WENCHUAN EARTHQUAKE (MW 7.9, 12 MAY 2008) SICHUAN, CHINA. GEOTECTONIC REGIME AND DAMAGE MACRO-DISTRIBUTION

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ABSTRACT :

The Mw 7.9 R earthquake on the 12th May 2008 that hit Sichuan prefecture caused tenths of thousands of casualties and had enormous consequences. The earthquake was triggered by a reverse fault of NE-SW trend dipping towards the NW, having a length of 100 km and focal depth of 19 km. According to the damage records, an estimation of the intensities was carried out based on the EMS – 1998 and a correlation of their distribution with the geotectonic, seismo-tectonic, morphological etc, data was carried out. From this investigation three macro-distribution intensity zones were identified: (i) Zone A in the mountainous region, west of the reverse fault with estimated intensities approaching $XI_{EMS-1998}$ and locally $XII_{EMS-1998}$ due to the prevailing morphological and geotechnical conditions as well as to the fact that the region represents the hanging wall, (ii) Zone B in between the mountainous region and a morphologically flat region, representing the trace of the seismic fault with intensities approaching $VIII_{EMS-1998}$ and locally $IX_{EMS-1998}$, and (iii) Zone C, the low land region with estimated intensities ranging from $VI_{EMS-1998}$ to $VII_{EMS-1998}$ due to the geotechnical conditions and to the fact that this region represents the footwall.

KEYWORDS: Wenchuan, earthquake, geotectonic regime, EMS-1998 scale, damage macro-distribution

1. INTRODUCTION

The earthquake that hit the Sichuan prefecture in Southern China on the 12th of May 2008 had a magnitude of Mw 7.9 R and affected a region characterized by high seismicity. The earthquake caused 69.172 casualties, 374.159 injuries, 17.420 people are still missing and 8 million people are homeless (official data 17/6/2008). The earthquake epicenter was located 80 km northwest of the capital Chengdu (31.119°N, 103.258°E) of the Sichuan prefecture, in the region Wenchuan, the focal depth is estimated to 19 km and according to the generation mechanism (USGS 2008) the shock was triggered by a dip-slip reverse fault of a NE-SW general trend dipping towards the NW (**Figure 1**).

The distribution of this seismic fault as well as its kinematics and dynamic characteristics are attributed to the geodynamic frame of the greater region, characterized by large scale thrusting of the Tibetan Plateau towards the east on the rigid block of Sichuan Basin. This geodynamic frame is a result of the prevailing compressional regime along the Himalayan Mountain belt (**Burchfiel et all 1995**, **Burchfiel et al 2008**, **Densmore et al, 2007**, **Gan et al 2007**, **Royden et al 2008**, **Zhang et al 2004**) attributed to the progression of the Indian plate towards the north.

The geomorphology of the region is in accordance with the existent geodynamic regime since (i) towards the east, an extensive morphologically flat region exist, including the capital city Chengdu of the Sichuan prefecture, and (ii) an extensive region towards the west with high relief and great altitudes. The elongated zone, having a length of approximately 100 km and NE-SW trend, located in between the lowland region to the east and the high relief region to the west is clearly defined near the towns of Dujiangyan and Mianzhu, that suffered the greater damages and represents a zone with large morphological discontinuities and diversities (**Figure 2**).

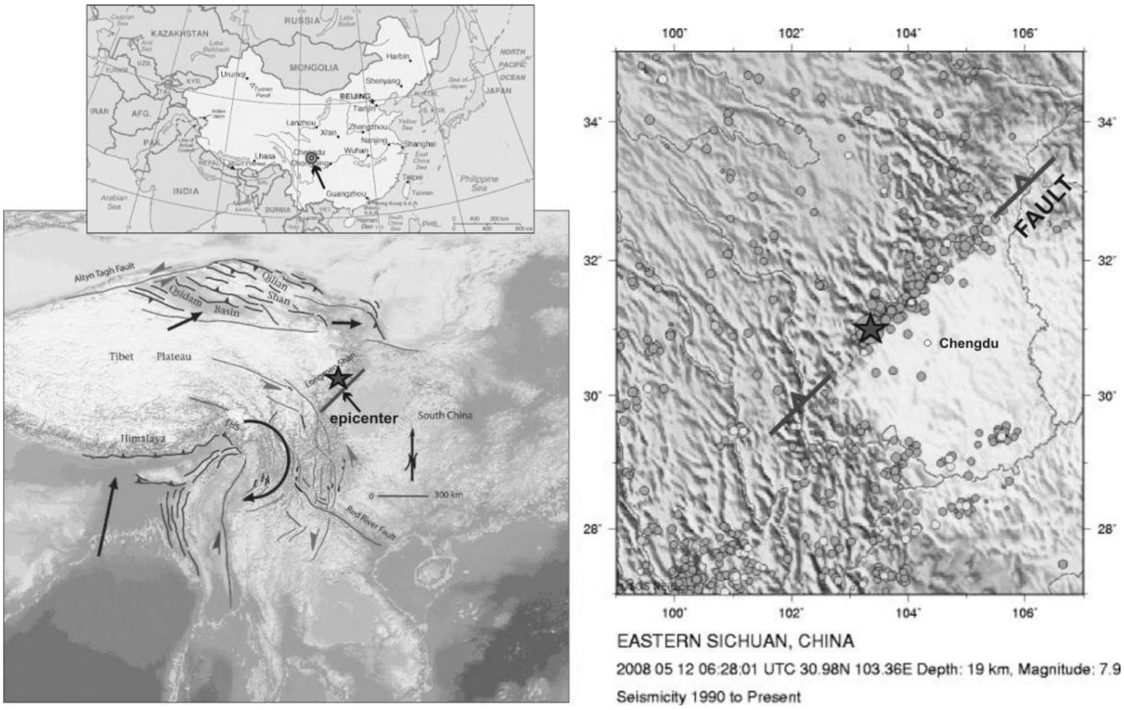

Figure 1: The geodynamic regime (**Burchfiel et al, 2008**), earthquake epicenter location (**USGS, 2008**) and the location of the seismic reverse fault that triggered the Mw 7.9R earthquake on the 12th of May 2008, in Sichuan prefecture.

Taking into account the epicenter location and the reverse seismic fault geometry, as it is estimated by the focal depth and the generation mechanism (**USGS 2008**), the surface projection of the fault should be expressed in the aforementioned zone, that is, in the boundary between the lowland region and the high relief region (**Figure 2**). The absence of surface expression of the fault is due to: (i) the nature of the reverse fault that does not produce surfaces similar to those produced by normal faults, (ii) the propagation of the principal seismic ground accelerations to secondary surfaces due to diffraction and (iii) the presence of large scale debris fans and the extensive deposits of river-stream formations along of the foothills of the mountains. It should be pointed out that according to the fracture models that have been suggested, it is ascertained that the greater slip took place not in the epicenter region but tenths of kilometers towards the NE near the town of Mianzhu. The geomorphology of the region is in accordance with the existent geodynamic regime since (i) towards the east, an extensive morphologically flat region exist, including the capital city Chengdu of the Sichuan prefecture, and (ii) an extensive region towards the west with high relief and great altitudes. The elongated zone, having a length of approximately 100 km and NE-SW trend, located in between the lowland region to the east and the high relief region to the west is clearly defined near the towns of Dujiangyan and Mianzhu, that suffered the greater damages and represents a zone with large morphological discontinuities and diversities (**Figure 2**).

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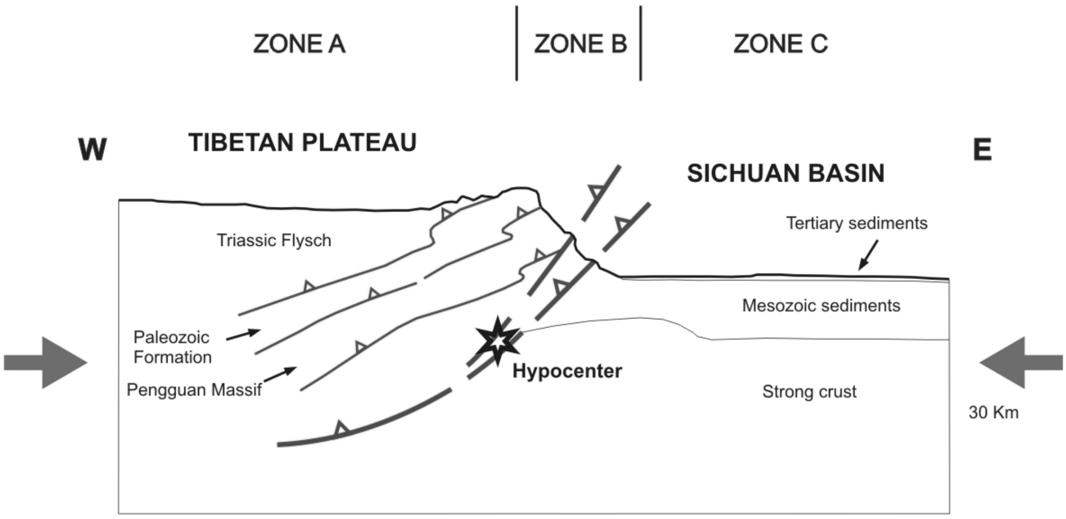

Figure 2: Geological section of general W-E trend across the tectonic structure of the affected region. The low land region to the east, the high relief region to the west and the intermediate region in between, on which the reverse seismic fault zone has been projected.

2. DAMAGE DESCRIPTION IN URBAN CENTRES

By the research carried out throughout the earthquake affected area which is of the order of 40.000 Km^2, the following damages were recorded for every urban centre or region (**Figure 3**):

Dujiangyan Region: The town of Dujiangyan is located 30km east of the epicenter, 50 km west of the capital city Chengdu, in the zone defined by the boundary between the lowland region and the high relief region. The town develops in its greater extent on a large scale alluvial fan, formed by the Min River that drains an extensive mountainous region, while some of its branches run through the town.

Moreover, a section of the town is founded on the Sichuan Basin Quaternary formations and more specifically on the lowlands at its eastern part, while another section, the western one, is founded on the rocky formations of the first morphological elevations of the mountainous region.

In the town, approximately 300 constructions collapsed while 25% of the buildings suffered serious construction damages. Mainly multistory buildings collapsed, modern or older, constructed of reinforced concrete. Most collapses are located on the foothills of the mountainous region towards the west and the morphologically higher areas and less on the lowlands. Especially interesting are the new buildings that are under construction of modern antiseismic design at the higher elevations of the town that collapsed or underwent serious foundation damages. In these areas, it seems that the nature of the founding ground which is composed of remnants of river deposits and debris of limited thickness on the rocky background played a determinant role. It is estimated that 50% of the building collapses observed in this town were founded on similar deposits and are located in the same morphological unit, (**Figure 4**).

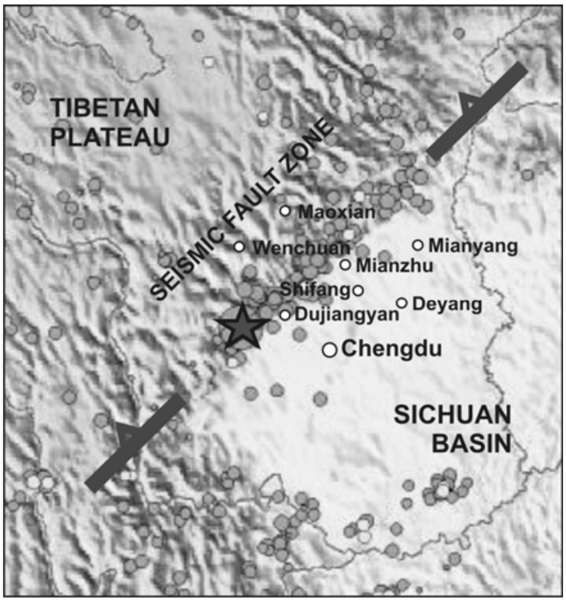

Figure 3: Geographical map of the affected region with the epicenter location (**USGS, 2008**) and the seismic zone location.

Figure 4: View of a building in Dujiangyan founded on river deposits with serious structural damages on the ground floor props. (type of building D, damage degree 4).

Moreover, serious damages were recorded in constructions with unfinished design, a fact that mainly concern old multistory constructions. Finally it should be mentioned that five schools, hospitals and tenths of factories and industrial constructions collapsed in the greater urban area while all sort of infrastructure suffered serious damages. The estimated preliminary general intensity in the area is of the order of $VIII_{EMS-1998}$ while locally it approached $IX_{EMS-1998}$.

Mianzhu Town: The town of Mianzhu is located 50km NE of the Dijiangyan town and suffered serious damages. It is estimated that 30% of the buildings collapsed, while 70% of the buildings suffered considerable damages. The damages are mainly on multistory buildings, modern or older, while constructions with 1 or 2 floors suffered fewer damages. Dominant causes for the damages in many constructions are the architectural mannerism and features, especially in cases where they were not supported by the design of the construction. Moreover, many schools, hospitals and industrial units collapsed causing thousands of casualties while the infrastructure was either destroyed or seriously damaged. The town develops practically on the foothills of the mountainous region to the west, while the founding ground formations correspond to alluvial deposits and debris that mainly develop towards the east. The estimated intensity in the area exceeded $VIII_{EMS-1998}$ and in some locations approached $IX_{EMS-1998}$.

Shifang Region: The Shifang town is located on the morphologically lowland section, approximately 15 km towards the east from the boundary of the Tibetan Plateau morphological elevation. It is estimated that 10% of the buildings collapsed or suffered serious damages, while more that 20% of the constructions underwent structural damages. These were multistory constructions usually from 2 to 6 floors which probably presented structural imperfections, while there was no systematic geographical differentiation of the collapses within the urban centre. It should be pointed out that the founding formations correspond to cohesive Quaternary formations which are unconformably thrusted on the rocky setting of the Sichuan Basin while as a whole, the geological – geotechnical conditions within the urban centre do not seem to differentiate significantly. The estimated intensity for this region is $VII_{EMS-1998}$.

Deyang Region: The Deyang Town is located on the morphologically lowland section of the greater area, approximately 30 km towards the east from the boundary of the morphological elevation. The observed damages in the region mainly include damages on the walls of the first floors of modern constructions, while a small number of multistory buildings collapsed or suffered severe structural damages. These were multistory constructions, usually 2 to 6 floors, which probably presented structural imperfections and did not have modern anti-seismic design. In addition it should be mentioned that the collapses and the damages presented random distribution within the urban centre. The geological – geotechnical conditions are uniform and do not differentiate from site to site within the residential grounds. Basically, the urban centre develops on cohesive Quaternary formations that unfold on the Sichuan Basin formations. It is estimated that the intensity in this region was of the order of $VI_{EMS-1998}$.

Mianyang Region: The Mianyang town is located on the morphologically lowland section of the greater region 20km to the NE from the morphological elevation boundary. The recorded damages mainly included damages on the walls of modern constructions first floors, while only a small number of multistory buildings collapsed or suffered serious structural damages. These were constructions with 2 to 6 floors that probably presented structural imperfections and did not have modern anti-seismic design. The geological – geotechnical conditions are uniform and do not differentiated from site to site within the urban centre. The centre develops on cohesive Quaternary formations that cover the Sichuan Basin formations. It is estimated that the intensities in the area were of the order of $VI_{EMS-1998}$.

Wenchuan – Beichuan Regions: The Wenchuan, Beichuan and Maoxian towns as well as smaller settlements, are scattered in the mountainous western section of the affected region. They develop mainly on the morphologically flat areas and especially on older and modern river terraces and on slopes that develop on both sides of the river terraces. Both slopes and river terraces are composed of unconsolidated formations and more specifically by river – stream deposits that are characterized by the dominant presence of pebbles, breccia, and graded material and by recent and old debris as well as slope formations of variable thickness. The above formations cover in a great extent the Tibetan Plateau formations.

As a result of this morphological, geological – geotechnical frame, were the general damages that old and new constructions suffered. It is characteristic that in the Wenchuan region, 85% of the constructions collapsed partially or totally while the rest suffered significant structural damages. It is indicative that only a few buildings did not collapse. Furthermore, all the bridges and road network collapsed while in general, the infrastructure suffered considerable damages within and beyond the urban centre. In addition, in many locations, large scale landslides were triggered that completed the frame of total destruction (**Figure 5**).

An unusual behaviour was exhibited by the existing dams in the mountainous region. More specifically, according to official data, from the 450 dams (large or small) in the region, 300 of them suffered considerable damages while some caused serious problems downstream due to the incontrollable water flow. In a great number of dams, the crown was destroyed and the connection between the two sides of the dam was not possible, blocking the road network for large areas. It is estimated that 30% of the dams in the mountainous region have been completely destroyed and their repairing is not possible. The estimated intensity for this region is $XI_{EMS\text{-}1998}$ while in some locations approached $XII_{EMS\text{-}1998}$.

Figure 5: View of large-scale landslides that formed natural dams and lakes along the river course (a) and view of a landslide triggered above the exit of the Zipingpu dams' emergency spillway causing considerable damages (b).

3. AN APPROACH TO THE CAUSES, THE NATURE AND THE DAMAGES DISTRIBUTION

According to all the aforementioned available data, it is possible to extract the following conclusions in relation to the nature, the causes and the geographical distribution of the damages (**Figure 6**). More specifically, the following three intensity macro-distribution zones were identified:

Zone A: The mountainous region of western Sichuan, corresponding to the region west of the reverse fault. Extensive damages were recorded throughout the towns of Wenchuan, Beichuan and Maoxian and the settlements of the greater area. Apart from the damages to all types of constructions the infrastructure, road network, bridges, and dams (including the Zipingpu dam) suffered severe damages while a large number of large-scale landslides was recorded. The estimated intensity in the area exceeded $X_{EMS-1998}$ and approached $XI_{EMS-1998}$ while locally it even reached $XII_{EMS-1998}$. This is due to mainly two reasons: (i) the extremely unfavourable morphological, geological and geotechnical frame of the mountainous region, and (ii) to the geotectonic frame and more specifically to the fact that the region as a whole represents the hanging wall of the reverse seismic.

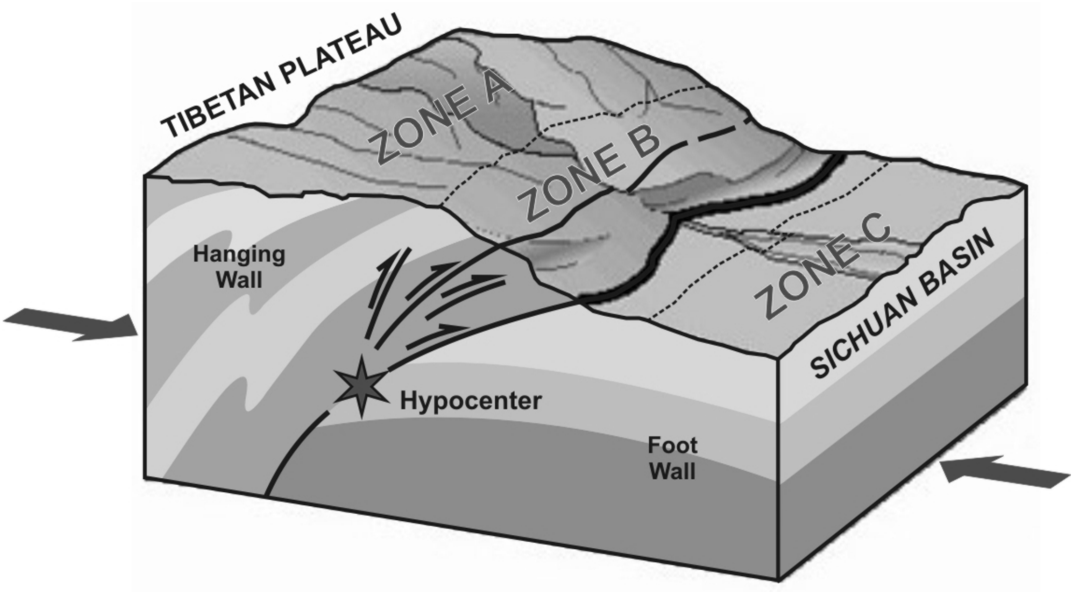

Figure 6: 3-D diagram of the region affected by the Mw 7.9R on the 12th of May 2008 that represents the prevailing geodynamic – morphotectonic regime, the seismic fault and the intensity macro – distribution zones.

ZONE B: The elongated zone between the mountainous region and the lowland region, having a length of the order of 100 km and a width of 10-15 km. This zone represents the surface expression of the seismic fault. This elongated zone includes a variety of geological formations and more specifically formations of the Tibetan Plateau units which are thrusted towards the west on the Sichuan Basin formations. Unconformably on the aforementioned formations, lie alluvial formations, alluvial fans, alluvial terraces and debris.

The two large towns that geographically belong to the elongated zone, that is the Dujiangyan and Mianzu towns but also the surrounding villages and scattered settlements suffered severe damages that vary from site to site relatively to the foundation ground formations and the type of the construction. The damages mainly affected tall buildings with 4-8 floors many of which although they were of modern design, collapsed. Furthermore, older constructions with 2-3 floors also collapsed. In addition, within this zone, serious damages were recorded in schools, hospitals, bridges, small dams, industrial constructions etc.

At this point it should be mentioned that towards the northeastern section of the zone and mainly in Mianzhu town, the intensities were higher than those in Dujiangyan, despite the fact that similar geological – geotechnical conditions prevailed. This can be attributed to the fact that the larger fault displacements were recorded in Mianzhu area and therefore the area underwent larger ground acceleration than in Dujiangyan that was closer to the epicenter. The intensities in this zone are estimated near $VIII_{EMS-1998}$ and locally $IX_{EMS-1998}$ and are attributed to the proximity to the fault zone that triggered the earthquake on the 12th of May and also to the nature of the geological formations that prevail on the surface.

ZONE C: The lowland region of Sichuan, that occupies the eastern section of the earthquake affected region. This area includes the towns of Shifang, Deyang, Mianyang and the Chengdu capital city. The geological formations on which the constructions are founded are cohesive Quaternary formations that lie on the Sichuan Basin formations and represent the rocky basement. The damages that were recorded in the area correspond to tall constructions with 3 – 6 floors. These buildings were mainly of old design or had structural imperfections. Moreover, tall buildings suffered damages on the first floors walls, and limited extent damages were recorded on old constructions up to 2 floors without anti-seismic design.

From this research it was indicated that there was no specific geographical differentiation within the towns and the geographical distribution of the damages was random. The residential units of Zone C located near the Zone B suffered relatively more damages than those located in the eastern section. The estimated intensities of Zone C are ranging from VI to $VII_{EMS-1998}$. The clearly smaller intensities in zone C can be attributed to: (i) mainly the relatively favorable geological – geotechnical conditions and (ii) the fact that the area corresponds to the footwall that suffered less seismic ground accelerations since this tectonic block was not displaced or it was displaced less in relation to the hanging wall.

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