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LARGE SCALE TECTONIC AND MEGA-SCALE SEISMIC ZONING. IMPLICATIONS ON CIVIL ENGINEERING CONSTRUCTIONS. THE CASE OF THE MAGHREB.

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ABSTRACT

This study presents substantial arguments that the effect of the regional stress field associated with the mega-scale lateral tectonic variations out weights by far the usually considered effect of sediment amplification and seismic source rupture complexities. Indeed, most of civil engineering hazard assessment studies either use statistical methods, or speak most of the time in term of micro-zonation at the scale of a city (sediment amplification etc.), and over-look the large scale deformation and the tectonic structures in general. Therefore, their results are not really useful practically. This study considers the case of the Maghreb and the overall influence of the regional stress field associated with the existence of the currently active Atlas faults system on the seismic safety of the constructions. From the engineering perspective we argue that the deformation of the Maghreb could be characterised by six mega seismic zoning. Those mega-seismic zoning have been determined on the basis of 1) the nature and styles of deformation and displacements deduced from seismic focal mechanisms; 2) the observed time recurrence of large destructive earthquakes and their spatial-temporal variations; 3) on the basis of the recent satellite and field mapping of mega scale tectonic provinces and structural features such as folds, quaternary faulting, basins etc. It is shown that a correct exposure of low elevated constructions orthogonal to the main components of the regional stress field has a weight four order of magnitudes larger than the usually considered sediment amplification and three orders of magnitudes larger than the effect of the accelerations caused by source complexities along faults planes; and an order of magnitude larger than the effect of the three dimensional resonance phenomena of a valley in a specific geodynamical context. On the basis of those rough but certainly meaningful evaluations a mega-seismic zoning of the Maghreb is provided based on regional stress field and the geodynamical context of the regions. Those results are largely fulfilled by the field observations after the El-Asnam earthquake of October 1980. Therefore, any construction planning should take in account those simple but crucial mega-structural and seismic zonings differences whose effects surprisingly out weight by far the usually considered site effect or sediment amplification. This study is not intended to address the issues of the art associated to constructions which is very important in regions at high seismic risk but we think that the modelling of the structures responses in those seismic prone areas remain incorrectly modelled because the seismotectonic excitation signal remain either poorly understood or poorly quantified. Therefore, the practicability of their results remains expensive or inefficient.

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Keywords - Atlas faults system - Seismic zoning - Sediments amplification - Resonance of a valley - Faults ruptures characteristics - Maximal acceleration- Seismic empirical relations for the Maghreb - Main components of the regional stress tensor.

TECTONIQUE A GRANDE ECHELLE ET MEGA-ZONATION SEISMIQUE. IMPLICATIONS SUR LA CONCEPTION DES CONSTRUCTIONS ET DES OUVRAGES D'ARTS EN GÉNIE CIVIL. LE CAS DU MAGHREB

RÉSUMÉ

Cette étude présente des arguments substantiels que le tenseur de contrainte régional lié aux variations latérales de la tectonique à grande échelle a un effet de loin plus prépondérant sur la stabilité séismique d'une construction que les effets classiques pris en compte jusque là tels ceux liés à l'amplifications des ondes séismiques par les sédiments ou les effets liés aux accélérations dues aux complexités du processus de rupture le long des failles. En effet la quasi totalité des études de génie en hasard séismique utilise des procédés de calculs statistiques diffus ou parle en termes de micro-zonations séismiques à l'échelle d'une ville (amplification par les sédiments, atténuation des ondes, distance de la zone séismogénique active etc.) et néglige un élément capital qui s'avère être de loin le principal facteur contrôlant la stabilité d'une construction: La tectonique et la déformation à grande échelle de la région considérée. Cette étude prend le cas du Maghreb et étudie l'influence globale du champ de contrainte régional lié aux failles actives de l'ensemble du système Atlasique sur la stabilité et la protection séismique des constructions. Pour parachever cet objectif nous présentons des arguments que la déformation tectonique active à grande échelle du Maghreb peut être caractérisée par six méga-zonations séismiques qui ont été déterminées sur la base de 1) la nature et les styles de déformations et déplacements déduits des mécanismes aux foyers; 2) les temps de récurrence observés des séismes historiques destructeurs qui ont eu lieu au Maghreb ainsi que leurs variations spatio-temporelles enfin; 3) sur la base des données d'images satellites, permettant la cartographie des provinces tectoniques et des traits structuraux majeurs tels que les plis, les failles actives quaternaires, les bassins etc. On montre dans cette étude qu'une orientation judicieuse des constructions disposées orthogonalement par rapport à la composante principale du champ de contrainte régional, assure une protection séismique efficace des constructions. En effet la contribution du champs de contrainte régional sur les constructions a un poids 10^4 plus important que la prise en compte de l'effet de l'amplification classique des ondes par les sédiments; un poids 10^3 plus important que celui des accélérations causées par les complexités du processus de rupture le long des failles; enfin un poids dix fois plus important que l'effet de résonance des ondes à trois dimensions dans une vallée localisée dans un contexte géodynamique particulier. Sur la base de ces ordres de grandeurs très grossiers mais ayant certainement une signification physique extrêmement importante; une zonation séismique à grande échelle pour l'ensemble du Maghreb est présentée basée sur l'orientation du champ de contrainte régional et du contexte géodynamique de la région. Ces résultats sont largement recoupés par les observations sur le terrain suite au dernier séisme d'El-Asnam d'Octobre 1980. Il s'en suit donc que toute construction ou ouvrage d'art devra tenir compte de ces considérations simples mais fondamentales de zonations tectoniques et séismiques à grandes échelles dont l'effet sur les constructions s'avère être à notre grande surprise beaucoup plus important que l'effet de l'amplification des sédiments ou des accélérations. Cette étude n'est pas destinée à expliciter le génie lié à l'art de la construction en régions à haut risque séismique mais nous pensons que la modélisation de la réponse des structures dans ces régions à risques ne se fait pas correctement à cause de la méconnaissance du signal d'excitation séismotectonique qui reste soit très mal compris soit mal quantifié. Donc la portée pratique de ces résultats de modélisations reste soit très coûteuse soit inefficace.

Mots Clés - Failles liées à l'ensemble du système Atlasique - Zonation séismique - Amplification par les sédiments - Effet de résonance séismique d'une vallée - Caractéristiques des ruptures de failles - Accélération maximale - Relations séismiques empiriques pour le Maghreb - Composantes principales du tenseur régional de contraintes.

INTRODUCTION

Current studies of the seismicity of the Maghreb for applied engineering purposes have most of the times over-looked the structure and features of mountain belts at global scale (McKenzie, 1972; Barazangi, 1983, Dewey *et al.*, 1989; Mattauer, 1977; Beauchamp, 1998) and lack to integrate those information of deformation at large scale for engineers (fig. 1 and 2). Therefore, most of the information used by those different scientific communities are incomplete and lack to integrate key practical information that will contribute to reduce effectively human and economical loss caused by earthquakes. The objective of this preliminary study is :

To use some basic very useful numerical empirical relations that have been established to describe satisfactorily the physical deformation and seismicity of the Maghreb from Morocco to Libya taking in account the lateral variations in deformation from the West to the East (Beghoul *et al.*, 2004)

Second, we use the spatial-temporal variations of catastrophic events and evaluate an order of magnitude of their recurrence time (Beghoul *et al.*, 2004) in each subsequently predefined region.

Third, an attempt is made to fill the gap existing between seismologists, construction engineers and geologists, by laying down on global scale the controlling physical parameters that really control the safety of constructions in highly seismic areas. In other words integrating in a more comprehensive manner all the seismotectonic factors that could have an effect on the safety of the construction:

-Effect of the ground acceleration

-Effect of the sediment amplification

-Effect of the three dimensional resonance of the sediments beneath a valley in a specific geodynamical context

-Effect of the tectonic and the regional stress field.

Those global informations are of particular importance for countries under-way of development in which the density of distribution of seismic network recording is insufficient to fully understand the physics of earthquakes related to those regions.

Finally, an attempt is made to differentiate regions and system of faults that have distinct seismotectonic responses in the Maghreb region and therefore, any construction planning should take in account those key differences to assure far more safer constructions in seismic prone areas.

Basic study of the seismicity of the Maghreb taking in account the variations in deformation from West to East and from North to South; using the historical and instrumental seismicity as well as various other geological and geophysi-

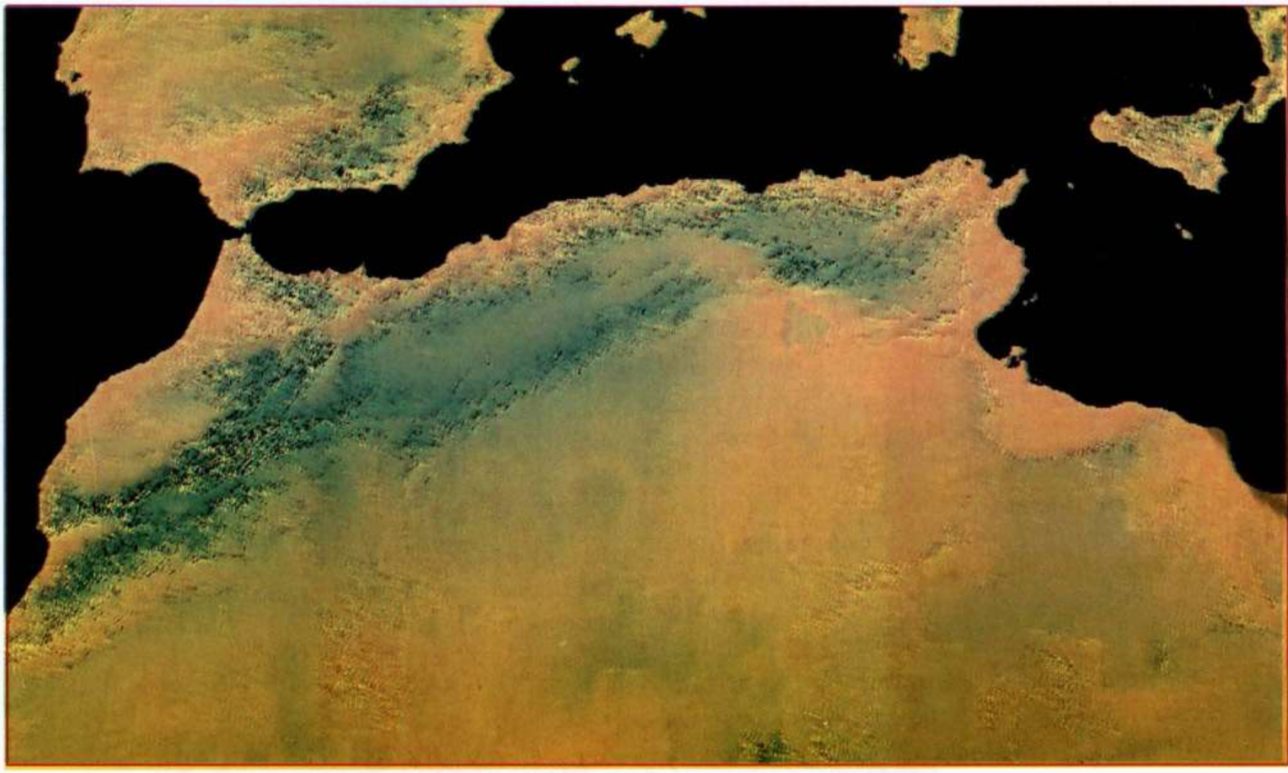


Figure 1 - Digital topography map of the Maghreb copied from the USGS Internet site. This spectacular topography is the result of the deformation created by the struggle between the African plate and the Eurasian plate. Note the major flat feature at about one kilometre elevation: The High Plains bounded at the North by the very seismically active the Tellian Atlas and at the South by the Saharan Atlas far less seismic than the Tell. Note in the region of Algiers the width of the Plateau decreases dramatically and bends too. This has important consequences on the seismicity of the Central part of Algeria.

Topographie digitale du Maghreb publiée sur le site Internet de l'USGS. Cette topographie spectaculaire est le résultat de la déformation crée par l'affrontement entre la plaque Africaine et la plaque Eurasienne. Notez la surface quasi-plate suspendue à environ 1 km d'élévation. Ce sont les Hautes Plaines limitées au nord par la chaîne de montagne très séismique qu'est l'Atlas Tellien et au sud par l'Atlas Saharien de loin moins séismique que le Tell. Notez que dans la région de l'Algérois l'épaisseur des Hauts Plateaux se réduit considérablement et subit même une courbure. Cela a des conséquences importantes concernant la séismicité de la partie centrale de l'Algérie (voir texte).

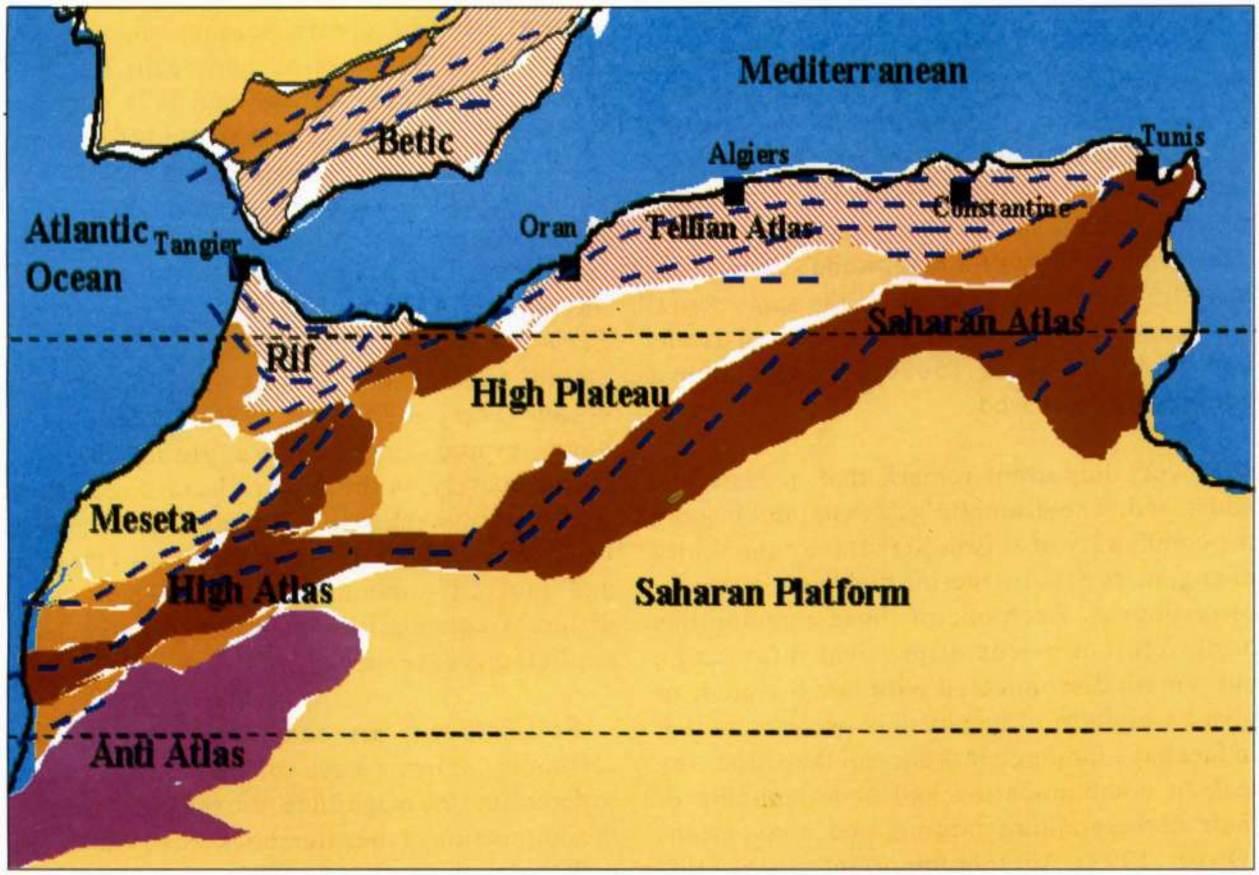


Figure 2 - Schematic map defining the different physio-geographic regions and the different components of the Atlas faults system. It is composed of the Rif and the Tell atlas belt in the north and the intracontinental mountain belt: The High Atlas and its prolongation in Algeria and Tunisia as the Saharan Atlas. Those two distinct belts (see text) are separated by a rigid quasi-undeformed block the High Plateau in Algeria and its extension as the Meseta in Morocco. The thick dashed lines represent the major mega fold axes of the Atlas system. Note the en echelon structure of the Saharan Atlas and note the corridors existing between those folds in the north Tellian Atlas location of very seismic recent intramountain basins of Oligocene – Miocene age such as the Cheliff or the Mitidja Basins. The basins represented in colour are much older basins of at least Cenozoic time such as Souss Basin in which is located the city of Agadir.

Représentation simplifiée de la carte tectonique de W. Beauchamp, 1988 définissant les régions physio-géographiques majeures du Maghreb et les différentes composantes du système Atlasique. Le nord du système Atlasique est composé du Rif marocain à l'ouest de l'Atlas Tellien au centre et à l'est. Au sud loin de cette fine chaîne de montagne composée du Rif et de l'Atlas Tellien s'étend la chaîne intracontinentale qu'est le Haut Atlas au Maroc se prolongeant en Algérie et en Tunisie en l'Atlas Saharien. Ces deux chaînes de montagnes distinctes sont séparées par un bloc quasi-rigide non déformé que sont les Hautes Plaines (Figure 1). Les lignes épaisses en tirés représentent les axes des plis majeurs du système Atlasique. Noter la structure en échellon de l'Atlas Saharien et notez les corridors existant dans l'Atlas Tellien. Ces corridors du nord sont tributaires d'intenses activités séismiques et correspondent en Algérie à des bassins intra-montagneux d'âge Oligocène-Miocène à l'image des bassins du Cheliff et de la Mitidja.

cal information reported in the literature; shed light on several aspects on how the deformation in the Northern Maghreb works and what are the quantitative laws that will eventually describe and assess the fracturation of the ground (Beghoul *et al.*, 2004). Those basic laws are important for construction planning in order that seismic events such as the recent one of El-Asnam in 1980 with a magnitude 7.3 will not have for the future generation the same social and economical impact with thousands of deaths and a city of about 150 000 people almost completely destroyed.

A very important remark that needs to be addressed. The dramatic gap existing between the community of seismologist, the community of engineers of construction and the community of geologists. Each one of those communities bring relevant pieces of physical information but remain disconnected with one the other or give a weight to some physical parameters that in fact have far much less control than others by lack of communication and understanding of their corresponding jargons and conventions (Oliver, 1992). Another important cause of this miss-communication is the scale of their interest (Oliver, 1992). The engineer works at the scale of a city. The seismologist at the scale of a region and the geologist at the scale of a structure or an outcrop. In fact as mentioned previously most of those communities over-look the structural features at global scale and therefore, in most of the situations their information is incomplete if not incorrect. Currently the state of things in most countries even the developed ones. There exist laboratories for technical control of construction, laboratories for seismic networks recording and analysis and finally, laboratories for establishing various geophysical and geological mapping. Each one of those laboratories has its own mission and mandate working as independent entities and few have realised the ultimate importance to put together their efforts in order to contribute to reduce life losses caused by earthquakes and natural catastrophes. Society should create science centres for studying natural hazards approached from a much broader perspective than it is going in general now; integrating pertinent information from several fields: civil engineering, seismology, geology, tectonics etc. As it is already the case for environmental studies in which several laboratories throughout the world study the interaction between the deep structure of the Earth and its surface, the atmosphere, the oceans and the biological processes in continents and oceans (Press and Siever, 1986). This field has been termed since 1980's global change. Unfortunately, in the field of hazard reduction we have not reached this comprehensive global vision and to illustrate the implication of this gap and lack of communication between those different communities mentioned above let's explicit this case specifically.

Seismologists are concerned by using the seismicity, seismic wave analysis and recording to determine the magnitude, the seismic moment, the delineation of the aftershocks distribution to map faults, their extends, their relative motions etc. They use also waves to characterise the type of deformation occurring (dip-slip or strike-slip) by determining the focal mechanisms of the recorded seismicity (Isacks *et al.*, 1968).

Construction Engineers measure from the field, displacements throughout a city for example and take usually the largest seismic event in the considered region and its accelerogram to predict the response of the structure to be build in a given geological context ; using for that mostly numerical computer simulation (Reiter, 1991). They rely mainly to characterise ground response on accelerograms which in a way describe source complexities along fault rupture (fig. 3).

Finally, geologists approach the deformation by mapping it in the field either the one that concern recent active faulting, old inactive

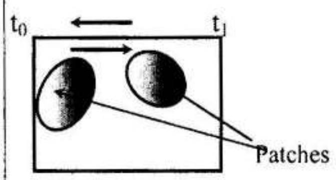
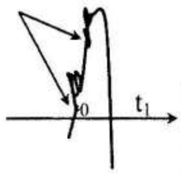
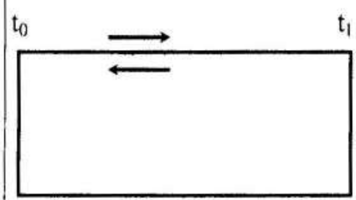
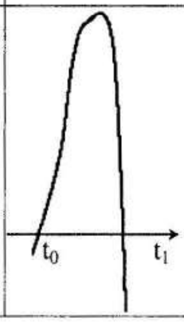
Size of the Fault Plane and its Internal Structure	Shape of the P Wave in Displacement	Magnitude	Acceleration	Importance of the Damages
	High frequencies caused by the patches 	**6.0**	**2.0g**	Significant damages, destructive earthquake
		**7.1**	**0.5g**	Some Damages

Figure 3 - Represents the relationship between source complexities along a fault plane represented by dashed patches (asperity, barrier heterogeneity), depending if they do exist or not, and the damages triggered by the rupture of this fault. A larger fault rupture plane with no patches trigger far less damages than smaller fault ruptures with patches. Therefore, there is no necessarily a one to one relationship between the magnitude and the damages caused by the earthquake. This is because magnitude is proportional to fault length whereas damages are proportional to accelerations caused by the existence or not of patches. A 7.1 magnitude earthquake with no source complexities can have acceleration of only about 0.5g and therefore, cause no substantial damages. On the other hand a 6.0 magnitude earthquake only but with a complex source can trigger accelerations as large as 2.0g causing a lot of damages (Reiter, 1991).

Représente la relation existant entre la nature des plans de failles dépendamment si elles contiennent ou pas des hétérogénéités (aspérité, barrière, etc.) ; et les dommages causés par ces plans de failles. Une grande faille sans hétérogénéités causera de loin moins de dommages qu'une faille plus petite contenant des complexités de source. Il n'existe donc pas de proportionnalité entre magnitude et dommages causés par un séisme mais il en existe une entre accélérations et les dommages causés par un séisme. Ceci est dû au fait que la magnitude est proportionnelle à la longueur de la faille alors que les dommages causés par un séisme sont proportionnels aux accélérations qui elles sont générées par l'existence ou l'absence d'hétérogénéités le long des plans de failles. Ainsi un séisme de magnitude 7.1 sans complexités de source n'a qu'une accélération de 0.5g et donc n'engendre pas de dégâts substantiels alors qu'un séisme de magnitude 6.0 avec une complexité de source n'a enregistré qu'une accélération de 2.0g (Reiter, 1991).

lineament or other relevant structural features such as folds and their eventual nucleation and/ or propagation. The purpose is to determine the current and the old tectonic stress regimes and therefore, help understand the evolution of the deformation in space and time. They determine the geological formation in which the faulting has occurred and their corresponding geodynamic context for detecting possible liquefaction, or sediments amplification risks (Meghraoui, 1988).

Synthesis : Engineers evaluate punctual measurements of slips, and peak accelerations associated with few events to extrapolate the effect of those punctual data for large areas and for a long time scale. In fact another event may occur in the near future not necessarily larger in magnitude but will trigger far more damage than predicted by their calculations just because a major variation in source complexities occurred along the fault rupture (fig. 3). Therefore, in order to really assess more surely the maximum motion and the maximum acceleration with which to excite a structure one has to use a given substantial statistics of past seismicity and not rely solely on few events. Furthermore, and more importantly, in the field, the observations show that the orientation of the principal components of the stress tensor compared to the geometry of the construction has far more weight than the peak acceleration that could simply be roughly estimated by using an empirical relation tying the maximum magnitude with peak acceleration. In most engineering studies this fundamental factor of orientation of the principal components of the stress tensor in a highly seismic region is not considered at all. Figure 4 and 5 illustrate for the case of the region of western and eastern Algeria, respectively the fundamental aspects of stress orientations relative to constructions geometry. Those factors relevant of the knowledge of the direction of the main components of the stress tensor evaluated either from the observed faulting, from in-situ stress measurements (Beghoul, 1984; Bloyet *et al.*, 1989) or from seismic focal mechanisms (Ouyed and Meghraoui, 1981; Deschamps, *et al.*, 1982) have far more weight than an underestimation of peak acceleration. During a joined field project in 1980 between the 'Université de Paris-Sud,', France and the CRAAG of Algiers, Algeria; after the El-Asnam earthquake in October 1980; one could easily report from the field a remarkable striking observation is that after the 1980 El-Asnam earthquake, most of the constructions units oriented as A in Figure 4 were by far less damaged than B and C. Those results are also consistent with the recent work of Dunand et al., 2004 that show indeed that during the Boumerdes earthquake of 2003 most of the construction units that were orthogonal to the direction of main components of the stress tensor were by far less damaged. However, one has to mention in their particular study if their observations do not stand elsewhere than their surveyed area; this will not be of great surprise because the earthquake was off-shore and therefore, the converted seismic waves that hit the continental margin such as T, Pg, Sn that convert in Lg leading in general to high frequencies and large amplitudes seismic waves: Lg that trigger non-linear phenomena and cause a lot of damages on the constructions regardless of their orientations. It follows from the above discussion that for countries with no dense distribution of accelerograms ; engineering planning has to consider four controlling factors :

1) Evaluation of the maximal peak acceleration at which a construction could be submitted. Figure 3 provides insight concerning the relationship between rupture faulting and accelerations. It will be discussed more thoroughly later on.

2) Location of the faulting area or the seismotectonic zone (fig. 4 and 5).

3) Evaluation of the effects of sediments amplifications.

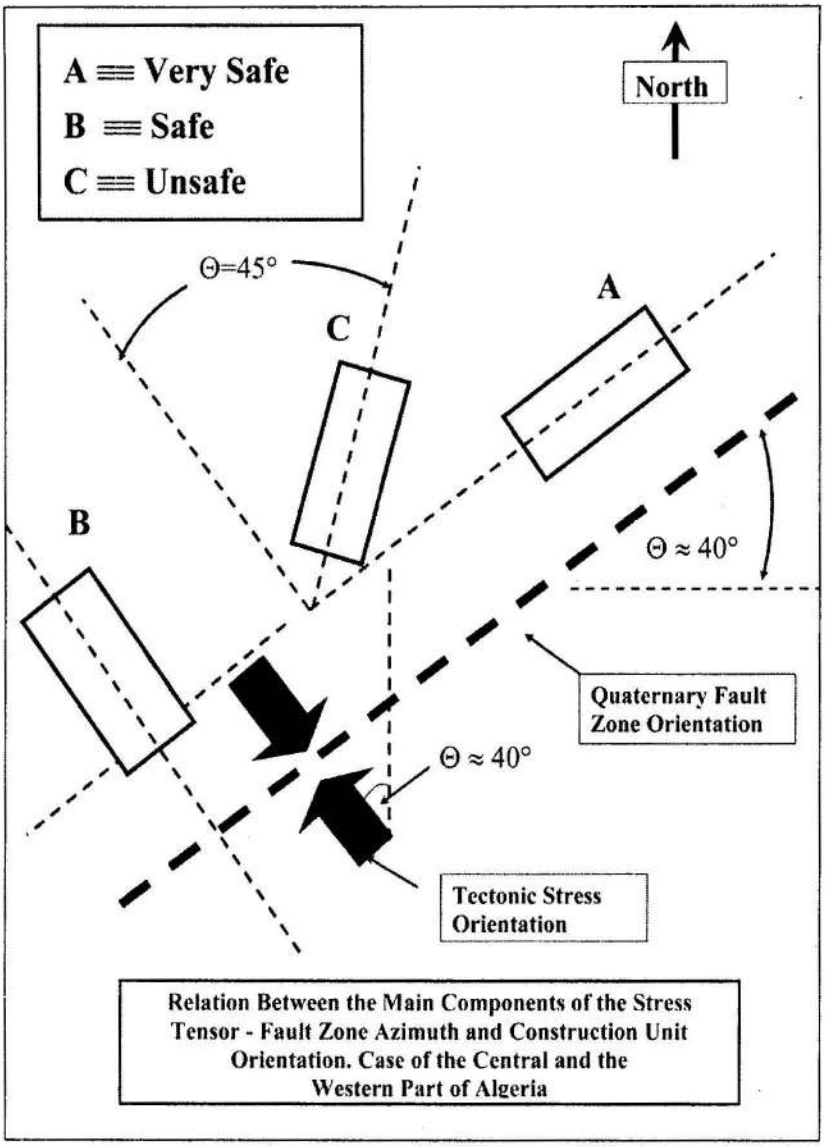


Figure 4 - Schematic diagram that concern the safe azimuth exposure of the construction units compared to the dominating stress field in the central and western part of Algeria. Relatively low elevated construction oriented orthogonal to the main components of the stress tensor (measured through focal mechanism, in-situ stress, geodesy etc.) are construction that have a much higher probability to stand to the destructive effect of earthquakes in a seismic prone area such as El-Asnam for example. Constructions units oriented at 45° from the Azimuth 40°W of the dominating compressive stresses, have less chance to not be ruptured because the rupture is the easiest at 45° (Mohr circle, Suppe, 1985).

Diagramme schématique élucidant l'orientation séismique optimale sécuritaire d'une construction dans la région de l'Algérois et dans la région de l'ouest de l'Algérie par rapport au champ de contrainte régional prédominant dans ces régions. Des constructions relativement basses orientées orthogonal aux directions des contraintes principales du tenseur des contraintes (mesuré à partir des mécanismes aux foyers, mesures in-situ, géodésie etc.) sont des constructions qui ont une plus grande probabilité de résister à l'effet des séismes dans une région séismique comme El-Asnam par exemple. Les unités de constructions orientées à 45° de l'azimut 45°W (direction des contraintes compressives à El-Asnam) ont une plus faible probabilité de ne pas être rupturé parce-que la rupture à 45° est la plus facile à réaliser (cercle de Mohr; Suppe, 1985)

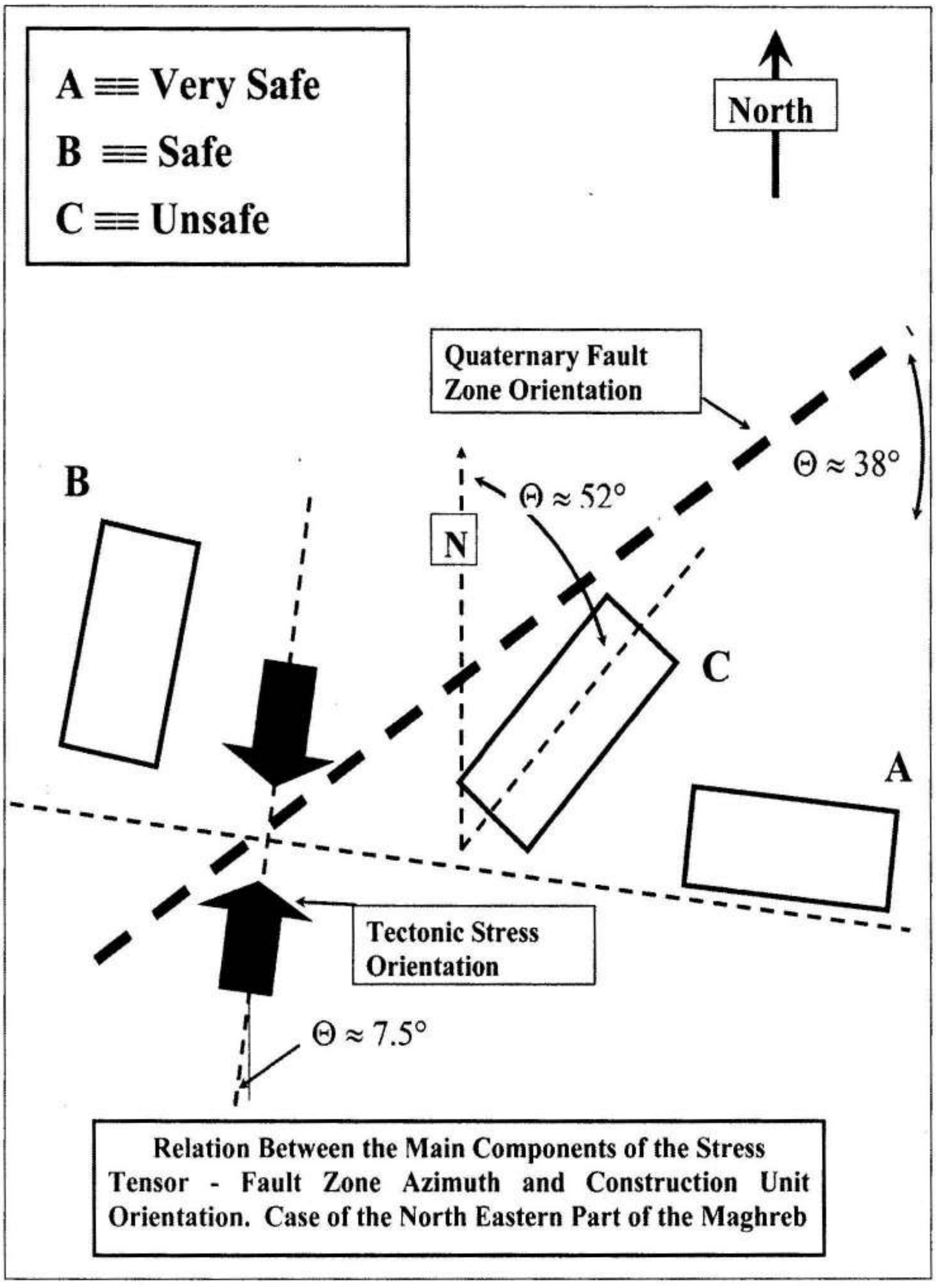


Figure 5 - Similar diagram with the same logic as figure 4 but concerns the North Eastern part of the Maghreb with a fundamentally different stress field, since the fracturation of the ground works in strike-slip faulting.

Diagramme similaire avec la même logique que figure 5 mais concerne la partie Nord – Est du Maghreb qui possède globalement un champ de contrainte régional fondamentalement différent que celui de l'ouest puisque la déformation se fait en coulissage.

4) The geological and the geodynamical context. Figures 6 and 7 show the geodynamical and geological context of some intramountain basins in the central part of Algeria: The Cheliff, the Mitidja and the Medea basin; all of them prone to high seismic risk.

5) The orientation of the main components of the stress tensor and their relative orientation compared to the geometry of the construction (fig. 4 and 5). Those figures will be explained later on more thoroughly.

Intensity and hazard maps have usually considered the first factors 1), 2) and 3) and have overlooked factors 4) and 5) (Embraseys, 1983; Benouar, 1994; Benouar *et al.*, 1996; Vaccari, *et al.*, 2001; Boughacha, *et al.*, 2003). Those parameters will be roughly evaluated for different areas in the Maghreb region. Therefore, if seismic risk assessment and construction management in seismic countries such as in United-States and Japan have considerably contributed to reduce human and economical loss; in many other countries moderate seismic events continue to trigger social and economical catastrophes that take hundreds of years to really recover. The 1906 San-Francisco earthquake, USA, of magnitude 7.7 killed only 100 people whereas the 2003 Boumerdes Earthquake, Algeria of magnitude 6.8 only killed about 2500 people and destroyed almost completely a city. A concerted multidisciplinary approach to seismic risk assessment and reduction is the key to really prevent the occurrence of such human and economical catastrophes such as the one that has occurred at El-Asnam in 1980 with about 3000 deaths and more than 36000 housing units destroyed. Another relevant example is the Agadir earthquake of only 5.7 in magnitude that killed about 12000 people. The incredible human loss that has occurred at Agadir is probably not only due to the lack of construction planning design but also due to the fact that Agadir is in the intramountain Souss Basin hanged in altitude trapped between two distinctive tectonic domains (fig. 7). Possibly, about the same geodynamical context as Mexico City that has also been seriously damaged by the earthquake of September 1985. The geodynamical context of the city of Agadir trapped between two topographies, contribute to create a resonance phenomena through the generation of standing waves beneath the sedimentary layer of the Basin leading to the resonance of the entire valley (Reiter, 1991). Asides from the effect of a basin of finite width (length ≈ width) trapped between two topographies and hanged in altitude, surface sediment layers alone amplify the motion of seismic waves in their travel crossing the sedimentary layer and can lead to serious damages as well. As it is the case at El-Asnam located in the Cheliff Basin (length >> width) at about sea level cover with a thick sedimentary layer exceeding five kilometres and trapped between the mountain belt the Dahra and the Bou Maad in the North and the Ouarsenis in the South. We show that the resonance phenomena by large exceeds the effect of sediment amplification and can trigger very important damages as illustrated by Agadir events. Since other basins in Morocco in the same geodynamical context as Souss Basin such as Tadla, Haouz, Ouarzazate, Missour, Guercif and the Rharb have not recorded any historical catastrophic seismic event similar to the one of Agadir although some major urban areas are located in those basins. It is tempted to think that in Souss Basin a reactivation of an old stable rifted crust such as in Libya might have occurred and was an additional factor that was added to the geodynamical context of the basin. This will be further developed.

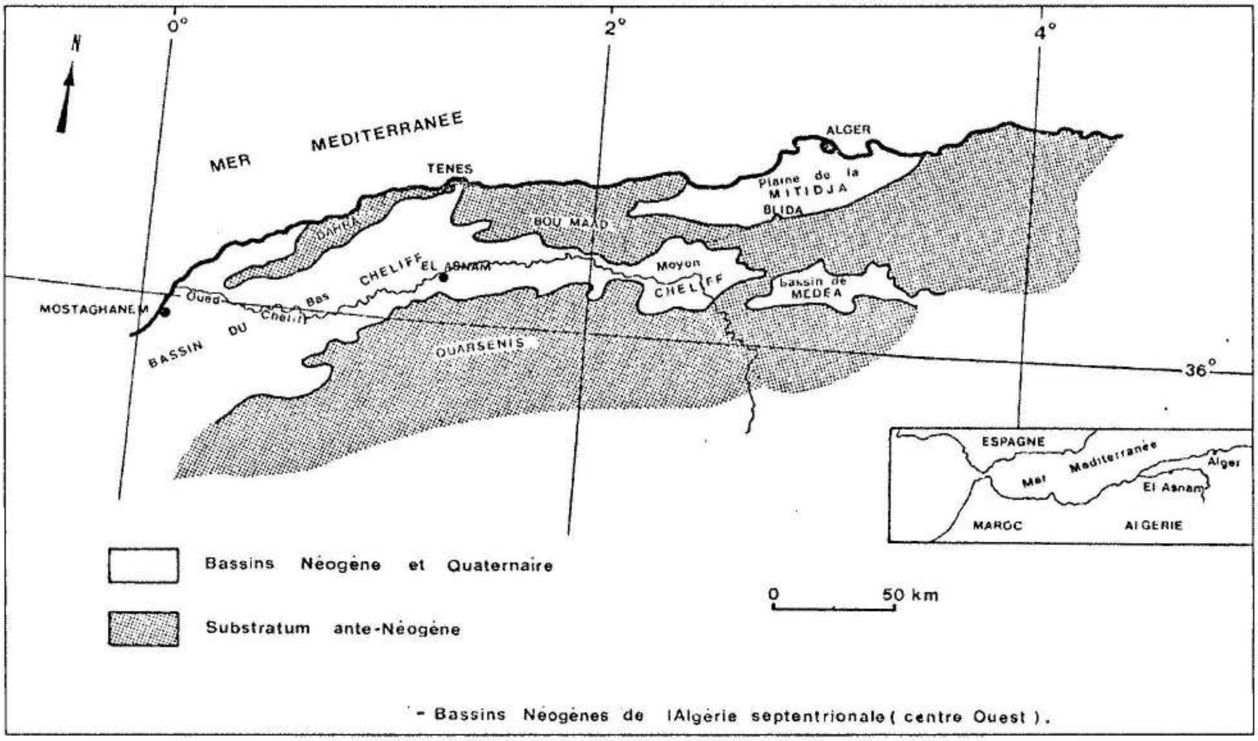


Figure 6 - From Meghraoui Ph.D Thesis, 1988, representing the typical most seismic prone areas to destructive earthquakes in the North of the Maghreb : They are in general a succession of basins (the Mitidja, the Cheliff and the Medea basins etc.) located between two topographies.

De la thèse de Ph.D de Meghraoui, 1988 représentant les régions typiquement les plus séismiques au nord du Maghreb et qui sont le siège de séismes destructeurs: Ce sont en général une succession de bassins sédimentaires (la Mitidja, le Chéliff et le basin de Médéa etc.) compris entre deux topographies.

AN ORDER OF MAGNITUDE OF THE VARIOUS SEISMOTECTONIC PROCESSES THAT CONTROL THE SAFETY OF CONSTRUCTIONS

The effect of two and three dimensional reverberations beneath the sediments of a valley

a) Some Remarks Concerning the Catastrophic Earthquake of Feb. 1960 Agadir Earthquake Mag ≈ 5.7; 12,000 Deaths

The Agadir city lies in Souss Basin bounded by two high topographies; the High Atlas (2000 m average elevation) in the north and the Anti-Atlas (1000 m average elevation) in the south. All the Basins existing in Morocco such as the Missour, the Ouarzazate, the Tadla (fig. 7) are features that are syn-rift that have been formed in the old time during the phase of extension corresponding to the opening of the Atlantic Ocean in Mesozoic time. Those basins contrast with the Algerian basins such as the Cheliff or the Hodna that have been created after the start of the Alpine orogeny. They are of Late Miocene age and post Alpine nappes orogeny. Those Moroccan Basins are by far more dangerous seismically than the Algerian basins because they are not only trapped between high topographies but also are suspended in altitude and present geometrical and geodynamical context that make them seismically at high risk. The Missour Basin for example is at 1500m elevation; 500 m lower than the average elevation of the High Atlas. The finite length, the

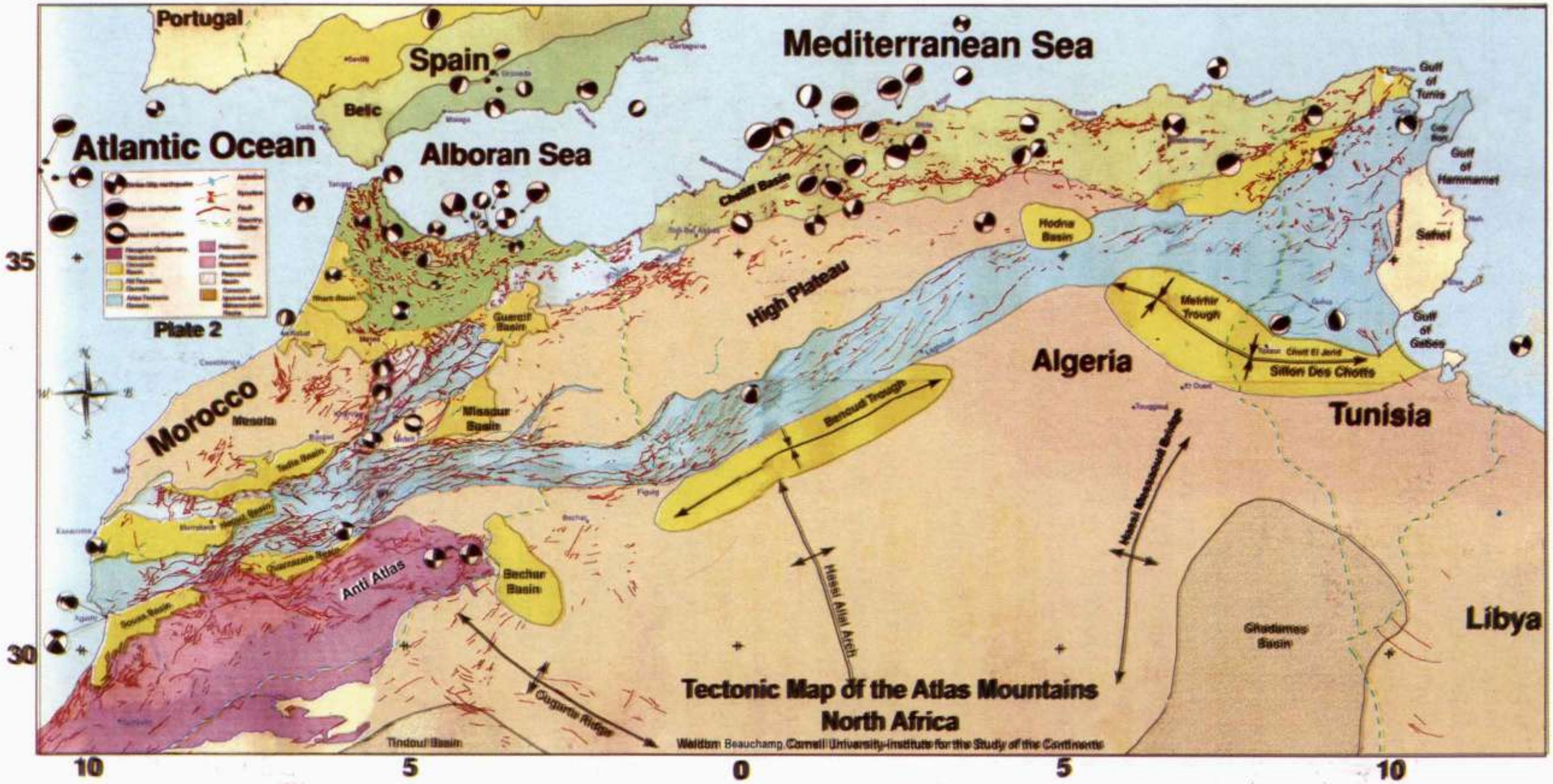


Figure 7 - From Beauchamp Ph.D thesis, 1998; a seismotectonic map of the Maghreb region with the delimitation of the different tectonic domains and their corresponding mode of fracturation represented by the focal mechanisms of recent earthquakes.

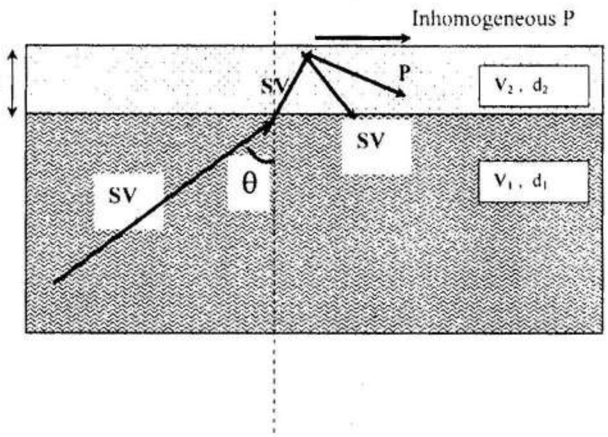
De la thèse de Ph.D de Beauchamp, 1998; une carte séismotectonique de la région du Maghreb avec la délimitation des différents domaines tectoniques et leurs modes de fracturation représentés par les mécanismes aux foyers des récents séismes.

elevation and the intramountain character of those basins favour the trapping of standing waves beneath them during an earthquake that generate reverberations phenomena that could trigger incredible catastrophes such was the case of Agadir earthquake in 1960 (Cherkaoui, 1991; Reiter, 1991). This earthquake of only magnitude 5.7 killed more than 12000 people. Even the magnitude 7.3 of El-Asnam earthquake in 1980 did not cause such destruction. This cannot explained solely by the fact that the fault rupture associated with Agadir event was closer to the city compared to El-Asnam fault rupture located about 10 km east of El-Asnam city. The most probable explanation of the occurrence of such damages for a magnitude 5.7 only is 1) amplification of the motion by sediments and 2) the geodynamical context of the Souss Basin suspended in altitude and trapped between two high topographies (Reiter, 1991; Bard and Bouchon, 1985).

The geodynamical context of El-Asnam laying between two topographies the Dahra in the north and the Ouarsenis (fig. 6 and 7) in the south but with the basin about sea level and extending on a wavelength much larger than the width of the valley which will permit to evaluate the intrinsic effect of sediment amplification since the basin is not suspended in altitude and has not a finite length. In contrast the geodynamical context of Agadir will permit to evaluate the effect of standing waves trapped beneath the basin due to the fact that the basin is an intramountain basin suspended in altitude with a finite length, a finite width and finite thickness of sedimentary layer. This effect of resonance is very important to assess for any serious construction management planning.

b) Quantification of the Effect of Sediment Amplification by Two and Three Dimensional Sedimentary Basins Symetry

Assume a half space of crustal rocks of shear wave velocity V_1 and of density d_1 overlaid by a sedimentary layer having a thickness H, a shear



velocity V_2 and a density d_2 as shown by the schematic diagram above. A unit impulse (harmonic wave of unit amplitude) of frequency f when reaching the boundary between the crustal rocks and the sedimentary layer is amplified. This factor of amplification depends on the frequency of the upcoming unit impulse and given by the following expression (Takahashi and Hirano 1941) :

$$|U(\omega)| = \frac{2}{\sqrt{\left\{\left[\cos\left(\frac{\omega H}{V_2}\right)\right]^2 + \left[\frac{d_2 V_2}{d_1 V_1}\sin\left(\frac{\omega H}{V_2}\right)\right]^2\right\}}} \quad (1)$$

with $\omega = 2\pi.f$

A maximum amplification occurs when the frequency of the upcoming wave is of the order of f_a and given by:

$$f_a = V_2/4H$$

the expression (1) takes then the form:

$$U(\omega)| = 2\ \{\ (d_1 V_1)\ /\ (d_2 V_2)\ \} \quad (2)$$

If we assume for the Cheliff basin the thickness of the sedimentary layer is H = 5 km, the density of the sediments d_2 = 2.5 and their corresponding shear wave velocity is 4/1.73 = 2.31 km/s (diagram above); the Poisson ratio is therefore assumed to be equal to 0.25; the density of the crustal rock is taken to be equal to $d_l = 2.8$ and the shear wave velocity of the crustal rock equal to 3.46 km/s; replacing those values into (2) leads to an amplification factor of the order of 3.36 around a frequency f_a of the order of 0.11 Hz. This amplification factor calculated through a one dimensional model takes in account the effect of the thickness of the overlying sedimentary layer, its spectral absorption and involves also the impedance contrast between the sediments and the crustal rocks. This amplification factor is consistent with the one found through the assumption of not a frequency impulse but an upcoming SV wave (see diagram above). This wave when transmitted in the sedimentary layer is the wave that is the most amplified. This amplification factor is given by Aki and Richards, 1980 and for the considered structure of El-Asnam basin is of the order of 3.3 and corresponds to an incidence angle θ of about 55°. The question arises if the transmitted amplified SV in the sediments is again amplified by the fact it reflects on the free surface and generate an inhomogeneous P wave. In the considered structure of the Cheliff basin this double amplification does not occur because the trans-mitted angle of incidence SV is of the order of 35° whereas the angle post-critical in order to generate an inhomogeneous P wave is about 38°. It is clear if a Poisson ratio of 0.25 is not assumed it is quite possible to find a structure that could have a double amplification. This case occurs when P wave velocity of the sedimentary layer is of the order of 4.25 km/s one assumes that all other parameters remain the same. A first amplification by a factor of 3.3 and a second one by a factor 4 due to the inhomogeneous P wave leading to an amplification of 13.2 of the upcoming SV from the rupture fault plane located at about 15 km depth in the case of El-Asnam. Though this double amplification factor cannot be excluded on a firm bases unless we have a more exact velocity structure for the region. We think that for the Cheliff Basin it does not occur and a one dimensional model assuming an upcoming impulse or SV wave is sufficient to describe sediment amplification. Indeed, the required P velocity of 4.25 km/s in order to have a double amplification for the underlying rocks beneath the sediments is too excessive for rocks at this depth. In contrast for basins of finite width, a finite length suspended in altitude and located between two high topographies such are Souss basin, the Ouarzazate, the Missour, the Tadla, the Haouz, the Rharb and the Guercif Basins in Morocco, a one dimensional model for quantifying the amplification of the waves by sediments for those basins is certainly incorrect. Indeed, the standing waves beneath the basin constructed through the lateral and vertical reflections from the rocks located at the boundary of the basin lead to constructive interferences of the body and surface wavefields and generate a three dimensional resonance of the entire valley (Reiter, 1991; Bard and Bouchon, 1985). It has been observed that the frequency of maximal amplification in the context of such valleys occurs at about the same frequency though the thickness of the sedimentary layer might very considerably from the centre of the valley to its margins. This is a surprising observation and justify therefore, on the non-linear character of three dimensional waves propagation in a valley of finite width. Therefore, the existence in the seismogram of amplified phases by sediments which are transmitted SV will lead for the considered earthquake as if we had an earthquake of larger equivalent magnitude Mb'and given by the the following equation:

$$Mb' \sim \log\{NA/T\} + Q(Z,\Delta) \qquad (3)$$

In which N is the amplification factor, T is its corresponding period and $Q(Z,\Delta)$ the correction factor due to the attenuation and depends on depth Z and on the distance Δ from the source.

It follows that the resulting difference $\Delta Mb'$ between the magnitude of the event computed from P wave and the equivalent magnitude computed from the transmitted SV wave is given by:

$$\Delta Mb' \sim \log\{NA/A\} = \log(N) = \log(3.3) \sim 0.518 \quad (4)$$

The amplification by sediments leads for the case of El-Asnam as if the earthquake was not of magnitude 7.3 but rather of magnitude 7.8. Since the magnitude does not really represent source characteristics it is more relevant to evaluate sediment amplification by considering the seismic moment. The shift from magnitude to seismic moment can be calculated from the equation tying magnitude to the seismic moment (Beghoul et al., 2004) and therefore, a straight forward deduction can be obtained from (4) leading to a source amplification by sediments of the order of seven times.

To quantify the reverberation due to the fact that the basin is suspended in altitude, a subjective but meaningful though a rough estimate is to use the ratio of people loss: 2590 at El-Asnam against 12000 at Agadir. The El-Asnam earthquake of 1954 of magnitude 6.7 led to about half loss (1243) compared to the one of 1980. Both of those events occurred not too far from the major urban area which is El-Asnam city and therefore it is not the distance that will explain the difference in loss but rather the difference in magnitude. It follows that a difference in magnitude of 0.6 has doubled the loss. Hence the question is what difference in magnitude should exist between Agadir event and El-Asnam in order to have as much as 4.6 times more losses ? The result is a difference in magnitude of the order of 1.3 in magnitude has to exist between El-Asnam and Agadir. Therefore, Agadir event behaved as if it had an equivalent magnitude of 8.6. 0.5 of this increase will account for sediment amplification effect and 2.4 for the effect of reverberation of standing waves beneath the basin suspended in altitude and trapped between two high topographies (Reiter, 1991; Bard and Bouchon; 1985). This is considerable and explain why at El-Asnam did not occur as much losses because the basin was of finite length and at sea level. In summary sediment amplification account for 0.5 in magnitude increase whereas reverberations of standing waves could create a difference in magnitude as large as 2.4. This will be the case also for Missour, the Tadla, the Ouarzazate, the Guercif, the Rharb and the Haouz Basins. However, one has to mention that no historical catastrophical events have occurred in any of those basins mentioned previously except Souss Basin although major urban areas are located in those basins. As mentioned previously, the fact that Souss crust corresponds to an old stable rifted crust (Jhonson and Kanter; 1990), located far from the thermal processes associated with the delamination event in the Rif; this might have additionally contributed to the seismically dangerous geodynamical context of the basin. All these basins are elevated basins contrasting with the post nappes basin in Algeria at sea level if not below sea level as mentioned previously.

In summary sediment amplification alone leads as if the earthquake source was seven times larger whereas a three dimensional resonance of a valley of finite width has an effect as if the earthquake source was 3980 times larger that explain the great destruction that has occurred at Agadir in 1960 with a magnitude earthquake of only 5.7. Similarly for the 1985 Mexico City earthquake.

The effect of acceleration caused by patches and heterogeneities distributed along the fault planes

Figure 3 shows that for a same magnitude earthquake the maximal acceleration triggered by the earthquake could vary by as much as 2g depending if the fault plane contains heterogeneities along the fault plane or not (Reiter, 1991). This increase in acceleration caused by patches corresponds to a maximal increase in magnitude of the order of 1.1 (Reiter, 1991). In other words for the same magnitude earthquake the effect of this earthquake on the construction will be at large as if the source was 45 times larger if patches exist along the fault plane rupture. To obtain this evaluation the relation tying magnitude to seismic moment for the western and central parts of the Maghreb having been used (Beghoul *et al.*, 2004)

The effect of the exposure of the constructions compared to the regional stress field.

The variation in shear stress $\Delta\tau$ acting on a plane oriented of θ from the direction of the main compressive stress σ_1, assuming that the horizontal plane stress σ_2 orthogonal to σ_1 is equal to zero; can be expressed as follow:

$$\Delta\tau = \frac{\Delta\sigma_1 . \sin(2\theta)}{2} \quad 5)$$

in which $\Delta\sigma_1$ corresponds to the stress drop that has occurred in absolute stresses σ_1 following a given earthquake. Combining the relation that gives the stress drop as a function of the fault geometry, the displacement D and the length of the fault L (Kanamori and Anderson, 1975):

$$\Delta\sigma_1 = C\ \mu\ D/L \quad (6)$$

C: constant that depends on the nature of the deformation
Dip-slip (normal fault or reverse fault) $C \approx 0.84$
Strike-slip $C \approx 0.64$
Circular fault $C \approx 1.37$
D: maximal displacement along the fault
L: length of the fault
W: fault plane width
if $D/L < 0.00001$ then $L \equiv W = Z/\sin(\theta)$

Combining the relation above and the definition of the seismic moment M_0 as a function of the displacement D and the fault surface area A; one can deduce an expression of the stress drop $\Delta\sigma_1$ as a function of the seismic moment given by :

$$\Delta\sigma_1 = \frac{CM_0}{L.A} \quad (7)$$

Combining the definition of the shear stress drop and the relation above on can express the shear stress drop as a function of the seismic moment as follow:

$$\Delta\tau = \frac{CM_0 \sin(2\theta)}{2.L.A} \quad (8)$$

This relation above gives the shear stress drop occurring along a plane oriented of $\theta°$ from the direction of σ_1, in the construction, when an earthquake of seismic moment M_0 occurs. An important question that needs to be addressed is: In order that the shear stress supported by this plane becomes maximal (this corresponds to the situation when $\theta=45°$ and leads to $\Delta\tau = \Delta\sigma_1/2$ according to equation (5)) how much should be the increase $\Delta M_0 = (M'_0 - M_0)$ of the seismic moment of the earthquake ? This can be expressed through the equation above as follow:

$$\frac{\Delta\tau'}{\Delta\tau} = \frac{(M'_0)(L.)^2}{(M_0)(L.')^2} \quad (9)$$

In which L and L' are the fault planes lengths associated with the seismic source M_0 and M'_0 respectively. It is assumed that the fracturation of the ground in the seismic prone area has about the same aftershocks depth and the same fault plane dip. This is a very reasonable assumption largely fulfilled in the field and that for each of the three main regions of Algeria

(Western part, Central part and the Eastern part). Indeed, for the western part of Algeria for example the fault plane depth does not exceed the 15 km and the dip of the fault plane is about 50°.

$$\log\left(\frac{\Delta\tau'}{\Delta\tau}\right)=\log\left(\frac{M_0'}{M_0}\right)\ +\ 2\log\left(\frac{L}{L'}\right) \qquad (10)$$

Expressing the ratio of the faults planes lengths from the empirical relations established by Beghoul et al., 2004 tying the fault plane length to the seismic moment (see table I) and considering the ratio $M'_0/M_0 = N$ one can re-write equation (10) as follow:

$$\log\left(\frac{\Delta\tau'}{\Delta\tau}\right)=0.34\log(N)\ .$$

This equation stands for all the three main regions of Algeria. Knowing that the order of maximal shear stress drop is about $\Delta\sigma_1/2$ (equation (5) for θ=45°) and since the order of maximal stress drop is about 100 bars; the ratio of shears $\left(\frac{\Delta\tau'}{\Delta\tau}\right)$ of the equation above is at most of the order of 50 leading therefore to an increase N of the earthquake seismic source of about 99300 times. The physical meaning of this result is extremely surprising and astonishing it means that the correct exposure of a construction orthogonal to the compressive field stress could reduce the shear stress acting on a plane as if the earthquake source was 99300 times smaller. Hence the variation in accelerations caused by patches along the fault plane has by far a less dominant effect compared to the correct exposure of the construction relatively to the regional stress field; a somehow very surprising result that turn to be largely fulfilled in the field observations after the 1980 El-Asnam earthquake. A correct exposure of the constructions in the region of El-Asnam would have dramatically reduced the risk and the construction would have behaved as if the earthquake was not of magnitude 7.3 but rather of the order of about 4.0 in magnitude. This seems incredible but largely fulfilled in the field after the earthquake of October 1980.

Summary of the results

Seismotectonic parameters	Source amplification
Acceleration	45
Sediments	7
3D resonance of a valley	3980
Effect of regional stress field	99300

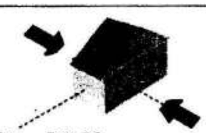
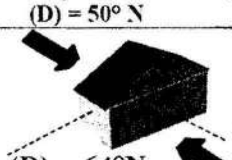
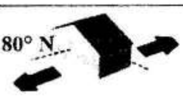
GENERAL OBSERVATIONS CONCERNING MAGHREB'S SEISMICITY AND ITS PRELIMINARY MEGA-SCALE SEISMIC ZONING

General Observations Concerning Maghreb Seismicity

The Tell Atlas is the region presently the most active area of the overall Atlas faults system where occurs the largest earthquakes with magnitudes that can be as large as 7.7 (Beghoul *et. al.*, 2004) (fig. 9). The relatively large known recent earthquakes that have occurred lately in the Tellian Atlas are the ones of El-Asnam of October 1980 of magnitude 7.3 and the one of Boumerdes in the centrale part of Algeria of May 2003 of magnitude 6.8. The nature of the deformation along the Tellian Atlas varies along strike in a context dominated by compressive stresses oriented NNW – SSE. The deformation in the central and western part of the Tellian Atlas extending from the region of Oran to the western part of Algiers, is in thrust faulting reflected by El-Asnam fault characteristics; whereas in its eastern part in the region of Constantine and north Tunisia, the deformation is mainly in strike slip faulting (Figures 10a,b,c). A striking observation in the central part of Algeria is the change in azimuth of the overall seismicity trend from NEE at the

Table I : Summary Table of important numbers for civil engineering constructions corresponding to more accurate seismotectonic parameters. They are useful for determining the dynamical response of structures in regions prone at a high seismic risk (zones I,II,IV and V)

Tableau récapitulatif de chiffres importants pour la modélisation de la réponse des structures en génie-civil. Ces chiffres représentent une quantification plus rigoureuse des paramètres séismotectoniques; nécessaires pour évaluer correctement la réponse dynamique des structures en régions à hauts risques séismiques (Zones I, II, IV et V).

Seismogenic Zone	**D_{max} (m)**	**γ_{max} (g)**	**Mag_{max}**	**Ampli f. of waves by sedim.**	**3D amplif. of waves in a valley**	**Static Inter-Reaction between the Regional Stress Field and the Construction. The safe Azimuth = (D)±15°**	**Recurre. Time Major Earthq. Mag_{max} (ans ± 20)**	**Fundamental Empirical Relations Mag-Seismic Source Characteristics $A[cm^2]$; M_0[dynes-cm]; D[cm] ; L[cm] + Nature of the Deformation**
I Western Part of Algeria	6.6	0.5	7.3	Yes	No	 (D) = 50° N	90	$\log A \approx Ms + 5.61$ $\log M_0 \approx 1.5\ Ms + 16.28$ $\log D \approx 0.5\ Ms - 0.85$ $Ms \approx 1.99 \log L - 5.84$ **Thrust faulting**
II Algiers Region	10		7.7	Yes	No	 (D) = 64°N	375 (7.7) 175 (7.3)	$\log A \approx Ms + 5.61$ $\log M_0 \approx 1.5\ Ms + 16.28$ $\log D \approx 0.5\ Ms - 0.85$ $Ms \approx 1.99 \log L - 5.84$ **Thrust faulting**
III Eastern Part of the Maghreb	1	-	6.5	No	No	 (D) = 97° N	100	$\log A \approx Ms + 6.25$ $\log M_0 \approx 3.0\ Ms + 6.78$ $\log D \approx 2.0\ Ms - 10.99$ $Ms \approx \log L - 0.25$ **Strike Slip Faulting**
IV North Lybia	7.7	-	7.1	Yes	Possible		95	**Normal Faulting** (Hum Graben) **Thrust Faulting** (along the coast)
V Moroccan Mesozoic Basins	0.5	0.1	6.5	Yes	Yes			**Thrust Faulting** Souss Basin Compression E-W
VI El-Hoceima Region, Morocco	0.5	0.1	6.5			(D) = 80° N 		**Normal and/or Strike Slip Faulting**

western part of the Tellian seismicity to SE in the central part of Algeria (fig. 9); extending from Algiers – Blida – margin of the Medea basin – crossing the Soummam basin – M'Sila (fig. 7 and 10a,b,c). This change in azimuth coincides with the narrowing of the rigid High Plateau and the intersection of the southern Tellian seismicity with the Saharan Atlas seismicity in the region of M'Sila (fig. 7). The seismicity associated with this structural feature generates reasonably large magnitude seismic events (> 4.5 and < 7.7). The overall seismicity of Morocco has been studied by numerous authors (Cherkaoui, 1991; Ramdani *et al.*,1989; Hatzfeld, 1978; Hatzfeld *et al.*, 1993; Calvert, *et al.*, 1997; Ben Sari, 1987; Ait Brahim *et al.*, 1990). Another dominant interesting observation in the northern part of Morocco in the Rif region is the existence of a significant seismicity in strike slip faulting and normal faulting contrasting with the thrust faulting existing few hundreds kilometres away in the Algerian Tell Atlas (fig. 8). A significant part of the current northern Rif seismicity is associated with the region of Al-Hoceima (fig. 7 and 9) that has recorded recently relatively large events of magnitude 6.0 on 1994 and on 2004 with a strike slip faulting (same orientation of P and T axes compared to El-Asnam earthquake with the difference that the P and T axes of Al-Hoceima

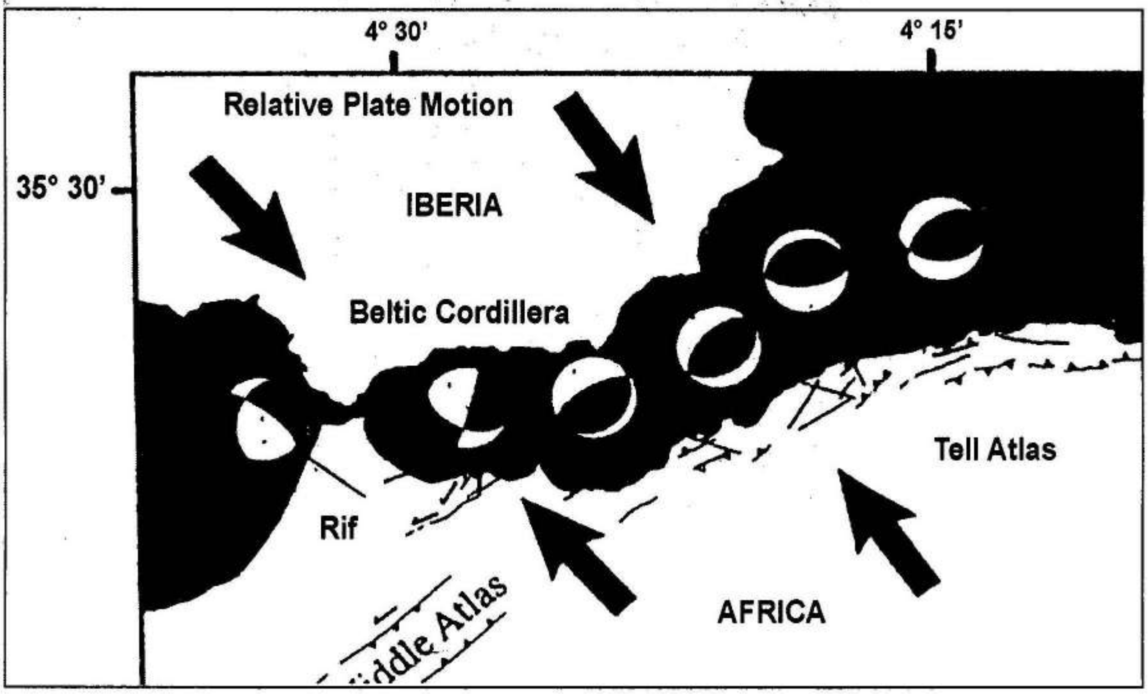


Fig. 8 - From Calvert, 1997, represents the overall direction of the current main components of the stress tensor deforming the North African plate with a compression of direction NNW-SSE. However one has to note that the nature of the deformation in the Rif is different than in the northern part of Algeria (see text). In the Rif normal and strike-slip dominate the deformation whereas in northern Algeria thrust faulting dominates reflected by the El-Asnam earthquake of October 1980.

De Calvert, 1997 représentant les directions approximatives des composantes principales du champ de contrainte actuel déformant le Nord de la plaque Africaine avec une compression de direction NNW – SSE. Cependant il est à noter que la déformation dans le Rif est différente de celle du nord de l'Algérie (voir texte). Dans le Rif la déformation se fait en failles normales ou en coulissages alors qu'au nord de l'Algérie elle se fait essentiellement en failles inverses à l'image du séisme d'El-Asnam en Octobre 1980.

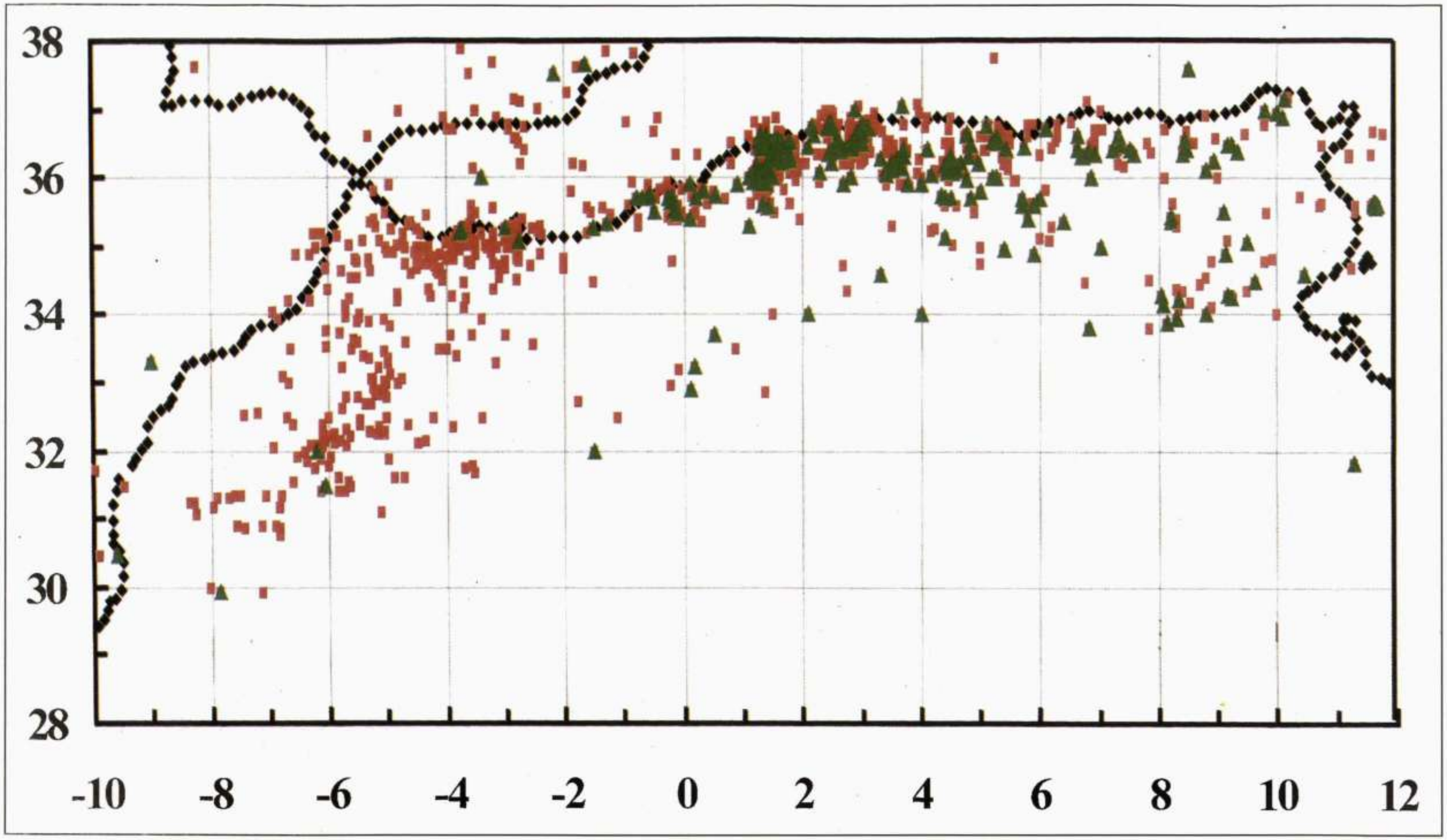


Fig. 9 - Seismicity of the Maghreb; the red points are earthquakes with a magnitude less than 4.5 and green triangles are events with a magnitude greater or equal to 4.5 in magnitude. Note that the main structural features of the Atlas faults system is outlined by the seismicity. Note in the north western part the most currently seismic region in Morocco the Rif; with though very few earthquakes larger than 4.5; contrasting with northern Algeria and Tunisia. This is consistent with the fact that thermo-mechanical processes are currently deforming the Rif lithosphere (Seber et al., 1996).

Séismicité du Maghreb; les points rouges sont les séismes ayant une magnitude plus petite que 4.5 et les triangles verts sont les séismes ayant une magnitude plus grande ou égale à 4.5. Notez que les grands traits structuraux du système Atlasique sont mis en relief par la séismicité. Notez à l'ouest du Maghreb au Rif qui est présentement la région la plus séismique au Maroc; très peu de séismes de magnitude plus grande que 4.5 ont lieu. Ce qui n'est pas le cas du nord de l'Algérie et de la Tunisie. Ceci est coincide avec le fait que des processus thermo-mécaniques sont présentement entrain de déformer la lithosphère du Rif (Seber et al., 1997).

are both sub-horizontal whereas one of those axes is sub-vertical in the case of El-Asnam and therefore, the Al-Hoceima fracturation is in strike slip rather than in pure thrust faulting) (Calvert, *et al.*, 1997; Ben Sari, 1987; Ait Brahim *et al.*, 1990). In fact this seismicity in strike slip and normal faulting is distributed in a diffuse manner all over the Rif and the northern part of the Middle Atlas (fig. 7 and 10a,b,c). We think that the strike slip deformation and the normal faulting existing in the Rif and in some parts of the Middle Atlas are the expression of the thermal delamination and/or thinning of the Rif's lithosphere (Seber *et al.*, 1996; Calvert *et al.*, 2000). This thermal delamination event by whatever process has affected the thermo-mechanical properties of the lithosphere in the Rif, and led to the rise normal faulting. As it is the case in Basin and Range Province in the South Western United States (Houseman et al., 1981; England and Houseman, 1989). The existence of intermediate seismicity to up 160 km depth beneath the Rif (Hatzfeld *et al*, 1993) and the existence of Quaternary volcanism (Beauchamp, 1998) are consistent with the delamination in the Rif and in the north part of the Middle Atlas as reported by Seber et al., 1996 and Calvert *et al.*, 2000. The competing mechanisms between compression due to th convergence of the African plate toward th Eurasian plate and the extension triggered b delamination led to the rise of a diffuse intens seismicity in normal and/or strike slip faultin with though no historical seismic event large than 6.5 in magnitude; a reflection of a relativel warm plate under compression. The curren most seismically active region in Morocco in the Rif associated with the Miocene new branche

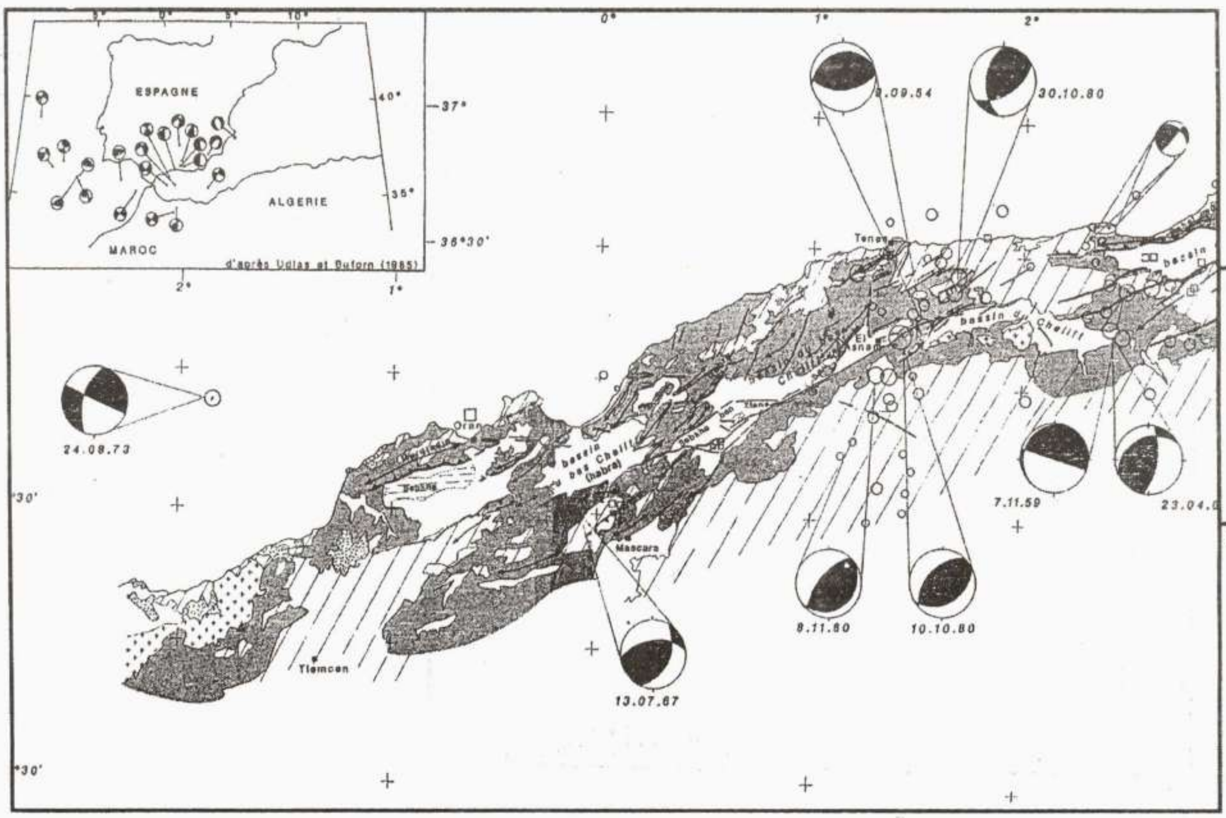


Fig. 10 a

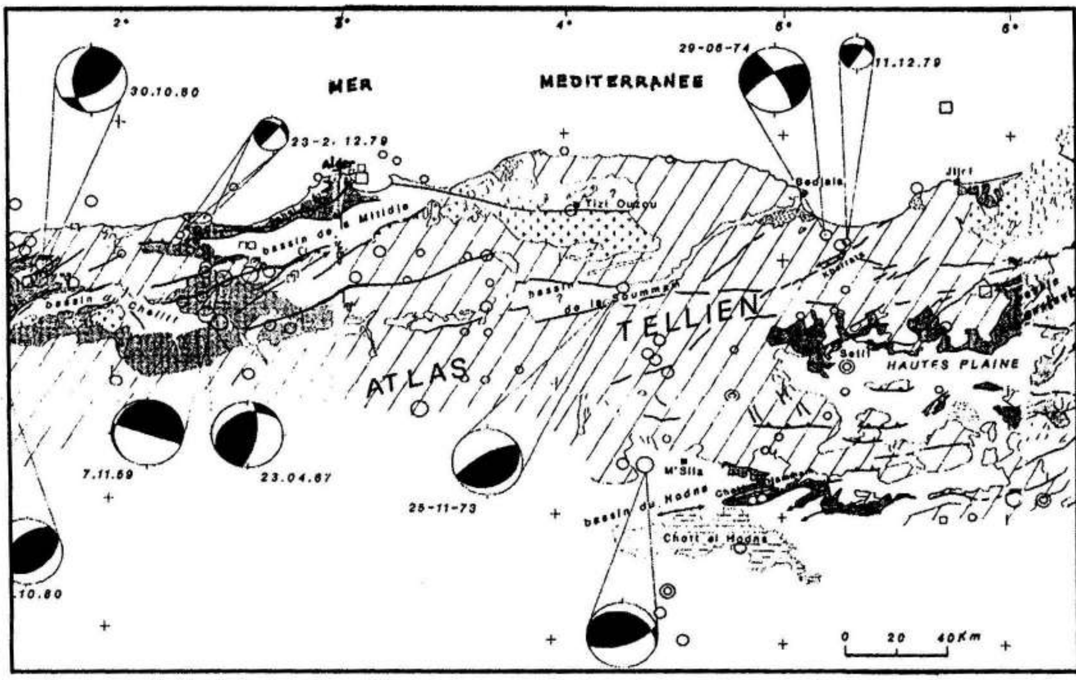


Fig. 10 b

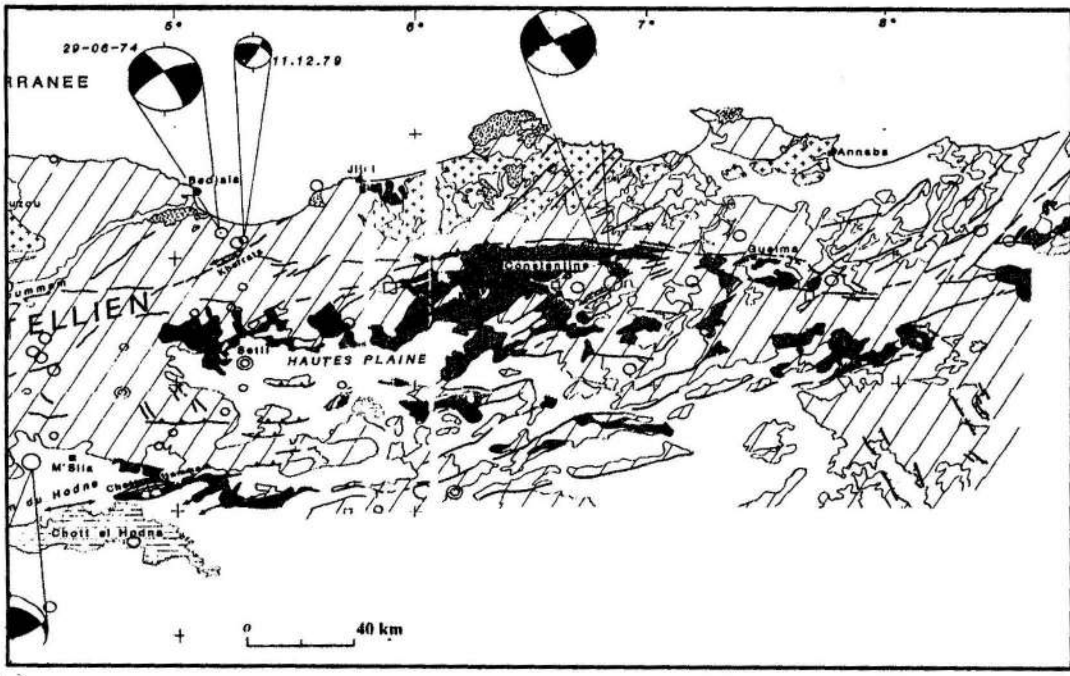


Fig. 10 c

Fig. 10 a,b,c - From Meghraoui Ph.D thesis, 1988; geological fault mapping of quaternary faults in the northern part of Algeria. Distribution of the major differences in mode of fracturation of the ground from the west to the east. Thrust faulting dominates the deformation in the west whereas strike-slip faulting dominates in the eastern part of the Maghreb.

De la thèse de Ph.D de Meghraoui, 1988; cartographie des failles Quaternaires au nord de l'Algérie. Distribution spatiale des différences majeures en mode de fracturation du sol d'ouest en est. Les failles inverses dominent la déformation à l'ouest alors que le coulissage domine la déformation à l'est du Maghreb.

of the Nekor Fault system in Al-Hoceima region (Calvert *et al.*, 1997) are part of this process of a warm plate under compression.

The frequency of earthquakes and the nature of deformations in the western and eastern parts of the Maghreb are not the same. Beghoul et al., 2004 show that the seismic moment rate of the eastern part of the Maghreb is an order of magnitude less than the central and the western parts that explain why earthquake frequency in the eastern part is an order of magnitude less. This can be explained by the fact that in the eastern part of the Maghreb the High plateau is replaced by the overall spread of the Saharan Atlas across most of the Northern part of the Eastern Maghreb region. The deformation occurring in the Saharan Atlas is by far less significant than the one of the Tellian Atlas. Furthermore the convergence rate of the African plate toward Eurasia is 5.4 faster in the Gulf of Tunis compared to the one of the Gulf of Gibraltar. That means at the west there is a situation of 'blockage' reflected by the spectacular deformation of the Atlas system in Morocco and the intense seismicity though with small magnitude earthquakes whereas at the Gulf of Tunis there is no strong struggle between the plates and therefore there is no situation of 'blockage'. Those both arguments of geolocical structure of the Saharan Atlas and the convergence rate of the African plate explain why the seismic moment rate in the Eastern part is an order of magnitude less than the one of the Western Tellian Atlas.

Preliminary Mega-Scale Seismic Zoning

The Maghreb in general and in particular Algeria lack of strong motion data and therefore, the existing distribution of maximal acceleration across the country are not really enough to be able to describe satisfactorily the ground response. Furthermore, as mentioned previously there is no one to one relation between maximal magnitude and acceleration (Reiter, 1991) therefore the existing seismicity cannot either provide reasonable statistics to describe ground acceleration. It follows that current hazard evaluation rely solely on some statistics of seimicity in which the fundamental information used cannot provide further crucial information other than seismicity itself (Benouar, 1994). We prefer to take a more conservative approach by using an invariant signal which is the geology and its deformation through time that is invariant for the Maghreb region for the past five millions years. We segregate the regions according 1) to their geodynamical context and their current nature and style of deformation and therefore, adapt accordingly the type of constructions that need to be designed 2) on the possible amplification and/or liquefaction of the soil. The current paper present some relevant arguments on the basis of the historical and the instrumental seismicity of the Maghreb as well as on the basis of some relevant geological and field work the existence of distinct regions with their corresponding empirical relations describing source parameters. Those regions have distinct regimes of deformation and therefore, nucleate earthquakes with different time recurrences. It is clear that further work has to be carried out in order to give further substance to those relevant arguments. It appears that the overall seismicity from the engineering perspective can be divided in six distinct mega seismic zoning (fig. 11):

Zone I, Western Algeria :

Defined by a system of faults that extends from Meknes – to the western part of Algiers that nucleate a major seismic with a magnitude about 7.3 every 90 years or so. The deformation is mostly in thrust faulting. The safe construction's azimuth is of the order of 50°N ± 15° (see text and table I).

Zone II Algiers Region :

Defined by a seismicity pattern oriented SE in the central part of Algeria and covering the regions from El-Attaf – Tipaza – Algiers – Blida – Medea – Mouzaia – M'Sila (fig. 10a,b,c).

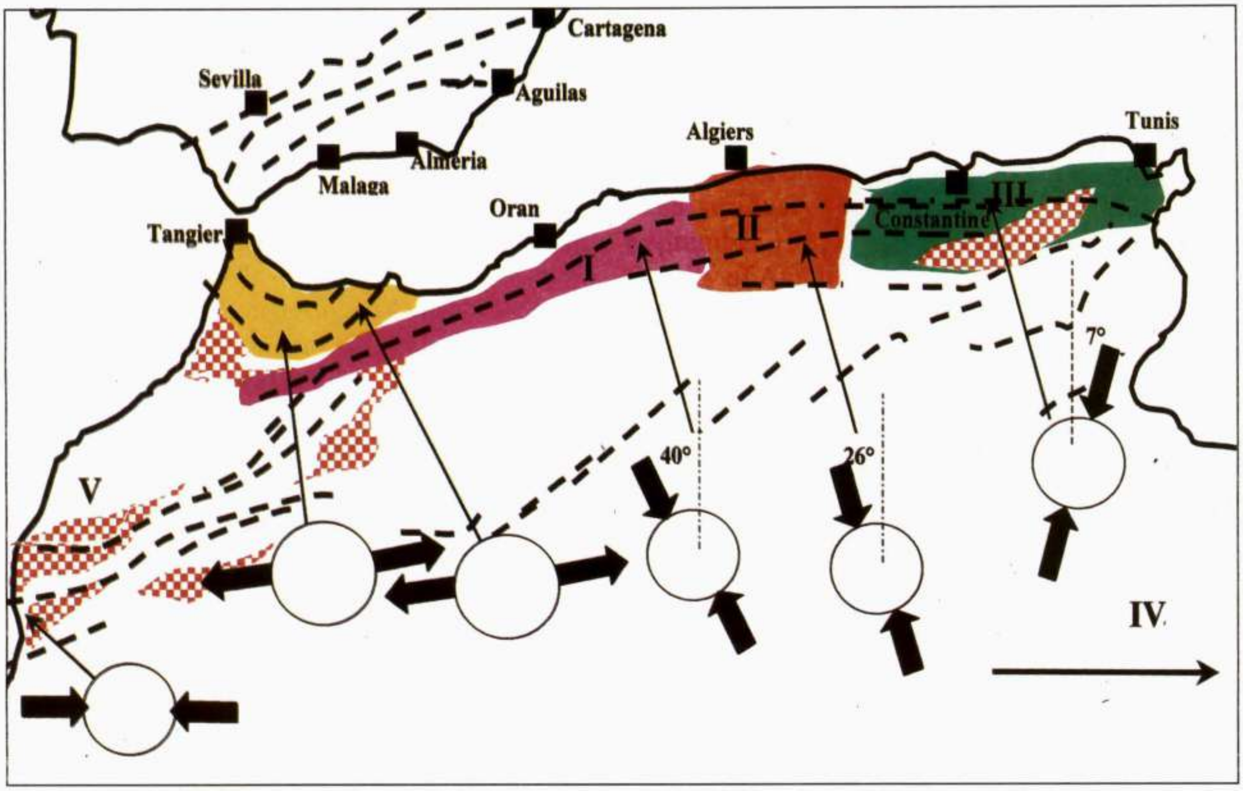


Fig. 11 - Schematic diagram summarising this study and representing the different mega seismic zoning that have a very high risk to nucleate a major earthquake (see text for their recurrence time) with their mode of fracturation represented by their corresponding stress field. Note the Zone I and II are deformed in thrust faulting with a fault plane oriented roughly East-West with a dip of about 50° whereas the Zone III is deformed in strike slip faulting with a fault plane oriented also East-West but with a vertical fault plane. The Zone IV is the zone associated with the Libyan and the Hum-Graben. The thick dashed lines represent the mega fold thrust axes mapped by Tapponnier, 1977 making the Atlas fault system. Note in the northern part in the Tell Atlas the seismic risk is concentrated along the corridor delineated by those mega fold thrust belts. Those seismic corridors are for most of them a succession of sedimentary basins. Most of those basins are of Miocene age such as the Cheliff and the Mitidja Basins. In contrast the basins associated with the Zone V (see text) are much older basins of Mesozoic age formed during the period of the opening of the Atlantic (see text).

Diagramme schématique résumant cette étude et représentant les méga-zonations qui ont une grande probabilité de générer un séisme majeur (voir texte pour leurs temps de récurrence) avec leur mode de fracturation très probable. Notez que la zone I et II sont déformés en failles inverses avec un plan de faille orienté approximativement Est-Ouest avec un pendage de l'ordre de 50° alors que la zone III est déformée en coulissage avec un plan de faille orienté aussi approximativement Est-Ouest mais avec un pendage quasi vertical. La Zone IV est la région côtière de Libye associée au Hum-Graben. Les traits épais en points tirés représentent les axes des méga-plis chevauchants : nappes cartographiées par Tapponnier, 1977 et qui en fait constituent le système de failles Atlasique. Noter au nord dans l'Atlas Tellien, le risque séismique est concentré le long des corridors délinéés par ces méga -nappes chevauchantes. Ces corridors séismiques sont en fait pour la plus part qu'une succession de bassins sédimentaires. La majorité de ces bassins sont d'âge Miocène comme les Bassins de la Mitidja ou le Bassin du Cheliff. En contre partie les bassins de la zone V (voir texte) sont des bassins beaucoup plus vieux d'âge Mesozoïque formés durant la période d'ouverture de l'Atlantique (voir texte).

This region could nucleate a major thrust faulting as large as 7.7 in magnitudes every 375 years or so with faults ruptures that might be as large as 65 km in length compared to about 40 km for El-Asnam region. This region lies at the north of the High Plateau. The High Plateau is the rigid uplifted undeformed block located between the Tell Atlas in the North and the Saharan Atlas in the south. This Plateau serves as a stress transmitter between the Tell and the Saharan Atlas. This seismic zone corresponds to the region near the part of the High Plateau that is the narrowest and might explain the change in trend of the seismicity from NE in the west to EW and SE in the central part of Algeria (Beghoul *et al.*, 2004). The safe construction's azimuth ortho-gonal to the direction of the main compressive stresses σ_1 is of the order of 64°N ± 15° (see text and table I).

Zone III Eastern Part of the Maghreb :

Corresponding to the region of Constantine and its extension to up north Tunisia. Those regions nucleate events of magnitude 6.0 every 40 years or so with a typical deformation in strike-slip faulting (fig. 10a,b,c). Destructive earthquakes of magnitude 6.5 have occurred in historical times with a recurrence of about 100 years or so. This region corresponds to the part of the Tellian Atlas in which the High Plateau in the south disappears replaced by a significant spread of the width of the Saharan Atlas topography. The safe construction's azimuth is of the order of 94°N ± 15° (see text and table I).

Zone IV The Lybian Region :

Not associated with the deformation of the Atlas system but with the reactivation of faults in stable old crust. If in the past the sites of historical earthquakes did not cause heavy damages; this is because no real urbanisation existed, if the same magnitude will occur in the future, it will cause most probably far more damages. Our calculations show that about every 95 years or so will occur a major earthquake of magnitude 7.0 or so. The deformation is in normal faulting in the Hum Graben and mostly in thrust faulting along the coast.

Zone V Old Moroccan Intramountain Basins:

Seismicity associated with basins trapped between two major topographies and hanged in altitudes as it is the case of the Souss basin in Morocco in which occurred in 1960 the devastating event of Agadir with magnitude of only 5.7 but caused more than 12000 human lives loss. The seismicity associated with those specific features have been analysed thoroughly in previous sections.

Zone VI Al-Hoceima Region in the Rif:

The most seismically active region in Morocco. However, this region did not record any catastrophic historical event in the past as the stress accumulation is released regularly by an intense seismicity with a couple of earthquakes of magnitude 5.0 each year but with no earthquake larger than 6.0 (Calvert, *et al.*, 1997). Therefore, this region is not seismically at very high risk compared to the other zones that might nucleate events as large as 7.7 in magnitudes. The safe construction's azimuth is of the order of 80°N ± 15° (see text and table I).

CONCLUSIONS

This study is intended to raise the issue of the effect of the regional tectonic stress field of the region and its effect on the propagation of waves generated by an earthquake and their effect on the construction. This study shows that in orienting the construction units orthogonal to the stress field of the region it is possible to reduce dramatically the destruction caused by the earthquake. Observation and simplified but reasonable calculations show that if the construction is oriented orthogonal to the stress field; the effect of the earthquake will be as if the earthquake source was 99300 times smaller.

In other words a correct exposure of the construction in the region of El-Asnam would have made the situation as if the constructions were not bearing an earthquake of 7.3 in magnitude but rather an earthquake of magnitude 4.0. This is a rough but certainly meaningful evaluation without going into a full modelling of the radiation of the waves and their corresponding focal mechanism. This simple safety measure is particularly useful for countries at high seismic risk and under-way of development. Indeed, most of those countries do not have substantial recorded seismicity and do not have a lot seismic stations to assess the seismic risk in a more full comprehensive manner as it is in countries such as United-States or Japan. To measure this regional stress field one can use one of the following methods:

-Focal mechanism using the seismicity
-In-situ stress measurement or hydrofracturation
-Neotectonic field measurements
-GPS measurements that gives the displacement field

Therefore, this study supports the fact that the usually used micro-zonation at the scale of a city for the reconstruction in considering all the local effects such as sediment amplification, attenuation, distance from the seismogenic zone, etc. all those effects expensive to get and time consuming have by far less weight than the easily obtained large scale stress field. The effect of the accelerations on the construction has three orders of magnitude less than the effect of the regional the stress field. If the valley has a finite width and is suspended in altitude between two topographies; the three dimensional effect of the resonance of the standing waves in the sediments could be an order of magnitude less than the effect of the stress field. This explain why an earthquake of 5.7 in magnitude led to more than 12000 people deaths in the City of Agadir in 1960 and in the similar manner for the 1985 Mexico City earthquake. A comprehensive map of the Maghreb (fig. 11) and a summary Table (table I) are presented summarizing the regions according 1) to the faulting system existing in them and its coherency on long time scale (Beghoul *et al.*, 2004) and 2) according also to their corresponding regional stress field and the existence of sedimentary basins that sustain a three dimensional resonance phenomena. Therefore, this simple and rough large scale seismic zoning map without going in detailed investigation of the ground response through micro-zonation could contribute to reduce the risk in a significant substantial manner. This study is not meant to minimize the work of civil engineers that work on determining the structure response of structures for which an entire science field exist; but we think in order to assure reasonable good safety of the construction with no significant costs it is important to better quantify and understand the seismotectonic signal that has tremendous control on the structure response. Therefore, their results based most of the time on extrapolated or simplified quantification of the important and complex seismotectonic signal leads to not well-adapted constructions for the regions at high seismic risk. What follows is a summary of some important numbers concerning the Maghreb. Those numbers as explained in the text are of fundamental importance for any construction planning in highly seismic region in particular in the Rif, the Tell Atlas and the old intra-mountain Moroccan basins.

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L'insuffisance de notes recueillies n'offrant pas la possibilité d'éditer, dans l'immédiat, un autre numéro spécialement dédié à ce séisme et, afin de ne pénaliser ni les auteurs ni les lecteurs, il a été décidé d'accueillir ces notes dans trois livraisons dinstinctes du "Bulletin" sur 2006 et 2007.

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