Seismic vulnerability of an existing RC building: comparison between Italian and Mexican design codes

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ABSTRACT

The study of the seismic vulnerability of existing reinforced concrete (RC) buildings is an actual research topic of structural engineering, since they are still in service although they were designed without considering or under estimating the seismic action.

This paper focuses on the seismic vulnerability of an Italian existing RC building constructed in the 60's and designed only for vertical loads. In this study, the Italian seismic assessment approach is compared with the Mexican one in order to estimate the seismic response of the considered case study. The paper concludes discussing of the application of FRP wraps as local intervention for strengthening primary elements of the considered building.

1 INTRODUCTION

The aim of this paper is the structural safety evaluation of an existing reinforced concrete building (RC), built by ATER (Azienda Territoriale Edilizia Residenziale Matera),. The building is located in Corso Di Vittorio No. 23 in the municipality of Irsina (MT). Verifications of the structure have been campared in accordance with the Complementary Technical Nom of the Federal District of 2004 (MXNTC-04,2004) and the Technical Complementary Norm of 2008 (NTC-08,2008).

The research has been developed following three phases:

1. Knowledge of the building
2. Modeling and numerical processing.
3. Synthesis of results, comparison between the two Codes and conclusions.

During the knowledge phase of the case of study, a geometric-structural characterization have been carried out by tests and surveys on the structural elements and materials. In this way, dimensions of structural elements, , characteristics of materials, and loads have been evaluated).

In the modeling and numerical processing phase, a finite element model have been developed, in order to assess the safety reffer to gravitational and seismic actions.

In the last phase, results and criteria design obtained between the Mexican codes (MXNTC-04,2004) and the Italian codes (NTC-08,2008) have been compared.

Subsequently, appropriate interventions with the application of FRP (Fiber Reinforced Polymer) have been proposed.

2 CASE STUDY

2.1 Description and mechanical characterization of the building.

The RC building was built on an area of 428 m^2, it has 4 floors of which correspond 2 appartments for each floor. The structure was built in reinforced concrete. It is composed by beams and columns structure with rectangular section. In order to identify a pathology of the building, a visual examination has been carried out. Then, non destructive tests (NDT), has been carried out to determine the mechanical properties of the structure.

The main pathologies identified are the presence of dark spots on the walls, as well as the loss of slab mortar. In the same way, some cracks have been found in columns, beams and part of the slab of the first level, where the deterioration of the concrete and part of the reinforcing steel could be observed. Figures 1 and 2 show some deteriorations located in the building.

Figure 1. Presence of moisture in slab.

Figure 2. Effects of weathering observed at the first level.

The NDT used have been made following the UNE-EN 12504-2: 2001 and UNE-EN 12504: 2005 codes.

The SonReb (Sonic/Rebound) test have been obtained by a combination of the sclerometric test (rebound factor S") and ultrasonic (velocity "V"), which gives an estimate resistance of the RC, the correlation of the ultrasound velocity and rebound sclerometer factor it has determined by the following equation:

$$Fc = a \cdot S^{b} \cdot V^{c} \tag{1}$$

Where:
a,b,c = correlation coefficients.

The SonReb test has been gotten a Fc value of 34.06 N / mm^2 of concrete compressive steength.

Compression test formed on four samples of concrete has been carried out too. The result are summarized in Figure 3.

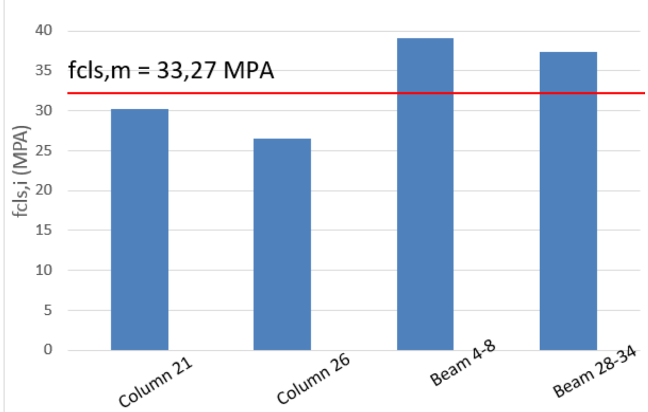

Figure 3. Compressive strength test on the extracted cylinders.

At the end, an average of both SonReb test and compression test Fc values results have been calculated, obtaining a Fc value of 33.83 N/mm^2

This value has been used to define the properties of the material during the modeling of the building, using SAP 2000V18 software.

On the other hand, the tension strength testd of the steel

have been provided an AQ 50 steel class of resistance with 270 N / mm^2 is the yeld tension.

The tests have been carried out by Technological Laboratory *"TECNO PROVE s.r.l." via dell'indutria, n. 6 72017 Ostuni (BR).* In the figures 4, 5 and 6, are shown the tests

Figure 4. Sclerometric test performed to column 26.

Figure 5. Ultrasonic test performed to the column 21.

Figure 6. Extraction of steel to the beam 23-29.

2.2 *Loads Analysis*

An loads analysis has been carried out, where the specific weights of materilas derive form the NTC-08. Load results values are summarized in table 1.

Table 1.Comparison of dead loads for each code of study.

	MXNTC-04	NTC-08
Slab	5.06 (kN/m^2)	5.06 (kN/m^2)
Internal Wall	1.60 (kN/m^2)	1.60 (kN/m^2)
Exterior Wall	6.86 (kN/m)	6.86 (kN/m)

According to the MXNTC-04 codes (that uses the Service Limit State combination), depending on the combinations of loads analyzed reffered to table MXNTC-04

It is necessary to say that the loads acting on the beams according to the NTC-08 are higher in relation to the loads evaluated by the MXNTC-04 because different amplification factors are used.

2.3 *Seismic Analysis*

According to the Department of Civil Protection (DPC), the *Instituto Nazionale di Geofisica e Vulcanologia* (*INGV*) it has presented a map that shows the seismic risk present in the Italian territory, published on the website http: //esse1.mi. Ingv.it/. from the risk map has been possible to obtain the maximum horizontal acceleration of the ground (ag), as well as the elastic spectral response in acceleration, as a function of the period T of the structure "Se (T)" measured in "*g*" gravity acceleration. Figure 7 shows part of the Basilicata region, particularly the community of Irsina and other neighboring communities, with reference to a probability of exceedance of 10% in 50 years, which considers the ultimate limit state of the structure, defined as "*Stato Limite di Salvaguardia della Vita (SLV)*". The SLV considers the effects caused by the earthquake where the building has suffered a break or collapse of structural and non-structural components.

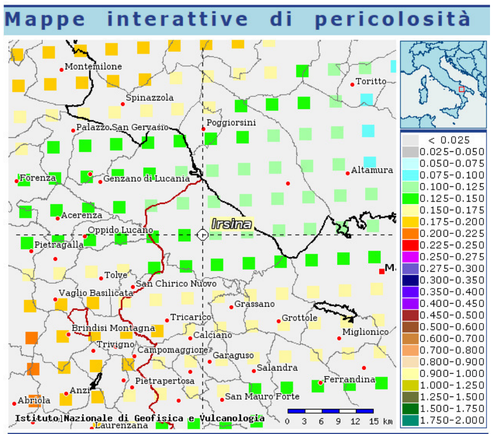

Figure 7. Seismic risk map of the Basilicata region and the community of Irsina. http://esse1-gis.mi.ingv.it//

The geographic coordinates (latitude and longitude) of the study site, together with the interpolation methods indicated by the code (NTC-08), allow to obtain the parameters that define the seismic risk for the case of study (table 2).

Table 2. Seismic risk for the case study. (unità di misrua in tabella)

T_R (years)	a_g / g	F_o	T_C^* (s)
30	0,040	2,522	0,278
50	0,051	2,498	0,318
475	0,125	2,595	0,418
975	0,155	2,636	0,440

The seismic action evaluated for the case study has been based on the evaluation of the horizontal seismic effects in reference to the modal analysis that considers the structure factor *q*. This method uses a design spectrum defined in section 3.2.3 p.to. Of NTC-08.

Results show that the columns are verified to the axial compressive load in reffer to permanent condition and the failure mode is ductile for this reason structural factor q has been assumed equal to 3 for bending and shear verifications in columnsand beams.

2.4 Seismic evaluation parameters

In relation to the seismic hazard where is the case of study, the seismic action has been defined following the next parameters:

- Useful life of construction VN equal to 50 years and one class of use II Cu = 1.
- Subsoil category B (Geological / technical report supplied by ATER).
- Topographic amplification factor of ST = 1 (topographic category T1).

In this way, the tests of resistance of the structural elements have been carried out with reference to the project of the seismic action.

Tables 3 and 4 present the parameters ag, F0, Tc* for the definition of the seismic action for VR = 50 years, as well as the important points that define the spectra of the different limit states.

Table 3. Definition of the seismic action for a VR = 50 years.

Limit State	PVR (%)	T_R (years)	Ag (g/10) (m/s^2)	F0	Tc* (s)
SLO	81	30	0.040	2.522	0.278
SLD	63	50	0.051	2.498	0.379
SLV	10	475	0.125	2.592	0.418
SLC	5	975	0.155	2.636	0.44

Table 4. Definition of the SLV spectrum of the horizontal action for VR = 50 years.

S_T	S_S	T_B	T_C	T_D
1	1.2	0.183	0.548	2.1

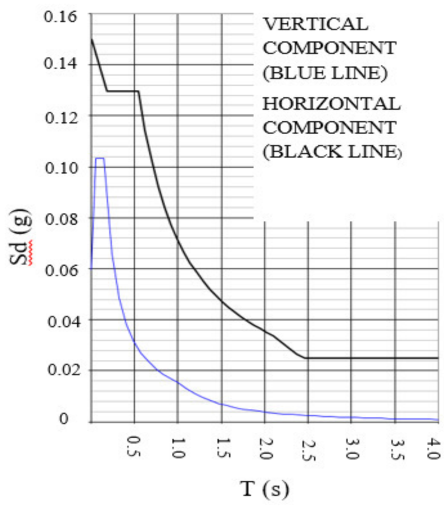

Figure 8. Response spectrum of the elastic project for q=3.

3 STRUCTURAL MODELING

The structure has been modeled using the finite element method, through a three-dimensional model, where beams and columns have been modeled as frames.

To take into account the high rigidity of the intersecting areas between beams and columns in the structural model, rigid elements have been inserted at the ends (Rigid End Offsets). The slabs, however, has been modeled as two-dimensional elements (shells) in order to take into account their real stiffness in the plane. Figure 9 shows the finite element model implemented.

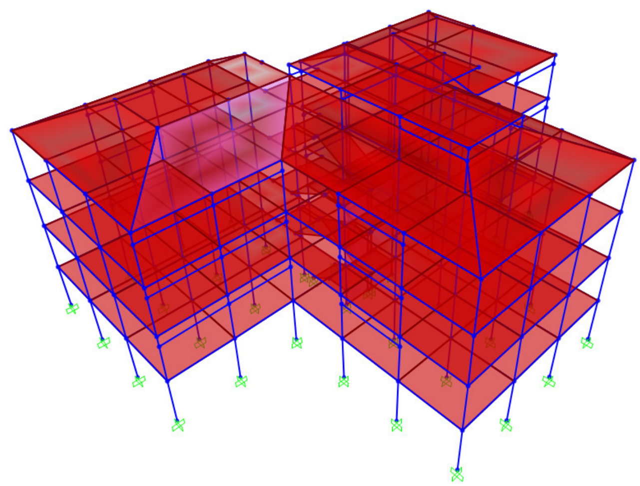

Figure 9. Isometric view of the structural model implemented by SAP2000v.18.

The results of modal dynamic analysis have been presented showing the structure modeled for the two study cases. The first three vibrate modes are show in figures 10 11 and 12. In table 5 are reported the results in terms of frequency and period.

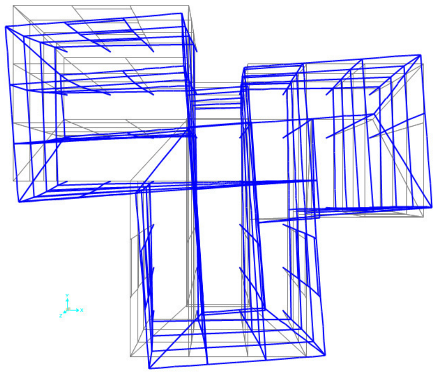

Figure 10. First mode of structural vibration.

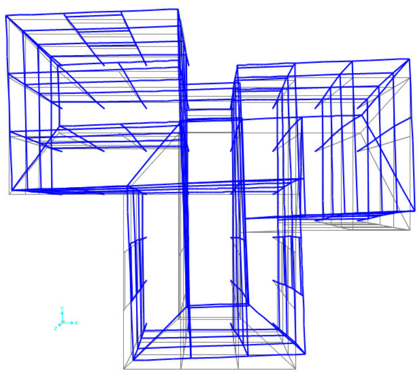

Figure 11. Second mode of structural vibration.

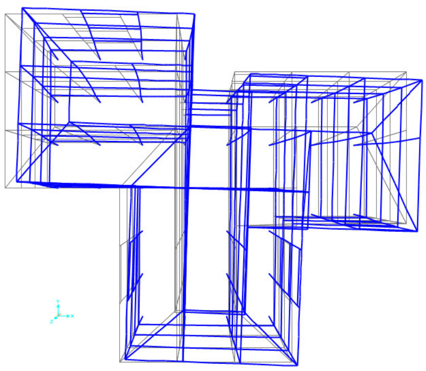

Figure 12. Third mode of structural vibration.

The first mode of vibration presents roto-translational characteristics with prevalence along “X” axis and with a prevalence along “Y” axis for the second and third mode of vibration (table 7). The first 12 modes are sufficient to excite substantially the entire mass of the building.

Table 5. Vibration Modes of the structure between Mexican and Italian codes.

Vibration Mode	MXNTC-04 – Frecuency (Hz)	MXNTC-04 -Period (s)-	NTC-08 – Frecuency (Hz)	NTC-08 -Period (s)-
First	1.024	0.976	1.077	1.03
Second	1.13	0.88	1.18	0.94
Third	1.19	0.84	1.25	0.88

4 NUMERICAL RESULTS AND VERIFICATION

In order to obtain an evaluation of the seismic response of the building the section of most stressed beams and columns have been analyzed (figure 13). The results are compared with Italian and Mexican rules.

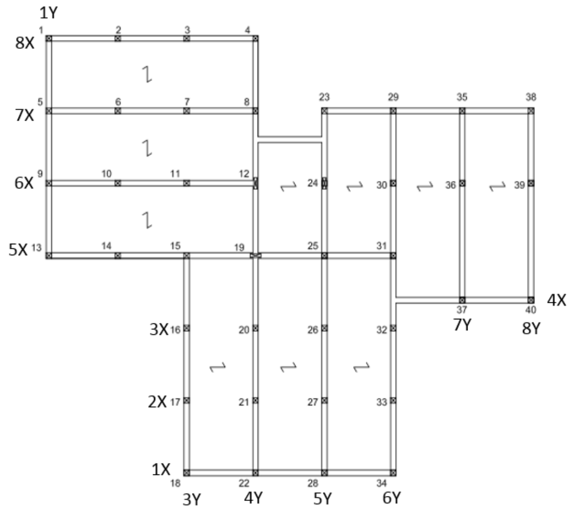

Figure 13. Identification of the study section of beams and columns (5Y).

4.1 Results – MXNTC-04,2004.

Following the Complementary Technical Codes on Criteria and Actions for the Structural Design of Buildings, the resistances must be affected by a reduction factor, F_R .

Resistance factors should have the following values (section 1.7 of MXNTC-04 Concrete Design):

- $F_{R=}$ 0.9 for Bending Moment.
- $F_{R\,=}$ 0.8 for Shear

Thus, taking into account the equilibrium conditions and general hypotheses of section 2.7 of the MXNTC-04 for concrete design, the expression that leads to the calculation for the bending moment, M_R, is presents in the equation 2 (Equation 2.4 of MXNTC -04):

$$MR = F_R \cdot b \cdot d^2 \cdot fc'' \cdot q \cdot (1 - 0.5q) \qquad (2)$$

Being:
$F_R = 0.9$
b = section width.
d = effective cant.
f'c= uniform compression stress.

Table 6 presents the results obtained for the bending moment calculation performed in the section of study beams.

Table 6. Bending Moment Calculation using the MXNTC-04, for studio beams.

BEAM	M_R (kN.m)
28-27	53.05
27-26	53.05
26-25	53.05
25-24	53.05

On the other hand, the shear force that the concrete takes (V_{CR}), have been obtained according to the relation, L / h, not less than 5, by the following critery of the equation 3 (Equation 2.19 and 2.20 of NXNTC-04,2004).

- If p<0.01

$$VCR = FR \cdot b \cdot d \cdot (0.2 + 20p) \cdot \sqrt{fc*} \qquad (3)$$

- If p≥0.015

$$VCR = 0.5 \cdot FR \cdot b \cdot d\,(0.2 + 20p) \cdot \sqrt{fc*} \qquad (4)$$

Where the value of "p" is defined as, the ratio between the steel area and the section of the element. The factor F_R, is 0.8 for elements subject to shear force.

The shear force taken by the transverse steel is in the function of the separation between stirrups, from which equation 5 has been obtained (Equation 2.23 MXNTC-04.2004)

$$V_{SR} = (F_R \cdot Av \cdot fy \cdot d \cdot (\sin\theta + \cos\theta)) / s \qquad (5)$$

Where:
$F_R = 0.8$;
s = disctance between steel wraps reinforcement;
Av = cross sectional area of the reinforcement by diagonal tension over a distance s.
θ= angle between the axis of the element and the direction of steel wraps.
fy= yeld stress (MPa)

Table 7 shows the results obtained from the shear forces performed in the section of study beams.

Table 7. Calculation of shear resistance by means of the MXNTC-04, for the studio beams.

BEAM	V_{CR} (kN)	V_{SR} (kN)	V_R (kN)
28-27	58.69	73.73	139.00
27-26	58.69	73.73	139.00
26-25	58.69	73.73	139.00
25-24	61.68	99.64	168.59

4.2 Results – NTC-08,2008 –

According to *Norme Tecniche per le Costruzioni D.M. 14.01.2008*, the resistance of concrete and steel materials, will be influenced by the following reductive factors (4.1.4 and 4.1.5 NTC-08,2008:

- Compressive strength of concrete

$$fcd = acc \cdot fck / \ yc \qquad (6)$$

Where:
a_{cc} = corrective coefficient for long-term resistance (value 0.85).
y_c = partial safety coefficient of concrete.
f_{ck} = cylindrical compressive strength of concrete.

$fyd = fctk / yc$ yeld tension of the steel bar (7)

Where:
y_c = safety coefficient of concrete (1.5)

According to the conditions of equilibrium and the definition of the resistance of the materials, the calculation for the bending moment, Mu, has been presented below:

$$Mu = 0.9 \cdot d \cdot As \cdot fyd \qquad (8)$$

Table 10 presents the results obtained for the bending moment calculation performed in the section of study beams.

Table 8. Beam bending moment resistence calculated by using the NTC-08.

BEAM	M_R (kN.m)
28-27	58.55
27-26	58.55
26-25	58.55
25-24	65.12

The shear force depends on the contribution of the resistant mechanisms of the concrete ($V_{R,}cd$), as well as the contribution due to the transverse reinforcement ($V_{R,}sd$). In this way, equations 9 and 10 (4.1.18 and 4.1.19 NTC-08) have been used for calculation:

$$VRsd = 0.9 \cdot (Asw/s) \cdot fyd \cdot (ctg\alpha + ctg\beta) \cdot \sin\beta \quad (9)$$

$$VRcd = 0.9 \cdot d \cdot bw \cdot ac \cdot f'cd \cdot (ctg\alpha + ctg\beta) \cdot \sin\alpha \quad (10)$$

$$V_R = V_{Rsd} + V_{Rcd} \quad (11)$$

Table 9 shows the results obtained from the shear forces performed in the section of study beams.

Table 9. Beams Calculation of shear resistance by NTC-08.

BEAM	Vsd (kN)	Vcd (kN)	V_R (kN)
28-27	83.20	92.17	175.37
27-26	83.20	92.17	175.37
26-25	83.20	92.17	175.37
25-24	108.61	95.65	199.28

5 COMPARISONS AND VERIFICATION OF CODES

In Figure 14 are shown comparisons of the bending moment in terms of the force and ultimate bending and in figure 15 the ultimate shear and the shear force. The comparisons have been done with Italian and Mexican codes.

From the results obtained, it is to possible to observe that for both codes the required moment is not verified, reason that it is possible to conclude it will be necessary to reinforce the beams.

For the verification to ultimate bending moment and shear it has taken into account both the vertical and horizontal loads (earthquake), in the same load combination.

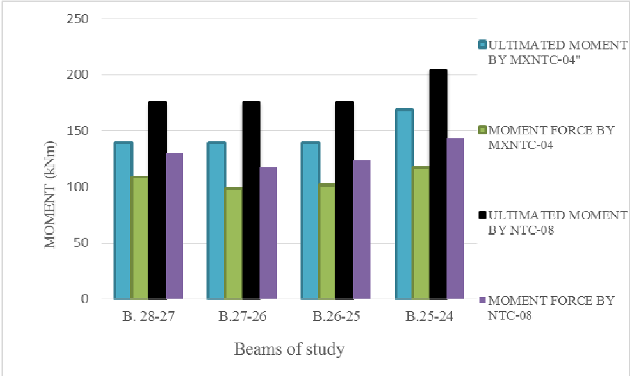

Figure 14. Bending moment for beam sections made with the Mexican and Italian codes, and compared to the required moment.

On the other hand, it is observed that the combination values used in the analysis (including vertical and horizontal loads), are much greater in the Italian code than in the Mexican one.

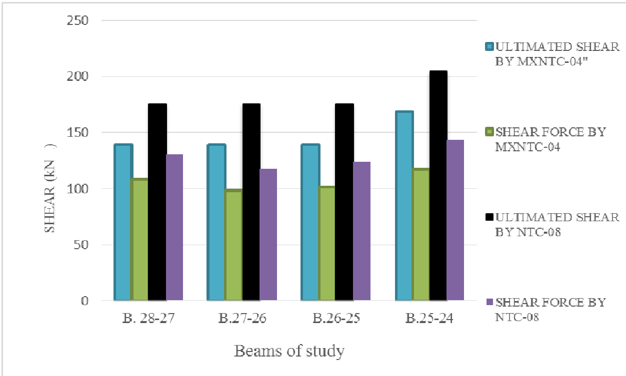

Figure 15. Shear Resistance of beams of study (expressed in kN), compared to required resistance.

On the other hand, the shear strengths of the Italian code turn out to be 26% higher than the Mexican code, thus providing greater resistance in this comparison.

For the case study, the 23,24,25,26,27 and 28 columns have been analyzed. According to the comparison made between the Italian and Mexican codes, table 10 shows, the report of the capacity of ratio, referred to the columns of both codes. The capacity ratio is determined by first extending a line from the origin of the PMxMy interaction surface to the point representing the P, M2 and M3 values for the designated load combination. Call the length of this first line L1. Next a second line is extended from the origin of the PMM interaction surface through the point representing the P, M2 and M3 values for the designated load combination until it intersects the interaction surface. Call the length of this line from the origin to the interaction surface L2. The capacity ratio is equal to L1/L2 (figure 16, Manual SAP2000).

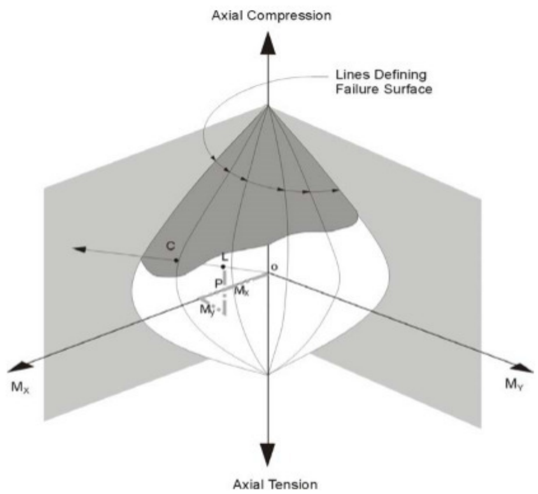

Figure 16. Geometric representation of column capacity ratio by SAP2000v.18

Consequently, if the L1 / L2 ratio is less than 1, the column section will require a larger area of steel. Table 10 shows the capacity of ratio of the columns analyzed by MXNTC-04 are within the ratio (ranging from 0.5 to 0.6) considered acceptable, however, for the NTC-08, the study columns have a tendency higher to the capacity of ratio (ranging from 0.7 to 0.9). Column 24, according to the NTC-08, having a capacity ratio of 0.96, it is recommended to reinforce it to avoid deformations in it.

Table 10. Resistance required for each column, the results were taken from the finite element program SAP2000.

Column	Capacity of Ratio (MXNTC-04)	Capacity of Ratio (NTC-08)
28	0.57	0.72
27	0.55	0.78
26	0.56	0.82
25	0.63	0.84
24	0.52	0.96
23	0.5	0.58

6 INTERVENTIONS

Fundamentally, for an adequate evaluation of the problems described above and according to the conservation of the state of the art, acceptable assessments must be made to the behavior and safety of the existing structure. At present, in Mexico, there is no relative norm to perform an intervention for structural reinforcement of existing structures, however, in recent years the use of FRP compounds has been promoted as an option to reinforce infrastructure works, housing and buildings. The normative on which they have based their design criteria is the American Construction Society (ACI), respectively (Abad & Recillas). In contrast, in Italy, the current normative for construction, has approaches to existing buildings, where according to the introduction of chapter 8 of the NTC-2008.

The importance in Italy for the safety of existing buildings is mentioned, due firstly to the high vulnerability of the area and subsequently to the value of the historical-architectural-artistic-environmental value of most existing buildings. Given the lack of Mexican legislation regarding the intervention of existing buildings and the presence of an Italian normative for this type of case, we opted for an intervention based on compounds made by polymers with FRP fibers (Fiber Reinforcing Polymer). These compounds have reached a level of development that makes possible their rational and competitive use, used for the reinforcement of structural elements, either to restore their original capacity or to increase it. In this way, for the development of the FRP intervention, the design criteria has been based on the National Research Council (NRC) codes.

6.1 Flexural Reinforcement

The flexural reinforcement for concrete elements using FRP elements, works by adhering the materials with epoxy resin to the surface of the element that is under tension, orienting the fibers parallel to the direction of main stresses. This stress transmission is performed through shear and normal stresses generated at the interface of the substrate and the alloying epoxy adhesive. To perform the intervention, CFRP has been used, whose reinforcement properties have a thickness of 0.0164 cm, a length of 30 cm and a deformation of 240,000 MPa. Figure 17 shows how the flexural reinforcement with CFRP compounds (column blue represent the flexural reinforcement with CFRP for the MXNTC-04 code and column black, represent the flexural reinforcement with CFRP for the NTC-08 code), satisfy the bending moment required (column green represent the bending moment required of MXNTC-04 code and column purple, represent the bending moment required of NTC-08 code).

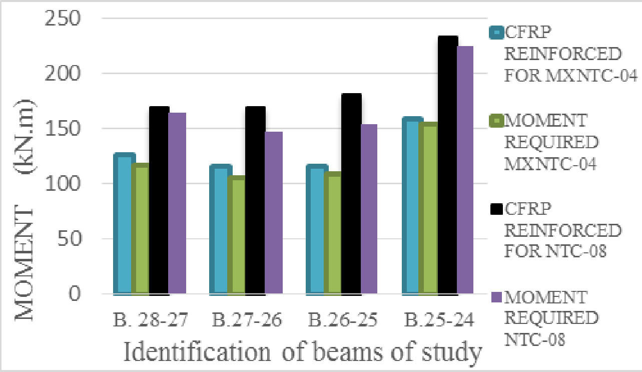

Figure 17. Flexural Reinforcement of beams of study by CFRP compounds (expressed in kNm).

6.2 Confinement

The increase in compressive strength of concrete columns with structural deficiency in seismic regions through confinement has been one of the first applications of FRP materials in infrastructure works. The confinement increases the rotational capacity of the plastic joints and prevents the separation of the internal reinforcement in the overlap zones, it also works for non-seismic regions, where the capacity of a column increases due to the action of vertical loads.

Containment is achieved by a perimeter wrapping of the element with FRP materials in such a way that the main direction of the fiber is perpendicular to that of the element.

Column number 24 (Italian code) has been reinforced by CFRP compounds whose properties are: Compressive strength of 44.1 MPa, tensile strength of 13.1 MPa. Reinforcement has been performed by the NRC-DT 200 R1 / 2013 normative. The column has been symmetrically reinforced, adding a layer of 10mm to each wall of the column.

7 CONCLUSION

In this paper, a comparison between two codes NTC-08 (Italia) and MXNTC-04 (Mexico), has been developed to the aim to compare the seismic vulnerability of an existing r.c. building designed in the 60's only refferd to the vertical loads.

Italian and Mexican codes use the same approach for seismic evaluation but different results are due to several facotrs for exampe the partical factor of the strength of the material, different combination of loads etc. The results show that the Italian code leads to results more conservative than the Mexican code with consequences in designing the elements.

It emerges that the Italian code considers higher safety criteria for the calculation of the resistance of the structural elements, compared with the Mexican code.

It is important to underline that not exist a codes in Mexico for the reliability interventions. It should be important to develop a reliability structural codes in Mexico takes into account of the indications reported in Italian and/or International codes.

8 ACKNOWLEDGMENTS

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9 References

A.T.E.R. *Azienda Territoriale Ediliazia Residenzial*. Obtenido de Azienda Territoriale Ediliazia Residenzial: http://www.atermatera.it

Abad, H. C., & Recillas, H. (Intervención de Estructuras con Refuerzos FRP. *Sociedad Mexicana de Ingeniería Estructural*.

CNR. (2013). *Istruzioni per la Progettazione, l'Esecuzione ed il Controllo di Interventi di Consolidamneto Statico mediante l'utilizzo di Composti Fibrorinforzati.* Roma.

Commissione di Studio per la Predisposizione e l'Analisi Tecniche relative alle costruzioni. (2013). *CNR-DT 200 R1/2013.*

CSLP. (s.f.). *Consiglio Superiore Dei Lavori Pubblici*. Obtenido de Consiglio Superiore Dei Lavori Pubblici: www.cslp.it

INGV.*Instituto Nazionale Di Geofisica e Vulcanologia*. Obtenido de Instituto Nazionale Di Geofisica e Vulcanologia: http://www.ingv.it

Meli, R. *Diseño Estructural*. México: Limusa.
NTC. (2004). *Normas Técnicas Complementarias para Diseño y Construcción de Estructuras de Concreto*. Ciudad de México.
NTC. (2008). *Norme Tecniche per le Construzioni D.M. 14.01.2008.*