Shorelines Changes in Bengkulu City and their Relation with Ground Shear Strain Based on Microseismic Data

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ABSTRACT

Coastal erosion that occurred in the west part of Bengkulu city since 1917 has significantly changed the shoreline. Those significant changes are supposed having a relation with the earthquake activities in the Indian Ocean and around Bengkulu province. Earthquakes are frequent in this region resulting a variation of the Ground Shear Strain’s values in some coastal areas and hence have impact on the environment.

This study aims to (1) determine the rate of beach erosion that occurred in Bengkulu City, (2) determine the value of the Seismic Vulnerability Index of coastal segments, (3) know the Ground Shear Strain values in some coastal zones.

For each zone, the microseismic data was acquired using a portable short period digital seismograph. We utilized the Horizontal to Vertical Spectral Ratio (HVSR) method to obtain the dominant frequency (f0) and peak amplitude of HVSR spectra (A) to calculate the seismic vulnerability index values (K4) and the Ground-Strain Shear value (γ).

From this research we found that rate of coastal erosion on various types of beach was ranging from 4.4 to 16.1 m yr. The K4 values are from 3.6 to 48.1 and γ values are from 0.0026 to 0.0161.

Keywords : The rate of abrasion, Seismic Vulnerability Index, Ground Shear-Strain, Bengkulu city

INTRODUCTION

Bengkulu city is located at 103.3 E-104.1 E and -3.35 - 3.9 S and directly facing the Indian Ocean in the west part. Considering the tectonics aspect, Bengkulu city is located in a subduction zone between the Indian-Australian and the Eurasian plates (Figure 1). The consequence of such a position is that the city of Bengkulu is an earthquake prone area. Earthquake activity with the magnitude more than 4 Richter scale from 13 to 15 times per month (BMKG Bengkulu, 2011).

According to the earthquake catalogue from 1900 to 2010, approximately 95% of the earthquake sources were below the Indian Ocean (BMKG Bengkulu, 2010). This fact supports the idea that the city of Bengkulu is vulnerable to earthquake hazards. Coastal erosion in Bengkulu is rapidly happen because of earthquakes which often occurred in the city. The magnitude of Ground Shear Strain at a point on the coast of Bengkulu city indicates how much shock occurred when there was earthquakes which destroy building and casualties, even damage allegedly due to shock coastal land.

Fig 1. Bengkulu city, Indo-Australia and Eurasia subduction zone (http://id.wikipedia.org/wiki/Subduksi)

The high rate of abrasion in the city of Bengkulu causes shoreline change significantly. Shoreline change is signifi-
cant not only in the city of Bengkulu but also at almost all coastline in Bengkulu province, but the number of urban dwellers are more dense than the other regions. The dynamics of the beach in Bengkulu city caused by the abra-
sion factor becomes more important given the impact
caused by the rate of erosion and a threat to the destruction
of settlements, farms and other buildings located in coastal
areas.

Using the reference maps made in 1917 and google
earth maps through 2004 there were changes to the coast-
line that are likely to lead to significant land erosion. Abra-
sion that occurs at shoreline in Bengkulu province ranged
from 4.4 to 16.1 meters per year. The rate of a relatively
large abrasion occurred in the district.

Causal relationship between changes in the coastline
and areas prone to earthquakes can be traced from the
Seismic Vulnerability Index values in the areas affected by
erosion or abrasion areas with relatively high speed.

LITERATURE
Nakamura (2008) measured microtremor to assess the seismic vulnerability index in the Marina district of San Francisco where severe damage was caused by the Loma
Prieta earthquake in 1989. Seismic vulnerability index value
on the coast to the hills shows a difference. The beach
area which is alluvial plain and reclamation has high seis-
mic vulnerability index, it suffered severe damage. Seismic
vulnerability index change decreases upon entering the
hilly region that did not experience damage during earth-
quakes.

Saita et al. (2004) conducted a seismic vulnerability
index in the district of Intramuros, Manila, Philippines,
precisely in the area that had suffered damage from 1990
Luzon earthquake. The results showed that areas that suf-
fered severe damage turned out to lie in the area of high
seismic vulnerability index based microtremor.

Nakamura et al. (2000) measures microtremor of 400 loca-
tions in areas that have experienced severe damage due
1995 Kobe earthquake. The results of this study showed a
correlation between seismic vulnerability index based on
the ratio microtremor damage. In coastal areas with high
vulnerability index suffered high damage ratio, while in the
hills that has a low susceptibility index had low damage
ratio.

Gurler et al. (2000) conducted measurements micro-
tremor at 200 locations in Mexico City were repeatedly hit
by the damage caused by earthquakes in 1957, 1979 and
1985. Line cutting hills microtremor measurements, the
transition region, and swamps that have been reclaimed.
The results can identify the "weak zone" characterized by
high seismic vulnerability index in the former marsh zone.
The seismic vulnerability index changed little after entering
the transition zone and zone hill. Former region was re-
claimed swamp proved to be a zone of high vulnerability
index and always suffered severe damage every strong
earthquake occurs.

Although not directly conduct research in the coastal
region but from the results of their research have described
in general that in areas of high seismic vulnerability value
will cause severe damage when the earthquake hit. If this
thought is reversed, the area which has a high damage such
as coastal erosion which has a high enough rate, and turns
in this region has a high value of Groun Shear strain is
suspected there is a relationship between the rate of abra-
sion with Ground Shear Strain.

THEORY
1. Shorelines Changes

Basically the change process includes the shoreline ero-
sion and accretion, erosion of coastal sediment transport
may occur when moving out or leaving an area larger than
the incoming sediment transport, when the opposite is hap-
pened that called sedimentation (Triantofyllo, 1991).

The coastline generally experienced a change from time
to time in line with changes in the activity of nature such
waves, wind, tides and currents and the sedimentation of
the river delta region. Shoreline changes also occur due to
interference with coastal ecosystems such as the manufac-
ture of dikes and canals as well as the buildings that sur-
round the beach. Coastal mangrove forests as a buffer to be
much altered function as a regional aquaculture, residential,
industrial and reclaimed area which resulted in a change in
the shoreline.

2. Earthquake vibration effect

Earthquake wave propagation through the ground
surface will affect the strength of the soil to maintain tens-
sile strength between the particles. As stated in the
Standard Planning for Earthquake Resistance Structure
Building (SNI-1726-2002), that in the planning of the
building structure and various parts of the equipment in
general, it must be standardized by calculating the influence
of the earthquake on the building plans."

With the Indonesian National Standard (SNI) is highly
likely that the propagation of seismic waves will affect the
strength of the soil in retaining power (belt style) between
the particles. In ISO-1726-2002 also revealed that the
earthquake vibration acceleration parameter maximum
ground shaking (PGA) value will depend on the type of soil
through which the earthquake vibrations. There are 3 types
of land in question refers to the average speed of a wave at
a maximum depth of 30 meters from the surface tank
(V\text{S}30) is a type of soft soil, soil type and the type of soil
being hard. The three types of land will respond to the
speed of earthquake waves at different speeds as table 2
below:

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Vs (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soft</td>
<td>$&lt;175$</td>
</tr>
<tr>
<td>Medium</td>
<td>$175 \leq Vs &lt; 350$</td>
</tr>
<tr>
<td>Hard</td>
<td>$\geq 350$</td>
</tr>
</tbody>
</table>

Propagation waves occur during earthquakes is strongly
influenced by local soil conditions. Wave propagation of
shear conducted bedrock to the surface to obtain maximum
acceleration, amplification factor and response spectrum at
ground level. The analysis is based on the assumption that
the coating consists of several layers of soil and soil re-
sponse due to the propagation of shear wave (shear wave)
vertically from the bedrock to the surface.

3. Peak Ground Acceleration (PGA)

Soil Vibration Maximum Acceleration (PGA) is a mea-
surement of ground shaking acceleration which is an im-
portant parameter to determine the impact of the earth-
quake shock (Campbell, Bozorgnia, 2003). PGA is ex-
pressed in g (acceleration of gravity) with units of m/s2 or
Gal, where 1 Gal is of 0.01 m/s$^2$ (1g = 981 gal).
The earthquake will cause acceleration called the Maximum Acceleration Vibration Land that ever happened in a place caused by the earthquake. The size can be selected from the PGA attenuation relationships defined by some experts. One of the attenuation relationships used in this study is the attenuation of Fukushima-Tanaka defined as:

\[ \alpha = 10^{0.41M - \log R + 0.035x10^2 + 0.34R + 1.3} \]  \hspace{1cm} (1)

\( \alpha = \) Peak Ground Acceleration in the Basement  
\( M = \) magnitude of the wave  
\( R = \) distance from hypocentrum to the station

**DATA AND METHODS**

1. **Data acquisition**

Microtremor data acquired using portable low frequencies seismometers at some point have been previously. Shoreline change data acquired through the overlay method Bengkulu city maps created in 1980 with the Bengkulu city map made in 2010.

Ishihara (1982) developed the relationship between ground shear-strain value with the surface soil conditions. High ground shear-strain values will cause the layer soil prone to deform, such as ground cracks, liquefactions and avalanches. Conversely, the smaller ground shear strain value shows a solid rock and hard layer to deform. There are only wave and vibration that will occur with 10⁻⁶ strain value but avalanche and liquefaction can occur with 10⁻² strain value (table 2). Ground shear-strain values can lead to deformation of the surface soil layer.

**Table 2. Strain value and the dynamics of soil (Ishihara, 1982)**

<table>
<thead>
<tr>
<th>Size of Strain</th>
<th>10⁻⁶</th>
<th>10⁻⁵</th>
<th>10⁻⁴</th>
<th>10⁻³</th>
<th>10⁻²</th>
<th>10⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phenomenon</td>
<td>Wave, Vibro, Diff. Settle-ment</td>
<td>Lamplitude, Soil, Compaction</td>
<td>Linear, oil, Contraction</td>
<td>Liquefaction</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dynamic Properties</th>
<th>Elasticity</th>
<th>Plasticity</th>
<th>Speed-Effect of Loading</th>
<th>Speed-Effect of Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. **Data analysis**

Microtremor data was processed to obtain the dominant frequency (fₒ) and the amplification factor (A). Processing data used Geopsy software by HVSR method (Horizontal to Vertical Spectral Ratio). Seismic Vulnerability Index (Kｇ) obtained using the formula:

\[ K_\text{g} = A^2/f_\text{o} \]  \hspace{1cm} (2)

Where \( K_\text{g} \) is Seismic Vulnerability Index, \( A \) is Amplification factor and \( f_\text{o} \) is resonance frequency \( \text{Ground Shear Strain} \) (GSS) obtained by the formula:

\[ \gamma = K_\text{g} \times (10^{-6}) \times \alpha \]  \hspace{1cm} (3)

Where \( \gamma \) is the GSS, \( \alpha \) is the peak ground acceleration (PGA) obtained from equation (1) where \( m \) is the moment magnitude and \( r \) is the distance from the earthquake center to the station. Shoreline change data were processed using arcgis. Map of the city of bengkulu in 1917 with a map of the city of bengkulu in 2010 in the overlay using arcgis. Abrasion speed at a given location is calculated by dividing the distance of shoreline change direction in a time of 93 years.

**RESULTS**

1. **The changes at the shoreline**

Coastal erosion in bengkulu city since 1917 until the year 2010 (for 93 years) occur along the shoreline between 3.1 to 5.4 meters per year as shown in the map below:

![Gb 2. Bengkulu city 1917](image)

Gb 3. Bengkulu city 2010

![Gb 4. Overlay shoreline value](image)
2. Seismics Vulnerability Index and ground shear strain

The value of the seismic vulnerability index (kg) and ground shear strain (γ) of the six types of rocks that make up the coastal town of bengkulu is shown in table 3:

<table>
<thead>
<tr>
<th>Location code</th>
<th>Ks</th>
<th>PGA</th>
<th>γ</th>
<th>ν</th>
<th>Rock type</th>
</tr>
</thead>
<tbody>
<tr>
<td>MB</td>
<td>23.0</td>
<td>258</td>
<td>0.0059</td>
<td>12.4</td>
<td>Qa (clay)</td>
</tr>
<tr>
<td>TS</td>
<td>3.6</td>
<td>875</td>
<td>0.0026</td>
<td>4.4</td>
<td>QTs (Sandy tuff)</td>
</tr>
<tr>
<td>RS</td>
<td>10.19</td>
<td>758</td>
<td>0.0076</td>
<td>7.1</td>
<td>QTs (Stone clay Tufaan)</td>
</tr>
<tr>
<td>GC</td>
<td>10.36</td>
<td>532</td>
<td>0.0055</td>
<td>7.6</td>
<td>Qa (sandstone)</td>
</tr>
<tr>
<td>KM</td>
<td>48.1</td>
<td>334</td>
<td>0.0161</td>
<td>16.2</td>
<td>Qa (surf)</td>
</tr>
<tr>
<td>KM</td>
<td>15.9</td>
<td>1141</td>
<td>0.0026</td>
<td>11.5</td>
<td>Qa (marsh)</td>
</tr>
</tbody>
</table>

DISCUSSION

Shoreline changes occur due to several reasons such as tides, sea level rise, ocean exploration and sand abrasion and accretion. Especially for abrasion and accretion of events is due to the dynamics of sediment. Under normal conditions coastal erosion occurs because of factors beyond the ease of exposure to the waves, but in special circumstances such as the coastal town of bengkulu, which is located in an earthquake-prone areas of internal factors such as seismic vulnerability index (Kh) in each district area which has a beach in the city of bengkulu, also try to know the ground shear strain (γ) or shear strain between the basement and sediments during earthquakes.

Microseismic data retrieval which was done at some locatio represent every sub-district in the city of Bengkulu. There are 5 sub-districts that have the coastal sub-district of Muara Bangkahulu, Teluk Segara sub-district, Ratu Samban sub-district, Gading Cempaka sub-district and Kampung Melayu sub-district. From each sub-district are selected types of beaches make up the dominant lithology, namely Qa (clay) for the sub-district of Muara Bangkahulu (MB), QTs (sandy tuff stone) for the Teluk Segara (TS), QTs (tufaan clay stone) for the sub-district Ratu Samban (RS), Qa (sandstone) to sub-district Gading Cempaka (GC), and Qa (surf) and Qa (marsh) to sub-district Kampung Melayu (KM). Therefore, the measurement value Seismic Vulnerability Index and Ground Shear Strain also performed on all five districts.

All factors that affect the level of seismic vulnerability in every type of beach static are within the beach itself. The value of seismic vulnerability index (Ks) for 5 types of beaches, each at 23.0 for Qa (clay), 3.6 for QTs (tufa sandy rock), 10.1 for QTs (stone clay tufaan), 10.3 for Qa (sandstone), 48.1 for Qa (surf) and 15.9 for Qa (marsh). There is a greater tendency Ks value the more susceptible the soil conditions at the beach. Coastal rock type peat bogs and clay have a relatively large vulnerability index is 48.1, 23.0 and 15.9. As shown in table 2, the condition of the beach is exposed to abrasion which is very strong and tends to slide from the top, as well as beach stones tufaan clay and sandstone, the condition is also exposed to abrasion. There is a tendency of the higher index of the seismic vulnerability of a coast more vulnerable to abrasion. And the beaches tend to be stable to the conditions of fine sandy beaches, rugged sandy and rocky.

Evaluated from the magnitude of peak ground acceleration (pga) of each type of beach has a value of 258 gal PGA for Qa (clay), 758 to QTs (sandy tufaan stone), 344 for Qa (surf) and 1141 for Qa (marsh). PGA values are not visible impact on coastal rock deformation. It seems the type of cly beach PGA actually have fairly low (258 gal), and otherwise the sandy beach tufaan stone is quite high PGA (758 gal).

Calculation of ground-shear strain (γ) microtremor data indicate different for each type of beach that is selecte in this study. Argilaceous beach type has a value of 0.0059 , type of stone has a sandy beach bertufa GSS value 0.0032, the type of clay tufaan rocky shore has a value of GSS 0.0076, rocky beach type sand gss has a value of 0.0055, the kind of beach bertagambut has value gss 0.0161, and the kind of muddy GSS value 0.0026.

GSS value is sufficient to provide clear information about the condition of a stable coastal rocks and deformed. Shape deformation is quite clear and easily affected by coastal erosion. In relation to the dynamics of the beach seems GSS give us even stricter than the PGA.

CONCLUSION

From the description of the discussion, it can be concluded that there was a significant relationship between the rate of abrasion of the Seismic Vulnerability Index. Influence of earthquakes in the coastal town of Bengkulu is comprehensive given the geological conditions of the region are still relatively young rocks.

REFERENCES

2. BMKG Bengkulu, 2009, Bengkulu Earthquake History from 1800 to 2010


9. PETA KOTA BENGKULU, 1917; Royal Institute, Amsterdam-Netherland.

