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DAMAGE INVESTIGATION AND RE-ANALYSIS OF DAMAGED BUILDING AFFECTED BY THE GROUND MOTION OF THE 2009 PADANG EARTHQUAKE

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ABSTRACT: The purpose of this paper is to introduce a complete assessment to damaged buildings due to earthquake event in earthquake-prone areas. Padang city is located on the western part of the island of Sumatra, Indonesia, an earthquake-prone area. One of the largest earthquake events (Mw 7.6) occurred on 30 September 2009, striking the west coast of Sumatra. A total of 106,658 houses and 4,000 other buildings suffered damage classified from slight to severe, and a reported 1,117 people were killed. Some large-scale reinforced concrete buildings in Padang, as the capital of West Sumatra province, were also damaged. In order to determine the anti-seismic deficiencies of these buildings, the authors assessed three buildings (BPKP, UNP and PU building) on soft soil (the predominant period is greater 2s and Vs30<150m/s), and re-analyzed the BPKP building based on the simulated ground motion of this earthquake event. In applying the current Indonesian seismic design code for the BPKP building and visual checks by applying Japan Building Disaster Prevention Association (1991) to evaluate the degree of damage at two further buildings, the results of this re-analysis revealed that one of these buildings did not satisfy the demand capacity. By computing, the effects of local soil conditions on ground motions from station ADS (Vs30 > 400m/s) to the BPKP building (Vs30<150m/s), the peak ground motion acceleration at BPKP was found to have amplified 1.47 times. This result enables us to conclude that the soil characteristics (rock to soft) influence ground motion amplification and affect the degree to which buildings suffer damage.

Keywords: *Reinforced concrete, Building assessment, Seismic design*

1. INTRODUCTION

According to recorded earthquake events in Indonesia, the number of earthquakes with a magnitude > 4.0 that have occurred in the Indonesian region exceeds 48,000 from 1779 to 2010 C.E. [1,2]. The most of occurred earthquake events are destructive and have caused significant damage to constructions [3] and produced enormous tsunami such as the 2004 Banda Aceh earthquake event, resulting in far more deaths and leaving a million people homeless [4].

Padang city is the capital of West Sumatera Province, In Padang, about 650,000 people live in the coastal area (covering about 60 km^2) in the year 2019. The population density is increasing year to year, currently, the population density is very high, about 10,833 people/km^2. Padang city located in the west of the island of Sumatra, and is thus located in an earthquake-prone area, specifically where the Indo-Australian tectonic plate is subducted beneath the Eurasian plate. The relative motion of the plates occurs at a rate of about 50 to 70 mm/year and represents the main source of subduction-related seismicity in the area [5]. According to the earthquake database, the Sumatran fault produces a very high annual rate of earthquakes, many of which occur in the shallow region under the island of Sumatra [6]. Due to this earthquake, about 1,117 people were reported killed, 1,214, 1,688, 3 severely, slightly injured and missing respectively. The earthquake destroyed 114,797 houses (67,198 moderately and 67,837 slightly), as well as 5,458 other buildings in Padang. The earthquake also affected vital infrastructure in Padang, including the destruction of public water distribution pipes, leading to 2,906 reported leakage points in total. The damage to the pipelines restricted water delivery to consumers for several weeks. The majority of earthquake events occurred at shallows depth with magnitudes above Mw4 from the years 1779 to 2010. There are four accelerometers in Padang city: three were donated by Engineers Without Borders Japan (EWBJ) and installed in 2008 and 2010. Due to an electric power cut during the earthquake, only the BMKG device recorded its time history. The record indicates about 20 s of strong shaking with a peak ground acceleration (PGA) of 0.3g and a predominant period of 0.5s. Padang city is one of the city has a high potential for heavy damage to a building when the predicted earthquake occurs in the future [7,8,9].

1.1 Indonesian design code for building

The Indonesian government's first earthquake loading code was published in 1970 with loading guidelines N.I.-18, where the design acceleration was 0.1 g for Padang. Given that the earthquake intensity increased in 1987, the seismic design requirements were changed to incorporate inelastic response modification factors and more stringent detailing requirements. Modelled on New Zealand's ACI-318 code (SNI 03-1726-1987), the Indonesian region was divided into six seismic zones, zone 1 having the highest and zone 6 the lowest seismic hazards. Soil conditions were soft and hard.

In 2002, Indonesia developed a new Earthquake Resistant Design Standard called SNI-1726-2002, in which the 1997 UBC and the 1999 ACI-318 concrete design provisions were adopted. This code revised the seismic zone designations, with zone 1 being the lowest and zone 6 the highest seismic hazard. The soil designations were also extended to three (soft, medium and hard), and the design spectra were modified to the short period range.

Based on updated seismotectonic data, GMPEs and fault model in Indonesia. The current earthquake loading code is the Earthquake Resistant Design Standard of 2012, which revised the design PGA for every region, the soil designation (soft, medium and hard) and included the design spectra. There are three ways to design a building related to dynamic load: static equivalent, response spectrum, and pushover analysis. Related to building assessment, two of the three buildings (namely the BPKP building and the language training center at UNP) were designed using static equivalent analysis, whereas the PU building obeyed the code of 1970. As shown in Figure 1, in the short period range, the elastic design spectra for the 2002 code are comparable to the spectral accelerations of the measured ground motions. whereas the values for the 1970 code and 2002 are smaller compared spectral acceleration of the measured ground motions. The elastic design spectra are shown in Figure 1 (red, blue and green) are of soft sites in downtown Padang. Comparison of response spectra in each standard; the red line is the current spectra of Padang earthquake 2009.

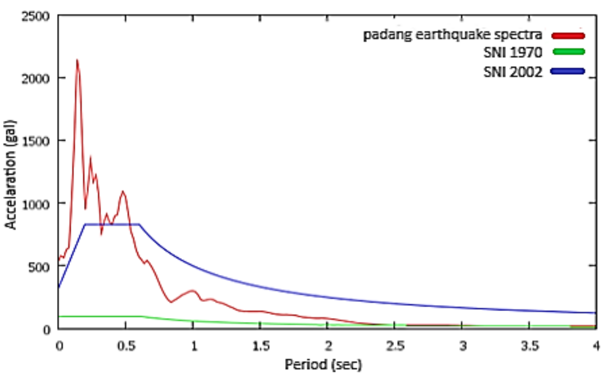


Fig. 1 Comparison of response spectra in each standard; the red line is the current spectra of the Padang earthquake 2009.

2. METHODOLOGY

These are public buildings that belong to the local government, including the public work (PU) building, the Financial and Development Supervisory Board (BPKP) building and the language training center at Padang State University (UNP) (Fig. 3 and Photos 1 (a), (b) and (c)). We considered these 3 buildings because these buildings are the highest buildings in Padang and affected by the Padang earthquake September 2019.

One of the damage features to buildings was the effect on the large RC buildings, which support the backbone functions of the capital city. Another feature was the site-dependent damage to low-rise residences. In order to achieve better earthquake-resistant engineering for buildings in Indonesia, we surveyed three damaged large RC buildings in the downtown area of Padang city (Fig. 2 and Photos 1 (a), (b) and (c))These are public buildings that belong to the local government, including the public work (PU) building, the Financial and Development Supervisory Board (BPKP) building and the language training center at Padang State University (UNP)) by applying Japan Building Disaster Prevention Association (1991) guidelines (survey sheet for BPKP building). The outline of each building was checked, such as columns, beams, and material property data. Given that severe damage occurred to the BPKP building, we focused on this building to re-analyze and evaluate the degree of damage. The BPKP and LTC buildings were designed in line with code 2002, whereas code 1970 was used for the public work building.

We performed a single observation of microtremors on the first and third floors of the BPKP building as well as the fifth floor of the LTC building.

The results enabled us to estimate the predominant period of structure of the BPKP and LTC buildings. Parallel to estimating the predominant structure, we determined soil response at the surface using single microtremor observations. The research flow of this research appears in figure 3.

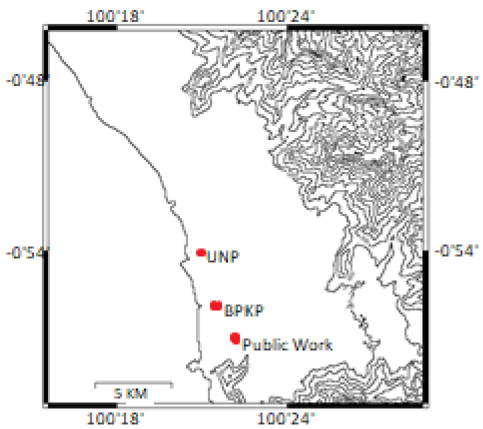


Fig. 2 Location of the assessed buildings

Ground profile
1. Microtremor array observation (previous study).
2. Microtremor single observation

↓

Determine and assess three damaged building on soft soil type
1. Visual check applied JBDPA (1991)
2. Microtremor single observation (predominant period of structure)

↓

Re-analysed one damaged building (BPKP building).
1. Simulated ground motion of the 2009 Padang earthquake (no data available and electricity was cut off during earthquake event).
   1.1 Soil characteristics from microtremor array observation (previous study).
   1.2 Simulated ground motion at station Andalas to bedrock, and bedrock to target site (BPKP building)
   1.3 Obtained a new response spectrum from simulated ground motion at target site (BPKP building) for soft soil type.
   1.4 Obtained predominant period of BPKP building using single microtremor observation.
2. Dynamic analysis using response spectrum seismic load.

Fig. 3 Research methodology flow chart

(a)

(c)

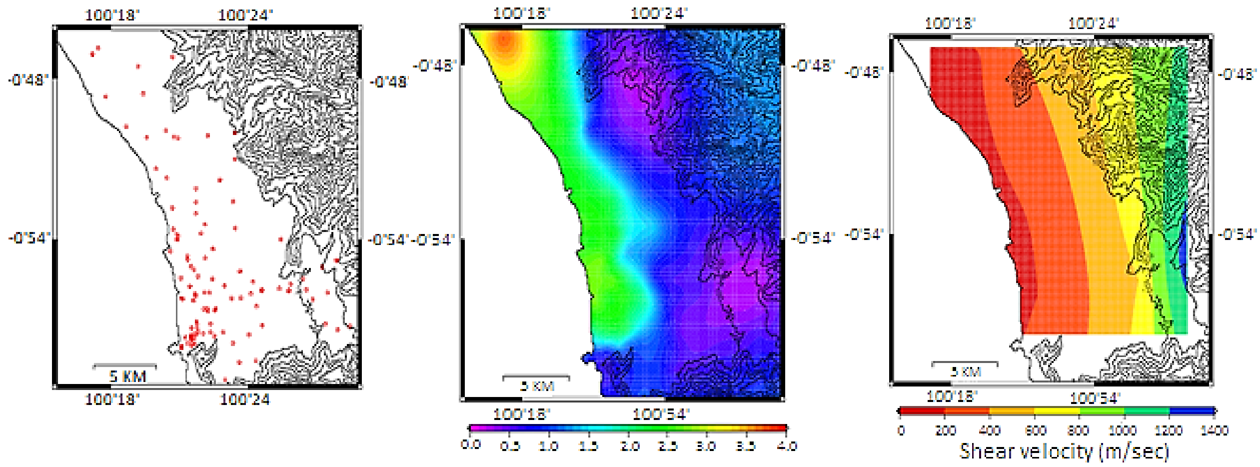
(b)

Photo **1.** Surveyed buildings: (a) Language training center at UNP, (b) Financial and Development Supervisory Board (BPKP), (c) Public work (PU).

2.1 Site Characterisation by Microtremor Observations

2.1.1 Single Observations

A microtremor is a very small ground motion that can be recorded on the ground surface. It can be



(a) (b) (c)

Fig.4 Observation sites and predominant periods: (a) single observation sites; (b) H/V ratio, red circles are building targets and (c) plotted Vs30.

produced by a variety of excitations, such as wind, traffic or breaking sea waves [10,11]. A full microtremor record can be described by one vertical and two horizontal components. Our analysis was conducted using the recorded microtremor. First, the horizontal and vertical spectrum ratios (HVSR) were computed for all sites. The peak period of the HVSR is known to correspond with the resonant period of the site. This method postulates the shape of the Fourier spectrum.

We observed examples of HVSRs that showed a clear peak with a long period range (> 1.0 s). We performed 140 single-site surveys to sample every district of the city of Padang. These observations were carried out in November 2008, September, November and December 2009, January 2010 and September 2019 (Fig. 3(a)).

Equation (1) shows the method used to calculate the HVSR using the observed records.

$$HVSR = \sqrt{\frac{F_{NSi}(\omega)^2 + F_{EWi}(\omega)^2}{F_{UDi}(\omega)^2}} \quad (1)$$

where $F_{NSi}(\omega)$ and $F_{UDi}(\omega)$ denote the Fourier amplitude of the North-South (NS), East-West (EW) and Up-Down (UD) components of each interval, respectively, and ω is the frequency. The locations of observations are plotted in Figure 4(a). The microtremor was measured using a GPL-6A3P sensor.

The two horizontal (NS and EW) and vertical (UD) components were recorded simultaneously for 10 minutes with a 100 Hz sampling frequency. We estimated the distribution of the peak periods of the HVSRs for all sites in Padang using the ordinary kriging technique. From single observations, we obtained a predominant period of 2.0 to 4.0 s in the central business district and less than 1.0 s in the mountainous areas (Fig. 4(b)). These results indicate an effect related to the thickness of the alluvium in the coastal area of Padang city, decreasing in thickness inland [12].

2.3 Building assessment

2.3.1 Visual check at language training building at Padang State University

The language training center (LTC) at the Faculty of Language and Art (Sastra dan Seni) at Padang State University is located at Jalan Belibis (entered from Jalan HAMKA), Padang City, West Sumatra Province, Republic of Indonesia. The building was constructed from 1993 to 1998, an extended length of time due to budget limitations. With the 2007 earthquake (Mw 7.9), several cracks appeared in non-structural parts. For retrofitting purposes, these cracks were covered with aluminum panels, which can be seen from the outside. In the 2009 earthquake, damage occurred to both non-structural and structural parts, including visible damage to the column on the fifth floor. Based on the visual check, this building can be categorized as slightly damaged because major damage only occurred on non-structural parts, specifically to one column with the lid opened the door.

We also performed microtremor observations on the fifth floor of the LTC building. The results enabled us to estimate the site-dependent amplification characteristics of the building. From the microtremor results, the predominant period was found to be about 1.7s (the long period where resulted period >1.0 second). Such seismic vibrations might be hazardous for large buildings.

2.3.2 Public work (PU) building

The four-story public work (PU) building is located at Jalan Batang Arau No. 86, Padang City, West Sumatra Province (Photo 1c). The PU building was built in the 1970s following the 1970 code (Fig.1).

According to the earthquake records, two giant earthquakes struck this building: the 2007 Bengkulu earthquake (Mw 7.9) about 300 km from Padang, and the 2009 Padang earthquake (Mw 7.6) approximately 70 km away from Padang city. The Padang earthquake was categorized as a shallow earthquake with a 10 km depth. Both earthquakes affected the PU building. In 2007, the PU building did not suffer any damage to its structural parts, although there was some non-structural damage. After the Bengkulu earthquake, the building was retrofitted in order to alter its structural characteristics. In the 2009 Padang earthquake, the public works building sustained severe damage. As the building is located 80 m away from the riverfront, liquefaction occurred, which may have contributed to the damage. Lateral deformations and residual drift occurred in the first story (Photo 1 (c)). Adjacent to the building, fine beach sand boiled up from ground cracks, indicating that liquefaction was causing the foundations to move. Evidence of ground deformation could also be seen near the smaller buildings along the river and in other parts of Padang.

Microtremor single observation was performed on the ground surrounding the PU building. The predominant frequency attained here was 1.1 Hz, it indicates that the predominant period microtremor H/V spectra were 1.1 (the long period where T>1.0 second). Such seismic vibrations might be hazardous for large buildings.

2.3.3 BPKP building

The Financial and Development Supervisory Board (BPKP) building is located in the center of the downtown area (Fig. 3 and Photo 1 (b)). Construction started in 2003, with just two floors completed at first. By 2006, five stories had been completed and were being used as offices. In t he 2007 Sumatra earthquake (Mw 7.9), the epicenter of which was 70 km north of Padang, the building was affected: in particular, the terracotta roof collapsed and non-structural parts were slightly damaged. To retrofit the building, the roof was replaced with thin, lightweight steel to reduce the dead load.

In order to attain more information pertaining to the degree of damage, the BPKP building was investigated. During the on-site survey, the covering near the top and bottom of all of the columns was removed and the yielding steel and concrete strength were measured. In accordance with the Japan Building Disaster Prevention Association (1991), the degree of damage to the building was evaluated. show typically damaged columns. Table 1 presents the degree of damage to each floor

We measured all major building components, including columns, floor heights, beams, plate thicknesses and reinforcing bars. The main bars were found to range from φ17×16 to φ19×12 and the stirrups were φ10 spaced at 120–150mm. The concrete strength of representative portions was measured with a Schmidt hammer, and the steel bar strength was measured using a Vickers hardness tester. The concrete strength was 24.6 MPa and 360 MPa for yield steel. From Table 1, the highest degree of damage could be obtained. Given that the third-floor columns suffered the most severe damage, we assumed that this was caused by the reduction in column cross-section on this floor. The first-floor column size was 550 x 550 mm, while on the second floor it was 450 x 450 mm. Microtremor single observation was performed on the third floor of the BPKP building, the result showing that the predominant period of this building was about 1.19, 0.67 and 0.95 for Sway X, Sway Y, and torsion respectively (Fig.5).

Table 1. Results of damage degree for each floor

Damage degree	1F	2F	3F	4F	5F
0	34	15	2	35	35
I	0	0	3	0	0
II	0	6	3	0	0
III	1	11	10	0	0
IV	0	2	10	0	0
V	0	1	7	0	0

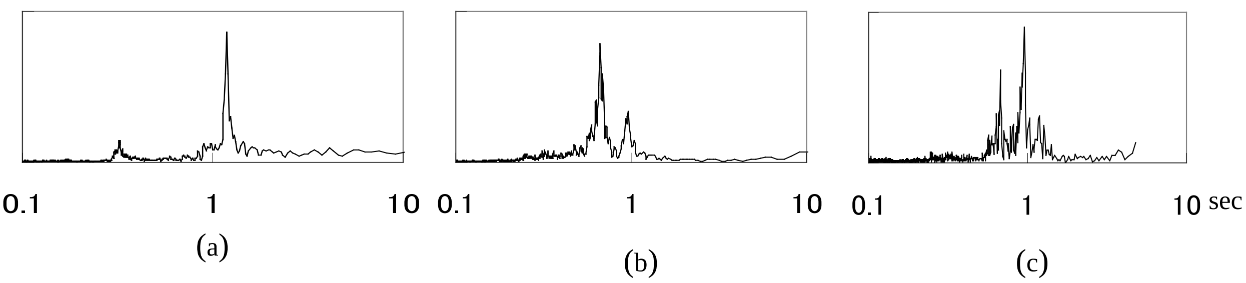


Fig. 5 Predominant period, (a) Sway x=1.19s, (b) Sway y=0.67s and (c) torsion recorded =0.9s on third floor.

2.4 Dynamic Analysis Using Response Spectrum Seismic Loading

Using these dimensions, a lumped mass frame model was developed. The weights of the inner and perimeter walls of the building were included in the floor plate lumped mass. The stiffness of the columns and beams was assumed to be 100% of the original elastic-range value. The frame model was analyzed by a versatile software system for structural analyses [13,14].

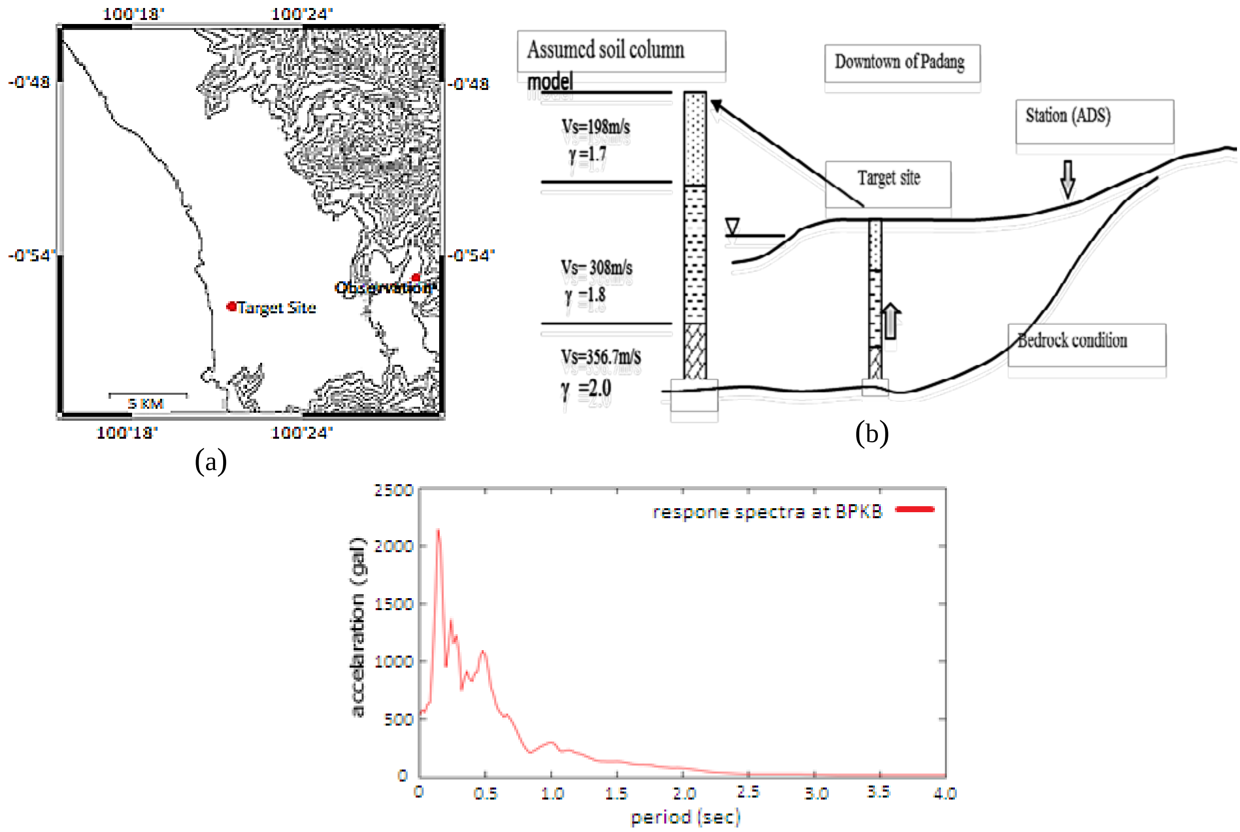
To analyze the BPKP building, we required a ground motion at the BPKP site as an input ground motion for the 30 September 2009 Padang earthquake. This was simulated using the recorded ground motion at the station (ADS) site (Fig. 6). Presented next are the sequence of steps to be followed to ensure that the earthquake motions at the bedrock account for the effects of the soil profile at the surface. From the computing effects of local soil conditions on the ground motion of station ADS, (where the Vs30 > 400m/s) to the BPKP building (where the Vs30 < 150m/s) (Fig. 4 (c)), profile) included shear wave velocity, specific gravity and primary wave at every layer. it can be seen that the peak ground motion acceleration at station BPKP was amplified 1.47 times.

For the seismic response analysis, the results of the (soil

Idealized soil profiles must be selected for the site of interest and target site. One must determine the characteristics of the motions likely to develop in the rock formation underlying the site and select an accelerometer with these characteristics to be used for analysis [15]. The maximum acceleration, predominant period and effective duration are the most important parameters of an earthquake motion. The empirical relationship between these parameters and the distance from the causative fault to the site have been established for different magnitude earthquakes [16,17]. A design motion with the desired characteristics can be selected from the strong motion acceleration recorded during previous earthquakes or from artificially generated acceleration. The dynamic equilibrium equation associated with the response of a structure to ground motion is given by:

$$M\,\ddot{u}(t) + C\,\dot{u}(t) + K\,u(t) = m_x\,\ddot{u_{gx}}(t) + m_y\,\ddot{u_{gy}}(t) + m_z\,\ddot{u_{gz}}\,(t) \qquad (2)$$

where K is the stiffness matrix, C is the proportional damping matrix, M is the diagonal mass matrix, $u, \dot{u}$ and $\ddot{u}$ are the relative displacements, velocities, and



(c)

Fig.6 Schematic representation of a procedure for computing effects of local soil conditions on the ground motion: (a) The map of station and target site, red circles are station ADS and BPKP as target site; (b) Schematic representation of procedure; (c) Response spectrum for target site (site BPKP).

$\ddot{u}_{gz}$ are the components of uniform ground acceleration.

Response spectrum analysis seeks the likely maximum response to the equations rather than the full-time history[18].

Up structures

X beam : 45 cm x 45 cm
beam : 45 cm x 45 cm
Column : 55 cm x 55 cm (at first floor)
:45 cm x 45 cm (second to fifth floors)
Foundation : Mini pile
Concrete strength (fc) : 24.6 MPa
Yield steel (fy) : 360 MPa

3. RESULTS

The Moment capacity of column, by using the properties of concrete and steel obtained from the survey regarding the second floor C3 column, we found that the moment capacity was as high as 240 kNm (Fig. 7 and Table 2). We re-analyzed the structure with the response spectra from the Padang earthquake and made a comparison with the actual capacity of the column on the second floor (Table 2).

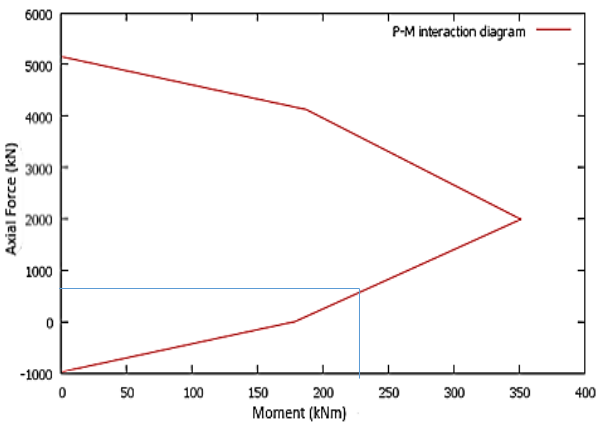


Fig. **7** P-M interaction diagram for second floor C3.

Table 2. Capacity moment vs. demand moment.

Axial force (kN)	Moment Capacity (kNm)	Moment demand (kNm)
375	240	769.36

4. DISCUSSION

We introduce a complete assessment to damage building and re-analysis damage building affected by ground motion of earthquake event in soft soil type. We performed a visual check by applying Japan Building Disaster Prevention Association (1991) guidelines to complete the field investigation and determine the anti-seismic deficiencies of these buildings on soft soil (Vs30<150m/s,). We prioritized the assessment of these edifices because they are major public service buildings located downtown with numerous employees, and have soil characteristics with Vs30 below 150m/s.

The field soil investigation using microtremor array observations to determine the soil characteristics and the predominant period Sway X, and Y corresponds to the resonant period of the structure of the building, and the simulated recording ground motion from a site (station) Andalas to target site (BPKP building) and developed a new ground motion. For field assessment, we applied the Japan Building Disaster Prevention Association (1991) guidelines and re-analyzed the results to find good agreement regarding why the BPKP building suffered such severe damage. From the computing effects of local soil conditions on ground motions from station ADS (Vs30 > 400m/s) to the BPKP building (Vs30,150m/s), we found that the peak ground motion acceleration at BPKP was amplified 1.47 times, enabling us to conclude that the soil characteristics influence ground motion amplification and influence a building's vulnerability to earthquake damage. From two comparison assessment methods we found a good relationship result.

5. CONCLUSION

This paper introduced how to investigate the damage and re-analysis damage building as an impact from the ground motion of an earthquake event even no recorded ground motion at the target building.

The predominant micro-tremor H/V spectra were at the rather long period of 1.0–2.0 seconds in the downtown area of Padang. Seismic vibrations in such an area might prove hazardous for large buildings. The concrete strength of 75% of the damaged reinforced concrete buildings proved to be sufficient. The deficiency of the large-scale reinforced concrete buildings was mainly due to the seismic design and the design procedure implemented.

The results of the re-analysis, applying the current Indonesian seismic design code 2012 for the BPKP building and visual checks at two further buildings, revealed that one of these buildings did not satisfy the demand capacity (BPKP building). The building that satisfied the demand collapsed most significantly in actuality (PU building). This underlines the importance of understanding the reinforcement bar arrangement and the structural detail in order to improve ductility. The design document of the buildings indicated that the building had been designed by an old seismic design concept, applied with excessively small earthquake load. The other two were also supposed to be in the same situation through the detailed site investigation. We found a good relationship result between two deferent methods (re-analyzed by finite element and visual check by applying Japan Building Disaster Prevention Association (1991) to evaluate the degree of damage).

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