The unit price of building changes to different design of seismic importance factors

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Abstract. The design of a building needs to accommodate the potential for earthquake risk. The function and utilization of buildings are closely related to the risks caused by earthquakes, especially for people using the building. In the design process, load changes due to utilization are accommodated through an index value called seismic importance factors (SIF). The application of the index will directly affect the structural dimensions of a building. Thus, the amount of building unit price (BUP) needed will also vary according to the function of the building. This research was conducted to analyze changes in BUP on some seismic importance factors in a building structure design. Changes in unit prices were explained by applying the price index approach in the form of the building unit price index (BUPI). This study was applied to a six-story building using reinforced concrete structures and following earthquake load conditions in four seismic zones in Aceh Province. The BUPI was analyzed based on comparing a building unit price (BUP) to the reference BUP that was set from the building designed with the lowest SIF index in the initial seismic zone. The analysis results show that the increase in the SIF indices will potentially increase the BUP to 6% (IDR. 105,061.25) for SIF 1.00 to 1.25, while the increase in costs for SIF 1.25 to 1.50 was 4% (IDR. 84,507.32). The BUPI values have clearly explained how the building unit price increases following the SIF indexes increase.

1. Introduction
Earthquake is one of the common natural disasters in Aceh, and the intensity is increasing. High intensity of earthquakes requires building design that can withstand earthquake loads. From the recent earthquake, many types of buildings were damaged or even collapsed. Hence, building infrastructure needs to be able to survive when an earthquake occurs. Structures are designed not only to meet the building requirements but also to consider economic aspects. Costs required for structural components are needed to consider the potential for earthquakes [1, 2-3]. The building is designed in a physical form as the results of construction works, integrate with the place of domicile, and serves as a place for people to carry out various activities, both for residence, religious (worship), business and social activities, as well as culture, and special activities, as stated in Indonesian Regulation No. 28 of the Year 2002 [4]. Therefore, a building must have the resilience and strength to ensure the safety of people who utilized it. The loss of building functions can be caused by the human activity itself or nature beyond previous estimates. Natural building failure due to natural disasters can occur due to earthquakes, volcanoes, floods, fires, and various other types of natural disasters.

The magnitude of the earthquake load will cause changes in building costs. The exact cost will be different based on earthquake zoning and dimensions of the building structure. The structural component is a component that has the most substantial portion of building costs. These components include the construction of foundations, columns, beams, slab, and roof structures [1].
Indonesia is vulnerable to earthquakes, so it is vital to understand the seismic potential in a building. Changes in building loads modify the dimensions of the structural components. The higher risk of seismicity in an area results in the more critical requirement for strengthening structural elements in a building to withstand the earthquake loads. All design of structures must consider the seismic importance factors (SIF) based on the risk category of the building (or other structure). SIF, applied in the seismic response coefficient (SRC) equation, aims to increase yield levels for essential structures (such as hospitals, fire stations, central emergency operations, dangerous facilities, and other essential structures). The use of a SIF higher than 1.00 is intended to provide lower inelastic demand for a structure that will result in a lower level of structural and nonstructural damages, which lower the risk to the building and the people using the building. There are three risk criteria for seismic importance factors based on SNI 2847: 2013, i.e., risk categories I and II with a SIF value of 1.00, risk category III (high occupancy) with a SIF value of 1.25, and risk category IV (important facility) with a SIF value of 1.50 [5, 6]. The seismic load is an essential factor that must be considered in cost estimation. The cost estimation process must be carried out by considering aspects of variations in seismic load in a building if planned to be built in a different location [7].

Cost estimation is a predictive process used to determine the size, cost, and price of resources needed by the scope of investment, work, or project choices [8]. Cost estimation results can be used as a reference to control so that the possibility of deviations can be reduced as much as possible. The accuracy of the estimation is mainly determined by the availability of information in the form of a relationship between cost estimation patterns or cost models [9]. Cost modeling in previous research was applied as a trend and recognizes the need for long-term construction costs so that it can benefit project stakeholders [10, 11]. Cost modeling is also more accurate to infer location adjustment factors and has the potential to improve industrial construction performance with more accurate and efficient costs [12].

The price index becomes an indicator by referring to the statistical index of the general level of price changes. In previous studies, the price index is used as measurement methods in compiling the price to reflect changes in quality and productivity and the introduction of new products [13]. Then the price index is also used to adjust housing sales [14]. Changes to prices can also be caused by other factors other than the economic factors, as explained in the previous section. Changes in the price of a building are closely related to the potential for earthquake vulnerability in each region. This finding has been shown by the results of the study of the unit price of work [7] and the total price of the building [15]. These changes arise due to structural dimensions and material quantities changes to adjust all loads received by the building [16]. The building unit price (BUP) is defined as the cost per square meter for the construction of buildings based on the classification, location, and time of construction [5].

By considering the above background, this research aims to analyze the changing patterns of the needs of building unit prices (BUP) using a price index approach referring to the seismic importance factor (SIF). The price index represents the unit price of a building and is defined by the term “Building Unit Price Index (BUPI).”

2. Object of the research

The location of the design of building structures studied was determined in four cities in Aceh Province. They represent four earthquake zones referring to the Indonesian earthquake zoning map. The object used in the study was a six-story building structure and was classified as a non-simple building as defined by the Minister of PUPR Regulation No. 22/PRT/M/2018 [17]. The building has a dimension of 40 m in length and 11 m in width on each floor and has a total floor area of 440 m². The structure of the building was designed using reinforced concrete material. The shape of the building structure is shown in Figure 1.
3. Data
The data was secondary data obtained from the building's technical manager at the relevant agency, as presented as follows.

1) The spectral response from the observed seismic zones, as can be seen in Table 1.

   | Zone | City    | SR (in gravity, g) |
   |------|---------|---------------------|
   | 10   | Langsa  | 0.691               |
   |      | Sigli   | 0.873               |
   | 14   | Sabang  | 1.192               |
   | 16   | Kutacane| 1.567               |

2) The data of the basic price of material and labor, and the unit price of works as referring to the standard prices established by the province government [15].

3) The data of dimension for all reinforced concrete structural components consist of foundation, columns, beams, and slab. This data was obtained from SAP2000 v.20.0.0 International Ultimate Academic software.

4. Analysis
The analysis process was carried out as follows.

1) Building volume analysis in this study was determined from the result of dimensions design for all structural components of the building.

2) The unit price of work is analyzed for three jobs related to reinforced concrete construction: concrete work, reinforcement work, and formwork.

3) The analysis of the cost of building components was based on the SIF by adding up all building cost components, both based on the type of reinforced concrete works and the type of structural components.

4) The building unit price ($BUP$) was analyzed based on the total building price of the total building area. The building unit price ($BUP$) can be calculated using Equation (1).

$$BUP = \frac{TBP}{TBA}$$ (1)
Where,  
\[ BUP = \text{The Building Unit Price (in Indonesian Rupiah, IDR)}; \]
\[ TBP = \text{Total Building Price (in Indonesian Rupiah, IDR)}; \]
\[ TBA = \text{Total Building Floor Area (in m}^2\text{)}. \]

5) The analysis of building unit price index based on FUG was done by comparing a unit price value of buildings with the reference price value on buildings in FUG 1.00. The building unit price index (BUPI) is one form of price index application to explain the pattern of HSB changes to a variable [18]. This study applies FUG changes to building unit prices. Changes in the building price index refer to one reference unit price (TBP) set for buildings designed with FUG 1.00. Mathematically, the building unit price index can be calculated using equation (2).

\[ BUPI_z = \frac{TBP_z}{TBP_R} \]  

(2)

Where,  
\[ BUPI_z = \text{Building Unit Price index of seismic importance factor indices.} \]
\[ TBP_z = \text{Unit price of seismic importance factor indices; (in Indonesian Rupiah, IDR).} \]
\[ TBP_R = \text{Reference unit price (rupiah).} \]

5. Results and discussion

5.1 Total costs of structural components

The total cost of the structure is defined as the total cost of all structural components of a building consisting of foundations, beams, columns, and slab. The price for each component changes following the seismic importance factor (SIF), as in Table 2. These changes are distributed according to the price of work consisting of concrete work, reinforcement, and formwork.

| Structural components | Seismic zone | Component cost based on SIF (in IDR Million) |
|-----------------------|-------------|---------------------------------------------|
|                       |             | 1.00 | 1.25 | 1.50            |
| Foundation            |             |      |      |                 |
| 10                    |             | 306  | 306  | 373             |
| 12                    |             | 306  | 373  | 392             |
| 14                    |             | 347  | 414  | 426             |
| 16                    |             | 347  | 426  | 426             |
| Average               |             | 326  | 380  | 404             |
| Std. Dev.             |             | 24   | 54   | 26              |
| Beams                 |             |      |      |                 |
| 10                    |             | 1,337| 1,386| 1,474           |
| 12                    |             | 1,349| 1,410| 1,484           |
| 14                    |             | 1,367| 1,493| 1,65            |
| 16                    |             | 1,564| 1,689| 1,856           |
| Average               |             | 1,404| 1,495| 1,618           |
| Std. Dev.             |             | 107  | 138  | 218             |
| Columns               |             |      |      |                 |
| 10                    |             | 1,134| 1,134| 1,173           |
| 12                    |             | 1,134| 1,134| 1,195           |
| 14                    |             | 1,231| 1,231| 1,430           |
| 16                    |             | 1,231| 1,430| 1,430           |
| Average               |             | 1,183| 1,233| 1,307           |
| Std. Dev.             |             | 56   | 140  | 142             |
| Slab                  |             |      |      |                 |
| 10                    |             | 1,853| 2,006| 2,006           |
| 12                    |             | 1,853| 2,006| 2,006           |
| 14                    |             | 1,976| 2,006| 2,006           |
| 16                    |             | 2,006| 2,006| 2,006           |
| Average               |             | 1,922| 2,006| 2,006           |
| Std. Dev.             |             | 81   | 0    | 0               |
Table 2 shows that the average change in the cost of structural components on the foundation with the highest average cost is SIF 1.50 (IDR. 404,972,353), while the lowest value is SIF 1.00 (IDR. 326,736,425). As with the beam component, the highest average cost change is at SIF 1.50 (IDR. 1,618,713,632) and the lowest at SIF 1.00 (IDR. 1,404,752,317). The highest value column is also at SIF 1.50 (IDR. 1,307,311,091) while the lowest at SIF 1.00 (IDR. 1,183,335,363). While for the Slab, the highest is at SIF 1.25 and SIF 1.50 (IDR. 2,006,439,615, no change between SIF 1.25 and SIF 1.50), while the lowest cost at SIF 1.00 (IDR. 1,922,151,545).

5.2 Total cost of works
The total price of the building is obtained from the sum of costs from all structural components of the building, or in another way, the total price of the building could also be generated from adding up the cost of works. The total cost of works for the three SIFs is provided in Table 3. The table indicates that the total cost of concrete work, reinforcement, and formwork increases from each SIF, the average cost increase is IDR. 99,602,470.93 (12%), IDR. 305,177,561.44 (14%) and the IDR. 95,681,008.37 (5%) in concrete work, reinforcement works, and formwork work, respectively.

| Seismic Zone | Concrete Cost of Works based on SIF (in IDR million) | Reinforcement Cost of Works based on SIF (in IDR million) | Formwork Cost of Works based on SIF (in IDR million) |
|--------------|------------------------------------------------------|----------------------------------------------------------|------------------------------------------------------|
| 10           | 820                                                  | 820                                                      | 820                                                  |
| 12           | 820                                                  | 820                                                      | 820                                                  |
| 14           | 827                                                  | 873                                                      | 970                                                  |
| 16           | 834                                                  | 960                                                      | 989                                                  |
| Average      | 825                                                  | 877                                                      | 925                                                  |
| Std. Dev.    | 6.64                                                 | 59.38                                                    | 63.39                                                |

5.3 Building unit price index
The total building price (TBP) was obtained from the sum of costs from all structural components of the building, or from adding up the cost of works. The building unit price (BUP) explains the cost requirements of the building structure for each square meter area. The TBP and the BUP are shown in Table 4.

| Seismic Zone | Total Building Price (in IDR million) | Building Unit Price (in IDR million) |
|--------------|---------------------------------------|--------------------------------------|
| 10           | 4,631                                  | 1.754                                |
| 12           | 4,643                                  | 1.758                                |
| 14           | 4,923                                  | 1.864                                |
| 16           | 5,149                                  | 1.950                                |
| Average      | 4,836                                  | 1.857                                |
| Std. Dev.    | 248                                    | 0.096                                |

Table 4 shows that the total price of the building structure changes with every 0.25 increase in the earthquake priority factor. The average price increase for the building structure from SIF 1.00 to 1.25 is IDR. 277,361,703 (6%), while the average increase in costs from 1.25 to 1.50 FUG was IDR. 223,099,337 (4%). The building unit price also increases in each 0.25 of the earthquake priority factors. The average increase in BUP from FUG 1.00 to 1.25 is IDR. 105,061.25 (6%) while the average unit price increase from FUG 1.25 to 1.50 is IDR. 84,507.32 (4%). The highest standard deviation for the total unit price is at SIF 1.50 (IDR. 337,645,553), while for the BUP, the highest standard deviation is at FUG 1.50 (IDR. 127,896,043).
The change in the value of $BUP$ for each type of building based on the parameters of the seismic priority factor is indicated by a price index value. The index is analyzed by comparing the value of a building from each parameter with the reference $BUP$ value. The reference $BUP$ determined in this study is the $BUP$ value at $SIF$ 1.00. $BUP$ changes for the types of structural components and types of work can be seen in Figure 2 and Figure 3.

**Figure 2.** Cost index for structural components.

Figure 2 reveals that the type of structural component increase in the index value for each $SIF$. The lowest $SIF$ of 1.00 was set as the reference cost index of 1.000, while for the highest $SIF$ of 1.50, the cost index raises to 1.239; 1.152; 1.105; and 1.044 for foundation, beams, columns, and the slab, respectively.

**Figure 3.** Cost index for the type of works.

According to Figure 3, the changes in the cost of works varies for the three observed $SIF$. The cost index of all works for $SIF$ 1.00 to $SIF$ 1.50 increases from an initial index (1.000) to 1.121 (concrete work), 1.140 (reinforcement work), and 1.052 (reinforcement work). This explains that the higher the seismic priority factor, the higher the cost of building structure.
Figure 4. The BUPI patterns for changes of SIF.

Figure 4 shows that for SIF 1.00, the lowest average index value of 1.000, while the index value for SIF 1.25 is 1.057, and for the SIF 1.50 is 1.103. This shows that the higher the seismic priority factor in a study area, the higher the building unit index value.

6. Conclusions

Based on the results of the analysis and the research objectives, it can be concluded that:

1) The building unit price indices (BUPI) indicate the increases in cost in responding to the change of building utilization as indicated by the seismic important factors (SIF) index. The increase in the building unit price (BUP) for every increase of the SIF index is about 6% for the change of SIF 1.00 to 1.25, and 4% for the change of SIF 1.25 to 1.50. On average, the cost of the BUP of structure potentially rises up to IDR. 81,958 for each 0.25 increase of the SIF index.

2) Changes in building functions that are marked the SIF index value directly affect the increase in the cost of the structural component and the cost of works. The largest changes in the cost of structural components are found in the foundation components, followed by beams, columns, and slabs. From the aspect of work costs, the largest change in costs occurs in reinforcing works, followed by concrete and formwork works.

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