CONSTRUCTION TECHNIQUE EVOLUTION IN MEXICO SINCE 1985 EARTHQUAKE

Ávila Córdoba Liliana I.[1]

[1] *Professor, Dept. of Civil Engineering , Universidad Autónoma del Estado de México, Toluca México*
Email: liac07@gmail.com

ABSTRACT :
In the present paper, the 1985 mexico earthquake and its influence in the research activity in the country are analyzed. The discussion is focused in the masonry and concrete structures, the main research results and its applications in the construction specifications a commented, also it is presented the evolution of construction code in mexico related to the main earthquake events in the country. Finally the application of the actual code recommendations and specifications in the construction practice are presented, remarking the most commons deficiencies and mistakes in the actual practice, in this part the differences between formal and non formal construction are compared

KEYWORDS:
Construction codes, Construction techniques, Mexico earthquake

1. INTRODUCTION

Because of its geographic situation, Mexico is subject to several natural phenomena; between them, earthquakes are considered the most hazardous. Historically earthquakes have been important, because of its frequency, magnitude or by the damage that have caused.

The occurrence of the disasters in Mexico, caused damages that have represented a main proportion that the occurred in the rest of Latin America during the last 20 years. Regarding his economic impact between the most important earthquakes in the recent history, are the Madero 1911 Earthquake (magnitude 7.7), the Jalisco 1932 Earthquake (magnitude 8.2, intensity VIII), the Acapulco 1957 Earthquake (magnitude 7.5, intensity VIII), and the Michoacán 1985 Earthquakes.

The 1985 Mexico Earthquake is the most important event and its effects are changed notably the life of a lot of people.

In the different regions of Mexico, the nature of the country, the type of the subsoil and the demographical density have caused an overhead seismic risk, this situation promote the research projects in this engineering area, creating with this a better understanding of the seismologic characteristics of the territory, in addition to an important collection of instrumental information, better understanding of the different materials and of the structural systems behavior and finally the implementation of the construction codes and building specifications. Based on this a better structural performance is expected.

1.1. The 1985 Mexico Earthquake
The September 19th 1985 was produced an earthquake that caused big destruction in the country and especially in the Mexico City area, the epicentre of the earthquake was located 300 Km of the country's capital and its magnitude was 7.8 (Ms) or 8.1 (Mw). Inside the most important effects of this earthquake in some regions of the country, can mention the following:

1.1.1. Epicenter region
The damages were classified from medium to strong in 80% of the houses and several deaths. Maximum ground acceleration of 0.8g was estimated. Strong damages in hotels, public buildings, hospitals and industrial facilities

were reported. Also partial destruction of rail roads and docks, sand liquefaction as well as soil settlement (in the order of 15 cm) was observed. The presence of a tsunami achieved to flood the low plant of some beach hotels.

1.1.2. Central region

Far from epicentre area, the main damages were recorded only in bad soil conditions zones. Such as the case of Ciudad Guzmán, Jalisco in which the intensity achieved VIII in the Mercalli scale. In this city, the grave destruction in houses and public buildings cause the death of 50 people.

The main damages were registered in the Mexico City downtown. The intensity variation moves from VI in the periphery of the Mexico Valley to VIII or IX in the centre of the city zone. The shake initiated in slight form (intensity II to III) and gradually incremented to harmonic movement, with approximated two seconds period.

The most affected areas were located in the central part of the Mexico valley; there were few damages in the borders of this area. These phenomena were due to the soil interaction. Around six thousand deaths were officially reported, but with the new information the amount is estimated in 35 thousand. The life lines systems were collapsed in the main affected area, the water, electricity, public transportations and main streets were the most affected, and 30 thousand houses were reported with partial or total collapse and 70 thousand with partial damages. Also the total collapse of four hundred buildings occurred.

The 19th September 1985 earthquake corresponded with the characteristics associated with a typical subduction earthquake in the pacific coast of Mexico but their effects 300 km far from epicenter area were unexpected for this magnitude. Specifically any experts imagine this scene in Mexico city caused by subduction earthquake.

Consequences of this earthquake the seismic engineering in Mexico experimented a quick development generating a research program focus on mitigate the country infrastructure. Actually the results of this program guide the construction code. In the next paragraphs the development and evolution of the Mexico city construction code are briefly commented. This document is the model for the construction codes in other parts of the country.

1.2. Mexico City Construction Code

The first seismic design recommendations in Mexico appears in the Construction Code for Mexico City published in 1942. This document was based on allowable stress and classified eight structural types according with their use and important. Seismic forces were determinate by the product of the structural weight by the seismic coefficient of 0.1 and there were no restrictions for the lateral displacement.

After the July 1957 earthquake the emergency norms were published, this is the first time that the structural performance is associated with the soil characteristics. The structural systems were again classified according with the use and important but in this occasion only three groups were considerate. The seismic coefficient was defined between 0 and 0.2 according with the soil characteristics. The lateral story drift were limited to 0.002.

In 1966 the new version of the construction code from Mexico city were implemented. In reference to seismic design a most explicit structural system classifications were adopted, the soil transitions zones is incorporated in the soft soil zones, resulting only two types of soil. For the conventional structures the seismic coefficient was between 0.04 and 0.15. For essential structures amplification factor of 1.2 were used.

The story drift were limited to 0.002. When the non structural elements were separated from the main structure. This limit increased to 0.003 for compressible soils and 0.004 for low compressible soils.

In 1976 a new version of this code were presented. This document was based on LRFD design criteria. Three soil types were considerate again (hard soil, transition soil and soft soil). For common structures the seismic coefficient of 0.16, 0.20 y 0.24 were considerate for each soil type respectably. The 1.3 amplification factor for essential structures was proposed.

This document considerate the ductile structural behavior reduction factor between 1 and 6 depending on the material, structural system and structural detailing. The story drift were limited to 0.008 and it could be increased to 0.016 when the non structural elements are separated from the structure.

After the 1985 Mexico earthquake and emergency norms were edited, the most relevant aspects in this document were the increase in the seismic coefficient for soft soil zone from 0.24 to 0.4 and for the transition zone from 0.2 to 0.27, also the maximum ductility factor changes from 6 to 4.

IN 1987 a new version of the construction code were presented also the technical norms complementary to the code were officially adopted. These documents remain with very few changes until 2004. they change the seismic coefficient for transition soil from 0.27 to 0.32, amplification factor for essential structures were 1.5 and the story drift were reduced to 0.006 in the case of non structural elements attached to the structure and 0.012 in other case.

Finally the present construction code was adopted en 2004, the main design requirements which are included in the document are: a clear and transparent handling of the demands and supplies structural deformation capacity, separation explicit review of each one of the two limit states, the proper microzoning, which consider accurately the design parameters, according to the type of soil.

2. “2004 CONSTRUCTION CODE”

This new regulation incorporates research findings promoted in the wake of the serious events during the earthquakes 1985 and therefore include field studies on the nature and extent of the damage as well as the observed performance of different structural systems, experimental and analytical studies of different elements and structural systems, review of the seismic hazard models; explorations field to better understand the geological conditions of the valley of Mexico. Among the main changes will include the following:

• Structural classification: Although the previous regulation required an amplification factor of 1.3 for essential structures, these were the most affected buildings types, during 1985 event. For this reason, this factor was increased to 1.5.

• Seismic coefficient and design spectra: The increase in seismic coefficients was one of the most important measures of the Emergency Norms. It was increased from 0.24g to 0.40g based mainly on the engineer’s group criterion (Norms Subcommittee).

The intensity studies conducted after of the 1985 earthquake and the seismic risk studies developed after the Emergency Norms, showed that the seismic coefficient values were extremely low, since at least it should have been increased minimum to 0.60g, for reach an adequate safety level, combined with static analysis, or 0.80g for dynamic analysis. Notwithstanding the foregoing, the empirical approach was adopted, because of the political difficulties associated with this change.

In addition to the seismic coefficients increment, the requirements for use high ductility reduction factor were stringent, among other things, very strict and exhaustive specifications for the reinforce detailing were included. The reduction factors for inelastic behavior were limited in the case of irregular structures, and different irregularity levels are considered.

• Seismic Zoning: different studies of the damage distribution during the 1985 earthquake enabled the importance of distinguishing the effects of interaction between geotechnical irregularities along the Mexico valley. As a result, the new seismic zoning of the Federal District were proposed. This zoning identifies two areas of high seismic activity they are located mostly within the area of soft soil. In addition, it is possible develop site spectra, for each point across the valley.

With regard to structural systems, highlights some important changes especially in the masonry and concrete structures. The most significant changes are listed below.

2.1. Masonry structures

In Mexico masonry structural systems can be classified in three types:
• Confined Masonry, with or without horizontal reinforce.
• Internally reinforced masonry.
• Unreinforced masonry.

The last decade an ambitious research program, focused on the very high quality masonry, were conducted in Mexico. With the manufactured masonry, the design specifications resulting from these investigations, and adequate quality construction control, it is possible design and build masonry structures with excellent structural performance, however, many of the homes erected in Mexico are still built without adequate materials and details, even in the high seismic zones. Recent research shows the great advantages in the use of reinforced masonry, emphasizing the virtues of horizontal reinforce, but their use is limited in common construction projects.

As a result of these research projects, some recommendations to select and elaborate a good quality masonry system have been proposed. Following these rules, it is possible get the next characteristics in masonry building.

• Grater resistance, security and capacity strain.
• More uniform cracking Patterns.
• Decrease the crack's size for the same lateral distortion level.
• Ability to affront temperature effects.
• Cracking reduction with service solicitations.
• Better performance in the presence of differential settlements.
• Elimination or reduction of the concrete walls to withstand the design actions.

The largest number of these studies has been focused on confined masonry and / or internally reinforced masonry systems; they have proven to be excellent structural performance technique, without being necessarily more expensive. The advantage of reinforce effects provide the following characteristics in masonry constructions (Alcocer, 1997):

• Castles have an important role in maintaining stability to vertical loads, especially in the presence of diagonal cracking patterns. For high horizontal distortions, where the masonry is extremely damaged, the load capacity is maintained and guaranteed by the castles.

• The contribution of castles to the lateral cracking load is insignificant.
• The confined elements have exhibited more stable behavior even for lateral distortions in the order of 0.5%. Internal reinforce have shown higher levels of damage to similar distortions, as well as the stiffness degradation.
• Castles control diagonal cracking that occurs in the wall.
• The adequate transversal reinforce distribution has shown generate stable hysteretic cycles, greater deformation capacity and energy dissipation.
• The post-cracking behavior of the wall depends on the strength of confining elements.
• Castles increase the deformation capacity, strength and lateral stiffness.

The horizontal reinforcement has shown to have a strong influence on the seismic performance. Among the features that contributes to the system are (Aguilar et al., 1994; Zepeda et al. 1997, and Alvarez et al., 1994):

• Favors a more uniform damage distribution and reduces the width of the cracks.
•The cracking shear and stiffness as well as the lateral distortion are not substantially increased by the horizontal; increments in the order of 20% have been measured.
• The elastic stiffness is not changed by the presence of horizontal reinforcement.
• Generates stable hysteretic cycles, with good energy dissipation.
• Increase significantly the maximum shear resistance.
• Increase the energy dissipation capacity.
• Increase the deformation capacity.
• Facilitate a lateral resistance degradation less pronounced, but not avoided it.

Additional to the above, have been established recommendations arising from those investigations to ensure good construction practice, among which include:

• Do not overlap horizontal reinforce and anchor it properly in castles.
• Ensure adequate penetration of the mortar in the masonry alveoli.
• Verify that the mortar covering completely vertical and horizontal pieces faces.
• Providing quality specified mortar.
• Verify the quality of the pieces.
• Building castles properly, whether internal or external, with anchors.
• Ensuring filled with concrete or mortar castles indoors.
• Arrange the stirrups of castles listed in planes with the appropriate hook.
• The running close to the base and roof are particularly important.
• detail adequately union between perpendicular walls,

It has been observed the omission of this aspects affected considerably the seismic capacity of the structure for example, superpose the horizontal reinforce or inadequate attachment to the confinement eliminate their effect. The inadequate mortar penetration in the pieces alveoli reduces significantly the masonry resistance. From the construction point of view there is small difference between an adequate system and not suitable system.

It could be said at the present we have the knowledge and basis design for construct safety masonry buildings with good quality and excellent seismic performance. That is possible with adequate reinforce and proper detailing because it determinate the lateral capacity and deformations, cracking patterns, ductility and energy dissipation capacity. At the same time the influence final reinforce cost is marginal, its influence is around 2 at 5% with a big difference structural performance.

2.2. Reinforced Concrete Structures

In the case of reinforced concrete structures great emphasis was focused in detailing reinforcement mainly in the beams-columns connections and transversal reinforcement amount for confinement of the plastic yielding zones.
Also the construction supervision is more detailed and rigorous. The main changes in this type of structures were being observed in the flat slab system principally in the slab column connection.

3. ACTUAL CONSTRUCTIVE PRACTICE

In Mexico as the same the other developing counties, is observed the deterioration of the infrastructure construction scenario due o different factors as the administrative rules, deficient technological process, financial problems, inadequate norms and inconsistent legal regulations as well as natural hazards.

The construction in Mexico is developed in two different and opposite scenarios: the formal industry and the auto construction sector, the first of them follows the construction codes and legal regulations, also the construction quality controls are applied.

In this sector the experience getting from different disasters and research projects is accumulated and used for reviews the structural vulnerability. In this way there is learning over structural defects and structural damages reflected in construction regulations.

All of these experiences have been the guide for the new regulations in aspects as: straight and stiffness distribution, ductility demands and its distribution, soil parameters designs, etc.

The lessons from different earthquakes has obligated to ensure better structural elements detailing, increase the quality control, pay more attention to tolerance and construction practice, looking for a total quality process.

The 1985 earthquake evidenced different deficiencies to be separated, for example, the imperfect knowledge of the hysteretic behavior of different structural materials and elements, mainly in the large deformation range, or the ability to predict the actual structural behavior near the collapse, with the available analysis and design tools,

As it has been mentioned the present construction code tries to reflect the cumulated experience and research results balancing the safety with design difficulty and construction costs.

In the other hand the non formal sector could not be obligated to follow the legal regulations, it grown by own way whit out technical instruction and any disposition for guaranteed adequate structural performance. A lot of low income persons construct their houses in this schema, into a hazardous zones and without any technical assistance, for that they are the most affected during a natural event.

It is estimated that only 30% of the construction projects in Mexico are erected with a formal design and technical conduction, this situation is worst in the case of housing construction, In this case the auto construction arise at 90 %.

In the actual construction practice it is observed different deficiencies and mystiques during different stage of the project, they come from design until operation stages, even for the formal sector. Among this deficiencies, it could be listed the followings:

- Poor position of steel reinforcement
- Traslape steel castles in more than 50% in one section.
- Manufacture of mortar unchecked.
- Poor implementation of the mortar.
- Lack of foresight in facilities that require walls to break.
- Lack of saturation in the pieces of clay.
- Saturation of the pieces of concrete blocks.
- Incorrect position of steel reinforcement.
- Error in the position of the poles of the upper bed massive slabs of mezzanine.
- Inappropriate proportions and re-mixed mortar.
- Thickness mortar boards less than 1 cm, Or more than 1.5cm.
- Separation excessive castles.
- Lack of Dale, in some cases it is thought that a massive slab can have this feature.
- Lack of reinforcement anchor longitudinal castles.
- Excess in the separation of the stirrups of the castle.
- Anchoring insufficient longitudinal steel.
- Steel longitudinal overlap in areas not recommended.
- Lack of resistance of the pieces.
- Error in the cast of castles when they are indoors.
- Charges steel Dale and castles in less than those specified.
- Lack of fences and Dale in vain and windows.
- Placement of facilities within the wall without taking into account the structural affectation.
- Lack of mortar joints in vertical and horizontal.
- Lack of penetration in the alveoli mortar pieces multyholes.
- When the castle interiors are often not placed their temper.
- When castles there are internal error in the positioning of vertical reinforcement.
- Failed coatings Dale and castles.
- Inadequate geometry of the stirrups of the castles indoors.
- Etc..

There are slight differences between good practice and deficient one, it is required to orientate the edification practice with proper design, specifications, quality materials and supervision controls. Unfortunately in the non formal sector, there are few options for improve the quality.

4. CONCLUSIONS

One of the elements for reduce the seismic vulnerability in developing countries is the technology transference, in which the innovation find a diffusion channel to allow it successful use by the society. In this way, there are a formal compromise between the different government actor and technical societies to include in the construction specifications and codes, the recommendation gotten from the experience and research work. These activities include technical publications, courses, conferences and capacitating programs and a great effort for include earthquake design courses in all the civil engineering carriers.

Even the great success in this field it should be recognized the tremendous outdistance, even a big number of construction professionals have a solid knowledge of the different materials and structural systems, it should be enforced the control instruments for granted a correct construction practice. It is well known That the contracts at lowest price with deficient supervision increase substantially the construction vulnerability.

The other part of the problem is the non formal sector, it remains absent from the technical development and it is lees susceptible to technological changes. But it represents the biggest part of the sector.

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