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A Seismic Risk Evaluation Method for School Buildings

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Abstract

In the last few decades, there was a noticeable increase in earthquakes activities that cause great losses related with human and structures. The losses have a negative effect on the economy especially in developing countries that should follow all possible scientific methods to minimize that bad effect. School buildings have an important role in the educational process and they may serve as emergency shelters after earthquake events. So, school buildings need a complete strategy for evaluating their capability to face the probable earthquakes. This paper is an important step for that required strategy to evaluate the seismic vulnerability of school buildings on the national level. A method is presented to develop qualitative norms for factors that supposed to have a major effect on the seismic behavior of the school buildings. This method is based mainly on questionnaire forms and a computer program in order to execute this method quickly and with reasonable accuracy based on scientific fundamentals .The method is calibrated using some affected school buildings by various earthquake events in different countries .The results showed good agreement with the state of damage of the school buildings, so it can be applied by the official authorities for preparing a prioritization plan of the structural safety of all existing school buildings in Egypt.

Keywords

School building; Seismic; Risk evolution; Earthquake

1. Introduction

The definition of “Seismic vulnerability “of an existing building is that describes its susceptibility to be damaged. On the other hand, “Seismic Risk” is defined as the ability of the building to sustain forces attributed from exposure to an earthquake, so it can be expressed by the following form:

Risk level = Hazard × Vulnerability level

The seismic vulnerability evaluation is a good guide to highlight local defects of the building, whilst the seismic risk evaluation is to obtain a global judgment of the capability of the building to sustain any future shock.

Table 1 . Choice of adequate method of the evaluation of the seismic vulnerability [2]

Expenditure	Increasing Computation Effort				
Application	Building Stock Buildings → Individual				
Methods	Qualitative → Quantitative				
	Hybrid				
	Observed Vulnerability	Expert Opinions	Score Assignments	Simple Analytical Models	Detailed Analysis Procedures

data collected by a "sidewalk survey". It is based on visual observation of the building from the exterior, and if possible, the interior. The factors considered are, plan irregularity, vertical irregularity, soil type and number of floors. ATC-21procedure is similar to that of FEMA 154 with more considered factors. The building judgment of both procedures is obtained by summing up the values of factors and the basic score. A study has been performed on actual damaged case "Nasser School Building" after Cairo Earthquake event of 12th. October1992 [8], [9]. An experimental study for seismic risk evaluation has been applied by, Islam (2017) on school buildings in Egypt [10].

There are several methods for the evaluation of seismic vulnerability (Calvi, G.M. et al. (2006) [1]. These methods are classified into qualitative and quantitative methods, and there are different interactions between them generating new hybrid methods as illustrated in Table1.The qualitative evaluation methods are based mainly on expert's judgments and the damage scale used from post-earthquake reconnaissance reports to produce damage statistics. The observed damage data is used to predict the effects of future earthquakes. The quantitative evaluation methods are based on the same methods used for new construction. Table 1 illustrates that the choice of the adequate method depends on the requirements, resources, available data, number of buildings under consideration and expenditure [2].

The qualitative methods have attracted many researchers. Whitman et al. (1973) [3] suggested the format of the damage probability matrix (DPM). According to the damage sustained in over 1600 buildings after the 1971 San Fernando earthquake, they compiled DPMs for various structure topologies. DPM is developed by ATC -13 (1985) [4] following the introduction of DPMs based on intensity.

Another development of (VIM) by Soliman (1992) [5] who presented a methodology to quantify the dynamic characteristics of the buildings and their effects on the overall response of the building. A study has been performed to relate the effect of these factors to the building response based on many field observations of previous research work and previous evaluation methodologies. The evaluation process is programmed with FORTRAN language to be applied systematically for the seismic vulnerability and risk evaluation of existing reinforced concrete buildings.

Ruggieri, Perrone, Leone, Uva, and Aiello (2020) has been applied on RC school buildings the "Rapid Visual Screening (RVS)" of buildings developed by FEMA 154 (2002) [6],[7] for potential seismic hazards is based on

All those previous methods are developed to be applied on any type of buildings, i.e., residential, commercial, etc. School buildings should have the priority for seismic risk evaluation because of their high public occupancy and they may serve as emergency shelters after any disaster. Schools need a rapid method to evaluate their seismic risk level and to provide basis for next steps of necessary mitigation actions.

A method is developed here-in-after to evaluate the seismic vulnerability and seismic risk for school buildings. This method aims to identify and classify the school buildings in terms of their seismic risk levels by a simple and quick procedure. The method consists of a two-questionnaire survey and a program in order to derive the seismic risk levels of all school buildings at a reasonable time. A "Priority List" of all inspected schools is obtained with their seismic risk levels arranged in ascending order. In Egypt, there is no emergency strategy for mitigation actions. It is very useful to decision makers to have that "Priority List" of all existing school buildings for the required strengthening plans.

2. The Seismic Risk Evaluation Method

The Method is based on a two-questionnaire survey and a program in order to derive the seismic risk levels of the school buildings at a reasonable time. The two questionnaires are designed to be effective in capturing deficiencies of the building that is supposed to have the major effects on its seismic behavior. Each deficiency considered to be a factor of a certain degree of effectiveness. The Method measured the relative importance of each factor by assigning a value representing its degree of effectiveness with respect to the other factors. It is based on previously-developed seismic evaluation methods, seismic codes and provisions, and the post- earthquake reconnaissance reports. Engineering sense and learning from past earthquakes are more important than any amounts of computation and analysis. Lessons could be learned from the damaged patterns from past earthquakes that have the demonstration of consequences of the deficiencies in design and construction. Therefore, the factors and their degree of effectiveness have been mainly derived from those lessons from post- earthquake reconnaissance reports in various countries that experienced destructive earthquakes. The valuable opinions of the experts, their observations had been recorded in those reports. The factors that considered in the current study are presented in the shown methodology in Fig. 1.

3. The Evaluation Procedure

The evaluation procedure is started with collecting data required for the evaluation process. A tour inside the school building gives a good idea of the actual state of the whole building and to obtain the required data. Photos are preferable to allow a later study of the building without returning to the school site. Once the survey questionnaires of the buildings are completed, all data obtained is programmed with C-Sharp (C#) language. All computation efforts are done by the program and the output comprising all the inspected schools in a list, called the "Priority List" arranged in ascending order of their seismic risk levels.

The method is based on the most important factors affecting the seismic behavior of the building. Each factor has a numerical value, and the sum of those values determines the seismic vulnerability and seismic risk levels. Those values are compared with the predefined ranges illustrated in the tables that will be explained later in the next sections. It should be mentioned that the "High Priority" schools should be defined in the questionnaire and recognized by the label H-P.

3.1 High Priority Schools H-P

The school is classified as H-P school if it has at least one of the following conditions:

3.1.1 Existence of Soft Storey

Soft storey mechanism is dangerous from the seismic point of view. It is the most frequent failure mode of school buildings since the soft storey usually located at the ground floor as a playground for the pupils. Those school buildings classified to be of high priority class should be firstly defined to take an immediate proper action to soft story problem by the decision maker, and then deal with any other defects detected from the evaluation process.

3.1.2 Existence of Two Adjacent Buildings

If there are two adjacent buildings with or without expansion joints, the decision maker should take an immediate proper action to control the pounding forces, and then deals with any other defects detected from the evaluation process.

3.1.3 Changes over the Lifecycle

Any changes, structural or non-structural, over the life cycle of the school buildings should not be ignored and recorded by the inspector in the questionnaire in details in the Notes section. Those cases considered to be of high priority class and involve immediate proper decision by the decision makers, and then deal with any other defects detected from the evaluation process.

3.1.4 Actual State of the Building FAS

The present state of the building reflects its ability to achieve the expected theoretical capacity. Cracks, maintenance, building age, the previous earthquake exposure are the factors considered within this factor. The non–conforming elements are the elements that do not satisfy the recommended condition. The non- conformity factor is obtained from Table 2 and denoted by FR that is used to account for the effect of the percentage of non–conforming elements in the whole building. Noting that a subscript for the considered factor must be added to the symbol FR to recognize each confirming factor for each case of evaluation as will be shown later.

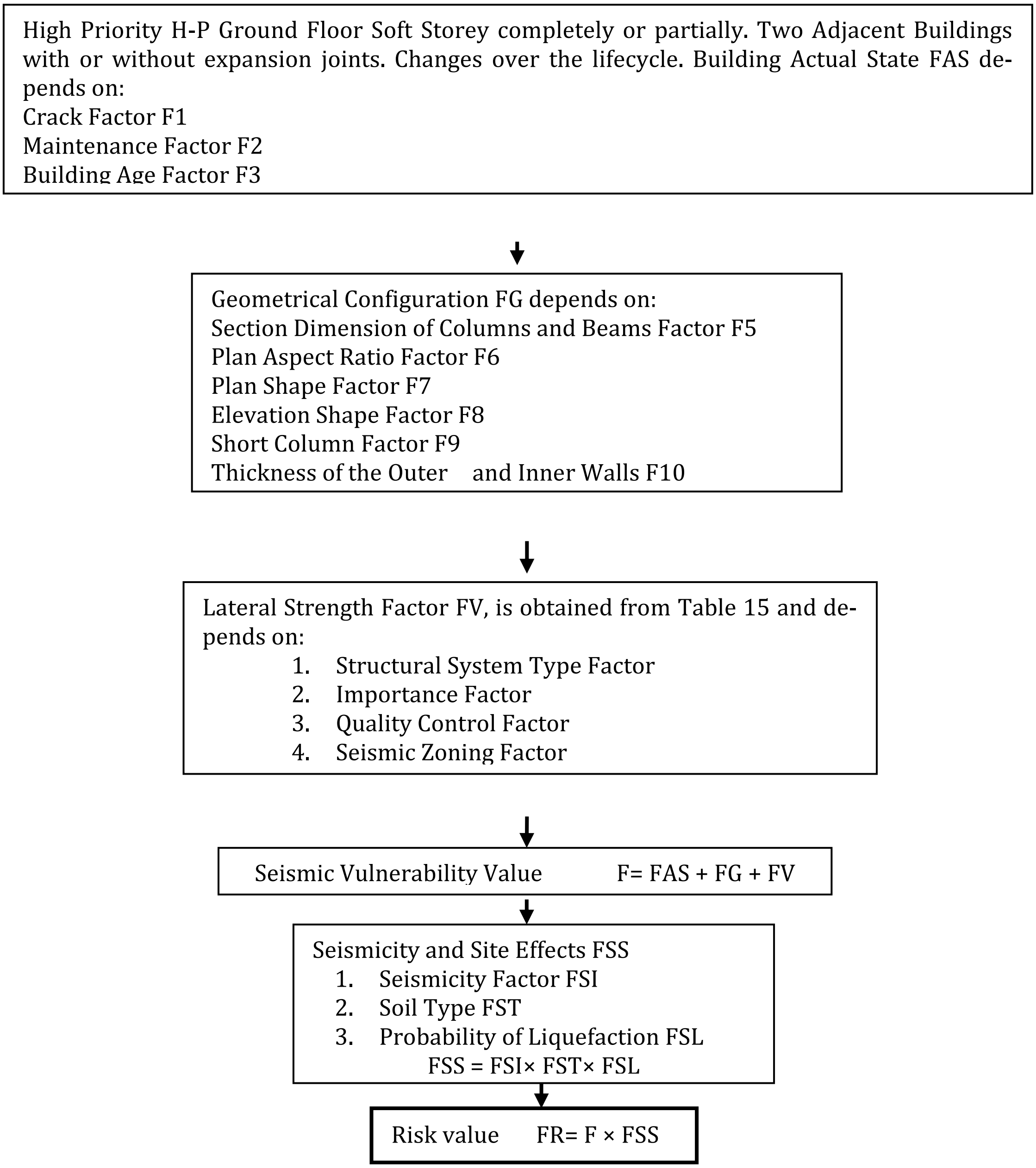


Figure1. Factors considered in the proposed evaluation methodology

Table 2 -Non-conformity factor FR

% Non-Conforming Elements	1-10	>10-25	>25-40	>40
Factor FR	1.0	0.75	0.50	0.0

3.1.5 Crack Factor F1

In general, the cracks are the features of the dissipation of energy. Building without cracks has the ability to sustain the shock and absorb the energy induced from earthquake more than buildings with cracks. This factor is obtained from Table 3, for different structural elements and different crack causes. If there are non-cracked elements Table 3 is used. Because all those elements composing the whole building the factor can be obtained by the summation of the cracked elements factors as illustrated in the following equation,

$$F1 = \sum (FC \times FR) \quad (2)$$

Where, FR: non-conforming factor obtained from Table 2 according to the percentage of the cracked elements to the total number of elements of the whole building.
The previous equation can expanded by adding of the subscript c , b , w ,and s for columns , beams, walls, and slabs Table 4 respectively as follow:

$$F1 = (FCc \times FRc) + (FCb \times FRb) + (FCw \times FRw) + (FCs \times FRs) \quad (3)$$

Table 3. Crack factor FC

Crack Cause*	I	II	III
Columns FCc	100	150	200
Beams FCb	30	50	70
Infill walls FCw	50	75	100
Slabs FCs	10	25	40

*I: Previous earthquakes, corrosion of steel, reduction in section dimensions or reinforcement, settlement, material deterioration or any other serious cause II: Change of use. III: Temporary local causes due to accidental effects.

Table 4. Values of F1 for non- cracked conditions

Element	Columns	Beams	Masonry Infill	Slabs
Crack Factor F1	300	100	150	50

3.1.6 Maintenance Factor F2

This factor takes into account the effect of maintenance on the seismic behavior of the building. It is based on the actual state factor Fas and the maintenance degree Dm obtained from Table 5 and Table 6, respectively. The summation of F1 previously determined and Fas that is obtained from Table 4 is the total value of the building actual state factor FTas .

Table 5. The actual state factor Fas

Actual State	Good	Pass	Poor
Fas	200	100	0

where,

$$F_{Tas} = F_1 + F_{as} \quad (4)$$

Table 6.Maintenance factor F2

FTas	Poor <550	Pass 500-700	Good >700
Degree of Maintenance Dm		F2	
No	0	50	150
Intermittent	30	100	150
Periodic	50	150	200

3.1.7 Building Age Factor F3

This factor represents the effect of building age on its overall seismic capacity. Material deterioration, corrosion of reinforcement, are some of the examples of the defects that may be encountered in old buildings, it is obtained from Table 7.

Table 7. Building age factor F3

Age / Life Time %	1-20	>20-40	>40-60	>60-80	>80-100
Age Factor F3	300	250	175	100	50

3.1.8 Seismic Exposure Factor F4

This factor reflects the effects of number of previous earthquakes and their intensities on the seismic capacity of the building and is obtained from Table 8. If the considered building never exposed to previous earthquake shocks the factor has a value as follow;

$$F4 = 300 \quad (5)$$

Table 8. Seismic exposure history factor F4

MMI Scale* / No. of exposure'	≤ V	VI	VII	>VII
1	300	200	150	100
2	200	150	100	50
≥3	150	100	50	0

* Modified Mercalli Scale Intensity MMI

The final actual state factor FAS of the building can be obtained from summing up all the previous four factors:

$$FAS = F1 + F2 + F3 + F4 \quad (6)$$

3.1.9 Geometrical Configuration FG

The geometrical configuration factor FG is obtained by summing up the following six factors:

3.1.10 Section Dimension Factor F5

This factor accounts for the effect of the section dimension of the columns and beams. In this current study the width of columns, dc and the width of beams, db are considered as shown in Table 9.

Table 9.Section dimension factor Fdc and Fdb

Column width dc (cm)	≥ 30 cm	< 30 cm
Fdc	100	0
Beam width db (cm)	≥ 25 cm	< 25 cm
Fdb	100	0

Then the factor F5 is obtained from the following equation,

$$F5 = FRco \times Fdc + FRbe \times Fdb \quad (7)$$

Where,
FRco : non-conforming factor for columns obtained from Table 1.
FRbe : non-conforming factor for beams obtained from Table 1.
Fdc : column section dimension factor.
Fdb : beam section dimension factor.

3.1.11 Plan Aspect Ratio Factor F6

This factor accounts for the unfavorable out-of-phase response of long strip buildings. This factor depends on the ratio of the maximum length, L to the maximum breadth, B of the plan. The factor is obtained from Table 10.

Table 10 - Plan aspect ratio factor F6

L/B	<3.0	3.0-4.0	>4.0
F6	200	150	0

3.1.12 Plan Shape Factor F7

The different possible plan shapes are shown in Fig.2. This factor is based on lx/LX and ly/LY ratios and is obtained according to the smaller resulted value of F7 of the two directions, as illustrated in Table 11.

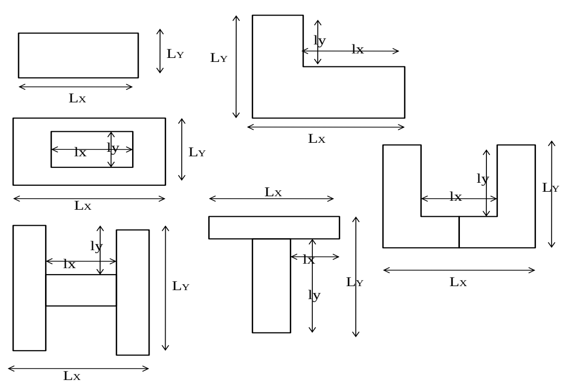


Figure 2. Different Plan Shapes

Table 11. Plan shape factor F7

lx / LX OR ly / LY	≤ 0.2	>0.2-0.4	>0.4-0.6	>0.6
F7	300	150	50	0

3.1.13 Elevation Shape Factor F8

Complicated elevation shape alters the uniformity of stress and deformation distribution. There are different features of elevation irregularity. The current study is concerned with the plan width over the height of the building. The factor F8 is obtained from Table 12 according to the two ratios, Rg and Rm such that, Rg = BG.L / Bmax and Rm = Bmin / Bmax, respectively. Bmax and Bmin are the maximum breadth and the minimum breadth of the building, respectively and BG.L, is the breadth at the ground level of the building.

Table 12 - Elevation shape factor F8

Rm	1	0.8-1.0	0.8-0.6	<0.6
Rg	1	0.9-1.0	0.9-0.8	<0.8
F9	300	200	100	0.0

3.1.14 Short Column Factor F9

Concentration of shear force in short columns is one of the frequently observed causes of damage in earthquakes in school buildings. The factor F9 is obtained from the two ratios, FH and FN. These depend on the ratios of the short column height hsh to the story height hs and the ratio of the number of short columns nsh to the total number of columns nc, respectively. FH and FN can be obtained from Table 13 and Table 14, respectively.

Table 13 - Short column height factor FH

hsh / hs	≥ 0.8	0.70-0.80	0.60 -0.70	< 0.60
FH	300	200	100	0

Table 14 - Number of short column factor FN

nsh / nc	0.0-0.05	0.05-0.15	0.15-0.30	> 0.30
FN	1	0.80	0.50	0

Both previous ratios are substituted in the following equation to obtain F9:

F9= FH × FN (8)

3.1.15 Wall Thickness Factor F10

Outer or inner masonry infill walls being the stiffer component attract most of the lateral seismic shear forces on buildings. Field evidence has shown that continuous infill masonry walls can help reduce the seismic vulnerability. The factor F10 is obtained from Table 15 and from equation (9).

Table 15 - Wall thickness factor F10

Outer wall thickness two	12cm	25cm	Inner wall thickness twi	12cm	25cm
Fo	100	200	Fi	100	200

This factor can be obtained from the following equation,

F10 = Fo + Fi (9)

Summing all previous factors FG is obtained,
FG = F5 + F6 + F7 + F8 + F9 + F10 (10)

3.1.16 Lateral Strength Resistant Factor FV

The lateral strength factor of the existing buildings takes into account the existing resistance of the building for seismic forces. This is obtained from Table 16, according to seismic design coefficient Cs that is defined as the ratio of the lateral design force calculated from empirical expressions presented by design codes to the total weight of the building. ESEE regulations (1988)[12] is applied in the current study to determine Cs ratio.

Table 16 - Lateral strength resistant Factor Fv

Cs	> 0.15	0.05-0.15	< 0.05
FV	0	150	300

4. The Seismicity Vulnerability Value F

The seismic vulnerability value F is obtained from the following equation:

F = FAS + FG + FV (11)

The current study considered that the seismic vulnerability level is inversely proportional to its value. The high values corresponding to low vulnerability level and vice versa. The maximum value of the seismic vulnerability is 3400, corresponding to the lowest vulnerability level of the evaluation process.

4.1 Seismicity and Site Effect Factor FSS

The seismicity and site effects are essential to determine the seismic risk level of the building.
Seismicity Factor FSI
The effect of the seismicity factor on the risk level of the building is based on the maximum expected magnitude within the building life time with a certain probability of reoccurrence period. The earthquake design magnitude M can be determined from the reoccurrence curve and hence the factor FSI is obtained from Table 17.

Table 17 - Seismicity site factor FSI

M	< 5.0	5.0-7.0	> 7.0
FSI	1.0	0.9	0.8

4.2 Soil Type FST

According to the property of the foundation soil strata the site factor can be determined. Three categories of soil are considered, stiff dense, medium dense, and soft that are denoted by, soil I, soil II, and soil III respectively, as shown in Table18.

Table 18. Site factor FST

Soil category	soil I	soil II	soil III
FST	1.0	0.90	0.80

4.3 Liquefaction Potential Factor FLI

The liquefaction phenomenon depends on the type of soil and the design magnitude M of the earthquake. Liquefaction susceptibility can be obtained using soil testing report. Hence, the liquefaction potential factor can be obtained from Table 19.

Table 19. 4Liquefaction potential factor FLI

Liquefaction probability	Improbable	Probable
FLI	1.0	0.80

The final factor for the evaluation of seismicity and site effects is obtained from the following equation:

$$FSS = FSI \times FST \times FLI \qquad (12)$$

4.4 The Seismic Risk FR

Final value of seismic vulnerability of the existing building F obtained from equation (11), if multiplied by final value of seismicity and site factor FSS, The seismic risk FR can be obtained from the following equation,

$$FR = F \times FSS \qquad (13)$$

The seismic risk factor value FR reflects the level of expected damage of a building if subjected to an earthquake of expected magnitude. The limits of the risk levels are illustrated in Table 20.

Table 20. The limits of risk levels

Risk Level	Low	Moderate	High
FR	>2000	2000-1500	<1500

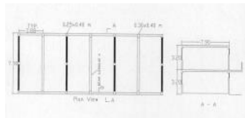
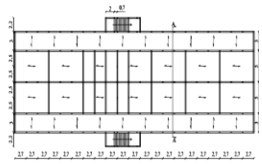
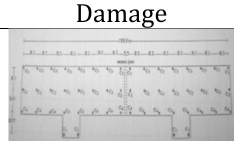
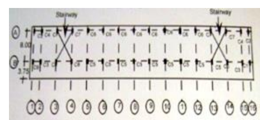
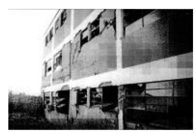
5. Application of The new Method

The method has been applied to eleven school buildings in different countries that have experienced different damage levels during previous earthquakes. The data required was obtained from the post-earthquake reconnaissance reports used as input data to the program.
A “Priority List” is resulted including the eleven schools arranged in ascending order according to their risk levels FR. The “Priority List” is illustrated in Table 21. The risk levels FR were found to be in good agreement with the observed damage recorded in the post-earthquake reconnaissance reports with or without photos as illustrated in Table 22.
It is worthy to mention that Nasser School in Egypt has completely collapsed during Cairo Earthquake in 1992, Sobaih and Soliman (1993) [9].

6. Conclusion

The method is a quick tool in order to generate the priority list which helps to identify the most critical school buildings. The results of the evaluation process of the school buildings were found to be in good agreement with the observed damage in the post-earthquake reconnaissance reports. The method can be applied by the official authorities for preparing a prioritization plan of the structural safety of all school buildings in Egypt. It should be mentioned that most of the high-risk buildings are of high priority class H-P, that interpret the reorganization of those H-P schools to take an immediate action by official authorities to mitigate their negative effects on schools' safety. Statistical studies and extensive analysis are still needed to correlate the values recommended in this methodology.

Table 21. The agreement of risk level of the study cases and their damage states

FR	High Risk<1500	FR	Moderate Risk 1500-2000	FR	Low Risk>2000
1160 H-P	 Case2 Cariaco,Venezuela	1685	 Case5 Nazca City, Peru Reported Poor Behaviour	2025	 Case 8 Peru Reported Damage in Short Columns
1280 H-P	 Case11 Cairo, Egypt Complete Collapse	1944	 Case 9 Arequipa City, Peru Reported Moderate Damage	2040	 Case 10 Guatemala, Colombia Reported Slightly Damaged
1357	 Case 6 Bingöl, Turkey	1980 H-P	 Case 1MexicoCity Reported Moderate Damage	2052	 Case 7 Mexico City Reported Slightly Damaged
1498 H-P	 Case 3 Cariaco, Venezuela		—	2340	 Case 4Nazca City, Peru Reported Slightly Damaged

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