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Basic Study on Problem Soils Encountered in Construction Works in Developing Countries

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Abstract: *Official Development Assistance (ODA) projects in developing countries frequently encounter geotechnical challenges due to problem soils, including expansive, dispersive, collapsible, and lateritic soils. These types of problem soils, which are rare in Japan, are frequently underestimated during the planning phase and insufficiently addressed during construction, resulting in structural failures, slope instability, pavement deterioration, and project delays or cost overruns. Although some countermeasures are implemented on a case-by-case basis, systematic knowledge sharing and risk management among stakeholders remain limited. To address these challenges, this study conducted comprehensive literature reviews domestically and internationally, field investigations in 13 developing countries, and interviews with relevant organizations. The findings were classified by soil type to support future risk mitigation and quality assurance in infrastructure development. The survey revealed that most countries lack design standards and distribution maps for problem soils. In many cases, no specific countermeasures were implemented; when countermeasures were applied, soil replacement with high-quality materials was the most common approach. Advanced techniques commonly used in Japan, including ground improvement, were rarely adopted. These results highlight the global need for standardized approaches and enhanced technical capacity to manage problem soils effectively. Further research and international collaboration are essential. A handbook compiling these findings is available through the JICA e-Library.*

Keywords: problem soil, expansive soil, dispersive soil, collapsible soil, laterite, handbook

1. INTRODUCTION

Problem soils, including expansive, dispersive, collapsible, and lateritic soils, present significant challenges for infrastructure development in many developing countries, particularly in Official Development Assistance (ODA)-funded projects. For example, expansive soils are characterized by substantial volume changes due to moisture fluctuations, which can cause severe structural failures. Despite their critical impact, these types of problem soil are frequently underestimated during project planning and insufficiently addressed during construction, resulting in costly failures and delays. Although some countermeasures are implemented, there is a lack of systematic knowledge sharing and risk management among stakeholders. This study aims to address these gaps by conducting comprehensive literature reviews, field investigations, and interviews with relevant organizations in 13 developing countries. The objective is to compile these findings into a practical handbook that provides a thorough understanding of problem soils and countermeasures for practitioners involved in infrastructure development.

2. METHOD OF FIELD SURVEY

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The field survey was conducted by collecting and categorizing information on countermeasures for problem soils encountered in JICA-funded projects, reviewing domestic and international literature and standards, and compiling findings from on-site interviews in developing countries. The survey also included current assessments of problem soil distribution and materials provided by construction project personnel. Table 1 shows the target countries and their corresponding major problem soils. These countries were selected based on their experience with ODA projects and the likelihood of encountering problem soils. During the overseas field survey, interviews and site visits were conducted. Table 2 summarizes the main topics covered in the interviews, including types and examples of problem soils, countermeasures, distribution maps, standards, guidelines, and technological needs for ground improvement and slope protection.

Table 1. Target countries and corresponding major problem soils

Area	Target Countries	Main problem soils
Southeast Asia	Cambodia	Dispersive soil, Expansive soil
	Indonesia	Expansive soil, Peat
	Thailand	Dispersive soil, Collapsible soil
Central Asia	Kyrgyzstan	Collapsible soil, Erodible soil, Dispersive soi
	Tajikistan	Collapsible soil, Erodible soil, Dispersive soil
Oceania	Palau	Coral-derived soil
	Marshall islands	Coral-derived soil
East Africa	Ethiopia	Expansive soil
	Kenya	Expansive soil
	Tanzania	Expansive soil
West Africa	Guinea	Laterite
	Côte d'Ivoire	Laterite
	Ghana	Laterite, Expansive soil

Table 2. Interviews topics covered in target countries

No.	Contents of the interviews
1	Types and examples of problematic soils encountered in construction works.
2	Countermeasures for problematic soils
3	Problematic soil distribution assumption maps
4	Standards, guidelines and manuals
5	Ongoing construction sites
6	Expected technological demands from Japan or other countries to solve problems in construction projects, such as ground improvement, slope protection etc.

3. SURVEY RESULTS

This section presents examples of survey results focusing on problem soils widely distributed around the world, including expansive soils, dispersive soils, collapsible soils, and laterite. The field survey was primarily based on sites introduced through interviews with relevant organizations. Furthermore, representative findings from 13 countries were selected and presented in this paper.

3.1 Expansive soil

Expansive soil, commonly known as clay shale, is widely distributed in Indonesia. This soil type is hard when dry but readily disintegrates upon exposure to water, transforming into clay and exhibiting expansive behavior. Fig. 1 shows the distribution and condition of clay shale along the Cipamingkis River in Jonggol. Depending on the degree of weathering, clay shale can cause landslides and swelling, resulting in structural damage. Indonesia has established guidelines for the handling of expansive soils in road construction [1] and maintains a distribution map of clay shale [2]. Typical countermeasures for expansive soils include soil replacement, stabilization, waterproofing with membranes, and preloading.

In East Africa, expansive soil is commonly referred to as Black Cotton Soil (BCS) and is widely distributed near the surface, making it suitable for agriculture but problematic for construction. Fig. 2 shows the distribution of BCS observed at an irrigation canal construction site in Kenya, where the BCS layer was approximately one meter thick. The adopted countermeasure involved replacing the BCS with high-quality material (Murram). While standards addressing expansive soils have been established for road construction in East Africa, and documentation exists for assessment methods and countermeasures, design methods that incorporate the swelling pressure of these soils have not yet been fully developed. Distribution maps for expansive soils are also largely unorganized; however, in Ethiopia, research-level mapping is underway through the Ethiopian Roads Administration - Road Research Center. Replacement methods are the most common countermeasure for expansive soils, but this approach also presents challenges regarding the disposal of excavated material.



Fig. 1. Distribution and condition of clay shale along the Cipamingkis river, Jonggol, Indonesia



Fig. 2. Black cotton soil observed at irrigation canal construction sites in Kenya

3.2 Dispersive soil

Dispersive soils are characterized by clay particles that readily disaggregate and disperse into suspension upon contact with water. These soils are widely distributed in Cambodia. Fig. 3 shows erosion observed on a slope along the levee near the headworks of the Tonle Sap Irrigation. Similar erosion has occurred at many locations in the region, yet no specific countermeasures have been implemented. Fig. 4 shows a large cavity, known as a "dragon hole," formed by the leaching of dispersive soil on an unpaved rural road. Dragon holes are commonly observed throughout Cambodia, and even on paved roads, cracks and potholes can develop when the subgrade consists of dispersive soil [3]. Fig. 5 shows pavement cracks resulting from road collapse along the Mekong River, where gradual collapse due to dispersive soil leaching was confirmed. Cambodia currently lacks standards or distribution maps for dispersive soils. Road countermeasures typically involve reconstructing the subgrade and base after pavement removal or conducting repairs using geotextiles. However, these are reactive measures; there are few examples of countermeasures being implemented proactively during the construction phase.



Fig. 3. Riverbank gullies caused by dispersive soils along the Tonle Sap river, Cambodia

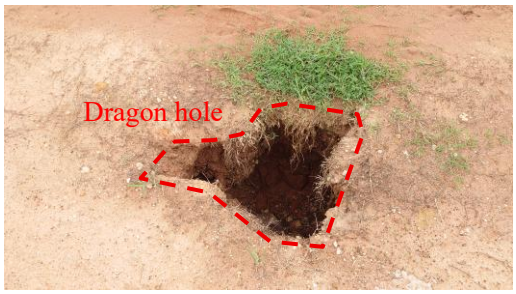


Fig. 4. Large "Dragon Holes" formed by dispersive soil on rural roads in Cambodia



Fig. 5. Pavement cracks and road collapse induced by dispersive soil along the Mekong river, Cambodia

3.3 Collapsible soil

Collapsible soils are a type of problem soil characterized by a sudden loss of structural integrity due to external factors such as moisture infiltration or increased loading, resulting in rapid volumetric reduction and subsidence. These soils are typically found in arid and semiarid regions and are formed from materials including debris flows, loess, aeolian deposits, and residual tropical soils. Loess, a representative type of collapsible soil, is distributed west of Bishkek in Kyrgyzstan. As shown in Fig. 6 (a), the overview of the loess region reveals steep, seemingly stable cliffs formed by dry outcrops. However, Fig. 6 (b) highlights gullies and surface holes on the loess outcrop caused by runoff. A section of the main road west of Dushanbe in Tajikistan has exhibited large-scale

deformation that continues to progress. This section curves around a ridge on terrain with a relatively gentle slope, yet subsidence and deformation persist, necessitating frequent repairs (Fig. 7 (a)). On the mountain side of the road, a landslide scarp was observed, with deformation progressing slowly in a landslide-like manner. The loess distributed in this area differs slightly in color from that in Kyrgyzstan, but it consists of fine-grained sand to silt-like material that has dried and consolidated (Fig. 7 (b)). Although geological maps exist in both countries, no distribution maps specifically for loess have been developed. Installing drainage facilities has proved effective on roads with unstable slopes, but this approach has been ineffective in some areas and remains unestablished in Kyrgyzstan. Sections of road experiencing deformation or damage are regularly repaired, but there is no established knowledge regarding effective countermeasures in Tajikistan.



(a) Overview of loess region



(b) Gullies and holes observed on loess outcrop

Fig. 6. Loess distribution in Kyrgyzstan



(a) Road sections with frequent pavement damage



(b) Exposed loess layer in the survey area

Fig. 7. Loess distribution in Tajikistan

3.4 Laterite

Laterite is a highly weathered residual soil rich in iron and aluminum oxides, commonly exhibiting a reddish-brown color due to the presence of hematite and goethite. It is predominantly found in tropical and subtropical regions characterized by hot and humid climates. In Guinea, laterite is distributed in the forested areas of the southern regions of Conakry. Numerous sections along the main national highway were identified with severely damaged pavement (Fig. 8 (a)) or with almost no pavement remaining (Fig. 8 (b)), significantly impairing drivability and reducing travel speeds to 20 km/h or less. The outcrops of laterite layers showed considerable variation, ranging from gravelly to fine sandy to silty textures, resulting in a wide range of engineering properties. Similarly, in Côte d'Ivoire, laterite has been used as a primary construction material. Near the capital Yamoussoukro, as shown in Fig. 9, laterite cut slopes remained stable for approximately 10 meters with a nearly vertical cut. The upper surficial layer was hard and compact, transitioning to fine sand to silt-like material with increasing depth. While each country has its own standards, generally accepted guidelines are followed in design and construction. However, no standards specifically addressing laterite have been identified, and no distribution maps for laterite have

been developed. Countermeasures for laterite include using materials that meet specified CBR values or replacing subgrade soils or roadbed materials if they are of poor quality. When high-quality laterite is unavailable, mixing with lime or cement may be employed for improvement; however, no established site investigation or quality assessment procedures have been identified.



(a) Pavement damage on paved road section



(b) Pavement damage on unpaved road section

Fig. 8. Laterite distribution in Guinea



Fig. 9. Laterite distribution in Côte d'Ivoire

3.4 Coral-derived sand

Coral soils are soils derived from the remains of marine organisms, such as coralline algae and corals. The calcareous strata formed by the accumulation of coral are known as coral reef rock. As coral reef rock weathers and disintegrates over time, the resulting debris may remain isolated or mixes with other soil types to form coral soils. These soils are commonly encountered in coastal and island environments, where they are frequently used as fill material for land reclamation and road construction. During field investigations in Palau, coastal roads and dredging sites were inspected. As shown in Fig. 10, dredging of coral-mixed soil was underway, with the dredged material being used for landfills and roadbeds. While some damage to road structures was observed, it was not possible to definitively attribute this to either general salt damage or the properties of the coral-mixed soil itself. In the Marshall Islands, inspections of coral quarries and reservoir construction sites revealed that coral-derived soils contain both hard and soft fractions (Fig. 11 (a)). At construction sites, rock fill using this material was being implemented, and the softer material generated during dredging was used as sediment fill (Fig. 11 (b)). From a geotechnical perspective, coral soils exhibit significant variability in particle size, strength, and durability, depending on their origin and degree of weathering. The presence of soft, easily crushable components can lead to settlement or instability when used as engineering fill, while the high calcium carbonate content may affect long-term durability, especially in aggressive marine environments. Projects constructed to international standards, such as those funded by ODA, frequently require the importation of high-performance materials, which increase costs. Currently, no distribution map for coral soils have been developed, and standardized guidelines for their engineering use are lacking.

3.6 Summary of Results

Table 3 presents a summary of the standards, manuals, and distribution maps related to problem soils, based on interviews with relevant organizations. The main types of problem soils identified in the 13 countries surveyed are expansive soils, dispersive soils, collapsible soils, laterite, and coral-derived soils. Among these countries, only four have established some form of standards or manuals addressing problem soils. However, distribution maps for these soils are generally lacking. Furthermore, no country has developed comprehensive countermeasures; soil replacement remains the predominant approach, and cases in which ground improvement techniques have been implemented are rare.

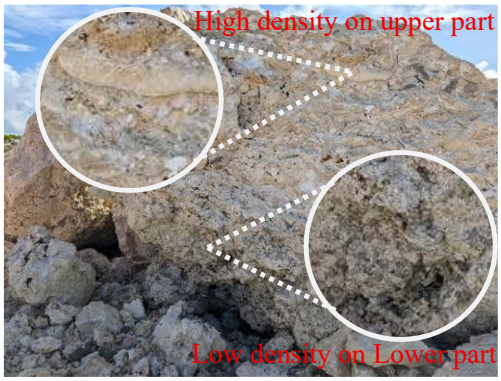


(a) Dredging site for coral-mixed soils



(b) Pysical condition of coral-mixed soils

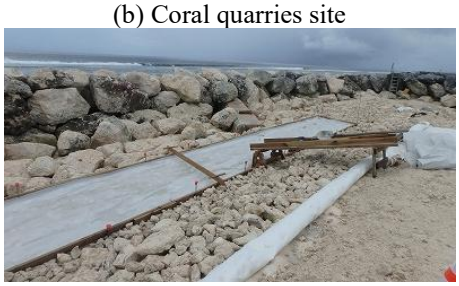
Fig. 10. Coral-derived soil observed in Palau



(a) Coral-derived rock fragments



(b) Coral quarries site



(c) Application of coral-derived rock as riprap

Fig. 11. Coral-derived soil observed in the Marshall Islands

Table 3 Overview of standards, manuals, and distribution maps for problem soils

Target Countries	Standards/ Manual	Distribution Map
Cambodia	No	No
Indonesia	Yes	Yes
Thailand	No	No
Kyrgyzstan	No	No
Tajikistan	No	No
Palau	No	No
Marshall islands	No	No
Ethiopia	Yes	Yes(Under study)
Kenya	Yes	No
Tanzania	Yes	No
Guinea	No	No
Côte d'Ivoire	No	No
Ghana	No	No

4. HANDBOOK ON PROBLEM SOILS

Based on the results of overseas field investigations, domestic and international literature reviews, and interviews, a handbook was compiled to help reduce risks and ensure quality in construction projects involving problem soils. Table 4 outlines the structure of the handbook. Chapter 2 focuses on problem soils commonly encountered in developing countries: expansive soils, dispersive soils, collapsible soils, and laterite. It summarizes their characteristics, presents case studies, describes recommended responses during the planning, design, construction, and maintenance phases, along with key considerations for consultants and contractors. Additionally, this chapter features a unique problem soil distribution map (see Fig. 12), created by integrating the WHSDB [4] with literature on problem soil distributions [e.g., 5]. Chapter 3 provides an overview of other problem soils, such as crushable soils, saline soils, peat, coral soils, and weathered rock, primarily to raise awareness. Chapter 4 details countermeasure techniques for problem soils, while Chapter 5 discusses risk management strategies for facility development projects that address problem soils. Chapter 6 compiles essential information on problem soils, including definitions, formation factors, processes, classifications, and distribution areas. The appendix is comprehensive, and the handbook is intended for professionals in fields such as civil engineering, architecture, and agriculture. The handbook is available free of charge from the JICA Digital Library [6].

Table 4 Structure of the handbook on problem soils

Chapter	Item

Chapter 1	Overview of the Handbook
Chapter 2	Problem Soil in Developing countries and Considerations for Project Implementation
Chapter 3	Other Problem Soils
Chapter 4	Problem Soil Measures
Chapter 5	Basic Policy for Infrastructure Development Projects related to Problem Soils
Chapter 6	About Problem Soil
Chapter 7	Conclusion
Appendix	- Method of Identifying Expansive Soil Based on Soil Properties - Identification of Expansive Soil and Dispersive Soil Based on Chemical Indices - Testing Standards in Japan, the United States, and the United Kingdom - Problem Soil Q&A - Case Studies of Problem Soil - List of Symbols - List of Abbreviations - References

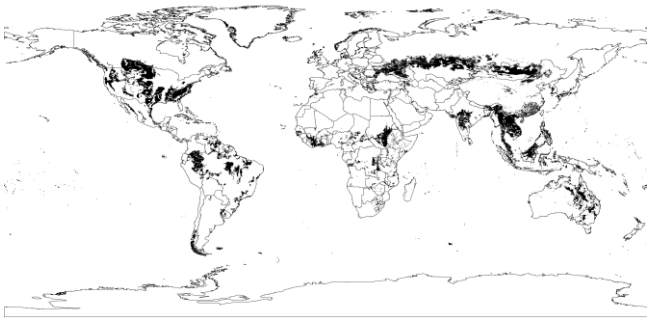


Fig. 12. Global distribution map of expansive soils

5. CONCLUSIONS

This study compiled a comprehensive handbook for problematic soil measures, systematically organizing information on global problem soil issues and countermeasures. This was achieved through a review of domestic and international literature and field survey results from 13 countries where problem soils are distributed. The main findings are as follows:

(1) Expansive soils are representative swelling soils that cause landslides and structural damage.
(2) Dispersive soils readily dissolve upon contact with water, leading to gully erosion on slopes and road damage.
(3) Collapsible soils rapidly disintegrate into sediment when triggered by water or other factors, resulting in large-scale deformations such as landslides.
(4) Laterite exhibits varying properties depending on its weathering condition, making it difficult to handle. When used as road subgrade or roadbed material, poor-quality laterite can cause road damage.
(5) Coral-derived soil, in gravelly form, was used for landfills and roadbeds. Coral-derived rock was utilized as riprap for its hard varieties and as sand and gravel for its softer varieties. Both were effectively used, with no confirmed instances of serious construction problems.
(6) Design standards, guidelines, and distribution maps for problem soils are largely unavailable in most countries.
(7) Primary countermeasures involve replacing problem soils with high-quality materials and implementing drainage treatment, while cases of ground improvement are few. No standardized countermeasure methods have been established.

The development of this handbook is the first initiative of its kind in Japan and is expected to serve as a valuable reference both domestically and internationally. However, standardized countermeasures for problem soils have yet to be established, and further research is required. It is essential that this handbook be updated as research progresses, thereby establishing methods to reduce risks in construction projects in regions where problem soils are distributed.

ACKNOWLEDGMENTS

The findings of this study incorporate results from JICA's project research titled “Basic Study on Reinforcement Measures for Local Natural Geomaterials and Problematic Soil Measures Encountered in Construction Works in Developing Countries.” In addition, during the implementation of this project, we exchanged views with ten Japanese experts and received numerous valuable insights. We sincerely thank all JICA personnel and experts who contributed to this research.

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