Assessing the physical condition state of structures in risk areas in the city of Tuxtla Gutierrez, Chiapas, Mexico

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Abstract

It is reported the development of a model for the evaluation of structures which allows to determines the status of a construction condition. This evaluation model propose a structure analysis from the stand point of structural and functional , applying to each main factors depending on the deterioration having the structure has at the moment of the inspection. With these two factors established the parameters and indices that qualify the structure in any of the five states of condition for the proposed.

Key words: Assessment, functional index, structural deterioration

Introduction

In previous research has developed research campaigns to social housing located in risk areas in the city of Tuxtla Gutierrez, Chiapas, Mexico, (Alonso, 2007; Gómez, 2008) with in order to determine the condition and to evaluating the damage depending on the pathology are presented. Various models have been used for evaluation; however, they do not fulfill the expected results that are the main reason why it has been proposed the development of a model based in experimental models with adjustments in line with the deteriorating conditions that these areas presented. It may be mention the significance of this model is the structure evaluated from the standpoint of the structural and functional main importance lies on the evaluation of the structure seen from de structural and functional point of view. The functional index to evaluate the structure from the point of view of the service provided to the user, allowing properly perform the functions for which the structure was built. The structural index provides the structural deterioration having the structure the time of the inspection, and it is calculated by taking in to account the deterioration that may have the slabs, walls, confinement or reinforcing elements and foundations.

Background

The city of Tuxtla Gutierrez is the capital of the state of Chiapas, which is located in the southeast past of Mexico; it is one of the most populated, urbanized and largest city in the state, even though it does not have a touristic or cultural importance, as the other cities; it is in fact, the economical and political center in the state. It is located in the central region of the state at 16°45’ 11” North Latitude and 93°06’ 56” West Latitude and 550 AMSL. It has an area of 412.4 km2.

In recent years, the city of Tuxtla Gutierrez has had a very important economic benefit generated by the private sector, who have invested in the construction and development of commercial and hotel complexes, as a result this spill has lead to the construction of s the of housing units producing an increase in the urban infrastructure and population.

Unfortunately, the city of Tuxtla Gutierrez city is located the Central Depression presenting a land with mountainous reliefs in the north and south part of the city, which is the reason why several housing units are being build in zones that can be consider risk areas due to the instability of the ground. In addition to this, each unit has different structural characteristics that does not allow the unification or the homogenization of the structure (floor structural system and foundation system), given this, it is common that the structures present several pathologies which does not allow the identification of the cause that produce the structural deterioration, given that it is not feasible to identify the cause that produces the injuries founded and it makes impossible the corrective action required to the problem presented.

Another factor that can be considered as a cause of failure is that the underground of the city of Tuxtla Gutierrez has some special features (clays) that make the proposals of foundation should be studied properly in each case required because depending on the zone where it will build it should be count with proposals for improvement or stabilization of the foundation soil on which the structure must be removed to avoid these faults during the process of volumetric changes of the terrain.

Finally, the city of Tuxtla Gutierrez is included in Zone C (Figure 1) within the Seismic Regionalization of the Federal Electricity Commission (CFE, 2008), which causes together with the accelerated pace of construction presented in housing units, the diverse construction processes and in some cases poor quality materials or supervision, which present a series of structural pathologies caused by the dynamic action and can jeopardize the structural stability of a home.

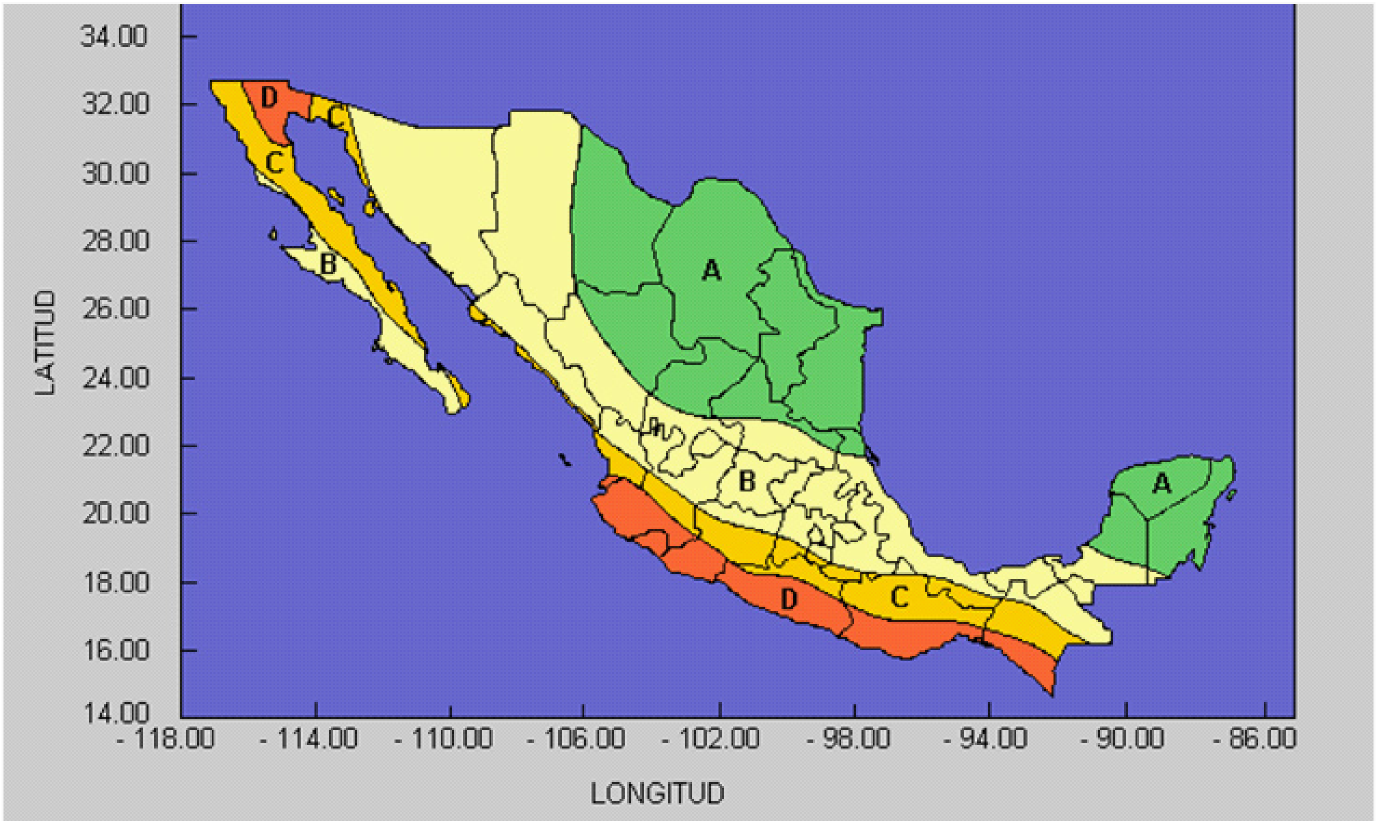

Figure 1 Seismic Regionalization of the Federal Electricity Commission (CFE, 2008)

Assessment of condition model

This article presents a model to assess the state of physical condition of a structure based on data collected in inspection campaigns. It builds on the model proposed in Alonso (2007), but with two main variants, as described below.

This evaluation model proposed the structure analysis from the standpoint of structural and functional, applying for each weight factor depending on deterioration having the structure at the moment of the inspection.

Therefore the state of condition of a structure is evaluated from the State of Condition Index (IEC)

$$IEC = IF + IE$$

Where IF = Functional Index
IE = Structural Index

At this rate, it is calculate the state of condition of the inspected structure taking into account the values given in Table 1, which describes the state of IEC obtained depending on the condition, description and extent of injury as the NTC- 04.

IEC	Condition Status	Description	Harm magnitude (NTC-04)
0.00 1	1 - Excellent	The structure presents no damage	
0.01 - 4.99	2 - Good	The structure has minor damage which can be solved with minimum maintenance	Negligible, which affects not relevant structural capacity (resistant and deformation). The repair will be surface type.
5.00 - 9.99	3 - Acceptable	Undamaged structure under emergency repair and long minor term maintenance	Lightweight, when slightly affects the structural capacity. Remedial measures are required for most simple elements and modes of behavior.
10.00 - 14.99	4 - Regular	The structure has major damage that can endanger the stability of the structure and it requires maintenance actions	Moderate medium term, when moderately affects the structural capacity. The rehabilitation of the damaged elements depends on the element type and mode of behavior.
15.00 - 19.99	5 - Poor	The structure presents several damage needing strengthening actions in a short period of time	Severe short term, when the damage significantly affects the structural capacity. The intervention involves extensive rehabilitation, with replacement or reinforcement of some elements.
20.00 - 59.00	6 - Damaged	The structure has major damage needing immediate enforcement and very serious actions	When damage has deteriorated the structure to the point that they are not reliable. It covers the total or partial collapse. Rehabilitation involves replacement or reinforcement of most of the elements, or even partial or total demolition.

Table 1. State Structure Condition

Functional Index Analysis (FI)

The previous model did not refer to the service state of the structure from the user's point of view, therefore it is proposed in this model using a functional index that allows assessing the structure from the point of view of service it provides to the user, and perform properly the functions for which the structure was built.

This index is calculated by the following equation:

$$IF = FF * FM$$

Where FF = Functional Factor
FM = Maintenance Factor

Functional Factor (FF) is a factor that assesses the structure from the functional point of view and assigns the values given in Table 2, depending on the discretion of the inspector at the time of evaluation. The proposed values for each observation in this table were taken from the study of 77 homes inspected in the city of Tuxtla Gutierrez located in risk areas (Figure 2), gathering the most frequent comments that caused a failure in the use of the home.

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Figure 2. Location of houses inspected

FF	Harm magnitude (NTC-04)
0	The structure is in excellent condition
1	Presence of dirt on walls, slabs and floors
2	Presence of peeling paint, doors and windows with minor defects, coating detachment
3	Small stains with minimal leakage, electrical and hydraulic malfunctions, missing tiles and carpet tiles, broken glasses
4	Detachment in four walls, and floors, major leaks, doors and windows in disrepair, missing glasses
5	Excessive leaks, damaged doors and windows
6	The structure is uninhabitable

Table 2. Functional Factors Values

The maintenance factor (MF) is a value placed on the type of maintenance that requires the structure to provide the best service status with respect to the functional requirements of the user. There are two types of maintenance: preventive and corrective. Most researchers define preventive maintenance as an activity related to cleaning, painting or coating replacement of structural elements, while corrective maintenance covers a wide range of activities ranging from the rehabilitation, repair, retrofitting or replacement of structural items that could support the actions that may occur. In the case of setting the values involved in the maintenance factor, it was taking into account only the activities that take place in preventive maintenance, ranking lower, medium and higher. The values assigned are described in Table 3.

FM	Description
0	The structure does not require any type of maintenance
1	Minor maintenance, general cleaning of the structure
2	Medium maintenance, restoration, glasses reposition, tiles, carpet tiles, hydraulic and electric restoration, total painting, under seal application in the slabs.
3	Higher maintenance, covering reparation, windows, doors and under seal application.

Table 3. Values for the Maintenance Factor

The previous values were taken from the inspection campaigns applied to the houses in the city of Tuxtla Gutierrez and taking into account the houses and each element within were tested to permanent use which causes a regular deterioration to each one and to preserve the good service throughout its utility and proper usefulness. The previous imply applying proper house care and knowing each element in the house.

The benefits generated by the correct use and maintenance in the housing are the following:

- Avoid the deterioration of the house, preserving the good state of it along its life.
- Improve the physical appearance of it.
- Prevent damages in the structural elements.
- Identify minor problems and solve them on time.

Structural Index Analysis (IE)

The structural index provides the structural deterioration presented in the structure at the moment of the inspection, calculating and taking into account the deterioration that could exist in the four main elements in the structure of the house which are: slabs, walls, confinement or reinforcing elements and foundations.

The expression to calculate the structural index (IE) is the following:

$$IE = DL + DM + DEC + DC$$

Where
DL = Slabs deterioration
DM = Wall deterioration
DEC = Confinement elements deterioration
DC = Foundation deterioration

Each of these deteriorations provides a list of damage that every structural element may content based on the three factors: Damage Factor, Action Factor and Urgency Factor.

The damage factor (FD) represents an index the engineer in charge of the evaluation established and this depends of the damage observed in the structural element at the moment of the inspection and of the probable cause that originate them.

The Action Factor (FA) represents the corrective maintenance level required, at least, the structural element returns to its original development level. This maintenance type may goes from the minor to the considerable reinforcements of the housing.

And finally, the urgency factor (FU) indicates the urgency of the intervention or action that requires the element taking into account the damage observed at time of inspection.

The values for each of the factors determining the structural deterioration of each structural element were established according to the observations obtained in the inspection campaigns carried out in various parts of the city of Tuxtla Gutierrez, taking certain structural characteristics and use when conduct random sampling of homes to inspect.

In Table 4 shows the frequent pathologies observed during the inspection campaigns and the coincidence numbers of each one.

Pathology	Coincidence
Detachment in the coat of the walls	48
Crack in supporting walls	47
Crack in walls by lose land	36
Stains in slabs by humidity	32
Coating detachment on slabs	21
Crack son floor by contractions	21
Cracking on floors	21
Crack son supporting walls	20
Crack son walls by lose land	19
Slabs cloating flaking	16
Dirt stains on walls	15
Bulging of sidewalks by volumetric changes	15
Coating flaked walls in moisture	12
Crack in walls	10
Detachment in walls caused by ornaments	10
Lack of anticorrosive painting in metallic elements	9
Coating peeling in slabs with efflorescence	8
Gaps in floor and walls	8

Cracks in slabs by contraction	6
Gaps in walls between axis	5
Holes in supporting walls	5
Steel corrosion in the support of the slabs	4
Gaps in floors	4
Stains in slabs caused by corrosion	3
Cracks in slabs caused by inflections	3
Settlements in walls	3

Table 4. Pathology Types and coincidence numbers

The general classification of each of these pathologies regarding to the classification of the structural element are shown in Table 5 and Figure 3.

Structural Elements	Incidence Numbers
Slabs	48
Walls	47
Elements of confinement	36
Foundations	32
Total	**21**

Table 5. Structural pathologies observed in structural elements

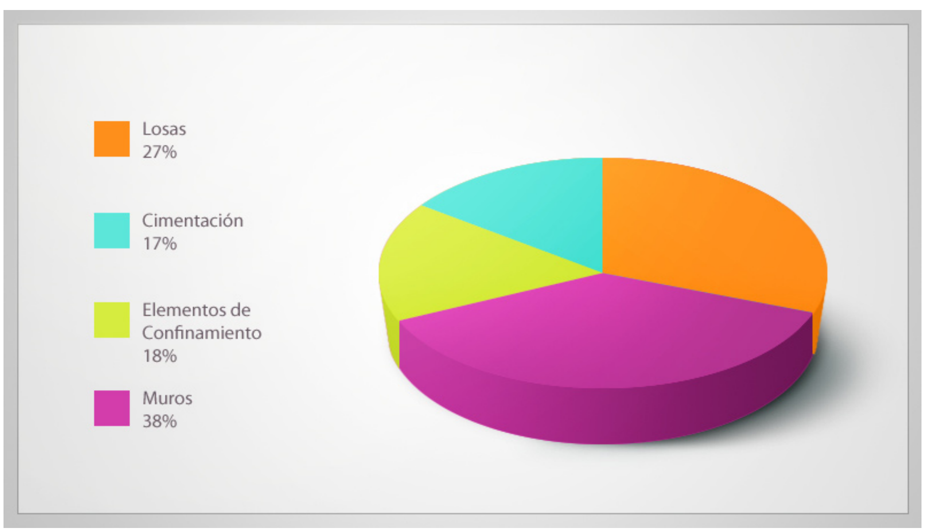

Figure 3. Percentage of deterioration in each structural element

Based on the analysis to the observations of the pathologies obtained during the inspection campaigns and proposals made by authors like Bellmunt et al. (2000), Emmons (2005), Escolá (1993), Garcia (2002) and Gomez (2008), set out the values for each of the factors determining the deterioration in the proposed structural elements.

Impairment Slabs (DL)

The DL is then calculated with the following expression

$$DL = FDL * FAL * FUL$$

The index for damage factor in the slab element (FDL) is established, as mentioned earlier, mainly to study the housing inspected and determined according to the pathology observed and representing each one of them with respect to total damage in the element. Assigning this value depends on the discretion of the evaluator. The values of these indices are shown in Table 6.

FD_L	Description
0	• There were no pathology
0.01 - 0.05	• Small cracks caused by shrinkage of less than 5 cm in length • Paint flaking caused by moisture. • Dirt stains
0.05 - 0.10	• Cracks caused by shrinkage between 5 and 10 cm in length • Minor fissures caused by bending under a 5 cm long • Coating peeling least 10% of the area
0.10 - 0.25	• Blocks fissures between 5 and 20 cms by bending or contraction. • Coating the scaly 10 to 20% • Small spots caused by humidity • Small leaks in the slab
0.25 - 0.50	• Cracks less than 5 mm thick with lengths less than 10 cms • Remarkable vibration of the slab • Coating the scaly from 30 to 50% • Moisture stains or efflorescence oxide presence • Detachment in particular less than 10%

0.50 - 0.75	• Cracks over than 5 mm in thickness with variable length • Humidity stains with spalling and excessive presence of rust or efflorescence • Detachment of concrete with rebar visible by 20% • Excessive vibrations
0.75 - 1.00	• Excessive leaks with rust stains and spalling of concrete • Cracks than 5 mm thick, with variable length and rust stains • Reinforcing steel and visible corroded • Detachment of coating steel exposed to over 20%

Table 6. - Factors proposed depends the pathologies analyzed for FD_L

To determine the Damage Factor, if the slab, it was observed that most diseases presented in the housing analyzed overall reinforcement required, so that these values were set as shown in Table 7.

FA_L	Description
0	Does not require any repair
1	Minor repairs cleaning consisting of small scaled, seal cracks
2	Minor repairs consisting of patching cracks and small landslides
3	Major repairs consisting detachment repair and cleaning or replacement of corroded steel
4	Major repairs consisting slab reinforcement

Table 7. Values for Action Factor in Slabs

In Table 8 it is presented the actions required in these slabs to recover at least its original performance level.

FU_L	Description
1	Long term action
2	Medium term action
3	Short term action

Table 8. Values for Urgency Factor in Slabs

Impairment Walls (DM)

The DM is then calculated with the following expression

$$DM = FDM * FAM * FUM$$

Damage Factor walls (FDM) is a factor from 0 to 1 and depends on the discretion of the evaluator and it is a factor of the amount of damage that has the wall element of the overall structure in Table 9 proposes some values for the FDM.

FD_M	Description
0	• There were no pathology
0.01 to 0.03	• Small shrinkage cracks in the coating.Paint peeling.
0.03 to 0.10	• Small cracks under 5 cm in length diagonally in the top of the wall. • Small cracks under 5 cm in length diagonally in the bottom of the wall. • Small cracks under 5 cm long horizontally on top. • Small cracks under 5 cm in length vertically. • Small cracks under cm long at the junction with the elements of confinement. • Detachment of coating up to 10% of the wall surface.
0.10 to 0.20	• Cracks between 5 and 10 cm length of a diagonal into the top of the wall. • Cracks between 5 and 10 cm length of a diagonal of the bottom wall. • Cracks between 5 and 10 cm in length in a horizontal upper wall. • Fissures between 5 and 10 cm vertically. • Cracks between 5 and 10 cm at the junction with the containment elements. • Detachment of coating up to 10% of the wall surface.
0.20 to 0.30	• Fissures between 10 and 15 cm in length diagonally into the top of the wall. • Cracks between 10 and 15 cm diagonal length of the bottom wall. • Cracks between 10 and 15 cm in length in a horizontal upper wall. • Fissures between 10 and 15 cm long vertically. • Cracks between 10 and 15 cm of length in union with the containment elements.
0.30 -0.40	• Cracks up to 10 cm length of a diagonal in the top of the wall. • Cracks up to 10 cm length of a diagonal in the bottom of the wall. • Cracks up to 10 cm in length in the horizontal upper wall. • Cracks up to 10 cm in vertical length. • Cracks up to 10 cm in length in union with the containment elements. • Detachment of coating more than 20% of the wall surface.

0.40 to 0.50	• Cracks between 10 and 20 cm in length diagonally into the top of the wall. • Cracks between 10 and 20 cm diagonal length of the bottom wall. • Cracks between 10 and 20 cm in length in a horizontal upper wall. • Cracks between 10 and 20 cm in length vertically. • Cracks between 10 and 20 cm of length in union with the containment elements. • Detachment of coating more than 20% of the wall surface.
0.50 to 0.60	• Cracks between 20 and 40 cm in length diagonally into the top of the wall. • Cracks between 20 and 40 cm diagonal length of the bottom wall. • Cracks between 20 and 40 cm in length in a horizontal upper wall. • Cracks between 20 and 40 cm vertically. • Cracks between 20 and 40 cm of length in union with the containment elements.
0.60 to 0.80	• Cracks between 40 and 80 cm in length diagonally into the top of the wall. • Cracks between 40 and 80 cm diagonal length of the bottom wall. • Cracks between 40 and 80 cm in length in a horizontal upper wall. • Cracks between 40 and 80 cm vertically. • Cracks between 40 and 80 cm of length in union with the containment elements.
0.80 - 1.00	• Cracks of more than 80 cm in length diagonally into the top of the wall. • Cracks of more than 80 cm in length diagonally into the bottom of the wall. • Cracks of more than 80 cm in length horizontally at the top of the wall. • Cracks of more than 80 cm in length vertically. • Cracks of more than 80 cm in length at the junction with the elements of confinement

Table 9. - Depending on the factors proposed to FDM analyzed pathologies

Worth mentioning that the assessor can use their experience and qualify with an index that considers adequate although it is not well specified in the table above.

In Tables 10 and 11 are show values for FUM and FAM, respectively.

FA_M	Description
0	Does not require any repair
1	Minor repairs cleaning consisting of small scaled, seal cracks
2	Minor repairs consisting of patching cracks and small landslides
3	Major repairs consisting of repairing of the damaged wall
4	Major repairs or replacement consisting of wall reinforcement

Table 10. Values for Action Factor in Walls

FU_M	Description
1	Long term action
2	Medium term action
3	Short term action

Table 11. Values for the Urgency Factor in Walls

Impairment Confinement Elements (DEC)

The DEC is then calculated with the following expression

$$DEC = FAEC * FUEC * FDEC$$

The FDEC is a factor from 0 to 1, it depends on the discretion of the evaluator and it is a factor of the amount of damage that has Confinement Elements of structure in general, in Table 12 suggests some values for FDEC.

FD_{EC}	Description
0	• There were no pathology
0.01 to 0.03	• Small shrinkage cracks in the coating. • Paint peeling
0.03 to 0.10	• Small cracks less than 5 cm in length in the underside of the containment element. • Small cracks under 5 cm in length in a diagonal direction to support • Small cracks under 5 cm in length in a diagonal direction to support
0.10 to 0.20	• Cracks between 5 and 10 cm long on the lower face of the enclosure element. • Cracks between 5 and 10 cm of length in diagonal direction to the support. • Cracks between 5 and 10 cm long in the direction diagonally opposite to the support. • Detachment of coating up to 3% of the surface of the landfill. • Corrosion or efflorescence stains up to 10% of the confinement surface.
0.20 to 0.40	• Cracks up to 10 cm long on the lower face of the landfill. • Cracks up to 10 cm in length in a diagonal direction to support. • Cracks up to 10 cm in length diagonally opposite direction to support. • Coating detachment between 3 and 5% of the surface of the landfill.

0.40 to 0.50	• Cracks of between 10 and 15 cm long on the lower face of the landfill. • Cracks between 10 and 15 cm in length in a diagonal direction to support. • Cracks between 10 and 15 cm diagonally in the opposite direction to support. • Detachment of the concrete, reinforcing steel visible to 5% of the confinement surface.
0.50 to 0.70	• Cracks between 15 and 20 cm long on the bottom of the landfill. • Cracks between 15 and 20 cm in length in a diagonal direction to the support. • Cracks between 15 and 20 cm diagonally in the opposite direction to the support. • Concrete detachment corroded reinforcing steel visible to 5% of the confinement surface.
0.70 - 1.0	• Cracks with lengths bigger than 20 cm in the lower face of the landfill. • Cracks with lengths bigger than 20 cm in diagonal direction to the support. • Cracks with lengths bigger than 20 cm diagonally opposite direction to support. • Detachment of concrete with visible corroded reinforcing steel of more than 5% of the confinement surface.

Table 12. - Factors pathologies depending proposed for FDEC

Considering the most important structural deterioration in these elements, it was identified an action factor most important in the above items. Table 13 shows the values for FAEC.

FD_{EC}	Description
0	Does not require any repair
1	Minor repairs cleaning consisting of small scaled, seal cracks
2	Minor repairs consisting of patching cracks and small landslides
3	Major repairs consisting of repairing of the damaged wall
4	Major repairs or replacement consisting of wall reinforcement

Table 13. Values for Action Factor in Confinement Items

However the values for emergency measures to repair are the same as the above elements to take into account of non-imminent failure if not reinforced, the deterioration can be controlled with bracing. Table 14 shows the values for FAEC and FUEC

FU_{EC}	Description
1	Long term action
2	Medium term action
3	Short term action

Table 14. Values for Urgency Factor in Confinement Elements

Impairment Foundation (DC)

The DC is then calculated with the following expression

$$DC = FAC*FUC*FDC$$

The determination of the indices for the deterioration in the foundation, could not be made taking into account the comments of the pathologies in the inspection campaigns, because many of the pathologies that were the cause foundation problems were made subjectively since the inspection campaigns were only visual character, but with the support of the literature reviewed these indices were determined, which are shown in Table 15.

Percentage	Description
0	• There were no pathology
0.01 to 0.05	• Small cracks of not more than 5 cm in length in the foundation.
0.05 to 0.10	• Cracks between 5 and 10 cm long in the foundation. • Detachment of concrete in less than 5% of the surface.
0.10 to 0.20	• Cracks up to 10 cm in length in the foundation. • Concrete detachment 5 and 10% of the surface.
0.20 to 0.40	• Cracks of between 10 and 15 cm long in the foundation. • Detachment of the concrete between 10 and 15% of the surface. • Settlements or heave by volumetric change causing cracks up to 5 cm at the bottom of column or bearing wall.
0.40 to 0.70	• Cracks between 15 and 20 cm in length in the foundation. • Detachment concrete with visible steel between 15 and 20% • Settlements or heave by volumetric change causing fissures up to 10 cm in length.

0.70 - 1.00	• Cracks between 15 and 20 cm in length in the foundation. • Detachment concrete with visible steel between 15 and 20% • Settlements or heave by volumetric change causing fissures up to 10 cm in length.

Table 15. - Factors proposed depends the pathologies analyzed for FD

Similar to the confining elements deterioration, damage to the foundations of actions required to ensure the stability of the structure, Table 16 shows the values for FAC.

FA_C	Description
0	Does not require any repair
1	Minor repairs cleaning consisting of small scaled, seal cracks
2	Minor repairs consisting of patching cracks and small landslides
3	Repairs major repair consisting of part of the foundation
4	Major repairs or change consisting of the reinforcement elements of the foundation
5	Major repairs consisting of total foundation reinforcement using new components and underpinnings

Table 16. Values for Action Factor in Walls

And this structural element to be responsible for transmitting the loads acting on the structure at ground rudeness, actions have to be done if you have damage to endanger the stability of the structure should be immediate. Table 17 shows the values for FUC.

FU_C	Description
1	Long-term action
2	Medium term action
3	Short-term action
4	Immediate action

Table 14. Values for Urgency Factor in Confinement Elements

Conclusions

It was evaluated the 77 homes inspected using the proposed model and compared the states of each housing condition with the model proposed above, obtaining as result differences between each model. These differences were mainly due to the previous model only visual opinion based on housing status from the point of view of the obtained structural inspection; however the proposed model, using both the functional and structural index, provided values of states more real condition of visual observation of the home. However, it is necessary to continue the validation of the model to calibrate the ranges proposed for each of the indexes.

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