FEMA 310 Tier 1 seismic evaluation of existing building: A case study of a 7-story academic RC building of Jenderal Soedirman University, Indonesia

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Abstract. A need to predict the seismic vulnerability of current buildings has led to a heightened interest in studies that deal with seismic vulnerability assessment methods. The easiest and fastest method, known as a walk-down survey or a street survey, involves just the superficial information accumulated during a short inspection of a building. This paper picks a fairly new seven-story academic building made of reinforced concrete (RC) located at the Jenderal Soedirman University in Purwokerto, Indonesia, which was designed in 2015 using construction details illustrative of that exact period, for FEMA 310 Tier 1 assessment in the context of Performance-Based Earthquake Engineering (PBEE). Mandatory checklists as a role of the region of seismicity and the building’s level of performance are done. The outcomes after a procedure projected the building in the case-study demonstrated a range of possible flaws and seismic vulnerability. Therefore, detailed comprehensive evaluation is intensely endorsed.

1. Introduction

Earthquakes threaten both buildings and people [1-6]. The amount of deaths as well as injuries caused by earthquakes is directly linked to the building’s vulnerability as well as the readiness to deliver first aid [7]. Hence, the seismic vulnerability assessment of the current buildings and particularly of the strategic buildings, e.g., the academic buildings, is of the utmost urgency. Academic buildings ought to be deemed as the top vital buildings in a society [8], as they play a vital part in the educational procedures and could be used as emergency shelters if an earthquake occurs. In that case, academic buildings require a comprehensive strategy for assessing their ability to confront possible earthquakes. Academic buildings are often particularly complicated structures and they have extremely varied roles, which range from functions common to class rooms, as well as meeting rooms, science labs, and offices to warehouses in which dangerous and degradable substances get stored. Because of their unique construction, academic buildings are sometimes quite vulnerable to seismic occurrences.

The requirement of foreseeing the seismic vulnerability of current buildings has brought heightened interest in studies which deal with developing seismic vulnerability assessment methods. Several methods have been suggested in the literature, and these can normally be put into 3 types. The easiest and fastest method, known as a walk-down survey or a street survey, involves only some superficial
information accumulated from a short examination of the buildings. The quantity of floors, as well as vertical and plan irregularities, where the building is located, how old the building is, the building’s fundamental structure, as well as the obvious material and the quality of its workmanship are the standard parameters utilized. FEMA P-154 [9], FEMA 310 Tier 1 [10] assessment and the Japanese assessment [11] falls into that classification. The objective of rapid evaluation methods is used to classify or rank extremely susceptible buildings which deserves more investigation [12].

In the past few years, because of the significance of educational facilities, a lot of scientists have concentrated on the seismic vulnerability of academic buildings. O’Reilly et al. [13] analyzed the seismic evaluation of 3 current school structures which are representative of Italian school construction stock. They assessed the expected annual loss (EAL) as well as the school’s collapse safety. Michel et al. [14] established reasonable probabilistic procedures centered scenarios for mid-size construction stock and did several chosen damage scenarios utilizing school structures in the Basel city. A methodology was submitted by Jaime and Nino [15] particularly for Mexican public school buildings to complete a cost-benefit assessment to evaluate the options for either retrofitting or reconstructing school buildings concentrated on the justification of direct physical losses due to future seismic occurrences. De Angelis and Pecce [16] established a cataloging of the seismic vulnerability of nonstructural elements in school buildings dependent on survey forms taken to assemble a nonstructural index along with a priority ranking which demonstrates the top vulnerable classification of nonstructural elements.

Mazumder et al. [17] submitted a seismic vulnerability evaluation method on a tiny scale for Chittagong University of Engineering and Technology (CUET) campus region in Bangladesh. At the close of the survey they established that the majority of the structure had excellent performance scores ranging from a level 1 evaluation. Amongst the structures surveyed, merely two percent of these structures can be placed in this classification where they are extremely vulnerable to earthquakes. After the earlier researches and as an extension which enlarges the extent of the work done by Haryanto et al. [18], this paper chooses a comparatively new seven-story academic structure made of reinforced concrete (RC) at the Jenderal Soedirman University in Indonesia. It was designed back in 2015 with the construction specifics being typical of that time period, for FEMA 310 Tier 1 [10] assessment in the context of Performance Based Earthquake Engineering (PBEE). Necessary checklists as a role of the region of seismicity and building’s performance level were done and the process results were reviewed.

2. Methodology

2.1. Description of the case-study building

The current academic structure studied, which was the Integrated Laboratory (Faculty of Economics and Business), is a seven-story RC building in Purwokerto, Indonesia; construction started in 2105. This structure is around 5810 m$^2$ in area along with being thirty meters high. Average slab elevation is 120 mm along with a 175 mm spacing out of longitudinal and transverse reinforcements. The structure is built using moment resisting frames as a lateral force resistance system in 2 horizontal directions. Figure 1 illustrates an isometric view as well as a plane view of a typical floor level of the building. Member dimensions, structural detail illustrations, foundation specifics as well as additional data was assembled from the structure’s owner, which is Jenderal Soedirman University in Indonesia.

2.2. Rapid Visual Screening

Rapid Visual Screening (RVS) in agreement with FEMA P-154 [9] is an example of the extremely recommended means of doing a seismic vulnerability evaluation and it can be done without doing structural computations, and instead utilizing a sidewalk visual survey of the structure as well as filling out an information collection form from the surveyor [19]. That provides a notion of where an in-depth research must be completed grounded on the prioritization of the weakness and suggesting actions for the equivalent. RVS survey sheets may be personalized centered on their context [20]. For instance, in India screening for masonry structures along with buildings made of reinforced concrete are individually treated for 5 different seismic regions [21,22]. In Japan, this form is centered on seismic index (intensity, ductility, and consistency) of structures [23] and in Canada both of the structural parameters (stiffness
and regularity) along with nonstructural parameters (occupancy and falling hazards) of the structure are considered [24].

(a) Isometric view of the building

(b) A typical floor plane

Figure 1. Illustration of the case-study building
The total order for executing the RVS process can be seen in FEMA P-154 [9]. After the project’s scope and budget are defined, enactment of the RVS program persists with further pre-field actions, as follows:

1) Pre-field development, to include selecting and developing a record-keeping procedure, development of any desired electronic scoring devices, as well as the assemblage and development of maps detail the local seismic risk data;

2) Choice of a Data Collection Form centered on the seismic risk and review and revision of the Data Collection Form for the specific requirements of the RVS system;

3) Choice and training of the screening personnel;

4) Procurement and the review of pre-field information, to include a review of accessible structure files and databases to gather existing data on the structures that is to be screened (e.g., the address, the lot number, amount of levels, and the date it was designed) and identifying the types of soil for the area being surveyed; and

5) Evaluation of current structure plans, if they are available.

2.3. Tier 1 Evaluation

Tier 1 evaluation (screening phase) comprises several groups of checklists which let a quick assessment of the building’s structural, nonstructural, as well as the foundation and the geologic risk aspects. As seen in table 1, the Basic Structural Checklist will be done for structures in areas of low seismicity getting assessed on the Immediate Occupancy Performance Level and structures in areas of both moderate as well as high seismicity. The Supplemental Structural Checklist will be done as well as a Basic Structural Checklist for structures in areas of moderate seismicity getting assessed for the Immediate Occupancy Performance Level and structures in areas of high seismicity.

The intention of the screening phase of FEMA 310 [10] is to detect those structures which seem to conform to the authorized seismic performance. During the screening phase, a building’s structural type is selected for each of the buildings utilizing one of twenty-four types of building. A FEMA change for 310 [10] in comparison to FEMA 178 [25] adds brand-new building types. The layout of the subject structure is first assessed in contrast to the design requirements of the model’s building codes dependent on the building’s structural type. If the structure is recognized as having been conceived and built in agreement with the selected model building code for that particular building style, called the benchmark structures, and after that the structure is considered to have passed the structural design constraints [26].

| Region of seismicity | Level of performance | Region of low seismicity | Required Checklist |
|----------------------|----------------------|--------------------------|-------------------|
|                      |                      | Basic structural | Supplemental structural | Geologic site hazard and foundation | Basic nonstructural | Supplemental nonstructural |
| Low                  | LS                   | ✓                      | ✓                   | ✓                   | ✓                   | ✓                      |
|                      | IO                   | ✓                      | ✓                   | ✓                   | ✓                   | ✓                      |
| Moderate             | LS                   | ✓                      | ✓                   | ✓                   | ✓                   | ✓                      |
|                      | IO                   | ✓                      | ✓                   | ✓                   | ✓                   | ✓                      |
| High                 | LS                   | ✓                      | ✓                   | ✓                   | ✓                   | ✓                      |
|                      | IO                   | ✓                      | ✓                   | ✓                   | ✓                   | ✓                      |

1A checkmark designates that the checklist must be completed for a Tier 1 Evaluation as a function of the region of seismicity and level of performance.

2LS = Life-Safety; IO = Immediate Occupancy

Limited structural computations, known as Quick Checks [10], are utilized within this phase of the assessment. Rough computations are done to approximate the seismic forces opposed by the main lateral force resisting aspects. These forces are then calculated dependent on an unlimited earthquake base shear yet subsequent forces are diminished at the element level and then contrasted with an acceptable
force. The intention is that these Quick Checks can be done with a small amount of computational energy and it does not necessitate a comprehensive structural assessment of the building.

3. Result and discussion

3.1. Final level 1 score

Figure 2 indicates the chosen Data Collection Form. Centered on the structure type, the case-study structure accepted as C1 (moment-resisting frame) and C3 (concrete frame structures with unreinforced masonry infill walls), so the basic scores are 1.7 and 1.4, respectively. Moreover, the assessment results reveal that with the RVS technique, the structure has a final level 1 score, $S_{L1}$, of +3.6, and +1.4 for structure type C1 and C3 respectively. As the final level 1 score, $S_{L1}$, for structure type C3 less than the cut-off score, 2.0, a detailed structural evaluation is necessary. Essentially, the score is an assessment of the likelihood (or chance) that the structure will collapse if ground motions happen that equal or surpass the maximum considered earthquake targeted risk (MCE) ground motions. For instance, a final score of +1.4 indicates a probability of $10^{-1.4}$, or 1 in roughly 4.00, that the structure will collapse if these ground motions happen. These score estimates are centered on limited noted and analytical information, hence the likelihood of collapse is consequently an estimate. It should be stated that the prior study done by Haryanto et al. supplied more details of the RVS findings for the case-study structure along with a further 8 academic structures at the Jenderal Soedirman University in Indonesia [18].

![Figure 2](image-url)
3.2. Screening phase
It is crucial to collect pertinent data of a structure as much as feasible via illustrations, analysis, design computations, a soil report (if offered), inspection and prior inspections report, and prior repair works [27]. At minimum one location official visit will be made to assess exposed conditions of the configurations, construction features, site and its base, and the adjoining structures [28]. The most crucial step for suitable condition assessment of a structure is identifying any current damages and the probable causes of the damage. Table 2 shows the checklists considered necessary in this research for the moment resisting frame in in high seismicity. With a structure in high seismicity, it is required to finalize the components for low along with moderate seismicity, along with the elements of high seismicity like a strong column and a weak beam, or column and beam bar splices and the spacing of stirrups. Each checklist evaluation statement will be marked as being Compliant (C), being Noncompliant (NC), being Unknown (U), or being Not Applicable (N/A).

| No | Parameters                                      | Statements |
|----|------------------------------------------------|------------|
| **Basic Structural Checklist** |                                                   |            |
| 1  | Load path                                      | C          |
| 2  | Adjacent buildings                             | C          |
| 3  | Soft story                                     | NC         |
| 4  | Geometry                                       | C          |
| 5  | Vertical discontinuities                       | C          |
| 6  | Mass                                           | C          |
| 7  | Torsion                                        | C          |
| 8  | Deterioration of concrete                      | C          |
| 9  | Redundancy                                     | C          |
| 10 | Interfering wall                               | NC         |
| 11 | Shear stress check                             | NC         |
| 12 | Axial stress check                             | C          |
| 13 | Connections of concrete coloums                | C          |
| **Supplemental Structural Checklist** |                                                   |            |
| 1  | Flat slab frame                                | C          |
| 2  | Shortcaptive coloums                           | C          |
| 3  | Coloums-bar splices                            | C          |
| 4  | Coloums-tie spacing                            | NC         |
| 5  | Stirrup spacing                                | C          |
| 6  | Joint reinforcing                              | NC         |
| 7  | Joint eccentricity                             | C          |
| 8  | Stirrup and tie hooks                          | C          |
| 9  | Deflection compatibility                       | NA         |
| 10 | Flat slabs                                    | C          |
| 11 | Diaphgrahm reinforcement at openings           | NA         |
| 12 | Lateral load at pile caps                      | NA         |
### Basic Non-Structural Checklist

1. Unreinforced masonry | NC
2. Integrated ceilings | C
3. Support | C
4. Canopies | C
5. Heavy equipment | C

### Geologic and Foundation Checklist

1. Liquefaction | C
2. Slope failure | C
3. Surface fault rupture | C
4. Foundation performance | C
5. Deterioration | C
6. Pole foundation | NA
7. Overturning | NA
8. Ties between foundation elements | C
9. Deep foundations | NA
10. Sloping sites | C

The case study applies Tier 1 screening and the checks of the axial and shear stresses of the columns are completed. The Integrated Laboratory, Faculty of Economics and Business, Jenderal Soedirman University, Indonesia doesn’t comply with a few elements of life safety performance goal. Following the procedure, it was discovered that a few deficiencies existed in the evaluated building. For example, the deficiencies formed the Basic Structural Checklist as follows: the stiffness of the lateral-force-resisting system in the first level is less than 70 percent of the stiffness in an adjoining level above. The next deficiency is that not all the infill walls were put in moment frames and separated from the other structural components. The 3rd deficiency was the shear stress of the concrete columns, computed utilizing the Quick Check process was discovered to be over 100 psi or $2\sqrt{f_c}$ for several levels. The design expert might decide to (1) report the deficiencies and advise mitigation or (2) conduct to bury in the 2nd phase (Tier 2). For Tier 2, the evaluation of the deficiencies will be done centered on the obligations of evaluation determined in Tier 1. In this occurs, the building assessment necessitates the as-built dimensions, the reinforcement particulars of all the structural components, a soil report and basic tests to ascertain the concrete’s strength.

### 4. Conclusions

This paper examined the seismic performance of a representative 7-story moment-resisting frame or concrete frame building with unreinforced masonry infill walls in Purwakerto, Indonesia that designed for an academic building in Jenderal Soedirman University during 2015. Rapid Visual Screening (RVS) and Tier 1 evaluation (screening phase) were carried out following procedures contained in two modern codes or guidelines: FEMA P-154 and FEMA 310. The results indicated:

- The building have a final level 1 score, $S_{LI}$, +3.6, and +1.4 for building type C1 (moment-resisting frame) and C3 concrete frame building with unreinforced masonry infill walls ) respectively.
- It has been found several deficiencies in the assessed building form the screening phase.
- The design professional may choose to report deficiencies and recommend mitigation or conduct to inter in the second phase (Tier 2).
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