The Hexa-Helix Concept for Supporting Sustainable Regional Development (Case Study: Citatah Area, Padalarang Subdistrict, West Java, Indonesia)

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Abstract. A regional development requires some analyses in terms of the constraint and the potential. Constraints of a development need to be managed by periodic monitoring, while the potentials need to be maintained or optimally improved. The hexa-helix concept is a development of penta-helix concept with addition in the role of law and regulation. Citatah area is a multipurpose area where there is limestone quarry, factories, tourist attractions, and rock-climbing area as territorial potential. The constraints is found in Citatah are landslides and faults. To support the potential of the region, infrastructures need to be safe from landslide. The stable slopes have been built through terracing and engineered slopes. This research is directed to identify potentials and constraint in development of the Citatah area; evaluate safety factors around landslide prone areas; and inventory the role of hexa-helix agents in the infrastructure of road around the engineered slope. The result shows that regional potential needs to be managed by utilizing the hexa-helix concept. Besides, the Citatah landslide zone needs to be aware. Environmental management and monitoring are required to avoid failure of development planning in the future. The result of this study will be useful for sustainable regional development in Citatah area.

Keywords: Hexa-helix concept, Sustainable regional development, Citatah Area

1. Introduction
1.1. Background

Sustainable regional development of an area requires comprehensive study of the area concerned. Citatah area requires support for the implementation of sustainable development. In Citatah area there are various potentials that support the local economy through tourism, mining, factories, and education areas, but in that area there are also various constraint [1–3]. One aspect of the disaster that needs to be reviewed is slope stability. In road segments around the Citatah area there are unstable slope. For this reason, an inventory of potential and constraint of the area is indispensable. Potential areas that
support development need to be maintained, while constraints that can hamper the development need to be managed by mitigation, stabilization, or limitation. The objectives of this study are: 1) identifying potential and constraint in development of Citatah area; 2) Evaluating Safety Factors around landslide prone areas; 3) Inventorying the role of hexa-helix agents as direction of Environmental Management Planning and Environmental Monitoring Planning on the road infrastructure around the engineered slope.

The research conducted in Citatah area, Padalarang subdistrict, West Bandung Regency. The location can be reached by using a vehicle (motorcycle or car) from Bandung city heading towards Cianjur city. This area is located approximately at KM 23 to KM 27 on Bandung-Cianjur highway, which is an important route for economic facilities and infrastructure, especially as a route that connects Bandung with western cities, such as Cianjur, Sukabumi, Pelabuhanratu, Cisolok, Ciletuh, and others (Figure 1).

**Figure 1.** Research location

### 1.2. Potential and Constraint Characteristics of Citatah Area

In Citatah, there are limestone quarry and limestone processing plant. The location of limestone quarry is in the northern as well as the southern hill. The two hills are separated by Bandung-Cianjur highway. In this area, there are also rock-climbing area for public at Tebing 125 and for soldiers elsewhere; both are in the southern hill. Around the northern hill, there are several hills namely Pasir Pawon and Gunung Masigit. Pasir Pawon has tourist attractions at the top of the hill, i.e. Stone Garden, and at the foot of the hill, i.e. Gua Pawon. Gua Pawon has fairly good economic value for tourism [1]. This condition strongly supports the development of Citatah but requires safe infrastructure so that the potential of the area remains beneficial.
Based on geological condition of Citatah area (Figure 2), there is lithological distribution of Batuasih Formation claystone, Rajamandala Formation limestone, Citarum Formation sandstone, and andesitic intrusion (Figure 2). Position of Batuasih Formation claystone is at the bottom. At the top of it, there is limestone of Rajamandala Formation. Limestone is younger than claystone. Stratigraphic condition of Rajamandala Formation limestone is above the Batuasih Formation claystone. The claystone of Batuasih Formation was revealed due to the geological structure of Cimandiri Fault [2,3]. This condition led to the emergence of geomorphological units of very steep to gently sloping hills. The geomorphological form of the hills gives a negative contribution in the form of landslide-prone zone [3]. Landslide-prone zone is a constraint in regional development. Landslides that occur around the road may cause the Bandung-Cianjur highway as provincial road to be cut off. The last landslide occurred in 1993 [4] which caused the road to be cut off. Landslide-prone areas need slope stability, so it is necessary to create engineered slopes and build new roads towards the hillside.

![Geological map of Citatah area][1]

**Figure 2.** Geological map of Citatah area [3]

### 2. Methods

#### 2.1. Helix Concept to Support Development

Innovation plays an important role in improving regional development. Realization of innovation requires participation from various parties. This support or participation is often called the helix concept [3]. The concept of helix continues to develop according to changes in society. Several concepts have been developed, from triple-helix, quadruple-helix, penta-helix, to hexa-helix. The triple-helix concept (Figure 3) focuses on the relation of university, industry, and government [5]. Quadruple-helix emphasizes the importance of integrating media-based and culture-based public perspectives [6]. Quadruple-helix complements triple-helix by adding "media-and-culture-based public" and "civil society" as the fourth helix. The quintuple-helix innovation model is even broader and more comprehensive by contextualizing quadruple-helix and by adding the helix (and perspective)
of the “natural environment of society” [7]. This last helix developed into the penta-helix (Academic, Business, Community, Government, and Mass Media). Penta-helix also developed into a more complete hexa-helix by adding laws and regulations [8].

![Figure 3. Triple-helix [6]](image)

2.2. Quadruple-helix and Penta-helix

In the aspect of environment and disaster, concept like quadruple-helix is expressed in the Starlet Model. Starlet stands for *Stabilisasi dan Rancangbangun Lereng Terpadu* (Integrated Slope Stabilization and Design) [3] which examines several aspects related to slope stability issues as follows:

- Stabilization and slope construction design with a series of engineering activities
- Engineering geological mapping
- Slope stability analysis, stable slope design simulation, and slope reinforcement
- Environmental management directive accompanied by environmental monitoring

In its implementation, collaboration between helix components is needed by combining four mutually supporting interests, specifically Academics (or education), Business (industry), Community or Society, and Government (Figure 4). This concept is known as the quadruple-helix.

![Figure 4. Quadruple-helix in the Starlet model](image)

The Quadruple-helix concept developed again into penta-helix (Figure 5). This concept supports many activities such as tourism, economy, and business. The penta-helix model is a relationship between...
five elements, consisting of government, educational institution, environmental assessment institution, society, and industry; each coordinates well with each other [9]. This concept is used to strengthen and develop alliance collaboration with stakeholder. This concept is a collaboration between Academics (or education), Business (industry) [10], Community, Government, and Media. The concept of penta-helix can also be used in industry, in research and community service [11], and in modification of Participatory Rural Appraisal (PRA) for debriefing the Student Study Service (Kuliah Kerja Nyata or KKN) in West Java [12].

2.3. Hexa-helix

Concept of hexa-helix is developed from penta-helix by adding aspects of law and regulation. This concept is used in Starlet Model (Model of Integrated Slope Stabilization and Design) for slope stabilization and then modified into Starlet Perdana Model (with the addition of soil bearing capacity for the foundation). Starlet Perdana Model utilizes hexa-helix concept to be more effective [8]. The six components of hexa-helix are Academics (or education), Business (Industry), Community, Government, Mass Media, and Law & Regulation (Figure 6) with following details:

- Government, consisting of the central government and regional governments
- Entrepreneur, industry, business, service, and trade
- Community, consisting of people from various professions and NGO
- Academics or education, or scientists, including the world of general education and higher education
- Mass media and communication media, including communication devices such as smartphone.
- Laws and regulations, including local government regulations.

The six components share the same views on regional potentials and constraints, as well as disasters that damage infrastructure. The same view of disaster is a must to reduce material losses and avoid casualties. It is required attention, especially for monitoring infrastructure damage.
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2.4. Slope Safety Factor

The basic principle of Safety Factor (SF or F) calculation is the comparison between driving forces (∑) and resisting forces (S) in a slope's body, or expressed by the formula: F = ∑ / S (Figure 7). Theoretically, a slope considered to be stable if F > 1, critical if F = 1, and unstable if F < 1, the slope is unstable. Based on the experience in slope analysis study, Bowles (1989) in [8] proposed a classification and the meaning of F value (Table 1).

| Safety Factor | Slope condition | Meaning          |
|---------------|-----------------|------------------|
| FS < 1.07     | Usually occurrence of slope failure | Unstable         |
| 1.07 < FS < 1.25 | Slope failure ever occurred | Critical         |
| FS > 1.25     | Slope failure events are rare | Stable           |

Figure 6. The six hexa-helix components [8]

Figure 7. Sketch of a slope section and forces acting on the slope [8]
3. Results and Discussion

3.1. Inventory of Development Potential in Economy, Tourism, and Education

Some activities that support the potential of regional development at Citatah and the surrounding areas (Figure 8) can be described as follows:

- In the southern limestone hills, there are mining activities of non-metallic mineral (limestone) located around Pasir Pabeasan. In the northern hills, some limestone hills have been strived so that they are no longer mined (in Gunung Masigit).
- In the southern part of Bandung-Cianjur highway, limestone processing plant is still active working. In some locations at the southern hill, there are limestone affected by metamorphosis due to high pressure and/or high temperature turning into marble.
- Rock climbing activities by a group of young people and rock climbers are usually done on holidays. The activity site is located in Tebing 125. On another cliff, there is a special site for rock climbing training for soldiers.
- In the northern hills, especially in Pasir Pawon, there are two tourist attractions. At the bottom of Pasir Pawon, a cave namely Gua Pawon is believed to be the home of ancient human. Here, a human skeleton was found. A replica of the skeleton is still stored in one corner of the cave. At the top of Pasir Pawon, there is the Stone Garden tourist area. Here, many stones are naturally arranged forming various configurations. Next to Stone Garden, there is a spot to take geomorphological photo of the Citatah area.
- To support geology education and training, especially Human Resources in the fields of geology, minerals, and coal, a Field Campus has been built for Education and Training Center. This campus belongs to PPSDM Geominerba (Center for Development of Geological, Mineral and, Coal Human Resources). It is located in the southern hills of Citatah area.
- To support the potentials mentioned above, it is needed to improve road access from each locations to Bandung-Cianjur highway. Some of the roads that have been built are made of stone, while the others are asphalt roads.

Figure 8. Some potential of development in Citatah area: a) Factory and limestone quarry (top left), b) Gunung Masigit and Pasir Pawon (top right), c) Stone Garden (bottom left), and d) The gate of PPSDM Geominerba Field Campus (bottom right)
3.2. Inventory of Development Constraints

The Citatah area is crossed by the Cimandiri Fault [2,3]. This fault extends almost in the direction of west-east. This fault is believed to be part of the Cimandiri Fault [13], so it is referred as the Eastern Cimandiri Fault. Citatah area has been deformed. An indication of the deformation is the existence of Batuasih Formation and Rajamandala Formation which are known to be Oligocene-aged. Both of these formations came to surface due to strong deformation. Limestone forms hills that extend in the direction of west-east. The Eastern Cimandiri Fault is cut by several dextral strike-slip faults. The indications are found in Pasir Pabeasan and around Pasir Pawon.

In some road segments between KM 23 to KM 26 in Bandung-Cianjur highway, there are landslide-prone areas with some indications of landslides. Landslide occurred in 1993. Slope stabilization was carried out by constructing engineered slopes on 1995. But, now, the engineered slope has changed. Some cracks on the slope terrace have occurred, some have collapsed, and there is bulging at the foot of the slope. Landslide is estimated to be active again. Location of unstable slope at KM 25 in Bandung-Cianjur highway, especially slope which have characterized by an indication of rotational landslides. The indication can be seen in the electric pile that tilt toward the slope (Figure 9). The position of the electric pile changed only in the surrounding area of the engineered slope.

Figure 9. Indication of the land returning to rotational movement. Left image was shot from east to west. Right image was shot from west to east. The sloping part is only around the location of the engineered slope.

3.3. Slope Stability Analysis

In previous studies [3], with data in 1999, the following analysis was obtained mechanical and physical properties i.e. water content, cohesion, internal friction angle, dry unit weight, and wet unit weight. Data are taken at conditions: 1) highest value of water content, 2) lowest value of cohesion, and 3) lowest value of internal friction angle. Dry and wet unit weight are taken at condition of highest water content. The results obtained: Water content ($\theta$) = 48.92%, dry unit weight ($w_{dry}$) = 10.7529
KN/M$^3$, wet unit weight ($w_{\text{wet}}$) = 16.1442 KN/M$^3$, angle of internal friction ($\psi$) = 10°, cohesion = 9.3160 KN/M$^2$.

The results of Safety Factors analysis give the value of $FS = 1.249$ or close to $FS = 1.25$ (stable) for slope 45 on terraced slopes with dry slope conditions or unsaturated condition (Figure 10). For wet slopes (saturated condition), the FS value drops to $FS = 0.987$ or $FS < 1.07$ or unstable slopes (Figure 11). The condition will be worse if there is an earthquake with seismic load $h = 0.3$ (at Citatah area, according to the National Earthquake Center), the FS value will be even lower by $FS = 0.727$ in dry conditions (Figure 12). In wet conditions $FS = 0.576$ (Figure 13). If there is an earthquake with seismic load $h = 0.3$, the slope will collapse.

Figure 10. FS value in dry conditions without earthquake effects

Figure 11. FS value in wet conditions without earthquake effects

Figure 12. FS value in dry conditions with earthquake effects

Figure 13. FS value in wet conditions with earthquake effects
Engineered slope has become unstable because there is no monitoring or weak supervision of monitoring. Engineered slopes built in the 1990s began to crack around the 2000s. In 2019, cracks and indications of unstable slopes are increasingly being shown. For example by tilting of electricity pile at the foot of slope.

3.4. The Concept of Hexa-helix to Support Development

To support sustainable development in an area, the concept of hexa-helix can be completely used. This concept needs to be supported by inventory data of potential and constraints in the local area. In sustainable development, the potential can be enlarged, while the constraint can be minimized or limited by mitigation, stabilization, or limitation. The concept of the hexa-helix in Starlet Perdana Model (or Stabilisasi dan Rancangbangun Lereng Terpadu & Perkuatan Dayadukung Tanah) can be modified to understand the role of six aspects of the project that is being run, tested, or verified; so in Figure 14, Starlet Perdana Model focuses on the center position and the other helix components are next to the center of the project. The role of hexa-helix can be reviewed for road infrastructure around engineered slopes, limestone quarries, infrastructure of limestone processing plant, and tourist attractions. In this paper, for example, the concept of hexa-helix for road infrastructure around engineered slope is given at Table 2.

![Hexa-helix transformation of Starlet Perdana Model](image)

**Table 2. Role of hexa-helix in the road infrastructure around the engineered slope**

| Agent                                | Management                                                                 | Monitoring                                                                                     |
|--------------------------------------|---------------------------------------------------------------------------|------------------------------------------------------------------------------------------------|
| Academics, scientists, education     | Calculate slope safety factor. Design stable slope. Provide direction in the process of management and monitoring. Provide counseling on stable slopes | Get information from the mass media, the public, and government institutions. Monitor directly. Field survey. |
| Business, entrepreneurship, industry, service, trade | Carry out slope engineering. Build drainage at the foot of the slope. | Get information from the mass media, the public, and government institutions. Monitor slope conditions periodically. |
| Society, Non-Governmental Organizations (NGO) | Maintain cleanliness of engineered slopes. Get counseling about slope failure warning system. | Monitor the presence/absence of slope change directly. |
| Central government, local government | Investigate slope stability. Coordinate with scientists and entrepreneurs. Give work permission. Provide counseling on stable slopes | Monitor slope conditions periodically. Get reports from various parties. Field survey |
| Mass media, communication            | Provide information of landslides event and indicating of landslide.       | Monitor information of slope change or landslide event directly. |
| Laws, regulations                    | Regulation of building construction permits. Regulations regarding the environment. Regulations regarding the Direction of Environmental Management and Monitoring Plan. | Monitor violations of laws and regulations. Supervise the implementation of environmental management and monitoring guidelines |
The support or participation of each agent in hexa-helix needs to be considered for the success and sustainability of various projects. This concept can be used for tourism, geopark, mining, infrastructure (road, bridge, foundation, building, engineered slope, factory, office, and other various public facilities), or service. The participation of six agents in hexa-helix can support the success of various projects (Figure 15).

4. Conclusions
- There are several potentials that will support development in Citatah area as well as constraints that will hamper the development. In efforts to support sustainable development, potential aspects need to be maintained and protected from damage, while constraints that will hamper the development need to be minimized (limited by mitigation, stabilization, or limitation).
- Infrastructure of engineered slopes in wet conditions will experience a decline in Safety Factor value. The slope will be unstable. The condition will be worse, if there is an earthquake. The slope will be collapse.
- The concept of hexa-helix may be a choice to address problems comprehensively. The potential and constraint of development will become a shared domain for hexa-helix agents to maintain and monitor together the infrastructure that has been built. Each helix, ABCGML (Academics or education, Business or industry, Community, Government, Media, and Law & Regulation), has its own responsibility in accordance to its function and ability.

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