Mobile Application to Assess Seismic Vulnerability of RC Buildings in Brazil

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Abstract. Similar to the Federal Emergency Management Agency's (FEMA) P-154 in the United States, which provides a rapid on-site survey method for building data to assess vulnerability indices and offers the RSV App mobile electronic form, this paper proposes the development of a mobile application for the visual rapid screening method for the Brazilian community of engineers and inspectors to assess the seismic vulnerability of existing structures. The simplified qualitative method adopted in the application originates in Japan, and a similar initiative was observed in that country at the symposium "Future of post-disaster assessment for buildings"; however, such an application was not found. Considering that the evaluation is carried out on-site, the application aims to facilitate the rapid screening process and disseminate the use of the method. Seismic-V was developed based on the Dart programming language and the Flutter framework. The Android Studio Giraffe IDE (Integrated Development Environment) — 2022.3.1 Patch 3 was chosen. Among the functionalities, it allows the structural verification for the five seismic zones with soil classes recommended in NBR 15.421. The user is required to provide real structural deterioration conditions, data, and structural characteristics such as number of floors, number of pillars, and respective cross-section that will support the seismic performance sub-index. Other features will be discussed in the paper and, at the end, a comparison will be developed between the results issued by the application and those calculated manually, with a discussion of the results. The proposal is relevant given the speed of application of the method and the initial screening that helps to prioritize existing buildings in future quantitative analytical approaches.

Keywords: Seismic assessment; Structural analysis; Safety evaluation; Rapid Visual Screening.

1 Introduction

In the last decades, the number of seismographic stationsin Brazil has increased, allowing for the monitoring of seismic activity in the country. The Brazilian Seismographic Network (RSBR) is composed of over 60 seismographic stations distributed throughout the country. Although the recorders indicate low seismic activity, the country is not free from the occurrence of earthquakes. Some recent studies have discussed the importance of not neglecting the seismic load in the designing of structures, even in regions with low seismic activity [1], [2].

Since the losses from earthquakes come from the structural weak of exsiting buildings, first attempt is to evaluate the seismic vulnerability of existing structures and then enhance their seismic performance. In this context, methods for assessing a large number of buildings in a short period are essential. They became popular in the beginning of 70's in many contries as Japan, United States, Italy, Canada, New Zealand and Turkish. Some authors [3] also refers to these methods as Rapid Visual Screening (RVS) methods because they are based on visual inspections of the buildings to determine the priority evel of the buildings and also identify the most critical ones with potential seismic hazard. Once the methodologie is based on walking around the building and observing the structural conditions, it is important to have a tool that can help the inspector to collect the data and also evaluate the building in real time.

The Federal Emergency Management Agency (FEMA) in the United States developed the manual FEMA P-154, which provides a rapid on-site survey method for building data to assess vulnerability indices. The method offers the RSV App mobile called the P-154 RSV Form , which allows the collection of data, visualization, and screening of buildings with potential seismic vulnerability [4]. A similar effort was observed in Japan at the ”Future of Post-Disaster Assessment for Buildings” Symposium however the application was not found available.

Considering that Japanese method was adopted to Brazilian reality by [5] and have been used by some researchers to evaluate heritage buildings [6] and taking account that part of the application of the method is conducted on-site, this research proposes a mobile application aimed at facilitating the rapid screening process of the seismic vulnerability of existing structures and promoting the use of the method. The tool enables the evaluation of structures across the five seismic zones and the soil classes of in [7].

2 Materials and Methods

This section is divided into two subsections: Theoretical Framework and Framework of Mobile Application. The first subsection presents the theoretical basis of the method used in the application, while the second subsection describes the application's development process.

2.1 Theoretical framework

The Japanese procedure for post-earthquake evaluation of buildings is a simplified qualitative method that assesses the seismic vulnerability of existing structures. It consists of three distinct levels of procedures: the first level, the second level, and the third-level procedures [8]. The first level is the simplest, whereas the third-level procedure involves the most complex calculations. According to [9], the first-level procedure aims to assess the strength of a structure based on the average strength of walls and columns, checking if the building can withstand earthquake forces without requiring ductility. In the second level, seismic capacity is evaluated by considering only the dynamic properties of the columns, such as ductility and resistance. Meanwhile, in the third level, both the resistance and ductility of the vertical and horizontal elements (columns, walls, and beams) are considered to evaluate the building's performance during an earthquake. In this study the first pier evaluation procedure for reinforced concrete buildings was followed. The seismic index of structure reflects the maximum elastic response of shear coefficient of each floor which is calculated by the following equation:

$$I_S = E_0 \cdot S_D \cdot T_D, \tag{1}$$

The seismic index of the structure is calculated by multiplying the Basic seismic index of structure E_0 by the Irregularity index S_D and the time index T_D which considers the deterioration of strength and ductility after construction [10]. These structural parameters are taken during the on-site inspection of the building. Thus the method depends on identifying information previously on field as structural irregularity, soft stories, short columns or even soil conditions, seismic zone and use of building. The seismic demand index is calculated by the following equation:

$$I_S = E_S \cdot Z \cdot G \cdot U, \tag{2}$$

Where E_S Basic seismic demand index of structure, standard values of which shall be selected as $E_S = 0.8$ for the first level screening. The Ground Index G accounts for the effects of the amplification of the surface soil, geological conditions and soil-and-structure interaction on the expected earthquake motions (Table 1). The usage index U takes in account for the use of the building.

[11] also employs the concept of the reserve of the structure's load-bearing capacity, R_{CR} , which is the difference between the seismic index, I_S, and the seismic demand index I_{S0}, expressed as a percentage of I_S. The reserve capacity of the structure is calculated by the following equation:

$$R_{CR} = \left(\frac{I_S - I_{S0}}{I_S}\right)\%, \tag{3}$$

Table 1. Values of Z for each seismic zone, G for each type soil and U for each usage of building

Seismic Zone	Z	Soil Type	G ($Z \leq 0.100$)	G($Z = 0.150$)	Usage Index	U
Zone 0	0.025	A	0.8	0.8	I	1.00
Zone 1	0.05	B	1.0	1.0	II	1.00
Zone 2	0.10	C	1.2	1.2	III	1.25
Zone 3	0.15	D	1.6	1.5	IV	1.50
Zone 4	0.15	E	2.5	2.1	-	-

2.2 Framework of mobile application

The Dart programming language is a multiparadigm, cross-platform, statically typed language developed by Google in 2011. It is designed to be fast, secure, and easy to use, and is employed for developing web, mobile, and desktop applications. As an object-oriented language, Dart structures applications using objects that interact with one another. Objects are entities that possess state and behavior. The state of an object is represented by its attributes, while its behavior is represented by its methods. Dart is compiled into JavaScript code, enabling its execution in web browsers. Additionally, it can be compiled into native code, allowing it to run on mobile devices and servers.

Flutter is a cross-platform application development framework developed by Google in 2015, based on the Dart programming language. It is used to create natively compiled applications for operating systems such as Android, iOS, Windows, Mac, and Linux. The development kit utilizes a set of widgets to build the graphical user interface of applications. These widgets are reusable building blocks that can be combined to create complex graphical interfaces. The mobile application, Seismic-V, was developed using the Dart programming language and the Flutter framework. The IDE (Integrated Development Environment) chosen for development was Android Studio Giraffe — 2022.3.1 Patch 3. The flowchart of the application is shown in Fig. 1. The application consists of ten screens: it begins collecting data and the last one displays the result of the screening. The screens are designed to guide users through the process of evaluating the seismic vulnerability of existing structures.

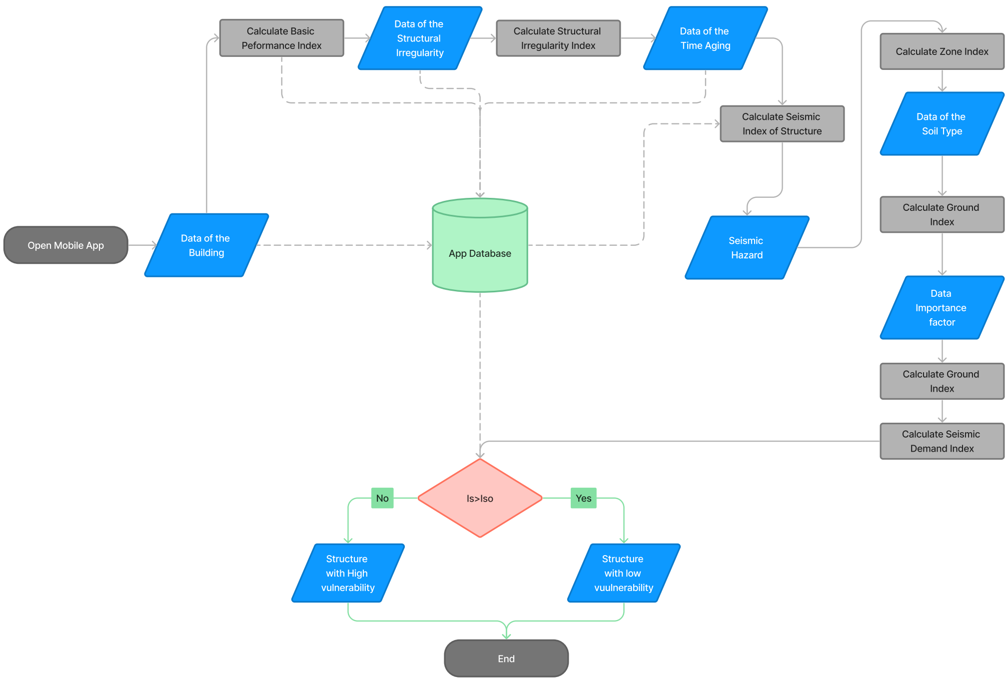
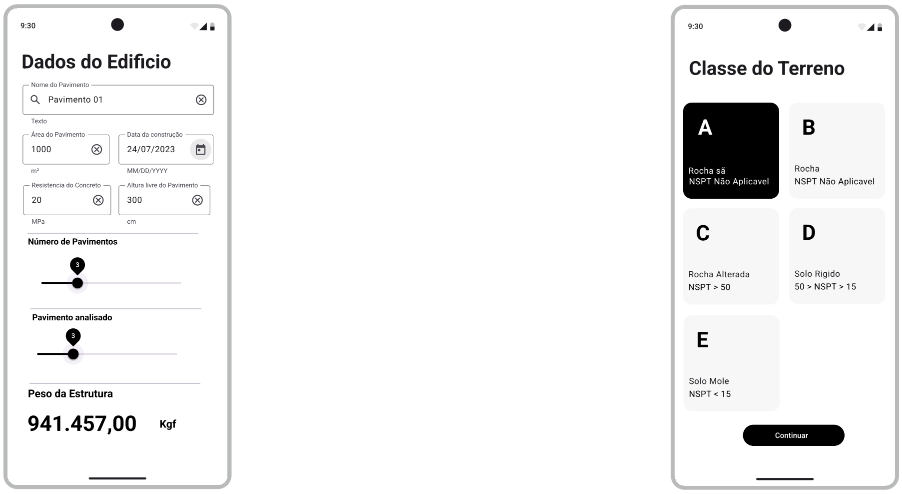


Figure 1. Flowchart of the mobile Application

Figure 2a illustrates the application's screen where users will enter relevant structural information such as the number of floors, the specific floor under study, and the structure's weight. Users will also input the quantity and cross-sectional area of the columns, which will determine the basic structural performance subindex. Subsequently, users proceed to the calculation of the Irregularity index S_d, where they will input the floor plan dimensions as required by the adapted Japanese method. In Fig. 2b the soil class must be informed.



(a) (b)

Figure 2. Details of application: (a) Input data of the structure; (b) Main screen of the application

Figure 3a prompts users to provide the actual condition of the structure, including deformation, cracks, fire damage, and finishing. In this stage, users must also specify the building's age. The screen depicted in Fig. 3b corresponds to the seismic hazard or seismic demand index, requiring the selection of the seismic zone in which the building is located and the importance factor of the building Fig. 4a.

(a) (b)

Figure 3. Pressure variation along the nozzle: (a) Time Index screen; (b) Zone Index screen

The final and principal screen of the application is shown in Fig. 4b, presenting the verification results by providing the seismic performance indices and seismic demand index. If $I_s > I_{so}$, a message indicating "Adequate Safety Level" will be displayed. Otherwise, a recommendation for verification using quantitative methods will be provided. A useful feature is the graph showing the reserve capacity of the structure.

(a) (b)

Figure 4. Comparison of Seismic index and Seismic demand index: (a) Usage index screen; (b) Output screen of the application

2.3 Case Study

Model structures obtained from literature [5] were used as an application example for the tool. The input values, including the sum of the cross-sectional area of the column and the weight of the building above the story under evaluation, are presented in (Table 2). Structure Model II has a concrete compressive strength of 20 MPa. The story height is 2.80 meters, and the clear span is 4.00 meters. The cross-sectional dimensions of the columns are 20x30 cm², while the beams have a cross-section of 15x40 cm². The slabs are made of reinforced concrete with a thickness of 10 cm. This structure model has three stories with a L shape plan (20.90 m x 20.90 m), covering an area of 1.363,68 m² (Fig. 5). According to the literature, the time index is $T_d = 0.9$ and the usage index is U=1.5 (essential usage).

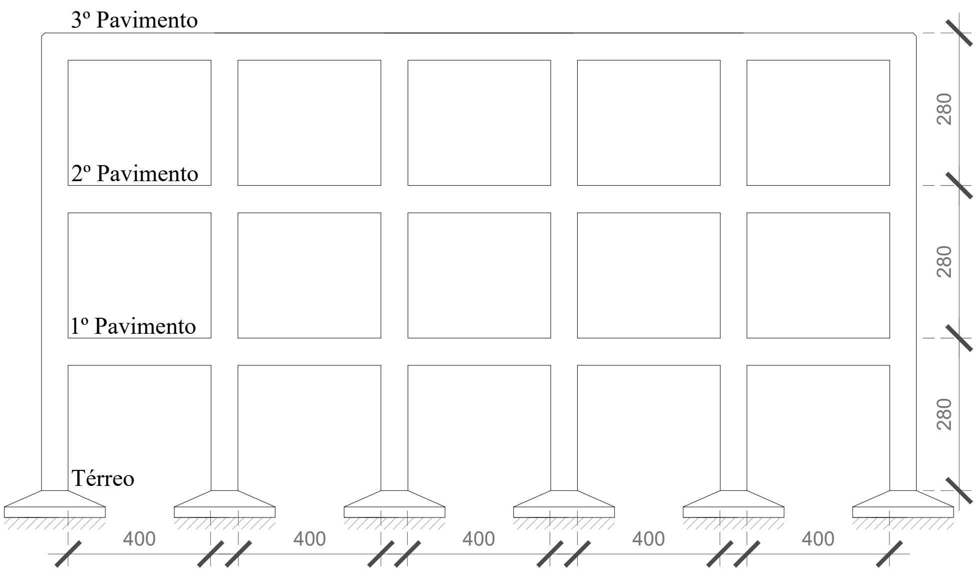


Figure 5. Model Structure II

Table 2. Input data of Model Structure II from [5]

-	Floor 1	Floor 2	Floor 3
Level of floor	2.80	5.60	8.40
Weight of the building upper the story (W) in kgf	941.457,00	628.936,00	316.415,00
Floor area in m2	454,66	454,66	454,66
Sum of cross-sectional area of column Ac2 in cm2	36.660,00	36.660,00	36.660,00
Basic seismic index of structure E0	0.17	0.20	0.34
Irregularity Index SD	0.80	0.80	0.80
Time Index TD	0.90	0.90	0.90
Seismic index of Structure	0.12	0.15	0.24

3 Results and discussion

The results from the mobile tool is compared with those obtained through hand calculations, as referenced in [5], and are displayed in Table 3. For Structure Model II, the time index T_d was identical to that adopted in the original example. The last two column of Table 2 shows the seismc demand index calculated by the mobile tool, which are very close to the manual calculations.

Table 3. Comparison between the results obtained by the mobile tool and manual calculations for first Floor

-	Mobile Tool	[5]	Seismic Zone	Soil Type E - I_{SO} [5]	Mobile Tool - I_{SO}
Index E0	0,17	0,17	0	0,08	0,08
Index SD	0,80	0,80	1	0,16	0,16
Index TD	0,90	0,90	2	0,31	0,31
Seismic index	0,12	0,12	3 e 4	0,39	0,39

4 Conclusions

The differences are attributed to the rounding of the values in the mobile tool. The results demonstrate the effectiveness of the application in calculating the seismic performance index of the structure. The application is user-friendly and provides a rapid screening of buildings, allowing the identification of those that require further evaluation using qualitative methods. The tool is essential for the Brazilian community of engineers and inspectors, as it facilitates the rapid screening process and promotes the use of the method. The development of the mobile application is not concluded, and further improvements are necessary as a database implementation to store the results of the evaluations and the inclusion of a feature to generate reports and compare performance for a large number of buildings. The application is available for download at the following link: GitHub.

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