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MAIN CHANGES IN THE 2014 DRAFT PERUVIAN SEISMIC CODE

Daniel Quiun
Professor, Pontificia Universidad Catolica del Peru, Peru
dquiun@pucp.edu.pe

Patricia Santillan
M. Eng., COSAPI, Peru
psantillan@cosapi.com.pe

ABSTRACT: Several changes in the Peruvian Seismic Code were required, and the upgrade of the new Code document was ready for the official approval at the end of 2014. This paper discusses the main changes in the Peruvian Seismic Code draft compared to the previous 2003 Code, with special focus in reinforced concrete buildings. The country of Peru has several years of economic growth, in which the urban development and building constructions are one the main economic activities in the cities. Lima, Peru capital city (about 9 million of people) is located in the Coast which has the largest seismic hazard, and will host the XVIII Pan American Games in 2019. Recent building constructions include base isolation and energy dissipation devices. In this context, the Seismic Code upgrades include changes in the seismic zones, the response spectra, the importance of the buildings, the inclusion of a set of different factors to consider irregularities in plan and elevation. The chapters referred to the non-structural elements, to the structural repair and strengthening, and to the seismic instrumentation required in buildings have been totally rewritten.

1. Introduction

Peru is located in the subduction zone between the Nazca Plate and the South American plate. The interaction between these two tectonic plates is the main source of strong earthquakes in Peru. Historic earthquakes of 1746 near Lima (Peru capital city) and 1868 in south Peru, had intensities larger then X in the Mercalli scale (Silgado 1978). More recent earthquakes of 1996 (M7.7), 2001 (M8.4) and 2007 (M8.0) affected several types of buildings while others had a good behavior (Muñoz, Quiun and Tinman, 2004) and (San Bartolome and Quiun, 2008).

The first Peruvian Code for seismic design of buildings was released in 1970, as part of the general construction code. In 1977, the Seismic Code was fully updated and printed as a single document. Since then, the Seismic Code has had two major revisions completed (SENCICO, 1997 and 2003). The first author is member of the Committee that prepared the draft version of a new version of the Peruvian Seismic Code. This technical committee included members of the Peruvian Geophysics Institute, university professors of structures and seismic engineering, and the Peruvian board of civil engineers.

This paper discusses the version from August 2014, which is at the final process of official approval at the Ministry of Housing, Construction and Sanitation. The Committee sessions were inspired by the 2010 ASCE/SEI-7 standard, the Chilean Code (Ministerio de Vivienda y Urbanismo 2010), and the Colombian code (AIS 2010), and the effects and lessons from the 2010 Chile earthquake (M8.8).

The 2014 draft version introduces several updates: a new seismic map, a new classification of soils and a new seismic coefficient are proposed. The structural classification of buildings has been improved. A new classification for building irregularities with different reduction factors is presented. The chapters on Non-structural elements and the instrumentation required in buildings were completely rewritten.

2. Seismic Map and Zone Factors

The previous Peruvian Codes (1977, 1997, and 2003) established three seismic zones, with the highest hazard near the Coast, mid hazard in the Andes mountainous regions, and a lowest hazard in the Amazon region. Since the 1997 Code, the seismic zone factor Z, is taken as the peak ground acceleration, with values of Z equal to 0.4g, 0.3g, and 0.15g as the highest acceleration for these 3 zones (Fig. 1 left). Table 1 shows a comparison between the seismic zone factors of the 2003 Code and the 2014 Code. The latest studies performed by the specialists of the Peruvian Geophysical Institute, have calculated a higher probable peak acceleration, and the Committee decided to divide the territory into four seismic zones, with values of Z equal to 0.45g, 0.35g, 0.25g, and 0.15g as the highest acceleration for these new 4 zones. Some historic strong earthquakes in the boundary of the Andes and the Amazon regions in Northern Peru produced an oval seismic zone 3, surrounded by seismic zone 2 (Fig. 1 right).

Table 1 – Seismic Zone Factor Z for the 2003 and 2014 Codes

Zone of 2014 Code	2003 Code	2014 Code
Z_4	Not defined, but geographically would be 0.40	0.45
Z_3	0.40	0.35
Z_2	0.30	0.25
Z_1	0.15	0.15

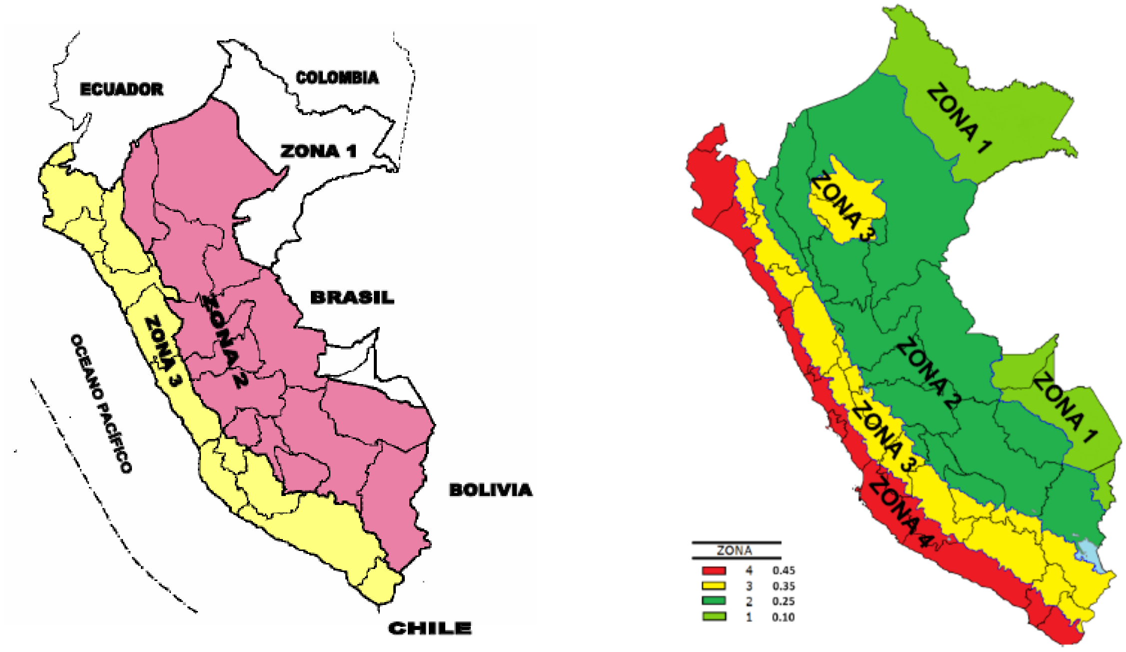

Fig. 1 – Change in Peruvian Seismic Maps, 2003 (left) and 2014 (right)

3. Geotechnical Conditions and Soil Factors

The 2003 Seismic Code established four types of soils: S1 rock or rigid, S2 intermediate, S3 flexible, and S4 exceptional. The soil factor S and predominant period Tp, were only given for soils S1, S2 and S3, as 1.0, 1.2, and 1.4, fixed regardless the seismic zone (Table 2); for S4 soil a special analysis should be conducted. The 2014 draft Seismic Code presents new soil factors S including soil S_0 as the bed rock (Table 3), and defines two distinct periods called T_p and T_L, which approximately define the spectral pseudo velocity zone range of periods in the Peruvian seismic records. These periods are different for each soil type (Table 4). The purpose of these new parameters is to adjust the expressions for seismic amplification factor C, which depends on the structure period T, as well as on T_p and T_L.

Table 2 – Periods T_P and soil factor S for the 2003 Code

Soil Type	Description	T_p	S
S_1	Rock or very rigid soils	0.4	1.0
S_2	Intermediate soils	0.6	1.2
S_3	Flexible soils	0.9	1.4
S_4	Exceptional conditions	*	*

(*) These values should be established by the specialist but in any case they cannot be less than those specified for soil type S_3.

Table 3 – Soil Factor S for the 2014 Code

Zone	S_0	S_1	S_2	S_3
Z_4	0.80	1.00	1.05	1.10
Z_3	0.80	1.00	1.15	1.20
Z_2	0.80	1.00	1.20	1.40
Z_1	0.80	1.00	1.60	2.00

Table 4 – Periods T_P and T_L for the 2014 Code

Period	S_0	S_1	S_2	S_3
T_P	0.3	0.4	0.6	1.0
T_L	3.0	2.5	2.0	1.6

The new soil classification and parameters indicate that for seismic zones with high hazard, the soil amplification factors are reduced respect of the previous values. This issue is going to require technical explanations to the community to be properly understand. For the proper use of Tables 3 and 4, the idea is that for the higher seismic hazard (seismic zone 4 and 3), the soil effects increase slightly and almost linearly, with soft soils showing low amplification. For seismic zone 2, the S values remain as the 2003 code, and for the lowest seismic hazard zone 1, the amplification in a soft soil is larger than the other seismic zones.

4. Seismic Amplification Factor

The 2003 Code uses only one equation to define the seismic amplification factor C, with a maximum value of 2.5 (Equation 1). For the 2014 Code, according to the site characteristics, the seismic amplification factor, C, is defined as Equations 2, 3 and 4. As the soil parameters vary with the seismic zone, different curves of C vs T can be prepared.

$$C = 2{,}5\ (\tfrac{T_p}{T}) \qquad (1)$$

$$T < T_P \qquad C = 2{,}5 \qquad (2)$$

$$T_P < T < T_L \qquad C = 2{,}5 \cdot \left(\frac{T_P}{T}\right) \qquad (3)$$

$$T > T_L \qquad C = 2{,}5 \cdot \left(\frac{T_P \cdot T_L}{T^{\,2}}\right) \qquad (4)$$

For example, the city of Lima, Peru capital city with a population of 8,5 million, is located in the coastal area, which corresponds to the highest seismic risk. In Fig. 2 the plot shows a comparison of the spectral acceleration Sa = Z S C, for the 2014 three soil types. For soil type S_1, the initial value has raised from 0.4x1x2.5=1.0 (2003), to 0.45x1x2.5=1.125 (2014). Most of the city of Lima is located in soil S_1, in Figure 2 the main change can be seen for a very narrow range of the smaller periods, for very rigid structures which correspond basically to low rise buildings. The taller buildings that have longer vibration periods are almost not affected, as both curves are almost coincident. Other Peruvian coastal cities have more soils type S_3, so the seismic forces will be lower respect to the actual, for all the range of periods.

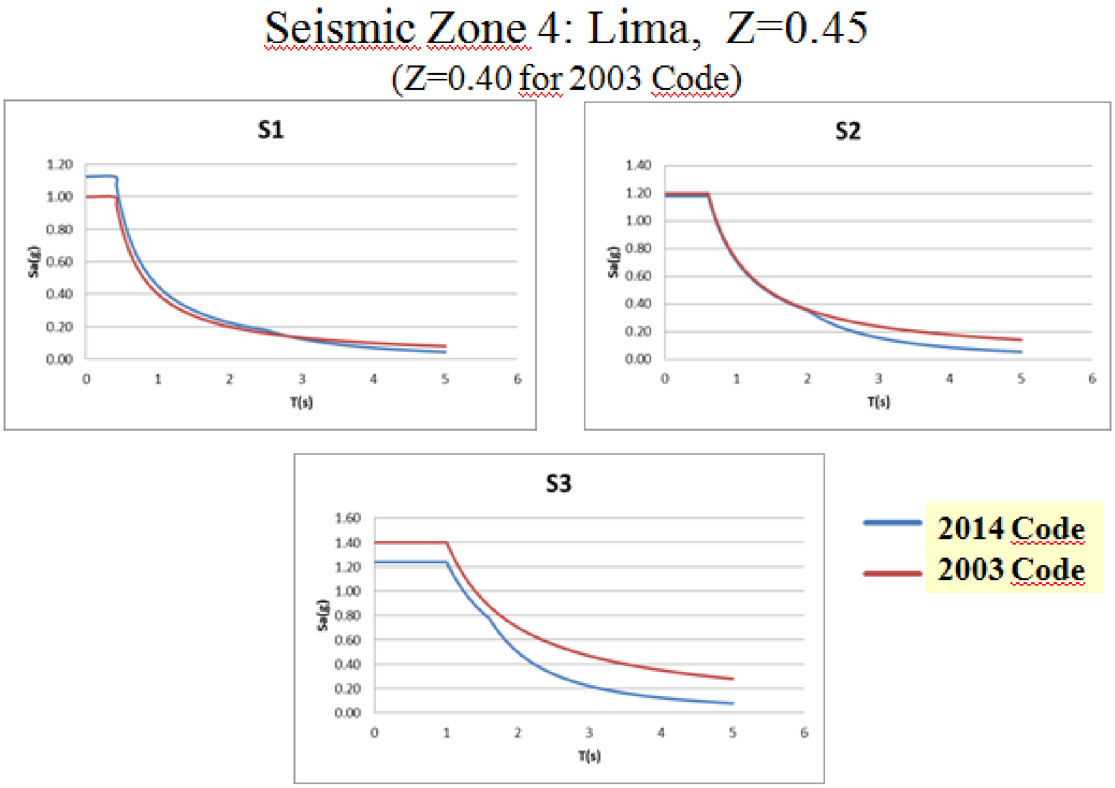

Fig. 2 – Comparison between spectral acceleration Sa, of the 2003 and 2014 Codes, coastal zone

Based on the values explained previously, Fig. 3 shows the spectral displacement $Sd=Sa/w^2$, for the same conditions of Fig.2, that is, for seismic zone 4, and the new three soil types of the 2014 Code. In the 2003 Code, the long period structures, typical of tall buildings, have increasing displacements for periods larger than two or three seconds. This shape has been modified in the 2014 Code version using period parameter T_L, and equation 4. The intention is that for periods larger than T_L, the spectral displacement has a limit in the soil displacement, and provides a viability for base isolated buildings in which lateral displacements must be strictly controlled. Similar Sd curves may be easily prepared for the other seismic zones.

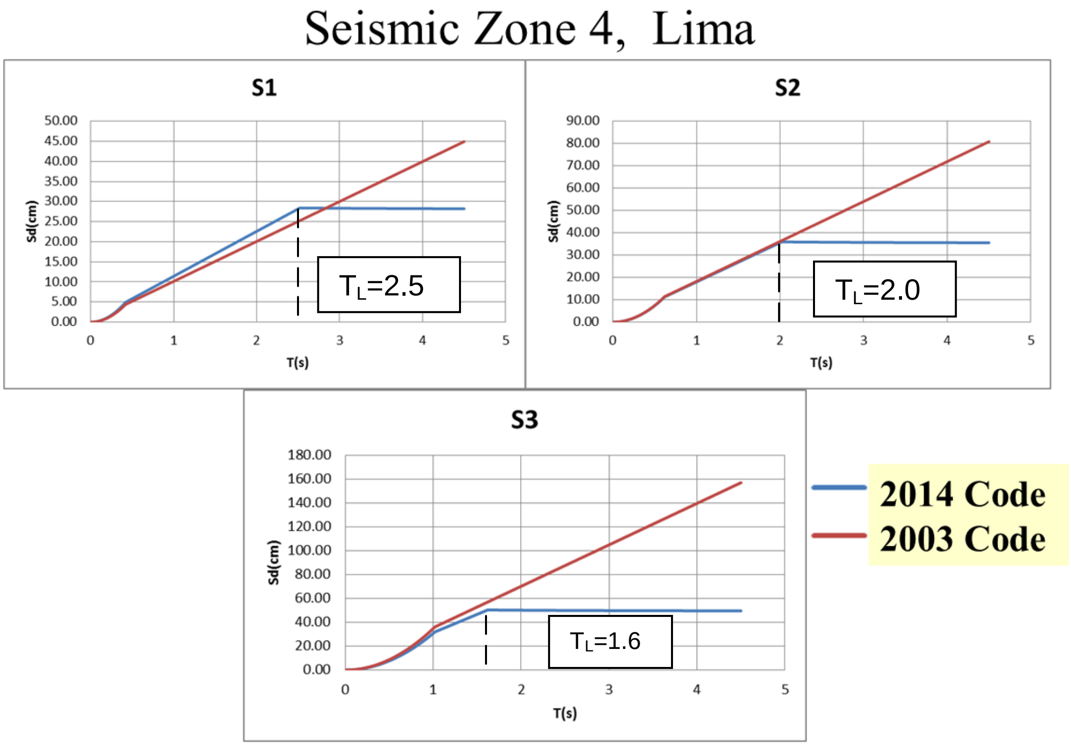

Fig. 3 – Comparison between spectral displacement Sd of the 2003 and 2014 Codes, coastal zone

5. Importance of Buildings, and structural systems

All the Peruvian Seismic Codes since 1977 have considered the importance of a building by using a factor U in the calculation of the base seismic force ***V***.

For the 2014 Code version, the Committee has revised all the building classification. The highest building category is called A, it has been divided into two types: A1 and A2. Subcategory A1 includes the hospitals and important health installations in which base isolation is required for seismic zones 4 and 3, and optional for seismic zones 2 and 1. Subcategory A2 has a factor U=1.5, and it includes all essential buildings whose operation must not stop due to a severe earthquake, such as other hospital buildings, private clinics, ports, airports, mass communication buildings, firehouses, police and army installations, electricity installations, water tanks and water treatment plants. Category A2 also includes school and university buildings that may serve as shelters after a disastrous earthquake (Fig. 4); finally, it also includes buildings that keep files and essential information of the nation.

The second category B, are important buildings with a factor U=1.3, in which a large number of persons can gather, such as theaters, cinemas, stadiums, commercial malls, jails, passenger terminals, buildings that held valuable objects as museums and libraries. It also includes grain deposits, and warehouses that are important for provision of the population.

The third category C, are common buildings with a factor U=1.0, used as housing, offices, hotels, restaurants, and alike. Provisional small buildings are at category D, in which the stiffness and resistance should be adequate according to the structural engineer criteria.

The allowable structural systems are divided according to the main building material of the seismic resistant elements. The reinforced concrete systems include frames, structural walls, dual, and thin walls (called in Peru buildings of walls of limited ductility). The steel systems are six, similar to the latest AISC code, which are known as SMF, IMF, OMF, SCBF, OCBF and EBF. Finally, other structural systems are masonry, wood, and earthen constructions.

Fig. 4 – Buildings of category A2 (university building with base isolators) and B (offices of government), located in Lima.

Both, the building category and the seismic zone, are needed to determine which structural system is adequate, as indicated in Table 5. In this way, the architect and structural engineer can work together to establish the seismic resistant system and the corresponding structural elements.

Table 5 – Category and structural systems for the 2014 Code

Building Category	Seismic Zone	Structural system
A1	4, 3	Base isolation in any system
	2, 1	Steel systems: SCBF, OCBF and EBF; Concrete systems: dual and walls; Masonry: confined and reinforced
A2	4, 3, and 2	Steel systems: SCBF, OCBF and EBF; Concrete systems: dual and walls; Masonry: confined and reinforced
	1	Any system
B	4, 3, and 2	Steel systems: SMF, IMF, SCBF, OCBF and EBF; Concrete systems: frames, dual and walls; Masonry: confined and reinforced; Wood constructions
	1	Any system
C	4, 3, 2, and 1	Any system

6. Irregularities in Buildings

One item that has been modified significantly is the set of factors to consider the building irregularities in plan and in elevation. In the previous Codes, any building irregularity was punished by decreasing the reduction coefficient R by 0.75, that is, the seismic force was increased by 4/3.

The updated Code version of 2014 has classified several building irregularities, divided into plan irregularities and elevation irregularities, and each one has now a reduction factor according to their structural effect and importance. Some irregularities are permitted or not, according to the building type and the seismic zones. The new Code introduces the term "extreme irregularities", in four aspects, which are classified and quantified, 1) stiffness; 2) resistance; 3) discontinuity; and 4) torsion.

The elevation irregularity factor I_a, is defined as the lowest of the values (in parenthesis) in two main directions, considering flexible floors or weak floors (0.75), extreme irregularity in stiffness and resistance (0.5), mass irregularity (0.9), and geometric plan dimension (0.9), discontinuity in the vertical resistant system (0.8) and extreme discontinuity (0.6). The plan irregularity factor I_p, is defined as the lowest of the values (in parenthesis) in the two main directions, considering torsion (0.75), extreme torsion (0.60), inner corners (0.9), diaphragm discontinuity (0.85), and non-parallel systems (0.9).

For example, a weak floor irregularity is defined as the case in which the shear resistance of any floor is less than 80% of the resistance of the floor above it, in any of the directions of analysis. The corresponding extreme irregularity in resistance is the case in which the above percentage is less than 65%. Also, the irregularity in torsion is defined as the case in which the maximum drift of one building border is larger than 1.2 times the drift of the mass center. The corresponding extreme irregularity in torsion happens when the above relation exceeds 1.5.

In the case the building does not present any irregularity, the factors I_a and I_p are equal to unity. Therefore, the new reduction coefficient R is now the product of the basic reduction coefficient R_0 (similar to the old values of R in the previous Codes), times the factor I_a and factor I_p ($R = R_0 \times I_a \times I_p$).

For example, Fig. 5 shows a RC dual building, it has a basic reduction coefficient $R_0=7$. The building has a discontinuity in the vertical resistant system, then $I_a=0.8$; and also it has torsion, then $I_p=0.75$. Therefore, the reduction coefficient in the main directions x, y, is $Rx=Ry=R_o x I_a x I_p=7x0.8x0.75 = 4.2$.

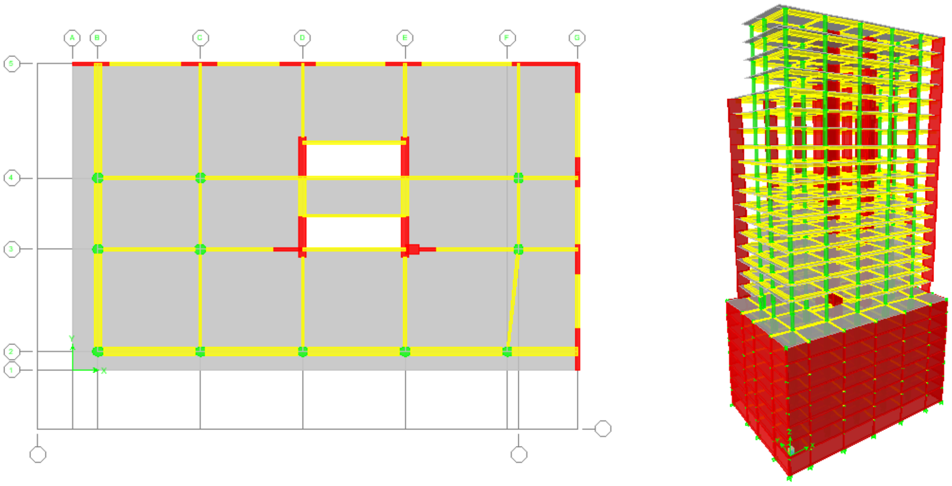

Fig. 5 – Building of category C, RC dual system with irregularities

The 2014 draft code introduces restrictions to the irregularities in the buildings, according to their category and the seismic zone, so that if a particular building has them, it may not be acceptable (see Table 6). The intention is to guide the options that the architects and structural engineers have in the definition of the structural system of the buildings.

Table 6 – Category and regularity of buildings

Category of Building	Seismic Zone	Restrictions
A1 , A2	4, 3, 2	Irregularities are not allowed
	1	Extreme irregularities are not allowed
B	4, 3, 2	Extreme irregularities are not allowed
	1	No restrictions
C	4, 3	Extreme irregularities are not allowed
	2	Extreme irregularities are not allowed except in buildings of two stories or 8 m of total height
	1	No restrictions

7. Base Shear Force and Allowable drifts

The base force for a building ***V*** in the 2003 and 2014 Codes, is given by V=ZUSC/R, in any of the main directions of the structure, in which the factors have been updated. The factors are as follow: Z is the seismic zone factor (see item 2), U is the importance factor of the building, S is the soil factor (see item 3), C is the seismic amplification factor (see item 4), and R is the reduction coefficient. In a structure with a long period of vibration (such as a tall slender building), the minimum base force is obtained using the Code specification of $C/R \geq 0.125$.

The maximum allowable drift for the 2014 Code is the same as the previous 2003 Code, according to the predominant material, being 0.007 for reinforced concrete, 0.01 for steel, 0.005 for masonry and RC wall buildings of limited ductility, and 0.01 for timber.

8. Seismic Base Isolation and Energy dissipation devices

The 2014 Peruvian Seismic Code version introduces the possibility of using seismic protection devices, as long that the requirements of minimum base force and maximum allowable drift are accomplished. A new technical committee is working in Peru in a base isolation Code for buildings, in which the preliminary agreements are to obtain the minimum base force using $C/R \geq 0.06$, and that the allowable drift for RC buildings is 0.003.

The absence of research and experience in Peru, has been filled in the 2014 Code by using the ASCE/SEI 7-10 standard for the analysis and design of such devices. The installation of the devices (base isolators or energy dissipation devices), must be supervised by a civil engineer, and required to get the construction permits for the building.

Figure 6 shows the installation of base isolators in the first basement of the 8-story university building of Fig. 4 (left), and the already finished building. Other office and housing buildings have been designed and are recently finished or under construction.

The first energy dissipation devices (viscous fluid) were installed at the Lima airport tower in 2008 (Fig. 7 left). Since 2012, more office buildings in Lima, have included different energy dissipation devices in their design, as viscous fluid devices every two stories (see Fig. 7 center, a 19-story tower); and yield devices (see Fig. 7, right a 27-story tower).

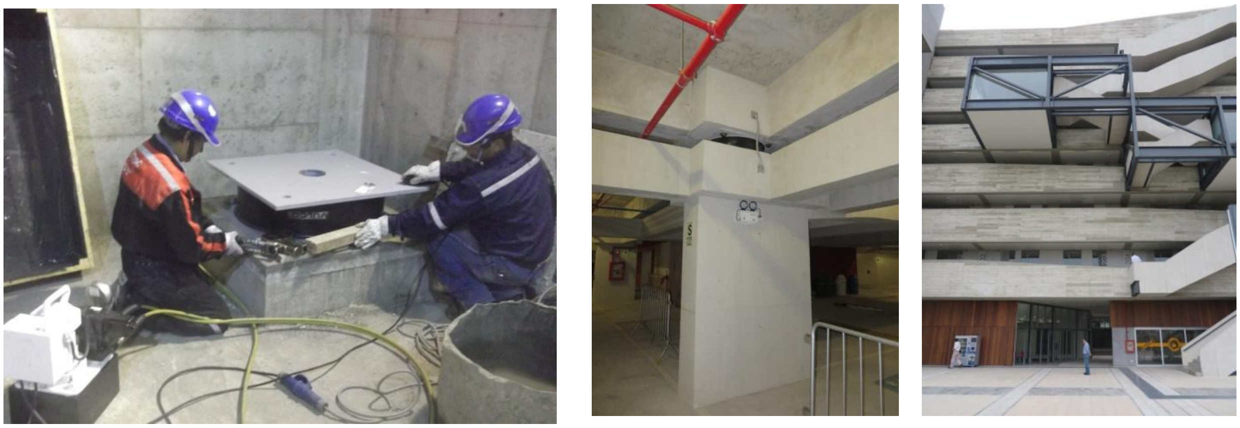

Fig. 6 – Seismic base isolators in university building

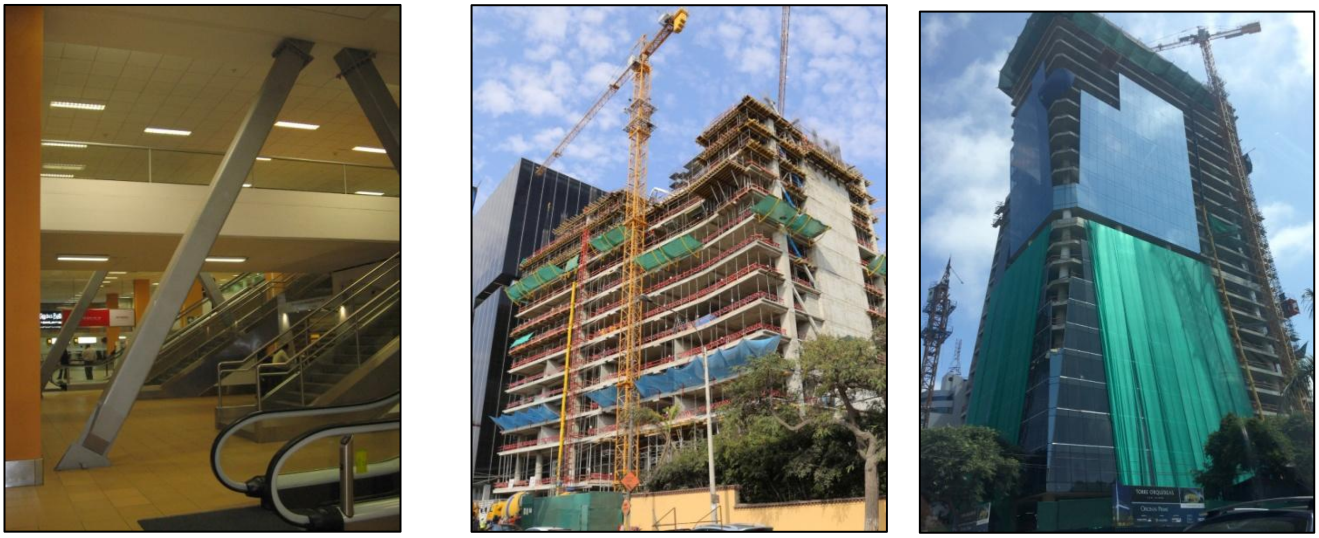

Fig. 7 – Buildings with energy dissipation devices in Lima

The Peruvian Ministry of Housing has ordered since March 2014, that the new hospital buildings should be base isolated in the high and medium hazard seismic zones. In other cities of the country, several new hospital buildings have been designed in such way.

9. Other important changes in the 2014 Code

In the building modeling and analysis no major changes have been done. The separation between adjacent buildings, s, have been reduced in the empiric formula used for dimensioning.

The chapter on non-structural elements has been completely rewritten. The concern on the great impact of the damage in non-structural components in large recent earthquakes as Peru 2007, Chile 2010, Japan 2011, have motivated this changes. The forces in non-structural elements are now a function of the height of the story (acceleration or seismic force) in which such elements are located.

Peru has had a rather poor net of accelerographic instruments, so the Code chapter on instrumentation has been rewritten putting emphasis in details of the position and operation of the apparatus. It is hoped that in the coming years many more instruments are available for recording strong ground motions.

10. Challenges for the future

Peru is a country under development, with around 30 million population. Lima, capital city has around 8.5 million population, with several infrastructure projects all around (by passes, underground trains, and alike). Somehow the economy indexes are rising in recent years. A large number of constructions are being built all around the country. The organization of the 2019 Panamerican games have been given to Lima, which mean a lot of construction works to be completed to attend such international massive event. Many civil engineers are graduating from a series of universities.

In this context, the expectation for a large earthquake in the near future must be considered seriously.

11. Acknowledgements

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