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Utilization of Work Breakdown Structure (WBS) and Building Information Modeling (BIM) for Dam Maintenance in Indonesia: A Literature Study

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Abstract: *The rapid construction of dams in Indonesia necessitates a more reliable and efficient maintenance process to prevent potential failures, which could result in substantial economic and social losses. This study highlights the importance of early damage detection through enhanced dam operation, maintenance, and monitoring, supported by detailed references for maintenance activities. By integrating the Work Breakdown Structure (WBS) with Building Information Modeling (BIM) technology, the research evaluates the current maintenance system and provides a structured approach for improvement. The proposed WBS, validated through BIM, facilitates a comprehensive and systematic maintenance framework. This integration demonstrates potential for cost efficiency, improved dam maintenance performance, and informed policy and decision-making processes in Indonesia.*

Keywords: *Building Information Modeling (BIM), Dam Maintenance, Work Breakdown Structure (WBS)*

INTRODUCTION

In the last 10 years, the Indonesian Government has built numerous dams with diverse functions and objectives. Between 2014 and 2024, approximately 30 new dams were completed across various regions in Indonesia (Malik Sadat Idris et al., 2019), while an additional 30 dams are still under construction. These constructions are primarily aimed at fulfilling community needs for raw water sources, drinking water, and irrigation. Based on data from the Ministry of Public Works and Public Housing (PUPR), Indonesia currently has 213 large dams with a total reservoir area exceeding 100,000 hectares.

While the addition of new operational dams is a significant achievement, it also creates substantial challenges for dam maintenance in the future. The risk of dam failure—potentially leading to property damage and loss of life—underscores the importance of effective dam maintenance (Augusto et al., 2020). Dam failure risks are not solely attributed to natural disasters; they are often exacerbated by factors such as deteriorating physical conditions, internal structural damage, malfunctioning infrastructure, sedimentation issues, and other aspects of poor dam management (Rosytha & Suryana, 2023).

Several cases of dam failure in Indonesia (Figure 1) highlight these vulnerabilities, including the collapse of the Situ Gintung dam wall in South Tangerang (2009), the collapse of the Titab dam wall in Bali (2018), and the construction failure of the Ameroro dam in Sulawesi (2023).

DOI:
https://opsearch.us/index.php/us/index

Figure 1. Collection of news on dam failures in Indonesia (from various sources)

The Situ Gintung case, which resulted in nearly 100 fatalities, was analyzed by BPPT (The Agency for the Assessment and Application of Technology). The analysis indicated that the primary cause of failure was the aging spillway structure, compounded by high-intensity rainfall and piping through cracks in the spillway (Widianto & Noerwidi, 2023). Similarly, other dam failures in Indonesia reveal deficiencies in operation and maintenance processes, which are often irregular or improperly conducted. Furthermore, increased rainfall, shifting weather patterns, and natural disasters such as earthquakes and landslides add complexity to dam maintenance efforts (Sari et al., 2020).

Dam safety forms an integral part of dam management and overall water resource management. Effective dam safety measures are essential to mitigate risks such as reduced storage capacity due to sedimentation and potential downstream flash flood disasters in the event of dam failure (Rosytha & Suryana, 2023). However, the recurring damage to dams highlights systemic shortcomings in Indonesia's water infrastructure management. The inability to perform timely maintenance and repairs threatens not only the functionality of the dams but also the socio-economic well-being of communities that rely on them (DAM & Goffstown, 2014). Prioritizing better management strategies and allocating adequate resources for dam maintenance are essential to improving food security and water resource management in Indonesia.

Despite the critical importance of operation and maintenance (O&M) activities, current dam maintenance practices lack the explicit and detailed guidelines needed for effective implementation. The Work Breakdown Structure (WBS), a project management tool that organizes tasks into manageable components, could serve as a framework for detailing maintenance activities (Elsye et al., 2018).

Moreover, the integration of advanced technology could optimize maintenance processes. Building Information Modeling (BIM), a technological innovation that supports infrastructure project management, has been widely adopted in developing countries to address challenges across the planning, construction, and O&M stages (Sari et al., 2020). While Indonesia is transitioning towards adopting such technologies, their application in dam maintenance remains underexplored.

Based on these challenges and gaps, this study aims to identify and evaluate the dam maintenance system currently implemented in Indonesia. It also seeks to establish a reference framework for dam management activities by leveraging WBS and BIM. WBS provides a systematic approach to dividing and organizing maintenance tasks into manageable units, while BIM enables accurate visualization and management of maintenance-related information (Abideen et al., 2022).

By combining these tools, this research aims to address the shortcomings in the existing maintenance system and contribute to improving dam maintenance performance in Indonesia.

MATERIALS AND METHODS

The methodology employed in this research is a qualitative approach grounded in a comprehensive literature review. To enhance the methodological validity, the study employs clearly defined criteria for literature selection, prioritizing technical documents, relevant regulations in Indonesia, peer-reviewed scientific publications, and documented case studies. Additionally, the research incorporates insights from discussions with experts and practitioners directly involved in dam management, particularly in the operation and maintenance domains. The study focuses on utilizing the Work Breakdown Structure (WBS) framework to systematically organize dam maintenance components based on current practices identified through regulatory guidelines and scientific research. The WBS outputs are further integrated with Building Information Modeling (BIM) technology to facilitate the efficient execution of maintenance activities. Ultimately, the study aims to propose improved dam maintenance management patterns and policy recommendations.

RESULTS AND DISCUSSION

Dam Maintenance in Indonesia

The Indonesian government has regulated several provisions related to dams, including maintenance activities. As a legal umbrella, Law no. 17 of 2019 regarding Water Resources mandates that water resources be managed in a comprehensive, integrated, and environmentally friendly manner to realize sustainable benefits of water resources for the greatest prosperity of the people through efforts to conserve and preserve water resources, develop water utilization, as well as controlling the destructive power of water. These efforts are carried out through the development and management of water resources infrastructure, including water dam infrastructure (Loucks et al., 2017).

Regulation of the Minister of Public Works and Public Housing (Peraturan Menteri PUPR) no.27/KPTS/M/2015 concerning Dams mandates the importance of dam management efforts, including through dam infrastructure O&M activities, including:

a) Activities for regulating, allocating, and providing water and water sources.
b) Activities to prevent damage and/or decline in the function of water resources infrastructure, as well as
c) Repair damage to water resources infrastructure.

Details of the implementation of dam management currently use and refer to the Guidelines for Operation, Maintenance, and Observation of Dams, which were approved by Decree of the Director General of Water Resources Number: 199/KPTS/D/2003, which also contains in full how to carry out dam operation and maintenance activities (Rinaldi & Mulyono, n.d.).

Furthermore, PUPR Ministerial Decree no.27/KPTS/M/2015 also regulates several provisions regarding dams, described as follows:

1) A dam is a building in the form of earth fill, rock fill, and concrete, which is built in addition to holding and holding water, it can also be built to hold and accommodate mining waste or hold mud to form a reservoir
2) Dam collapse of part or all of the dam or its accessory buildings and/or damage that results in the dam not functioning.

3) Dam safety is an activity that is systematically carried out to prevent or avoid the possibility of dam failure.
4) Dam management is a government agency appointed by the dam owner, a business entity appointed by the dam owner, or the dam owner to manage the dam and its reservoir.
5) Dam management unit is a unit that is part of the dam management which is determined by the dam owner to carry out management of the dam and its reservoir.
6) Management of dams and their reservoirs for water resources management is aimed at ensuring the preservation of the function, benefits of the dam and its reservoirs, effectiveness and efficiency of water use and dam safety.
7) Management of the dam and its reservoir as intended is carried out by taking into account the balance of the ecosystem and the carrying capacity of the environment, which is carried out through operation and maintenance activities, conservation of water resources in the reservoir, utilization of the reservoir and control of the destructive power of water through control of the dam and its reservoir.

The concept of dam safety as referred to in one of the points above, consists of 3 (three) pillars, namely:

a) Structural safety in the form of safety against structural failure, safety against hydraulic failure, and safety against seepage failure;
b) Operations, maintenance, and monitoring; and
c) Emergency preparedness

Maintenance as intended includes:

a) Preventive maintenance, aimed at preventing damage and deterioration in the quality of the dam and its supporting structures, as well as extending its useful life. This preventive maintenance activity is carried out routinely or periodically (scheduled)
b) Extraordinary maintenance, carried out based on needs outside the established maintenance schedule, is aimed at repairing damage caused by quality deterioration, floods, earthquakes, equipment jams, failures (structural, hydraulic, seepage, operations, etc.), vandalism, etc. so on. The extraordinary maintenance activities referred to include repair work, strengthening work and rehabilitation.

Dam maintenance components have been included in the Decree of the Director General of Water Resources number 199 year 2003. Aspects of dam performance assessment have also been regulated in the 2017 Circular Letter of the Director General of Water Resources (Surat Edaran DirJen Sumber Daya Air). Figure 2 below shows the layout of dam components which performance needs to be considered.

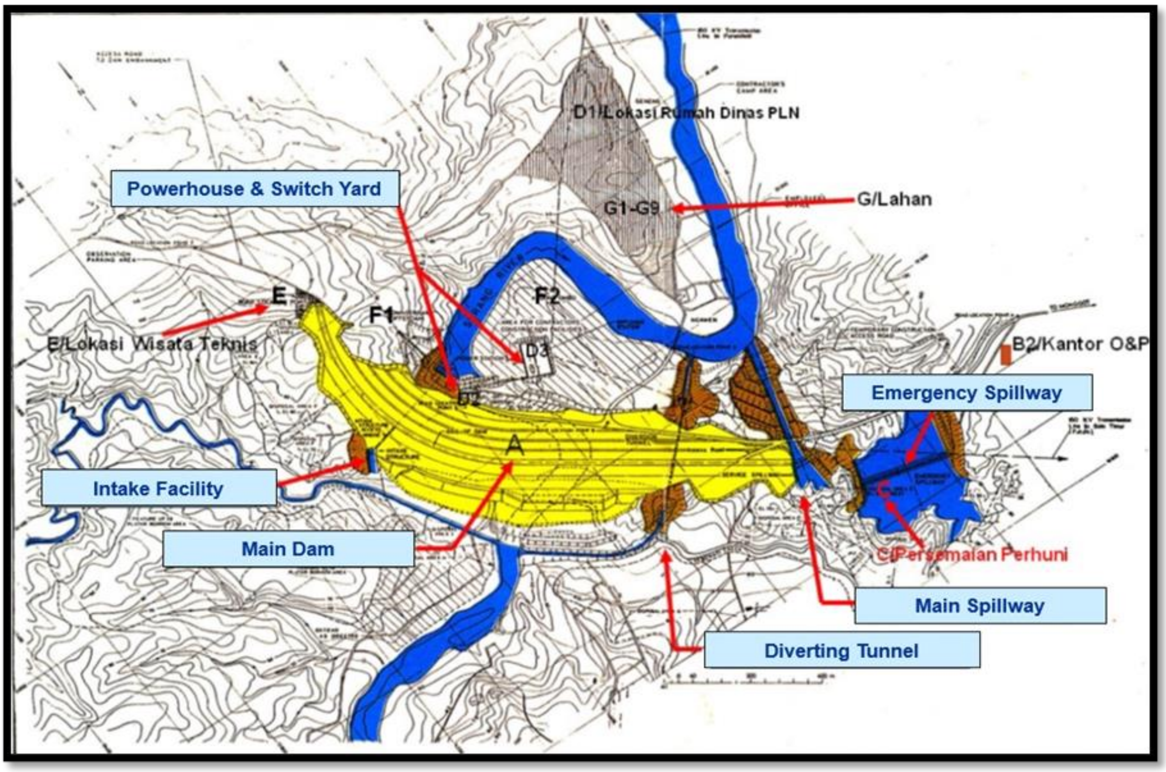

Figure 2. Dam Component Layout
Source: Surat Edaran Dirjen SDA, 2017

Based on this regulation, dam performance assessments are measured based on four aspects, namely physical performance, operational and service performance, security and environmental system performance, and institutional performance (Hervani et al., 2022). Guidelines for assessing dam performance have been regulated in the 2017 Circular Letter of the Director General of Water Resources as a reference for dam managers in conducting dam performance assessments to determine priorities for handling dam management under their guidance.

The objectives of dam performance assessment include:

1) Identify/measure the service level of a dam in general.
2) Identify the condition of the dam when assessing the dam.
3) Identify and measure any minor or major damage to each dam component.
4) Identify and measure the effectiveness of dam operations during the assessment.
5) Recognize problems that threaten dam safety
6) Accelerate an effective response to prevent dam collapse.
7) Prepare measures to minimize the risk of loss of life and reduce damage to property, if a dam collapse occurs

From the discussion of policies related to dams above, it can be seen that the dam maintenance system currently implemented is still normative and has weaknesses, especially in terms of standardization and integration of technology. Existing systems may not be optimal in utilizing the latest technology, such as Building Information Modeling (BIM) (Salzano et al., 2023). Salzano also emphasized that there has been no development of a BIM model for dam maintenance that is integrated with WBS.

Utilization of WBS and BIM in Indonesia

The use of WBS in infrastructure projects in Indonesia has been around for quite some time, while the use of BIM is still said to be quite new. However, the use of WBS and BIM is still limited to the planning and construction stages of buildings and roads. Previous research related to the development of building maintenance and monitoring systems has been carried out by several researchers with varying focuses (Rao et al., 2022). In 2019, Deka Watchson designed a maintenance and upkeep information system for flats buildings based on Work Breakdown Structure (WBS) using Building Information Modeling (BIM). In the following year, Anita Hendayani Putri (2020) developed an e-maintenance system that was applied to green building maintenance and upkeep work, with the main aim of increasing efficiency and effectiveness in the maintenance process. Continuing this development, in 2021, Dyah Ayu Pangestuti created a simple building maintenance system that is integrated with WBS and BIM using a web-based platform to improve building maintenance performance within the DKI Jakarta Provincial government. These researches significantly contribute to improving technology and more effective methodologies in the field of maintenance, especially increasing maintenance performance in buildings.

Currently, the performance of dam maintenance information systems is still limited to manual monitoring which is not based on WBS and periodic maintenance without in-depth technological integration as has been applied to buildings using BIM. In Indonesia, the application of BIM and WBS in the context of dam maintenance is still limited and has not been integrated with existing information systems. This not only hinders maintenance optimization, but also increases the risk of errors, delays, and higher costs (Muller et al., 2008).

Utilization and Development of WBS and BIM for Dam Maintenance

The approach used in this study is based on Work Breakdown Structure (WBS) combined with Building Information Modeling (BIM) to produce a more efficient and effective system. This is to develop a more integrated and optimal maintenance system, which can be widely adopted, especially in the maintenance of dam construction in Indonesia (Pribadi et al., 2021).

The regulations and policies regarding dam maintenance do not specifically form a WBS, but the components and sub-components in the Decree of the Director General of Water Resources Number 199/KPTS/D/2003 and Circular Letter of the Director General of Water Resources Number /SE/D/2017 which were submitted previously, can be the basis for preparing a WBS that will be developed for dam maintenance.

Previous research has identified several components related to dam construction that can be used as a reference for developing a dam maintenance WBS. Based on the activity details compiled by Yusuf Latief and PT. Brantas Abipraya (2023), the components of dam construction are as follows:

1) Roads and bridges are components of dams that function as connections between dam building areas. Road and bridge construction work includes excavation and embankment work, drainage, pavement layers, drainage, bridge substructures and bridge superstructures.
2) Cofferdam, is a temporary structural component of a dam designed to divert or retain water so that construction activities can be carried out without being influenced by water. Cofferdam construction work includes dewatering, excavation and embankment work, and excavation protection work.
3) Tunnels and circumvention channels, this component aims to divert water flow from one area to another. Tunnel and bypass channel work includes dewatering, excavation and embankment work, tunnel excavation protection work, concreting of channels and tunnels, and tunnel drilling and grouting work.

4) Main dam, components which constitute the dam body which includes the peak, upstream slopes and downstream slopes. Main dam work includes dewatering, excavation and embankment work, excavation protection work, foundation drilling and grouting work, dam crest pavement, drainage work, dam instrumentation, and dam mechanical and electrical work.
5) Spillway, a structural component built to drain excess water from a reservoir or lake downstream safely. Spillway work includes dewatering, excavation and embankment work, spillway protection work, spillway concreting work, drilling and grouting work, drainage work, spillway instrumentation, and spillway mechanical and electrical work.
6) Intake, a component used to take or direct the flow of water from sources such as rivers, lakes or reservoirs. Intake work includes dewatering, excavation and embankment work, intake protection work, intake concreting work, drilling and grouting work, drainage work, and intake mechanical and electrical work.
7) Public facilities, are facilities and infrastructure that function to support dam operations and maintenance. Public facility work includes structural work on public facilities, architecture of public facilities, interior of public facilities, landscape of public facilities, and mechanical and electrical work on public facilities.

Planned work is reflected in WBS components at the lowest level, known as work packages. These work packages are used to group activities where work is scheduled, estimated, monitored, and controlled. In the context of WBS, work refers to the results or deliverables of an activity, not the activity itself. WBS decomposition structure from level 1 to level 6 to break down project work into smaller and more manageable parts in dam maintenance (Andy Maulana & Latief, 2020), as follows:

a) Level 1: Project Name; This level provides an overview of the project as a whole and is the basis of the entire WBS structure.
b) Level 2: Job Family; At this level, the project is divided into major work families or major work categories required to complete the project.
c) Level 3: Type of Job; These levels for job types are broken down further into specific job types.
d) Level 4: Work Packages; types of work are broken down into smaller work packages and managed. Each work package consists of the tasks required to complete a specific part of that type of work.
e) Level 5: Activities; each work package is broken down into individual activities. These are the more specific and detailed tasks that must be performed to complete each work package.
f) Level 6: Resources; at this level, the resources required to carry out each activity are identified. Resources can include labor, equipment, materials, and other tools needed to complete the activity.

The WBS structure is displayed in table form, with columns showing all WBS components down to the smallest level (Andy Maulana & Latief, 2020). In this research, the WBS compiled is only limited to level 5, namely the activity component. The dam maintenance WBS compiled from the results of this study can be seen in table 1.

BIM provides detailed information about the monitored facility, thereby forming a strong basis for decision making throughout the facility's life cycle. BIM functions to create, manage and maintain all important information related to assets in infrastructure projects from the design to maintenance stages (Li et al., 2022). Various benefits can be obtained by implementing BIM in construction projects, including improved data quality, more collaborative design, higher project efficiency, and reduced risk during construction. BIM helps ensure that construction projects run smoother, faster, and with higher quality end results (Ghaffarianhoseini et al., 2017).

The use of BIM in dam projects is possible, provided there are adequate government regulations and a qualified workforce, although this may increase investment costs (Wangchuk et al., 2024). Sourced from Minister of Public Works and Public Housing Regulation No. 9 of 2021 concerning Guidelines for Implementing Sustainable Construction, there are principles for implementing BIM, as follows:

1) Informative: BIM must be able to provide complete, accurate and relevant information for all stages of a construction project, from planning to maintenance.
2) Interoperability: BIM must be able to be used and integrated with a variety of software and other systems, allowing for seamless data exchange between the various parties involved.
3) Collaborative: BIM encourages cooperation between teams and stakeholders in construction projects, ensuring all parties can share information and contribute effectively.
4) Sustainability: BIM should support sustainable construction practices, considering environmental impacts and resource efficiency throughout the building life cycle.
5) Coordination: BIM facilitates better coordination between different disciplines and project phases, reducing the risk of errors and conflicts during the construction process.
6) Data Integration: BIM integrates all project-related data into a single model that can be accessed by all authorized parties, ensuring consistency and ease of access to information.
7) Comprehensive: BIM should cover all aspects of the project, including planning, design, construction, operations, and maintenance, providing a comprehensive view.
8) Transparent and Authentic: Information in BIM must be transparent and trustworthy, allowing stakeholders to access data that is authentic and free from manipulation.

After validating the WBS components from level 1 to level 5, the next stage is to validate the WBS components that will be integrated into BIM. The validation process for WBS and BIM components was carried out through discussions and the input of several experts who work in the field of dam maintenance. The results of this preparation also assess the effectiveness of using BIM in improving dam maintenance performance if applied practically in the field. The validation process includes checking various operational and maintenance aspects to ensure that BIM can provide significant benefits in work efficiency, cost reduction and increased safety.

WBS components that have been successfully integrated into BIM include critical structures such as roads and bridges, main dams, spillway buildings, intake buildings, emergency spillways, outlet buildings and facility buildings on dams (Table 1).

Based on information from table 1, there are a total of 71 element clusters which are divided into six main components in the Dam structure using Building Information Modeling (BIM). The Roads and Bridges component has 14 element clusters, showing the diversity and complexity in supporting transportation and access infrastructure. The Main Dam consists of 10 element clusters, reflecting the crucial components that form the core of the dam structure. The spillway building has 13 clusters, which are important for water management and dam safety. The Intake Building, which plays a role in controlling water inflow, consists of 9 clusters. The Outflow Building manages the outflow of water from the dam and has 12 element clusters. Finally, the Facility Building, which supports dam operations and maintenance, has 15 element clusters. The total cluster of BIM elements found reflects the complexity and diversity of structures and functions associated with dam construction and maintenance. It also shows the utilization of Building Information Modeling (BIM) to detail and organize every aspect of dam maintenance in a systematic and structured manner, which helps in effective planning, implementation and maintenance.

Table 1. The Developed WBS for Dam Maintenance

LEVEL 1: **Dam Maintenance Works**

page 1/2

LEVEL 2: Component	LEVEL 3: Main Element	LEVEL 4: Element Cluster	LEVEL 5: Activities (Maintenance) Rou	Rep	Rei	Rhb	P
Access Road & Bridge	Road & Bridge Drainage System	Supporting Drainage	v	v	v	v	
		Bridge Drainage	v	v	v	v	
	Road & Bridge Pavement	Concrete Pave		v	v		v
		Asphalt Pave		v	v		v
	Bridge Lower Structure	Gabions		v		v	v
		Pile Cap		v	v	v	v
	Bridge Upper Structure	Abutment			v	v	v
		Column		v	v		v
		Pier Head		v	v		v
		Diaphragm		v	v		v
		Floor		v	v		v
		Barrier			v		v
	Bridge Accessories	Railing	v				v
		Streetlight	v				v
		Guard Rail	v				v
		Guide Post	v				v
Main Dam	Dam Concret Structure	Pedestrian					v
		Railing	v				v
	Dam Crest Pavement	Concrete Pave		v	v		v
		Aspal Pave		v	v		v
	Dam Crest Accessories	Hand Rail	v				v
		Safety Post	v				v
		Lighting	v				v
		Cansteen	v				v
	Dam Drainage	Dam Crest Drainage	v	v	v	v	
		Dam Foot Drainage	v	v	v	v	
	Floating Dock & Trashboom	Floating Dock	v				v
		Trashboom				v	v
	Others	Vegetation	v				
Spillway	Spillway Structure	Spillway	v	v		v	v
		Plugging					v
	Spillway Drainage	Side Ditch	v	v	v	v	v
	Energy Reducer	Stilling Pool				v	v
		Plunge Pool				v	v
		Leap Pool				v	v
	Spillway Gate	Gates	v				v
		Lifting Equipment	v				v
		Gate Motor		v		v	v
	Spillway Accessories	Hand Rail					v
		Lighting	v				v
		Safety Fences	v				v

Notes: **Rou:** Routine **Rep:** Repair **Rei:** Reinforce **Rhb:** Rehab **P:** Periodic
(red) Exclude for **BIM** Element

LEVEL 1:	Dam Maintenance Works							page 2/2
LEVEL 2:	**LEVEL 3:**	**LEVEL 4:**	**LEVEL 5:**					
Component	**Main Element**	**Element Cluster**	**Activities (Maintenance)**					
			Rou	Rep	Rei	Rhb	P	
Intake	Intake Structure	Intake Tower	v	v		v	v	
		Inclined Intake	v	v		v	v	
		Plugging					v	
	Intake Drainage	Side Ditch	v	v	v	v	v	
	Intake Gate	Stoplog	v				v	
		Trashrack	v				v	
		Trashboom	v				v	
	Hydromechanical	Automatic Panel	v				v	
		Manual Drive	v				v	
	Motor (Intake)	Motor Crane	v				v	
		Sling Wire	v				v	
		Panel	v			v	v	
		Genset	v			v	v	
Emergency Spillway	Spillway Structure	Spillway	v	v		v	v	
		Plugging					v	
	Spillway Drainage	Side Ditch	v	v	v	v	v	
	Energy Reducer	Stilling Pool				v	v	
	Rockfill/Piling	Density					v	
		Slope					v	
		Vegetation	v					
Outlet	Tunel	Pipe			v	v	v	
		Connection					v	
	Valve	Operating Panel	v	v			v	
		V-Valves, W-Valves	v	v			v	
		Tranducher	v	v	v	v	v	
		Air Fine	v	v	v	v	v	
	Motor (Outlet)	Panel	v	v	v	v		
		Genset	v	v	v	v		
	Outlet Cover	Walls	v				v	
		Floor	v				v	
		Inspection Ladder	v				v	
		Protective Roof	v				v	
	Gallery	Concrete Wall	v				v	
		Inspection Ladder	v				v	
		Lighting	v				v	
Facility Buildings	Buildings	Intake Operational					v	
		Gateway					v	
		Office					v	
		Official Residence					v	
		Laboratory	v				v	
		Generator House	v				v	
		Reservoir					v	
		Viewing Post					v	
		Guard House					v	
		Praying Facility					v	
		Workshop					v	

Notes: **Rou**: Routine; **Rep**: Repair; **Rei**: Reinforce; **Rhb**: Rehab; **P**: Periodic; (red) Exclude for **BIM** Element

CONCLUSION

The WBS structure is considered relevant to the existing conditions of dam maintenance, encompassing the scope, components, and buildings, as well as the main elements and their clusters. This structure provides a comprehensive foundation for maintenance activities and can serve as a standardized framework for more effective and efficient dam maintenance. At the institutional level, it is recommended to adopt the WBS framework as a standard operational guideline across relevant agencies and establish policies to ensure its consistent application. This would include regular training for staff to align with WBS-based workflows and integration practices.

At the technical level, the integration of the WBS structure with BIM offers a powerful tool to enhance the organization and management of dam maintenance activities. The validation of BIM components demonstrates the potential to integrate most maintenance-related elements into a digital model, allowing for systematic and data-driven decision-making. To maximize these benefits, institutions should prioritize the development of BIM capabilities that address gaps in the representation of underdeveloped elements, ensuring alignment with operational requirements. This includes the adoption of advanced tools for real-time data collection and analysis, enabling field teams to access up-to-date information seamlessly.

Furthermore, the combination of WBS standards and BIM provides a robust mechanism to improve efficiency, accuracy, and sustainability in dam maintenance management. BIM's technological innovation supports enhanced collaboration, resource optimization, and sustainability throughout the dam's lifecycle. For technical implementation, it is essential to develop comprehensive BIM models that incorporate key components such as roads, bridges, main dams, spillways, intake buildings, outlet buildings, and supporting facilities. These models should be designed to facilitate structured planning, execution, and maintenance processes, ensuring all stakeholders have access to a unified and data-rich platform.

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