COMPARISON OF SIESMIC RETROFITTING GUIDELINES FOR REINFORCE CONCRETE STRUCTURES IN VENEZUELA AND INDIA

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ABSTRACT. The paper focuses on the similarities and special cases among the techniques for retrofitting reinforce concrete structures using the experiences of Venezuela and India, based on standards, guidelines, manuals or any known source of technical information regarding this topic. The paper starts by reviewing the current situation in standards for both cases and then progresses to several research studies that explored the necessities and urgencies found. It is highlighted how other factors have a level of influence in the application of the different retrofitting methods and how these affect the final outcome. The comparison is based on parameters like earthquake category, structural configuration, site subsoil category, deformation criteria and non-structural element design. Thus, factors relating to construction may also need to be included when considering solutions of the presented issues. The paper then explores the relationship between both cases and compares the vulnerabilities found with actions taken by other standards such as American and European codes. The lack of an official Venezuelan standard for retrofitting RC structures hinders the possibility of structural modelling, thereby is not presented. The corrective steps to ensure that the built environment is capable of resisting the expected earthquakes in both regions are also noted. A general criterion is proposed, taking into account the majority of similarities in both countries but applicable in the Venezuelan case.

Keywords: Seismic Performance, Retrofitting, RC Structures, Guidelines, Venezuela, India

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INTRODUCTION

Venezuela is a country located at the border of the northern part of the South American (SA) plate which is subducted under the Caribbean (CAR) plate. Historically, this has represented a continuous yet relatively mild seismic activity. As a reference of activity, the motion data registered of the CAR plate relative to the SA is about 20 mm/year eastward [1], being comparatively low in comparison with the northern border of the Indian plate, having motions of approximately 50mm/year [2] while colliding with the Eurasian plate. The most destructive earthquake registered in Venezuela occurred in Caracas, during the night of July 29th in 1967, resulting in collapses, severe structural damages all around the city and over 250 casualties. Meanwhile, four earthquakes of magnitude around 8 have struck India in span of 53 years [3] with thousands of victims. The amount of fatalities registered in India may lead to think that the locations affected were highly populated, but Bhuj and Sumatra-Andaman are places with relatively small population in comparison with bigger cities around the country, though they are in the top ten list of most destructive earthquakes in India. This highlights the necessity to categorize a country's territory into zones that considers its vulnerability, based on the quality of the infrastructure developed in the region.

Human history shows a tendency of learning from mistakes, and seismic engineering is no exception. Materials, devices, approaches and studies have evolved after major events occurred. The predictability on the behaviour of our structures under specific excitations has always been under continuous scrutiny and research. National standards represent a conglomerate of the latest advances on the fields related to the design process for the structures. These updates affect directly the design of new structures, leaving aside the fact that existing buildings might not meet these requirements. Acknowledging this, the corresponding entities have started to evaluate reasonable ways to improve the conditions of aging buildings. As a reference, the American Society of Civil Engineers (ASCE) came up with the Seismic Evaluation and Retrofit of Existing Buildings Standard (ASCE/SEI 41-13, the European Commission stablished a Part 3 for the Design of Structures or Earthquake Resistance, adding the Assessment and Retrofitting of Buildings. These codes target the different approaches that are widely applied and accepted and brings them together into refined methods that are beyond the scope of design codes for new structures [4].

Research has always brought to light advances taken by the mentioned codes to make structures safe. Among the factors that affect the research pace, founding is one that plays an important role. Economic stability is every country's goal, facing various adversities they try to fulfil the needs of their people: food, services, entertainment, etc. The infrastructure related to every level of need is a good indicator of how well the economy of a country is. In the particular cases of Venezuela and India, economy has had ups-and-downs, revealing patterns of infrastructure development in different periods with similar features before and after their highest levels, which will be further analyzed. This has conditioned the solutions that every country applied concerning the rehabilitation and maximization of a building serviceability.

SEISMIC ACTIVITY AND CURRENT RISK

Zoning is an important tool for seismic resistant design. Records of previous earthquakes or geological research on site are the most commonly used approaches to define seismic regions. In the Venezuelan case, geological research was taken to identify 7 regions with low-to-high seismic risk, being the northern part of the country the one having 3 of the high-risk categories. In India, there are 4 zones describing the seismic risk with the peninsular areas representing the ones with the highest seismic risk along with the northern borders. Similarly, the areas exposed to the highest seismic risk seem to have a similar type of subsoil, excepting the peninsular zone. However, the seismic activity on these regions comes from interactions with different features between the plates involved. India has a complex condition due to the activity of the Indian plate with its surroundings, currently penetrating into Asia and rotating slowly anticlockwise [5] resulting into plate boundaries with motions partitioned between thrust and strike-slip components [6], bringing high seismic activity. Meanwhile, the northern side of the South American plate is being subducted under the Caribbean plate, originating high seismic activity due to the geometry of the crustal structures in the subducting area, which changes along the boundary zone [1].

The level of risk is divided into the areas where the infrastructure was built under skill supervision and according to the technical codes with the latest updates, and those built under inadequate or non-existent supervision without knowledge or understanding of the established standard, mainly due to economic restrains. Both countries share a common situation, self-constructed structures using traditional or modern building materials that do not meet safety standards. In a research published in 2014, experts from the Engineering School of the Central University of Venezuela (UCV by its Spanish acronym) and the Venezuelan Foundation for Seismological Research (FUNVISIS) classified existing buildings in a small sample area by priority indexes for seismic risk, finding that 31% of the buildings analyzed have a very high vulnerability index and 23% are in high seismic risk [7]. On the other side of the globe, India faces a similar situation having about 11 million housing units in the very severe seismic zone and 50 million under the severe zone [8]. These vulnerable areas are usually highly populated, both increasing the consequences of a major event if happened and complicating the application of solutions accordingly.

STANDARD IMPLICATIONS

In exploring suitable retrofit strategies for the vulnerable structures is crucial to classify them according to the most characteristic feature. Both countries have similar vulnerable building typologies, mainly focusing in the materials used (which can vary from stones with mud mortar to steel mixed structures with reinforced concrete) but also considering the structural design, only if relevant since the most commonly used in both countries are RC rigid frames, RC shear walls and a dual system that includes both [9], knowing their main disadvantages.

The guidelines given by the National Disaster Management Authority in India suggest categories where the usage, location and other non-structural features are considered. The exercise of risk assessment most be from qualified technical professionals, architects and engineers and most be based on (a) qualitative performance for non-engineered constructions, and (b) both qualitative and quantitative performance for engineered constructions [10]. Regarding standards and legal documentation, many Indian agencies and academic centers address seismic retrofitting guidelines, offering recent knowledge towards improving structural performance for pre or post-seismic events. Indian Standard IS-15988:2013 and IS-13935 are focused on seismic evaluation, repair and strengthening of concrete and masonry buildings respectively, representing the main source of legal obligations addressing retrofit strategies. Unfortunately, in Venezuela there’s no official standard for such cases, implicating a serious legal gap that is only faced in academic research. Experts of the Central University of Venezuela and the Venezuelan Foundation for Seismological Research have worked together and published recent findings related to seismic assessment but the corresponding agencies have failed to agree upon the development of a national standard.

According to most codes, the vulnerabilities evaluated for retrofit assessment are focused on design-related checks, building priority and performance objectives. The main verification lies on known structural weaknesses such as short columns, weak/soft storey, mass irregularity, geometry, torsion and vertical discontinuities.

SUITABLE RETROFIT STRATEGIES

As mentioned before, official codes gather the most widely accepted knowledge and, for retrofitting strategies to be used, the available options focus on local modification of structural elements, removal or reduction of existing irregularities, global structural stiffening, global structural strengthening, mass reduction and seismic isolation [11]. After collecting documentation and data about the as-built information and agreeing on the performance objectives, a number of retrofit techniques should be evaluated.

Concrete Jacketing is one of the most commonly used procedures, aiming to strengthen columns, beams and walls and increase bearing capacity, flexural and/or shear strength, deformation capacity or to improve the strength of deficient lap-splices [12]. The Indian Standard 15988 [13] first mentions reinforced concrete (RC) jacketing, defining indexes of the existing area of both concrete and steel member's cross section over the one designed to be added. Research has shown that RC jacketing exhibits higher percentage of increase of strength than Fibre Reinforced Polymers wrapping [14]. Furthermore, even when experimental results demonstrated that RC jacketing can enhance the structural properties for RC members, studies addressing issues related to the behaviour of old and new concrete in the bonding area are being held along with other interface-related problems. Numerous projects around India have use RC jacketing as its main retrofit procedure: hospitals, office buildings, schools and others, reported its use. On the contrary, Venezuela lacks of official data of the usage of RC jacketing, but considering it is widely known as a strengthening technique and the costs of other methods, there's a possibility it's frequently used in various sectors.

Fibre Reinforced Polymers (FRP) composites were used in the construction sector during the late 60's. By the time, costs were high enough to easily discard wide usage; it wasn't until mid-80's that researchers throughout the world started to seriously study its benefits. Reduce on the manufacturing costs and a wide range of applications have brought FRP wrapping as a broadly accepted retrofitting method, having its place in standards around the world. Used to enhance shear capacity of structural members, ductility at members end (through different forms of confinements) and to prevent lap slice failure, FRP applications are tied to the effectiveness of its bond with the member. The transportation and handling of the FRP sheets are easy and it doesn't require highly skilled application, although it needs proper surface preparation to avoid uneven bonding surfaces, which may cause peeling of the plate away from the concrete surface [15]. Its versatility makes it a feasible option in Venezuela, since economic factors diminishes the amount of possible solutions for deteriorated structures. On the other hand, its Asian counterpart has a vibrant economy, with manufacturers offering plenty of options for most cases, nourishing solutions rather than drawbacks.

INFLUENCING NON-TECHNICAL FACTORS

Over the past few years, Venezuela faced strong changes, including protective legislations for the workforce. As a consequence, syndicates around the country started to grow influence, being able to stop all activities several times before the project close. This rapidly became in a major challenge for small and large-scale projects [16]. Together with economic aspects, the impact of the situation affected many areas, including manufacturers that reduced their capability to cover the demands of the construction sector for specific components, e.g. dampers, fibre reinforced polymers composites, etc; finding themselves forced to offer a minimum stock on the market and importing specific products only when are specially requested. Economy affected many institutions [17], among them, those which train personnel to specific procedures, decreasing availability of skilled labour, influencing the decision-making process.

An underestimated factor in Venezuela, turns out being a major concern in India. Environment degradation is one of the primary causes of diseases, health issues and long-term livelihood impact for India [18]. The rapid growth of population in combination with economic development and overuse o natural resources are the primary causes of environmental issues. The importance of ecology protection and development of sustainable working sites have scaled in recent years. This has modified the common approach for project development, increasing requirements and specifications for environment protection that might affect the decision-making process for determined issues, changing logistics and modifying costs.

CONCLUDING REMARKS

The paper points out the main resemblances between both countries, highlighting their strengths and drawbacks, and how each country has deal with them so far. Seismic risk is evidently higher in India but it shares an important similarity with Venezuela, the vulnerability of self-constructed structures under little or non-existence skilled supervision, caused by economic limitations of certain areas. Then, the role played by national standards is introduced. A comparison with other codes of reference have been made, commenting on the context and the main strong points that are being or could be applied on both countries. Furthermore, other factors are included to emphasize the importance of the background surrounding each country's current situation.

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