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Analysis of Abandoned Mine Wastes Disposal Techniques in Malawi: A Concept of Circular Economy

Horris K. Nangulama[1,2]

[1] Department of Mining Engineering, Malawi University of Business and Applied Sciences, Blantyre 312225, Malawi
[2] Research Center of Coastal and Urban Geotechnical Engineering, Zhejiang University, Hangzhou 310058, China

Correspondence: Horris K. Nangulama, Department of Mining Engineering, Malawi University of Business and Applied Sciences, Blantyre, Malawi. E-mail: hnangulama@poly.ac.mw.

Abstract
Non-operational mines mostly constitute of significant quantities of valuable mineral resources within tailings and waste rock that can be disposed properly using innovative techniques. Proper waste disposal techniques do not only reduce the need for new mines to be developed but also have broad beneficial results on mining environmental impact. This paper presents a solution on abandoned mine wastes in Malawi. Malawi government wants to embrace techniques on former mine waste recycling operations that incentivize investment. Thus, this analysis proposes abandoned mine waste recycling technique for Malawi government to adopt. Recycling technique, as one of the current direction methods, is determined for adoption. The powerful impacts of recycling principles in turning Malawi's abandoned mine wastes into beneficial products that can support and sustain its economy are given. The concept of circular economy is prominently in the picture, so the wastes can be changed into wealth and other created benefits.

Keywords: Abandoned Mine Waste, Recycling Technique, Circular Economy, Environmental Protection, Integrated Business Model

1. Introduction

The idea of circular economy is acquiring popularity globally among different stakeholders such as governments, industries, and consumers. Initially, the concept focused on manufactured products such as goods and services. Abandoned mine wastes were not conspicuously in the picture (Knapp, 2016; Lèbre., 2017). This can be because abandoned mine wastes seem like the antithesis of circular economy (Ellen, 2014; Soderqvist et al., 2015; Thimmiah, 2014). Over the last few years, mining wastes from abandoned mines have quickly caught up. Major consultancies have published articles that shape abandoned mine wastes circular economy transition as not a threat but rather an opportunity (ICMM, 2018). However, the concept of circular economy on abandoned mine wastes is yet to gain momentum in Malawi. If Malawi government can start applying the circular economy concept principles on its abandoned mine wastes, then more revenue will be generated that can sustain its economy (Daniel et al., 2019; Hubert, 2016; Zhenling et al., 2010).

Malawi is one of the south-eastern African countries. It is rich with natural resources such as deposits of coal, uranium, cement, bauxite, gold, nickel, niobium, graphite, precious stones, rare earths, gemstones, gas, and oil (Carter et al., 1973; Lombe, 2003). Many coal sites and small uranium areas are in northern part of the country (Rumphi and Karonga districts). Gemstones and rare earths deposits are in the southern region (Phalombe district). Gas and oil deposits are around Lake Malawi. Gold minerals are in central region (Lilongwe district-Nathenje, and Nkhotakota district), and eastern region (Mangochi district-Makanjira) (Ezekwesili et al., 2009).

Over tens of years, mining of resources from these areas has left many mine sites abandoned (Ezekwesili et al., 2009). Associated wastes from these abandoned mine sites have resulted in extensive damage to the environment: They have destroyed more land by making them impossible for re-use purposes; affecting the microbial communities, destroying the vegetation, and hindering the humans (EITI, 2019; Grynberg et al., 2021). Some of the major abandoned mines in Malawi include the Nkhachira coal mine, Kayerekera uranium mine, Kaziwiziwi coal mine, Mchenga coal mine, Eland coal mine, Kautsi hill quarry mine, Strabag quarry mine, and Zunguziwa quarry mine (Mines and Minerals Act, 2019; Thokozani, 2018). The associated mine wastes from these Malawi abandoned mines have not been disposed (Thokozani, 2018).

Hence, the main necessity of this analysis is to propose a disposal technique using the circular economy concept that include a recycling-focused approach as a clean-up strategy of Malawi's abandoned mine wastes. The analysis focuses on Malawi government to:

1) Know that wastes from abandoned mine sites comprise minerals due to uneconomic or inefficient extraction methods during initial processing, and that proper disposal techniques together with policy incentives make them economical.
2) Consider abandoned mine wastes as immeasurably recyclable, and that recycling is significantly cost effective as compared to new metal mining. This implies that, reprocessing abandoned mine waste straddles between the line of mining and recycling.
3) Develop an enhanced capability that track abandoned mine waste minerals from their source to enable for new business models potentiality.

Thus, Malawi government should aim at acting more like a commodity company. It can sell abandoned mine wastes from own recycling facilities or right away from mines, that's the wastes can be changed into wealth and other created benefits in an integrated business model approach.

2. Status and Challenges of Abandoned Mine Wastes Disposal Techniques in Malawi

2.1 Status

High demand for minerals in Malawi has left a lot of mining areas abandoned and associated wastes non-disposed (Ezekwesili et al., 2009; Human Rights Watch, 2016; International Union for Conservation of Nature, 2012; Kabir et al., 2015). Abandoned mines have created wastes that have caused great losses of both aquatic and terrestrial habitation (Human Rights Watch, 2016). Still Malawi government is yet to determine techniques on abandoned mine wastes that give more value to economic benefits and to environment protection (Kabir et al., 2015). Recently, Phiri et al., (2010) observed the lack of detailed information and policies by Malawi government on how abandoned mine wastes can be effectively disposed into valuable benefits despite their inclusion in the decommissioning activities of mine closure. Maneya et al., (2014) supported Phiri et al., (2010) observation and reported that the need to reclaim abandoned mine waste mineral commodities with emerging techniques for economic generation purposes are not properly managed or given much attention in Malawi.

The abandoned mine waste management is part of Environmental and Social Impact Assessment (ESIA) in Malawi (Government of the Republic of Malawi, 2002; Kapyepye, 2012; Land Use Consultants, 2014). ESIA mining jurisdiction requires companies of mining to restore mine site to a condition that approaches the original state (Government of the Republic of Malawi, 2010). ESIA does not specifically address the issue of abandoned mine waste proper disposal methods after the mine closure. Recently, ESIA abandoned mine site restoration stipulation has focused on ecosystems – restoration of interconnected relationship between fauna and flora that was present before mining operation. This implies that the topsoil taken out is kept and then replaced at mine closure. Tree species and native plants are seeded. Native animals are re-introduced (Malawi Government Ministry of Finance Economic Planning & Development, 2017). Nonetheless, it is not easy to restore ecosystem as it was, even though this sounds idealistic. In fact, ecosystem is a by-product of centuries of environmental changes. Soil fungi, bacteria, and other organisms in topsoil might not last storage years. Geological materials below the topsoil might have altered the hydrological conditions (Denholm et al., 2008; Emma et al., 2018; FRTR, 2007; USEPA, 2008). Thus, the difficulty in recreating ecosystems underscores the falsity of this belief in Malawi ESIA mining jurisdiction.

2.1.1 Eland Coal Mine

At abandoned Eland coal mine in Mwaulambo, Karonga district, there are more coal gauge and coal sludge mineral wastes (Chimwala, 2016). The Eland coal mine was closed in 2015 (Thokozani, 2018). The surrounding communities have been complaining about the negative impacts associated with the abandoned mine wastes since its closure. They complain about being not informed of the mine closure plans, including measures by the responsible company or the Malawi government intended at mitigating risks stemming from the deserted mine site (Chimwala, 2016). The company left behind unprotected deep holes, several piles of coal, and open pits filled with contaminated waters that still threaten the lives of the surrounding communities (Human Rights Watch, 2016).

2.1.2 Kautsi Hill Quarry Site

Another case is the abandoned Kautsi hill quarry at Nathenje, Lilongwe district, which contains contaminated soils, waste rocks, and small dams of mine influenced waters (Phiri et al., 2010). This site was abandoned in 2010 (Thokozani, 2018). The Malawi government recommended measures for mitigation of the abandoned mine wastes impacts on the proximity communities (Government of the Republic of Malawi, 2002). The summary primarily highlighted infrastructures and other socio-economic community needs such as hospital construction and medication provision at a proximity health clinic. Decommission activities included all machinery and equipment removal. Mine structures demolition. Contour of landscape dumps. Land rehabilitation to return it back to original state. Access road rehabilitation, Indigenous trees and grass planting in open areas. Mine site fencing off to restrict humans and animals entry (Phiri et al., 2010). There was nothing related to mine waste disposal technique in the summary (Phiri et al., 2010). The summary did not include or suggest any disposal method, for all the contaminated soils, waste rocks and mine influenced waters at the site, that can transform the wastes into generated beneficial products and guarantee environmental protection (Phiri et al., 2010; Thokozani, 2018).

2.1.3 Kaziwiziwi Coal Mine

Another example is Kaziwiziwi coal mine which was abandoned in 2012 (Maneya et al., 2014). Kaziwiziwi coal mine contains fly-ash wastes (Maneya et al., 2014). Public consultation was conducted to establish perception about abandoned mine fly-ash wastes in order to help the Malawi government to come up with propositions (Malawi Government Ministry of Finance Economic Planning & Development, 2017). The approaches employed were observations and key informant interviews (Maneya et al., 2014).. The determinations from the consultation of the public were summarized by government representatives. The summary mainly focused on campaigns of afforestation and reforestation (Maneya et al., 2014).. There was no explanation in the summary on how the abandoned fly-ash mine wastes and all contaminated wastes at the site are to be re-gained, and very little on environment related issues (Maneya et al., 2014).. Only negative impacts mentioned in the summary were the loss of informal business, loss of jobs, and loss of government revenue due to mine closure. The benefits that can be obtained from the abandoned waste fly-ash which might include job opportunities creation, integrated business models, revenue generation, and etc., were not mentioned in the report (Doley, 2013; Haibin, 2010; US GAO, 2011).

2.2 Challenges

The setup of planning in Malawi abandoned mine wastes relies upon ESIA process (Government of the Republic of Malawi, 1981; Land Use Consultants, 2014). This is alike to other countries where planning is performed as part of ESIA or as separate but still linked process. ESIA guidelines only explain basic statements on possible mitigation measures of abandoned mine wastes (Bergquist, 2013; Clewell et al., 2004; World Bank, 2004). The details on how the abandoned mine associated wastes are to be re-gained for other created benefits are not directly addressed (World Bank, 2004). Some specific challenges include:

1) Lack of detailed guidelines and codes of practices on techniques of disposing wastes from Malawi abandoned mines. Abandoned mine wastes have become a serious threat to humans and environment rather than an opportunity. This is a pressing problem to be figured out by Malawi government.
2) In ESIA, there is no implementation of time lined priorities and goals that ensure that the Malawi abandoned mine wastes are addressed first, and are clearly defined. This implies that abandoned mine wastes are not conspicuously in the first picture, and seem like the antithesis of circular economy.
3) Lack of an efficient, repeatable disposal technique and methodology that considers abandoned mine wastes as a possible business model to be pointed out and protected on the basis of multiple and corroborative efforts.

3. Abandoned Mine Wastes Disposal Techniques in Selective Countries

3.1 Status

The current direction in many mineral resource based countries world-wide (such as the Eastern Europe, Caucasus, and Central Asia (EECCA) region countries) is recycling, which is among the most circular economy principles direct applications in mining industry (Ellen 2014; European Commission, 2014; Thimmiah, 2014). Recycling involves reprocessing wastes from old mining operations. Former mine wastes are reprocessed to recover mineral resources (Ambec, 2013; Government of Western Australia, 2015). This action potentially creates jobs, increases environmental protection, and integrates abandoned mine wastes into commodity value chains (Bergquist, 2013; Knapp, 2016).

3.1.1 Kazakhstan - Kounrad Copper Mine

The Kounrad copper mine, near the city of Balkhash in Kazakhstan country, was abandoned in 2005 (OECD, 2017). The abandonment left behind substantial waste dumps comprising of recoverable copper [(OECD, 2017). In the year 2007, the Central Asian Metals developed interest on the site abandoned mine wastes. By the year 2012, it already built a solvent extraction – electro winning (SX-EW) plant. The recycling exercise removes metals from waste dumps by employing in-situ leaching. It then uses electro winning and concentrating processes to produce copper cathode. The copper cathode is exported for business to Turkey and other countries (Central Asian Metals, 2018). Recycling of existing waste dumps at the abandoned mine has been profitable (Central Asian Metals, 2018). The abandoned mine waste recycling technique has resulted in a low environmental impact since the recycling activities commenced (OECD, 2017). In the year 2016, the recycling activities were further expanded to reprocess more abandoned copper wastes. The project was pursued based on market principles. The operations have demonstrated support for circular economy approach on the abandoned mine wastes in both Kazakhstan and neighboring countries (Central Asian Metals, 2018).

3.1.2 USA – Tar Creek Superfund Site

Tons of chat piles at abandoned Tar Creek tristate zinc and lead mine sites in Oklahoma, USA caused widespread environmental contamination (Reisman et al., 2008; USEPA, 2008). The Oklahoma state highway department assessed the potential for recycling the chat waste materials (USEPA, 2008). The former mine chat wastes went through a mechanical wash process that distinguished the fine chat (which contains high concentrations of lead, cadmium, and zinc) from coarse chat, making it suitable for re-use purposes (Heden, 2002). The recycled chat waste was applied in an environmentally safe way as aggregate capsulized in asphalt and other sanctioned materials for road construction works and other construction activities. The recycled chat wastes at the site reduced mine waste volume environmental impacts, and boosted the Oklahoma construction business industry economically (Denholm et al., 2008).

3.1.3 Australia - Mount Morgan Mine

The Mount Morgan mine which is located at Central Queensland in Australia was abandoned in 1982 (Carbine Resources, 2018). The abandonment resulted in extensive environmental damage associated with the abandoned wastes (Terzon, 2018). In the same year of abandonment, 1982, tailings recycling operation began. The reprocessing project minimized further environmental damage. After eight years, operations were increased (Lèbre, 2017). The government took over the mine. It empowered measures which included new earthworks to enhance environmental protection (Lèbre, 2017). In 2016, Carbine Resources Company joined the initiative, and completed a feasibility study which targeted on mine waste recycling process continuation at the Mount Morgan site. The study aimed at recycling copper tailings (in form of copper sulphate), pyrite (as iron pyrite concentrate), and gold bullion (Carbine Resources, 2018). The project has created more economic benefits including reducing unemployment levels, environmental protection, and generating government revenue than initially anticipated (Lèbre, 2017).

4. Option for Malawi Abandoned Mine Wastes

4.1 Recycling

The current development option is recycling. Recycling method is one of the current techniques commonly adopted in many resource based countries for abandoned mine wastes clean-up exercises (Haibin, 2010; US GAO, 2011). Recycling option takes abandoned mine wastes and re-work them into useful materials. Recycling technique ensures that the abandoned mine waste is not discarded or thrown away but changed into riches, and also plays a crucial role in the concept of circular economy and environmental protection (Kokko, 2015; Söderholm, 2014; Thimmiah, 2014).

Some of the examples of mine wastes which can be recycled into created benefits from the perception of abandoned mine wastes in Malawi are:

- Coal gangue wastes at former Eland coal mine and Mchenga underground coal mine can be used for power generation. Coal gangue undesirable for power generation can be used for the purposes of forestation, coverage and landfill. Coal sludge from these abandoned mines can also be converted into electrical energy through burning it. These abandoned coal wastes can play a crucial role in transforming the Malawi's energy sector, and also hiking the country's economy simultaneously if recycled (Haibin, 2010). The atmospheric pollution and malicious substances associated with coal wastes can also be effectively prevented at the same time. Thus, dramatically creating wealth and enhancing environment protection (Daniel et al., 2019; Moffat et al., 2014).
- Fly-ash from abandoned Kaziwiziwi underground coal mine wastes can be recycled. Colored bricks can be obtained out of the recycling process. The colored bricks can be sold, as it is useful for beautifying road surfaces, in building architecture, for landscaping, aluminium production, surface subsidence mitigation, and many uses (Zhenling et al., 2010). This can generate business investments and boost the Malawi's economy.
- Abandoned Nkhachira underground coal mine contains wastes that include gases such as methane from coal bed which together with underground coal-berried pollutes the atmosphere (Emma et al., 2018). This coal-bed methane gases can be extracted, and re-used as a valuable natural resource in industrial productions. The coal bed methane can also be properly disposed by re-using it in world industries for civil engineering usages, production industry usages, car fuel usages, and generation of power usages

(Emma et al., 2018; Yosoon, 2016). Thus, creating an economic system that can be used to support the needs of Malawians.

- The Mine Influenced Water (MIW) and waste rock stockpiles at abandoned Kautsi hill quarry mine, Kayerekera uranium mine, Strabag rock aggregate quarry mine, and Zunguziwa rock aggregate quarry should not just let go, but controlled and recycled for other activities that can support the Malawi's economy. Such activities may include using the MIW for industrial production, for construction works, for consumption, for agricultural irrigation, as fire protection water, and etc. MIW from these sites can be treated. Water resources such as artificial lakes which might lead to tourist attraction and generate foreign revenue in the process can be established out of MIW after treatment (Paladin Energy, 2017). Similarly, the recovered MIW can be recycled and used for generation of electricity or externally traded out (Barr Engineering, 1986; Oruonye et al., 2018).

5. Recommendation

Malawi ESIA should consider abandoned mine waste as an opportunity rather than a threat. Recycling abandoned mine waste not only generates economic benefits but also minimizes environmental risk factors which non-operational mine constitutes. ESIA jurisdictions should present confluence of policies that together regulate, support, and motivate adoption of recycling technique, make processes more efficient in generating revenue, and reduce abandoned mine waste environmental impacts. Specific recommendations are as follows:

- Consider abandoned mine waste comprehensive utilization as one of best results from former mines. Malawi government needs to adopt recycling techniques to win over its former mine wastes into wealth. This saves natural resources, enhances environmental protection, and realizes great economic and social profits.
- Ensure promotion and encouragement of abandoned mine waste recycling techniques for the sustainable gain of the natural environment, local communities and nation as a whole. This can be achieved by the Malawi government coming up with code of practice for abandoned mine wastes reclamation, more detailed requirements, guidelines, and good policies.
- Prioritize abandoned mine waste recycling as a country priority for accomplishing sustainable growth in an integrated business model. Recycling techniques should be adopted as a significant objective for ecological restoration of abandoned mines.
- Implement clear, comprehensive, and consistently enforced regulation. The regulatory framework should go beyond the mine life. It should promote good environmental management, and provides details on how the mine wastes are going to be recycled into created benefits that can both boost the country's economy and enhance environmental protection at mine closure.
- Draw on international co-ordination, agreements, conventions, and information on proper recycling techniques that establish standards and frameworks for reprocessing abandoned mine wastes.
- Establish that mine operators can import environmentally sensitive and more efficient abandoned mine waste recycling equipment with an exception of import duty. Malawi government needs to remove barriers on importation of new technologies for abandoned mine waste recycling purposes. This should include tax structure which motivates new equipment purchases that recycles abandoned mine wastes and meets environmental standards.
- Use the means of training, education, and work experience to build human capacity. Ensure that abandoned mine wastes and environmental concerns together with solutions and new recycling techniques are included in mining related engineering curriculum. This helps enable better performance through skills availability.

6. Conclusion

This paper has determined that recycling technique eliminates environmental risk factors from abandoned mines. It converts the mine wastes into wealth and other created benefits. Once the mining operations have stopped, the associated remaining mining waste materials must be recovered. The recovered waste must be recycled into useful materials that both protect environment and generate economic and social profits. Proper recycling techniques of wastes from Malawi abandoned mines should prioritize on the attraction of a zero-waste society, in which a market and demand for virgin resources should likely continue for the foreseeable future. The specific conclusions drawn are:

- Recycling technique is proposed for adoption for Malawi abandoned mine waste clean-up exercise.
- Abandoned mine waste is an opportunity and not a threat. It is a valuable asset to Malawi government. Under this very situation, the recycling technique for Malawi abandoned mine wastes is particularly important.
- The recycling technique must be endorsed by public policy together with consumer buy-in in order to support new business models that integrate Malawi abandoned mine wastes into a global economy.

Lastly, further studies should be conducted. They should be aimed at inventing the most active, feasible, lower cost, and easily useable abandoned mine waste disposal modern technologies, modelling software, and machines that are to turn abandoned mine wastes into beneficial products which can support and sustain Malawi's economy in the concept of circular economy.

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Declaration of Competing Interest

The author declares no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Ambec, S., et al. (2013). *The Porter Hypothesis at 20: Can environmental regulation enhance innovation and competitiveness?* Review of Environmental Economics and Policy, Vol. 7/1, (pp 2–22). http://dx.doi.org/10.1093/reep/res016.

Barr Engineering. (1986). *Feasibility assessment of mitigation measures for Gabbro and waste rock stockpiles—Dunka Pit Area*. Prepared for Erie Mining Company, Hoyt Lakes, Minn.

Bergquist, A., et al. (2013). *Command-and-control revisited: Environmental compliance and technological change in Swedish industry 1970–1990.* Ecological Economics.

Carbine Resources. (2018). *Mount Morgan project.* Carbine Resources, Subiaco, United States.

Carter, G.S., & Bennett, J. (1973). *Geology and mineral resources of Malawi*. Malawi Geol. Surv. Dep. Bull, 6, (pp 1–62).

Central Asian Metals. (2018). *Kounrad, Kazakhstan*. Central Asian Metals PLC, London.

Chimwala M. (2016). *A resource curse that is Mwaulambo Village in Malawi*. Lilongwe, Malawi.

Clewell A., & Aronson J. (2004). *The SER International primer on ecological restoration,* Society for Ecological Restoration.

Daniel A., & Vallero, V. (2019). *Introduction to Waste Management*. Elsevier BV.

Denholm, C., Danehy, S., Bulsler, R. (2008). *Presentation at the national meeting of the American Society of Mining and Reclamation.* June.

Doley, D., et al. (2013). *Adopting novel ecosystems as suitable rehabilitation alternatives for former mine sites*. Ecological Processes, Vol. 2/1. http://dx.doi.org/10.1186/2192-1709-2-22.

EITI Malawi. (2019). *Malawi industries transparency initiative report*. BDO LLP.

Ellen MacArthur Foundation. (2014). *Towards the circular economy 3: Accelerating the scale-up across global value chains*. Ellen MacArthur Foundation, Cowes, United Kingdom.

Emma Sandell Festin, Mulualem Tigabu, Mutale Chileshe, Stephen Syampungani. (2018). *Progresses in restoration of post-mining landscape in Africa.* Journal of Forestry Research.

European Commission. (2014). *Critical raw materials for the EU*. European Union.

Ezekwesili, O.K., Baxter, M., Gilbo, T., Sa, D.P., Land, B., Husband, C. (2009). *Malawi: Mineral sector review, source of economic growth and development.* World Bank: Colombia, WA, USA.

FRTR. (2007). *Remediation technologies screening matrix and reference guide.* Version 4.0, Federal Remediation Technologies Roundtable, U.S. Agencies.

Government of the Republic of Malawi. (1981). *Malawi Mines and Mineral Act.* Malawi.
Government of the Republic of Malawi. (2002). *Environmental impact assessment guidelines for mining projects. Malawi Growth Development Strategy.* Government Printer: Lilongwe, Malawi, 2005, (pp33–34).
Government of the Republic of Malawi. (2010). *Malawi growth and development strategy II (2011-2016).* Ministry of Finance and Development Planning, Lilongwe, Malawi.
Government of Western Australia - Department of Mines and Petroleum. (2015). *Guidelines for preparing mine closure plans.* Government of Western Australia, Western Australia.
Grynberg, R., Kandaswamy, V., Singogo, F. (2021). *The ASGM sector in Africa—A child of misery and desperation.* Dev. South. Afr.
Haibin Liu. (2010). *Recycling utilization patterns of coal mining waste in China*. Resources, Conservation and Recycling.
Heden, R.S. (2002). *Presentation at the national meeting of the American society of mining and reclamation,* June.
Hubert, D. (2016). *Future mining revenues for Malawi, a case study of Mkango's. OXFAM.* Malawi.
Human Rights Watch. (2016). *They destroyed everything*. Mining and Human Rights in Malawi, United States of America.
ICMM. (2018). *The "circular economy" in mining and metals.* International Council on Mining and Metals, London.
International Union for Conservation of Nature. (2012). *IUCN members in Malawi speak on the environmental situation*. Malawi.
Kabir, S., Rabbi F., Chowdhury M. (2015). *Mine closure planning and practice in Canada and Australia: A comparative review.* World Review of Business Research 5, (pp 1–22).
Kapyepye, M. (2012). *Kanyika Niobium Project Social Impact Assessment Report.* Blantyre.
Knapp, F. (2016). *The birth of the flexible mine: Changing geographies of mining and the e-waste commodity frontier.* Environment and Planning A: Economy and Space, Vol. 48/10, http://dx.doi.org/10.1177/0308518x16652398.
Kokko, K., et al. (2015). *Sustainable mining, local communities and environmental regulation.* Barents Studies: Peoples, Economies and Politics, (pp 51–81). https://lauda.ulapland.fi/handle/10024/6.
Land Use Consultants. (2014). *Strategic environmental and social assessment of Malawi's minerals sector interim report.* Ministry of Natural Resources, Energy and Mines, Lilongwe, Malawi.
Lèbre, É. (2017). *The role of the mining industry in a circular economy: A framework for resource management at the mine site level*. Journal of Industrial Ecology, Vol. 21/3, (pp 662–672).
Lombe, W. (2003). *Small scale mining and the environment: Bloom beyond the doom and gloom.* J. Clean. Prod, 11, (pp 95–96).
Malawi Government Ministry of Finance Economic Planning & Development. (2017). *Annual economic report 2017*. Malawi.
Maneya, G., Chigamba W., Msika B. (2014). *Environmental Audit for Kaziwiziwi Coal Mine.* Kaziwiziwi Mining Company, Malawi.
Mines and Minerals Act. (2019). *Mines and minerals.* Malawi.
Moffat, K., Zhang A. (2014). *Australian attitudes toward mining: Citizen survey - 2014 results.* CSIRO, Australia.
OECD. (2017). *Multi-dimensional review of Kazakhstan: In-depth analysis and recommendations*. OECD Development Pathways. OECD Publishing, Paris.
Oruonye, E.D and Ahmed Y.M. (2018). *Inventorisation of abandoned mines and quarry pits in Taraba state.* Nigeria.
Paladin Energy. (2017). Kayelekera uranium mine. Malawi.
Phiri, SM., Chigamba, W., Phiri, F. (2010). *EIA of Kautsi hill quarry project.* Lilongwe.
Reisman, D., Ruttcowski, J., Smart, J. (2008). *The construction and instrumentation of a pilot treatment system at the standard mine superfund site.* National Meeting of the American Society of Mining and Reclamation, June, Ric. Lexington, Ky: American Society of Mining and Reclamation.
Söderholm, K., et al. (2014). *Environmental regulation and mining sector competitiveness.* Luleå University of Technology, Sweden.
Soderqvist, T., Brinkhoff P., Norberg T., et al. (2015). Cost-benefit analysis as a part of sustainability assessment of remediation alternatives for contaminated land. *J. Environ Manage*, *157*, (pp 267–278).
Terzon, E. (2018). *Mount Morgan abandoned mine site brings together environmentalists and farmers.* Australian Broadcasting Corporation.
Thimmiah, S. (2014). *Where are miners and metals in the circular economy?* The Guardian.
Thokozani Chenjezi. (2018). How a 'Ghost' coal company duped Malawi. Malawi.
US GAO. (2011). *Abandoned mines: Information on the number of hardrock mines, cost of cleanup, and value of financial assurances.* US Government Accountability Office, Washington, DC.

USEPA (U.S. Environmental Protection Agency). (2008). *Record of decision, operable unit 4, chat piles, other mine and mill waste, and smelter waste.* Tar Creek Superfund Site.

World Bank. (2004). *Striking a better balance.* The World Bank Group and Extractive Industries - the Final Report of the Extractive Industries Review. World Bank.

Yosoon, C. (2016). *Sustainable development of abandoned mine areas using renewable energy systems: A case study of the photovoltaic potential assessment at the tailings dam of abandoned sangdong mine.* Korea.

Zhenling, L., Gang, L., Zhengquan, G. (2010). *Notice of retraction: Study on the waste recycling and reuse patterns in coal mines.* 2010 IEEE International Conference on Advanced Management Science (ICAMS 2010).

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Effect of Building Configuration on Overstrength Factor and Ductility Factor

Sagun Kandel[1], Rajan Suwal[2]

[1] Department of Civil Engineering, Pulchowk Campus, IOE, TU, Nepal

Correspondence: Sagun Kandel, Department of Civil Engineering, Pulchowk Campus, IOE, TU, Nepal.
Mobile: +977 9840052765. E-mail: 075msste017 / sagun@pcampus.edu.np

Abstract
It is important for the structure to be economical and still have a high level of life safety. The lateral force sustained by the structures during a large earthquake would be several times larger than the lateral force for which the structures are designed. This is opposite to the fact that design loads such as gravity in codes are usually higher than the actual anticipated load. It is based on the probability that the occurrence of large earthquakes is quite rare and the capacity of the structure to absorb energy. The co-factors of response reduction factor which is the overstrength factor and ductility factor reduce the design horizontal base shear coefficient. A total of 36 low-rise residential buildings having different storey, bay and bay lengths are selected and analysed in this paper. NBC 105: 2020 is selected for the seismic design of RC buildings while provision provided in FEMA 356:2000 is used to carry out non-linear pushover analysis. The results indicated that between the different structures, the value of overstrength factor and ductility factor has a high deviation.

Keywords: Overstrength Factor, Ductility Factor, Response Reduction Factor, Pushover Analysis

1. Introduction

1.1 Background

Reinforced concrete (RC), is a composite building material where compressive strength is provided by concrete and tensile strength is provided by rebars. RC buildings are the ones in which members resisting lateral and gravity loads are made up of reinforced concrete. A total 54,23,297 buildings exist in Nepal out of which 5,39,004 of them are RC structures which tallies to around 9.94%. Post 2015 Gorkha earthquake, RC structures in Nepal is increasing rapidly and are replacing the load-bearing masonry structure.

The structure should be designed in a way that it is economical without compromising the safety and serviceability. The design philosophy followed by most of the design code states that absolute safety and no damage, even in an earthquake with a reasonable probability of occurrence, cannot be achieved. Utilization of inelastic responses of the structure helps in reducing the member sizes making the structure economical while still maintaining a high level of life safety. A term referred to as force reduction factor or response reduction factor is used in most of the seismic design codes to reduce the elastic lateral force to a lateral design force.

1.2 Need for Research

The force reduction factor in most of the seismic design codes makes use of a constant pre-determined value mostly depending just upon structural type and the detailing procedure for seismic analysis and design. The NBC 105:2020 has a single value for overstrength factor and ductility factor on behalf of response reduction, both of which are governed by the type of structural system. This may not be justified as it has been found that it depends upon various parameters such as building configuration. Very few researches account for their effect on overstrength factor and ductility factor in RC buildings. Therefore, it is essential to study the real behavior of RC buildings through non-linear analysis to assess the value of these factors considering different geometry of the structure in the context of Nepal.

1.3 Literature Review

Literature review is carried out as a part of this study to gain insight into the works to be carried out and to act as a guide for the successful completion of this paper. The problems related to this work are identified and necessary references was taken from the literatures shown below:

H. Chaulagain et al. (2015) published a paper on seismic response of RC buildings in Kathmandu valley. The house survey was done in 10 districts and a total of 300 houses were surveyed out of which 200 houses were taken for the study and were classified under various topics. Some of the conclusions were that engineered structures have higher strength and lower deformation whereas non-engineered buildings in Nepal exhibited high vulnerability with low ductility.

Barakat et al. (1997) carried out seismic nonlinear time-history analysis three-dimensional G+3, G+5, and G+7 storey RC buildings. These buildings had shear walls in both orthogonal directions. The number of bays and bay sizes also differed in both orthogonal directions. The code of practice for design was the Jordanian Seismic Code and seismic zones were varied from zones 4, 3, 2, to 1. The El Centro (N-S) earthquake record of May 1940 as an actual earthquake excitation was used for time-history analysis. It was observed that the seismic zoning has a slight effect on the ductility reduction factor for different buildings and the value of the ductility reduction factor was almost the same as the displacement ductility ratio. The overstrength factor was found to vary with number of stories, seismic zones, and design gravity loads. However, seismic zones affected the overstrength most. The overstrength decreased as the number of storeys increased. The variation in response reduction factor has a significant implications for the seismic design codes which currently does not account for it.

Elnashai et al. (2002) published a paper to address the issue of overstrength in modern code-designed RC buildings. The nonlinear static pushover analysis and time history analysis for twelve buildings of various characteristics were carried out. He concluded that the nonstructural elements contribute to producing higher overstrength in the building. He also stated that pushover analysis is more appropriate for low-rise and short period structures to predict the responses.

Humar and Rahgozar (1996) published a paper to establish a concept of overstrength in seismic design. A static nonlinear pushover analysis was carried at the moment resisting steel building frames from G+1 to G+29. The result concluded that the building designed using a current seismic code possesses considerable reserve strength. He also highlighted the sources contributing to the reserve strength in the buildings i.e., serviceability criteria, actual vs nominal material strength, discrete member sizes, code-based strength, presence of non-structural members etc.

$$\Omega = \frac{V_y}{V_d} \tag{1}$$

Miranda (1993) evaluated the site-dependent strength reduction factor that is used to reduce elastic design spectra to account for the hysteretic energy dissipation of the structure. A total of 124 earthquake ground motions which were recorded on 3 different soil conditions i.e., rock soil sites (38 records), alluvium soil sites (62 records), and soft soil sites (24 records). After carrying out the regression analysis the equation for ductility reduction factor (R_μ) was computed assuming 5% critical damping. The findings also included that soil condition also greatly affects the mean strength reduction factor. The total of 3 different equations was proposed for 3 different soil conditions which depend upon displacement ductility ratio (μ) and period of vibration (T).

The equations are as follow: -

$$R_\mu = \frac{\mu - 1}{\phi} + 1 \geq 1 \tag{2}$$

For rock soil sites

$$\phi = 1 + \frac{1}{10T - \mu T} - \frac{1}{2T} \exp\left[-\frac{3}{2}\left(\ln T - \frac{3}{5}\right)^2\right] \tag{3}$$

For alluvium soil sites

$$\phi = 1 + \frac{1}{12T - \mu T} - \frac{2}{5T} \exp\left[-2\left(\ln T - \frac{1}{5}\right)^2\right] \tag{4}$$

For soft soil sites

$$\phi = 1 + \frac{T_g}{3T} - \frac{3T_g}{4T} \exp\left[-3\left(\ln \frac{T}{T_g} - \frac{1}{4}\right)^2\right] \tag{5}$$

Where,

ϕ	=	Function necessary to compute approximate strength reduction factor
T	=	Period of vibration
Tg	=	Predominant period of ground motion

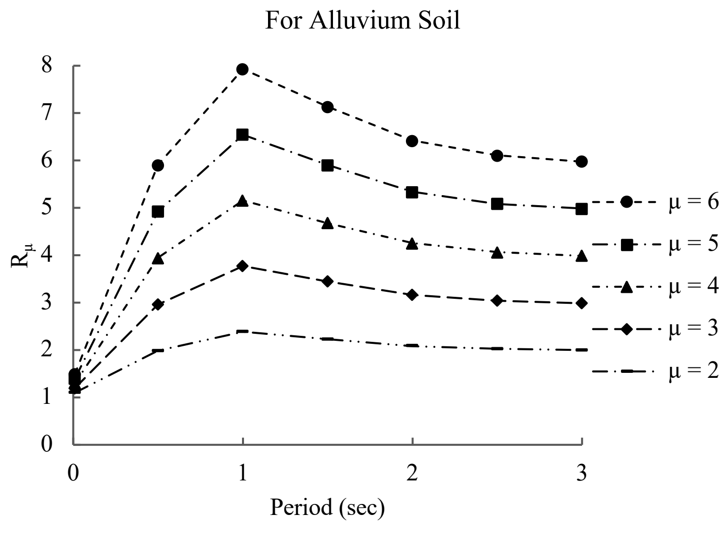

Figure 1: Ductility factor for alluvium soil as per Miranda

2. Building Description and Modelling

For modeling, analyzing (linear and non-linear), and designing of all the models, finite element analysis software ETABS v19.0.0 is used. The mathematical model is created in the software which closely represents the real model. 3D models of the structures are created where beams and columns are modelled as the frame elements and slabs as shell elements that are interconnected at nodes.

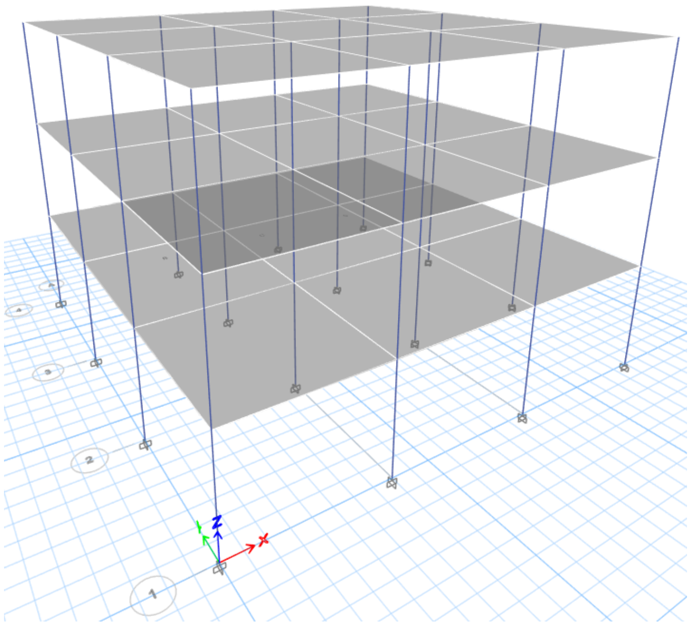

Figure 2: Finite element modelling of 3 storey 3 bay 4m bay length model

2.1 Structural Modelling Parameters

To incorporate the maximum number of different configurations of RC buildings of Nepal, following modeling parameters are selected.

1) Low-rise buildings having 2, 3, 4, and 5 number of storeys with a regular storey height of 2.9m are modeled.
2) The number of bays is taken as 2, 3, and 4 having bay lengths of 3m, 3.5m, and 4m which make these buildings have the plinth area from 36m2 to 256m2.
3) The buildings having regular plan and elevation with an equal number of bays in both the horizontal directions are considered in this study.

Table 1: Material properties

Properties	Reinforcement	Concrete
Grade	HYSD 500	M25
Unit Weight	76.97 kN/m^3	25 kN/m^3
Modulus of Elasticity	200 Gpa	25 Gpa
Poisson's Ratio	0.3	0.2

Table 2: Structure details

Building and Seismic Parameters	
Storey Height	2.9 m
Slab Thickness	125 mm
Soil Type	Medium Soil
Seismic Zoning Factor	0.4

Importance Factor	1
Damping in Structure	5%

Table 3: Loads on structures

Applied Loads	
Floor Finish	1 kN/m^2
Roof Live Load	1.5 kN/m^2
General Floor Live Load	2 kN/m^2
Outer Wall Load	7.5 kN/m
Partition Wall Load	4 kN/m
Lateral Load	NBC 105: 2020

2.2 Structural Members

The total of 36 unique configuration of buildings are modelled with smallest size of beam and column possible to satisfy the necessary design and serviceability check following NBC 105:2020 in which sizes of column and beam differ according to number of storeys only i.e., within a particular storey for different number of bay and bay length, the sizes of beam and column does not differ. However, all the frame elements (column, beam) in a particular building model are of the same size.

For Storey	Beam Dimension (D X B)	Column Dimension (D X B)
2	14“ X 9“	12“ X 12“
3	14“ X 9“	13“ X 13“
4	14“ X 10“	14“ X 14“
5	16“ X 10“	15“ X 15“

3. Pushover Analysis

The non-linear analysis is also known as pushover analysis is carried out to obtain the base shear vs top floor displacement curve. ASCE 7-16 is used to assign default hinges based on ASCE 41-13 at beam column joint where the members are expected to fail. This captures the material non-linearities. A non-linear gravity case is applied which incorporates total dead load plus 30% of live load which is a force-controlled load. The pushover load case is continued at the end of the gravity case until the displacement reaches an assigned value or the structure becomes unstable due to the formation of a plastic hinges. The base shear vs top floor displacement curve also known as capacity curve is obtained which is then idealized based on the provision provided in FEMA 356:2000 to obtain yield displacement (dy), ultimate displacement (du), significant yield strength (Vy). The bilinearization based on equal energy concept.

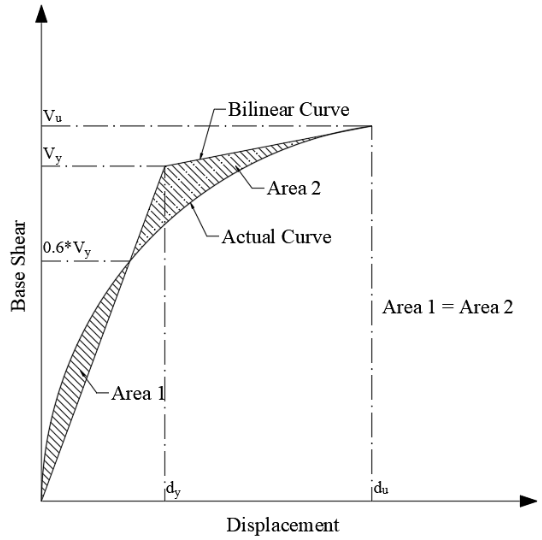

Figure 3: Bilinearization of pushover curve

4. Results and Discussions

This section presents the results obtained from the non-linear pushover analysis of the building models. The results are evaluated and compared to find the influence of different parameters on overstrength factor (Ω) and ductility factor (R_μ).

4.1 Effect on Overstrength Factor

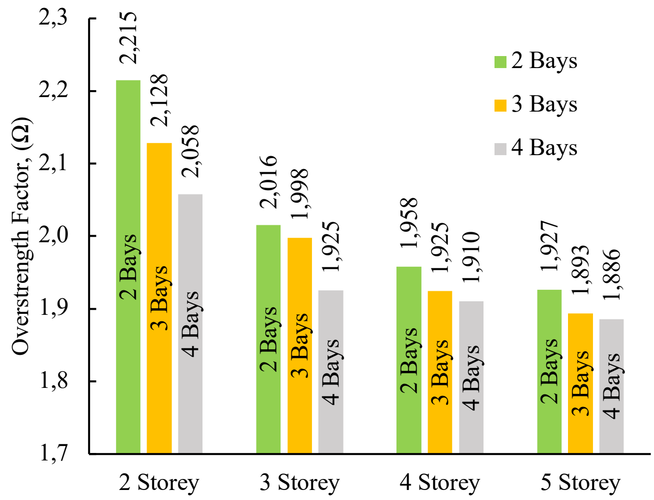

Figure 4: Overstrength factor for 4m bay length model varying number of storey and bay

The overstrength factor decreases while increasing the number of storey. While increasing the number of storey, both the design base shear and the yield strength increase but the yield strength increases at a lower rate than the design base shear which eventually decreases the overstrength factor. While increasing the number of bay does not affect the overstrength factor, as both the design base shear and the yield strength increases at almost the same rate. So, the overstrength factor varies only slightly. Also, its effect further decreases with an increase in the number of storey.

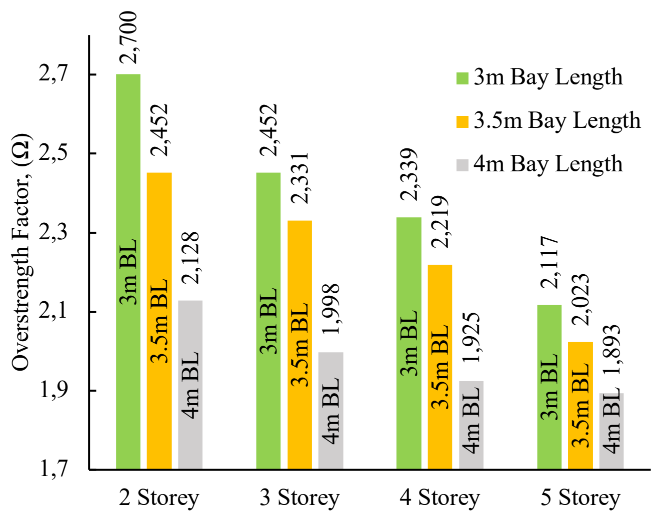

Figure 5: Overstrength factor for 3 bay model varying number of storey and bay length

In the case of bay length, increasing it decreases the overstrength factor. This can be explained as increasing the bay length only increases the seismic weight / design base shear but does not increase the lateral stiffness.
The overstrength factor varied from the highest 2.873 for the smallest model having 2 storey, 2 bays and 3m bay span to the lowest 1.886 for the largest model having 5 storey, 4 bays and 4m bay span.

4.2 Effect on Ductility Factor

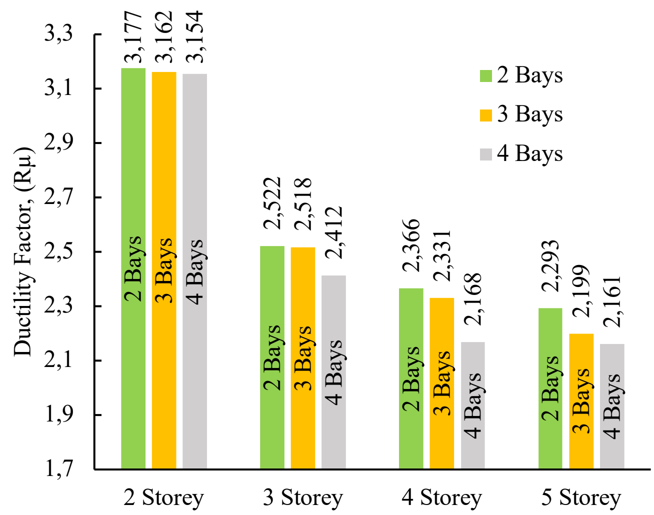

Figure 6: Ductility factor for 4m bay length model varying number of storey and bay

The value for ductility factor is higher for 2 storey buildings but reduces with the increase in number of storey from 2 to 5. Even though the time period increases as the number of storey increases but the value of displacement ductility ratio (μ) decreases significantly which then reduces the ductility factor. The effect of number of bays on the ductility factor is very less showing slight decrease with an increase in number of bay. This can be explained as increasing the number of bay makes the building stiff. But contrary to overstrength factor, the effect of number of bay further demises as the storey decreases.

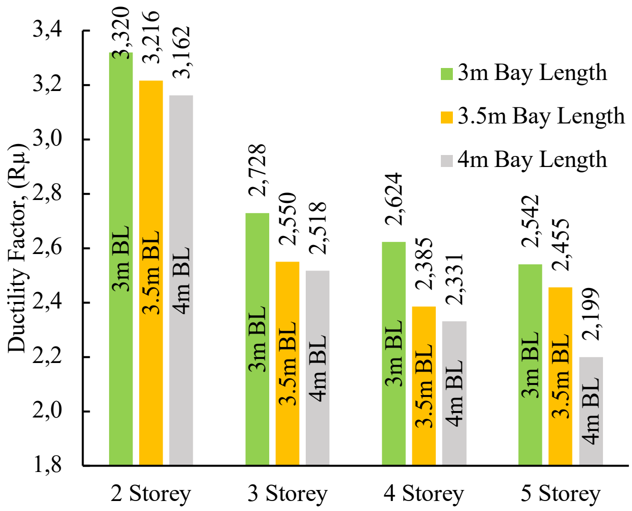

Figure 7: Ductility factor for 3 bay model varying number of storey and bay length

Similar to the overstrength factor, increasing the bay length decreases the ductility factor. This can be justified cause increasing the bay length decreases the displacement ductility ratio (μ), decreasing the ductility factor.

4.3 Generalized Equation for Overstrength Factor and Ductility Factor

A generalized equation has been proposed to calculate the overstrength factor and ductility factor by carrying out the regression analysis. The factors considered are number of storey, number of bay and bay length.

$$\Omega_u = 4.4668 - 0.1233S - 0.0601B - 0.4627BL \quad (6)$$
$$R_\mu = 4.6839 - 0.2603S - 0.0502B - 0.2719BL \quad (7)$$

Where,

Ω_u = Overstrength Factor
R_μ = Ductility Factor
S = Number of Storey
B = Number of Bays
BL = Bay Length

5. Conclusions

A total of 36 buildings models were analysed to obtain the overstrength factor (Ω_u) and ductility factor (R_μ). The force vs displacement curves were obtained by non-linear static pushover analysis. Using extensive statistical tools, an empirical equation has been proposed for overstrength factor and ductility factor.

$$\Omega_u = 4.4668 - 0.1233S - 0.0601B - 0.4627BL \quad (8)$$
$$R_\mu = 4.6839 - 0.2603S - 0.0502B - 0.2719BL \quad (9)$$

In addition to the formulation of empirical relation, the following conclusions has been made from the analytical study carried out by varying the building configurations.

- Both the overstrength factor (Ωu) and ductility factor (Rμ) is dependent upon many parameters such as building configurations. Using a single value for them will introduce the unwanted uncertainty in the building.
- The dependency on bay length and number of storey is more than the number of bays for both the overstrength factor and ductility factor. For the overstrength factor the effect of bay length and number of

bays reduced as the number of storey increased but it is opposite in the case of ductility factor.

- According to NBC 105: 2020 for ultimate limit state, the value of overstrength factor and ductility factor are 1.5 and 4 respectively for RC moment resisting frame. The value obtained from the analysis showed the higher value (>1.5) for overstrength factor ranging from 1.886 to 2.873 while for the ductility factor the value fluctuated from 2.161 to 3.283 which were less than (<4) that specified in the code.

These conclusions are limited to the scope of the work carried out in this research. More wider parameters need to be included to reduce the limitations of this research in order to accurately predict the overstrength factor and ductility factor.

References

American Society of Civil Engineers. (2010). ASCE 7-16 Minimum design loads for buildings and other structures. *ASCE standard. American Society of Civil Engineers: Structural Engineering Institute.*

Barakat, S. A., Malkawi, A. I. H. & Al-Shatnawi, A. S. (1997). A step towards evaluation of the seismic response reduction factor in multistorey reinforced concrete frames. *Natural Hazards*, *16*, 65-80. http://dx.doi.org/10.1023/A:1007972616511

Chaulagain, H., Rodrigues, H., Spacone, E., & Varum, H. (2015). Seismic Response of Current RC Buildings in Kathmandu Valley. *Structural Engineering and Mechanics*, *53*(4), 791-818. http://dx.doi.org/10.12989/sem.2015.53.4.791

Elnashi, A., & Mwafy, A. (2002). Overstrength and force reduction factors of multistorey reinforced-concrete buildings. *The Structural Design of Tall Buildings*, *11*(5), 329-351. https://doi.org/10.1002/tal.204

Federal Emergency Management Agency. (2000). FEMA356:2020 Prestandard and Commentry for the Seismic Rehabilitation of Building.

Humar, J. L. & Rahgozar, M. A. (1996). Concept of Overstrength in Seismic Design. *Eleventh World Conference on Earthquake Engineering*.

Miranda, E. (1993). Site dependent strength reduction factors. *Journal of Structural Engineering*, *119*(12), 3503-3519. https://doi.org/10.1061/(ASCE)0733-9445(1993)119:12(3503)

Nepal Building Code. (2020). NBC 105: 2020 Seismic Design of Buildings in Nepal. *Kathmandu: Ministry of Urban Development.*