TEST Engineering & Management

November-December 2019
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Low Head Dams Awareness in Malaysia

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Article Info
Volume 81
Page Number: 5913 - 5920
Publication Issue:
November-December 2019

Article History
Article Received: *5 March 2019*
Revised: *18 May 2019*
Accepted: *24 September 2019*
Publication: *27 December 2019*

Abstract

Low head dams impose dangerous counter currents near the downstream face of the structure. Fatalities at low-head dams with such currents often referred to as “drowning machines” or “hydraulic” were poorly documented in Malaysia history. Emergency rescues at low head dams can be hazardous to rescue personnel because of the reverse roller phenomenon (hydraulic). Malaysia has published Malaysia Dam Safety Management Guidelines (MyDAMS) in 2017. The primary purpose of the guidelines is to raise awareness, generate interest, and educate the general public and decision-makers regarding these dangerous structures and the need for remediation. Finally, MyDAMS highlights technical strategies required for dam safety management and the roles and duties of the key players' involvement, including Dam Owner's dedication to safety programs, chance management, and the provision of sufficient economic and human resources. The apprehension of the potential impacts among professionals and interventions of the dam was crucial.

Keywords: *Weir, Low-head dams, Hydraulic structure, Drowning Machines*

1. Introduction

Human-made dams play essential roles in utilizing hydro resources; a remarkably useful human engineering technology offers a good deal of pros and cons considerably influenced human civilization, benefited billions of humans, additionally as impacts on the environments (geomorphology and ecology).

In general, a dam falls into several distinct classes defined by structures (size criterion, height and width limitation, and reservoir volume) and by material construction. The International Commission on Large Dams (ICOLD) specifies large dams as 15 meters or higher or high between 5 and 15 meters with an impounded reservoir greater than 3 x 10^6 m^3 [1]. Meanwhile, the low head dam and small dam or “weirs and barrages” belong to “run-off river” categories, used consists of a small reservoir (head pond) for water leveling, and unable to control downstream flows effectively.

Overall, there is no acknowledged definition between dams classification; however, the limitation for each category as recorded as large dam (> 15 m), low head dam (< 7.6 m), and a small dam (< 15 m) respectively.

Dams are perceived as human-made hydraulic structures or barrier significant disturbance the flow of water, made of impermeable material (earth, rock, masonry or concrete), installed over a stream or waterway create a reservoir on its upstream side for single or for multipurpose advantages including flood control, hydroelectric power, river navigation, fisheries, recreation, and water supply for irrigation as reflected in Fig.1 (a) [2].

Fig.1(a) demonstrated the breakdown of the primary purpose of dams construction, which shown the highest as 32 percentages to fulfill recreation or river sports activities such as boating, fishing, canoeing, kayaking, and rafting while the lowest was river navigation with 0 percent [2].

There are 91468 dams recorded in the US Army Corps of Engineers National Inventory of Dams, as shown in Fig.1(b), with 46820 low-head dams the most prevalent, dominating the fragmentation riverscapes in the United

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States which leads to the highest percentages of recreation purposes [1]. The low-head dam usually serves the same purpose as large dams; nonetheless, most low head dams continue to degrade and pose a threat for most unwary recreational users [3]. The "low head dam" or "weir" consists of a drop structure or barrier in a river with a hydraulic head not exceeding 25 feet (7.6 m) while the small dam's height was not more 50 feet (15 m) of fragmented riverscapes, allowing water to flow over the top of the dam.

In contrast to their benefits, dams still have the potential to impose significant harm or risk to humans. Dam failure or accidents can endanger lives and property, inclusive of the low head dams. As the existing dams are aging, environmental concerns are growing due to the controversies on the dam's impact on safety and environmental issue.

Large dams' impact is significant compared to small dam failure, resulting in fatalities, destruction of downstream buildings, soil denudation, pollutions, and degradation of downstream ecosystems, economies, and communities. Nevertheless, the impact of a small dam's failure cannot be neglected.

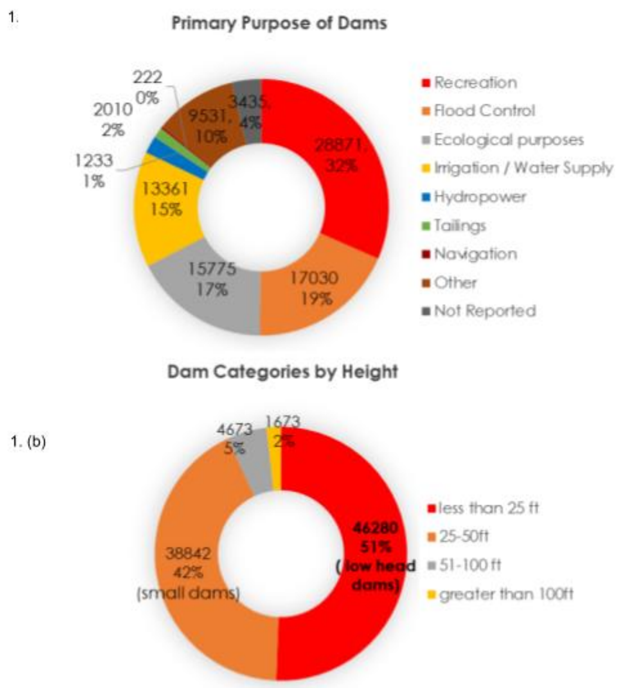

Figure 1: a) Primary purpose of Dams b) Dam categories by Height

Of all the danger created for river users, the hydrology behind the low head dams may present the most hazardous compared to large dams since the physics of the dangerous flow conditions that are disregard, overlook, and still poorly understood.

One of the reasons why the low head dams received so much attention in the literature is due to the dangerous phenomenon associated, which is known as "drowning machines" or "hydraulic." Possessed inherent hazards for mostly recreational users include boaters, kayakers, swimmers, anglers, and emergency rescuer into a false sense of security. The low head dams demonstrated the effect of high tailwater hydraulics with a camouflage appearance reflecting sheer and tranquil appearance underestimate the power of strong hidden reverse currents that cannot be overcome by swimmers [3]. Therefore risk assessment analysis and policy issues related to dam safety management are essential [6].

Growing concerns on low head dam safety have drawn increasing public interest in recent years. A good assessment of low head dam characteristics and safety management procedures may improve the likelihood of low head dam failures resulting in loss of lives, property, financial, and environmental damage. Dam management systems are committed to reducing the reverse impact of ecological and socio-economic modifications between dams, humans and the environment [4].

Malaysia claims 72 dams, which most of the dams are ancient and aging dams of which 15 are over 50 years of age; 29 dams between 25 and 50 of age and 28 dams below the age of 25[3]. Malaysia's oldest dam is the Bukit Merah Dam built-in 1906 until the latest dam, Susu Dam, in Jelai, Pahang [24].

There are problems with the safety of the dam and the dam efficiencies in Malaysia. According to Ir. Zainal Abidin bin Othman, SMEC Malaysia Sdn's Managing Director. Bhd., there were no dam failures in Malaysia [6]. However, the dams ' condition is likely to get worse as indicative of the aging process. Therefore, in terms of safety precaution and consideration of circumstances of these dams before it becomes a catastrophe for everyone.

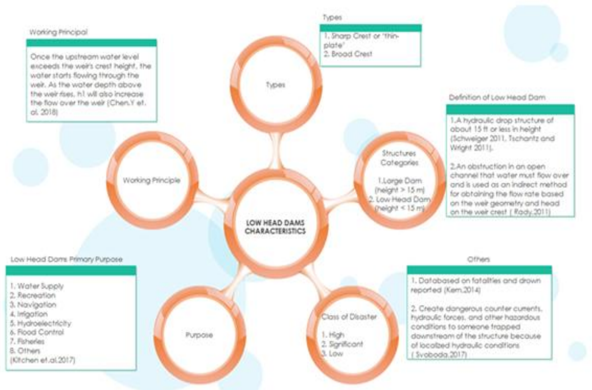

Figure 2: Low Head Dam Characteristics

Malaysia Dam Safety Management Guidelines (MyDAMS) has published good practice based on international dam safety guidelines from recognized references on dam engineering such as Federal Guidelines

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for Dam Safety (FEMA), International Commission on Large Dams (ICOLD), Australian, New Zealand and Canadian Guidelines on Dam Safety. This guideline is freely accessible online and is applies at those with dams enthusiasm, and similar techniques could also refer to evaluating the potential consequences of the collapse of other hydraulics structures such as low head dams application.

2. Low Head Dam Purpose

Although dams and weirs are similar structures that help in controlling water flow across a river, dams are considerably large and high while weirs are smaller, characterized by specially designed opening to increase the water flow rate. As mention earlier, weirs are useful and serve many purposes but they create a very forceful hydraulic counter-current that has known to kill people through drowning [3].

General description for low-head dams or weirs is a small overflow barrier that extending across a stream or a channel, and its direction is normal to flow; that supply a single relationship between upstream and downstream water levels [8; 9].

While low-head dams or weirs have the same general definition, their implementation and characteristics depend on their specifications [10]. Technically, there were two types of low head dams or weirs, which are sharp crest and broad crest.

Low-head dams have used for various purposes for humankind's benefits in engineering processes as depicted in Fig.3 by Kitchen et al. [11]. Additionally, low head dams or weirs can be utilized to channel water into hydropower plants as an approach to alleviate the potential damage pertaining result of dam development [2].Low head dams or weirs will facilitate riverine or fish habitats, stabilize water levels, and stabilize the impacts of stream modification.

The low-head dam’s impacts with limited awareness between hydrological, geomorphic, and ecological restoration were the current difficulties for future studies and management to understand. Countries with the most dams are the United States of America, 2nd is in Europe, 3rd in Mainland China, followed by India, South Africa, and South America [2].

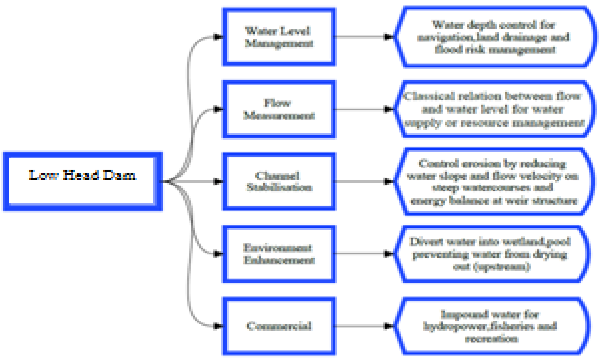

Figure 3: Primary purpose of low-head dam [11]

By their abundance, low-head dams can substantially disrupt riverine habitat [21]. China and India are the current leaders for low-head dams. Their contribution to generating electricity is undeniable, particularly in isolated terrain. Nonetheless, just like large dams, their environmental, hydrological and social implications should be investigated. Low-head dams hold minimal cumulative impact mainly unknown, particularly the local communities burdened with socio-environmental damages and loss of livelihoods. The low-head dams may have comparatively less or minimal impact compared to large dams, but they are more dangerous and known as killer dam or drowning machines [19]. Fencl et al. claim of their minimal impact are largely untested [30].

Malaysia, with its submersible weir with 1.5 meters in height, was located at Sarawak Kiri River at Batu Kitang, 64.37 km from the sea to conserve and secure water supply 98% of treated water for domestic and industrial purpose in Kuching city [13]. As seen in Fig.4a), a broad crested weir notably as Batu Kitang submersible weir functioned in a free flow conditioned and located at the downstream of the Sarawak Kiri river begin and operated since July 2005 with 144 million m3 of freshwater storage covering reservoir area of 8.77 km2 [14]. Under the Sarawak State Water Ordinance 1994, the Sarawak Kiri River Basin was officially gazetted as a water supply catchment area to meet growing water demand for population growth, tourism, and agricultural development in 2010-2030 [14].

Figure 4: Batu Kitang Submersible Weir [14]

3. Low Head Dam Hydraulic

Functional low-head dams or weir gives advantages to communities; they typically turn out a really dangerous downstream condition called a submerged hydraulic jump. The term “hydraulics” or “reverse roller” itself is often very dangerous, benign physical feature on the surface, yet can trap anyone via powerful recirculating motion currents downstream of the structure. Aerated flow downstream reduces the buoyancy of trapped individuals presenting no escape route leading to exhaustion and drowning, as seen in Fig. 5.

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The occurrence of ‘hydraulic jump’ was when the two regimes interaction from the supercritical conditions at downstream of a low-head dam and bring the flow back to subcritical conditions to dissipate excess energy. Thus resulting in a sudden increase in the water surface elevation in turbulent regimes poses a high risk to unprepared victims.

At certain hydraulic conditions, a combination of high flow rates with low downstream tailwater depth, the plunging nappe submerged forming a horizontal vortex at the riverbed or dams bed floor with massive power flow circulation directed to the surface of the water as shown in Fig.5. Entrained air within the jump impose risk by reducing buoyancy, made inescapably trapped bodies as well as to stay afloat. The low-head dam features indicate a strong and dangerous counter-current based on such conditions:

- drop height over the low head dam or weir
- The low head dam or weir face steepness
- Floating debris (stuck in the hydraulic)
- Walled edges to the low head dams
- Flow rate

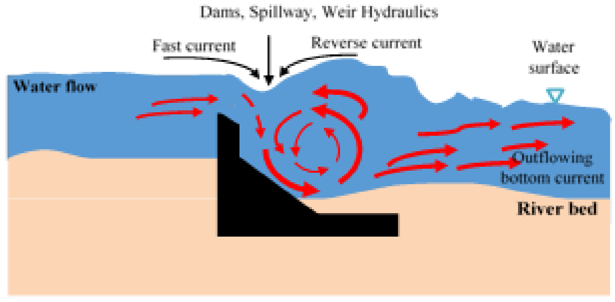

Figure 5: An illustration of the submerged roller generated at a low-head dam riverbed

Fig. 6 shows a diagram of a hydraulic diagram. Typically, hydraulic jumps occur in human-made channels as a means of dissipating energy, frequently obtained when liquid flows through a system of overflow. A hydraulic jump happens to transition from a supercritical point at the base of the dam to a subcritical level. The hydraulic jump velocity was rated as a skillful swimmer in which is 2 m/s in which exceed standard human swimming capabilities [21] as listed in Table 1.

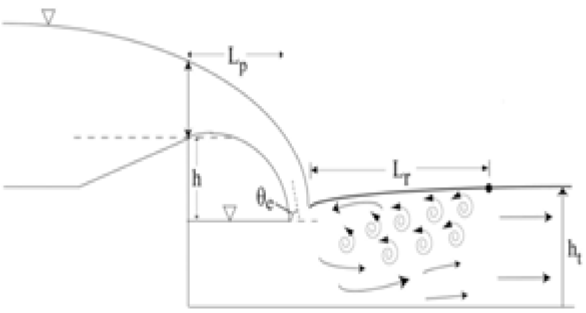

Figure 6: Diagram of hydraulic jump

According to Table 1, the force of the water increased by double within the rise in speed. If the speed of the water doubles, then the force of the water quadruples. It implies that a low increase within the water speed produces a larger increase within the water force, explained that wearing life jackets won't eliminate the risk of hydraulic structures as the massive water force will pull down the trapped bodies to the base of the riverbed.

Table 1: Water speed related to water force

Water Speed	Water Force	Speed Category
1m/s(2.2 mph)	40N (4 kg)	Slow walk
2m/s (4.5mph)	160N(16.3kg)	Fast walk
3 m/s (6.7 m/s)	360N(36.7kg)	Jog

Low-head dams potential to cause the greatest concern include hydraulic structure itself such vertical drops, horseshoe weirs (curved in the plan), low head dam with uniform hydraulic jumps, or potential entrapment features such as scour sills. Hazards can also be created by deep scour pools, submerged objects, and difficult access.

Low-head dams or weirs are dangerous and could cause the risk of people drowning and deaths in weirs in every year. An effort by Kern created a low head dam’s database of fatalities in the United States. The aim was to increase public awareness of the potential impacts presented by low-head dams as well as gain support to rectify dangerous structures [21]. An online database for river-related incidents provided by The American Whitewater Association collected via www.americanwhitewater.org.

Critical considerations should be given for any structure that is fit for creating a submerged hydraulic jump over a range of operational conditions reflects the difficulty of access for entrained object or person to escape.

Malaysia was also involved with low head dams fatalities, as reported in Fig. 7. with tragically six firefighters drown at low head dam attempting the recovery operation of a fisherman who had died earlier in the day on October 3, 2018.

In this incident, the rescue operations were performed at night and not postponed to a better-illuminated time as someone’s life was at stake. The certified rescue diving six firemen or rescuer, planned for a surface water rescue without wearing diving equipment as they were walking in a single file below the weir. The heavy rains with a chest-deep water level have vertical drop structures with full-width spans across the river or stream. A full-width span structure able to form a uniform counter-current across the channel width poses a risk that caused the water flow to be much faster, creating a strong current that turned the weir into a death machine. This tragic incident has

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become an eye-opener to the importance of safety. An effective, safe and low-cost remediation options must be explored to prevent further fatalities at these structures.

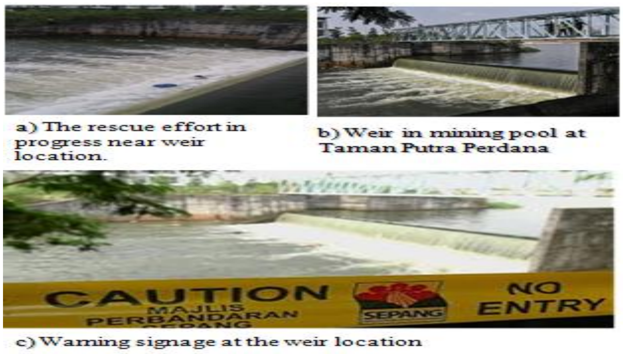

Figure 7: Location of weirs fatalities of six fire-fighters in the mining pool at Taman Putra Perdana, Puchong. (Sources from the Star online posted on twitter 6 Oct 2018)

There are methods for mitigating the risk of failure of a low-head dam's failure. Consideration should be given to eliminate or reduce the hazard by modifying the low head dams or channel. Public awareness, signage, buoys, lighting, and portage may reduce hazards, but still, the hydraulic forces are dangerous.

Mitigating risk should be achieved by limiting access neither land nor water, such as the safety booms, fencing, or safe access of water base installation. Safety chains or buoys should be given as a last resort. The owners of low head dams hold responsible for all tourists and should handle the risks posed by low-head dams, particularly for a navigated river.

Historically, the security of low-head dams and threats to river users has not been discussed as the legacy of weirs is known as unsafe under certain flow circumstances.

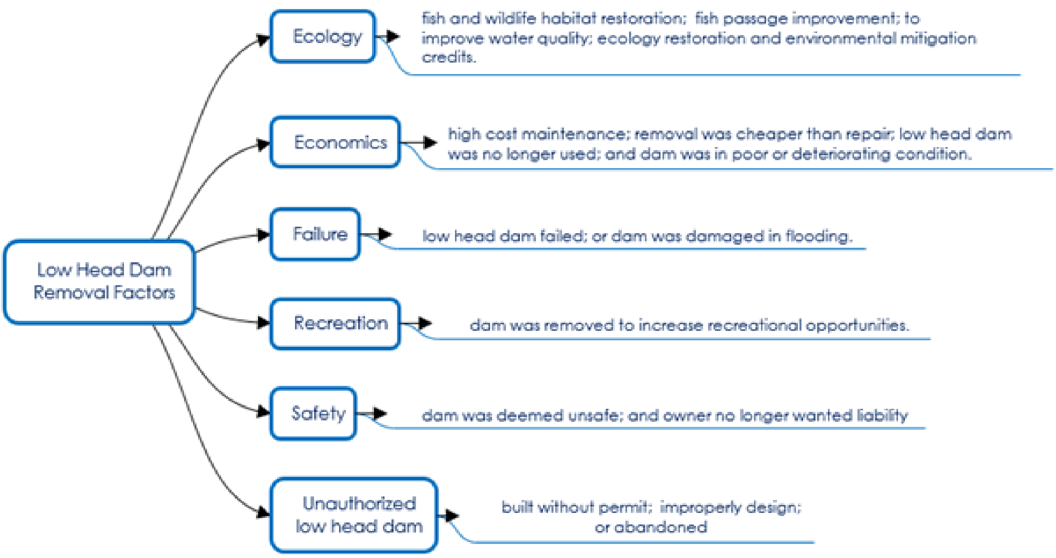

Figure 8: Factors Affected Low Head Dam Removal

4. Low Head Dams Impact On The Environment

While low-head dams bring many advantages, they also have negative impacts on the river ecosystem structure and function in several ways by hindering the migration of organisms or nutrients and substantially altering the flow regime of rivers as well as in-stream habitat conditions [21].

Low-head dams have drawbacks as they are rerouting river flows and dredging sediment. Slow flow in the upstream basin contributes as water temperature escalates. Oxygen concentration reduction and deposition of sediments with effects on the geomorphological conditions, quality of water (water clarity), habitat, ecology, flora, and fauna. Furthermore, disrupted sediment transport produces scour of the bed and banks, forming a deep plunge pool at the downstream.

Furthermore, low head dams can delay fish migration, affecting upstream populations and breeding patterns [2]. Thus, fish ladders integrated into low head dams or weirs for the fish migration process.

Removal of low head dams is becoming a popular option, as most of the low-head dams have finite life span become outdated, costly maintenance, or inefficient. Their removal increasingly seen as an effective way to carry out ecological restoration as well as released contaminated sediment is a significant environmental concern.

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5. Low Head Dam Intervention

A functional low head dam or weir, which is in the best condition hydraulically, structurally, and environmentally is essential in management practices to ensure it would serve well in terms of safety performance terms generates good impacts with no intervention is a likelihood in most cases. In general, dam removal for a variety of reasons, but safety concerns as seen in Fig.8, cause many low-head or small dam removals.

Fig.8 demonstrated factors affecting low head dams removal involved comparison on the cost-effectiveness of maintenance and removal, river revitalization, increased income for local fisheries and boating industries, and costs reduction related to improving water quality, recreational, and fisheries management.

Aging infrastructure, inadequate maintenance, and sedimentation accumulation were factors of low head dam failures. Aging or obsolete dams are prone to failure, leading to countless fatalities and loss of property at times. Consideration of poor condition low head dam removal or bypass should be considered for ecology and stream restoration, alleviate environmental impact and maintenance requirements.

Dam removal represents issues associated with aging structures, river and fish passages restoration, improve the diversity of flow conditions and habitat funding opportunities.

For a functional low head dam or weir, remediation is advisable to rehabilitate the structure. Alternative structural modification, such as a ramp and platform viable option, would minimize the submerged hydraulic jump condition.

The process of low head dam modification must be a collaborative process involved between multiple stakeholders with mutual interests such as owners or policymakers, local authorities, communities, costs effective, advantages, potential environmental effects, social and long-term and cumulative impacts, need to be discussed.

6. Conclusion

Low-head dam's safety is a global issue, often neglected or disregard during the framework design process of these systems. These low-head dam structures are the public's inherent risk that may arise under normal operating conditions. Guidance is necessary for strengthening the low-head dam quality and safety policy in Malaysia to increase community-level assurance and achieve world-class standards.

A guideline is essential for improving the low-head dam safety and quality policy in Malaysia to increase community assurance levels and meet world-class standards. The Malaysian government, politicians, and local authorities put greater importance on the life of the local community by proposing dam hazard identification depending on both the danger and the threat posed. Likewise, local communities living at risk of low-head dam collapse should be interested in the maintenance and preparedness of local dam safety management.

It is necessary to coordinate with the design of low head dams how regional and national policies impact local issues to diminish constraints of present low-head dam-safety procedures. The information must be made freely accessible in a transparent manner to viably affected communities.

Addressing well the lack of regional planning for multinationals on the impact of low head dams is essential to ensure the networking of the ecosystem. The objective is to enhance evaluations to integrate community issues and improvise the design of new low-head dams to enhance livelihoods by expanding crop growth, ensuring fishing profits, securing food safety, and improving project access to water and power. A fresh guideline is required that will represent evolving business requirements, with environmental guidelines and health enhancement, as well as topics such as geomorphology, natural and historical climate. It is highly recommended to handle low-head dams that do not meet performance requirements, the possible consequences of intervention, and assessment.

Acknowledgment

The authors would like to thank the research fund provided by Mechanical Engineering Department of Politeknik Ungku Omar and by the Ministry of Higher Education, Malaysia, through an in-service scholarship, obtained by the first author for her Ph.D. thesis at the Faculty of Mechanical and Manufacturing Technology, Universiti Tun Hussein Onn Malaysia (UTHM).

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