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The effect of Soil-structure interaction on Multi-Storey building resonance and Dynamic Shear modulus for Pidie Jaya Aceh earthquake

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Abstract. Earthquake resistance building design must be considered as a design standard in the future for Pidie Jaya - Aceh government as 7th December in 2016 earthquake in Pidie Jaya Aceh which destroyed many major and minor infrastructures. Therefore, soil dynamic parameters must be obtained for design purposes in Pidie Jaya reconstruction and rehabilitation in the future. To avoid the structural failure during the earthquake process, the value of structural vibration frequency (f) should not similar to the value of natural soil vibration frequency (f_n). This article aims to determine the soil dynamic parameter of soil layers for disaster mitigation purposes. Several existing buildings namely Dayah Mudi Samalanga, Baitul Muttaqin Mosque, Cubo Bridge, Regent Office Building, Local Lawyer Office and around Pidie Jaya fault were chosen for soil sampling locations. Dynamic parameter of G_{max} and V_s are the result of this research. Moreover, the f_n value was calculated by Kramer method. Comparison of fn values was performed by simple modeling off values based on SNI 1726-2012. The highest value of the void ratio (e) was obtained in Baitul Muttaqin Mosque soil sample which is 1.84. The highest f_n value is at Pidie Jaya fault, which is 2.01 H_z and the lowest f_n value is at Baitul Muttaqin Mosque, Pidie Jaya, which is 1.301 H_z.

1. Introduction

Soil where construction foundations rests performance a significant part in geotechnical engineering rules. Many natural disasters play some important roles in changing dynamic parameters and bearing capacity of soils like an earthquake. Earthquake effect of the building must be considered deeply in construction design as it affects not only the soil but also above structures which widely known as soil-structure interaction (SSI). [1] explain that at least three-four factors that caused by earthquake damages namely source of the earthquake, path characteristics, local geotechnical characteristics, and quality of structural design. Some other articles also conduct research regarding dynamic soil parameters caused by an earthquake [2] [3] [4] and [5]. Moreover, [2] explained a control how to determine dynamic parameters of soil to applied in design among soil-structure interaction (SSI) framework. [6] researched earthquake hazard analysis for safety design purpose in Aceh due to some earthquake events.

Pidie Jaya of Aceh – Indonesia in Sumatera Island experienced 6.4 Mw earthquake on 7th December 2016 which caused loses and fatalities. [7] noted that the earthquake happens in the depth of 15 km below earth surface and coordinate at 5.29º N, 96.22º E. The shaking followed by several aftershocks for a few days later. Around 48 times of following earthquake impacts recorded in that day and 17 times of aftershock in the following day [4]. Meuredu, Manohara, Samalanga and Bireun are

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the major affect area of the earthquake. Pidie fault was the cause of this Pidie Jaya 6.4 Mw earthquake [8] as can be seen in Figure 1. In fact, Pidie fault is not the most active fault in Aceh. The main faults in Aceh are Tripa Fault, Aceh Fault and Seulimum Fault as can be seen in Figure 1. From 2004 to 2012, at least three large earthquakes recorded which are larger than 8 Mw in Sumatera Island [9].
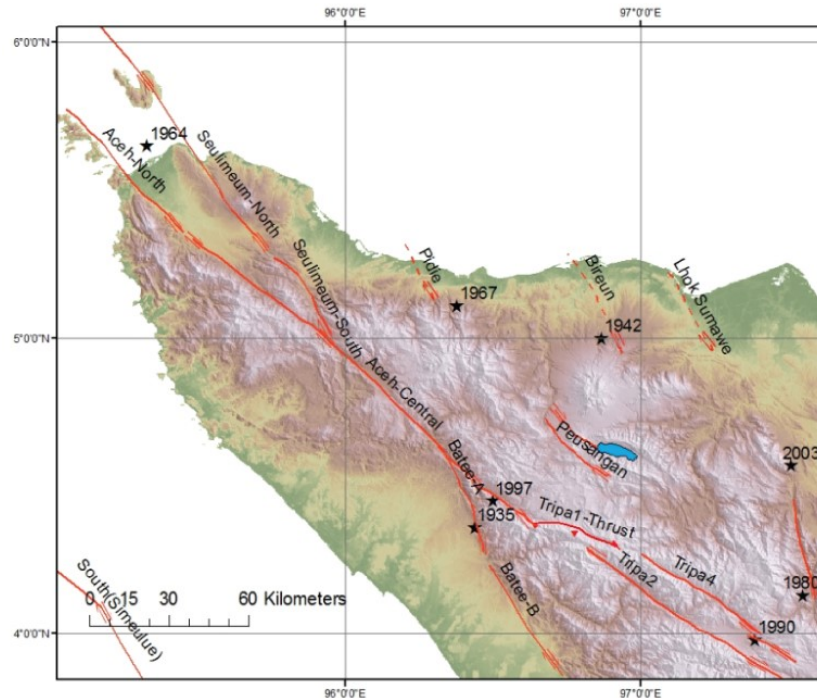

Figure 1. Aceh Faults along Aceh Province (PUSGEN, 2016 [8])

The earthquake wave vibration to the building foundations analysis (SSI) have to concern two factors namely structural vibration frequency (f) and natural vibration frequency (f_n). The two factors also depending on the value of surface peak horizontal acceleration of soil (a_{max}). [1] describe that site conditions and amplification parameters need to be analyzed in order to obtain the surface peak horizontal acceleration (a_{max}). From [10], vibration transfer functions, soil natural frequencies, ratio of damping and shapes of the construction are the limitation in analyze structural vibration frequency (f). There are also several soil-structure vibration frequency analyses from [3] [11] [12] [13] and [14]. The soil-structure model due to seismic damage can be explained by Figure 2. Shear modulus (G), Poisson's Ratio (v) and soil friction angle are soil parameters that need to obtained for SSI analysis. To avoid structural failure during the earthquake process, the value of structural vibration frequency (f) should not equal to the value of natural soil vibration frequency (f_n).
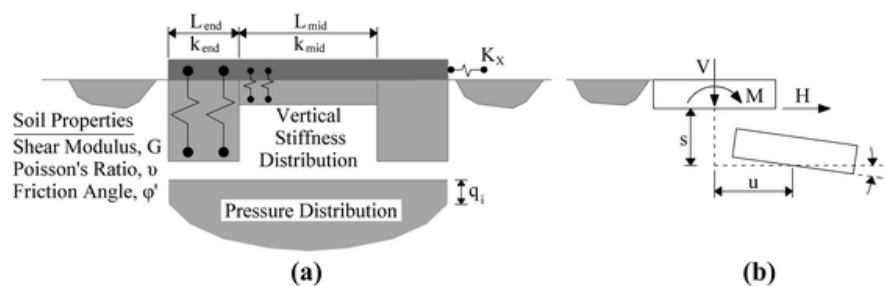

Figure 2. Soil-Structure Model of Seismic Damage (Sotiriadis et al., 2017 [14])

2. Material and Methods

This study was based on experimental works in Syiah Kuala University Soil Mechanics Laboratory Indonesia. Several soil samples were taken around the study area along with their coordinate. Several existing buildings namely Dayah Mudi Samalanga, Baitul Muttaqin Mosque, Cubo Bridge, Regent Office Building, Local Lawyer Office and around Pidie Jaya fault were chosen for soil sampling locations. Some physical and mechanical properties of soil test were then performed namely water content, unit weight of soils, Atterberg limit tests, grain size distribution test and void ratio test. Mechanical tests of soil were also conducted to obtain soil cohesion and friction angle. All of the soil experiments were follow the ASTM standard. The maximum shear modulus (G_{max}) were then calculated in order to obtain the value of soil natural vibration frequency (f_n).

The bearing capacity of soil and wave transfer along the soil layers were influenced by soil-structure interaction (SSI) for dynamic loads. [12] maximum shear modulus (G_{max}) must be obtained first to calculated the value of resonance frequency and vibration amplitude in structural foundations. Soil-structures interaction due to dynamic loads effect the wave propagation and bearing capacity of soil. The empirical equation of G_{max} correspondence with site condition with the influence of fine content (f_c) soil gradation, void ratios (e) and soil plasticity (PI) have been introduced by [12] in equation (1) (2) (3) and (4).

$$G_{max} = 0.0012 f_c^3 - 0.1995 f_c^2 + 8.4718 f_c + 273.86 \text{ (kPa)} \tag{1}$$

$$G_{max} \text{ (vertical)} = 1067{,}3 \text{ exp}^{-1,51e} \text{ (kPa)} \tag{2}$$

$$G_{max} \text{ (horizontal)} = 811{,}9 \text{ exp}^{-1,11e} \text{ (kPa)} \tag{3}$$

$$G_{max} = -0.04 PI^2 + 2.7 PI + 289.81 \text{ (kPa)} \tag{4}$$

The meaning of natural soil vibration frequency is a occurrence at which a systematically tends to oscillate in the nonappearance of any forces which are drive and damp. Natural soil vibration frequency (f_n) was then calculated from equation (5) (6) and (7) as introduced by [15]. Unit weight of soil (ρ) in kg/m3, ω_0 (H_z) as fundamental frequency, Vs as shear wave velocity (m/s), and H (m) is depth of soil.

$$f_n = \frac{\omega_0}{2\pi} \tag{5}$$

$$\omega_0 = \frac{\pi \times v_s}{2H} \tag{6}$$

$$v_s = \sqrt{\frac{G_{max}}{\rho}} \tag{7}$$

Structural vibration frequency (f) were calculated by equation (8) and (9) as Indonesia standard procedure of SNI 1726-2012 [16]. Ta (s) is a fundamental period, and N is a number of multi-story building which is less than 12 levels of building. The value of f_n should not equal to f to avoid resonance which will lead constructions to fail. Resonance ratio of building (R) to identify construction resonance level then calculated with equation (10) where f_b (H_z) is building frequency and f_t (H_z) is natural soil frequency.

$$f = \frac{1}{T} \tag{8}$$

$$T_a = 0{,}1 \text{ N} \tag{9}$$

$$R = \frac{fb - ft}{ft} x 100\% \tag{10}$$

3. Results and Discussion

Table 1 shows the results of dynamic soil parameter around Pidie Jaya. The highest void ratio value was in Baitul Muttaqin Mosque for 1.84, however the highest G_{max} value was in Pidie Fault for $166,598.51$ kg/ms^2. It may because that the void ratio value in Pidie Fault was the lowest for 1.23. Natural soil vibration frequency (f_n) 0f Pidie Fault of 2.013 Hz was the highest along with other dynamic soil parameter like shear wave velocity and fundamental frequency which effect the natural soil vibration frequency.

Table 1. Dynamic Soils Parameter Results

No.	Location	e	Gmax (kg/ms^2)	ρ (kg/m^3)	Vs (m/s)	ω_o (Hz)	f_n (Hz)
1.	Cubo Bridge	1.27	156,833.91	2.55	7.84	12.31	1.961
2.	Pidie Jaya Fault	1.23	166,598.61	2.57	8.05	12.64	2.013
3.	Local Lawyer Office	1.29	152,168.33	2.59	7.67	12.03	1.916
4.	Regent Office	1.47	115,953.28	2.61	6.67	10.46	1.666
5.	Dayah Mudi	1.54	104,322.53	2.55	6.40	10.04	1.599
6.	Baitul Muttaqin Mosque	1.84	66,319.73	2.45	5.20	8.17	1.301
	Average	1.44	127,033	2.55	6.97	10.94	1.743

Resonance in building able to lead construction to collapse if natural soil vibration frequency (f_n) is equal to structural vibration frequency (f). Therefore, modelling simple multi-storey construction with maximum 12 level of structural were then applied as SNI 1726-2012 with fundamental period approach as can be seen in Table 2.

Table 2. Structural Frequency Model with Fundamental Period Approach

N	Ta (s)	f (Hz)
1	0.100	10.000
2	0.200	5.000
3	0.300	3.333
4	0.400	2.500
5	0.500	2.000
6	0.600	1.667
7	0.700	1.429
8	0.800	1.250
9	0.900	1.111
10	1.000	1.000
11	1.100	0.909
12	1.200	0.833

The meaning of natural soil vibration frequency should not equal to structural vibration frequency is that the difference between these two parameters should not zero. The structures will failure/ collapse if the two parameters are equal. Taller building will have lower structural frequency but the period value will be higher. In contrast, lower building will have high structural frequency and low period value. The comparison is based on closest construction around and the natural soil vibration frequency was from calculation. The resonance ratio will show the resonance probability as shown in Table 3.

Table 3. Comparison Between Natural and Structural Frequency

No.	Location	Building Condition	f_n (Hz)	f (Hz)	N	difference	Resonance Ratio (%)	Resonance Probability
1.	Cubo Bridge	Failure	1.96	2.00	5	0.04	1.97	High
2.	Pidie Jaya Fault	No Failure	2.01	2.00	5	0.01	0.64	High
3.	Local Lawyer Office	No Failure	1.92	2.00	5	0.08	4.19	High
4.	Regent Office	No Failure	1.67	1.67	6	0.00	0.02	High
5.	Dayah Mudi	Failure	1.60	1.67	6	0.07	4.06	High
6.	Baitul Muttaqin Mosque	Failure	1.30	1.25	8	0.05	4.06	High

The comparison of f_n and f for resonance in Table 3 display that all the location has high probability of resonance. However, in reality not all the construction collapse during and after earthquake even the construction with difference close to zero. It may have explained that resonance not the caused of building failure. Furthermore, other technical problems may take account like low bearing capacity, construction strength, liquefaction and good design plan of buildings.

4. Conclusion
To conclude, building failure may also cause by resonance in building if natural soil vibration frequency (f_n) is equal to structural vibration frequency (f). Construction can fail if f_n and f value are similar. In general, higher construction will have lower structural frequency but the period value will be higher. On the other hand, lower construction will have high structural frequency and low period value. Comparison of f_n values was performed by simple modelling of f values based on SNI 1726-2012. The highest value of void ratio (e) was obtained in Baitul Muttaqin Mosque soil sample which is 1.84. The highest f_n value is at Pidie Jaya fault, which is 2.01 Hz and the lowest f_n value is at Baitul Muttaqin Mosque, Pidie Jaya, which is 1.301 Hz.

5. Acknowledgments

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