncertain, however, it is believed to be around the final setting time [R. Combrinck *et al.* Interaction between settlement and shrinkage cracking in plastic concrete, Construct Build Mater (2018), S. Ghourchian *et al.* Susceptibility of Portland cement and blended cement concretes to plastic shrinkage cracking

Cement Concr Compos (2018)]. This plastic cracking can compromise the eventual serviceability, durability and aesthetics of the mature concrete . When fresh concrete is placed, there is a movement of its solid particles under their weight [R. Combrinck *et al.* Influence of concrete depth and surface finishing on the cracking of plastic concrete Construct Build Mater

- (2018)], ranging from cement particles to aggregate particles [V. Slowik *et al.*

Capillary pressure in fresh cement-based materials and identification of the air entry value Cement Concr Compos(2008)]. This vertical downward movement is termed self-settlement in this study. Any form of constraints such as steel reinforcement or change in formwork section [J.H.J. Kim *et al.* Effects of the geometry of recycled PET fiber reinforcement on shrinkage cracking of cement-based composites Compos B Eng (2008)] within a concrete specimen can cause non-uniform settlement leading to plastic settlement cracking.

Crack zones can be modeled either with methods such as Linear Elastic Fracture Mechanics (LEFM), Crack Tip Opening Displacement (CTOD) or a more recently Cohesive zone method (CZM)

The following three **figures** show the $S_{,Mises}$ results of concrete beam in the presence of a transversal crack at three crack sizes, it is shown that the presence of a crack induce high stress in the contour tip, which increase with the evolution of this crack, causing plastic deformation, and even failure of the material.

The Cohesive zone model is the most important evolution in the area of Fracture mechanics. It is widely used to simulate crack initiation and its propagation in solids. It is also an alternative method for model separation. For CZM fracture formation is regarded as a gradual phenomenon in which the separation of the surfaces involved in the crack takes place across an extended crack tip, or cohesive zone, and is resisted by cohesive traction. Thus cohesive zone elements do not represent any physical material but describe the cohesive forces which occur when material elements (such as grains) are pulled apart, therefore cohesive zone elements are placed between continuum (bulk) elements.[17]

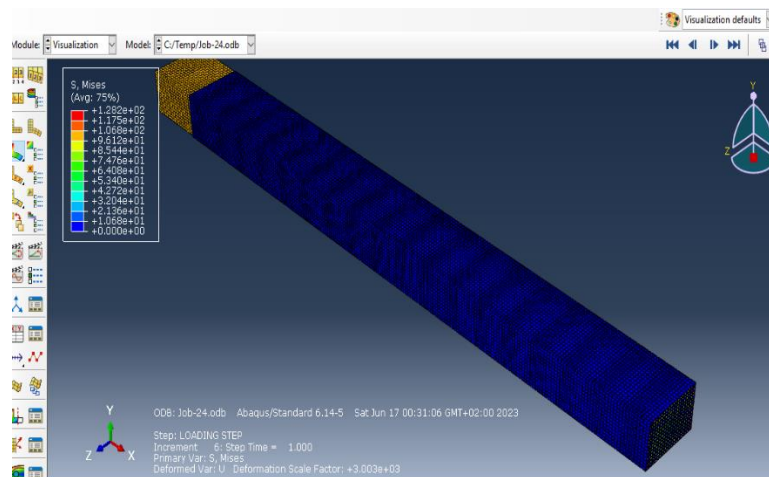


Figure 4.5: FEM Results of Von Mises Stress for a crack size of 100mm

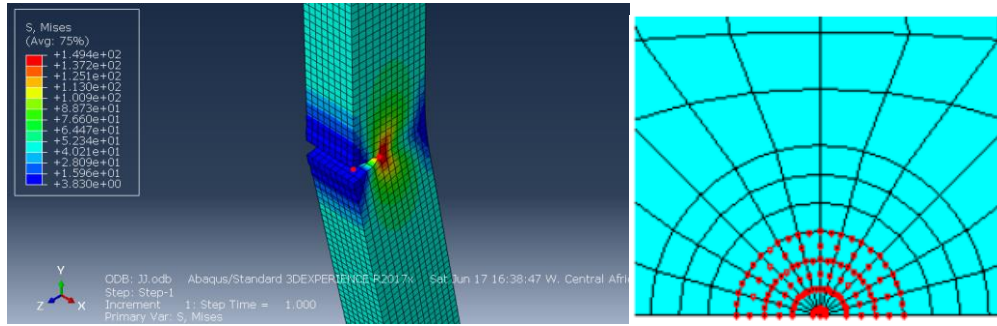


Figure 4.6: FEM Mesh, and Results of Von Mises Stress near the crack size

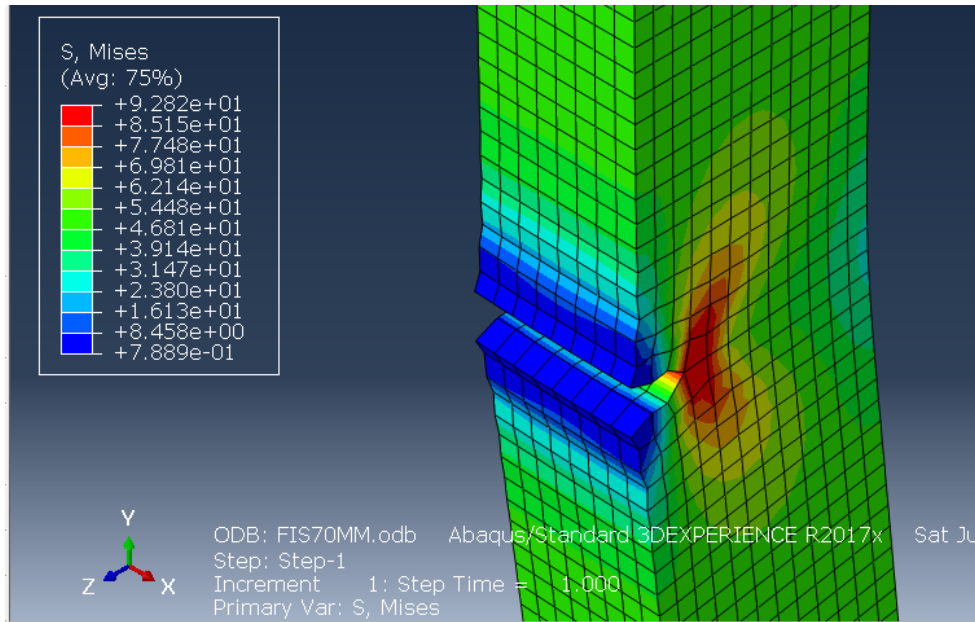


Figure 4.7 : FEM Results of Von Mises Stress for a crack size of 70mm

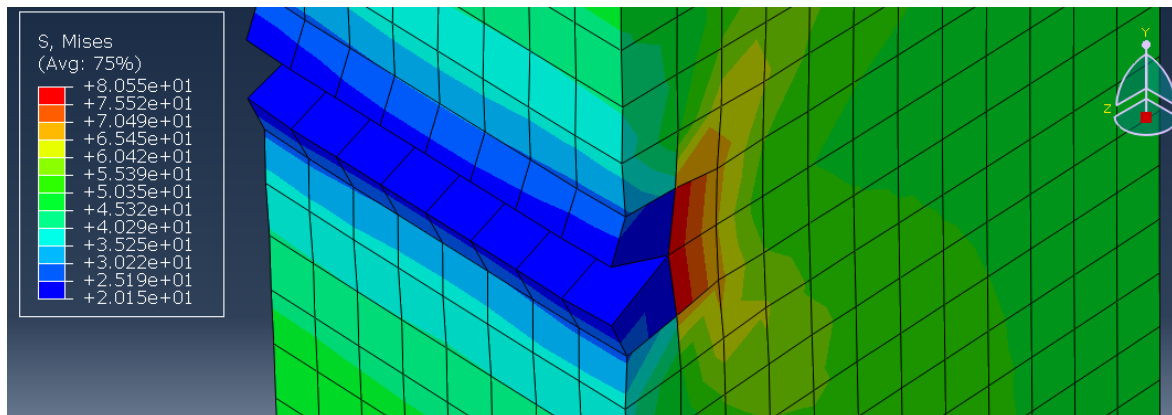


Figure 4.8 : FEM Results Von Mises Stress for a crack size of 30mm

The cracking process in quasi-brittle materials such as concrete and other cement-based composites is usually characterized by the formation of micro-cracks that eventually merge and form a propagating macro-crack [Wei Dong et al, A comparative study on two stress intensity factor-based criteria for prediction of mode-I crack propagation in concrete] . The region where the micro-cracks distribute and the damages accumulate as fracture proceeds is called the fracture process zone (FPZ), which reflects the nonlinear characteristic of concrete as a quasi-brittle material. Due to the existence of FPZ ahead of the crack tip, the whole fracture process in concrete can be divided into three stages, i.e., crack initiation, stable and unstable crack propagation. Effective modelling of the crack initiation and propagation process is significant for assurance of a concrete structures safety and durability. Since the introduction of the fictitious crack model [Hillerborg et al Analysis of crack formation and crack growth in], it has been widely used for simulating the fracture process of concrete and other cement-based materials. In addition, in order to predict crack propagation, an appropriate criterion is a prerequisite for determining crack propagation in concrete. Together with the fictitious crack model, there are three other types of propagation criteria commonly used in the fracture analyses of concrete, i.e., stress-based, energy-based, and stress intensity factor (SIF)-based. Considering that the size of the plastic zone in the fictitious crack is very small for concrete, the maximum tensile stress criterion was proposed as the crack propagation criterion to determine crack propagation in concrete.

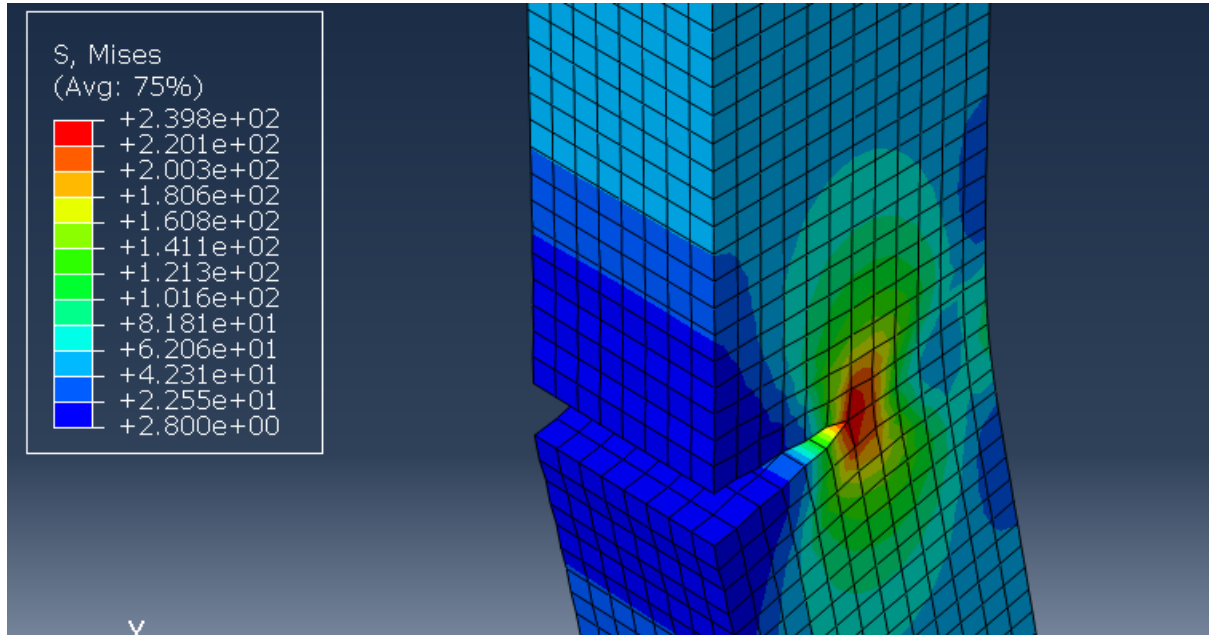


Figure 4.9 : Von Mises Stress for a crack size of 150mm

REPAIRED CONCRETE BEAM

Traction load 50MPa, TRANSVERSAL CRACK SIZE 150MM

Table : Patch and adhesive's dimensions

Dimensions	L(MM)	B(mm)	T(mm)
Patch	300	200	10
adhesive	300	200	0.2

Table : Patch and adhesive's properties

Dimensions	L(MM)	B(mm)	T(mm)
CFRP	300	200	10
T300/934	300	200	10

Adhesive properties

$E = 2\text{GPA}$ $\text{Nu}=0,35$

Patch properties (T 300/934)

E1	E2	G	NU
148 GPA	9.65 GPA	4.55	0.33

Patch cfrp (Carbon Fiber Reinforced Polymer)

D1111	D1122	D2222	D1133	D2233	D3333	D1212	D2323
21000	1000	5000	23456	90090	2100	5600	4560



Figure 4.10 cfrp (Carbon Fiber Reinforced Polymer)

The following figure represents Von Mises Stress, and Stress Intensity factor variation along the concrete beam, in the presence of a crack . It is clear that SIF variation are highly more remarkably increasing toward a critical value, however S, Von Mises increases gradually, but we can assert that this parameters are both used to characterise the structure behaviour in the presence , and propagation of cracks.

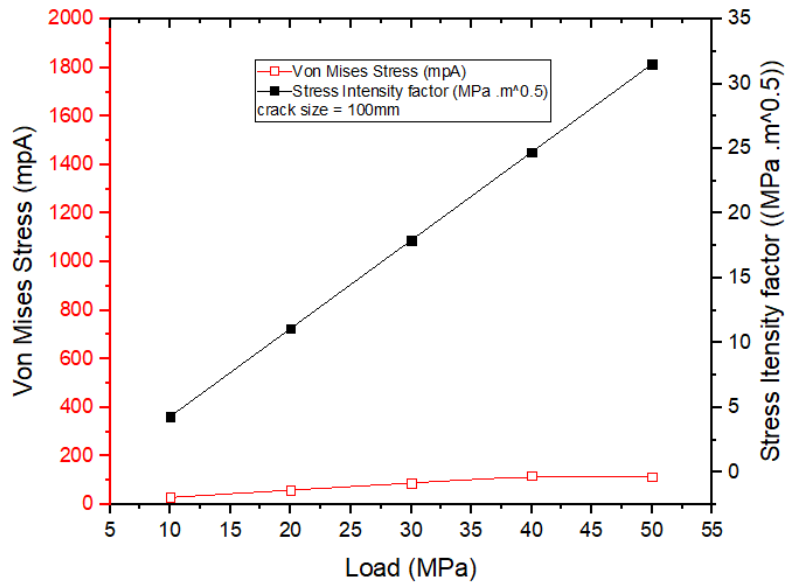


Figure 4.11 : Von Misses stress-load plot for cracked beam

Repaired structure

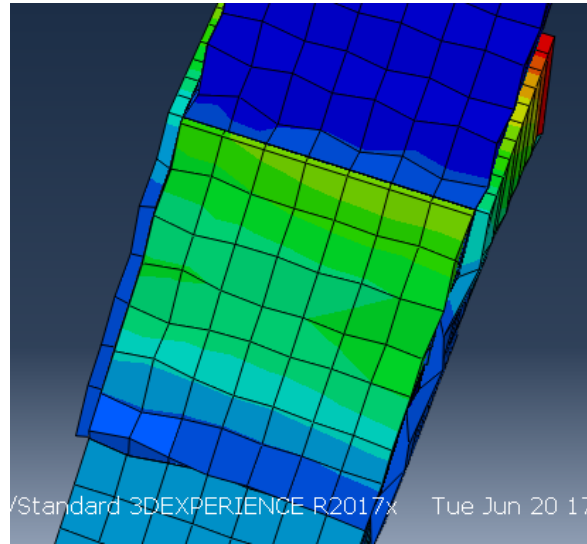


Figure 4.12 : FEM Results of Von Mises Stress for a repaired beam (crack size of 110mm)

The **figure** represents the variation of Sif values for both cases of repaired and unrepaired structure along the variation of the crack's size, it IS clear tha Sif values of the repaired structure are significantly reduced compared to the unrepaired structure (almost 3 Times less) which proves the capacity of the composite patch to attenuate Sif values, and this to reinforce the structure, which asserts the efficiency of this method of repair.

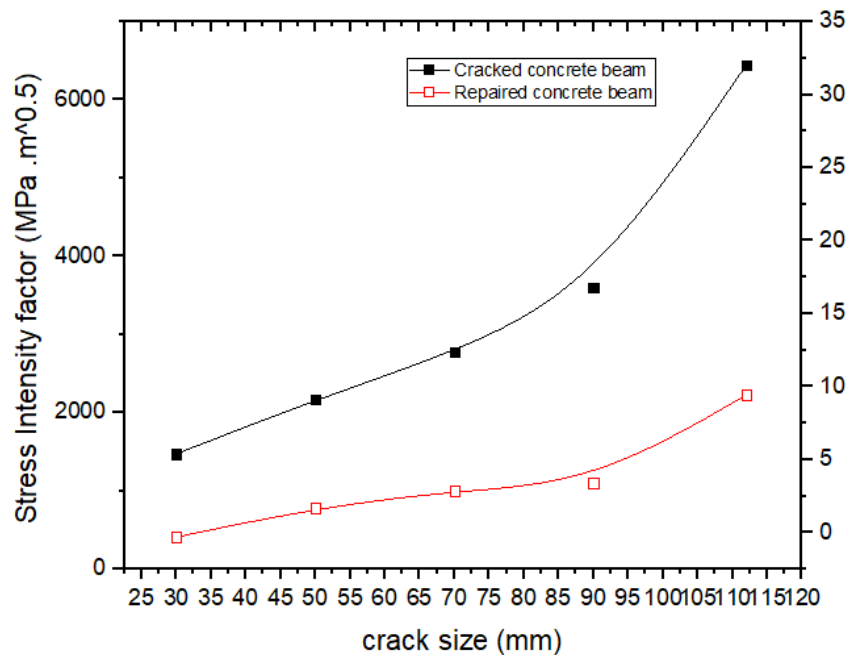


Figure 4.13 : Stress intensity factor-crack size plot for repaired and unrepaired beam

Conclusion

The analysis allowed us to assert that crack propagation is a phenomenon that threat the structure, and lead it to failure, since it minimizes it's strenght and degradate the mechanical properties of material used in this structure

Von Mises Stress is a value used to determine if a given material will yield or not, if tgis value of a material under load is equal to or greater than the yield limit of the same material under simple tension the materiel will yield.

Cracked beam repaired with patch is a method that allows us to highly reduce stress intensity factor, because it transmit the charges from the concrete beam to the Patch on both sides, SIF is then minimized, since crack propagation on the front tip of the crack is reduced.

General conclusion

GENERAL CONCLUSION

The durability of engineering structures is now a key issue: after a number of spectacular accidents on all five continents involving bridges of all kinds, engineers have become aware of the importance of maintenance, at the same time as they have had to undertake what are often major strengthening operations. The first chapter of this research work, devoted to a literature review, highlighted the benefits of composites materials and their performance in terms of tensile strength, coupled with low crack opening. It confirmed the effectiveness of reinforcement of reinforced concrete beams using composite material reinforcement methods.

The last two chapters, which constitute the essence of this project, are based on a numerical modelling analysis using the finite element method and Abaqus software for the shear strengthening of a reinforced concrete beam. We first designed the reference numerical model before designing the four other strengthened numerical models to simulate their mechanical behaviour under loading.

Composite materials significantly improve the mechanical performance of reinforced concrete structures. Detachment and delamination of the reinforcement plate caused by high concentration at the edges of the beam are the main problems observed with external reinforcement. The limitations of this strengthening technique have prompted us to think about another innovative type of strengthening that has been less well known until now: internal strengthening.

Reinforcement using Composites Patch are encouraging and augur well for further in-depth research. The mechanical properties introduced into the numerical simulation must be identical to those found in the experimental work.

Our recommendations for future work are:

- repair Steel reinforced beams, by wrapping the composites around the tension and compression reinforcements before casting. This reduces the structure's own weight and improves its mechanical performance, particularly its mechanical strength and deformability.

- Study the long-term behaviour of Composite Patch concrete structures, in particular creep and fatigue.

GENERAL CONCLUSION

- . - To take account of the adhesion between the beam and the Soil, by integrating geotechnical properties, and characteristic to be modeled into the numerical simulations.
- In order to promote the use of composite materials in rehabilitation and repair work, it would be essential to carry out an in-depth technical and economic study to demonstrate the profitability of this technique.

- [1]BOULEBD . adl ;2021 (etude de renforcement des poutres de beton armé par materiaux composites) université de Oum el bouaghi
- [2]BEDDIAR abd ; 2004 (renforcement des poutres en beton armé a l'aide de materiaux composites) université de Biskra
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- [5]JEAN claud charmet (élasticité-plasticité- rupture) ESPCI
- [6]BRIDINA khld ;2019 (analyse du comportement élastique des structures par élément finis 2D membranaire)
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- [8]HISHAM tariq ;2022 (effet of thickness of cement asphalt mortar layer on the performance of slab track system) Indian institute of technology Kharagpur
- [9] web site [Stress Intensity Factor \(SIF\) \(ptc.com\)](#)
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- [16]John Temitope Kolawole and al. 'Plastic cracking behaviour of concrete and its interdependence on rheo- physical properties',Journal of Composites Part B: Engineering, Volume 230, 1 February 2022
- (17) Ajinkya K. Salve, Sudhindra N. Jalwadi, Implementation of Cohesive Zone in ABAQUS to Investigate Fracture Problems